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THE NATIONAL RESIDENTIAL RADON SURVEY DESIGN REPORT

by

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1.0 SURVEY DESIGN

1.1 Purpose of the National Residential Radon Survey

In the Superfund Amendments and Reauthorization Act of 1986 (SARA, P.L. 99-499), Congress required the Administrator of the Environmental Protection Agency (EPA) to conduct a national assessment of radon gas "found in structures where people normally live and work, including educational institutions." One component of this national assessment is the National Residential Radon Survey (NRRS), which will investigate radon concentrations in occupied housing units.

The results of this survey will be used by the EPA to assess the effectiveness of various radon program strategies. In particular, the EPA will use the information obtained from the survey to answer the following questions:

1. What is the frequency distribution of annual average radon concentration in occupied housing units?
2. What are the relationships between specific housing construction types and concentration of radon in occupied housing units?

In addition to characterizing the national distribution, we also plan to study subsets of the surveyed homes to learn how radon levels vary among smaller segments of the population. To ensure that we can make statistically accurate conclusions about the country's geographic regions, we will stratify our sample by the 10 EPA Regions and select a representative sample from each. In this way, we will be able to estimate the radon distribution for each region and also be able to highlight differences in radon levels across various parts of the country.

Comparisons of other subgroups of the population will also be made. For example, we will compare the radon distribution of single family homes with that for homes in multi-unit structures and compare the distribution for rental units with that for owner-occupied units. In addition, we will compare radon levels of different floors within the same residence. This will show, for example, how radon concentrations in the basement relate to concentrations in other parts of the home.

The data gathered from this survey will also provide information on how much radon people are actually exposed to in their homes and what the resulting increased risks of lung cancer are. For example, a high radon level in a rarely used storage basement is less of a health risk than a moderate radon level in a living room or bedroom where people spend hours every day. Although residential exposure is only part of a person's total exposure, EPA should be able to estimate the fraction of lung cancers that could be averted by achieving various reductions of radon concentrations in homes.

1.2 Summary of the National Residential Radon Survey Design

The National Residential Radon Survey will obtain personal interviews and 12-month measurements of radon concentrations on each level of a nationwide random sample of approximately 5,000 residences.

The sample will be a three-stage area probability sample of housing units. A nationwide probability sample of approximately 125 primary sampling units (PSUs), each consisting of one or more counties or county equivalents, will be selected, and one or more interviewers will be hired in each sample PSU. A probability sample of second stage units (SSUs), each consisting of a small geographic area, for example, a Census-defined city block, will be selected within each sample PSU. The sample SSUs will be visited and the addresses of each housing unit (HU) will be listed. A probability sample of addresses will be selected from these listings to obtain the sample of HUs for the survey.

Each sample home will be visited and screened for survey eligibility. (The household must have no firm plans to move within the following 12 months to be eligible for the survey. A personal interview will be attempted in each survey eligible sample home to obtain information about the structural, heating and ventilation characteristics of the home and to obtain information about the residents. In addition to demographic characteristics, we will request information about smoking characteristics of the residents and about the amount of time each resident spends on the different levels of the home. Finally, an alpha track detector will be placed on each level in the home and will be left there for 12 months.

The design calls for maintaining contact with the sample homes during the 12 month radon measurement period and for the collection of the detectors at the end of the 12 months, or beforehand if the household has an unexpected move from the sample housing unit.

1.3 Definition of Survey Population

Because the congressional mandate calls for the measurement of radon concentrations in places "where people normally live and work, including educational institutions," a decision must be made about how each different type of living place should be handled. Our proposal assumed that the National Residential Survey would cover only the household population, that is, the population living in housing units. However, we will identify the remaining segments of the population living in other types of quarters and recommend a procedure for handling each. The possible options for handling these special groups are:

- Include the group in the National Residential Radon Survey
- Include the group in the school survey
- Include the group in the place of work survey
- Include the group in a special survey
- Exclude the group altogether.

The Census Bureau classifies the population into the following categories.

The household population:

- Persons living in housing units (comprising about 97.5 percent of the nation's population in 1980.)

  --A housing unit is typically a house, apartment, or mobile home, but may also be one or more rooms occupied as separate living quarters. The latter are quarters in which the occupants live and eat separately from others in the building and which have either direct access to the outside or access throught a common hall.

The nonhousehold population:

- Inmates of institutions (comprising about 1.1 percent of the nation's population in 1980.)

  --Inmates of mental institutions,
  such as mental hospitals, psychiatric wards in general hospitals or veteran's hospitals, alcohol or drug treatment centers, etc.
  --Inmates of homes for the aged,
  such as nursing homes, county homes for the aged and dependent, etc.
  --Inmates of correctional institutions,
  such as reformatories, local jails, and work houses
  --Inmates of other institutions,
  such as hospitals or wards for tuberculosis, homes, schools, hospitals, or wards for the mentally or physically handicapped, orphanages, residential treatment centers for emotionally disturbed children, homes for unwed mothers, etc.

- Other persons in group quarters (comprising about 1.4 percent of the population of the nation in 1980.)
  --Military personnel living in military barracks or on ships.
  (Residents of housing units on military bases are counted as part of the household population.)

--Residents of college dormitories, fraternity or sorority houses, or rooming houses exclusively for college students, provided there are 10 or more unrelated students or 9 or more unrelated to the resident who operates the place.

--Residents of rooming houses with 10 or more unrelated persons or 9 or more unrelated to the resident in charge. Also included in this category are people living in hotels, motels, Y's and residential clubs who have no permanent resident elsewhere.

--Persons living in other group quarters such as convents, monasteries, halfway houses, communes, low-cost transient quarters. This category also includes crews of commercial ships, institutional staff residing in group quarters, persons residing in parks, campsites, etc.

Our recommendation is that the National Residential Radon Survey exclude a) housing units that are located on military bases, b) all institutional residences of the institutionalized population, and c) all "other" types of living quarters. The target population for the NRRS would therefore be a) all housing units that are continously occupied for 12 months that are not located on military installations and b) the permanent residents of these housing units.

Our reasons for excluding certain groups from the National Residential Radon Survey and our recommendations for handling these groups are given below:

1. <u>Housing units and other places of residence on military bases or installations</u>: We recommend the exclusion of these groups from the NRRS because of difficulty of access. We do not recommend that they be covered in any other EPA sponsored survey, for the same reason. EPA should, however, provide the Department of Defense (DOD) with copies of survey design reports and survey materials so that DOD can implement comparable surveys, if they so choose.

2. Inmates of institutions: We recommend the exclusion of the institutionalized population from the NRRS for two reasons, a) because the need for separate sampling and data collection procedures would make this a very costly and time consuming addition, and b) because of access difficulty. Typically, whenever the institutionalized population of the nation is included in a survey research project, it is covered using procedures that are separate from those used for the household population survey, for these same two reasons. If EPA does wish to measure the residential exposure of the institutionalized, we recommend that a survey covering this population segment be made a component of the survey of places of work. This would be a realistic supplement to the latter survey, because institutions are places of work that would be sampled and measured in that survey.

3. Other persons living in group quarters: We recommend the exclusion of this group from the NRRS. As with the institutionalized population, including this group would require different sampling and data collection procedures and would be costly and time consuming.

   --Students: We do recommend that residents of college dormitories, fraternities or sorority houses and rooming houses exclusively for college students be covered in the survey of schools. Coverage of these types of living quarters for all types of residential schools (excluding the institutionalized discussed above) should be relatively easily fit into the school survey design. The students' school exposure and residential exposure could be measured using the same sample schools that were selected from a stratum of schools having residential students.

--Military: We recommend excluding all military, as explained above.

--Residents of large rooming houses, monasteries, transient quarters, and persons living in parks, on boats, etc.: We recommend not obtaining residential radon exposure for this very small group of people. Their residences are sufficiently different to make sampling and data collection more difficult. They are also different enough to call for analysis as a separate group, thus requiring substantial oversampling and the associated increase in cost.

2.0 SAMPLE DESIGN

2.1 Introduction

The general goals of the survey, which were described in Chapter 1, need to be reformulated into explicit statistical objectives for the key population parameters. The statistical objectives, including the associated precision constraints, can then be put in priority order and used as the basis for developing a sample design. EPA reformulated and prioritized the study objectives as follows:

(1) First priority: The survey should provide a scientifically sound estimate of the frequency distribution of annual-average radon concentrations in occupied residences nationwide.

- Precision constraint: The national estimate of the percent of homes with radon concentration over 10 pCi/L should have a relative standard error of no more than 0.5, if the estimate is in the neighborhood of 0.5 percent.

(2) Second priority: The survey should provide estimates of the frequency distributions of annual-average radon concentrations in occupied residences for subgroups such as the 10 EPA Regions and for subgroups defined along other lines, such as whether the home is rented or is owner-occupied. The survey should also permit us to assess the relationship between indoor radon concentration and house construction and heating, ventilation, and air conditioning (HVAC) characteristics.

- Precision constraint: The estimate of the percent of homes with radon concentration over 4 pCi/L, for an EPA Region, should have a relative standard error of no more than 0.5, if the estimate is in the neighborhood of 7 percent.

These two precision constraints will be used in developing an optimal sample design. Then, assuming the implementation of the optimal sample design, the likely precision of other domain estimates will be assessed. The setting of expected percentages at 0.5 percent of homes with radon levels over 10 pCi/L and 7 percent with radon levels over 4 pCi/L was based on work by Nero, et al.[1]

1Nero, A.V., Schwehr, M.B., Nazaroff, W.W., Revgon, K.L. (1986). Distribution of Airborne Radon-222 Concentrations in U.S. Homes. Science, Vol. 234, pp. 992-997.

2.2 Optimization Procedure

The optimization procedure that was used develops an optimal sample design that satisfies the specified precision constraints for minimal cost. Two models had to be specified for use in the optimization, a variance model and a cost model. A three stage area probability sample of residences, which was described in Chapter 1, is assumed for each model.

The variance model for this three stage design is given by the following equation:

$$V\{\hat{p}\} = V\{p\}\,[RHO1]/n(1) + V\{p\}(1-[RHO1])[RHO2]/n(1)n(2)$$
$$+ V\{p\}(1-[RHO1] + [RHO1][RHO2] - [RHO2])/n(1)n(2)n(3) \qquad (1)$$

where $V\{p\} = p(1-p)$, the population variance for the proportion p,

RHO1 = the intracluster correlation among secondary sampling units (SSUs) within primary sampling units (PSUs).

RHO2 = the intracluster correlation among housing units (HUs) within SSUs.

n(1) = the number of PSUs selected into the sample.

n(2) = the average number of SSUs selected per PSU.

n(3) = the average number of HUs selected per SSU.

The variance model in equation (1) is appropriate for an unstratified design. For a stratified design, which will be employed for this survey, we would use instead:

$$V\{\hat{p}\} = \Sigma\, W(h)^2 V\{\hat{p},h\},$$

where $V\{\hat{p},h\}$ is given by equation (1) and is the variance of $\hat{p}$ in stratum h, W(h) is the stratum weight, and the sum is taken over all strata.

Precision constraints can be expressed as upper bounds on the relative standard error of estimated parameters. The relative standard error (RSE) of $\hat{p}$ is given by the equation

$$RSE(\hat{p}) = sqr(V\{\hat{p}\})/(\hat{p}),$$

where sqr indicates the square root. Multiple precision constraints can be imposed by establishing upper bounds for acceptable relative standard errors for total population estimates and for domain estimates.

The cost model for the three stage sample design is given by the following equation:

$$\text{Total cost} = C0 + C1*n(1) + C2*n(1)n(2) + C3*n(1)n(2)n(3), \qquad (2)$$

where C0 = fixed cost, that is costs that are not affected by the size or distribution of the sample,

C1 = cost associated with the number of PSUs in the sample, on a cost per PSU basis,

C2 = cost associated with the number of SSUs in the sample, on a cost per SSU basis,

C3 = cost associated with the number of HUs in the sample, on a cost per HU basis.

The values of the cost components used in developing the sample designs are

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71.

The cost components were developed by partitioning the total estimated cost of conducting all phases of the National Residential Radon Survey into subparts and assigning each part either to the fixed cost component or to one of the three stages of the sample. The total cost was made up of

a) all costs for Phase I of the survey, which includes design, data collection, and detector placement, b) all costs for Phase II of the survey, which includes panel maintenance, detector retrieval, and data analysis, and c) $300,000 for the purchase and reading of the radon detectors. (The $300,000 cost for detectors was divided by 5,000, which was the number of responding sample HUs that was budgeted, and assigned to C3 as $60 per participating HU.)

The sample designs and allocations discussed in section 2.3 were determined using the techniques described in Chromy 1981.[2]

2.3 Optimizations Undertaken

In our attempt to develop a sample design that will produce the most precise survey estimates within the allocated budget, we will proceed in a stepwise fashion, examining for each of the following three cases the effect of meeting two different precision constraints:

- Case 1: We assume that the percentage of residences with radon concentration above 4 pCi/L is the same for each of the 10 EPA regions and that the percentage of residences with radon concentration above 10 pCi/L is the same for each of the 10 EPA regions.
- Case 2: We assume that the percentage of homes above each of the two cut-off points varies across EPA regions.
- Case 3: We assume that the percentage of homes above each of the two cut-off points varies across EPA regions and that they can also vary across major geographic areas within an EPA region, as well.

The two precision constraints, which were specified in Section 2.1, are:

2Chromy, J.R. (1981). Variance Estimators for a Sequential Sample Selection Procedure. Current Topics in Survey Sampling, edited by Krewski, D., R. Platek, and J.N.K. Rao, Academic Press, New York.

(1) The national estimate of the percent of homes with radon concentration over 10 pCi/L should have a relative standard error of no more than 0.5, if the estimate is in the neighborhood of 0.5 percent.

(2) The estimate of the percent of homes with radon concentration over 4 pCi/L, for an EPA Region, should have a relative standard error of no more than 0.5, if the estimate is in the neighborhood of 7 percent.

In order to develop the sample allocations shown in the exhibits that are presented, we first set up a simple model for a three stage stratified sample design, which was described in Chapter 1. For this hierarchical design, our primary sampling units (PSUs) were defined as counties, county equivalents, or combinations of these entities. The second stage units (SSUs), to be selected within the selected PSUs, were defined as smaller identifiable compact geographic areas, such as census-defined blocks or enumeration districts (EDs). The third stage units, to be selected within sample SSUs, were the individual housing units (HUs), a random portion of which will be included in the National Residential Radon Survey.

Three sets of assumptions were made in producing the calculations presented in the exhibits provided in this report. The first set consists of the partitioning of the survey costs into the four cost components, C0, C1, C2, and C3, which were described in the previous section.

The second set of assumptions that were made relate to the homogeneity of the radon characteristic of interest within PSUs and SSUs. Two radon characteristics were considered, the proportion of housing units with radon readings greater than 4 pCi/L, and the proportion of housing units with radon readings greater than 10 pCi/L. All of the calculations presented were made assuming that RHO1, which is a measure of the intraclass correlation of the radon characteristic "between" SSUs within PSUs, was equal to .05. RHO2, which is a measure of the correlation "between" HUs within SSUs, was assumed to be .10. These assumptions were made after investigating the homogeneity of radon concentration among the homes measured in the EPA/State radon surveys. (Note that the intraclass correlation is a measure of homogeneity within clusters. For example, if the HUs within each SSU were identical on a given variable, but different from the HUs in other SSUs, the intraclass correlation would be equal to 1. If the HUs within an SSU are no more alike than HUs in all the SSUs combined, the intraclass correlation would be 0. We are assuming some but not perfect homogeneity among the HUs in an SSU and among SSUs within a PSU.)

The third set of assumptions involves the distribution of radon levels across strata, which were defined as the 10 EPA Regions. For Case 1 we assumed that in each of the 10 strata, 7 percent of the housing units will have radon readings over 4 pCi/L and 0.5 percent will have radon readings over 10 pCi/L. For Case 2, these two percentages are allowed to vary from stratum to stratum. For Case 3, the two percentages are allowed to vary from substratum to substratum as well as from stratum to stratum.

Because of the great number of exhibits that will be presented in this Chapter, we have chosen to place them all at the end of the Chapter. A description of each exhibit is provided in Figure 1, which immediately precedes the exhibits, to give the reader a quick reference for the exhibit comparisons.

2.3.1 Case 1

For Case 1, we assumed that in each of the 10 strata, each representing one of the 10 EPA regions, 7 percent of the homes will have radon readings over 4 pCi/L and 0.5 percent will have readings over 10 pCi/L.

Exhibit 1 shows the sample allocation when the only restriction placed on the sample is precision constraint (1), that a national estimate of the magnitude of 0.5 percent have a relative standard error no larger than 0.5. This would mean that the actual standard error would be no larger than (0.5)(0.5 percent) = 0.25 percentage points. To obtain this level of precision, the optimal design calls for a total of 89 PSUs, 398 SSUs, and 1,879 HUs.

Notice that in computing the optimum sample allocation, the cost components and intraclass correlations used are those described above and are the same as those used for all of the other optimizations presented.

Eleven estimates are described, the national estimate of the proportion of homes with radon concentration over 10 pCi/L and, for each of the 10 EPA Regions, an estimate of the proportion of homes with radon concentrations over 4 pCi/L. Both variables, the proportion over 10 pCi/L and the proportion over 4 pCi/L, are set uniformly across the 10 strata, defined by EPA Region, at .005 for the former and .07 for the latter.

The exhibit column headed "Desired Maximum RSE" shows the precision requirements that we used in the calculations. For Exhibit 1 the only precision requirement that we used in the optimization procedure was that a national estimate of .005 have a relative standard error of 0.5, which is shown by the 0.500 entry in this column for the U.S. Total. The other entries in this column were set to 9.000, a number so large that the sample allocation would not be affected by regional constraints. The actual relative standard errors that should result from the sample allocation shown in the lower portion of the table are shown in the column headed "Achieved RSE." For the national estimate of 0.5 percent, the relative standard error will be about 0.500, as shown in the top entry of this column. For regional estimates of about 7 percent, the relative standard errors range from a low of .298 for EPA Region 5 to a high of .728 for EPA Region 8.

Notice that the percentage distributions of the population of HUs and of the sample of HUs are the same, reflecting the fact that an equal probability design is optimal under the set of assumptions employed in the calculations for Exhibit 1. An equal probability design results in a proportional allocation of the sample across strata. For the cost components assumed, the cost of the survey using this allocation would be about $1,717,000.

Exhibit 2 reflects the setting of precision requirements on regional estimates as well as on the national estimates. If for each of the 10 EPA regions we require the estimated proportion of homes with radon measurements over 4 pCi/L to have a relative standard error of no more than 0.5, we would need about 93 PSUs, 415 SSUs, and 1,959 HUs. This allocation increases the sample size over that shown in Exhibit 1 for each of 4 strata, identified as Regions 1, 7, 8 and 10, all of which had relative standard errors larger than 0.5 for the first sample allocation. The somewhat larger sample shown in Exhibit 2 also has a somewhat higher estimated total cost, about $1,756,000 as compared to $1,717,000 for the sample described in Exhibit 1.

If the only purpose of the survey were to generate 11 estimates meeting the stated precision, the sample described in Exhibit 2 would be sufficient. A larger sample size was invisioned, however, because estimates for other domains were also desired, even though precision constraints for these other estimates were not explicitly incorporated into the optimization procedure. Exhibit 3 shows the sample allocation described in Exhibit 2, expanded to a sample size of 5,000 HUs, which was the size that was specified in EPA's Request for Proposal and the size used for estimating costs for the survey. Keeping the same relative allocation of housing units to strata, as was shown in Exhibit 2, each stratum allocation was increased by a constant factor to force the total number of HUs to 5,000. Similarly, each stratum allocation of segments was increased by a constant factor to force the total number of segments to 1,000 and each stratum allocation of PSUs was increased by a constant factor to increase the total number of PSUs to 125. The total estimated cost now equals that budgeted for the all phases of survey, namely about $2,268,000. This type of adjustment will be made for each of the three cases examined, permitting easy comparisons of the different sample allocations.

2.3.2 Case 2

For Case 2, we continue to assume that, nationwide, the proportion of homes with radon concentration over 4 pCi/L is 7 percent and the percent over 10 pCi/L is 0.5 percent, but we allow these percentages to vary from region to region. Using results of short term measurements taken in the EPA/State Radon Surveys that have been conducted and also long term measurements taken by firms that produce alpha track detectors, we classified each region as High, Medium or Low, and assigned approximate percentages to each category. These percentages were then adjusted so that they would produce national estimates of 7 percent and 0.5 percent for the two radon levels, as we have assumed. We arrived at the following set of assumptions:

Area	Assumed percent over 4 pCi/L	Assumed percent over 10 pCi/L
USA	7	0.5
"High" strata	13	1.0
"Medium" strata	7	0.2
"Low" strata	1	0.1

Exhibit 4 shows the optimal sample allocation when the only constraint placed on the sample is that for the national estimate of the percentage of homes having a radon concentration over 10 pCi/L. Assuming the estimate is approximately 0.5 percent, the relative standard error should be no larger than 0.5. This constraint can be satisfied, given the set of assumptions for Case 2, with a sample of 70 PSUs, 313 SSUs, and 1,480 HUs, and a total price tag of $1,525,000. By comparing the two columns "Pop % of HUs" and "Samp % of HUs" you can see that the sample is now more highly concentrated than the population in regions classified as having high radon potential.

Exhibit 5 shows the optimal sample allocation when constraints are placed on regional estimates as well as on the national estimate. The additional constraints that were set are as follows:

- For a regional estimate in the neighborhood of 7 to 13 percent of the homes having radon concentrations over 4 pCi/L, the relative standard error should be no more than 0.5.
- For a regional estimate of 1 percent of the homes having radon concentrations over 4 pCi/L, the relative standard error should be no more than 2.

The constraint on regional estimates of small percentages was relaxed for two reasons. First, from a decision-making standpoint, one does not need as great relative precision for estimates of very small percentages as for estimates of larger percentages. For example, the development of action programs would dictate that when estimating the percent of homes having very high radon concentrations, it is more important that an estimate of 13 percent have a standard error of no more than 6.5 percentage points than it is for an estimate of 1 percent to have a standard error of no more than 0.5 percentage points. One would not, therefore, require that the relative standard error be no greater than 0.5 for estimates of magnitude 1 percent as well as for estimates near 13 percent.

The second reason for relaxing the precision constraints for small estimates is that, in order to achieve a very small relative standard error for a small estimated percentage, a very large proportion of the sample must be concentrated in strata classified as having a low residential radon potential. Because such strata have smaller variances, increasing the sample there reduces the sample size in strata with larger variances causing the precision of the two major national estimates to be reduced.

To achieve the precision constraints listed above for the national estimate of the percent of homes with radon concentration above 10 pCi/L and for the regional estimates of the percent of homes with radon concentration above 4 pCi/L, we would need 77 PSUs, 344 SSUs, and 1,625 HUs, for a total survey cost of $1,595,000. (Exhibit 5.)

By keeping the same relative sample allocation across strata but expanding the sample to include 125 PSUs, 1,000 SSUs, and 5,000 HUs, we have a survey that is expected to cost $2,688,000, the amount budgeted. (See Exhibit 6.)

Our attention so far has been entirely focused on estimates of two characteristics, the percentage of homes with radon concentration over 4 pCi/L and percentage with concentrations over 10 pCi/L. There are of course other characteristics that will be estimated from the survey data. For estimating characteristics having variances that do not parallel those assumed for the two radon variables on which we are optimizing, our "optimal" design will not produce the greatest precision. For characteristics whose variance is the same from stratum to stratum, for example, a proportional allocation, similar to that shown in Exhibit 1, would produce the greatest precision. One of the trade-offs associated with using a design that is optimum for certain estimates is that one may well substantially decrease the precision of other estimates.

In order to assess the potential loss in precision for estimates for which a proportional allocation of the sample to our defined strata is optimal, we have determined the relative standard error for such estimates, assuming we used the design shown in Exhibit 6. Exhibit 7 shows the sample allocation described in Exhibit 6 but presents for the relative standard errors those that we would obtain if the characteristic being estimated actually had the same distribution from stratum to stratum. As can be seen in the column headed "Achieved RSE," a national estimate of 0.5 percent would have a relative standard error of 0.431 and all regional level estimates of the magnitude of 7 percent would have a relative standard error no larger than 0.455, if the population proportions were in fact as given in the second and third columns, namely 7 percent and 0.5 percent.

Another way of looking at the information in Exhibit 7 is to see what the precision of our most important estimates would be if we were all wrong in the way we classified regions into high, medium and low radon potential. If we based our design on the assumption that these classifications were correct and later found that they were incorrect, that in fact the values were the same in all strata, we would, nevertheless, achieve the desired precision. The national estimate of 0.5 percent would have a relative standard error of 0.431 and the regional estimates of 7 percent would have a relative standard error of no more than 0.455. (Exhibit 7.)

2.3.3 Case 3

For Case 3 we continue to assume that, nationwide, the proportion of homes with radon concentration over 4 pCi/L is 7.0 percent and that the proportion of homes with radon concentration over 10 pCi/L is 0.5 percent, but we allow these percentages to vary, not only from one EPA region to another, but also from one state to another within a single EPA region. Using the results of short term measurements taken in EPA/State Radon Surveys and also the results of long term measurements taken by commercial firms that produce alpha track detectors, we classified states or major portions of states within each EPA region into High, Medium, and

Low radon-potential substrata. These classifications are shown in Exhibit 8.

Exhibit 9 shows the optimal sample design for achieving the relative standard error listed in the "Desired Maximum RSE" column and shows the actual relative standard errors that would result from the design in the "Achieved RSE" column. The allocations to the substrata are presented on the second page of Exhibit 9. The design calls for 71 PSUs, 317 SSUs and 1,498 HUs.

Exhibit 10 inflates the allocation shown in Exhibit 9 so that we have the proposed 125 PSUs, 1,000 SSUs, and 5,000 HUs. Note that for both Exhibit 9 and Exhibit 10, the precision constraints were set at 0.5 for the maximum acceptable relative standard error for the national estimate of 0.5 percent of the homes with readings over 10 pCi/L. The constraints on the precision of the regional level estimates for the percent of homes with readings over 4 pCi/L were a maximum relative standard error of 0.5 for estimates of 5.0 percent or larger, a maximum relative standard error of 1.0 for estimates of 2.0 percent or more but less than 5.0 percent and a maximum relative standard error of 2.0 for estimated percentages less than 2.0. With the Exhibit 10 design, the national estimate of 0.5 percent has a relative standard error of 0.325. The precision of the regional estimates varies from a low relative standard error of 0.133 for an estimate in the neighborhood of 11.3 percent for Region 5 to a high of 0.718 for the relative standard error of an estimate of 1.4 percent for Region 9.

Exhibit 11 shows the relative standard errors that would be achieved if we used the allocation described in Exhibit 10, when in reality the substrata did not vary on residential radon concentration as we have assumed, but instead were constant across substrata. The requirement for the national estimate is still met, with a relative standard error of 0.415 for an estimate of 0.5 percent. The precision requirements for the regional estimates are met in all regions except Region 10, which would yield a relative standard error of 0.580 for an estimate of 7.0 percent.

We feel that, even if the substrata values assumed in the optimization are not exactly correct, the worst-case actual occurrence would be that assumed in Exhibit 11. We are not, therefore, presenting a table showing the relative standard errors if the substrata values were the reverse of what we assumed, that is, were actually high in substrata we called low and low in substrata that we called high.

2.4 Recommended Design

The sample design that we recommend is that presented in Exhibit 12. This is essentially the same design as shown in Exhibit 10, with the following adjustments:

- The number of PSUs in a substratum was rounded to a whole number and set at a minimum of 2 PSUs.
- The numbers of SSUs and HUs in a stratum were also rounded to whole numbers. The number of SSUs per PSU was set at 8, and the number of participating HUs per SSU was set at 5, for staffing and work-load reasons. (The actual number of HUs that will be selected into the sample will of course be enough larger than 5 per SSU to yield an average of 5 participating HUs per SSU.)

The distribution of the population of HUs and the proposed sample of HUs is shown on the second page of Exhibit 12. The Low substratum of Region 5 will have the lowest sampling rate, with only 1.6 percent of the sample coming from that substratum, which contains 3.7 percent of the population of HUs. The High substratum of Region 9 will be sampled at the highest rate, with 1.6 percent of the sample coming from this substratum, which contains only 0.5 percent of the population of HUs. The ratio of the lowest to the highest sampling rate is about 7.8. Note that, if the substratum values are as we have assumed here, we will identify about 36 HUs with radon levels over 10 pCi/L using the recommended compared to only about 25 using an equal probability design.

Exhibit 13 contains additional values for the expected precision of estimates of the two key parameters, percent >4 pCi/L (Column 5) and percent >10 pCi/L (Column 6). The precision of domain estimates is given for domains ranging in size from 50 percent to 5 percent of the HUs in the nation. This generalized precision table can be used to evaluate the anticipated precision of estimates for domains not explicitly included in the design criteria, for example, domains based on HU construction or HVAC characteristics.

Row 1 of the table represents the precision for national estimates (100 percent domain). Rows 2 and 3 give the range of the expected precision for 50 percent domain estimates, reflecting two extremes of clustering. Row 2 assumes that half of the HUs in each sample SSU fall in a particular domain. This is the "best case" scenario. Row 3 assumes all of the HUs in half of the sample SSUs are in the domain and none of the HUs in the remaining half of the sample SSUs are in that domain. These two extremes represent a lower bound and a likely upperbound for the RSE of an estimate for a 50 percent domain that covers all of the PSUs. All domains described in Exhibit 13 are assumed to be represented in all 125 sample PSUs, which would be typical of domains defined along other than geographic lines.

Rows 4 and 5 give the likely precision of estimates for domains comprising 25 percent of the population. Rows 6 and 7 and Rows 8 and 9 provide the same information for domains representing 10 percent and 5 percent domains of the population of HUs, respectively.

Inspection of the table reveals that good precision (RSE$<$0.25) can be achieved for estimating the percent $>$4 pCi/L for domains as small as 5 percent. Acceptable precision (RSEs) can be achieved for estimating the percent $>$10 pCi/L for domains as small as 25 percent.

Exhibit 14 presents precision estimates in a format identical to that used in Exhibit 13, but with one important modification. In Exhibit 14 we assume that the key parameters were equal in all of the design strata. This exhibit can be used to evaluate how "robust" the recommended design is to errors in our assumed radon distribution.

As one would expect, the precision of the domain estimates in Exhibit 14 are inferior to those in Exhibit 13. However, the precision constraint for the national estimate of percent $>$10 pCi/L is still attained and acceptable precision (RSE $<$ 0.50) is still attained for the percent $>$4 pCi/L for even the 5 percent domain.

In addition to the precision constraints used in developing the optimal sample design, EPA has a number of other domain estimates which they hope will have small relative standard errors. Some of these domains are described in Exhibit 15. If we wished to estimate the proportion of single family homes with radon concentration over 4 pCi/L, for example, we would expect that an estimate of 7 percent would hae a relative standard error of 0.09, as can be seen in the top row of Exhibit 15. In determining the relative standard error that we would expect, we had to make some assumption about the geographic dispersion of single family homes. We found that about 65 percent of housing units in the population are single family homes and we expect about that same percentage of single family homes in the sample (column 1). We also expect that they will be distributed over 100 percent of the 125 PSUs (column 2), 80 percent of the SSUs (column 3), and 80 percent of the HUs within the SSUs in which they are located. Note that all of the entries in column 5 of Exhibit 5 are less than 0.5. This means that for each of the subgroups described, estimates in the neighborhood of 7 percent would have relative standard errors that we expect to be less than 0.5.

The recommended sample design should, therefore, yield estimates of the percent of homes having high radon concentration with precision sufficient to satisfy EPA's needs. We expect both national estimates and estimates for important domains to have greater than the minimum required precision.

2.5 Comparing the Recommended Design with the Minimal Design

The recommended design shown in Exhibit 12 satisfies a) EPA's two explicitly stated precision requirements and b) the 5,000 sample size specified in EPA's Request for Proposal. Recall that the recommended design was adapted from the design shown in Exhibit 9 by first expanding the sample size to 5,000, using certain guidelines imposed by practical field work constraints, then incorporating certain statistical restrictions, such as rounding the number of PSUs to be selected from a stratum to a whole number and requiring at least two PSUs to be selected per stratum. Exhibit 16 shows the Exhibit 9 sample design adjusted in a similar manner, but to a sample size of about 2,000, rather than a sample size of 5,000.

As can be seen in the last column of the top portion of Exhibit 16, for a sample of 2,130 HUs the national estimate of 0.5 percent of the homes having radon concentration above 10 pCi/L, is subject to an expected relative standard error of 0.49, which meets the precision requirement that the relative standard error be no more than 0.50. Similarly, for regional estimates of the percent of homes with radon levels over 4 pCi/L, the constraints that were used for the recommended design, and listed in section 2.3.3, are satisfied. These constraints were: a maximum relative standard error of 0.5 for estimates of 5.0 percent or larger, a maximum relative standard error of 1.0 for estimates of 2.0 percent or more but less than 5.0 percent, and a maximum relative standard error of 2.0 for estimated percentages less than 2.0.

A sample of 5,000 obviously costs considerably more to implement than a sample of 2,130. We will examine here some of the benefits obtained from using the recommended design rather than the minimal design.

The most apparent advantage a sample of 5,000, rather than a sample of 2,130, is that we will pick up about 2 1/2 times as many HUs with high radon levels. For example, we expect about 36 sample homes with radon levels over 10 pCi/L using the recommended design compared to only about 15 using the minimal design, providing us with a greater ability to characterise high radon level homes.

Even though the minimal sample design, shown in Exhibit 16, satisfies the minimum precision constraints that were set, estimates using this design will not be as precise as those based on the 5,000 size sample design. The relative standard errors contained in Exhibit 17 can be compared to those in Exhibit 13 to see what differences in precision are likely to occur as a result of the difference in sample size. Comparing the values in the fifth columns of the two exhibits reveals that the expected relative standard errors of estimated percentages of homes with radon concentration over 4 pCi/L are 40 to 60 percent higher for estimates based on a sample size of 2,130 than they are for estimates based on a sample size of 5,000. The same relationship holds when comparing the precision of estimates of the proportion of homes with concentrations over 10 pCi/L, the values found in the sixth columns of the two exhibits.

Comparing the expected precision of the estimates described in Exhibit 18 with those shown in Exhibit 15 shows again that a sample of 2,130 HUs can be expected to produce estimates having relative standard errors in the neighborhood of 40 to 60 percent higher than those obtained from a sample of 5,000.

In general, we can conclude that the confidence intervals for domain estimates would be about one and one half times as large using the smaller, minimal sample design than they would be if the recommended design were used. Increase in precision is one of the major advantages derived from an increase in sample size. This type of advantage will also occur when carrying out more complicated statistical analyses of the survey data. The larger sample will of course support more detailed data analysis than the 2,130 sample will.

In addition to comparing the precision of estimates made from each of the two designs, we can also investigate their respective ability to detect differences that exist between different subgroups in the population. Power curves, which will enable us to make these comparisons, are presented in Figures 2, 3, and 4.

To help the reader better understand the concept of power, let us consider three equal size population subgroups that have different percentages of homes with radon concentrations in excess of 4 pCi/L. Let us suppose that the percentage of homes above 4 pCi/L is 7 percent for group A, 8 percent for group B, and 93 percent for group C. What size samples must we have to be able to show that the percentage of homes with radon levels over 4 pCi/L is smaller in group A than it is in group B? What size samples must we have to be able to show that the percentage of such high radon homes is smaller in group A than it is in group C? Intuitively, we would guess that we would need much larger samples to demonstrate the group A and group B relationship than we would need to demonstrate the group A and group C relationship. Our ability to detect a difference between two population subgroups is in fact related to: a) the magnitude of the difference between the two population subgroups, b) the variability of the characteristic within each of the two population subgroups, and c) the size and design of the samples from the two population subgroups. The power tables described in this section demonstrate the effects of two different sample sizes, 5,000 and 2,130, on our ability to detect differences that exist in population subgroups of different sizes. The type of question that the power tables answer is the following: If two population subgroups differ on the percentage of homes with radon levels over 4, with the percentage being larger for group 2 than it is for group 1, what is the likelihood that our survey results will show that group 2 has a higher percentage of high radon homes than group 1?

The curves in Figure 2 show the power of the surveys to detect a difference in the residential radon concentrations of two population subgroups that do in fact differ from one another. More specifically, the curves show the probability of our detecting a difference in the predicted direction if 7 percent of the homes in population subgroup j have radon levels over 4 pCi/L and only 1 percent of the homes in population subgroup i have radon levels over 4. To test for such a difference, we would test the hypothesis that groups i and j have the same proportion of homes with radon levels over 4 pCi/L, which is called the null hypothesis, against the alternative hypothesis that a larger proportion of homes in group j than in group i have radon concentrations over this level. If we use an alpha of .05, the probability of our detecting a difference between p_j and p_i would be that shown by the four curves in Figure 2. If each of two such subgroups is a geographical subpart of the nation, and each contains about 0.05 of the nation's housing units, the sample of 2,130 has only a 40 percent chance of detecting the difference between the groups (the far left point on the lowest curve). On the other hand, the sample of 5,000 has about a 64 percent chance. As we follow the two lower curves to the right to determine the power associated with larger and larger subgroups, we can see that if each geographic subgroup contains about 40 percent of the nation's housing units, the chance of detecting the difference becomes almost a certainty for both of the sample sizes.

The top two curves on the Figure 2 graph show the ability of the two different sample designs to detect differences between subgroups defined on other than geographic lines. These are power curves for somewhat of a "best case" scenario, where instead of comparing two different geographic subgroups, we compare two subgroups, each of which is widely dispersed across all of the sample segments. The "best case" scenario assumes that there is a cancelling out of certain correlation terms, resulting in error variances equivalent to those of a simple random sample. For small subgroups of approximately 0.05 of the population, the sample of 2,130 has only about a 73 percent chance of detecting a difference between the two subgroups, whereas the sample of 5,000 has about a 96 percent chance. This can be seen in the far left points of the two top curves in Figure 2. For larger subgroups, each containing about .20 of the population, the power is about the same for the two designs. Figure 2 shows, therefore, that the recommended sample design has a much greater power than the alternative design to detect a difference between "low" and "medium" radon levels in small population subgroups.

Figure 3 shows comparable power curves for detecting differences between medium level and high level groups, the former defined as 7 percent of homes with radon concentrations over 4 pCi/L and the latter as 13 percent of homes over that level. Notice that the curves are less steep than those shown in Figure 2 and that the differences between the 5,000 sample size design and the 2,130 sample size curves are more pronounced than they were in Figure 2. Even when comparing two large geographic groups, each containing about half of the nation's population, the larger sample size has considerably more power than the smaller sample size, demonstrating the consistent greater ability of the larger sample to detect differences between medium and high level radon groups.

The powers to detect a difference between a "low" radon level group having only 1 percent of the homes over 4 pCi/L and a "high" group having 13 percent of the homes over 4 pCi/L are shown in Figure 4. Again, the larger sample size consistently shows a greater power of detecting differences between even large geographical groups. For nongeographically defined subgroups (the two top curves), the recommended design is clearly more powerful than the alternative design for small subgroups, but for subgroups, each of which is about one quarter or more of the population, the two designs are about equally powerful.

There are, of course, many other ways in which the recommended sample design and the minimal sample design can be compared. The comparisons described in this section simply highlight the greater precision of estimates provided by the recommended design and the greater ability of the recommended design to detect existing differences between population subgroups. The additional cost associated with implementing the larger design does indeed "buy" some important advantages.

2.6 Procedures for Selecting the Sample

In earlier sections we briefly discussed the manner in which the three stage area probability sample of HUs would be selected for the ational Residential Radon Surveys. These procedures will described in greater detail in this section.

2.6.1 Selecting PSUs

A probability sample of PSUs will be selected within each of the 22 strata shown in Exhibit 8. We will select the exact number of PSUs called for in the recommended design described in Exhibit 12.

Using the latest (1987) Market Statistics, Inc. data that provide estimates of the number of housing units for each county in the nation, we will assign a current housing unit count to each county or county equivalent. Those with fewer than 1,000 HUs will be linked with adjoining counties or county equivalents to form PSUs having a minimum of 1,000 HUs.

We will append the following 1980 Census information to each PSU record:

- SMSA Status: Whether or not the PSU is part of an SMSA.
- Urbanization: Percent of HUs located in areas classified as urban.
- Heating equipment: Percent of HUs with warm air furnace or heat pump.
- Heating fuel: Percent of HUs with utility gas.

Using these variables, the PSUs within a stratum will be ordered in a serpentine fashion, so that PSUs with similar characteristics will be next to one another on the list. We will then use Chromy's sequential selection procedure, which was referenced earlier in this chapter, to select the specified number of PSUs from each stratum, with probability proportional to the estimated number of HUs in the PSU. Using a sequential selection procedure on an ordered list produces an effect similar to the effect that could be derived from a formal stratification procedure. Such procedures help assure that all aspects of the population are properly represented in the sample and may provide some increase in the precision of the sample estimates.

2.6.2 Selecting SSUs

The SSUs within each sample PSU will be made up of Census defined blocks or enumeration districts (EDs). Units containing fewer than 25 occupied HUs in the 1980 Census will be combined with nearby units to form SSUs having a minimum size of 25 HUs. We will append the following 1980 Census information to each SSU record:

- **Urbanization:** The place size code for the largest place in the PSU will be identified. An SSU that is all or partly in a place of this size will be classified as high urban. Other SSUs will be classified as low urban. (A place is a heavily populated area, typically, but not always, incorporated as a city or town. Place size codes of 01, indicating a population under 200, to 16, indicating a population of 1,000,000 or more, were assigned to the 23,000 places by the Census Bureau.)

- House value: An index of house value will be computed by taking the weighted average of 1 percent of the house value for owner occupied HUs and the rent value for rental HUs.

- Ownership: Percentage of occupied HUs that are owner occupied.

Within each sample PSU, the SSUs will be ordered in a serpentine fashion using the variables listed above, and Chromy's sequential selection procedure will be used to select exactly 8 SSUs with probability proportional to the number of occupied HUs in the SSU.

Each sample SSU will be identified on a map, and a sketch of the SSU will be prepared. Maps, sketches, listing forms and a copy of RTI's Field Listing Manual will be sent to experienced field representatives, who will visit each sample SSU in the PSU. Each sample SSU that contains 150 or fewer HUs will be listed in its entirety. Using explicit instructions, the field representative will proceed around the SSU in a prespecified manner listing the addresses of all HUs located within the SSU boundaries. In order to avoid listing an excessively large number of HUs, SSUs containing more than 150 HUs may be partitioned into subparts, one or more of which will be randomly selected for listing.

Field representatives will maintain close contact with RTI's sampling personnel, so that any discrepancies between the expected number of HUs and the actual number can be resolved. This close interaction will help avoid problems of improper field identification of sample SSUs and will help maintain field listing costs. Field materials will be returned to RTI and carefully edited, on a flow basis. This will permit us to identify problems at an early stage so that corrective action can be taken.

2.6.3 Selecting HUs

A random systematic sample of a specified number of listed addresses will be selected from each sample SSU. The sample addresses will be sent to the field for inclusion in the National Residential Radon Survey. When a field interviewer visits a sample address, she will include in the sample all HUs at the sample address and all HUs between the sample address and the "next listed" address on the SSU listing form. Using this "half open interval" procedure assures that HUs that were missed in the listing process will be given their proper chance of being included in the survey.

Records showing the probability of selection of each sample address will be maintained so that sampling weights that reflect the sample inclusion probabilities can be assigned. Such sampling weights are needed for the generation of unbiased population estimates from the sample data. All data analysis will be carried out using properly weighted data, that reflect sampling inclusion probabilities, adjustments for nonresponse, and the full complexity of the sample design.

2.6.4 Controlling Sample Size

In order to obtain a sample of 5,000 participating HUs, a much larger sample must be selected. Some sample addresses will yield more than one survey-eligible HU while other sample addresses will yield only HUs that are ineligible for the survey, for reasons such as vacancy or residents having definite plans to move. In addition, some sample households will refuse to participate, others will participate but fail to return their detectors, and others will return detectors that prove to be unreadable. We must estimate the amount of expected loss for each of these types of nonresponse in order to determine the number of sample addresses to be fielded. If we underestimate the expected loss, our sample will end up smaller than the 5,000 we had hoped for. This likelihood could be reduced by using somewhat higher estimates of expected loss, but this approach could bring about higher field costs and a sample considerably larger than the 5,000 targeted.

We do plan to implement the survey using methods that will provide us with additional control over the size of the sample. Two SSUs in each PSU will be randomly identified as "early report" SSUs. The field interviewers will be instructed to work the sample addresses in these SSUs first. Evaluation of the early returns will provide us with additional information on vacancy rates, expectation of moves, response rates, etc. Using this information, we can make a more informed decision on the number of sample addresses that should be included in the survey.

We will have selected from the SSUs that were not designated to be "early report" SSUs a somewhat larger number of addresses than we think we will need. These sample addresses will be randomly partitioned into a regular sample and two reserve samples. Each sample address will be identified and color coded to indicate its classification. Field interviewers will implement only the regular sample addresses until instructed to do otherwise. After we have had a chance to evaluate the results obtained from the early report SSUs, we will decide whether one or both of the reserve sample of addresses is needed. The field interviewers will then be provided with instructions pertaining to the implementation of the reserve samples. Use of this early report-reserve sample methodology will provide us with some additional control over the sample size for a very minimal cost.

Figure 1. Summary of the Exhibits and Figures Presented

The Exhibits that follow are based on a) three different sets of assumptions about the distribution of residential radon concentration and b) the following two types of precision constraints on the survey estimates:

- The estimated percent of homes with residential radon concentration above 10 pci/l, for the nation as a whole, should have a relative standard error of no more than 0.5 when the estimate is in the neighborhood of 0.5 percent.
- The estimated percent of homes with residential radon concentration above 4 pci/l, for each of the 10 EPA Regions, should have a relative standard error of not more than 0.5 when the estimate is in the neighborhood of 7.0 percent.

Exhibits 1-3 are based on the assumption that the distribution of residential radon concentration is the same for all 10 EPA Regions.

Exhibit 1 — The minimum-cost sample allocation when only the national level precision constraint is considered.

Exhibit 2 — The minimum-cost sample allocation when both the national level and the regional level precision constraints are considered.

Exhibit 3 — The Exhibit 2 sample allocation expanded to a sample size of 5,000 housing units.

Exhibits 4-7 are based on the assumption that the distribution of residential radon concentration varies across the 10 EPA Regions.

Exhibit 4 — The minimum-cost sample allocation when only the national level precision constraint is considered.

Exhibit 5 — The minimum-cost sample allocation when both the national level and the regional level precision constraints are considered.

Exhibit 6 — The Exhibit 5 sample allocation expanded to a sample size of 5,000 housing units.

Figure 1 (continued)

Exhibit 7 — The expected relative standard errors of estimates based on the Exhibit 6 sample allocation, if in fact the distribution of residential radon were actually constant across the 10 EPA Regions.

Exhibits 8-12 are based on the assumption that the distribution of residential radon concentration can vary from one geographical area to the next within each of the 10 EPA Regions.

Exhibit 8 — The minimum-cost sample allocation when only the national level precision constraint is considered.

Exhibit 9 — The minimum-cost sample allocation when both the national level and the regional level precision constraints are considered.

Exhibit 10 — The Exhibit 9 sample allocation expanded to a sample size of 5,000 housing units.

Exhibit 11 — The expected relative standard errors of estimates based on the Exhibit 10 sample allocation, if in fact the distribution of residential radon were actually constant across the different substrata.

Exhibit 12 — The recommended design. This is the Exhibit 10 sample allocation adjusted as follows:

- The number of PSUs in a substratum is rounded to a whole number and set at a minimum of 2 PSUs.
- The number of SSUs and HUs were also rounded to whole numbers and for interviewer work-load reasons were set at 8 SSUs per PSU and an expected 5 participating HUs per SSU.

Exhibits 13-15 present expected relative standard errors of estimates based on the recommended sample design described in Exhibit 12.

Exhibit 13 — Expected relative standard errors for domain estimates, when the distribution of residential radon concentration varies across substrata, as shown in Exhibit 12.

Figure 1 (continued)

<u>Exhibit 14</u> Expected relative standard errors for domain estimates, if in fact the distribution of residential radon were actually constant across substrata.

<u>Exhibit 15</u> Examples of relative standard errors for domain estimates, when the distribution of residential radon concentration varies across substrata, as shown in Exhibit 12.

<u>Exhibit 16-18</u> present expected relative standard errors of estimates based on the minimal design in Exhibit 9.

<u>Exhibit 16</u> <u>The minimal practical design</u>. This is the Exhibit 9 sample allocation adjusted as follows:

- The number of PSUs in a substratum is rounded to a whole number and were set at a minimum of 2 PSUs.
- The number of SSUs and HUs were also rounded to whole numbers and were set at 6 SSUs per PSU and an expected 5 participating HUs per SSU.

<u>Exhibit 17</u> Expected of relative standard error for domain estimates for the minimal design, when the distribution of residential radon concentration varies across substrata, as shown in Exhibit 16.

<u>Exhibit 18</u> Examples relative standard error of domain estimates for the minimal design, when the distribution of residential radon concentration varies across substrata, as shown in Exhibit 16.

<u>Figures 2-3</u> illustrate the power of detecting differences between subgroups for the recommended design and the minimal practical design.

Exhibit 1. The Minimum-Cost Sample Allocation When Only the National Level Precision Constraint is Considered. (Calculations Assume that the Distribution of Residential Radon Concentration Is the Same For All 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.500
Region 1	0.070	0.00500	9.000	0.563
Region 2	0.070	0.00500	9.000	0.399
Region 3	0.070	0.00500	9.000	0.400
Region 4	0.070	0.00500	9.000	0.303
Region 5	0.070	0.00500	9.000	0.298
Region 6	0.070	0.00500	9.000	0.384
Region 7	0.070	0.00500	9.000	0.577
Region 8	0.070	0.00500	9.000	0.728
Region 9	0.070	0.00500	9.000	0.350
Region 10	0.070	0.00500	9.000	0.668

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	4.7	21.0	98.9	5.3	5.3
2	9.3	41.7	196.9	10.5	10.5
3	9.3	41.5	195.7	10.4	10.4
4	16.2	72.4	342.1	18.2	18.2
5	16.7	74.7	352.8	18.8	18.8
6	10.1	45.1	212.8	11.3	11.3
7	4.5	19.9	94.1	5.0	5.0
8	2.8	12.5	59.2	3.1	3.1
9	12.1	54.3	256.4	13.6	13.6
10	3.3	14.9	70.2	3.7	3.7
Total	88.9	398.0	1,879.2	100.0	100.0

Exhibit 2. The Minimum-cost Sample Allocation When Both the National Level and the Regional Level Precision Constraints are Considered. (Calculations Assume that the Distribution of Residential Radon Concentration Is the Same for All 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.500
Region 1	0.070	0.00500	0.500	0.500
Region 2	0.070	0.00500	0.500	0.413
Region 3	0.070	0.00500	0.500	0.414
Region 4	0.070	0.00500	0.500	0.313
Region 5	0.070	0.00500	0.500	0.308
Region 6	0.070	0.00500	0.500	0.397
Region 7	0.070	0.00500	0.500	0.500
Region 8	0.070	0.00500	0.500	0.500
Region 9	0.070	0.00500	0.500	0.362
Region 10	0.070	0.00500	0.500	0.500

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	5.9	26.6	125.5	5.3	6.4
2	8.7	39.0	184.3	10.5	9.4
3	8.7	38.8	183.2	10.4	9.4
4	15.1	67.8	320.1	18.2	16.3
5	15.6	69.9	330.2	18.8	16.9
6	9.4	42.2	199.1	11.3	10.2
7	5.9	26.6	125.5	5.0	6.4
8	5.9	26.6	125.5	3.1	6.4
9	11.4	50.8	240.0	13.6	12.3
10	5.9	26.6	125.5	3.7	6.4
Total	92.6	414.8	1,958.8	100.0	100.0

Exhibit 3. The Exhibit 2 Sample Allocation Expanded to a Sample Size of 5,000 Housing Units. (Calculations Assume that the Distribution of Residential Radon Concentration Is the Same for All 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.372
Region 1	0.070	0.00500	0.500	0.372
Region 2	0.070	0.00500	0.500	0.307
Region 3	0.070	0.00500	0.500	0.308
Region 4	0.070	0.00500	0.500	0.233
Region 5	0.070	0.00500	0.500	0.229
Region 6	0.070	0.00500	0.500	0.295
Region 7	0.070	0.00500	0.500	0.372
Region 8	0.070	0.00500	0.500	0.372
Region 9	0.070	0.00500	0.500	0.269
Region 10	0.070	0.00500	0.500	0.372

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	8.0	64.0	320.2	5.3	6.4
2	11.8	94.1	470.5	10.5	9.4
3	11.7	93.5	467.6	10.4	9.4
4	20.4	163.4	817.2	18.2	16.3
5	21.1	168.6	842.8	18.8	16.9
6	12.7	101.7	508.3	11.3	10.2
7	8.0	64.0	320.2	5.0	6.4
8	8.0	64.0	320.2	3.1	6.4
9	15.3	122.5	612.6	13.6	12.3
10	8.0	64.0	320.2	3.7	6.4
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 4. The Minimum-Cost Sample Allocation When Only the National Level Precision Constraint is Considered. (Calculations Assume that the Distribution of Residential Radon Concentration Varies across the 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00499	0.500	0.500
Region 1	0.070	0.00200	9.000	0.751
Region 2	0.130	0.01000	9.000	0.253
Region 3	0.130	0.01000	9.000	0.254
Region 4	0.010	0.00100	9.000	1.310
Region 5	0.130	0.01000	9.000	0.189
Region 6	0.010	0.00100	9.000	1.661
Region 7	0.070	0.00200	9.000	0.770
Region 8	0.130	0.01000	9.000	0.462
Region 9	0.010	0.00100	9.000	1.513
Region 10	0.070	0.00200	9.000	0.891

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	2.6	11.8	55.7	5.3	3.8
2	11.7	52.3	246.8	10.5	16.7
3	11.6	52.0	245.3	10.4	16.6
4	6.4	28.8	136.2	18.2	9.2
5	20.9	93.6	442.1	18.8	29.9
6	4.0	17.9	84.7	11.3	5.7
7	2.5	11.2	53.0	5.0	3.6
8	3.5	15.7	74.2	3.1	5.0
9	4.8	21.6	102.1	13.6	6.9
10	1.9	8.4	39.5	3.7	2.7
Total	70.0	313.4	1,479.5	100.0	100.0

Exhibit 5. The Minimum-Cost Sample Allocation When Both the National Level and the Regional Level Precision Constraints Are Considered. (Calculations Assume that the Distribution of Residential Radon Concentration Varies across the 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. **Total**	0.070	0.00499	0.500	0.500
Region 1	0.070	0.00200	0.500	0.500
Region 2	0.130	0.01000	0.500	0.261
Region 3	0.130	0.01000	0.500	0.262
Region 4	0.010	0.00100	2.000	1.353
Region 5	0.130	0.01000	0.500	0.195
Region 6	0.010	0.00100	2.000	1.715
Region 7	0.070	0.00200	0.500	0.500
Region 8	0.130	0.01000	0.500	0.477
Region 9	0.010	0.00100	2.000	1.563
Region 10	0.070	0.00200	0.500	0.500

Optimal **sample allocation** by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	5.9	26.6	125.5	5.3	7.7
2	10.9	49.0	231.4	10.5	14.2
3	10.9	48.7	230.0	10.4	14.2
4	6.0	27.0	127.7	18.2	7.9
5	19.6	87.8	414.5	18.8	25.5
6	3.8	16.8	79.4	11.3	4.9
7	5.9	26.6	125.5	5.0	7.7
8	3.3	14.7	69.5	3.1	4.3
9	4.5	20.3	95.7	13.6	5.9
10	5.9	26.6	125.5	3.7	7.7
Total	76.8	344.1	1,624.7	100.0	100.0

Exhibit 6. The Exhibit 5 Sample Allocation Expanded to a Sample Size of 5,000 Housing Units. (Calculations Assume that the Distribution of Residential Radon Concentration Varies across the 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00499	0.500	0.339
Region 1	0.070	0.00200	0.500	0.339
Region 2	0.130	0.01000	0.500	0.177
Region 3	0.130	0.01000	0.500	0.177
Region 4	0.010	0.00100	2.000	0.916
Region 5	0.130	0.01000	0.500	0.132
Region 6	0.010	0.00100	2.000	1.161
Region 7	0.070	0.00200	0.500	0.339
Region 8	0.130	0.01000	0.500	0.323
Region 9	0.010	0.00100	2.000	1.058
Region 10	0.070	0.00200	0.500	0.339

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	9.7	77.2	386.1	5.3	7.7
2	17.8	142.4	712.2	10.5	14.2
3	17.7	141.6	707.8	10.4	14.2
4	9.8	78.6	393.0	18.2	7.9
5	31.9	255.1	1,275.7	18.8	25.5
6	6.1	48.9	244.4	11.3	4.9
7	9.7	77.2	386.1	5.0	7.7
8	5.4	42.8	214.0	3.1	4.3
9	7.4	58.9	294.6	13.6	5.9
10	9.7	77.2	386.1	3.7	7.7
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 7. The Expected Relative Standard Errors of Estimates Based on the Exhibit 6 Sample Allocation, If in fact the Distribution of Residential Radon Were Actually Constant across the 10 EPA Regions.

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.431
Region 1	0.070	0.00500	0.500	0.339
Region 2	0.070	0.00500	0.500	0.249
Region 3	0.070	0.00500	0.500	0.250
Region 4	0.070	0.00500	2.000	0.336
Region 5	0.070	0.00500	0.500	0.186
Region 6	0.070	0.00500	2.000	0.425
Region 7	0.070	0.00500	0.500	0.339
Region 8	0.070	0.00500	0.500	0.455
Region 9	0.070	0.00500	2.000	0.388
Region 10	0.070	0.00500	0.500	0.339

Optimal sample allocation by EPA Region

Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	9.7	77.2	386.1	5.3	7.7
2	17.8	142.4	712.2	10.5	14.2
3	17.7	141.6	707.8	10.4	14.2
4	9.8	78.6	393.0	18.2	7.9
5	31.9	255.1	1,275.7	18.8	25.5
6	6.1	48.9	244.4	11.3	4.9
7	9.7	77.2	386.1	5.0	7.7
8	5.4	42.8	214.0	3.1	4.3
9	7.4	58.9	294.6	13.6	5.9
10	9.7	77.2	386.1	3.7	7.7
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 8 Classification of States into Substrata within Strata Defined Along the Lines of the EPA Regions

EPA Region	Substratum	State
Region 1:	High:	ME, NH, VT.
	Medium:	MA, CT, RI.
Region 2:	High:	northern NJ.
	Medium:	NY.
	Low:	southern NJ.
Region 3:	High:	PA, western MD, WV, western VA.
	Low:	DE, central and eastern VA.
Region 4:	High:	western NC, western SC, northern GA, northern AL, eastern TN.
	Medium:	KY, western and central TN.
	Low:	central and eastern NC, eastern SC, southern GA, southern AL, MS, FL.
Region 5:	High:	MN, WI, IL, IN, OH.
	Low:	MI.
Region 6:	High:	NM
	Medium:	OK, western and central TX, northern AR.
	Low:	LA, southern AR, southeastern TX.
Region 7:	High:	NE, IA.
	Medium:	KS, MO.
Region 8:	High:	MT, WY, UT, CO, ND, SD.
Region 9:	High:	NV.
	Low:	CA, AZ, HI.
Region 10:	High:	AK, ID.
	Low:	WA, OR.

The above classifications were made using the following data and procedures:

- Using data from the first two years of State Radon Surveys.
- Using the results of ATD testing by Landauer and Terradex, presented at the Radon Symposium in Denver in October, 1988.
- Grouping states with similar geographic location and terrain into the same stratum as contiguous areas.
- The percentage of homes with a basement was not taken into consideration. This information is available for the State Radon Survey samples, but was not provided for the Landauer-Terradex homes. The vast majority of homes in the northern part of the nation do have basements, but the proportion of homes with basements is quite small in some southern states.

Exhibit 9. The Minimum-Cost Sample Allocation When Both the National Level and the Regional Level Precision Constraints are Considered. (Calculations Assume that the Distribution of Residential Radon Concentration Can Vary from One Geographical Area to the Next within Each of the 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.500
Region 1	0.085	0.00471	0.500	0.500
Region 2	0.081	0.00459	0.500	0.407
Region 3	0.106	0.00834	0.500	0.286
Region 4	0.042	0.00298	1.000	0.440
Region 5	0.113	0.00887	0.500	0.204
Region 6	0.044	0.00244	1.000	0.588
Region 7	0.095	0.00592	0.500	0.500
Region 8	0.138	0.01080	0.500	0.441
Region 9	0.014	0.00134	2.000	1.105
Region 10	0.031	0.00260	1.000	1.000

Optimal sample allocation by EPA Region

EPA Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	4.7	21.2	99.9	5.3	6.7
2	7.4	33.0	155.8	10.5	10.4
3	9.8	43.9	207.1	10.4	13.8
4	9.5	42.7	201.7	18.2	13.5
5	18.5	82.7	390.4	18.8	26.1
6	5.7	25.7	121.4	11.3	8.1
7	4.2	18.8	88.6	5.0	5.9
8	3.6	16.1	75.9	3.1	5.1
9	5.1	23.0	108.4	13.6	7.2
10	2.3	10.2	48.3	3.7	3.2
Total	70.8	317.2	1,497.6	100.0	100.0

Exhibit 9 (Continued)

Sample allocation by stratum

EPA Region	Radon class	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs	Samp Rate	Rel. Samp Rate
1	HIGH	1.5	6.8	32.2	1.2	2.2	1.86	3.79
1	MED	3.2	14.3	67.7	4.1	4.5	1.10	2.24
2	HIGH	2.7	11.9	56.1	2.3	3.7	1.61	3.27
2	MED	4.4	19.9	94.0	7.4	6.3	0.85	1.73
2	LOW	0.3	1.2	5.7	0.8	0.4	0.49	1.00
3	HIGH	8.9	39.8	187.9	7.8	12.5	1.61	3.27
3	LOW	0.9	4.1	19.3	2.6	1.3	0.49	1.00
4	HIGH	3.5	15.5	73.4	3.0	4.9	1.61	3.27
4	MED	1.9	8.4	39.6	3.1	2.6	0.85	1.73
4	LOW	4.2	18.8	88.8	12.1	5.9	0.49	1.00
5	HIGH	17.2	76.9	363.2	15.1	24.3	1.61	3.27
5	LOW	1.3	5.8	27.2	3.7	1.8	0.49	1.00
6	HIGH	0.7	3.1	14.6	0.6	1.0	1.61	3.27
6	MED	3.1	14.0	66.1	5.2	4.4	0.85	1.73
6	LOW	1.9	8.6	40.8	5.5	2.7	0.49	1.00
7	HIGH	2.2	9.8	46.4	1.9	3.1	1.65	3.36
7	MED	2.0	8.9	42.2	3.1	2.8	0.90	1.83
8	HIGH	3.6	16.1	75.9	3.1	5.1	1.61	3.27
9	HIGH	0.5	2.4	11.3	0.5	0.8	1.61	3.27
9	LOW	4.6	20.6	97.0	13.2	6.5	0.49	1.00
10	HIGH	0.9	4.0	19.0	0.6	1.3	2.09	4.24
10	LOW	1.4	6.2	29.2	3.1	2.0	0.62	1.27
Total		70.8	317.2	1,497.6	100.0	100.0		

Exhibit 10. The Exhibit 9 Sample Allocation Expanded to a Sample Size of 5,000 Housing Units. (Calculations Assume that the Distribution of Residential Radon Concentration Can Vary from One Geographical Area to the Next within Each of the 10 EPA Regions.)

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.325
Region 1	0.085	0.00471	0.500	0.325
Region 2	0.081	0.00459	0.500	0.265
Region 3	0.106	0.00834	0.500	0.186
Region 4	0.042	0.00298	1.000	0.286
Region 5	0.113	0.00887	0.500	0.133
Region 6	0.044	0.00244	1.000	0.382
Region 7	0.095	0.00592	0.500	0.325
Region 8	0.138	0.01080	0.500	0.287
Region 9	0.014	0.00134	2.000	0.718
Region 10	0.031	0.00260	1.000	0.650

Optimal sample allocation by EPA Region

EPA Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	8.3	66.7	333.7	5.3	6.7
2	13.0	104.0	520.2	10.5	10.4
3	17.3	138.3	691.6	10.4	13.8
4	16.8	134.7	673.5	18.2	13.5
5	32.6	260.7	1,303.5	18.8	26.1
6	10.1	81.1	405.4	11.3	8.1
7	7.4	59.2	295.8	5.0	5.9
8	6.3	50.7	253.3	3.1	5.1
9	9.0	72.4	361.9	13.6	7.2
10	4.0	32.2	161.1	3.7	3.2
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 10 (Continued)

Sample allocation by stratum

EPA Region	Radon class	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs	Samp Rate	Rel. Samp Rate
1	HIGH	2.7	21.5	107.6	1.2	2.2	1.86	3.79
1	MED	5.7	45.2	226.1	4.1	4.5	1.10	2.24
2	HIGH	4.7	37.5	187.4	2.3	3.7	1.61	3.27
2	MED	7.8	62.8	313.8	7.4	6.3	0.85	1.73
2	LOW	0.5	3.8	19.1	0.8	0.4	0.49	1.00
3	HIGH	15.7	125.4	627.2	7.8	12.5	1.61	3.27
3	LOW	1.6	12.9	64.4	2.6	1.3	0.49	1.00
4	HIGH	6.1	49.0	245.0	3.0	4.9	1.61	3.27
4	MED	3.3	26.4	132.1	3.1	2.6	0.85	1.73
4	LOW	7.4	59.3	296.4	12.1	5.9	0.49	1.00
5	HIGH	30.3	242.5	1,212.6	15.1	24.3	1.61	3.27
5	LOW	2.3	18.2	90.9	3.7	1.8	0.49	1.00
6	HIGH	1.2	9.8	48.8	0.6	1.0	1.61	3.27
6	MED	5.5	44.1	220.5	5.2	4.4	0.85	1.73
6	LOW	3.4	27.2	136.1	5.5	2.7	0.49	1.00
7	HIGH	3.9	31.0	154.9	1.9	3.1	1.65	3.36
7	MED	3.5	28.2	140.9	3.1	2.8	0.90	1.83
8	HIGH	6.3	50.7	253.3	3.1	5.1	1.61	3.27
9	HIGH	0.9	7.6	37.9	0.5	0.8	1.61	3.27
9	LOW	8.1	64.8	324.0	13.2	6.5	0.49	1.00
10	HIGH	1.6	12.7	63.5	0.6	1.3	2.09	4.24
10	LOW	2.4	19.5	97.5	3.1	2.0	0.62	1.27
Total		125.0	1,000.0	5,000.0	100.0	100.0		

Exhibit 11. The Expected Relative Standard Errors of Estimates Based on the Exhibit 10 Sample Allocation, If in fact the Distribution of Residential Radon Were Actually Constant across the Different Substrata.

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U. S. Total	0.070	0.00500	0.500	0.415
Region 1	0.070	0.00500	0.500	0.373
Region 2	0.070	0.00500	0.500	0.307
Region 3	0.070	0.00500	0.500	0.288
Region 4	0.070	0.00500	1.000	0.283
Region 5	0.070	0.00500	0.500	0.206
Region 6	0.070	0.00500	1.000	0.350
Region 7	0.070	0.00500	0.500	0.404
Region 8	0.070	0.00500	0.500	0.418
Region 9	0.070	0.00500	2.000	0.359
Region 10	0.070	0.00500	1.000	0.580

Optimal sample allocation by EPA Region

EPA Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	8.3	66.7	333.7	5.3	6.7
2	13.0	104.0	520.2	10.5	10.4
3	17.3	138.3	691.6	10.4	13.8
4	16.8	134.7	673.5	18.2	13.5
5	32.6	260.7	1,303.5	18.8	26.1
6	10.1	81.1	405.4	11.3	8.1
7	7.4	59.2	295.8	5.0	5.9
8	6.3	50.7	253.3	3.1	5.1
9	9.0	72.4	361.9	13.6	7.2
10	4.0	32.2	161.1	3.7	3.2
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 11 (Continued)

Sample allocation by stratum

EPA Region	Radon class	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs	Samp Rate	Rel. Samp Rate
1	HIGH	2.7	21.5	107.6	1.2	2.2	1.86	3.79
1	MED	5.7	45.2	226.1	4.1	4.5	1.10	2.24
2	HIGH	4.7	37.5	187.4	2.3	3.7	1.61	3.27
2	MED	7.8	62.8	313.8	7.4	6.3	0.85	1.73
2	LOW	0.5	3.8	19.1	0.8	0.4	0.49	1.00
3	HIGH	15.7	125.4	627.2	7.8	12.5	1.61	3.27
3	LOW	1.6	12.9	64.4	2.6	1.3	0.49	1.00
4	HIGH	6.1	49.0	245.0	3.0	4.9	1.61	3.27
4	MED	3.3	26.4	132.1	3.1	2.6	0.85	1.73
4	LOW	7.4	59.3	296.4	12.1	5.9	0.49	1.00
5	HIGH	30.3	242.5	1,212.6	15.1	24.3	1.61	3.27
5	LOW	2.3	18.2	90.9	3.7	1.8	0.49	1.00
6	HIGH	1.2	9.8	48.8	0.6	1.0	1.61	3.27
6	MED	5.5	44.1	220.5	5.2	4.4	0.85	1.73
6	LOW	3.4	27.2	136.1	5.5	2.7	0.49	1.00
7	HIGH	3.9	31.0	154.9	1.9	3.1	1.65	3.36
7	MED	3.5	28.2	140.9	3.1	2.8	0.90	1.83
8	HIGH	6.3	50.7	253.3	3.1	5.1	1.61	3.27
9	HIGH	0.9	7.6	37.9	0.5	0.8	1.61	3.27
9	LOW	8.1	64.8	324.0	13.2	6.5	0.49	1.00
10	HIGH	1.6	12.7	63.5	0.6	1.3	2.09	4.24
10	LOW	2.4	19.5	97.5	3.1	2.0	0.62	1.27
Total		125.0	1,000.0	5,000.0	100.0	100.0		

Exhibit 12. The Recommended Design.

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $432.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U.S. Total	0.070	0.00500	0.500	0.329
Region 1	0.085	0.00471	0.500	0.337
Region 2	0.081	0.00459	0.500	0.273
Region 3	0.106	0.00834	0.500	0.188
Region 4	0.042	0.00298	1.000	0.281
Region 5	0.113	0.00887	0.500	0.134
Region 6	0.044	0.00244	1.000	0.395
Region 7	0.095	0.00592	0.500	0.340
Region 8	0.138	0.01080	0.500	0.294
Region 9	0.014	0.00134	2.000	0.700
Region 10	0.031	0.00260	1.000	0.664

Optimal Sample Allocation by EPA Region

EPA Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	8.0	64.0	320.0	5.3	6.4
2	14.0	112.0	560.0	10.5	11.2
3	17.0	136.0	680.0	10.4	13.6
4	17.0	136.0	680.0	18.2	13.6
5	32.0	256.0	1,280.0	18.8	25.6
6	10.0	80.0	400.0	11.3	8.0
7	7.0	56.0	280.0	5.0	5.6
8	6.0	48.0	240.0	3.1	4.8
9	10.0	80.0	400.0	13.6	8.0
10	4.0	32.0	160.0	3.7	3.2
Total	125.0	1,000.0	5,000.0	100.0	100.0

Exhibit 12 (Continued)

Optimal Sample Allocation by Stratum

EPA Region	Radon class	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs	Samp Rate	Rel. Samp Rate
1	HIGH	3.0	24.0	120.0	1.2	2.4	2.079	4.801
1	MED	5.0	40.0	200.0	4.1	4.0	0.973	2.247
2	HIGH	5.0	40.0	200.0	2.3	4.0	1.717	3.965
2	MED	7.0	56.0	280.0	7.4	5.6	0.759	1.754
2	LOW	2.0	16.0	80.0	0.8	1.6	2.060	4.758
3	HIGH	15.0	120.0	600.0	7.8	12.0	1.539	3.553
3	LOW	2.0	16.0	80.0	2.6	1.6	0.611	1.412
4	HIGH	6.0	48.0	240.0	3.0	4.8	1.576	3.639
4	MED	4.0	32.0	160.0	3.1	3.2	1.031	2.380
4	LOW	7.0	56.0	280.0	12.1	5.6	0.465	1.073
5	HIGH	30.0	240.0	1,200.0	15.1	24.0	1.592	3.676
5	LOW	2.0	16.0	80.0	3.7	1.6	0.433	1.000
6	HIGH	2.0	16.0	80.0	0.6	1.6	2.636	6.086
6	MED	5.0	40.0	200.0	5.2	4.0	0.772	1.782
6	LOW	3.0	24.0	120.0	5.5	2.4	0.434	1.002
7	HIGH	4.0	32.0	160.0	1.9	3.2	1.709	3.947
7	MED	3.0	24.0	120.0	3.1	2.4	0.765	1.767
8	HIGH	6.0	48.0	240.0	3.1	4.8	1.524	3.519
9	HIGH	2.0	16.0	80.0	0.5	1.6	3.397	7.844
9	LOW	8.0	64.0	320.0	13.2	6.4	0.486	1.122
10	HIGH	2.0	16.0	80.0	0.6	1.6	2.628	6.069
10	LOW	2.0	16.0	80.0	3.1	1.6	0.512	1.182
Total		125.0	1,000.0	5,000.0	100.0	100.0		

No of Expected HUs with radon level > 4 = 491.6
No of Expected HUs with radon level > 10 = 36.3

Exhibit 13 Expected Precision of Domain Estimates of the Percent of Homes with Radon Concentration Above 4pCi/L and Above 10pCi/L for the Recommended Design if the Residential Radon Levels Vary Across Strata, as Shown in Exhibit 12

Row No.	Percent Domain (1)	Percent of PSUs (2)	Percent Segments (3)	Percent HU's within Segment (4)	Expected Precision (RSE) for Percent >4pCi/L (5)	Expected Precision (RSE) for Percent >10pCi/L (6)
1	100	100	100	100	0.09	0.33
2	50	100	100	50	0.10	0.37
3			50	100	0.10	0.40
4	25	100	100	25	0.11	0.44
5			25	100	0.13	0.49
6	10	100	50	20	0.16	0.61
7			10	100	0.18	0.70
8	5	100	25	20	0.21	0.83
9			5	100	0.25	0.96

For example, if we estimate that 0.5 percent of all homes in the nation have radon concentrations above 10 pCi/L, the "Percent Domain" is 100 because the estimate pertains to 100 percent of the survey eligible homes in the nation. Each of the values for columns 2, 3, and 4 is also 100 because our estimate would use the entire sample, all sample HUs in all sample SSUs in all sample PSUs. We would therefore read the relative standard error for our estimate from row 1 column 6, and find that it is 0.33. Not that this is the same relative standard error that was provided in Exhibit 12 under the "Achieved RSE" for the "U.S. Total" domain.

Let us consider now estimates describing a subgroup in the population. Suppose that subgroup A consists of half of the homes in the nation, and that these homes are distributed uniformly over the entire nation. We would use row 2 to determine the relative standard error of our estimate because we would expect our subgroup to be represented in all of the sample PSUs, all of the sample SSUs, and half of the sample HUs in each sample SSU. If we consider subgroup B that also consists of half of the homes in the nation, but homes in only half of the SSUs, we would use row 3 to determine the relative standard error of the estimate.

Exhibit 14 Expected Precision of Domain Estimates of the Percent of Homes with Radon Concentration Above 4pCi/L and Above 10pCi/L for the Recommended Design if the Radon Distribution is Uniform Across Strata

Row No.	Percent Domain (1)	Percent of PSUs (2)	Percent Segments (3)	Percent HU's within Segment (4)	Expected Precision (RSE) for Percent >4pCi/L (5)	>10pCi/L (6)
1	100	100	100	100	0.11	0.42
2	50	100	100	50	0.12	0.47
3			50	100	0.13	0.50
4	25	100	100	25	0.15	0.56
5			25	100	0.16	0.63
6	10	100	50	20	0.20	0.79
7			10	100	0.23	0.91
8	5	100	25	20	0.27	1.06
9			5	100	0.32	1.24

For example, if we estimate that 0.5 percent of all homes in the nation have radon concentrations above 10 pCi/L, the "Percent Domain" is 100 because the estimate pertains to 100 percent of the survey eligible homes in the nation. Each of the values for columns 2, 3, and 4 is also 100 because our estimate would use the entire sample, all sample HUs in all sample SSUs in all sample PSUs. We would therefore read the relative standard error for our estimate from row 1 column 6, and find that it is 0.42. Note that this is larger than the relative standard error that was shown in row 1 column 6 of Exhibit 13 because Exhibit 14 assumes that the radon levels do not vary from one geographic area to the next, as we assumed in developing the optimal sample design. Exhibit 14 provides a "worst case" scenario, showing the relative standard errors for estimates if the assumptions we made about radon levels differing from one geographic area to the next were not correct and that instead residential radon levels were the same all over the nation.

The procedures for using rows 2-9 of Exhibit 14 follow the same logic as was described in Exhibit 13.

Exhibit 15 Some Additional Domain Estimates Where a Maximum Relative Standard Error of 0.50 is Desired for the Percent of Homes with Radon Levels above 4 pCi/L (Recommended Design)

Domain Description	Likely Distribution[3]				Expected Precision for percent > 4 pCi/L
	Percent of total population	Percent of PSUs	Percent of SSUs	Percent of HUs within a segment	
Single family homes	65	100	80	80	0.09
Residences in multi-unit structures	35	100	60	60	0.10
Homes with 1+ smokers	25	100	100	25	0.11
Homes with 0 smokers	75	100	100	25	0.09
Homes with 1+ children under age 12	15	100	50	30	0.15
Homes without children under age 12	85	100	100	85	0.09
Homes with 1+ children under age 12 and 1+ smokers	5	100	25	20	0.21
Average radon level for homes with basements	40	80	60	70	0.10
Average radon level for homes without basements	60	100	80	75	0.10

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3 Footnote appears on following page.

Exhibit 15 (Continued)

The "Likely Distribution" information provided in Exhibit 15 is based on the most recent data we could find plus some educated guessing. For example, the 1988 Statistical Abstract provides an estimate that in 1983 67 percent of the housing units in the nation were in one unit structures. Because we were providing only very rough "estimates," we rounded the number to 65 percent. It seemed reasonable to expect that there will be single family homes in all or virtually all PSUs, so we listed 100 as the percent of PSUs that would contain single family homes. Because neighborhoods tend to be somewhat homogeneous on a characteristic such as single family homes, we "guessed" that about 80 percent of the SSUs would have one or more such homes and that on the average about 80 percent of the homes in these SSUs would be in single family structures. This type of reasoning provided some rough guidelines for us to use to determine the approximate relative standard errors that we would expect for estimates of the percentage of homes with radon levels greater than 4pCi/L. The precision figures listed in the far right column of Exhibit 15 were obtained a) assuming that the "likely distribution" information was correct, and b) using the values in Exhibit 13 and interpolating.

Exhibit 16. Minimal Practical Design. (Based on Allocation in Exhibit 9).

Assumed cost components

C0 = $810,928.00
C1 = $4,567.57
C2 = $497.78
C3 = $174.71

Assumed intracluster corr coef. RHO1 = 0.05
Assumed intracluster corr coef. RHO2 = 0.10

Domain	Prop>4	Prop>10	Desired Maximum RSE	Achieved RSE
U.S. Total	0.070	0.00500	0.500	0.490
Region 1	0.085	0.00468	0.500	0.460
Region 2	0.075	0.00417	0.500	0.409
Region 3	0.108	0.00850	0.500	0.289
Region 4	0.044	0.00322	1.000	0.403
Region 5	0.112	0.00877	0.500	0.199
Region 6	0.048	0.00256	1.000	0.636
Region 7	0.095	0.00587	0.500	0.469
Region 8	0.137	0.01068	0.500	0.385
Region 9	0.014	0.00133	2.000	1.198
Region 10	0.031	0.00258	1.000	0.710

Optimal Sample Allocation by EPA Region

EPA Region	No. of Cty's	No. of SEGs	No. of HUs	Pop % of HUs	Samp % of HUs
1	5.0	30.0	150.0	5.3	7.0
2	8.0	48.0	240.0	10.5	11.3
3	9.0	54.0	270.0	10.4	12.7
4	9.0	54.0	270.0	18.2	12.7
5	17.0	102.0	510.0	18.8	23.9
6	6.0	36.0	180.0	11.3	8.5
7	4.0	24.0	120.0	5.0	5.6
8	4.0	24.0	120.0	3.1	5.6
9	5.0	30.0	150.0	13.6	7.0
10	4.0	24.0	120.0	3.7	5.6
Total	71.0	426.0	2,130.0	100.0	100.0

Exhibit 17 Expected Precision of Domain Estimates of the Percent of Homes with Radon Concentrations above 4 pCi/L and above 10 pCi/L for the Minimal Design If the Residential Radon Levels Vary across Strata, as Shown in Exhibit 16

Row No.	Percent Domain (1)	Percent Of PSU's (2)	Percent Segments (3)	Percent HU's within segments (4)	Expected Precision (RSE) for Percent >4pCi/L (5)	>10pCi/L (6)
1	100	100	100	100	0.13	0.49
2	50	100	100	50	0.14	0.56
3			50	100	0.15	0.59
4	25	100	100	25	0.18	0.68
5			25	100	0.20	0.76
6	10	100	50	20	0.25	0.97
7			10	100	0.29	1.12
8	5	100	25	20	0.34	1.32
9			5	100	0.40	1.54

Exhibit 18 Some Additional Domain Estimates Where a Maximum Relative Standard Error of 0.50 Is Desired for the Percent of Homes with Radon Levels above 4 pCi/L (Minimal Design)

Domain Description	Likely Distribution				Expected Precision for percent > 4 pCi/L
	Percent of total population	Percent of PSUs	Percent of SSUs	Percent of HUs within a segment	
Single family homes	65	100	80	80	0.13
Residences in multi-unit structures	35	100	60	60	0.14
Homes with 1+ smokers	25	100	100	25	0.18
Homes with 0 smokers	75	100	100	25	0.14
Homes with 1+ children under age 12	15	100	50	30	0.27
Homes without children under age 12	85	100	100	85	0.13
Homes with 1+ children under age 12 and 1+ smokers	5	100	25	20	0.34
Average radon level for homes with basements	40	80	60	70	0.16
Average radon level for homes without basements	60	100	80	75	0.15

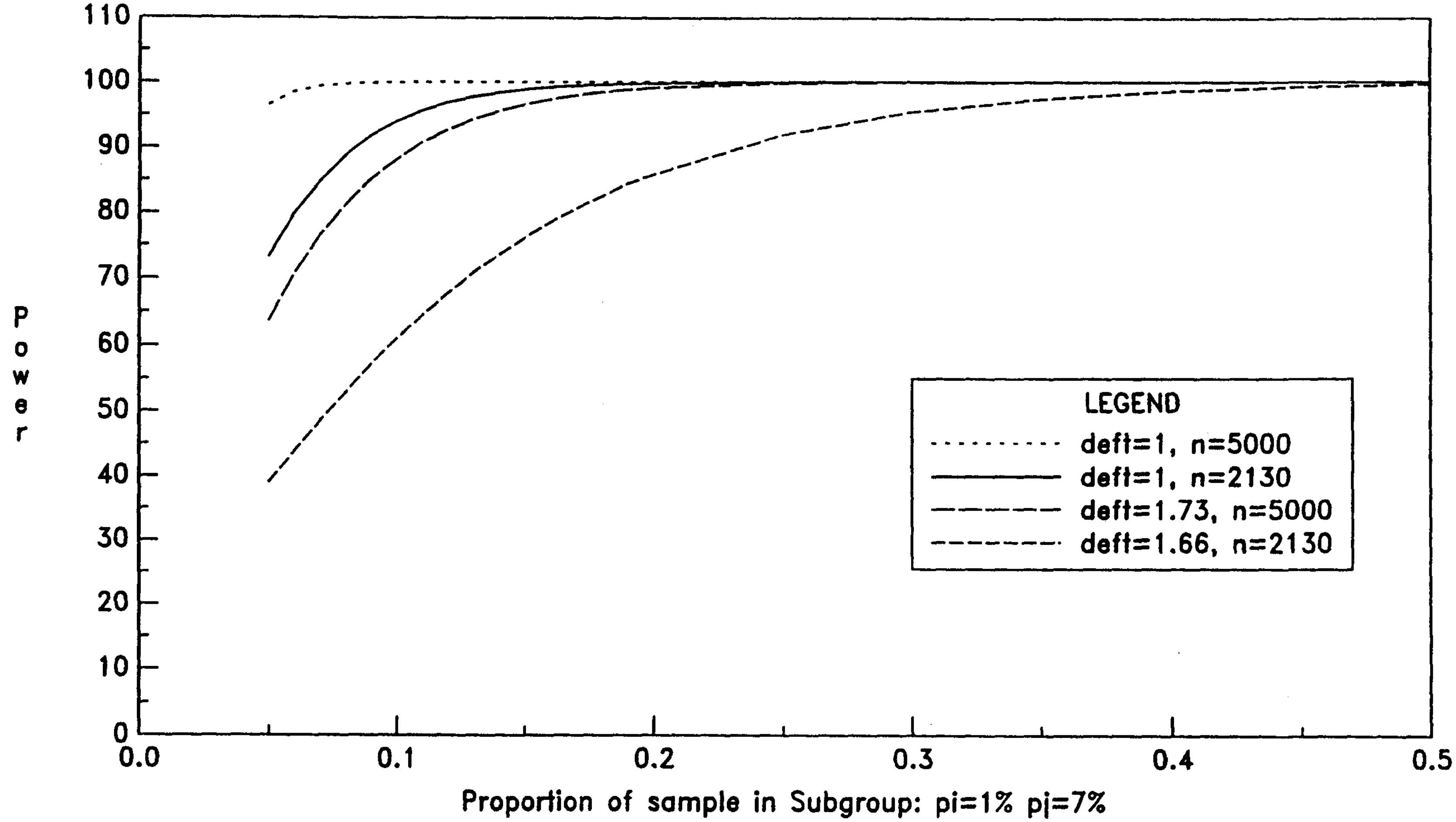

Figure 2. Power of Detecting a Difference Between Estimated Percentages for Two Subgroups i and j, Predicting Direction of Difference Expected, alpha=.05

Sample Designs: n=5000 deft=1.73 and n=2130 deft=1.66

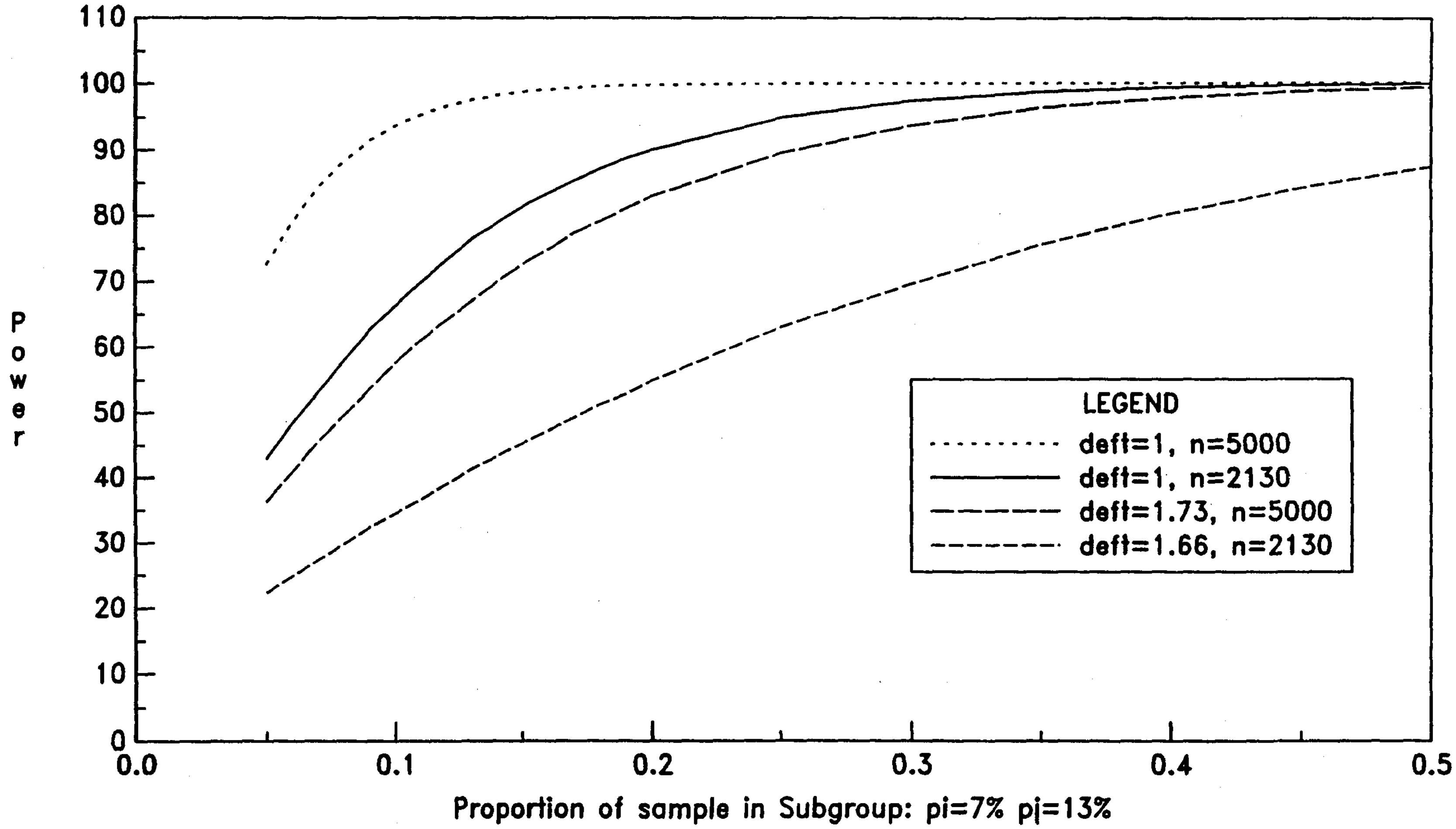

Figure 3. Power of Detecting a Difference Between Estimated Percentages for Two Subgroups i and j, Predicting Direction of Difference Expected, alpha=.05
Sample Designs: n=5000 deft=1.73 and n=2130 deft=1.66

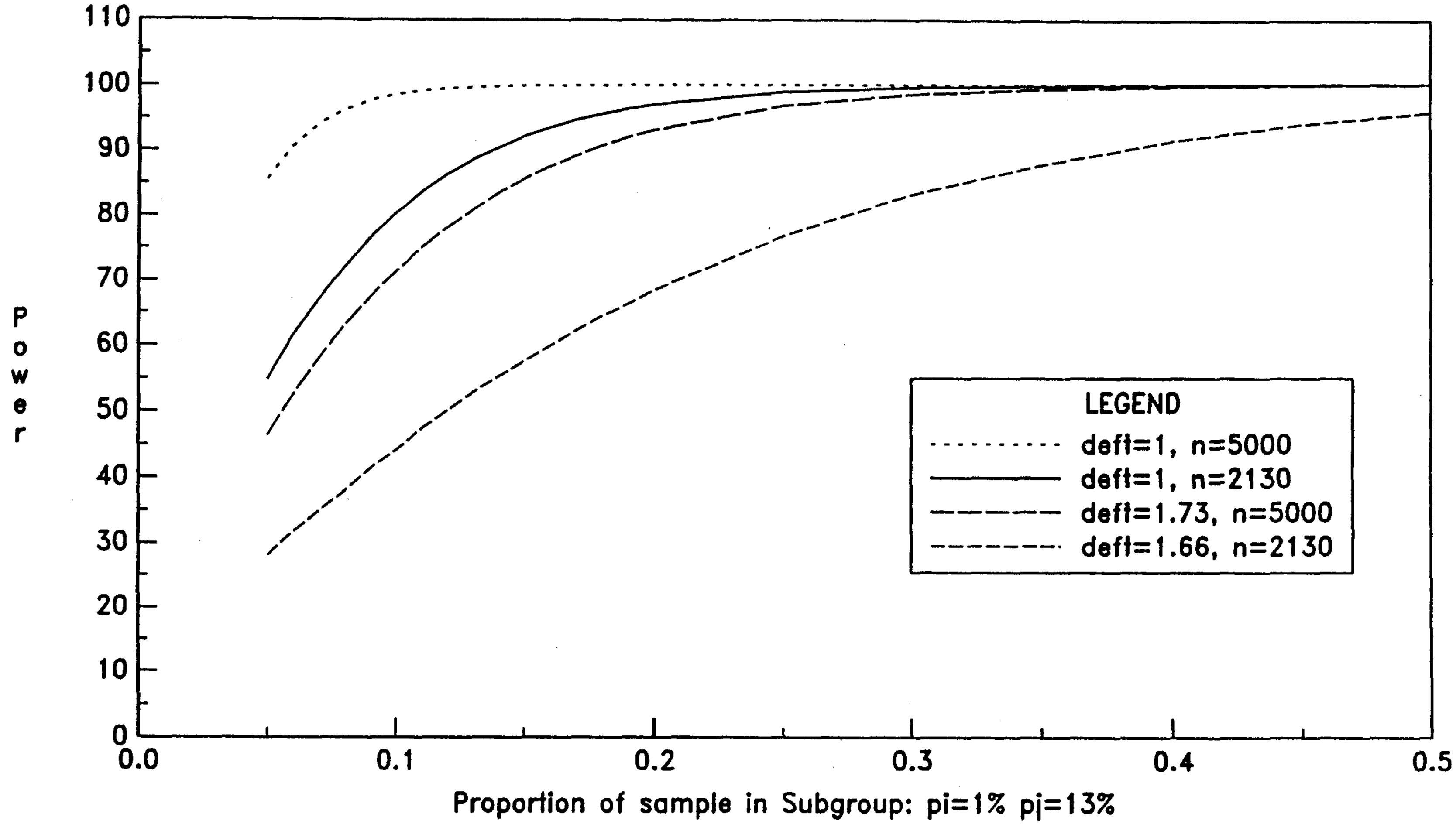

Figure 4. Power of Detecting a Difference Between Estimated Percentages for Two Subgroups i and j, Predicting Direction of Difference Expected, alpha=.05

Sample Designs: n=5000 deft=1.73 and n=2130 deft=1.66

3.0 SURVEY IMPLEMENTATION

This chapter is divided into four sections that address those components necessary for successful implementation of the National Residential Radon Study. Section 3.1 discusses those data collection instruments already developed, as well as those to be developed. The OMB submission and pretest plans are discussed in this section. Section 3.2 describes the training materials that will be utilized in the study. Those materials specific to the study and those that are universal to any survey are presented in this section.

Section 3.3 details the selection, training, and responsibilities of the field staff, at both the supervisor and interviewer levels. Among the topics covered are the counting and listing training of the supervisors, the responsibilities of the supervisors in addition to counting and listing, the training of interviewers, and the subsequent responsibilities of these same interviewers. Finally, Section 3.4 provides information on the steps we will take to assure that the highest quality data are collected.

3.1 Data Collection Instruments

3.1.1 Existing Instruments

A household questionnaire has been developed for the National Radon Study. This instrument incorporates comments to a draft questionnaire that was submitted to the Science Advisory Board and also incorporates the result of an iterative review process that has included both EPA and RTI project staff. The questionnaire includes items that address the substructure type, heating, cooling and ventilation systems, and construction techniques and materials. Household composition and occupancy patterns of the residences have been incorporated in this revised instrument. Other items address the number and ages of the household occupants and the approximate percentage of time each occupant spends in each level of the house.

Since the primary risk factor of lung cancer is cigarette smoking, a smoking history section has been added to the questionnaire to assess the smoking patterns in the sample households. A draft of the questionnaire will be submitted for inclusion in the OMB package. The OMB version of the questionnaire will be pretested on less than sixty households to: 1) assess the comprehensibility of the questions to the respondent, 2) determine if adequate data are obtained and 3) identify other problems with the instrument and the data collection protocol.

In addition to pretesting the questionnaire, we will also pretest the control/screening form and the consent form for these same three areas of concern. The control/screening form has been developed for use by the field interviewer to determine if a housing unit is eligible for inclusion in the study. Eligibility criteria are: 1) the housing unit must be a primary residence, and 2) the occupants for the household must have no firm plans to move within the next 12 months. The placement of ATDs will be tested as a part of the overall data collection protocol.

Along with the other components of the survey, the lead letter will be scrutinized during the pretest. Since we are conducting a pretest and not a pilot study, it will not be possible to utilize the lead letter in the same manner as it will be for the main survey. However, we plan to focus attention on the language of the letter and its subsequent impact on respondent participation. To do this, the pretest staff members will present the letter to one-half of the pretest population prior to the onset of screening or household data collection. The remaining half will see the letter only after deployment of the dummy detectors. This will allow us to administer the entire protocol to a respondent who is blind to the presurvey publicity and other information contained in the lead letter.

Should the pretest experience indicate changes are necessary in either the questionnaire, the control/screening form, the lead letter, or the data collection protocol, these changes will be made. A copy of the questionnaire appears in Appendix A; a copy of the control/screening form appears in Appendix B. The lead letter and consent form will be development in conjunction with EPA and our Human Subjects Committee at a later date.

3.1.2 Forms to be Developed

Four other forms will be developed for use in the national study. These include a lead letter for the housing unit, a consent/incentive receipt form for the occupant of the housing unit in which detectors are to be placed, a respondent notification-of-results letter, and a landlord notification-of-results letter. The lead letter will be mailed before the onset of data collection activities. This letter will describe the study and inform the household residents that an interviewer will visit. An EPA brochure on radon gas or an excerpt from "A Citizen's Guide to Radon" may be included with the lead letter. In the case of rental property, landlords will not be sent lead letters or contacted prior to dector placement.

We will develop a consent form for the occupant of the housing unit that will explain the purpose of the study and its confidential nature. One copy will be retained by the occupant and another copy will be kept with the completed data forms. The consent form will include an incentive receipt section for the respondent to sign to verify that the incentive was received from the interviewer.

The respondent notification-of-results letter will be designed to inform respondents of the results of the radon testing. The landlord notification-of-results letter will be designed to inform landlords radon testing has been conducted on one of their properties and that results are available upon request.

Additionally, various administrative forms will be developed for use during data collection. These forms will facilitate the administration and monitoring of data collection activities. The primary administration form will be the combination Control/Screening Form used for recording the outcomes of each attempted contact with the household (see Appendix B).

3.2 Training Materials

While the field supervisors are listing segments and recruiting interviewers, RTI in-house project staff will develop materials for supervisor and interviewer training and data collection. This will include the preparation of field training and procedural manuals, and the development of the training agenda.

We will prepare a Field Supervisor's Manual, which will cover project specific supervisory procedures. Supervisors will use this manual as a supplement to the interviewer manual. The manual will include information on such topics as:

- assisting with interviewer training,
- preparing interviewer assignments and work schedules,
- maintaining close communications with each interviewer through regular telephone and at least one in-person observation visit,

- reviewing the status of each active case during each supervisory contact, authorizing appropriate additional action for potential noninterviews, and assisting the interviewer with difficult cases as necessary,

- contacting households that refuse to be interviewed and attempting to obtain their cooperation,

- monitoring interviewer production, efficiency, and costs,

- validating a sample of each interviewer's field work,

- editing completed data collection forms, and

- reporting field work progress to the RTI central office on a weekly basis.

Additionally, we will prepare a Field Interviewer's Manual that will contain detailed descriptions of all field procedures that interviewers will be required to follow during the data collection period. The manual will serve both as a training manual and as a reference manual during field work. The topics covered will include:

- study sponsorship, background, specific objectives, and importance of the study,

- other EPA programs, such as the EPA/State Radon Surveys,

- importance of collecting accurate data,

- schedule of work,

- informed consent and confidentially procedures and their importance,

- procedures for screening households and identifying eligibles,

- contact procedures, explaining the study, overcoming objections, scheduling appointments, and using other basic interviewing techniques,

- conducting the interview, including detailed instructions for questionnaire administration,

- question-by-question specifications containing a detailed description of each question, including the purpose, definitions of terms, and special probing instructions and other instructions as required,

- procedures for preserving confidentiality of data and respondent anonymity in the return of completed questionnaires to RTI,
- quality control procedures, including in-house scan edits, validations, and the need for immediate referral of problems that might affect the quality of data collection to the supervisor for resolution,
- refusal conversion strategies and approaches for handling problem situations that may arise during contact with households, and
- completing project administrative forms and reporting progress to the field supervisor.

Three existing RTI manuals will be used by the field staff during training and data collection: the RTI Field Interviewer's General Manual, the RTI Field Supervisor's General Manual, and the RTI Field Counting and Listing Manual. These three manuals contain basic information applicable to field work for all of our surveys, and their use will eliminate the need to provide extensive coverage of general subject in the project field manuals. These three manuals are attached for reference.

A series of handout cards will be developed to aid the interviewer in capturing accurate data regarding various aspects of the questionnaire. These cards will graphically illustrate house types, construction materials, foundation types, HVAC systems, and other items as determined by the project staff.

3.3 Field Staff Selection, Training, and Responsibilities

Field work for the National Radon Study will require a large, highly qualified field staff. Selection of this staff and the provision of thorough training will be critical to the success of the study. The approaches we plan to use in achieving this goal are described in this section.

3.3.1 Field Supervisors

The quality of supervisory direction and support received by the field interviewers will impact greatly on the quality of data collected and the overall success of the study. Supervisors will be located as close as is practical to the interviewers with whom they will work.

3.3.1.1 Selecting and Assigning Supervisors

Field supervisors for this study will be selected from our pool of approximately 75 individuals who have worked as field supervisors on other RTI projects. The criteria for selection will be quality past performance and proximity to the sampled geographic areas. Since these individuals have worked for RTI in the past, we will not need to interview them, only obtain their commitment by phone.

Each field supervisor will supervise approximately 15 interviewers, so we will require 12 to 15 field supervisors and approximately 200 to 250 field interviewers for a sample size of 7,400.

3.3.1.2 Supervisor Training

Field supervisors will attend a two-day briefing session at RTI. The briefing will cover:

- study purpose and procedures,
- field interviewer recruiting and selection criteria,
- questionnaire specifications,
- interviewer training,
- supervisory and reporting responsibilities,
- extensive review of counting and listing procedures, and
- counting and listing exercises in the local community.

The RTI Field Supervisor's Manual discussed in an earlier section explains these topics in detail. Supervisors will attend and participate in the field interviewer training. Prior to the commencement of interviewer training, each field supervisor will be given a special briefing at their training site. This briefing for supervisors will be conducted by the central office trainers and will cover all supervisory procedures in detail.

3.3.1.3 Supervisor Responsibilities

Field supervisors will recruit field interviewers in their area and count and list housing units. Supervisors will screen the interviewer prospects by phone. During their counting and listing circuit through the interviewers' area, supervisors will interview the strongest candidates in person and hire two field interviewers for every primary sampling unit, giving optimal staff coverage for the projected sample yield and allowing for interviewer attrition and project scheduling constraints.

Supervisors will use standard RTI procedures for counting and listing housing units within their assigned SSUs. Sampling materials will include:

- a census map showing the SSU location,
- a hand-drawn map showing the SSU boundaries and the number of housing units expected, and
- a SSU listing form for recording the address or a description of each housing unit.

Initially the supervisors will verify the physical boundaries of the SSU as shown on the SSU map and do a quick count of housing units in the SSU. Boundaries and counts that vary significantly from what is expected will require the supervisor to call the RTI sampling staff for instruction. In some cases, supervisors may be instructed to list only part of the SSU, to subsegment.

The supervisors will apply prescribed rules for traveling through the SSU, following roads in a specified order to ensure that all possible housing locations are investigated. Standard rules will specify handling of multiple-unit dwellings, such as apartment or condominiums and atypical structures, such as boarding houses.

Supervisors will mail completed listing materials to RTI sampling staff. If errors are detected, the supervisors will be contacted and asked to resolve same.

3.3.2 Field Interviewers

3.3.2.1 Recruiting and Hiring Interviewers

RTI will identify potential interviewers listed in our National Interviewer File, a computerized file of over 3,000 individuals who have worked, or applied to work, as field interviewers on other RTI projects. The file includes information about each individual's capabilities, experience, language fluencies, location and availability. The field supervisors will receive a list of individuals from the file who appear to have the necessary qualifications and live in the appropriate geographic area for this survey. Other interviewer candidates may be identified by contacting other survey organizations, by advertising in local newspapers, or by recruiting through state employment agencies.

Interviewer applicants will be screened by field supervisors over the phone and strong candidates interviewed in person during the supervisors counting and listing circuit in the interviewers area.

3.3.2.2 Interviewer Training

Approximately 200 to 250 interviewers will be trained for the survey. Two 2.5 day training sessions will be held, each involving three

RTI in-house trainers, the field supervisors for that region of the country, and the interviewers assigned to work that region. Field supervisors will assist trainers during each training session.

A pre-training study package, which will include study materials and a questionnaire, will be mailed to each field interviewer several days before the training session, with specific self-study instructions and authorization for four hours of pre-training study time. The RTI in-house training staff will meet prior to the onset of training to to review the training guide, discuss training procedures and clarify training instructions and related materials.

The training methods used will include lectures, question-and-answer review sessions, demonstrations, small group discussions, and structured drills. Field supervisors will work with their interviewers during training exercises. A formal training guide will maximize participation and require trainees to react to potential field situations and to deal with field forms and procedures. Topics to be covered during the 2.5 day session will include:

- mailing lead letters to sample households,
- identifying a sample housing unit,
- contacting a household member,
- determining eligibility and completing the screener,
- introducing the study and explaining its importance and confidential nature,
- obtaining participation and signed consent from all occupant respondents,
- administering the questionnaire, question-by-question,
- answering questions raised by the respondent in clarifying terms,
- placing the radon detectors and recording their location prior to the interviewer leaving the residence,

- paying the incentive and getting a signed receipt,
- editing completed questionnaires,
- reporting to field supervisors, and
- completing time and expense reports.

Interviewer trainees will be encouraged to ask questions about any of these topics. They will practice and review all procedures, in a "mock interview" setting. Emphasis will be placed on the objectives of the study, housing characteristics and the importance of correct detector placement.

We anticipate that we will lose some interviewers during training. However, by hiring two field interviewers for every county, we compensate for this attrition.

At the conclusion of training, the interviewers will be given their assignments, materials, and picture ID badges. They will begin their interviewing assignments immediately after training.

3.3.2.3 Interviewer Responsibilities

The interviewer will be responsible for contacting the household, determining eligibility, administering the questionnaire, aiding in the placing of, or placing, radon detectors, and paying the incentive. The interviewer will also be responsible for identifying any missed listing units in the segment.

The interviewer will mail a lead letter, a copy of the Citizen's Guide, and an information sheet to each sampled housing unit a few days before beginning work in a segment. The letter will explain the survey and its importance and will alert the household members that an RTI interviewer will be contacting them in the next week. Our experience dictates that a lead letter on government letterhead (i.e., EPA) increases response rates.

Initial visits to sample households will be made in the late afternoon or early evening on a weekday or on a Saturday to maximize the chance of finding either the householder or the spouse at home. If neither the householder nor spouse are at home, the interviewer will call a second time between 5:30 and 9:00 pm on a weekday or Saturday. Additional visits will be made at varying times and days in order to find someone at home.

Vacant housing units, non-residential units, and temporary or vacation homes will be reported to the field supervisor after the interviewer has verified the status of these units. Upon approval of the supervisor, these units will be classified as ineligible for the survey and this information will be routed to RTI to update the control system.

If the householder is at home, the interviewer will identify the study and ask if the lead letter was received by the household. If not, the interviewer will give a copy to the respondent and either read the letter out aloud or allow time for it to be read before proceeding. Then the interviewer will determine if the households is eligible for the survey and if so, will proceed with questionnaire administration. If the household is ineligible, the interviewer will thank the respondent and proceed to the next housing unit.

Prior to administering the questionnaire, the interviewer will perform the following tasks:

- describe the survey,
- explain the kinds of questions that will be asked,
- emphasize the importance of the information,
- assure the respondent that the study is completely confidential, and
- read the consent form and obtain verbal agreement to continue with the questionnaire.

The interviewer will have the respondent sign the informed consent form before proceeding with detector placement.

Other adult household members will be invited to join in the interview process, as necessary, to increase the accuracy and completeness of the information obtained. If the respondent does not know the answer to a question about the house, the interviewer may accompany the respondent while he/she investigates (e.g., by going outside, they can determine if the entire house is over a crawl space or if it is partially on a concrete slab.)

The radon detectors will be placed in the home by an occupant according to the instructions of the interviewer. As the detectors are placed, the interviewer will record the location and ID number of each detector and give the respondent information about the detectors and precautions for their use.

The interviewer will give the participating respondent $5.00 in cash after the detectors are placed. The respondent will sign the incentive receipt portion of the consent form to verify that the money was received.

3.4 Field Quality Assurance

Close supervision of field data collection activities in a study of this kind is essential to achieve high quality data and the maximum response rate possible within the allotted time and budget. The staffing plan we will use for the National Residential Radon Study will provide this supervision. The issues and procedures associated with this project's overall quality assurance plan are addressed in Section 5.

3.4.1 Supervision

The field supervisors will oversee the work of the field interviewers assigned to them. Each supervisor will recruit, assist in training, and monitor the data collection activities of their respective interviewers.

Each interviewer will contact his/her supervisor at least once a week, usually by telephone. During these contacts, the supervisor will review each active case with the interviewer and resolve any problems. The supervisor will summarize the information received from the interviewers and send an updated field report to the RTI in-house regional supervisor every week.

The supervisor will also visit each interviewer at least once during the data collection period to observe their work, help with problem cases, answer questions, and offer suggestions to improve participation rates. Also during this visit, the field supervisor will make in-person follow-up contacts with refusals and perform validation checks on the interviewer's work.

Each field supervisor will report to an in-house regional supervisor at RTI's central office. The regional supervisor will review the field supervisor's weekly reports and help resolve problems. The regional supervisor will monitor field costs and will advise the field supervisor if there are budgetary problems. The data collection manager will have overall responsibility for all data collection activities and questions which cannot be resolved by the field and regional supervisors will be referred the manager.

3.4.2 Validation

A random sample of at least 10 percent of each interviewer's completed interviews will be validated by telephone. Supervisors, who will be maintaining the completed household screening forms containing name and address of the respondents, will be responsible for this activity. Noninterviews will not be included in the validation sample since follow-up efforts will be made on all such cases routinely.

4.0 DATA REDUCTION PROCEDURES

The data reduction procedures include all data processing steps, including data receipt, edit/coding, error resolution, data entry, machine edit, data file preparation, and document storage. An automated event monitoring system will monitor the receipt of all survey forms, as will each data processing step. Also included are the linking of data from the survey forms with the sample design information such as stratum, PSU, SSU, and HU. This linkage is necessary to calculate sampling weights for each sample HU and to compute appropriate nonresponse adjustments to the sampling weights for the statistical analysis.

4.1 Survey Monitoring System

Effective monitoring of the data receipt and data processing task requires an efficient and flexible system. We will use our automated survey monitoring system for the National Residential Radon Survey, a software tool developed by RTI to assist in monitoring data collection and data processing operations. The system operates under control of FICS (Fully Integrated Control System), which is a database management system developed at RTI for managing research data on studies where tracking is involved and data access is required. FICS allows interactive and batch processing. It is fully menu driven and supported by a flexible language that allows users to develop their own routines.

The monitoring activity is controlled by an event table defined by the user. The events are defined as actions within the task being monitored. The events mirror a sequence of activities that follow a logical pattern dictated by the task. Each event is defined within the system as a predecessor or outcome of another event. Each processing event is dated so that duration times may be followed and the user can be alerted when activities fall behind schedule. Reports may be produced directly from FICS or the user can design his own reports. The user can tabulate and print any items from the database. In addition to reports, FICS can make additional files available to other software systems for management activities.

4.2 Questionnaire Processing

The data processing task include data receipt, data preparation, data entry, and hardcopy storage. Each of these activities is discussed in this section.

4.2.1 Data Receipt

Data receipt involves receipt of the mail, check-in and identification, scan-edit, and batching. Part of the check-in procedure is keying events to the automated monitoring system.

After being checked in, a scan-edit checks the forms for completeness and usability. If the form fails to meet preset specifications for processing, it is turned over to the field operations manager for resolution.

All data forms that pass scan-edit are batched for easier handling by the receipt clerks. These batches are numbered and logged into the data receipt log book and the monitoring system. The form is entered into the monitoring system by the data receipt clerk. If the package does not match a study ID, it is turned over to the data collections operations staff for resolution. Each form is identified by number and assigned to a batch and entered into the log. We expect batches to have 25 questionnaires or 75 to 100 screening forms.

4.2.2 Data Preparation

The batches will be assigned to an edit clerk. The edit specifications and coding requirements will be described in a Edit and Coding Manual that will be written for the task. A training session will instruct the clerks on these procedures. Once work has started, the supervisor will periodically check a sample of each clerks work to insure quality work as a quality control measure.

We will follow-up with the respondent on questionnaires that fail edit. The edit clerk will call the respondent in an attempt to resolve any problems we find. We expect to recontact 10 percent of the respondents that complete the questionnaire.

4.2.3 Data Entry

All data received in hard copy form will be keyed by RTI in our data entry unit. Our full-time data entry operators work up to two shifts a day as required by study schedules. They use a data entry software system to check formats and ranges; it can also be programmed to make logic checks. Skip patterns are checked through detailed machine edits.

A detailed machine-readable codebook describes every element of the instrument. The codebook contains a short item name and a longer description for use in analysis. The format type and the acceptable range of each item is part of the codebook record and is used by the data entry program to check the data as it is being entered. These codebooks become part of the permanent documentation for the data entry program and are used to create documentation for the edit files.

Each keyer is trained by the programmer and each supervisor is instructed on how to monitor the work. We will rekey two 10 percent samples of the data as a quality control measure. The rekeyed data is compared to the original to ensure that the data is being keyed within the prescribed specifications. Two different keyers will do the rekeying. If poor quality data is found, those batches will be rekeyed and the keyer will be retrained.

4.2.4 Questionnaire Storage

After data entry, the survey forms will be stored in a secure, vault-like storage area until the project is completed; they will then be disposed of according to SC&A or EPA instructions and confidentiality requirements.

4.3 Data File Preparation

Once the data is in machine-readable format, it will undergo some level of machine edit. At a minimum, the data will be checked for skip-pattern errors. More extensive edits may be programmed by specifying the logic checks of certain key items.

The final data file will be documented with a complete codebook, formatted as described in the section on Data Entry above. In addition the frequency of each variable will be calculated and become part of the codebook. The data file and documentation will be submitted to SC&A as part of the final report.

4.4 Constructing the Statistical Analysis File

Once all of the data from the survey instruments have been keyed the raw data file will be merged with the design information file. Result codes from the control/screening form will be used to ascertain which HUs were eligible for the study. Among the eligible HUs, each unit will be classified as a respondent or nonrespondent. The eligibles will be partitioned into weighting classes that are similar by known important characteristics associated with radon levels and other parameters of interest. The sampling weights will then be ratio adjusted so that the sum of the respondents' weights equals the sum of the eligible's weights within each weighting class.

The nonresponse adjusted weights will be used to inflate parameter estimates to population levels in the statistical analysis. All estimates of population parameters and their variances will properly reflect the stratification and stages of selection employed in the sample design.

5.0 QUALITY ASSURANCE

A draft Quality Assurance Project Plan (QAPP) has been prepared for the NRRS according to current EPA guidelines (QAMS 005/80). The specific and detailed steps that will be implemented to assure that the NRRS will generate high quality data and satisfy the objectives of the survey are given in the QAPP. This chapter briefly overviews the issues addressed in the QAPP, the interested reader is referred to the QAPP for specific details.

Quality assurance procedures will be applied to essentially all components of the survey including

- Sampling procedures
- Sample custody
- Measurement calibration
- Analytical procedures
- Data receipt and processing procedures.

The QAPP also outlines steps that will be taken to assure that the five above items will be performed correctly. These include

- Internal quality control checks
- Audits of the analytical laboratory
- Specific procedures for assessing the precision and bias of the measurements and the estimates of radon levels for the nation and important subsets of the nation.
- Corrective action.

The QAPP is organized into 15 Sections and begins in with a general description of the project. Section 2 specifies the project organizational structure and describes the responsibilities of the each organizational unit. The QA Objectives are stated in terms of precision, bias, representativeness, completeness, and comparability in Section 3. The planned sampling procedures are described next including radon measurements within each home and the process used to select homes in which detectors will be placed.

In Section 5, the sample custody procedures that will track detectors from the point of purchase, during in-house and field handling, and return to the laboratory for analysis. Section 5 also describes the procedures that will track all other survey forms including the questionnaire and control/screening form.

Calibration procedure and their frequency are specified in Section 6. The analytical procedures including the preprocessing of detectors and their counting are covered in Section 7. Chapter 8 describes the receipt and processing of all data forms, their manual editing, and automated processing.

Section 9 outlines the internal quality control checks that will be required of the laboratory, sample design, survey operations, and data processing. Audits to assure that the procedures specified in Section 9 are followed are planned. Section 10 describes the form and frequency of the audits. Section 11 specifies the preventive maintenance planned for the laboratory equipment used to analyze the detectors. Section 12 specifies the procedures that will be used to assess the precision, bias, and completeness of the measurement data. The steps to be taken if corrective actions are necessary are described in Section 13.

The content the required QA reports to management are described in Section 14. The references are given Section 15.

APPENDIX A.

GLOSSARY OF TERMS USED IN CHAPTER 2

Alpha	The alpha level is set by the researcher and is the probability of rejecting the null hypothesis when, in fact, it is true. This type of error is called a type 1 error. (A type 2 error, as you might expect, is the probability of failing to reject the null hypothesis when, in fact, it is false.
C0	The fixed survey cost, that is, costs that are not affected by the size or distribution of the sample.
C1	The cost associated with the number of PSUs in the sample, on a cost per PSU basis.
C2	The cost associated with the number of SSUs in the sample,, on a cost per SSU basis.
C3	The cost associated with the number of HUs in the sample, on a cost per HU basis.
Deff.	Deff is an abbreviation for the term "design effects" and is a measure of the inefficiency of a sample design. The Deff for an estimate is computed as the ratio of two variances, the error variance of the estimate based on the sample design used to the error variance of a comparable estimate if a simple random sample of the same size had been used.
deft.	Deft is merely the square root of Deff.
Domain	A subportion of the population for which statistical estimates are desired. A domain can be defined in a variety of ways. Examples of domains of interest for the National Residential Radon Survey are geographical regions within the United States and houses with certain construction characteristics, such as having a basement.
Housing Unit HU	A house, apartment, mobile home or trailer, group of rooms, or single room occupied as a separate living quarter or, if vacant, intended for occupancy as a separate living quarter. Separate living quarters are those in which the occupants live and eat separately from any other persons in the building and which have direct access from the outside of the building or through a common hall. The occupants of a housing unit may be a single family, one person living alone, two or more families living together, or any other group

of related persons or up to 9 unrelated persons who share living arrangements.

Each sample SSU is visited by a field representative. Typically the sample SSU contains no more than 150 housing units (HUs), in which case the addresses of all HUs are listed on a special listing sheet, using a separate line for each address, and following explicit instructions contained in a special RTI Field Listing Manual. When an SSU contains more than 150 HUs, it is usually "subsegmented," and one or more of the subparts is randomly selected for listing.

Place	A concentration of population which may or may not have legally prescribed limits, powers, or functions. Most of the places identified in the 1980 census are incorporated as cities, towns, villages, or boroughs. In addition, census designated places (called "unincorporated places" in earlier censuses) are delineated for 1980 census tabulations. There are about 23,000 places recorded in the 1980 census, of which about 20,000 are incorporated places and 3,000 are not incorporated. Places may cross county boundaries but do not cross state boundaries.
Place size code	00 Not in a place 01 Under 200 02 200-499 03 500-999 04 1,000-1,499 05 1,500-2,499 06 2,000-2,499 07 2,500-4,999 08 5,000-9,999 09 10,000-19,999 10 20,000-24,999 11 25,000-49,999 12 50,000-99,999 13 100,000-249,999 14 250,000-499,999 15 500,000-999,999 16 1,000,000 or more
Primary Sampling Unit PSU County	The population to be sampled is partitioned into primary sampling units (PSUs) each of which is a county or county equivalent (or on occasion a combination of two counties or county equivalents.) A probability sample of PSUs is selected. The PSU is sometimes referred to as a county.

RHO1	The intracluster correlation among SSUs within PSUs.
RHO2	The intracluster correlation among HUs within SSUs.
Relative Standard Error RSE	The ratio of the standard error of an estimate to the parameter being estimated.
Secondary Sampling Unit SSU Segment	A sample PSU is partitioned into smaller areas such as census defined blocks, block groups or enumeration districts (EDs). These are secondary sampling units (SSUs). A probability sample of SSUs is selected within each PSU. The SSU is typically referred to as a segment in instructional materials prepared for field interviewers.

APPENDIX B

NATIONAL RESIDENTIAL RADON SURVEY

QUESTIONNAIRE

OMB Number:
Expires:

March 20, 1989

QUESTIONNAIRE

THE NATIONAL RESIDENTIAL RADON SURVEY

Sponsored by

U.S. Environmental Protection Agency

The purpose of this study is to determine the extent of radon concentrations in residential structures throughout the United States. Radon is a radioactive gas that occurs naturally in soil and rocks and in building materials. Your household was randomly selected for this important study.

Interviewer Name: ____________________

Date of Interview: ____/____/____
Mo Day Yr

Time Interview Began: ________am/pm

Time Interview Ended: ________am/pm

PLACE ID LABEL HERE

1. IF READILY OBSERVABLE, DO NOT ASK.

Which of the following best describes this residence?

[CIRCLE ONE]

A multi-unit building...............01 → GO TO Q3
A mobile home.......................02 → GO TO Q6
A single unit, detached dwelling....03 → GO TO Q2

2. Which of the following house-types best describes this house...

[CIRCLE ONE]

Ranch style or 1 story.............01
Split level........................02
Split foyer........................03
2 story............................04
3 or more stories..................05

(01–05) → Q6

3. How many housing units are in this building?

___/___/___ HOUSING UNITS

4. How many floors are in this building, including any below ground?

___/___ FLOORS
DK..........94
RE..........97

5. In this building, on which floor is the lowest level of your home located?

___/___ LOWEST LEVEL OF HOME IN BUILDING
DK..........94
RE..........97

6. About how old is this (home/building)?

LESS THAN 1 YEAR OLD......................01
1-5 YEARS OLD............................02
6-10 YEARS OLD...........................03
11-20 YEARS OLD..........................04
21-40 YEARS OLD..........................05
OVER 40 YEARS OLD........................06
DK.......................................94
RE.......................................97

7. Do you have a full or partial basement, a cellar, or a level of the house that has one or more walls partially or completely below ground level? (PROBE: A level is the area within a home that is all of the same height and is not separated by any stairs.)

YES.......01 ⟶ CONTINUE

NO........02 }
DK........94 } ⟶ Q12
RE........97 }

8. For the purpose of this study we are calling the floor or level that has one or more walls partially or completely below ground a basement. Can you enter the area we are calling a basement from inside your home?

YES.......01 ⟶ CONTINUE

NO........02 }
DK........94 } ⟶ Q10
RE........97 }

9. Is there a door that can be closed between what we are calling a basement and the next higher level?

YES.......01
NO........02
DK........94
RE........97

10. Which of the following describes the construction of most of the outside basement walls? Are they mostly made of...

[CIRCLE ALL THAT APPLY]

concrete block or cinder block.....01
poured concrete....................02
stone and mortar...................03
wood...............................04
brick/brick veneer.................05
earth/dirt or......................06
something else ....07 ⟶ [SPECIFY]________________|__|__|
DK.................................94
RE.................................97

11. Is any part of your basement floor exposed earth?

YES.......01
NO........02
DK........94
RE........97

12. Is any part of this home excluding a basement on a concrete slab? [IF MOBILE HOME: AXLE OR WHEELS RESTING ON CONCRETE PAD SHOULD BE CODED AS A "NO".]

YES.......01
NO........02
DK........94
RE........97

13. Is any part of your home over a crawl space? (PROBE: A crawl space is space between the ground and the floor structure that cannot be occupied. This is space other than a basement or cellar.)

YES.......01 ⟶ CONTINUE

NO........02 }
DK........94 } ⟶ Q20
RE........97 }

14. Does any part of the crawl space have exposed or visible earth, sand or rock?

YES.......01 ⟶ CONTINUE

NO........02 }
DK........94 } ⟶ Q15
RE........97 }

14a. What, if anything, covers all or part of the surface of your crawl space?

____ |__|__|

15. How much of the crawl space is enclosed by foundation walls- all, part or none?

ALL.......01 }
PART......02 } ⟶ CONTINUE

NONE......03 }
DK........94 } ⟶ Q20
RE........97 }

16. Which of the following describes the construction of most of the outside foundation or crawl space walls? Are they mostly made of....

[CIRCLE ALL THAT APPLY]

concrete block or cinder block.....01
poured concrete....................02
stone and mortar...................03
wood...............................04
brick/brick veneer.................05
earth/dirt or......................06
something else ....07 ⟶ [SPECIFY]________________ |__|__|
DK.................................94
RE.................................97

17. Can you enter any part of the enclosed crawl space without going outside the house?

YES.......01
NO........02
DK........94
RE........97

18. Are there air vents in the foundation walls of the crawl space?

YES.......01 ⟶ CONTINUE
NO........02 }
DK........94 } ⟶ Q20
RE........97 }

19. What percentage of the time during the year are the vents open? ENTER WHOLE NUMBERS.

___/___/___ PERCENT
DK........94
RE........97

20. Is any part of your home over open air, that is, on blocks, or pillars? (PROMPT: These may also be know as columns, pylons, or piers)

YES.......01
NO........02
DK........94
RE........97

21. What percent of your home rests over a....

a.	basement..................	|__|__|__| %
b.	concrete slab.............	|__|__|__| %
c.	crawl space...............	|__|__|__| %
d.	open air..................	|__|__|__| %
e.	something else............	|__|__|__| % ⟶ [SPECIFY] ______|__|__|
f.	DK........................	|__|__|__| %
g.	RE........................	|__|__|__| %

(INTERVIEWER: THESE PERCENTAGES MUST ADD UP TO 100%. IF NOT, RECALCULATE OR PROBE AS NECESSARY.)

SCRIPT 1 -- READ TO RESPONDENT:

Radon levels tend to be different in different levels of homes. We need to determine how many levels or floors your home has. A level is the area within a home that is all at the same height and is not separated by any stairs. We are not counting as separate levels such things as sunken living rooms or sunken foyers.

22. How many levels or floors are in your home? (PROBE: This includes basement or cellar.) **[CIRCLE ANSWER BELOW AND RECORD ANSWER IN BOX AT THE INTERVIEWER CHECKPOINT ON PAGE 19.]**

[CIRCLE ONE]

One level...............01
Two levels..............02
Three levels............03
Four levels.............04
Five levels.............05
Six levels..............06
DK......................94
RE......................97

23. Which of these levels has one or more walls partially or completely below ground?

[CIRCLE ALL THAT APPLY]

Level one...............01

Level two...............02

Level three.............03

Level four..............04

Level five..............05

Level six...............06

None....................00

DK......................94

RE......................97

24. We are interested in the levels of your home that are used as living quarters. By living quarters we mean the rooms in which you sleep, eat, watch television, or do other activities of daily life. Starting with the lowest level of your home as level one, which of these levels do you use as living quarters? (PROBE: This includes a basement or cellar if it is used as living quarters.)

[CIRCLE ALL THAT APPLY]

Level one...............01

Level two...............02

Level three.............03

Level four..............04

Level five..............05

Level six...............06

None....................00

DK......................94

RE......................97

25. Think about the building material used for the **floor** of the lowest level of your home, or what we think of as your primary radon barrier. Which of the following building materials makes up your lowest level floor?

[CIRCLE ALL THAT APPLY]

poured concrete......01
wood.................02
earth, or............03
something else.......04 ⟶ [SPECIFY] ____________________________ |__|__|
DK...................94
RE...................97

26. Do you have a garage or underground parking structure?

YES.......01 ⟶ CONTINUE
NO........02 }
DK........94 } ⟶ Q29
RE........97 }

27. Is this garage or underground parking structure attached to your home?

YES.......01
NO........02
DK........94
RE........97

28. Does this garage or underground parking structure rest on a concrete or asphalt surface that is attached to or bordering the foundation of your home? (PROBE: Bordering means actually touching the foundation.)

YES.......01
NO........02
DK........94
RE........97

29. Are there any other concrete or asphalt surfaces attached to or bordering the foundation of your home? (PROBE: Bordering means actually touching the foundation and includes such things as a carport or a patio.)

YES.......01 → CONTINUE

NO........02 }
DK........94 } → Q31
RE........97 }

30. Which of the following structures are attached to or border the foundation of your home? [CIRCLE ONE RESPONSE FOR EACH ITEM, a-i]

		Yes	No	DK	RE
a.	carport	01	02	94	97
b.	driveway	01	02	94	97
c.	sunroom	01	02	94	97
d.	porch (slab on grade, only)	01	02	94	97
e.	patio	01	02	94	97
f.	workshop	01	02	94	97
g.	sidewalk	01	02	94	97
h.	anything else?	01	02	94	97

[IF YES, SPECIFY]____________________|__|__|

31. The next few questions are about the heating, air conditioning and ventilation systems in your home. Does this home have a main or primary heating system?

YES.......01 → CONTINUE

NO........02 }
DK........94 } → Q37
RE........97 }

32a. Do you use the following appliances for main or primary heat during the heating season?

FOR EACH YES CIRCLED, ASK:

32b. Do you use this (NAME)...

	Y	N	DK	RE	ALWAYS/ ALMOST ALWAYS	ABOUT HALF THE TIME	OCCASSION-ALLY	DK	RE
1. **unvented** kerosene space heater	01	02	94	97	01	02	03	94	97
2. kerosene space heater **vented to the outside**	01	02	94	97	01	02	03	94	97
3. **unvented** gas or propane space heater	01	02	94	97	01	02	03	94	97
4. gas or propane heater **vented to the outside**	01	02	94	97	01	02	03	94	97
5. woodstove	01	02	94	97	01	02	03	94	97
6. fireplace	01	02	94	97	01	02	03	94	97

33. Which one of the following fuels do you use for your main or primary heating system?

[CIRCLE ONE]

oil....................01
electricity...........02
coal..................03
other.................04 ⟶ [SPECIFY] ______________________ |__|__|
none used.............05
DK....................94
RE....................97

34. Which **one** of the following best describes the type of distribution system you use for your main or primary heating system?

forced air..01 ⟶ CONTINUE
hot water (i.e. radiator or baseboard)............02
natural convection (i.e. fireplace, woodstove
or floor furnace: without a blower).............03 } ⟶ Q37
or, something else................................04
↓
[SPECIFY]_______________________ |__|__|
DK..94
RE..97

35. Is this system in a basement or crawl space?

YES...........01
NO............02
DK............94
RE............97

36. Do any ducts carrying the warm air for this system run under the house?

YES...........01
NO............02
DK............94
RE............97

37. Do you use any supplemental system to heat your home?

YES.......01 ⟶ CONTINUE
NO........02 ⟶ Q43

38a. Do you use the following appliances for supplemental heat during the heating season?

FOR EACH YES CIRCLED, ASK:

38b. Do you use this (NAME)...

	Y	N	DK	RE	ALWAYS/ ALMOST ALWAYS	ABOUT HALF THE TIME	OCCASION-ALLY	DK	RE
1. **unvented** kerosene space heater	01	02	94	97	01	02	03	94	97
2. kerosene space heater **vented** to the outside	01	02	94	97	01	02	03	94	97
3. **unvented** gas or propane space heater	01	02	94	97	01	02	03	94	97
4. gas or propane heater **vented** to the outside	01	02	94	97	01	02	03	94	97
5. woodstove	01	02	94	97	01	02	03	94	97
6. fireplace	01	02	94	97	01	02	03	94	97

39. Which of these other fuels are used for supplemental heat?

[CIRCLE ALL THAT APPLY]

oil............01
electricity....02
coal...........03
other..........04 ⟶ [SPECIFY] ______________________ |__|__|
none used......05
DK.............94
RE.............97

40. Do you use any of the following distribution systems for supplemental heat?

		Y	N	DK	RE
a.	forced air	01	02	94	97
b.	hot water	01	02	94	97
c.	natural convection (fireplace, woodstove, floor furnace, without blower)	01	02	94	97
d.	something else	01	02	94	97

[SPECIFY] ______________________ |___|___|

[IF YES TO Q40A CONTINUE; IF NO, DK OR RE TO Q40A ⟶ Q43]

41. Is this system in a basement or crawl space?

YES...........01
NO............02
DK............94
RE............97

42. Do any ducts carrying the warm air for this system run under the house?

YES...........01
NO............02
DK............94
RE............97

43. How many fireplaces do you have?

|___|___|
DK........94
RE........97

44a. Do you use any of the following humdification devices during the heating season?

FOR EACH YES CIRCLED, ASK:

44b. Do you use this (NAME)....

		Y	N	DK	RE	DAILY	MORE THAN ONCE PER/WK	LESS THAN ONCE PER/WK	DK	RE
a.	ultrasonic humidifier (PROBE: This humidifier reduces water to a fine spray using ultrasound; ultrasound is inaudible to the human ear.)	01	02	94	97	01	02	03	94	97
b.	cool mist humidifier (PROBE: This humidifier uses the blade of a rotor to spray small droplets of water into the air.)	01	02	94	97	01	02	03	94	97
c.	steam mist humidifier (PROBE: This humidifier uses a heating coil to create steam.)	01	02	94	97	01	02	03	94	97
d.	humidifier, DK type	01	02	94	97	01	02	03	94	97

45. Is there an air-to-air heat exchanger or heat-recovery ventilator in your home? (PROBE: This is a system that blows stale air out of the house, brings in fresh air from outside, and transfers heat from the stale air to the fresh air.)

YES.................01

NO..................02

DK..................94

RE..................97

46. On the average, what temperature do you usually keep your entire home in the winter? [USE MARGIN/MARGINAL NOTES TO CALCULATE AVERAGE TEMPERATURE.]

|___|___| DEGREES

DK...........94

RE...........97

47. Do you have any of the following gas or propane fueled appliances in this home? [CIRCLE ONE RESPONSE FOR EACH ITEM.]

		YES	NO	DK	RE
a.	water heater	01	02	94	97
b.	clothes dryer	01	02	94	97
c.	stove	01	02	94	97
d.	oven	01	02	94	97
e.	refrigerator	01	02	94	97
f.	air conditioner	01	02	94	97
g.	heat pump	01	02	94	97
h.	other	01	02	94	97

↓ [SPECIFY] ______________________________ |__|__|

48. Does this home have a central air conditioning system?

YES.......01
NO........02
DK........94
RE........97

49. Do you use any of these other air conditioning systems? [IF YES TO A OR B, ASK NUMBER USED AND ENTER AT Q50 FOR THE APPROPRIATE ITEM(S). IF NO TO A AND B, SKIP TO Q51.]

		Q49 DK	Q49 RE	Q49 NO	Q49 YES		Q50 NUMBER USED
a.	window or wall mounted unit(s)	94	97	02	01	⟶	|___|___|
b.	swamp or evaporative coolers	94	97	02	01	⟶	|___|___|

51. On the average, what temperature do you usually keep your entire home in the summer? [USE MARGIN/MARGINAL NOTES TO CALCULATE AVERAGE TEMPERATURE.]

|___|___| DEGREES
DK..........94
RE..........97

52a. Some stove fans or bathroom fans simply blow air through a filter, or blow exhaust to an unvented attic. They do not blow air or exhausts out of the house. We are only interested in exhaust fans which are vented to a vented attic or to the **outside**.

Do you use these built in exhaust fans vented to the outside?

FOR EACH YES CIRCLED, ASK:

52b. Do you use this (NAME)...

		YES	ON	DK	RE	WHENEVER COOKSTOVE USED	OCCASIONALLY WHEN COOKSTOVE USED	SELDOM OR ALMOST NEVER	DK	RE
1.	cook stove exhaust fans	01	02	94	97	01	02	03	94	97
		YES	NO	DK	RE	WHENEVER BATHROOM USED	OCCASIONALLY WHEN BATHROOM USED	SELDOM OR ALMOST NEVER	DK	RE
2.	bathroom exhaust fans	01	02	94	97	01	02	03	94	97
		YES	NO	DK	RE	DAILY	MORE THAN ONCE PER WEEK	SELDOM OR ALMOST NEVER	DK	RE
3.	clothes dryer	01	02	94	97	01	02	03	94	97

53. Does the home have a whole house exhaust fan which blows air out of the home?

YES...... 01

NO....... 02
DK....... 94
RE....... 97 } ⟶ 54a

53a. How frequently do you use the whole house fan in the cooling season:

Use every day.................................. 01
Not daily but more than once a week........... 02
Use regularly but less than once a week....... 03
Seldom or never use during cooling season..... 04
DK... 94
RE... 97

53b. How frequently do you use the whole house fan during other seasons?

Use every day.................................. 01
Not daily but more than once a week........... 02
Use less than once a week..................... 03
Seldom or never use during other seasons...... 04
DK... 94
RE... 97

54a. Does this home have...

FOR EACH YES CIRCLED, ASK:

54b. What percent of your home has (TERM)?

		Y	N	DK	RE	PERCENT	DK	RE
1.	double pane windows	01	02	94	97	|_|_|_|%	94	97
2.	storm windows	01	02	94	97	|_|_|_|%	94	97
3.	insulation in the walls	01	02	94	97	|_|_|_|%	94	97
4.	insulation in the ceiling	01	02	94	97	|_|_|_|%	94	97
5.	storm doors	01	02	94	97	|_|_|_|%	94	97
6.	weather stripping	01	02	94	97	|_|_|_|%	94	97

55. All things considered regarding the insulation and weatherization of your home, would you say that your home is tight, leaky, or are you uncertain about the tightness of your home?

TIGHT................01

LEAKY................02

UNCERTAIN............03

RE...................97

56. Which months of the year is your home usually closed up for heating season, that is, your windows and doors are usually kept closed?
[CIRCLE ALL THAT APPLY]

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
01	02	03	04	05	06	07	08	09	10	11	12

57. Which months of the year is your home usually closed up for cooling season, that is, your windows and doors are usually kept closed?
[CIRCLE ALL THAT APPLY]

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
01	02	03	04	05	06	07	08	09	10	11	12

58. During the time when your home is usually closed for the heating and cooling seasons, you may take steps to ventilate your home. This may involve such things as opening windows, or when cleaning, cooking, using insecticides, etc. Which of the following best describes your ventilation practices during heating and cooling seasons?

Do you....

ventilate on a daily basis...........................01

not daily, but more than once a week.................02

regularly, but less than once a week.................03

only during specific activities......................04

do not ventilate at all..............................05

DK...94

RE...97

SCRIPT 5 -- READ TO RESPONDENT:

In order to get estimates of individual exposure to radon, I need to ask some questions about the people who usually live here. First I will ask some background questions about these people and then ask where they spend their time in the house.

[RECORD ANSWERS ON NEXT PAGE]

59. How many people live in this household?

60. Starting with you, tell me the first names of the people who live in this household. After your name, let's begin with the oldest and work down to the youngest.

61. Next, I need [your/NAME'S] age on [your/their] last birthday.

62. [IF NOT OBVIOUS ASK] Is (NAME) male or female?

63. How many years and months (have you/has NAME) lived in this home?

64. (Do you/Does NAME) smoke cigarettes?

[ASK Q65, Q66 AND Q67 FOR EACH "YES" IN Q64]

65. On average, how many packs or partial packs of cigarettes (do you/does NAME) smoke during a typical week?

66. On average, how many cigarettes (do you/does NAME) smoke in the home each during a typical 24-hour weekday?

67. On average, how many cigarettes (do you/does NAME) smoke in the home each during a typical 24-hour weekend day?

INTERVIEWER INSTRUCTION: ASK QUESTIONS 68 THROUGH 71 FOR R, THEN PROCEED WITH QUESTIONS 68 THROUGH 71 FOR EACH ADDITIONAL MEMBER OF THE HOUSEHOLD, ONE PERSON AT A TIME]

68. Think about a usual Monday through Friday. During a typical 24-hour weekday, how many hours (do you/does NAME) spend in the house, on the average?

69. Of the (number) weekday hours (you/NAME) spend in the home, how many hours (do you/does NAME) spend on the (first/second/etc.) level of your home?

70. Think about a usual Saturday and Sunday. During a typical 24-hour weekend day, how many hours (do you/does NAME) spend in the house, on the average?

71. Of the (number) hours (you/NAME) spend in the home on a typical weekend day, how many hours (do you/does NAME) spend on the (first/ second/etc.) level of your home?

INTERVIEW CHECK POINT: RECORD NUMBER OF LEVELS INDICATED IN Q6 HERE. ____/____

Q59. Number People in Household: ____/____

Q60. First Name: (Respondent First, then Oldest to Youngest	Q61. Age:	Q62. Sex: Males=1 Female=2	Q63. Years and Months Lived Here	Q64. Smoke Cigarettes: Yes = 1 No = 2	Q65. Average Packs Per Week (One Decimal)	Q66/Q67. Average # Cigarettes Smoked in House Per: Week Day / Wkend Day. Enter Code From Below*	Q68. Average Weekday (24) Hours in House	Q69. Weekday Hours by Level 1 2 3 4 5 6	Q70. Average Wkend Day (24) Hours in House	Q71. Wkend Hours by Level 1 2 3 4 5 6
R. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
2. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
3. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
4. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
5. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
6. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
7. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
8. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
9. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||
10. ____	____	1 2	__/__ Yrs Mos	1 2	__ . __	____ ____	__/__	|||||	__/__	|||||

* **NUMBER SMOKED**

None......01
1-5.......02
6-10......03
11-20.....04
Over 20...05
DK........94
RE........97

72. Are you currently renting this home or is it owned or being bought by you?

OWN.......01
RENT......02 ⟶ Landlord: ______________________
DK........94 Address: ______________________
RE........97 ______________________
____

73. Finally we would like to ask about any other radon testing. Has your home been tested for radon in the past?

YES.......01 ⟶ CONTINUE
NO........02 }
DK........94 } ⟶ SCRIPT 2
RE........97 }

74. How many measurements have been taken?

___/___
DK........94
RE........97

75. Did (any of) the tests indicate that the radon levels in your home were high or elevated?

YES.......01
NO........02
DK........94
RE........97

76. Have you had anything done to reduce the levels of radon in your home?

YES.......01 ⟶ CONTINUE
NO........02 }
DK........94 } ⟶ SCRIPT 2
RE........97 }

77. What was done? ____
____

SCRIPT 2 READ TO RESPONDENT

That's all the questions I have. There are just two more tasks I have to do -- place the detectors and get your name, mailing address, and telephone number.

To obtain accurate measurements, the detectors should remain in place for approximately 12 months. At that time, we will send you instructions on how to package and return them. We will also send you postage-paid envelopes for their return.

PLACE (OTHER) DETECTOR AND ENTER INFORMATION BELOW.

	DETECTOR ID#	LEVEL	V	H		DUPLICATE DETECTOR ID
#1	________________	|__|__|	1	2	#1.	________________
#2	________________	|__|__|	1	2	#2.	________________
#3	________________	|__|__|	1	2	#3.	________________
#4	________________	|__|__|	1	2	#4.	________________

01 = Level One

02 = Level Two

03 = Level Three

CIRCLE ONE NUMBER BELOW TO INDICATE DETECTOR PLACEMENT.

	DETECTORS							
	Originals				Duplicates			
	01	02	03	04	01	02	03	04
PLACED BY RESPONDENT WITH INTERVIEWER DIRECTION...01	01	01	01	01	01	01	01	01
PLACED BY INTERVIEWER.............................02	02	02	02	02	02	02	02	02
PLACED BY RESPONDENT ALONE........................03	03	03	03	03	03	03	03	03
REFUSED PLACEMENT.................................04	04	04	04	04	04	04	04	04
PHYSICALLY/MENTALLY INCAPACITATED.................05	05	05	05	05	05	05	05	05
OTHER (EXPLAIN IN FULL BELOW).....................06	06	06	06	06	06	06	06	06

____

____

____

____

INTERVIEWER:

WHEN YOU HAVE COMPLETED THE QUESTIONNAIRE, COMPLETE PART E OF THE CONTROL FORM.

APPENDIX C

NATIONAL RESIDENTIAL RADON SURVEY

CONTROL/SCREENING FORM

March 2, 1989

OMB Number:
Expires:

CONTROL/SCREENING FORM - NATIONAL RESIDENTIAL RADON SURVEY

PART A. HOUSEHOLD IDENTIFICATION

IF ADDED HU, CHECK HERE ☐

AND ENTER LINK LINE NO. ☐☐☐

ATTACH AND COMPLETE ADDED HU LABEL

IDENTIFICATION LABEL

PART B. RECORD OF CALLS

Day of Week	Date	Time	Results	Code*	FI No.
		am pm			
		am pm			
		am pm			
		am pm			
		am pm			
		am pm			

*CODES:

- 10 = No Answer
- 11 = Appointment
- 12 = Refused
- 13 = Callback
- 20 = Complete, detectors left
- 21 = Complete, detectors not left
- 30 = Terminated
- 31 = Vacant
- 32 = Not a housing unit
- 33 = HU Demolished or moved
- 34 = Not Year Round Residence
- 35 = Moving within 12 months
- 36 = Other (Specify Below) ______

PART C. INTRODUCTION AND SCREENING QUESTIONS

Hello. My name is (YOUR NAME). I'm an interviewer from Research Triangle Institute which is located in North Carolina. We are conducting an important research project called the National Residential Radon Survey, which is sponsored by the U.S. Environmental Protection Agency. You may have seen reports about radon on TV or in the newspaper. Many of these reports were based on EPA sponsored State Radon Surveys. This survey is to determine household radon levels, nationwide. Your household is among several from this area that have been randomly selected through scientific sampling procedures. Your home will represent thousands of homes in this part of the United States. A letter and other materials were sent to each household. Did you receive these materials? IF NOT, HAND LETTER AND INFORMATION MATERIALS TO RESPONDENT AND EITHER READ OR ALLOW TIME FOR READING. SHOW SAMPLE DETECTOR IF NECESSARY.

First, I need to ask a few questions to find out if this household is eligible for the survey.

1. Does anyone in this household live here at least nine or more months out of the year? IF RECENT MOVE IN - Does anyone from this household plan to live here nine or more months out of the year?

   YES . . . . 01 → CONTINUE.
   NO . . . . 02 → STOP, NOT ELIGIBLE. ENTER CODE 34 IN PART B.

2. Does your household have firm plans to move from this home within the next 12 months?

   YES, FIRM PLANS TO MOVE . 01 → STOP, NOT ELIGIBLE. ENTER CODE 35 IN PART B.
   NO FIRM PLANS TO MOVE . . 02 → CONTINUE.

Your home is eligible for the study.

To answer the questions in the questionnaire, I need to talk with the head of the household or another person who is responsible for the upkeep of the house. Are you that person?

IF "YES", CONTINUE WITH THE QUESTIONNAIRE.

IF "NO", ASK TO SPEAK TO A KNOWLEDGEABLE INFORMANT. IF NOT AVAILABLE, DETERMINE BEST TIME TO RETURN AND END. DOCUMENT RESULT IN PART B.

WHEN KNOWLEDGEABLE INFORMANT AVAILABLE/CONTACTED, RE-READ THE INTRODUCTION AND CONTINUE WITH THE QUESTIONNAIRE, PART D.

PART D. QUESTIONNAIRE ADMINISTRATION

PART E. RESPONDENT IDENTIFICATION

So that we can contact you about the return of the detectors, please give me your name, correct mailing address, and telephone number.

NAME: ______________________________

ADDRESS: ______________________________

TELEPHONE: (________)______________________________

In case we can't get in touch with you, we need to have the name and telephone number of someone who does not live with you but who will always know how to get in touch with you.

NAME: ______________________ Phone # (____)______________

Thank you for being a part of this important study. To show our appreciation for answering our questions and placing the 12 months detectors, we want you to have this $5.00. So that I may be reimbursed, please sign this receipt portion of the consent form. RTI will send you the rest of the incentive as soon as the detectors are received after the 12 month exposure period.

GIVE THE INCENTIVE AND INSTRUCTION SHEET TO RESPONDENT.
HAVE RESPONDENT SIGN AND YOU COMPLETE THE INCENTIVE RECEIPT PORTION OF THE CONSENT FORM.

I am going to leave this instruction sheet with you. This sheet has more information about the detectors and it also has a phone number to call if you have questions now or at anytime during the time the detectors are in place.

Thanks again for your help.