A Survey of Radon Measurement Needs and Activities in State Radiation Control Programs

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A SURVEY OF RADON MEASUREMENT NEEDS AND ACTIVITIES IN STATE RADIATION CONTROL PROGRAMS

RADON SUBCOMMITTEE

COMMITTEE ON RADIATION MEASUREMENTS

CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS, INC.

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PREFACE

The Conference of Radiation Control Program Directors is an organization whose membership consists of program directors responsible for radiation protection and control in each of the 50 states, the District of Columbia, the U.S. Territories, and certain metropolitan areas. The Conference was formed to serve as a forum for exchanging information between the states and federal agencies, as well as between the state programs themselves, in areas of mutual concern and interest.

In 1981, the Committee on Radiation Measurements of the Conference established a Radon Subcommittee. The preliminary charge to the subcommittee is to evaluate:

1. types of radon (or radon progeny) measurements required in state programs;

2. availability of instruments to perform these measurements.

3. availability of calibration services for those instruments;

4. availability of calibration services in regard to a) accuracy, b) uniformity and c) agreement with national standards;

5. possible intercomparisons or periodic testing programs; and to provide

6. a statement of problems, needs, and possible solutions.

As one of its first tasks, the Radon Subcommittee conducted a survey of the state radiation control program directors to determine the radon measurement needs and present activities in state programs. This report summarizes the responses obtained in this initial survey which was conducted in April-May, 1981.

ABSTRACT

This report summarizes the findings of a survey which was conducted in April-May, 1981 to determine radon measurement needs and present activities in state radiation control programs. The survey focuses on a wide variety of methods for measurements of radon and related quantities. This includes methods for measurement of radon (^{222}Rn) concentration in air, potential alpha energy concentration, individual radon progeny concentrations, radon exhalation or flux density from surfaces, radon concentration in water, and thoron (^{220}Rn) or thoron progeny concentrations in air. The report identifies the sources of radon and thoron which necessitate measurements in the states; the types of measurements and measurement methods that are performed routinely, or that the states would like to obtain or improve the capability of performing; existing calibration capabilities for these measurement methods; and the perceived needs for improving the quality of the measurements.

Key words: Calibration; measurements; radiation; radon; radon progeny; standards; states; thoron.

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I. INTRODUCTION

State radiation control programs have a major responsibility for ensuring public health and safety. In addition to the states' own legislative authority for radiation monitoring, inspection and enforcement, they often must assume responsibility for implementing federal regulations. To perform these functions and thereby assure the public health and safety, state radiation control programs are very dependent upon their ability to perform radiation measurements. In recent years, there has been a growing national concern over the potential health hazards of radiation exposure to the public from various natural and technologically enhanced sources of radon. This concern has been extensively documented.[1-6] Yet, it has become apparent that the accuracy of measurements of radon and related quantities will often not withstand critical scrutiny.[4-8] Many state radiation control program directors lack complete confidence in the quality of their radon measurements*. In part, this is due to the absence of some of the most basic services that are required to support these measurements.[9] The state programs now need and will continue to need demonstratively adequate measurement instruments and methods, readily available measurement standards and calibration facilities, and established measurement quality assurance programs.

In order to more specifically identify and address these radon measurement needs, the Conference of Radiation Control Program Directors (CRCPD) established a Radon Subcommittee in 1981 under the auspices of the CRCPD Committee on Radiation Measurements. As one of its first tasks, the subcommittee conducted a survey of the states for the purpose of determining the current scope and status of their radon measurement programs. It was anticipated that this information would also help to plan future subcommittee activities.

*The term "radon measurements" will be used generically in this report to refer to any types of measurements used to characterize ^{222}Rn (radon) or ^{220}Rn (thoron) sources. This may include concentrations of ^{222}Rn, ^{220}Rn, and their progeny, potential alpha energy concentration, ^{222}Rn flux density, etc.

II. SURVEY OVERVIEW

The survey of radon measurement needs and activities in state radiation programs was conducted in April-May, 1981. The information for the survey was obtained from a questionnaire sent to 55 state* radiation control program directors (selected from the Directory of Personnel Responsible for Radiological Health Programs[10]), and from several follow-up telephone conversations.

The questionnaire, which is reproduced in an appendix, focused on the sources of radon and thoron that necessitate measurements in the states; the types of measurements and measurement methods that are performed routinely, or that the states would like to obtain or improve the capability of performing; existing calibration capabilities for these measurement methods; and the perceived needs for improving the quality of the measurements.

Of the 55 questionnaires that were sent, 46 were completed and returned. Responses were received from:

Alabama	Maryland	Oklahoma
Arizona	Massachusetts	Oregon
California	Michigan	Pennsylvania
Colorado	Minnesota	Puerto Rico
Connecticut	Mississippi	Rhode Island
District of Columbia	Montana	South Carolina
Florida	Nebraska	South Dakota
Guam	Nevada	Tennessee
Hawaii	New Jersey	Texas
Idaho	New Mexico	Utah
Illinois	New York (Dept. Health)	Vermont
Indiana	New York (Dept. Labor)	Virginia
Kansas	North Carolina	Washington
Kentucky	North Dakota	West Virginia
Louisiana	Ohio	Wisconsin
Maine		

The high percentage of responses (nearly 85%) is probably indicative of the wide interest in radon measurements by the state programs. The remainder of this report summarizes the results of the survey.

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*For the purposes of this report, the District of Columbia, Guam and Puerto Rico are counted as states.

III. SURVEY RESULTS

A. Radon Measurement Programs in the States

The extent of existing and anticipated radon measurement programs in the states can be estimated from the aggregate data in Table 1. At present, less than one half of the states are performing ^{222}Rn (radon) or ^{222}Rn-progeny measurements; and only a few states are performing ^{220}Rn (thoron) or ^{220}Rn-progeny measurements. Within 5 years, however, the need for a ^{222}Rn and ^{222}Rn-progeny measurement program may expand to nearly 80% of the states; and the need for a ^{220}Rn and ^{220}Rn-progeny measurement program may expand to approximately one-third of the states.

TABLE 1

Existing and Anticipated Radon Measurement Programs in the States

TYPE OF MEASUREMENT	NUMBER OF STATES*			
	PRESENTLY MEASURING	NOT PRESENTLY MEASURING	NOT PRESENTLY MEASURING, BUT ANTICIPATING NEED FOR MEASUREMENT WITHIN NEXT 5 YEARS	TOTAL, PRESENTLY MEASURING OR ANTICIPATING NEED
^{222}Rn (radon)	17	29	19	36
^{222}Rn Progeny	21	25	16	37
^{220}Rn (thoron)	3	43	11	14
^{220}Rn Progeny	6	40	12	18

*out of 46 responses

Table 2 summarizes the age distribution of the existing measurement programs. As indicated, the majority of the programs appear to have been in place for at least a few years. It is somewhat surprising that so many states anticipate a need for programs within the next 5 years, while so few have initiated programs in the past 2 years. This may reflect either a very recent heightened awareness of their need for a radon measurement program, or their desire for specific guidance prior to starting a program.

TABLE 2

Age Distribution of Existing Radon Measurement Programs in the States

TYPE OF MEASUREMENT	NUMBER OF STATES* PERFORMING MEASUREMENTS FOR				
	LESS THAN 1 YEAR	1-2 YEARS	2-5 YEARS	MORE THAN 5 YEARS	TOTAL
^{222}Rn (radon)	3	4	3	7	17
^{222}Rn Progeny	3	7	2	9	21
^{220}Rn (thoron)	0	0	0	3	3
^{220}Rn Progeny	0	1	1	4	6

*out of 46 responses

B. Radon or Thoron Sources Necessitating Measurements

When asked to identify the sources of radon or thoron which necessitate measurement in their state, a wide variety of both natural and technologically enhanced sources were identified. These sources are categorized in Table 3. Forty-three of the 46 responses identified at least one source that necessitates measurement in their state (i.e., only three states did not identify any); and most identified several sources. In three of these source categories, some states identified more than one subcategory. As a result, the number of states in the subcategories do not sum to the total number of states in the category.

The mineral wastes and entire mineral exploration, mining, and milling/processing cycle dominates the list. Nearly half of the responding states are concerned about sources in these categories.

The source most often cited by the states was drinking water supplies (34 out of 46 responses). This large response may be a result of the states' participation in the Environmental Protection Agency national survey of ^{222}Rn concentration in ground water, and/or the anticipation of possible rule-making under the Safe Drinking Water Act.

TABLE 3

Radon or Thoron Sources Necessitating Measurements in the States

CATEGORY OF RADON OR THORON SOURCES	NUMBER OF STATES*	
Mineral Exploration	3	
Uranium		3
Mineral Mining	22	
uranium		9
thorium		0
lignite		2
phosphate		4
other (n.s.)†		11
Mineral Milling and Processing	20	
uranium milling		8
thorium milling		2
phosphate processing		11
granite industry		1
rare earth recovery facilities		1
radium/thorium facilities, contaminated sites		4
Mineral Wastes	17	
uranium mill tailings		11
phosphate wastes		10
other mine tailings (n.s.)†		1
abandoned mines		1
reclaimed phosphate-mined lands		4
Non-Nuclear Power	7	
geothermal		2
coal-fired plants		1
natural gas		4
Drinking Water Supplies	34	
Building Materials	9	
Indoor, Solar & Energy Efficient Buildings	4	
Other Natural Unenhanced Sources (n.s.)†	13	

*out of 46 responses

†not specified

Sources related to indoor air quality (e.g., energy efficient buildings) and building materials were also significant. Considering the amount of publicity and attention given to this source category in the past few years, even by the popular press, it is surprising that this category was not cited more frequently.

Lastly, there was a relatively large response (13 out of 46) for other natural unenhanced sources.

In addition to identifying the sources which necessitate measurements, the states were also asked to identify the needed "levels of measurement" (i.e., the ^{222}Rn, ^{220}Rn and progeny concentration ranges that they anticipate having a need to measure). These results are summarized in Figures 1 and 2.

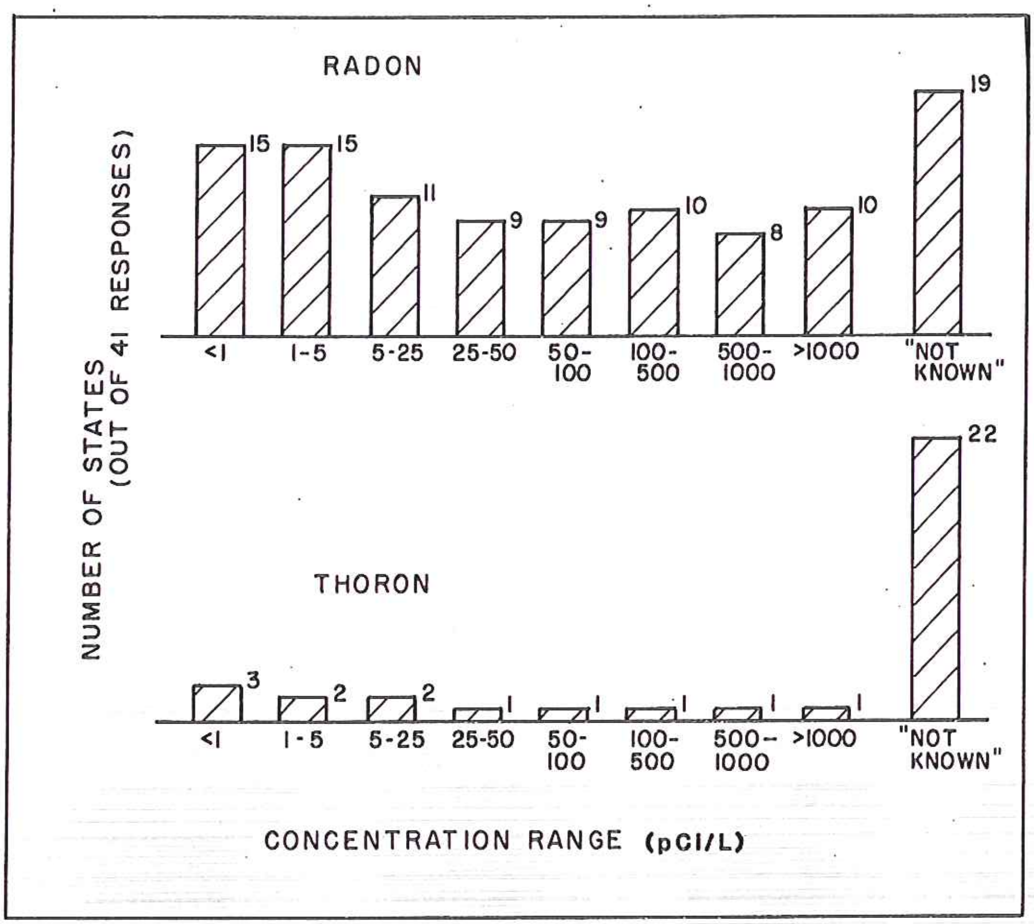

Figure 1. Distributions of the radon and thoron concentration ranges that the states anticipate having a need to measure. For example, 11 of 41 responses indicated that they have a need to measure radon concentration in the range 5-25 $pCi \cdot L^{-1}$.

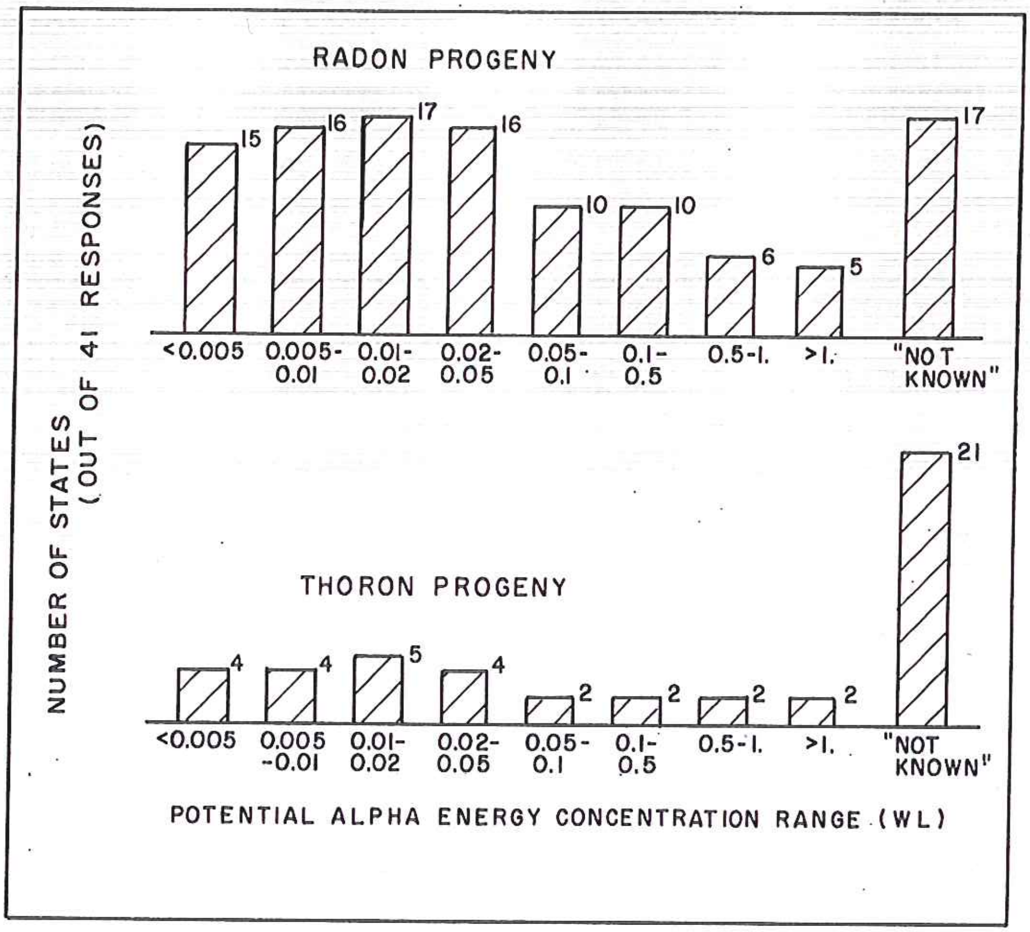

Figure 2. Distributions of the potential alpha energy concentration ranges for radon progeny and thoron progeny that the states anticipate having a need to measure. For example, 5 out of 41 responses indicated that they have a need to measure potential alpha energy concentration for thoron progeny in the range 0.01-0.02 WL.

The concentration range labeled "not known" was the most frequently chosen response. This was the only response given by 10 of 41 states (5 states did not respond to these needed "levels of measurement" questions). As indicated in Figures 1 and 2, additional states chose the "not known" category as well as other concentration ranges. The most striking feature of these results is the very wide range of concentrations identified by the states. These include even abnormally high ranges exceeding 1000 $pCi \cdot L^{-1}$ for radon and thoron concentrations, and exceeding 1 WL for potential alpha energy concentrations. Perhaps it is just another indicator of the states' general uncertainty about the needed concentration ranges, which reinforces the "unknown" responses.

C. Needs for Improving Measurements

The response to the question, "What are your needs for improving your radon and radon progeny measurements?", is summarized in Table 4. As indicated, about two-thirds of the states expressed a need for personnel training and instrument calibrations. Significantly, 17 states identified "other" needs not listed on the questionnaire, and many of these 17 listed more than one need.

TABLE 4

Needs for Improving Radon Measurements in the States

TYPE OF NEED	NUMBER OF STATES* IDENTIFYING NEED	
Training of Personnel	28	
Instrument Calibration "Traceable" to NBS	31	
Field Calibration of Instruments	26	
Other†	17	
Instrumentation		15
Other Calibration & MQA Mechanisms		4
Research		3

*out of 46 responses; 4 states identified none

†see text

The majority of the "other" responses (15 of 17) concerned some aspect of measurement instrumentation and equipment. About half of these did not explicitly identify the need other than list "instruments". Although a few states (4) thought there is a need for new and improved instruments, most of the states focused on the need for guidance on appropriate commercially available instruments, and the need for evaluation of measurement methodologies and instrument prototype testing. The following sampling of comments is representative:

> "listing of instrumentation"
>
> "rational basis for selection and purchase of instruments"
>
> "establish validity of available procedures"
>
> "(need to) know where to get good equipment"
>
> "instruments--enough available, but they need to be evaluated"

With respect to instrumentation, several states also mentioned institutional problems that have to do with insufficient funding to obtain instruments or personnel to use them. This is an immemorial and universal lamentation of the state programs!

The remainder of the "other" responses involved the need for different calibration and measurement quality assurance (MQA) mechanisms (e.g., "cross calibrations" and "interlaboratory comparisons"), and the need for research into the sources and dynamics of radon and its progeny, and the need for interpretation of measurement data (e.g., "breakthrough to predict annual averages from limited measurements").

D. Measurement Methods

The survey also addressed the present scope and anticipated needs of the state programs in terms of the types of measurements and methods that are required. It is important to recognize that the characterization or monitoring of radon and thoron sources may involve the measurement of several different quantities. These quantities include:

- ^{222}Rn (radon) concentration in air;
- potential alpha energy concentration (in units of working level);
- ^{222}Rn-progeny concentrations in air;
- ^{222}Rn exhalation rate or flux density from surfaces such as soil, tailings piles, building foundations, etc.;
- ^{222}Rn concentration in water;
- ^{220}Rn (thoron) and ^{220}Rn-progeny concentrations in air; and
- special aerosol measurements, such as particle size distributions and the uncombined fraction of ^{222}Rn progeny in air.

TABLE 5

Representative Methods for Measurement of Various Radon Quantities

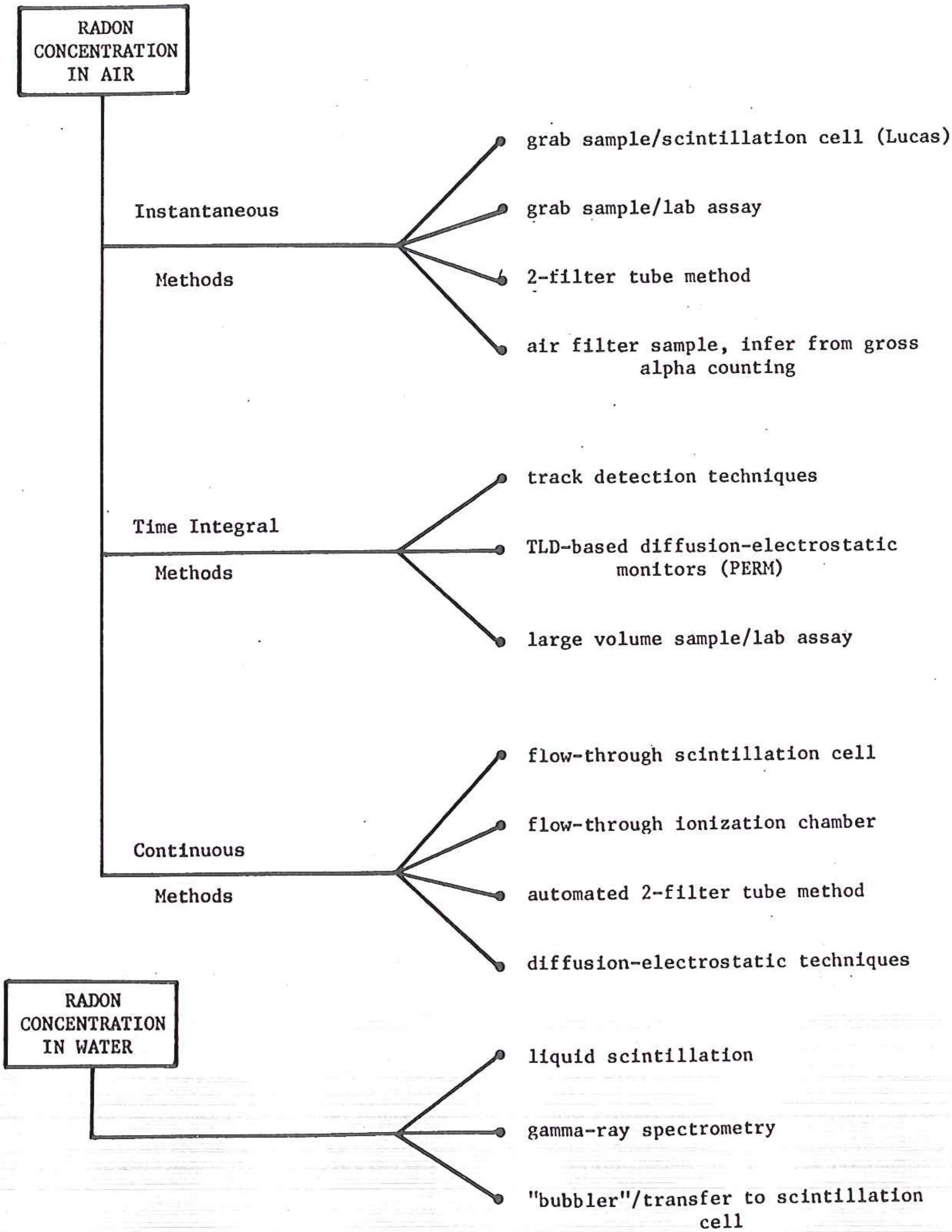

Table 5 (continued)

- **POTENTIAL ALPHA ENERGY CONCENTRATION**
  - Instantaneous Methods
    - air filter sample, single alpha count (Kusnetz, Rolle)
    - calc. from individual progeny concentration measurements
  - Time Integral Methods
    - air filter, TLD (WLM, RPISU)
    - track detection techniques

- **RADON PROGENY CONCENTRATIONS IN AIR**
  - Instantaneous Methods
    - air filter sample, multiple alpha counts (Tsivoglou, Thomas)
    - air filter sample, alpha spectrometry
    - automatic collection filter sample, alpha and beta count [also Continuous]

- **RADON EXHALATION RATE OR FLUX DENSITY FROM SURFACES**
  - accumulation can, assay radon concentration
  - charcoal canister, gamma spectrometry

For each of these quantities, there usually are several measurement methods utilizing widely different protocols and instrumentation. Many of these methods have been summarized by Budnitz[11], and more recently by Breslin[12], by George[13], and by Collé, et al.[14] Although there are common elements in some methods, in many cases the specific method for a given measurement quantity has to be considered and treated as a unique entity. Table 5 illustrates the large variety of available measurement methods for several of these radon quantities*.

1. Radon Concentration in Air

The present scope of the state programs for measurement of ^{222}Rn concentration in air is illustrated in Figure 3. Six states routinely perform these measurements; an additional 13 states have the capability, but do not perform the measurements routinely; and 27 states have no measurement capability. Two of the 6 "routine" states (those that routinely make these measurements) and 7 of the 13 "capable" states (those that have some capability) indicated that they would like to improve their present measurement capability. Twenty of the remaining 27 states indicated that they would like to obtain the capability to measure ^{222}Rn concentration in air.

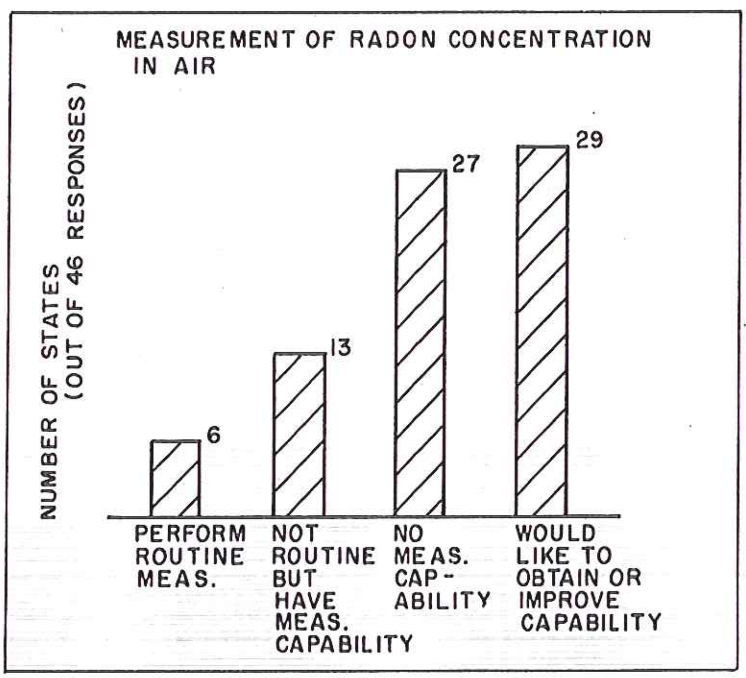

Figure 3. Scope of state programs for measurement of radon concentration in air.

*Part III of the Questionnaire in the appendix to this report contains slightly more complete descriptions of these methods.

Figure 4 demonstrates the wide variety of methods used by the 6 "routine" and 13 "capable" states*. As indicated in the figure, many of these 19 states use more than one method. In fact, only 5 states are dependent on a single method, and most have at least some capability for 3 or more methods.

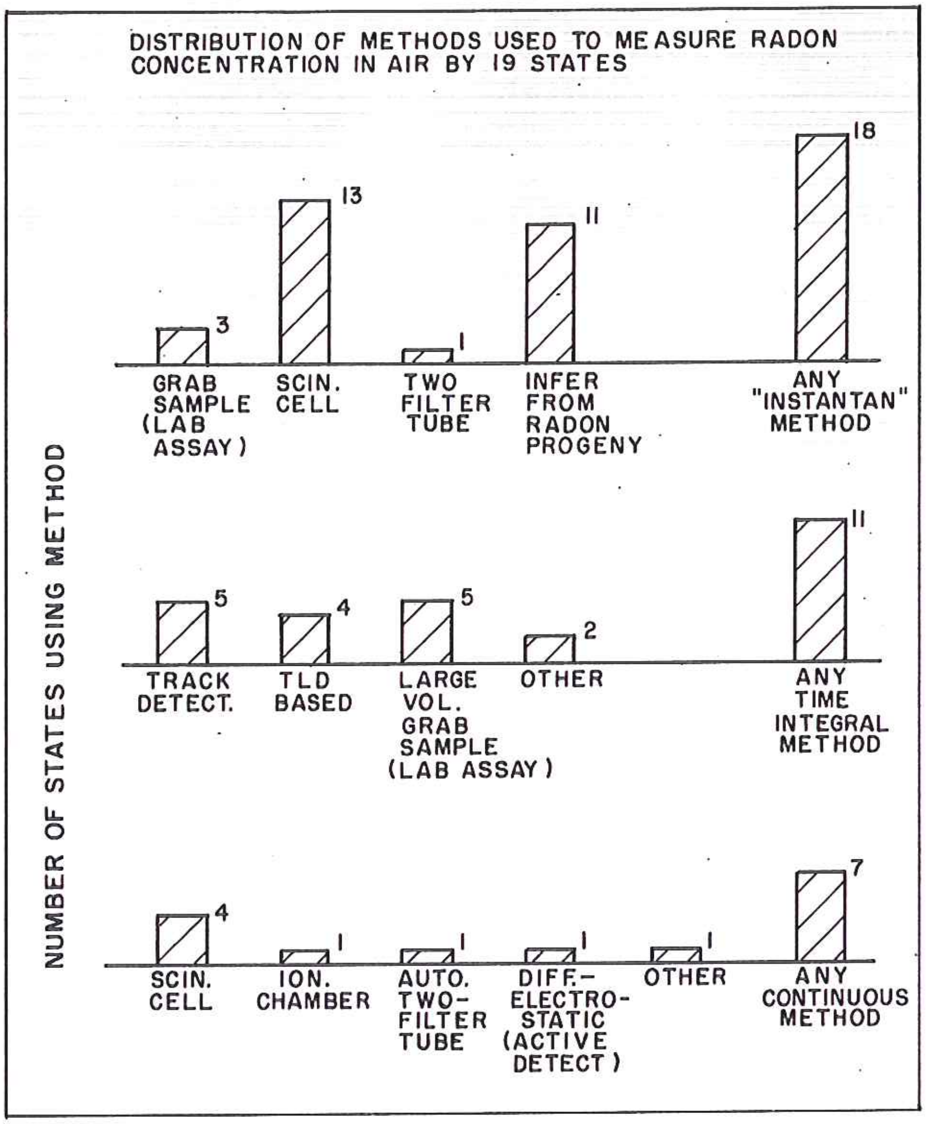

Figure 4. Distribution of methods used to measure radon concentration in air by 19 states. Instantaneous methods are represented in the upper portion; time integral methods in the middle; and continuous methods in the bottom.

*It should be noted that there are apparent, but minor, inconsistencies between the number of "routine" and "capable" states used throughout this section and the numbers in the first column of Table 1. The questions used to obtain the data for Table 1 (e.g., "Are you presently measuring radon?") were interpreted differently by different states. Some states did not interpret "presently measuring" to be synonymous with "have the capability of measuring." Nevertheless, Table 1 provides a useful overview of the state programs, while the data in this section are more specific and less vague.

Eighteen of the 19 states routinely measure or have the capability of measuring ^{222}Rn in air by "instantaneous" (grab-sample) methods in which an air sample is obtained nearly instantaneously or over a few-minute sampling period. The most frequently used instantaneous method was collection of a grab sample in an evacuated ZnS(Ag)-coated scintillation flask[15]. This was closely followed by methods in which ^{222}Rn progeny are collected on an air filter, and the ^{222}Rn concentration is inferred from the gross alpha or beta emission rate. These latter inferential methods are clearly inferior, and are not routinely used by any state. Lastly, one state reported using the two-filter tube method[16].

Eleven of the 19 states use time-integral methods which provide a single, average ^{222}Rn concentration for an extended period of time ranging from a few days to a week or longer. Three methods are almost equally popular. First, track detection techniques[17] are used by 5 states. Three of these states use a commercially available service, while 2 states have developed their own capability. Second, thermoluminescent detector (TLD)-based diffusion-electrostatic monitors[18] are used by 4 states. Commercial versions of these monitors, such as the Passive Environmental Radon Monitor (PERM) which was developed by the Environmental Measurements Laboratory[18], are now available. Third, 5 states use a time-integral method based on the slow collection of a large-volume sample in a plastic bag which is returned to the laboratory for assay[19]. Two "other" methods were reported, but these were not sufficiently identified to be classified.

Seven states either routinely use or have the capability of using continuous monitoring methods which determine individual ^{222}Rn concentrations continuously over time intervals ranging from a few days to a week or longer. The most common method is that based on flow-through scintillation cell monitors[20]. This was the only continuous method that was reported to be routinely used. Other methods included: a flow-through ionization chamber[21]; automated two-filter tube[16]; and the diffusion-electrostatic "Wrenn meter"[22].

2. Potential Alpha Energy Concentration

Potential alpha energy concentration expressed in units of "working level" (WL)* is the radon quantity most frequently measured by the states. As shown in Figure 5, 24 states either routinely make or have the capability of making this measurement. Of these, 3 of the 7 "routine" states and 12 of the 17 "capable" states indicated a need for improvement in their capability. In addition, 13 of the remaining 22 states expressed a desire to acquire a capability to perform this measurement.

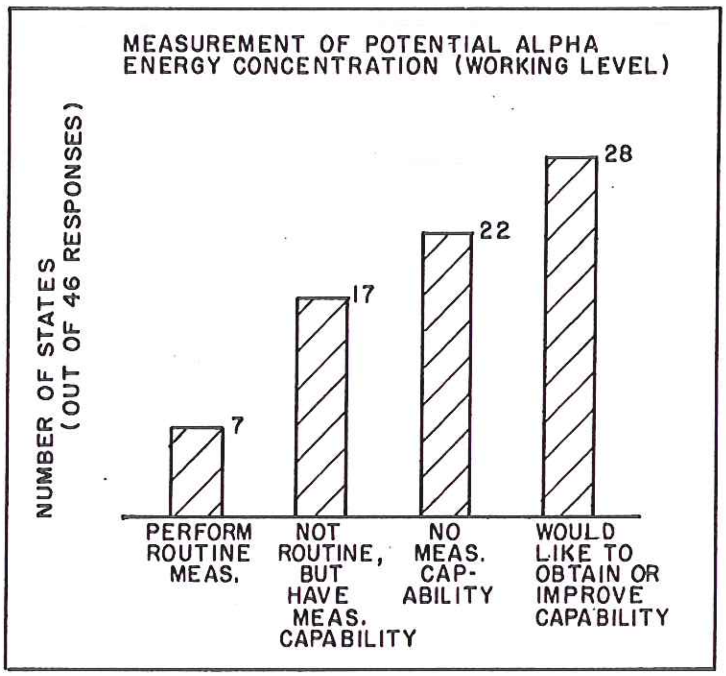

Figure 5. Scope of state programs for measurement of potential alpha energy concentration.

*The WL unit is defined as any combination of the short-lived radon progeny (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of alpha-particle energy [1]. The numerical value of the WL (1.3×10^5 MeV per liter) is derived from the total α-particle energy ultimately emitted in the decay of the short-lived ^{222}Rn progeny that are in radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air. Although this numerical value is derived with the assumption of radioactive equilibrium (i.e., 100 $pCi \cdot L^{-1}$ of each ^{222}Rn progeny), the unit is applicable for any mixture of short-lived ^{222}Rn progeny including nonequilibrium situations.

The methods used to measure potential alpha energy concentration by the 24 "routine" and "capable" states are given in Figure 6. The majority (13 states) use the Kusnetz[23] or Rolle[24] method which is based on measuring the gross alpha-particle emission rate from an air-filter sample. The second most popular method (8 states) utilizes TLD-based monitors[25,26], such as the Radon Progeny Integrating Sampling Unit (RPISU) originally developed by Schiager[25]. Track detection techniques[17], another time-integral method, are used by 4 states; two of which use the commercially available service. Six states indicate they obtain potential alpha energy concentration from measurements of the individual ^{222}Rn progeny concentrations. Based on the responses given in the next section (see Figure 8), it is not clear why 10 more states did not list this method. Lastly, one state reported using its "own method" which is based on a "single count of a grab sample". It is quite likely that this "other" method is a variant of the Kusnetz method.

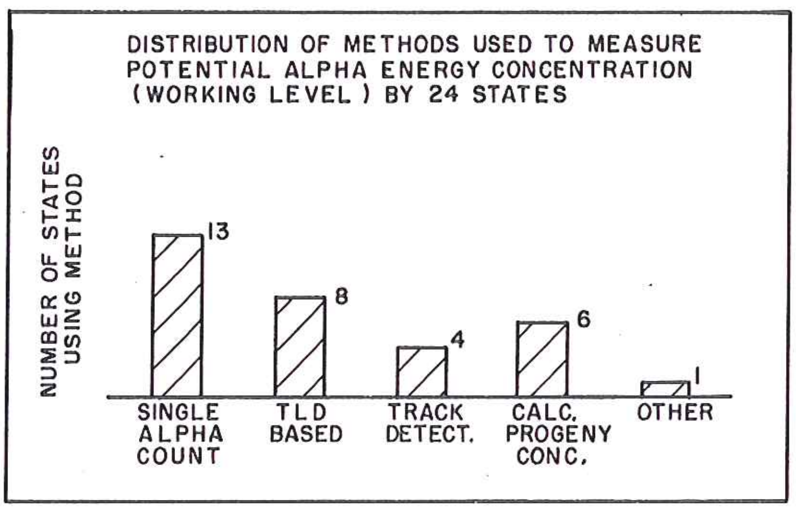

Figure 6. Distribution of methods used to measure potential alpha energy concentration by 24 states.

3. Radon Progeny Concentrations

Unlike potential alpha energy concentration which is a single-parameter measure of effective airborne radioactivity, ^{222}Rn progeny concentrations refer to the individual concentrations of ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po in air. The present scope of state programs for the measurement of these individual radionuclides is shown in Figure 7. The categories used in Figure 7 are the same as those in preceding sections. The 29 states that would like to improve or obtain capability for measuring ^{222}Rn progeny concentrations are comprised of 11 "capable" states and 18 states with no present capability.

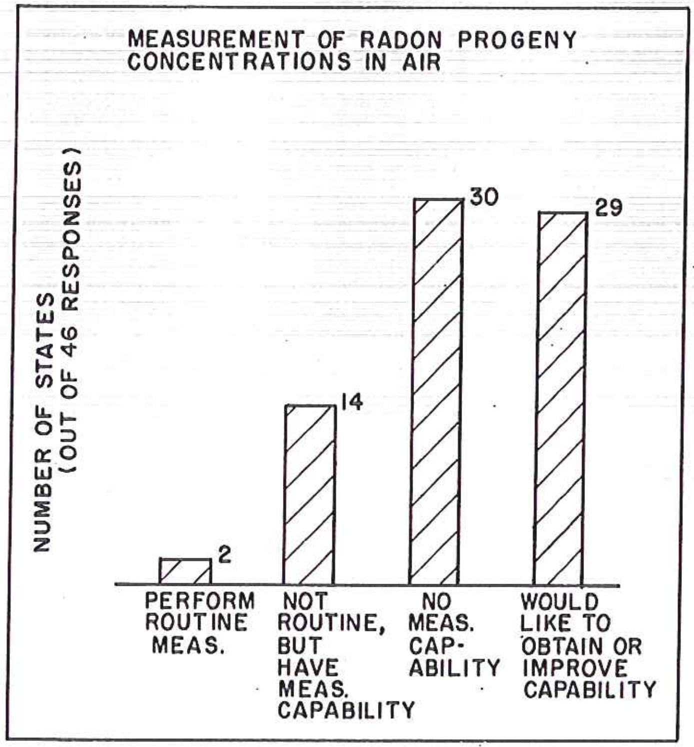

Figure 7. Scope of state programs for measurement of radon progeny concentrations in air.

The distribution of methods used by the 2 "routine" and 14 "capable" states to measure ^{222}Rn progeny concentrations is given in Figure 8. As indicated, the most common (10 states) is the multiple-count Tsivoglou[27] (or its variants, e.g., the Thomas modification[28]) method which is based on measuring the alpha-particle emission rate from an air-filter sample for several time intervals. Similar methods employing alpha-particle spectrometry[29] to measure ^{218}Po and ^{214}Po separately are used by 6 states. One state uses a commercial version of the Instant Working Level Monitor (IWLM) developed by Groer, et al.[30]. This type of instrument, popularly known as a working level monitor, is based on continuous automatic collection of an air-filter sample and combined alpha and beta detectors to determine the individual concentrations of ^{218}Po, ^{214}Pb, and ^{214}Bi. Three states reported "other" methods including gamma-ray spectrometry with a Ge(Li) detector to measure ^{214}Pb and ^{214}Bi, and a multiple-count beta detection method.

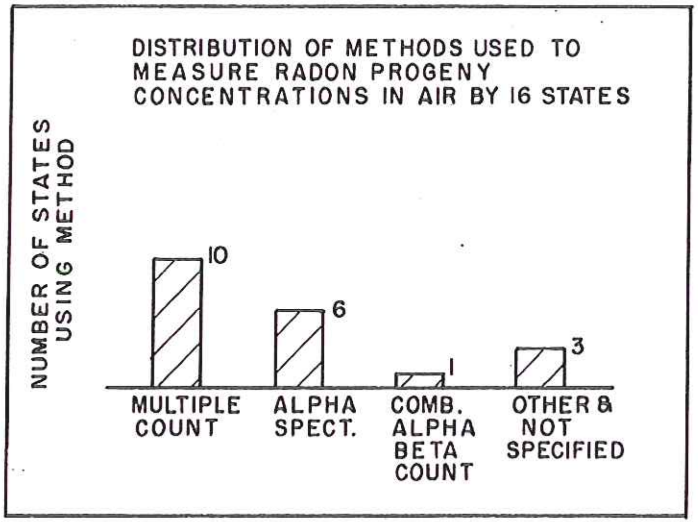

Figure 8. Distribution of methods used to measure radon progeny concentrations in air by 16 states.

4. Radon Exhalation or Flux Density

Figure 9 summarizes the present scope of state programs for the measurement of ^{222}Rn exhalation rate or flux density from surfaces*. Eleven states presently possess some measurement capability (3 "routine" and 8 "capable"). Of these, 4 "capable" states would like to improve their capability. Twenty-two of the 35 states without a present measurement capability indicate a need to obtain it. Compared to other radon quantities, the measurement of flux density is the type of measurement for which the largest number of states (with no existing capability) would like to obtain some measurement capability. On a percentage basis, it follows only the measurement of ^{222}Rn concentration in air (22/35 compared to 20/27).

*"Exhalation", as used here, refers to the liberation or release of radon from a material. The use of the term "emanation" for this concept is not recommended. Hence, the "exhalation rate" is just the time rate of release of radon from a material, and is normally expressed in units of the number of atoms or a submultiple of the curie released in a suitable unit of time (e.g., $pCi \cdot s^{-1}$). It is not normalized to area, mass, radon or radium content of the material, etc. The radon "flux density" for the surface of a material is just the exhalation rate normalized to unit area, and is normally expressed as a submultiple of the curie released in a suitable unit of time and area (e.g., $pCi \cdot m^{-2} \cdot s^{-1}$) [14].

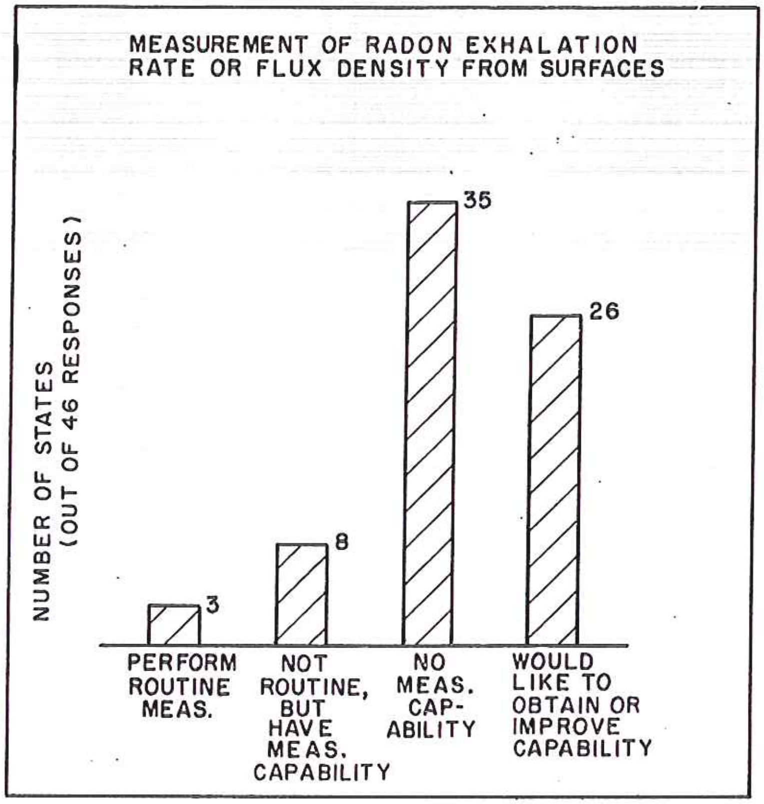

Figure 9. Scope of state programs for measurement of radon exhalation rate or flux density from surfaces.

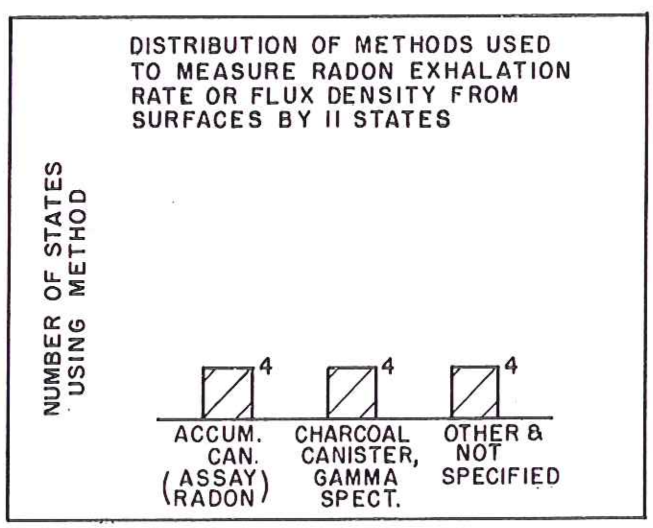

Figure 10. Distribution of methods used to measure radon exhalation rate or flux density from surfaces by 11 states.

As shown in Figure 10, the methods used to measure radon exhalation rate and flux density are equally divided between the well-known accumulation[31] and charcoal canister[32] methods, and "other" methods. The accumulation method, used by 4 states, involves the direct accumulation of ^{222}Rn in an open-faced vessel which is inverted and placed or sealed on a surface. In this way, the vessel and surface forms a closed container for the accumulation of exhaled radon. The method relies upon either a long accumulation period followed by a single sampling and assay of the ^{222}Rn concentration, or by periodic sampling and assaying to follow the growth of ^{222}Rn concentration in the accumulator. In the charcoal canister method, also used by 4 states, the surface to be measured is covered directly with a canister filled with granular activated charcoal. The exhaled radon is adsorbed onto the charcoal and collected for 1 to 2 days. The quantity of radon collected is then determined by directly assaying the charcoal for the radon progeny radionuclides by gamma-ray spectrometry. Two states use both the accumulation and charcoal canister methods. Four "other" methods were also reported. Two were unspecified. Another was stated to be a "liquid scintillation" method used to measure exhalation from small samples (details unreported). This may be a variation of the accumulation method in which the ^{222}Rn is assayed by liquid scintillation counting. Lastly, one state reported using an alpha-sensitive "surface barrier detector for 3 weeks". Although an automatic instrument which directly measures radon exhalation from a mine wall using an active detector has been developed[33], it is not known how the surface barrier detector is deployed in this state's method.

5. Radon Concentration in Water

Radon concentration in water is apparently one of the more important and popular radon measurement programs in the states. See Figure 11. Eight states perform routine measurements of ^{222}Rn concentration in water, which is more than the number of states performing routine measurements for any other radon quantity. In total, 24 states (8 "routine" and 16 "capable") possess some measurement capability. Thirteen of these (2 "routine" and 11 "capable") would like to improve their capability; and 13 additional states would like to obtain a capability.

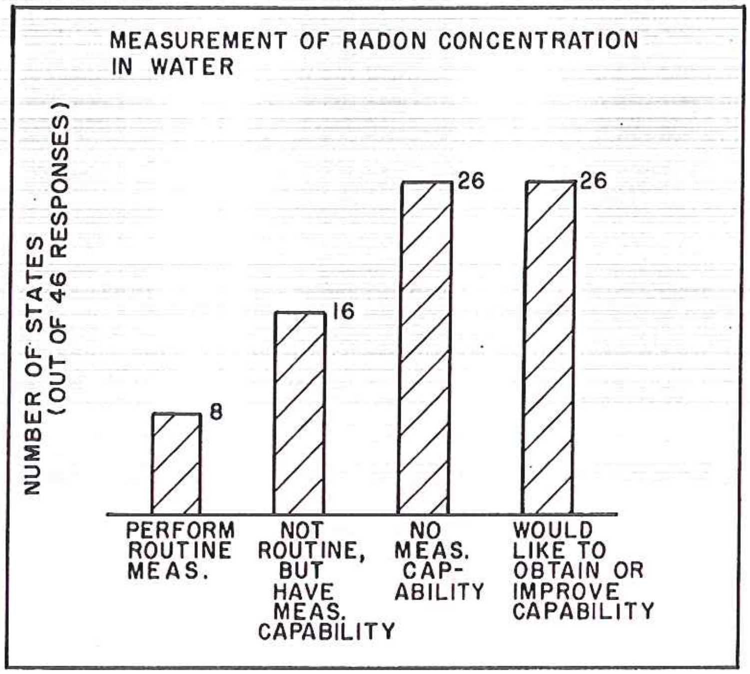

Figure 11. Scope of state programs for measurement of radon concentration in water.

Figure 12 shows the distribution of methods used by the 24 states to measure ^{222}Rn concentration in water. Two-thirds of the states (16) use liquid scintillation[34] as at least one of their methods. Half (12 states) use a method in which radon is degassed from the water sample and transferred for subsequent assay of the ^{222}Rn concentration. Although any technique that measures ^{222}Rn could be used to perform the assay, all 12 states use conventional scintillation flasks. Less sensitive direct gamma-ray spectrometry[35] on a water sample is used by 11 states. It is apparent that many of the 24 states possess a capability for more than one method. In fact, 7 states use two methods, and 4 states use all three methods.

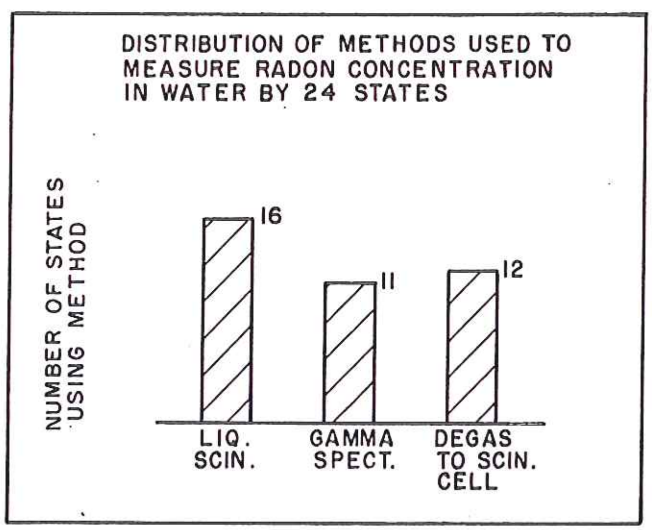

Figure 12. Distribution of methods used to measure radon concentration in water by 24 states.

6. Thoron or Thoron Progeny Concentrations

State programs for measurement of ^{220}Rn or ^{220}Rn progeny concentrations in air are at present rather limited. As indicated in Figure 13, only 2 states perform routine measurements, and an additional 6 states are "capable". The need for these thoron measurements was also judged to be not as great as the need for other types of measurements. Only 3 of the 6 "capable" states indicated that they would like to improve their capability, and 11 of the 38 states with no capability wanted to acquire it. This may be contrasted to almost every other type of measurement for which nearly twice as many states wanted to obtain or improve capability.

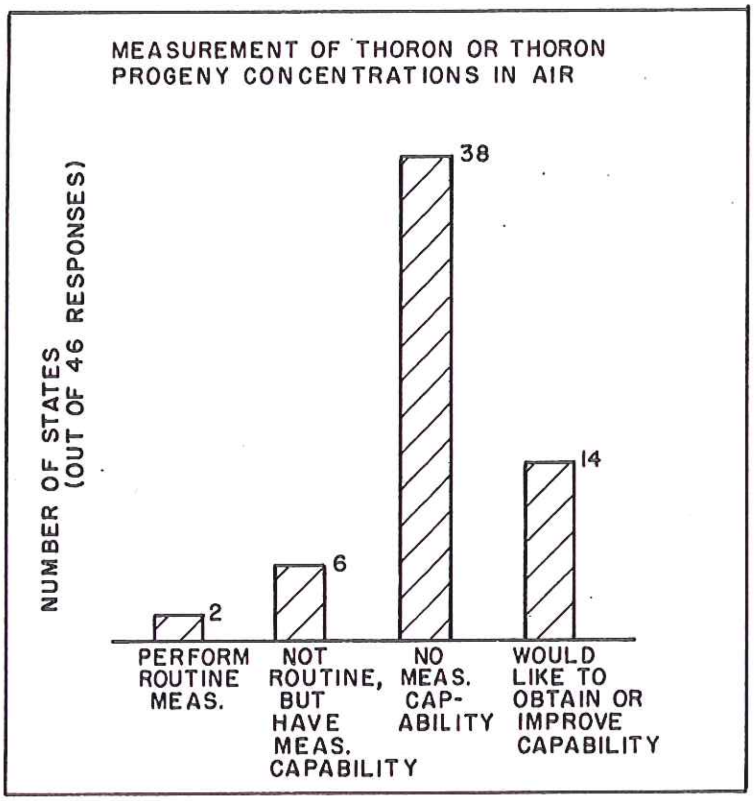

Figure 13. Scope of state programs for measurement of thoron or thoron progeny concentrations in air.

7. Special Aerosol Measurements

The present scope of state programs for special aerosol measurements is illustrated in Figure 14. Two types of aerosol measurements were specifically identified on the questionnaire, viz., uncombined fraction[36] of radon progeny in air and particle size distributions[37] in air. Not surprisingly, 44 out of 46 responding states have no capability of performing either of these very difficult measurements. What is surprising, however, is the large number of states that would like to obtain a capability in this area. Twenty states indicated that they would like to obtain the capability of measuring uncombined fractions, and 18 states indicated that they would like to obtain the capability of measuring particle sizes. At present, only 2 states have either of these capabilities. One state reported having a capability for measuring both uncombined fractions and particle sizes; and a second state reported having a capability of measuring particle size distributions.

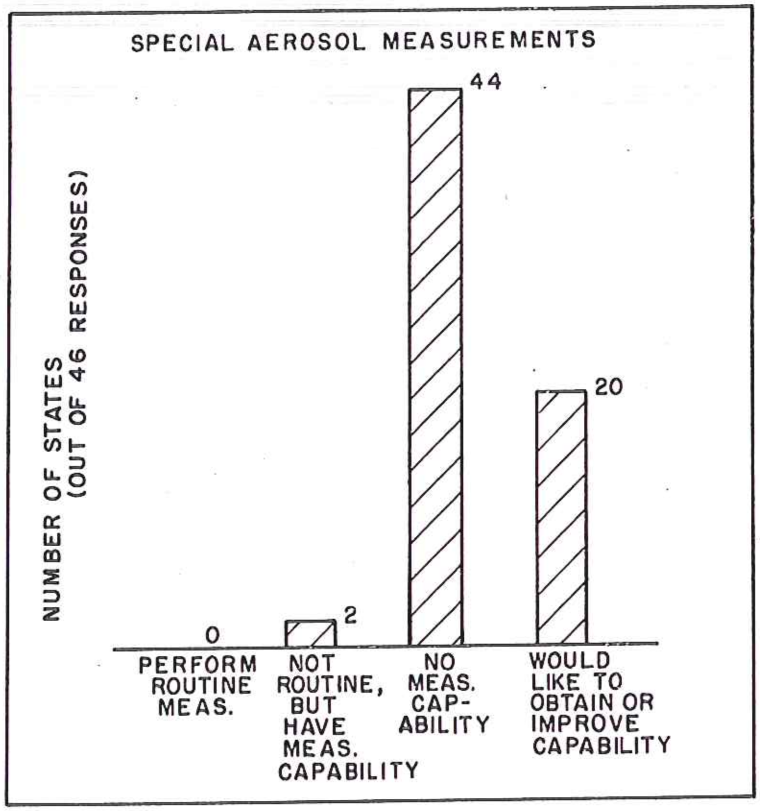

Figure 14. Scope of state programs for special aerosol measurements.

E. Instruments

The responses to the instrumentation portion of the questionnaire (see Appendix) are very difficult to summarize. For each radon measurement method, the states were asked to identify whether they use commercial instruments or items of equipment that were specifically made or purchased for radon measurements; to specify the manufacturer of the instrument or equipment; and to indicate whether the manufacturer stated that the instrument or equipment was calibrated. Part of the difficulty in summarizing these results can be attributed to the high percentage of incomplete responses, which may be evidence of "questionnaire fatigue". The instrumentation portion was near the end of the questionnaire, and was the most complex and difficult part to answer. As a result, the number of responses should not be compared directly to the numbers in other sections. The trends, however, are probably reliable.

The states possess a wide variety of both laboratory-based and field survey instruments for various types of radon measurements. Table 6 lists the number of commercial instruments that are used in the state programs. Only those that could be clearly identified as being commercially available are included. Because of incomplete reporting, the instruments are categorized only in terms of the types of measurements for which they are used, and not in terms of specific instruments and measurement methods. It was felt that further subdivision would make the results more misleading. Although many of the well-known manufacturers are represented, a considerable number of states (at least 11) rely on "homemade" instruments either wholly or partially assembled and made by them. These are not included in the tabulation of Table 6. In addition, several states use instruments that are on loan from the Environmental Protection Agency. These loaned instruments were also not included unless they were explicitly identified as being commercially available. More detailed analyses suggest that the numbers in Table 6 represent roughly 50 to 75% of the instruments in use by the states. The origin and nature of the remaining 25 to 50% of the instruments is unknown.

F. Calibration Capabilities and Measurement Accuracies

Four conceivable mechanisms for states to obtain calibrations of their measurement instruments and methods can be identified. They are:

a) using calibrations provided by instrument manufacturers;

b) performing "in-house" calibrations;

c) obtaining calibrations from other laboratories; and

d) participating in interlaboratory field measurement comparisons in which "calibrations" can be obtained from the pooled results of the participants.

The survey attempted to ascertain the extent of the use of these calibration mechanisms for the various radon measurements made by the state programs.

TABLE 6

Distribution of Commercial Instruments and Manufacturer-Provided Calibrations for Various Radon Measurements

TYPE OF MEASUREMENT	NUMBER OF COMMERCIAL INSTRUMENTS IN USE*		NUMBER OF INSTRUMENTS CALIBRATED BY MANUFACTURER**	
^{222}Rn Concentration in Air	31		12	
"Instantaneous" Methods		19		5
Time Integral Methods		7		3
Continuous Methods		5		4
Potential Alpha Energy Concentration	31		7	
^{222}Rn-Progeny Concentrations in Air	12		2	
^{222}Rn Exhalation Rate or Flux Density	4		1	
^{222}Rn Concentration in Water	19		4	

*This may not be the total number in use by all states. See text.

**For some instruments, manufacturer-provided calibrations are not appropriate.

Of the identifiable commercial instruments that are used by the states for various radon measurements, the numbers that were calibrated by the manufacturer are shown in Table 6. In general, approximately 20 to 40% of these instruments are reported to be provided with a manufacturer's calibration. It must be emphasized, however, that for some instruments a manufacturer-provided calibration is neither appropriate nor reasonable. For example, the calibration of an alpha detector used to measure individual ^{222}Rn progeny or potential alpha energy concentrations may be very dependent on the characteristics of the air-filter sample used to make the measurement. For such a general purpose instrument, it is unlikely that the manufacturer would provide a calibration for specific alpha-particle energies and for specific air-filter sample to detector geometries. Unless the instrument is specifically designated for that type of measurement, it is probably unreasonable to expect the manufacturer to do such a calibration. Field instruments designed and sold for a unique type of measurement (such as flow-through scintillation cell monitors, WLMs, PERMs, and commercial track detection services) should be provided with a manufacturer's calibration. Based on the results of this survey, a higher percentage of these instruments generally are calibrated by the manufacturer. There are, however, notable gaps. Further, whether or not the calibrations are reliable is debatable.

Table 7 summarizes the use of other calibration mechanisms by the states for the various types of radon measurements. The most prevalent is "in-house" calibrations. As indicated, half or less of the states possess this capability for any given type of measurement. In total, only 14 states possess any capability for in-house radon calibrations. An earlier general survey of state radiation measurement needs[38,39] indicated that most states believed that in-house capability was the most desirable method for maintaining the calibration of field instruments. In this earlier survey, the use of external calibration services was in a distant second, and reliance on manufacturer-provided calibrations was in a losing third place compared to having an in-house capability. The present survey seems to reinforce this earlier finding.

The states' capability for performing in-house calibrations is limited by the small number of available measurement standards[9]. The response to the question, "Do you presently have a calibrated radium source or standard that can be used as a radon source (i.e., a liquid or solid radium source from which radon can be extracted without disturbing the integrity of the source)?", indicated that only 12 states have an available standard. Two of these were obtained from commercial suppliers; 4 were from NBS; and 7 were from EPA. One state has 2 sources.

Obtaining calibrations from other laboratories, and participating in inter-laboratory field measurement comparisons are the two other calibration mechanisms that the states used. The latter is similar to obtaining an external "calibration" from a pooled number of laboratories. It may have the additional advantage of providing a mechanism for proficiency testing of a laboratory's performance. These two mechanisms were used by 11 and 9 states, respectively. The distribution of their use by the type of measurement is given in Table 7.

Table 7

Distribution of Calibration Mechanisms Used by the States for Various Radon Measurements

TYPE OF MEASUREMENT	NUMBER OF STATES* THAT			
	PERFORM MEASUREMENT TYPE**	PERFORMED IN-HOUSE CALIBRATION	OBTAINED CALIBRATION FROM ANOTHER LABORATORY	PARTICIPATED IN FIELD INTER-COMPARISON
^{222}Rn Concentration in Air	19	7	6	3
"Instantaneous" Methods	18	6	5	2
Time Integral Methods	11	3	5	2
Continuous Methods	7	1	4	1
Potential Alpha Energy Concentration	24	7	6	4
^{222}Rn-Progeny Concentrations in Air	16	4	3	2
^{222}Rn Exhalation Rate or Flux Density	11	2	2	1
^{222}Rn Concentration In Water	24	12	3	7

*Out of 46 responses.

**Either routinely perform, or have the capability of making (but do not routinely perform) See Figures 3, 5, 7, 9, and 11.

Several laboratories, as a courtesy, have provided states with calibration services, and to a certain extent have been serving as informal national reference laboratories for radon measurements. In particular, the two EPA laboratories at Montgomery and Las Vegas, the Bureau of Mines Laboratory at Denver, and especially the DOE Environmental Measurements Laboratory at New York are to be commended for their assistance to the states. Although these efforts are laudable, these informal arrangements are very fragmentary and unsatisfactory. Similarly, there have been several informal interlaboratory field comparisons over the years, but these have been very infrequent and incomplete, involving only a few state laboratories.

In total, it appears that over a third of the measurements either routinely performed or that the states have the capability of performing are not based on any of the four calibration mechanisms. There are over 160 combinations of the use of 28 measurement methods (Figures 4, 6, 8, 10, and 12) by 32 states, of which about 60 were not reported to be provided with a calibration. Furthermore, of these 32 states performing any type of radon measurement, 9 states did not report the use of any calibration mechanism. It is not clear whether these states succumbed to questionnaire fatigue and failed to report, or failed to calibrate! As dismal as this may appear, it should not be surprising because of the limited availability of suitable transfer standards and calibration facilities[9].

Questions concerning the perceived accuracy of measurements invariably generate interesting responses[38,39]. This survey was no exception. The states were asked to estimate how accurate they believe their radon measurements are. They were asked to specify the accuracy for each of their measurement methods and instruments, and were explicitly given the option to answer "Don't know". Although many states did not reply, the overwhelmingly most frequent response was "Don't know". Only 12 states made estimates for any of the measurement methods. The only apparent trend in the responses was that some states were always more conservative than others. There did not appear to be any trends in the estimated accuracy for the various measurement methods. In all cases, the responses ranged from 5 to 50%. The median response was 10 to 20% which was typical for any type of measurement. Accuracies (more correctly, inaccuracies) in this range are probably, in most cases, very optimistic.

IV. SURVEY HIGHLIGHTS AND CONCLUSIONS

This survey provides an excellent overview of the radon measurement needs and present activities in state radiation control programs.

The states have a very high interest in radon measurements. This is evidenced, in part, by the high percentage of completed responses to the questionnaire. Nearly 85% (46 out of 55) were returned. For comparison, an earlier general survey of state radiation measurement needs[38,39] was based on 38 responses.

At present, at least 32 states are either routinely performing or have the capability of performing some type of measurement for a large variety of environmental radon or thoron sources. Many of these states have expressed a need to develop a capability for other types of measurements, as well as to improve their existing capabilities. Additional states with no present radon measurement capability have indicated a need to develop capabilities for various radon measurements. Table 8 summarises the present status and needs of the state programs for various radon measurement quantities. As shown, there are very widespread needs to improve or obtain measurement capabilities, and for the services that are required to support these measurements.

The seven major radon measurement quantities of interest listed in Table 8 may be ranked in three groups by their approximate order of importance. They are:

1. ^{222}Rn concentration in air, and
2. potential alpha energy concentration;

closely followed by

3. ^{222}Rn exhalation rate or flux density,
4. ^{222}Rn-progeny concentrations in air, and
5. ^{222}Rn concentration in water;

and distantly followed by

6. ^{220}Rn and ^{220}Rn-progeny concentrations in air, and
7. special aerosol measurements, e.g., particle size distributions, uncombined fraction of radon progeny, condensation nuclei.

For each of these quantities, the states employ a variety of measurement methods which utilize widely different protocols and instrumentation. Although there are common elements in some methods, in many cases the specific method for measurement of a given quantity will have to be considered and treated as a unique entity.

Table 8

Present Status and Needs of State Programs for Various Radon Measurement Quantities

MEASUREMENT QUANTITY	NUMBER OF STATES* THAT							
	ROUTINELY PERFORM MEAS. (A)	HAVE CAPABILITY OF PERFORMING (B)	HAVE NO CAPABILITY FOR MEAS. (C)	(OF A) WOULD LIKE TO IMPROVE OR OBTAIN CAPABILITY (D)	(OF B)	(OF C)	PERFORM MEAS. (A+B)	REQUIRE SUPPORT SERVICES (A+B+D)
^{222}Rn Concentration in Air	6	13	27	2	7	20	19	39
Potential Alpha Energy Concentration	7	17	22	3	12	13	24	37
^{222}Rn-Progeny Concentrations in Air	2	14	30	0	11	18	16	34
^{222}Rn Exhalation Rate or Flux Density	3	8	35	0	4	22	11	33
^{222}Rn Concentration In Water	8	16	26	2	11	13	24	37
^{220}Rn or ^{220}Rn-Progeny Concentrations In Air	2	6	38	0	3	11	8	19
Special Aerosol Measurements	0	2	44	0	1	~20	2	~22

*out of 46 responses (A+B+C)

In general, however, the needs for measurement support services are similar. Based on this survey and subsequent deliberations, the subcommittee identified eight generic needs which "cut across" and are applicable for all of the measurement quantities and methods. These are:

1. identification of appropriate commercially available instruments;
2. evaluation of measurement methodologies and instrument prototype testing;
3. development of suitable transfer standards;
4. availability of external calibration facilities;
5. development of internal calibration capabilities;
6. measurement intercomparisons, and proficiency testing;
7. personnel training; and
8. research into the sources and dynamics of radon and progeny, and the interpretation of measurement data.

The need for Measurement Quality Assurance (MQA) programs was not individually listed since any effective MQA program is comprised of the essential features contained in the above list.

At present, very few of these measurement support services exist; and as a result, the accuracy of radon measurements made by the state programs will often not withstand critical scrutiny. Accurate and compatible measurements throughout the U.S. are urgently needed. To accomplish this, the states now need and will continue to need readily available measurement standards, calibration services, and established measurement quality assurance mechanisms.

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APPENDIX

Questionnaire

Part I

Please check the appropriate blocks which best describe the radon sources of interest to you, your radon/radon progeny measurement program, and program needs.

1. Are you presently measuring
   - (a) radon? Yes ☐ No ☐
   - (b) radon progeny? Yes ☐ No ☐
2. If your answer to 1(a) or 1(b) is yes, for how many years has your program been involved in the measurement of:
   - (a) radon: Less than 1 year ☐ 1-2 years ☐ 2-5 years ☐ more than 5 years ☐
   - (b) radon progeny: Less than 1 year ☐ 1-2 years ☐ 2-5 years ☐ more than 5 years ☐
3. Are you presently measuring
   - (a) thoron? Yes ☐ No ☐
   - (b) thoron progeny? Yes ☐ No ☐
4. If your answer to 2(a) or 2(b) is yes, for how many years has your program been involved in the measurement of:
   - (a) thoron: Less than 1 year ☐ 1-2 years ☐ 2-5 years ☐ more than 5 years ☐
   - (b) thoron progeny: Less than 1 year ☐ 1-2 years ☐ 2-5 years ☐ more than 5 years ☐
5. If you are not presently measuring radon or thoron or their progeny, what measurements do you anticipate a need for within the next 5 years?

   Radon ☐ Radon Progeny ☐ Thoron ☐ Thoron Progeny ☐ None of the preceding ☐
6. What are the sources of radon or thoron which necessitate measurement in your state?

Uranium Mining ☐	Displaced Uranium Mill Tailings ☐	Reclamation of Mined Phosphate Lands ☐	Drinking Water Supplies ☐
Thorium Mining ☐	Phosphate Mining ☐	Displaced Phosphate Wastes ☐	Building Materials ☐
Uranium Milling ☐	Processing of Phosphate Ores ☐		Natural Gas ☐
Thorium Milling ☐	Other (please specify ☐ ______________________		Natural Unenhanced Sources ☐
Mines (other than uranium or thorium mines) ☐			

7. For what levels of measurement do you have a need?

Radon (pCi/l)		Radon Progeny (Working Levels)		Thoron (pCi/l)		Thoron Progeny (Working Levels)	
< 1	☐	< 0.005	☐	< 1	☐	< 0.005	☐
1-5	☐	0.005-0.01	☐	1-5	☐	0.005-0.01	☐
5-25	☐	0.01-0.02	☐	5-25	☐	0.01-0.02	☐
25-50	☐	0.02-0.05	☐	25-50	☐	0.02-0.05	☐
50-100	☐	0.05-0.10	☐	50-100	☐	0.05-0.10	☐
100-500	☐	0.10-0.50	☐	100-500	☐	0.10-0.50	☐
500-1000	☐	0.50-1.0	☐	500-1000	☐	0.50-1.0	☐
> 1000	☐	> 1.0	☐	> 1000	☐	> 1.0	☐
Not Known	☐	Not Known	☐	Not Known	☐	Not Known	☐

8. What are your needs for improving your radon and radon progeny measurements?

Training of Personnel ☐
Instrument Calibration Traceable to NBS ☐
Field Calibration of Instruments ☐
Other (please specify) ☐

____

Part II

1. Please check those types of measurements of radon and related quantities which you (a) routinely perform; (b) have the capability of making, but do not routinely perform; (c) have no capability of performing; and (d) would like to either obtain or improve capability of performing.

	a) Perform Routine Measurements	b) Have Capability of Measuring	c) No Capability of Measuring	d) Would like to Obtain or Improve Capability
Radon Concentration in Air (outdoor or indoor)	☐	☐	☐	☐
Potential Alpha Energy Concentration (Working Level)	☐	☐	☐	☐
Individual Radon Daughter Concentrations in Air	☐	☐	☐	☐
Radon Concentration in Water	☐	☐	☐	☐
Uncombined Fraction of Radon Daughters in Air	☐	☐	☐	☐
Particle Size Distributions in Air	☐	☐	☐	☐
Radon Emanation/Exhalation Rate from Surfaces (e.g., soil, tailings piles, building foundations, etc.)	☐	☐	☐	☐
Thoron or Thoron Daughter Concentrations in Air	☐	☐	☐	☐
Other ______ (please state)	☐	☐	☐	☐

2. If you routinely measure or have the capability of measuring radon concentration in air, please check the methods you use.

A. "Instantaneous" (grab-sample) methods in which an air sample is obtained nearly instantaneously or over a few-minute sampling period.

- A1. ☐ collection of grab sample in an evacuated flask which is returned to the laboratory for assay
- A2. ☐ collection of grab sample in an evacuated scintillation flask (Lucas cell)
- A3. ☐ two-filter tube method
- A4. ☐ collection of radon daughters on an air filter, and inferring the radon concentration from the gross alpha emission rate
- A5. ☐ Other (please state)__________

B. Time-integral methods which provide a single, average concentration for an extended period of time ranging from a few days to a week or longer.

- B1. ☐ track-etch techniques
- B2. ☐ TLD-based diffusion-electrostatic monitors (Passive Environmental Radon Monitor, PERM)
- B3. ☐ slow collection of large volume sample in plastic bag which is returned to the laboratory for assay
- B4. ☐ other (please state)__________

C. Continuous monitoring methods which determine individual radon concentrations continuously over time intervals ranging from a few days to a week or longer

- C1. ☐ flow-through scintillation-cell (Lucas) monitor
- C2. ☐ flow-through ionization chambers
- C3. ☐ automated two-filter tube method
- C4. ☐ diffusion-electrostatic techniques using active detector-e.g., surface barrier or scintillation (Wrenn monitor)
- C5. ☐ other (please state)__________

3. If you routinely measure or have the capability of measuring potential alpha energy concentration (working level), please check the methods you use

D1. ☐ Kusnetz or Rolle method (air filter sample, single alpha count after delay, counted within one hour after sampling)

D2. ☐ Working Level Monitors (WLM), integrating working level monitors, Radon Progeny Integrating Sampling Unit (RPISU), etc. based on air filter samples and thermoluminescent (TLD) detectors

D3. ☐ track-etch techniques

D4. ☐ Calculation of working level from measurement of individual daughter concentrations (see Question #4)

D5. ☐ Other (please state)______________________________

4. If you routinely measure or have the capability of measuring individual radon daughter concentrations in air, please check the methods you use

E1. ☐ Tsivoglov method, Thomas-modification or similar modifications (air filter sample, alpha-counted for several time intervals)

E2. ☐ airfilter sample, alpha spectrometry

E3. ☐ Instant Working Level Monitor (IWLM), automatic sample collection, alpha and beta count

E4. ☐ Other (please state)______________________________

5. If you routinely measure or have the capability of measuring radon concentration in water, please check the methods you use

F1. ☐ liquid scintillation

F2. ☐ gamma-ray spectrometry

F3. ☐ radon bubbler and transfer to scintillation cell (Lucas)

F4. ☐ Other (please state)______________________________

6. If you routinely measure or have the capability of measuring radon emanation, exhalation rate, or "flux" from surfaces, please check the methods you use

G1. ☐ accumulation can, assay radon concentration

G2. ☐ charcoal canister collection, gamma-ray spectrometry

G3. ☐ Other (please state)____________________

7. For those methods checked in Questions #2-#6, please (a) mark those that use commercial instruments or equipment which were specifically made and purchased for radon measurements; (b) specify the name of the instrument or equipment manufacturer; (c) indicate whether the manufacturer stated that the instrument or equipment was calibrated; (d) state whether you have your own in-house capability to perform calibrations for this instrument/method; and (e) estimate how accurate you believe your measurements made with this method/instrument are

Method From Question	(a) Use Commercial Instrument	(b) Name of Instrument Manufacturer	(c) Manufacturer Calibrated		(d) Can Calibrate In-House		(e) Estimated Accuracy of Measurements	
			yes	Did not state	yes	No	Don't Know	or specify
#2-A1.	☐	____	☐	☐	☐	☐	☐	____
-A2.	☐	____	☐	☐	☐	☐	☐	____
-A3.	☐	____	☐	☐	☐	☐	☐	____
-A4.	☐	____	☐	☐	☐	☐	☐	____
-A5.	☐	____	☐	☐	☐	☐	☐	____
-B1.	☐	____	☐	☐	☐	☐	☐	____
-B2.	☐	____	☐	☐	☐	☐	☐	____
-B3.	☐	____	☐	☐	☐	☐	☐	____
-B4.	☐	____	☐	☐	☐	☐	☐	____
-C1.	☐	____	☐	☐	☐	☐	☐	____
-C2.	☐	____	☐	☐	☐	☐	☐	____
-C3.	☐	____	☐	☐	☐	☐	☐	____
-C4.	☐	____	☐	☐	☐	☐	☐	____

Method From Question	(a) Use Commercial Instrument	(b) Name of Instrument Manufacturer	(c) Manufacturer Calibrated		(d) Can Calibrate In-House		(e) Estimated Accuracy of Measurements	
			yes	Did not state	yes	No	Don't Know	or specify
-C5.	☐	______	☐	☐	☐	☐	☐	______
#3-D1.	☐	______	☐	☐	☐	☐	☐	______
-D2.	☐	______	☐	☐	☐	☐	☐	______
-D3.	☐	______	☐	☐	☐	☐	☐	______
-D4.	☐	______	☐	☐	☐	☐	☐	______
-D5.	☐	______	☐	☐	☐	☐	☐	______
#4-E1.	☐	______	☐	☐	☐	☐	☐	______
-E2.	☐	______	☐	☐	☐	☐	☐	______
-E3.	☐	______	☐	☐	☐	☐	☐	______
-E4.	☐	______	☐	☐	☐	☐	☐	______
#5-F1.	☐	______	☐	☐	☐	☐	☐	______
-F2.	☐	______	☐	☐	☐	☐	☐	______
-F3.	☐	______	☐	☐	☐	☐	☐	______
-F4.	☐	______	☐	☐	☐	☐	☐	______
#6-G1.	☐	______	☐	☐	☐	☐	☐	______
-G2.	☐	______	☐	☐	☐	☐	☐	______
-G3.	☐	______	☐	☐	☐	☐	☐	______

8. Do you presently have a calibrated radium source or standard that can be used as a radon source (i.e., a liquid or solid radium source from which radon can be extracted without disturbing the integrity of the source)?

☐ No

☐ Yes, obtained in 19__ (specify year)

from ☐ NBS

☐ Commercial supplier (specify) ____________________

☐ Other (specify) ____________________

9. For any of the measurements and methods checked in Questions #2-#6, have you ever (a) performed your own in-house calibrations; (b) obtained a calibration from another laboratory; or (c) participated in an interlaboratory field measurement intercomparison?

Measurement	By Method in Question	Performed In-House Calibration		Obtained Calibration From another Laboratory		Participated in an Interlaboratory Field Intercomparison	
		yes	no	yes	no	yes	no
Radon Concentration in Air							
Instantaneous	#2-A	☐	☐	☐	☐	☐	☐
Time-Integral	2-B	☐	☐	☐	☐	☐	☐
Continuous	2-C	☐	☐	☐	☐	☐	☐
Potential Alpha Energy Concentration-Working Level	#3-D	☐	☐	☐	☐	☐	☐
Radon Daughter Concentrations in Air	#4-E	☐	☐	☐	☐	☐	☐
Radon Concentration in Water	#5-F	☐	☐	☐	☐	☐	☐
Radon Emanation/Exhalation or Flux from Surfaces	#6-G	☐	☐	☐	☐	☐	☐

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report summarizes the findings of a survey which was conducted in April-May, 1981 to determine radon measurement needs and present activities in state radiation control programs. The survey focuses on a wide variety of methods for measurements of radon and related quantities. This includes methods for measurement of radon (^{222}Rn) concentration in air, potential alpha energy concentration, individual radon progeny concentrations, radon exhalation or flux density from surfaces, radon concentration in water, and thoron (^{220}Rn) or thoron progeny concentrations in air. The report identifies the sources of radon and thoron which necessitate measurements in the states; the types of measurements and measurement methods that are performed routinely, or that the states would like to obtain or improve the capability of performing; existing calibration capabilities for these measurement methods; and the perceived needs for improving the quality of the measurements.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Calibration; measurements; radiation; radon; radon progeny; standards; states; thoron.

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