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A PRELIMINARY EVALUATION OF THE CONTROL OF INDOOR RADON DAUGHTER LEVELS IN NEW STRUCTURES

THE UNITED STATES
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PREFACE

The Office of Radiation Programs of the Environmental Protection Agency carries out a national program designed to evaluate public health impact from ionizing and nonionizing radiation, and to promote development of control necessary to protect the public health and the environment. In response to this latter mandate, this preliminary evaluation of the control of indoor radon daughter levels in new structures was prepared. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors. Comments or requests for further information are also invited.

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for Radiation Programs (AW-458)

This report has been reviewed by the Office of Radiation Programs, U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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ABSTRACT

As part of its assessment of the radiological impact of the phosphate industry in Florida, the U.S. Environmental Protection Agency has surveyed residences built atop uraniferous reclaimed phosphate mining land. These surveys have shown elevated radon daughter levels to exist in structures built on this land. In order to allow safer use of this land for residential construction, various state-of-the-art radon daughter control technologies were evaluated by the Agency. These included forced ventilation, polymeric sealants, excavation, crawl space construction, and improved slab quality. From a cost-effectiveness evaluation, crawl space construction was determined to best satisfy the criteria for "optimal" radon daughter control. These criteria were established as: (1) operative passivity (i.e., requiring no occupant responsibilities); (2) uniform effectiveness over the lifetime of a structure; (3) a one-time reasonable cost upon implementation; and (4) not having a significant impact on the lives of future occupants.

Presented at the Health Physics Society Tenth Midyear Topical Symposium on Natural Radioactivity in Man's Environment, Saratoga Springs, New York (October 10-13, 1976).

I. SUMMARY AND CONCLUSIONS

An evaluation is presented on state-of-the-art radon daughter control measures for proposed structures which have radon exhalation through the foundations. This evaluation is largely based on a literature survey, preliminary field studies by the U.S. Environmental Protection Agency in central Florida, and communications with private industry concerning control technology. Five technologies are evaluated for cost-effectiveness: ventilation, polymeric sealants, excavation, ventilated crawl space construction, and improved slab construction. The implementation of these control measures by the builder through interaction with local health authorities is also evaluated.

From the data the Environmental Protection Agency has collected and data provided in this report, the following conclusions can be drawn concerning the implementation of control measures in new structures built on phosphate land in Florida:

1. <u>The potential for construction of structures on reclaimed phosphate land is high.</u>

The amount of reclaimed phosphate mining land in Florida has been estimated at approximately 25,000 acres. Of the 20,000 reclaimed acres in Polk County, the County Health Department estimates that about 29 percent of the land has residential structures and 8 percent has commercial structures. The remainder consist of undeveloped land and land being utilized for parks, farming, and grazing. At the current rate of mining, 4,700 acres per year, assuming that 40-50 percent of the mined area may be reclaimed and that phosphate mining in Florida will continue at the current rate for at least 30 years, there could be as much as 70,000 additional acres open to reclamation. Because a large portion of this land is located adjacent to several large cities and towns, as well as major highways, the potential for further residential or commercial construction is high (1). In addition, a large area of land may exist that naturally contains phosphate deposits near the surface. This land may also pose a potential hazard for occupants.

2. <u>Surveys to date have shown elevated radon daughter working levels* in conventionally-built structures located on reclaimed land.</u>

The Surgeon General of the U.S. Public Health Service in making recommendations to the State of Colorado, established the following indoor radon daughter working level guidelines for the Grand Junction remedial action program (all values have background subtracted):

>.05 WL	Remedial action indicated
.01 - .05 WL	Remedial action may be suggested
<.01 WL	No action indicated.

Although these recommendations were written for dwellings constructed on or with uranium mill tailings, they are relevant as a tool for evaluating levels measured in structures built on phosphate land. Data from Appendix B are provided in the following table and indicate that, as a group, structures on reclaimed land have greater radon daughter levels than structures not on reclaimed land.

*Working Level (WL) - the potential alpha energy from the short-lived daughters of radon which will produce 1.3×10^5 MeV in one liter of air (applied originally as a unit of lung exposure for uranium miners).

Percentage Range of Radon Daughter Levels*

February 1976

Reclaimed Land (n=12)		Nonreclaimed Land (n=9)	
>0.5 WL	: 33.3%	>0.05 WL	: -0-
0.05 - 0.01 WL	: 33.3%	0.05 - 0.01 WL	: 22.2%
<0.01 WL	: 33.3%	<0.01 WL	: 77.8%

3. Control technologies do exist which should substantially reduce radon daughter levels.

The technologies discussed in this report have been shown, theoretically or in actual use, to have radon daughter reduction efficiencies ranging from 40 percent to greater than 80 percent. At this time there is an uncertainty as to the long-term effectiveness of these measures, since they have not been assessed in actual field use. It is expected that as experience is gained from the use of these and other control measures, their selection will become a more refined process with less uncertainties over the actual efficiencies to be realized.

4. There will be a cost, significant with some control measures, associated with the implementation of these measures in structures.

A particular control measure or combination of measures may be selected for implementation based on desired working level reduction,

*All working level measurements have "background" subtracted out. Background radon daughter activity for unmined land in the phosphate deposit area is assumed to be 0.003 WL based on an average of measurements made in structures built on such land (see Appendix B). It should be stressed that this value was chosen to facilitate comparison with existing guidelines and cannot be deemed representative until more extensive background radiation surveys are conducted.

builder preferences, and cost. The total cost (capital and operational) projected for implementation of a few control measures, such as excavation and forced ventilation, could prove to be a significant fraction of the capital and maintenance cost of a structure.

5. The optimal control measure is one that is "passive" in its operation (i.e., requiring no occupant responsibilities), uniformly effective over the lifetime of a structure, involving a one-time reasonable cost upon implementation and not having a significant impact on the lives of future occupants.

Although what constitutes a "reasonable" cost is open to debate, this definition of an optimal radon daughter control measure contains the elements by which criteria can be established not only for the selection of measures, but also the development of innovative control technologies. At this time, it is difficult to determine which of the control measures discussed would meet these criteria. As Table 3 details, however, a few could approach such optimality if radon exhalation through the slab is the primary pathway. For example, if a high effectiveness for ventilated crawl spaces and improved slab construction can be supported by actual field application, they would provide a favorable cost-effective means to effect a working level reduction. Likewise, if the durability of polymeric sealants under normal residential conditions can be proven, then it too would be favorably cost-effective if applied properly. It should be kept in consideration, though, that conditions at some sites may cause control measures other than these to be preferred.

6. <u>There is need for further research, coupled with field studies, to develop and improve radon control measures and their attendant cost-effectiveness.</u>

The basis for much of the effectiveness and cost estimates for the control measures evaluated are theoretical modeling and calculations. What data is available, on control measures applicable to radon daughter control, concerns applications for other purposes (except for the studies performed by Culot, *et al.*, and Auxier, *et al.*, on polymeric sealant effectiveness). There is a need for further research, coupled with field studies, to develop and improve radon control measures and their attendant cost-effectiveness. As part of this effort, the Office of Radiation Programs, U.S. Environmental Protection Agency, is continuing its assessment program involving structures built on reclaimed phosphate land. A part of this assessment will encompass field studies of newly built slabs and unoccupied homes in order to quantify more precisely the effect of variables such as ventilation and slab construction on radon working levels.

II. INTRODUCTION

A recent study by the Office of Radiation Programs (ORP), U.S. Environmental Protection Agency, has found that elevated radon daughter levels exist in a number of structures built on reclaimed phosphate mining land in Florida as compared to unmined land (see Figure 1) (1). These daughter products result from the decay of radon-222, an inert gas which may diffuse into a structure from the underlying ground. Radon and its daughters are members of the uranium decay series which is illustrated in Figure 2. Uranium is a natural constitutent of phosphate rock. Throughout the world it ranges in concentration from a few ppm to a few hundred ppm depending upon the particular deposit. In the marine phosphate formations of central Florida, uranium concentrations of about 150 ppm have been noted (2). In the natural state, the uranium is approximately in secular equilibrium with its daughters through radium-226.

In the process of strip-mining, the overburden is removed and piled adjacent to the pit. After the ore is extracted, a common reclamation practice in preparation for future residential or commercial development has been to fill these mined pits with the overburden to obtain a flat plane. Another technique involves regrading the mined overburden so as to permit multi-purpose utilization of the land. These mining and reclamation methods lead to mixing of the overburden layers, uraniferous leach zone material and other high activity material with "normal" activity soil. As a result, elevated concentrations of radionuclides may be distributed near the surface and thus allow radon to migrate into

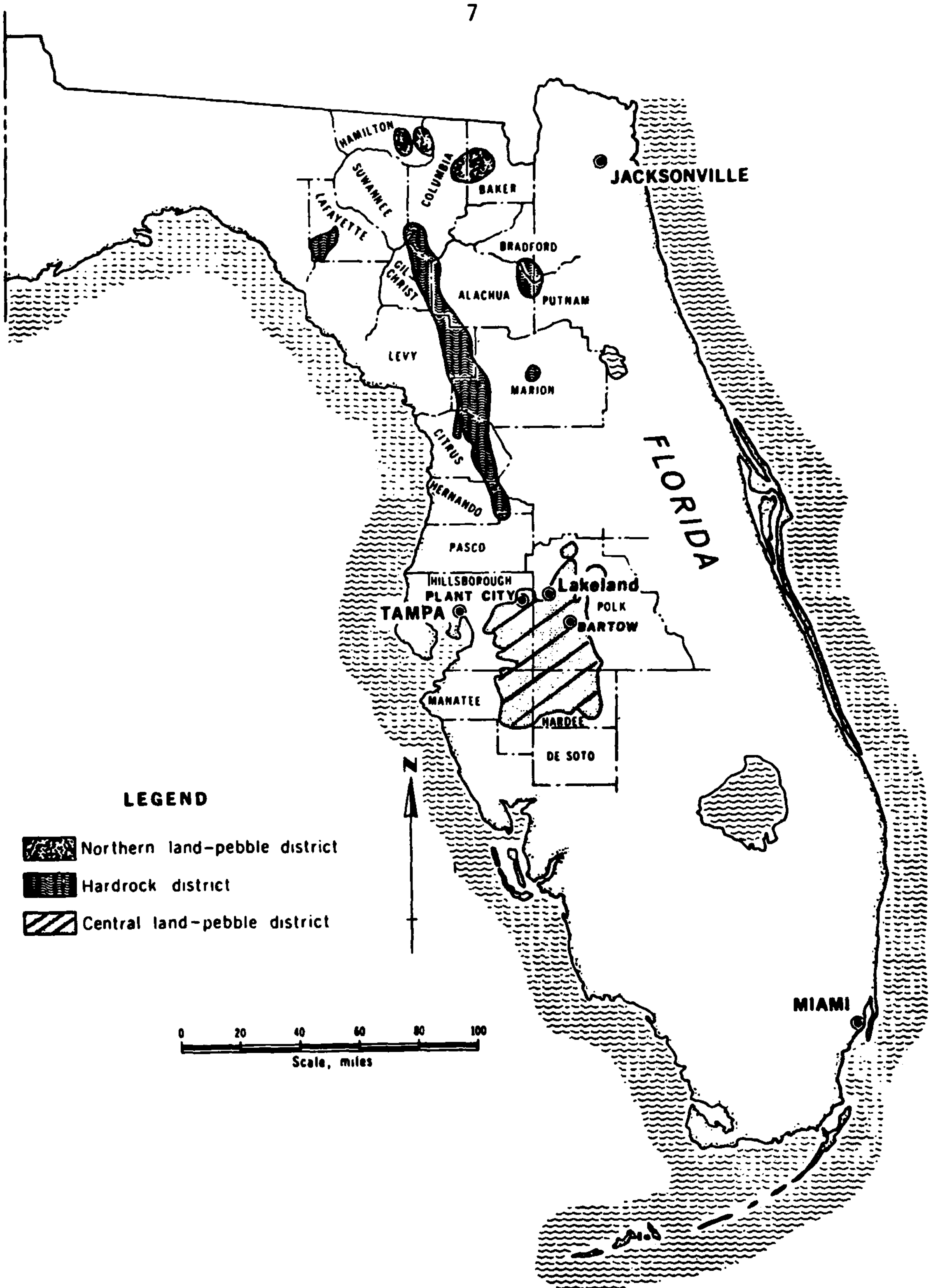
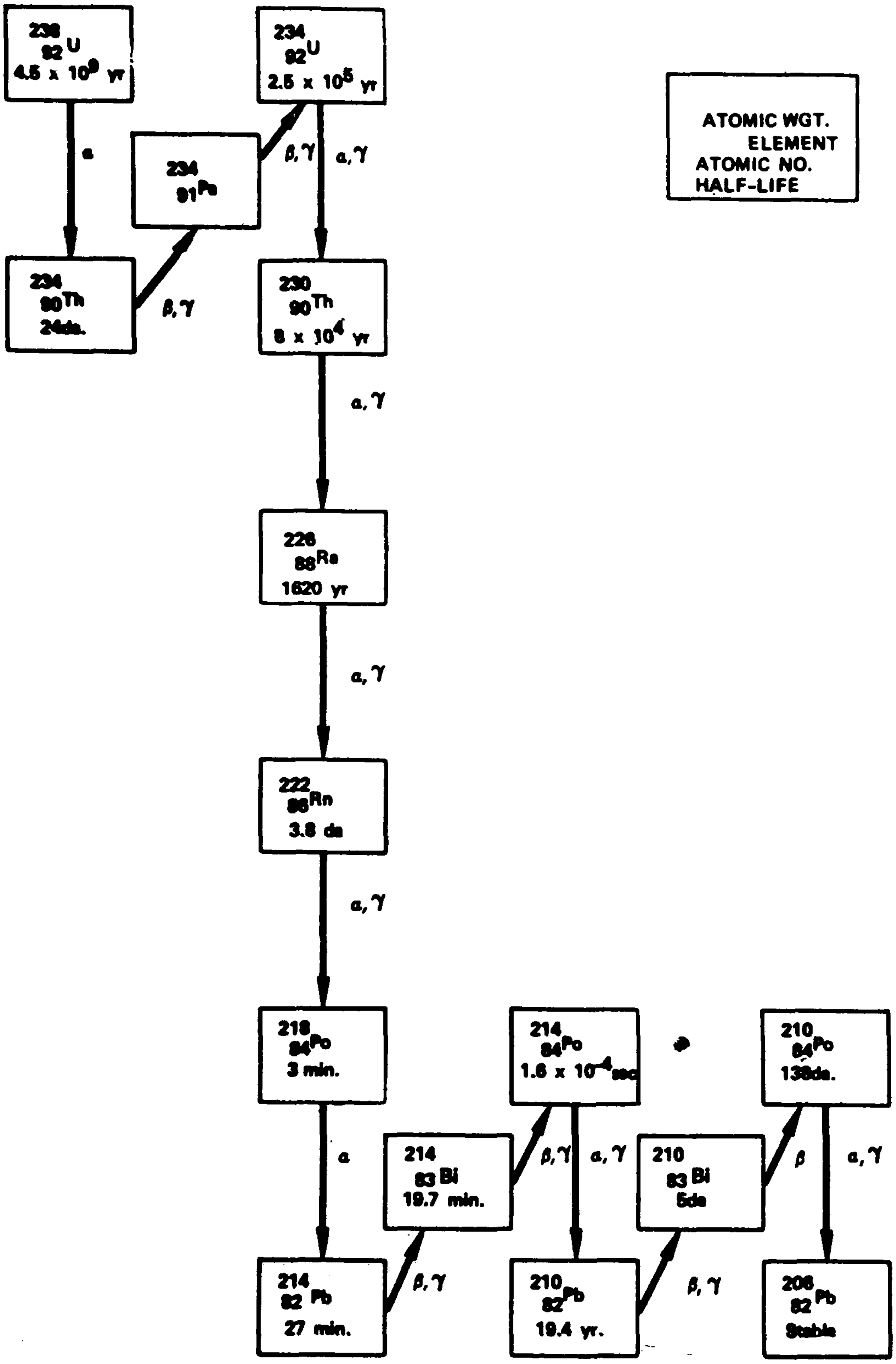


Figure 1 — Phosphate deposits in Florida.

(From Bureau of Mines Circular 8653, Economic Significance of the Florida Phosphate Industry)

FIGURE 2

URANIUM - 238 DECAY SERIES



the atmosphere. Without several feet of overburden acting as a barrier, a large fraction of the radon gas produced by the decay of radium-226 can diffuse to the surface and into the atmosphere. Due to the generally high mixing and dilution characteristics of the lower atmosphere, radon and its progeny do not build up in the open air as they can in a confined space. When structures are built over these phosphate areas, radon seeps into the structures and as a result of the buildup of decay products, increased radiation exposure to the occupants may occur.

The Environmental Protection Agency, as part of its role in providing radiation protection guidance on this potential health hazard, has reviewed various radon progeny control measures for their cost-effectiveness. The purpose of this report is to provide an evaluation of the most practicable technologies based on present data and information that may be used to control radon daughter levels in proposed structures to be built on phosphate lands. It is emphasized that this report does not provide new field data on the effectiveness of the control technologies, but represents an evaluation of applicable existing studies and data. Further, although the subject of reclamation of phosphate mining areas is outside the scope of this report, it is recognized that with proper management of reclaimed land, no radon control measures for structures may be necessary.

III. RADON CONTROL TECHNOLOGY

Although the potential radiation exposure problems associated with residential construction on phosphate land may be known to a builder, he may choose to initiate construction for a number of reasons. First, gamma surveys (as outlined in Appendix C) may show the site to be below the interim guideline of 10 μR/hr average gamma exposure. Second, even though the land may survey greater than 10 μR/hr, due to the desirability of the site (e.g., for economic or zoning reasons), the builder may decide to implement some type of control measure to reduce the indoor radon daughter working level.

The five basic control measures which will be discussed and analyzed in this report are: 1) improved effective ventilation, 2) ventilated crawl space construction, 3) polymeric sealants, 4) site excavation and fill, and 5) improved slab construction. These technologies were selected because they have been shown to be technically feasible, applicable to residential situations and are reasonably cost-effective.

A. Improved Effective Ventilation*

The function of improved effective ventilation is to lower the indoor radon daughter exposure to occupants through dilution with outside air and/or physical removal of the daughter products by a filter

*"Effective" ventilation is the replacement of air within a structure with air containing background radon concentrations through either movement of air through an air cleaner or natural infiltration of outside air.

or electronic air cleaner.* As Figure 3 shows, with no ventilation or filtration, radon and its daughter products are assumed to be in "secular" equilibrium, that is, having the same activities. When both the radon and its decay products are removed through ventilation or when the latter is removed by filtration, the ratio of the parent to each daughter becomes something less than 1:1. This effect is most obvious at ventilation rates of one air change per hour or more. As the rate of ventilation increases, the activity of the fresh makeup air becomes more critical because there is less time for radon daughter in-growth in the room air. For the purpose of the report, though, ventilation rates of this magnitude (>4 air changes per hour) will not be considered and makeup air will be assumed to have background levels of radon (0.5 - 1.0 pCi/l for phosphate land) (3).

When polonium-218, a daughter product of radon, is formed, it occurs as a single charged ion which remains suspended in the air until collision with an aerosol or macro-surface (including larger particulates) whereupon attachment occurs (4,5). The attachment rate for these ions to aerosols has been found to be proportional to the surface area of the aerosol itself (5). Thus, the number and particle size distribution of dust particles, and condensation nuclei in home atmospheres are critical in determining the behavior of these radon daughters.

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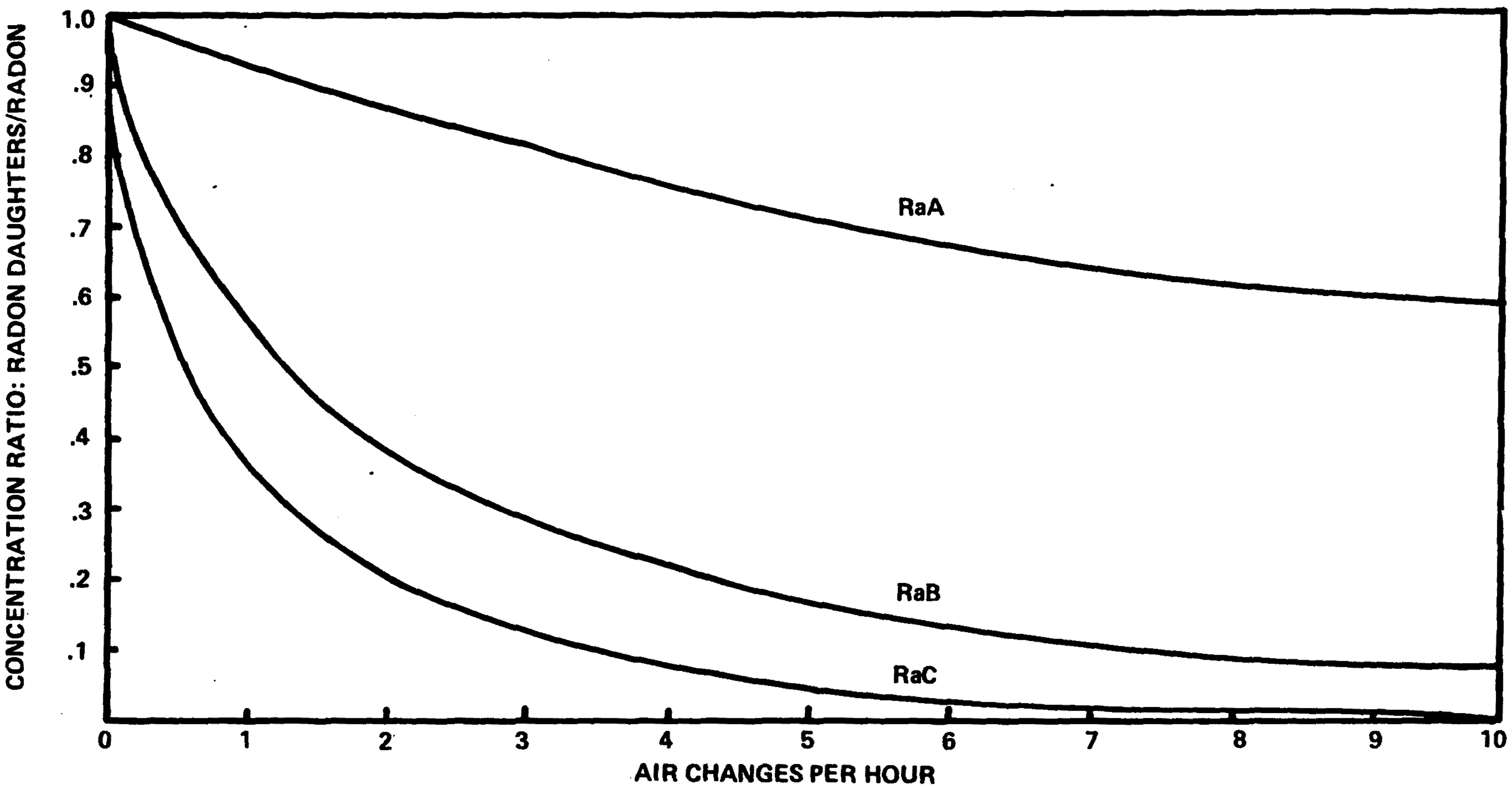
*Improved ventilation at high air exchange rates or selective removal of aerosols by high efficiency filters may actually lead to an increased radiation dose to the lungs. This effect, due to an increase in the "free ion fraction" of the radon daughters, is discussed in subsequent sections dealing with this parameter and with air cleaners.

FIGURE 3

CALCULATED EFFECT OF VENTILATION ON RADON/RADON DAUGHTER EQUILIBRIUM (from modeling calculations - see Appendix A)



The average aerosol concentration for homes in the United States was found to be approximately $3x10^4$ particles per cc with particle sizes ranging from 0.012 to 0.2 micron, with a mean value of 0.05 micron. This concentration and size range is supported in studies performed by Haque and Collinson (6), who concludes that 60 percent of in-house daughter product activity is associated with particles between 0.012 and 0.08 micron; by Mercer and Stowe (7), who found that the mean aerodynamic diameters approximated 0.2 micron; and by Jacobi (4), who estimates that 50 percent of the daughter product activity is associated with particles with less than 0.1 micron diameter. For centrally air-conditioned and heated homes, such as those in the Florida study area, though, aerosol concentrations less than 10^4 particles per cc are more likely.

The free ion fraction, the fraction of daughter ions which remain unattached to surfaces or aerosols, is of particular concern in lung deposition of daughter particulates. Harley and Pasternack (8) note that unattached RaA ions deposit with 100 percent efficiency in the tracheobronchial region. Subsequent decay of these particulates give rise to a substantial fraction of the total alpha dose to this region of the lung. Jacobi (9) indicates that the uncombined fraction (that fraction of the ions which are free ions) of the total potential alpha energy f_p (for RaA + RaC') provides a better measure of the dosimetry of the inhaled ions deposited in this region. He also indicates (10) that f_p is a function of aerosol concentration and the ventilation rate of a volume. With decreasing aerosol concentrations and an increasing ventilation rate, the ratio of the absorbed alpha energy or integral alpha energy in the bronchial and pulmonary region to the inhaled potential alpha energy increases for the former and decreases for the latter. This effect may lead to higher dose levels to lung tissue than would normally be associated with radon daughter working levels. Because of the complexities in estimating this parameter quantitatively under various control conditions, for the purposes of this report, it will be considered a constant with working levels assumed to be proportional to dose.

Particle distribution and concentration is largely dependent upon the ventilation rate. Typical residential structures have some degree of air infiltration through the walls and ceiling. The magnitude of this infiltration is a function of the "tightness" of construction, insulation, and outside weather conditions. In addition to these factors, others, such as room occupancy, and the number of windows and doors will significantly affect radon daughter levels in various rooms of the house. A survey by Handley and Barton (11) indicates that average single family housing units in the United States have ventilation (or infiltration) rates ranging from 0.5 to 1.5 air changes per hour. This is in general agreement with studies performed by Kaye (12) and Johnson, et al. (13,14).

The "effective" ventilation rate for homes with elevated radon daughter particulate concentrations is the rate at which the in-house atmosphere is replaced with air containing background levels of radon daughter products. In order to increase the effective ventilation rate, either the natural infiltration rate must be enhanced or the internal air must be cycled through an air cleaner. These two approaches will be discussed further in the following sections.

1. Utilization of Natural Ventilation

Although continuous natural ventilation through open doors and windows is effective in reducing indoor radon progeny levels (1), such external ventilation is not always desirable because of climate conditions. In Florida, a majority of new homes being built (approximately 65 percent in 1973) have central air-conditioning which is installed primarily because of the prevalent warm weather conditions (15). Another underlying consideration is that individual preference governs the degree to which such natural ventilation is used, therefore, introducing a significant variability in the overall effectiveness of such control when considered on a large population basis.

Another technique makes use of outdoor makeup air in an air exchange system which is coupled with the central air-conditioning and heating unit. This system maintains a continuous influx of outdoor air to add to the normal complement of internal air being recirculated. Although the use of fresh makeup air is effective in increasing the number of air changes per unit time, it may decrease to some degree, the natural air infiltration through leakage into the house by creating a positive pressure differential (16). This effect can be overcome by increasing the amount of makeup air accordingly until the desired equilibrium makeup fraction is achieved. From modeling calculations (to be discussed later), a theoretical working level reduction of about

45 percent could be obtained with 25 percent makeup air. Of course, this method of control would involve larger capacity air refrigeration and heating systems than would normally be used and require higher energy consumption, which would make it energy intensive for areas with generally warm climates, such as Florida.

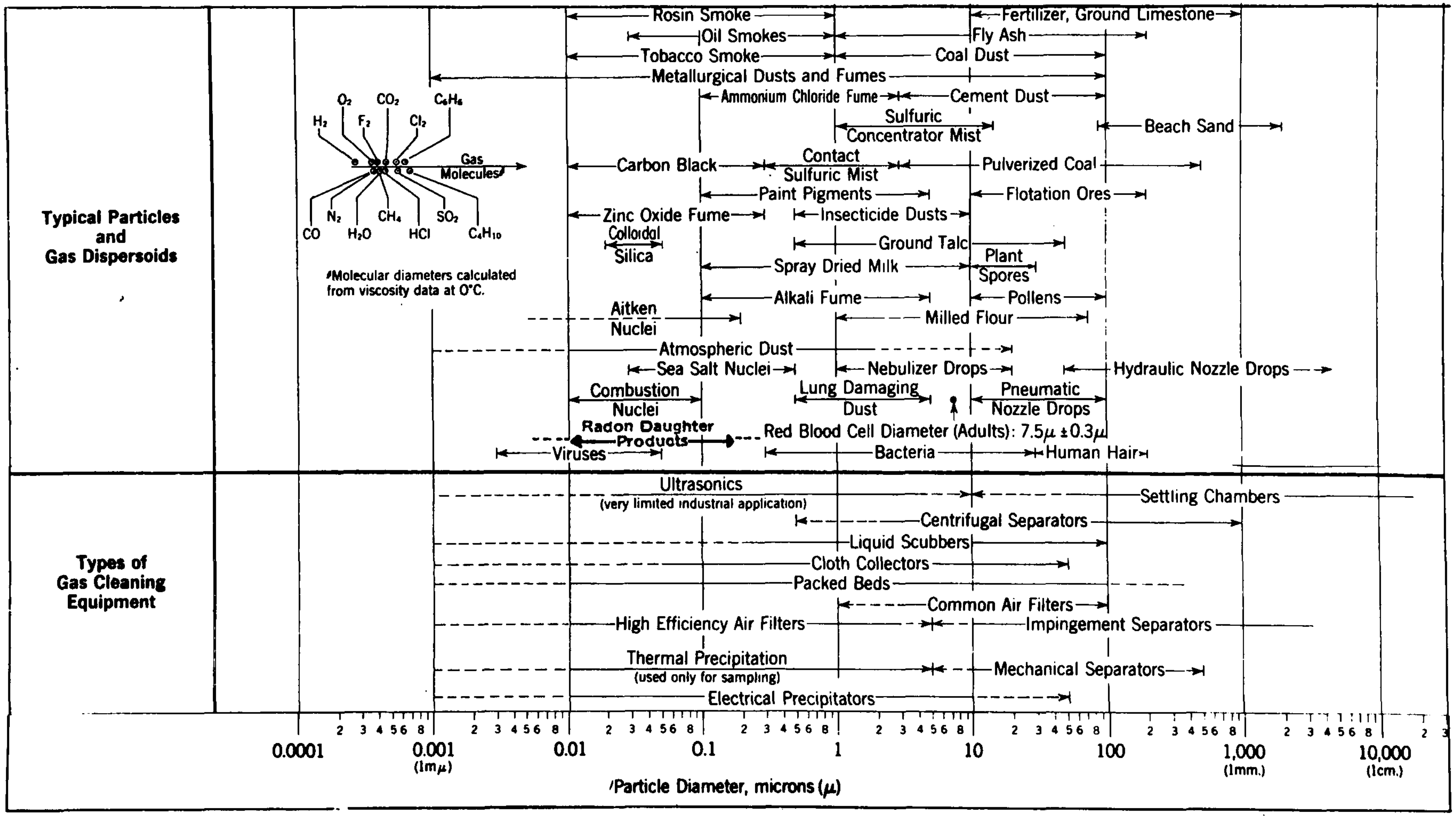
2. Utilization of Air Cleaners

Air cleaners are designed to remove particulates from the circulating air of building interiors. The type of air cleaner used depends upon the particle size and shape, specific gravity, concentration of the particulates, and the efficiency of removal desired. The particle size is the most important characteristic by which an air cleaner is chosen. Figure 4, from Chapter 10 of the 1972 ASHRAE Handbook of Fundamentals, gives data on the sizes and characteristics of airborne particulates and the cleaning equipment effectiveness range for a wide range of particulate size (17).

The three operating characteristics that distinguish the different types of air cleaners are: 1) efficiency, 2) air flow resistance, and 3) life- or dust-holding capacity (18). Efficiency is a measure of the ability of an air cleaner to remove particulates from an air stream. Air flow resistance is the static pressure drop across the filter at a given air flow rate. Dust-holding capacity is the amount of a particular dust which an air cleaner can hold when operated at a certain flow rate to some maximum resistance value. The air cleaners are tested for these various characteristics and are rated accordingly.

FIGURE 4.

DIAMETERS OF TYPICAL PARTICLES (INCLUDING RADON DAUGHTER PARTICULATES) AND GAS DISPEROIDS, AND APPLICABLE EFFECTIVE CLEANING EQUIPMENT



(Adapted from original table prepared by C.E. Lapple, Stanford Research Institute)

Three major types of air cleaners are in general use at the present (18):

1. Fibrous media unit filters in which accumulating dust load causes the pressure drop to increase (and thereby the efficiency) up to some maximum permissible value. This category includes both viscous impingement and dry type air filters.

2. Renewable media filters in which fresh media is introduced into the air stream as needed to maintain constant resistance. This filter system also maintains essentially constant efficiency.

3. Electronic air cleaners, which have essentially constant pressure drop and efficiency, unless their precipitating elements become severely dust-loaded.

These air cleaners can be used in tandem in numerous combinations to improve overall efficiency and operating life. For example, a renewable media filter may be used upstream of a HEPA (High Efficiency Particulate Air) filter in order to prolong its effectiveness.

Fibrous media filters can be divided into two major types: 1) viscous impingement filters, and 2) dry type air filters. The former, utilizing a viscous media coating, is characterized by a low pressure drop, low cost, good efficiency on lint, but low efficiency on normal atmospheric dust. Because of the particle size limitation, such a filter would not be effective for removing radon daughter particulates. Dry type air filters use a medium composed of random fiber mats or blankets of varying thicknesses, fiber sizes, and densities. Media of bonded glass fiber, cellulose fibers, wood felt, asbestos, synthetics, and other materials have gained commercial and residential application. This type of filter is characterized by a generally higher efficiency produced by the smaller fiber size and inter-fiber spacing. The higher the efficiency of the filter, the greater the operating resistance against which the air must flow. With HEPA filters, resistance may reach 2.0 inches of water at duct velocities of 200 feet per minute, necessitating the use of backup fans. HEPA filters have been in standard use in hospital clean rooms and in radioactive and toxic-particulate applications. They are unsurpassed in filter efficiency (99%+) and are effective at particulate size ranging down to 0.03 micron (18).

The advantages of the HEPA filter include its low initial installation cost and lack of mechanical moving parts. Disadvantages include the cost of replacing spent filters, the lower efficiency realized at higher air flow rates and the electrical cost associated with fan operation. A particular disadvantage of concern is the increased free ion fraction (f_p) resulting from a decreased aerosol concentration due to their selective removal by the filter. As has been discussed, a higher effective dose to the tracheobronchial region of the lung is associated with such an increase. The magnitude of the increase is dependent on numerous variables including the infiltration rate, the air cleaner pass-through rate, and the equilibrium concentration of indoor aerosols. This effect would predominate at the higher effective ventilation rates (2-3 air changes per hour) (10).

The renewable media filters make use of moving rolls of either viscous fiber or dry fiber media to trap particulates. When the media roll is exhausted, the entire roll is disposed of, and a new roll is installed. As this type of filter is less than 30 percent efficient for dust-sized particulates (>1.0 micron diameter), it will have little application for radon daughter particulate removal.

Electronic air cleaners use electrostatic precipitation principles to collect particulate matter. Unlike their industrial counterparts, residential electronic air cleaners operate on standard house current and with normal operation use electricity at the same rate as a 50-watt lightbulb (19). There are two general types of electronic air cleaners: 1) charged media filters (single-stage electronic air cleaners) and 2) the two-stage electronic air cleaners.

In the charged media filter, either a dielectric media consisting of glass, cellulose fibers or other material, or a series of charged plates are utilized to form the electrostatic field. The field, produced by a voltage of up to 12,000 volts, polarizes particulates and attracts them to the charged fiber media or metal plates. Cleaning of the plates or fiber media is necessary periodically to remove excess particulate loading.

The two-stage electrostatic precipitator makes use of a two-stage electronic cell. The first stage forms an electric field that ionizes particulates as they enter the system, while the second stage contains an alternating series of grounded and positive plates. The grounded plates attract and hold the ionized particulates, while positively charged plates repel particulates toward the grounded ones. Normally, molecular adhesion and interparticle cohesion are sufficient to maintain particulate adhesion to the plates. However, when excessive loading with fine dry particles takes place, some type of prepared adhesive may be necessary. As with the charged media filter, periodic cleaning of the plates is necessary in order to maintain efficiency (18).

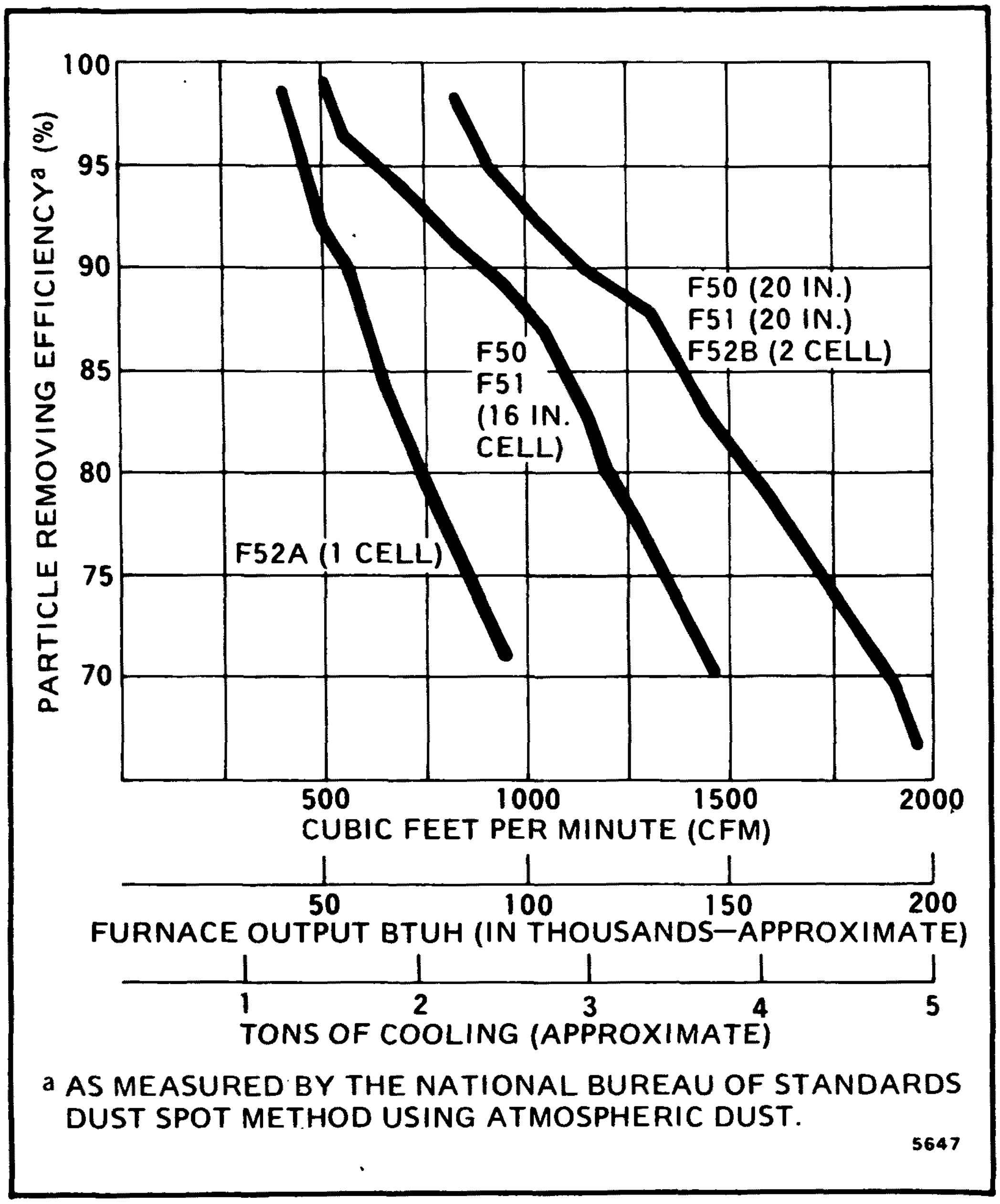
The performance of electronic air cleaners depends upon the rate of air flow and the quality of installation. A number of commercially available models are designed to meet these performance parameters, as well as others such as the volume of air to be cleaned and the size of the heating or cooling unit. Figure 5 illustrates particle removal efficiencies as a function of flow rate for typical residential electronic air cleaners (20).

Installation of an electronic air cleaner into the central heating or cooling system of a residence requires care in order to insure efficient operation. Generally, the air cleaner must be situated so that there exists an even air flow through the plates. This requirement will sometimes necessitate alterations in the feed duct work. Location of humidifiers, if present, are critical in that excess humidity lowers the effectiveness of the cleaner significantly.

Although no field or experimental studies have been performed as yet to determine the effectiveness of this air cleaner on free radon daughter ions, from its operating characteristics it can be assumed that as many, if not more, free ions will be proportionally removed as will particulates (21). This assumption is based on the

FIGURE 5

CAPACITY–EFFICIENCY CHART FOR HONEYWELL ELECTRONIC AIR CLEANER MODELS F50, F51 AND F52.



(From Electronic Air Cleaner – Application and Installation, Honeywell Corporation, # 70-9723.)

basic operation of the electronic air cleaner, which involves the formation of a "corona" of positively charged ions in the first stage in order to enhance the removal of the attached particulates by the oppositely charged plates in the second stage. It is extremely doubtful that a charged ion would be able to escape from this charged field. Therefore, it is unlikely that the utilization of an electronic air cleaner for radon daughter level control will have a significant effect on the equilibrium value of the free ion fraction in a structure.

The advantage of the electronic air cleaner lies in its high efficiency over a wide range of particulate sizes, down to submicron diameters, as well as its ease of maintenance. The disadvantages are its relatively high initial cost and the discharge of ozone which, at moderate concentrations (0.003 to 0.10 ppm), is perceivable by the average person as an odor and at higher levels (0.3 ppm) can lead to such symptoms as nausea, headaches, and pulmonary edema. The concentration of ozone produced in a home by an electronic air cleaner ranges from 0.005 to 0.02 ppm (20). These levels are several factors lower than those found in many cities and are also lower than the Food and Drug Administration (FDA) concentration standard of 0.05 ppm for electrical devices (21 CFR 3.96 (1975), 21 CFR 801.415 (1976)).

As no data is available concerning the efficiency of air cleaners in reducing the concentration of radon daughters, modeling was performed to make such an estimation. These calculations, provided in Appendix A, show that most of the radon daughter level reduction occurs at effective ventilation rates of less than two air changes per hour (approximately 70 percent). Therefore, assuming that natural infiltration accounts for one air change per hour, air cleaners, which can effectively handle ventilation rates of about one to two air changes per hour, would have a relatively marginal effect on working level reduction. For HEPA and electronic air cleaners, a 38 percent reduction in the equilibrium radon daughter working levels was calculated. For HEPA filters, though, increased effective ventilation rates could lead to an increased tracheobronchial dose (and therefore, a potentially higher total lung dose), due to the resulting increase in the free ion fraction of radon daughters (10).

For a combined electronic air cleaner and outside air exchange system, an efficiency of 62 percent was calculated for working level reduction. This model assumes a flow rate through the system of 1.5 air changes per hour and about 25 percent makeup air (see Appendix A).

B. Ventilated Crawl Space Construction

The function of building a crawl space for radon progeny control is to provide a highly ventilated space between the soil surface and the overlying structure in which the emanating radon gas can be diluted or removed before diffusion into the structure. The degree to which such ventilation is effective is dependent upon the number of air changes per unit time within the enclosure below the floor. Assuming that a wooden floor would allow radon gas to diffuse readily, the fractional reduction of radon gas diffusion into the structure would be proportional to the reduction in partial pressure of the radon in the crawl space due to ventilation. There are two means by which the ventilation characteristics of a crawl space can be enhanced, involving respectively, passive and nonpassive measures. First, the crawl space can be constructed utilizing oversized, properly spaced vents on all sides of the structure. Second, a fan could be set up for forced ventilation of the crawl space, thereby establishing a lower limit of ventilation. Although there is no readily available data concerning the magnitude or range of the ventilation rate achievable by these means, with proper construction it could compare favorably with a well-ventilated house (2-4 air changes per hour). Assuming such ventilation rates, radon daughter working level reductions of 80 percent or more would be possible. The level of reduction achievable could be increased, if desired, through the use of a radon impervious barrier in the floor. Such a barrier, possibly in the form of a polymeric sealant underlying a seamless tile floor, would have side advantages such as moisture proofing and a reduction in heating and air-conditioning infiltration loss.

The advantages of nonmechanical crawl space construction as a control technique are that it is passive, permanent, maintenance-free, effective, and easily constructed. The advantage of mechanical construction lies in its use of forced ventilation, from which a minimum effectiveness can be selected and maintained. Disadvantages would be its nonpassivity, inconvenience, and expense (maintenance and electrical). Disadvantages for both types are the additional cost such construction would entail as compared to a slab-on-grade construction and the greater natural infiltration rate through the floor which would necessitate either additional insulation, or greater heating and cooling capacity. There is also the expense and effort involved in changing blueprints and construction specifications on the part of the builder. In turn, the prospective purchasers may object to the crawl space on aesthetic grounds, or on grounds that it may attract insects or a rodent population.

C. Polymeric Sealants

Ideally, if one could completely seal all of the floor and wall space below ground level for a structure with radon diffusing through the floor, the problem would be largely alleviated. The radon gas that would normally diffuse through the floor would be trapped by this barrier so that it would decay in the structural material and not enter the structure's atmosphere.* Polymeric sealants, having low permeability to radon gas, have been proven to be effective in reducing in-house radon progeny when properly applied. An EPA funded study by Culot, et al. (22), showed that radon diffusion into a structure could be reduced by more than one-half utilizing an epoxy sealant. An important finding of this study was that a significant reduction of radon diffusion into structures could be obtained only in a situation free of other major pathways for radon. From past analyses with test structures on slabs, as well as experience with remedial action in structures

*There is a whole-body gamma exposure related to such decay, although in regard to potential health effect it is insignificant in comparison to radon daughter alpha exposure in the lung. From past field studies (22), fractional gamma increases of 2 to 20 percent were measured for a 4-inch concrete slab after sealant application.

in Grand Junction, Colorado, it was determined that such pathways do exist and are common in typical residential structure. One such pathway is minute cracks in the concrete slab at the juncture of the slab and wall. Another is the channel through which pipes and drains enter the slab. These analyses and field experience have shown that with incomplete sealing of these pathways with a radon-impermeable base, only a relatively small working level reduction could be obtained. The thoroughness of sealant application, then, is of prime importance in this control measure. Sealants must be applied at a thickness appropriate for the expected wear in an area. The applied sealant should be protected from such wear (e.g., by a floor covering such as quartz seamless) whenever possible, although multi-layer application of newly developed wear-resistant epoxy may be durable enough to withstand such wear. All wiring and piping junctures in the slab should be sealed thoroughly to prevent radon seepage.

The Bureau of Mines has been active in the development of effective radon sealant barriers for use in uranium mines to reduce the emanation of radon gas from uranium ore. In a recent lab analysis, 46 different single-coat polymers and 14 two-coat applications were tested on uranium rock samples. Franklin, et al. (23), reported reduction efficiencies of up to 100 percent (see Appendix D). Subsequent field studies conducted at Grants, New Mexico, have shown radon gas emanation reductions of up to 62 percent. The Bureau's Spokane Mining Research Center has developed these criteria for a good radon gas barrier (23):

1. Material must stop at least 50 percent of gas emitted from ore samples.

2. Material must be easily applied.

3. Material must not emit toxic or noxious vapors during application or curing.

4. Material must be flame resistant (not readily burnable and not emitting toxic vapors should heat be applied).

5. Material must cure in a mine environment (45° to 60° F, 40 to 100 percent relative humidity).

6. Material should be cost competitive.

7. Material must adhere to wet or dry, dusty, porous rock.

Although these criteria were developed for polymer application in mines, they would also apply to a large degree in residences.

Lawrence Livermore Laboratory (LLL) of the University of California conducted further investigations into the properties of available commercial polymers in order to identify the best overall sealants (24). The sealants evaluated by LLL were selected from ones already tested at the Bureau of Mines, SMRC, with the exception of a few polymers obtained from the chemical industry through a survey. Radon permeability coefficients for each polymer were determined by the use of two similar noble gases, krypton and argon, and a conversion factor derived from the molecular diameters of these gases. Besides permeability, the polymers were tested for fire resistance and toxic properties. The results showed that virtually all coatings with permeation constants lower than 10^{-10} cm^3 (STP)$\cdot$cm/s$\cdot cm^2\cdot$cm Hg and thickness between 5 and 10 mils will provide nearly 100 percent radon exhalation reduction. As many of the polymers did, in fact, meet this criteria, the research staff recommends that selection should be based on factors other than efficiency, such as cost, vapor toxicity during application and binding properties. The authors ranked the nine polymers that were analyzed and commented on their potential shortcomings (see Appendix D).

An efficiency range of 70-90 percent radon progeny reduction for polymeric sealants was derived from test data by Culot, et al. (22). Their experiments involved the use of sealed tanks above a sealed concrete slab with uranium tailings underneath. Assuming an equilibrium radon progeny concentration over the slab equal to 10 percent of the source term under the slab, which they had previously determined, the range of reduction was approximately 75-99 percent using polyester styrene, polyester resin, and Omnitech* polymers. From a similar experimental analysis, Auxier, et al., suggests that an 88 percent reduction in airborne radon progeny could be obtained (25). As these reductions were achieved in an experimental lab situation, the reduction range of 70-90 percent was chosen as a conservative approximation of actual residential application. Again, the degree of reduction achievable would be dependent upon the method and thoroughness of application.

Application of polymeric sealants in new home construction would involve much less effort and expense than would the same procedures in an existing residence. In fact, one innovative technique which may prove effective at increasing the durability of the polymer

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*Omnitech Industries, Inc.

is to "sandwich" it between two layers of concrete in the slab. This would be done by applying a water-based polymer after half of the slab (by depth) has been poured and then pouring the other half. The water-based polymer would then form a bond with the cement which would be extremely durable (26). However, cracking of the slab itself would be just as detrimental in this application as in a conventional application if the integrity of the sealant is breached.

Another innovative sealant application would involve its use as a ground surface preparation before slab pour. This would require careful ground preparation (leveling and rolling) and a heavy-duty sealant application. The durability of such an arrangement has not been tested under field conditions and, therefore, would be in question. If its long-term efficiency can be shown, though, it could prove valuable as both an adjunct to conventional application and as a control measure in itself.

In conventional applications, the concrete slabs or basements should be treated before any other structure or flooring is built over them. Once the concrete slab is set, its surface should be ground smooth as with a wire brush, and all cracks should be sealed with an epoxy caulk. Quartz seamless flooring or other such similar flooring can then be installed (assuming that wall-to-wall carpeting is not being considered). The sealants are applied in five coats:

1. 60 percent solid, water resistant epoxy primer at approximately 3 mils thickness.

2. 100 percent solid, pigmented epoxy, no less than 15 mils thickness.

3. 100 percent solid, clear epoxy, at no less than 15 mils thickness, with ceramic coated quartz granules broadcast at no less than one-half pound per square foot of floor.

4. 100 percent solid, clear epoxy, glaze coat at approximately 10 mils thickness.

5. 100 percent solid, clear epoxy, glaze coat at approximately 6 mils thickness.

The preceding appliation technique for Omnitech epoxy sealant was utilized by Culot, et al. (22), in their experimental analysis of the product. They found that radon diffusion through the slab had been reduced to background levels for the 15 days after treatment.

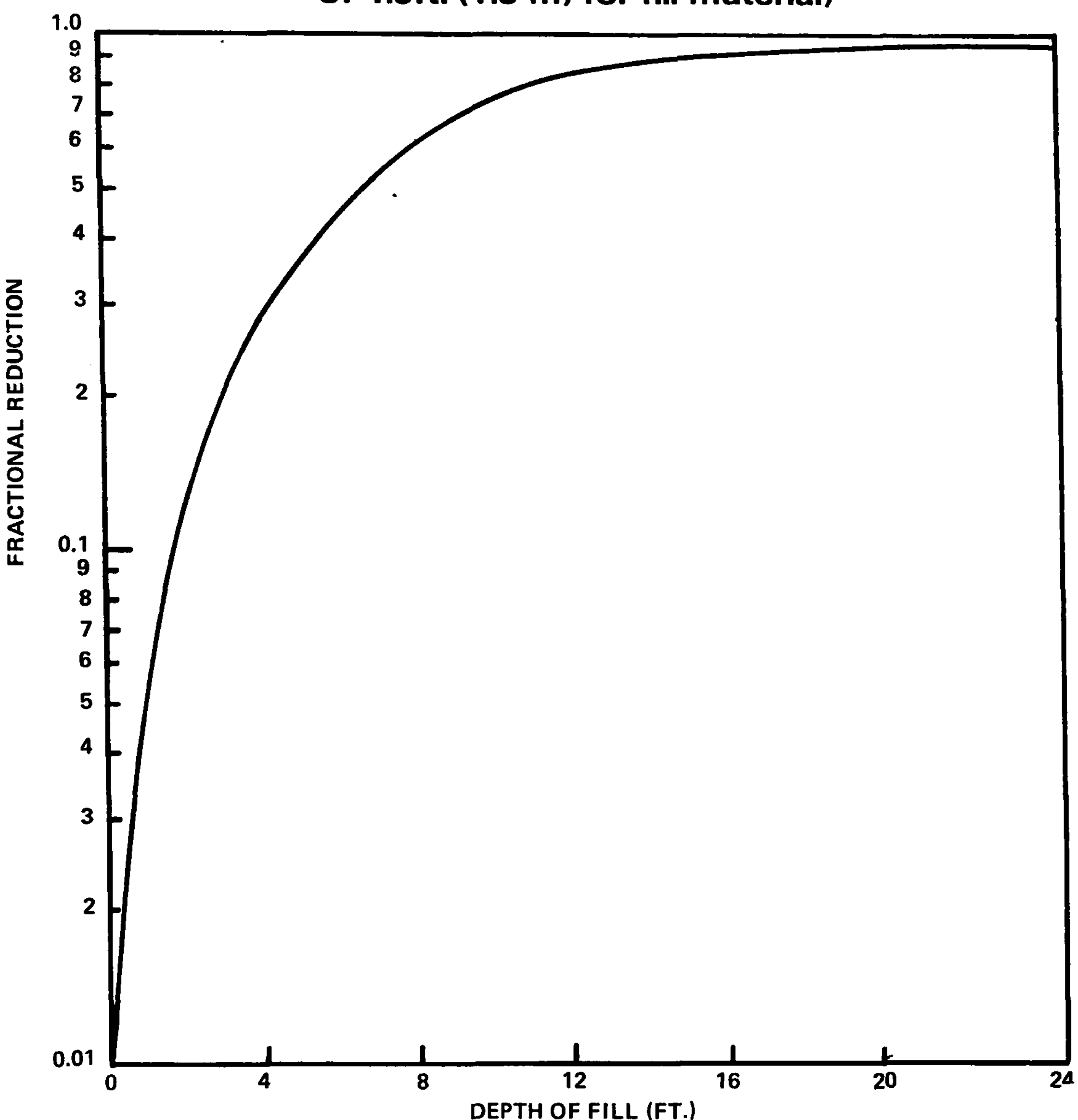
The advantage of using polymeric sealants is that it is relatively effective and does not impact on the lives of residents. The major disadvantage is that the longevity of the seal provided by the sealant is untested. Therefore, it is conceivable that sometime during the lifetime of the structure either a reapplication or some type of maintenance will be required on the sealed slab. As many new homes have wall-to-wall carpeting installed, such a procedure could entail some expense and inconvenience to the homeowner. Likewise, hardwood floors and tile surfaces would have to be removed for slab resealing.

D. Site Excavation and Fill

As Figure 6 shows, a ten-foot layer of soil with a relaxation length* of 4.9 feet (for moist packed earth and dry packed uranium

*The depth of a uniform layer of material of the same density in which a diffusing gas (radon in this case) is reduced in concentration by a factor of "e" (2.703).

FIGURE 6
FRACTIONAL REDUCTION IN THE RADON EMANATION RATES AS A FUNCTION OF OVERLYING FILL MATERIAL
(assuming relaxation of distance* of 4.9ft. (1.5 m) for fill material)



*SEE DEFINITION, PAGE 31.

tailings with a diffusion coefficient of 5×10^{-2} cm^2/s) (22) can be as much as 80 percent effective at reducing radon emanation from the ground surface. Such data indicates that by removing this depth of reclaimed phosphate soil and replacing it with non-uraniferous soil of the same density and porosity, approximately 80 percent of the radon would be retained in the ground. If such a procedure were done for a home site on phosphate land, the diffusion rate of radon into the structures to be built would then be proportionally less, assuming negligible lateral radon diffusion.*

Such an operation would involve the use of earth-moving equipment to excavate the soil at the site to a suitable depth. This soil would then be dumped or spread at a location owned and approved by the county or State for such purpose (such land could be zoned to disallow residential and commercial construction). A gravel or soil replacement fill would be trucked in, dumped at the excavation site and packed thoroughly. A slab would then be poured on-grade.

The advantages of such a control measure are that it is relatively simple, efficient, and permanent. Disadvantages would be the cost involved in the excavation, the purchase of material and the expense in hauling it to the site.

E. Improved Slab Construction

Another technique by which the overall effectiveness of radon daughter control measures could be enhanced would be improving the

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*Although no field studies have been performed concerning lateral diffusion, the cost-effectiveness calculations in Section V allow for excavation to a distance of 3 feet from the foundation.

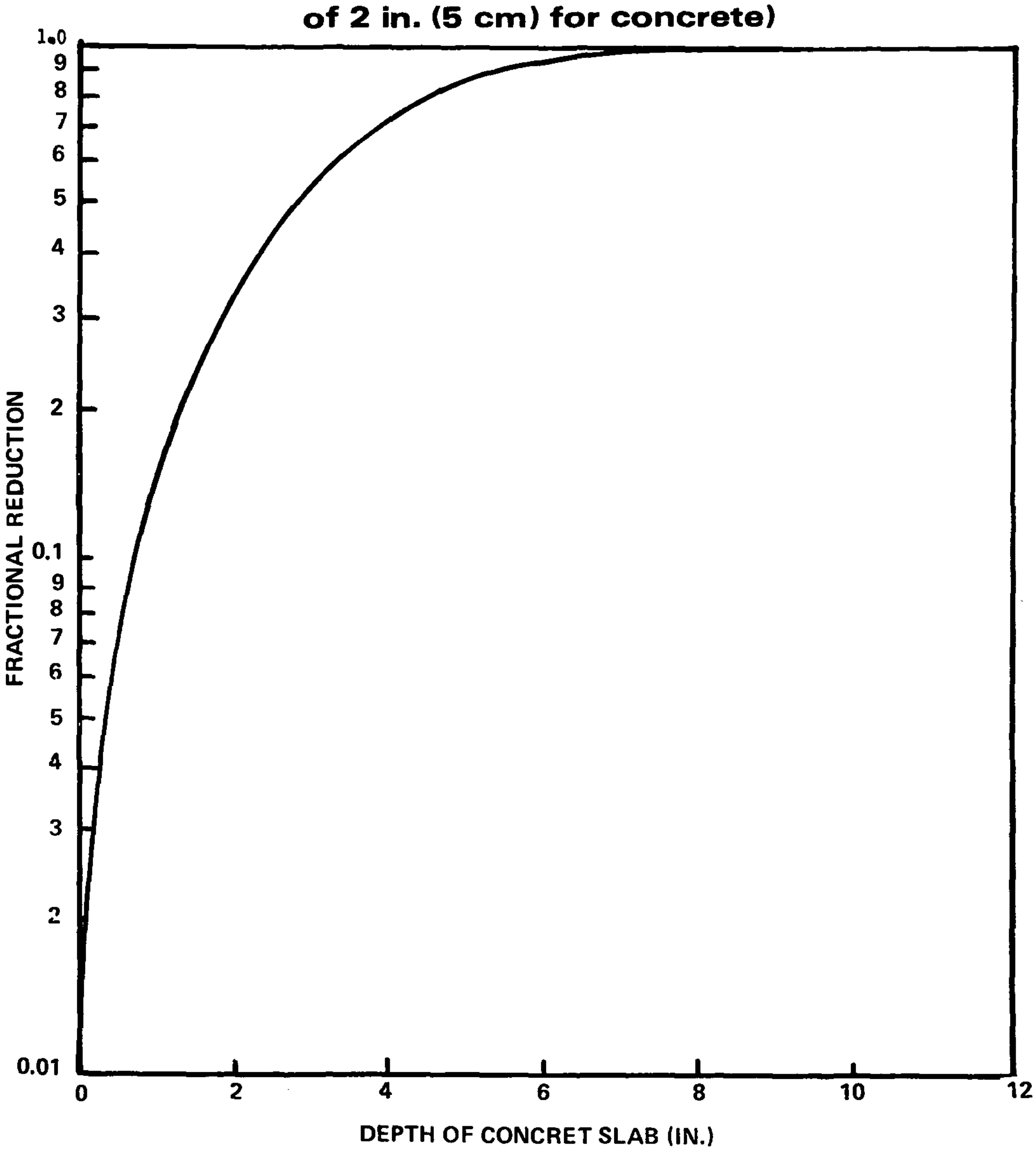
quality control of slab pour (quality, reinforcement and thickness). As the pore size present in the cement has a large influence on its radon stopping ability, utilizing concrete with a low water to cement ratio by weight (W/C) and dense aggregate material (such as granite or marble) will decrease radon permeability.

Increasing the thickness of the concrete slab will, likewise, reduce the radon diffusion rate, assuming this is the major pathway. As radon gas has a relaxation distance of about 5 cm (2 inches) in a standard concrete (density = 2.35 g/cm^3), by doubling the thickness of a normal 4-inch slab to 8 inches, 80 percent reduction in exhalation is possible (see Figure 7). This technique is advantageous in that it represents a passive control measure, thereby not permitting any occupant interaction, and also because it does not require any major changes in structural specifications. A disadvantage is the likelihood of cracking in the slab which would provide a conduit for the underlying radon. Also, if the piping should prove to be a major pathway for seepage, much of the effectiveness of this measure would be negated.

Another innovative technique which may prove effective in reducing radon diffusion is the laying of a perforated tile field under a slab construction. The field would tie into a number of surface vents which would permit the radon to bypass the slab and be diluted in the open air. Although a reduction in indoor working levels is likely with this technique, the lack of field work makes it impossible to estimate the magnitude of such reduction and the cost involved with installation.

FIGURE 7

FRACTIONAL REDUCTION IN THE RADON EXHALATION RATE AS A FUNCTION OF CONCRETE SLAB THICKNESS (assuming relaxation distance* of 2 in. (5 cm) for concrete)



*SEE DEFINITION, PAGE 31.

The advantages and disadvantages of the control measures discussed are summarized in Table 1. There are three major pathways identified for radon exhalation into a structure. They are: 1) exhalation through the concrete slab and/or flooring; 2) exhalation through the walls of the structure; and 3) seepage in and around piping entering the slab and flooring.

The first has been well-documented in experimental studies by Culot, et al. (22), and Auxier, et al. (25). The second has also been documented by Culot, et al., in their study of structures built on or adjacent to uranium mill tailings in Grand Junction, Colorado. The third pathway is under study at present by the Environmental Protection Agency's Eastern Environmental Radiation Facility. Preliminary findings to date indicate that this pathway could be a potentially significant source of radon in structures (27). As this piping would be buried at depths of at least several feet under the slab, it may serve as a pathway for radon gas into the house. This potential radon pathway will be studied further by EPA to determine the magnitude of the influx.

Some of the control measures discussed will have efficiencies that are pathway-dependent. For example, sealing a concrete slab would be effective for radon exhalation through the slab and possibly around the piping (if applied properly), but not for any exhalation through the walls. A crawl space, likewise, would be effective for the floor and walls, and possibly the piping pathways. Excavation would similarly be effective at posing a barrier for the floor and wall pathways, but probably not the piping pathway, if it should exist. Ventilation,

TABLE 1
CONTROL MEASURES: ADVANTAGES AND DISADVANTAGES

CONTROL MEASURE	ADVANTAGES	DISADVANTAGES
FULL MEASURES		
VENTILATED CRAWL SPACE	1–PASSIVE, LIFE-OF-HOUSE MEASURE 2–HIGH EFFECTIVENESS WITH PROPER VENTILATION	1–EXPENSE ASSOCIATED W/CHANGES IN HOME'S STRUCTURAL SPECIFICATIONS 2–BUYER'S OBJECTIONS ON AESTHETIC OR OTHER GROUNDS 3–HIGHER ELECTRICAL COST FROM INFILTRATION
POLYMERIC SEALANT	1–PASSIVE MEASURE 2–WITH PROPER APPLICATION, HIGH EFFECTIVENESS ACHIEVED AT RELATIVELY LOW COSTS 3–SEALANT PROVIDES ADDITIONAL WATER–PROOFING	1–UNCERTAINTY AS TO LONGEVITY OF SEALANT EFFECTIVENESS 2–THOROUGH APPLICATION NECESSARY FOR EFFICIENT RADON REDUCTION
EXCAVATION AND FILL (W/NOMINAL FILL COST)	1–PASSIVE, LIFE-OF-HOUSE MEASURE 2–NO ALTERATION IN HOUSE PLANS OR CONSTRUCTION PROCEDURES NECESSARY	1–EFFECTIVENESS BASED ON THEORY ALONE 2–PROBLEMS ASSOCIATED WITH IMPROPER COMPACTION OF FILL 3–RADON INFILTRATION ALONG PIPING LAID UNDER SLAB
EXCAVATION AND FILL (AT COMMERCIAL RATES)	SAME AS ABOVE	SAME AS ABOVE EXCEPT FOR HIGH COST ASSOCIATED WITH FILL
ELECTRONIC & AIR EXCHANGER	1–SYSTEM DURABLE 2–LITTLE MAINTENANCE REQUIRED 3–PARTICULATE CONCENTRATION REDUCED IN HOME	1–NON-PASSIVE 2–HIGH COST INVOLVED WITH OPERATION 3–OZONE RELEASED BY PRECIPITATOR
IMPROVED SLAB CONSTRUCTION (8" SLAB)	1–PASSIVE, LIFE-OF-HOUSE MEASURE 2–VERY LITTLE ALTERATION IN CON–STRUCTION PLANS REQUIRED	1–CRACKING IF IT OCCURS, WOULD NEGATE MUCH OF EFFECTIVENESS
LIMITED MEASURES		
ELECTRONIC AIR CLEANER	1–MINIMAL ELECTRICAL COST AND MAINTENANCE NECESSARY 2–PARTICULATE CONCENTRATION REDUCED IN HOME	1–NON-PASSIVE 2–OZONE RELEASED BY PRECIPITATOR
HEPA FILTERS	1–EFFECTIVE AT SMALL PARTICLE SIZE RANGE 2–NON MECHANICAL PARTS, NO MAIN-TENANCE NECESSARY	1–NON-PASSIVE 2–HIGH COST OF FILTERS 3–HIGH PRESSURE DROP (AS AIR FLOW RATE INCREASES, EFFICIENCY DECREASES)

however, would be uniformly effective for any pathway, as it removes radon daughters after they are already present in the structure's atmosphere.

IV. IDENTIFICATION OF PARAMETERS USED IN EVALUATION

In order to facilitate an objective comparison and ranking of the control measures that were reviewed, two parameters were chosen by which each measure could be assessed. The two, cost and effectiveness, were determined separately, but combined in the cost per percent reduction ranking of the control measures. It should be stressed that although this ranking is largely based on cost-effectiveness, there may be other factors of importance to the builder or developer which may play a role in the selection of a control measure. These may include building costs and availability of equipment and labor. Whatever the method of selection, the control measure chosen should achieve and maintain the level of radon daughter reduction pursuant to existing guidance at the time of implementation.

A. Cost

The cost associated with implementing control measures for reducing radon progeny levels in homes is a combination of several factors:

1. Capital Investment in Equipment or Structural Alterations

For air cleaners, this would include the cost of HEPA filters and backup fans, or an electronic air cleaner, as well as any duct work alteration needed. For crawl space construction, it would be the additional expense inherent in building a house in this manner. With polymeric radon barriers, the cost of the polymer and its application would be included. With excavation, costs would include removal of the reclaimed phosphate soil and replacement with gravel or soil fill.

2. Maintenance and Replacement Costs

These costs would largely apply to mechanical equipment, such as air cleaners. HEPA filters, for example, would require periodic replacement, while electronic air cleaners would require occasional servicing and parts replacement. Other costs are intangible, such as those involved with maintenance activities by the homeowner, while others are unpredictable, such as reapplying a polymeric sealant. These costs, although potentially significant, cannot be quantified definitively.

3. Cost of Electricity

This cost would be associated with the use of electronic air cleaners, backup fans for HEPA filters, and for any additional heating or cooling necessary to balance the additional infiltration or makeup air used in some control measures.

B. Effectiveness

The effectiveness of control measures in reducing the activity level of radon daughter products in a structure is measured in percent reduction from levels which would exist without any control technology. As many of the techniques discussed in this report have not been field tested in residential structures for verification, the efficiencies used are rough estimates which would be expected to vary accordingly.

V. COST ANALYSIS

A cost analysis on the utilization of radon daughter control technology is critical to any decision-making process in this area. As with pollution control equipment in industry, the cost of radon daughter control measures would probably be passed on to the consumer, or the homeowner in this case (except when government subsidization is involved). In order to minimize expenses, the builder must first determine, from available data, which control measures reduce the radon progeny concentrations down to acceptable residential levels, and second, which of these measures can be implemented and maintained at the least cost.

The cost figures utilized in this analysis are best average estimates based on data derived from literature, government, and private industry. Because of their different sources, a degree of variability is to be expected for the actual cost of application in specific localities of the country. Another source of variability is inherent in the use of an average value. Such an estimate is applicable only for an average site and, therefore, cannot be generally applied. The "plus" (+) sign is utilized in Table 2 to permit more flexibility in estimating cost values. It signifies that one or more components of the total cost represent minimum values that are likely to be higher based on nonquantitative information. All cost figures utilized in this analysis are present dollar values and are discounted at rates of 0 and 6 percent.

There are numerous components of the total cost, both tangible and intangible, which will be considered. The capital cost is the most important component to the prospective builder. This expenditure would be made by him to implement the control measure. With mechanical equipment, such as air cleaners, maintenance and replacement costs also become important in calculating the total cost. As most equipment of this type has a useful life of roughly ten years (19), some maintenance and possibly replacement will be required on this equipment over the average life span of a building. Another component is electrical cost which is, again, primarily associated with the use of mechanical air cleaning equipment. Due to probable increased air infiltration in homes with crawl spaces, there would be additional electrical costs as a result of the corresponding increase in the use of air-conditioners or electrical heating units.

A. Ventilation Costs

Table 2 shows that the capital cost for the installation of a HEPA filter is about $350. This cost includes the cost of the filter, filter holder, backup fan, and actual installation into the residential heating/cooling system (28). If an optional prefilter is installed upstream of the HEPA filter, an additional $50 cost will be accrued. As this system has no mechanical parts, the maintenance costs would consist of replacing the filter periodically. The length of time between replacement will vary according to the particulate concentration in the house, the air flow characteristics of the ventilation equipment,

TABLE 2
ESTIMATED AVERAGE COST OF RADON DAUGHTER CONTROL MEASURES*

CONTROL MEASURE	CAPITAL COST	ANNUAL MAINTENANCE & REPLACEMENT COST	ANNUAL ELECTRICAL COST	ANNUAL AVG. OPERATING COST	TOTAL COST (30 – 50 YRS) DISCOUNT RATE 0%	6%
AIR CLEANERS:						
HEPA	$ 350	$ 100	UNDEFINED	$ 100	$3250–5250	$1725–1925
ELECTRONIC	300	20+**	17	37+	1400–2200	800– 900
ELECTRONIC & AIR EXCHANGE	800+	20+	140+	160+	5600–8800	3000–3325
VENTILATED CRAWL SPACE	450	NONE	UNDEFINED	NONE**	450	450
POLYMERIC SEALANT	400–1300	UNDEFINED**	NONE**	NONE**	400–1300	400–1300
EXCAVATION AND FILL						
(TO 10' DEPTH):						
COMMERCIAL FILL RATE	2100–3700	NONE	NONE	NONE	2100–3700	2100–3700
W/NOMINAL FILL COST	1575–1850	NONE	NONE	NONE	1575–1850	1575–1850
(TO 5' DEPTH):						
COMMERCIAL FILL RATE	1100–1900	NONE	NONE	NONE	1100–1900	1100–1900
W/NOMINAL FILL COST	800– 950	NONE	NONE	NONE	800– 950	800– 950
IMPROVED SLAB CONSTRUCTION	450	NONE	NONE	NONE	450	450

*ASSUMING 1000 SQ. FT. FLOOR AREA AND PRESENT DOLLAR VALUE.

**SEE TEXT FOREXPLANATION; "+" SIGNIFIES THAT THE ESTIMATE IS GIVEN MOST LIKELY A MINIMAL ONE, ALTHOUGH THE ACTUAL AVERAGE IS UNDEFINABLE USING AVAILABLE COST DATA.

and whether a prefilter* is installed. Assuming a replacement rate of once a year and a unit cost per filter of $100 (28), the expense to the homeowner per year and the total over the range of 30-50 years (the assumed life span of the structure) would be approximately $100 and $1725-$1925, respectively (assuming a 6 percent discount rate, and neglecting price increases and electrical consumption by the fan). The average total cost ($1825) coupled with an approximate lifetime reduction efficiency of 40 percent for radon progeny results in an average $45 cost per percent reduction (see Table 3).

A capital cost estimate of $300 is given for electronic air cleaners. This figure includes the estimated cost of the air cleaning unit ($250), and the cost of a prefilter ($50) (29). This estimate is probably an upper limit one, as in many cases (especially in new home construction) the cost of installing a prefilter and special duct work to improve air flow into a unit can be minimized through standardization and large volume purchases. The maintenance cost for an installed electronic air cleaner would include filter changes for the prefilter (assumed to be once a quarter at $5 a filter), and parts replacement or repair for the electrostatic unit. The former comes to $275-$315 (discounted at 6 percent) over 30-50 years while the latter is difficult to quantify. It would be expected, though, that a warranty would be in effect for the first few years after installation. The cost of the electricity needed to operate the air cleaner on a 24-hour basis is

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*The replacement rate would decrease through the use of a renewable or cleanable prefilter, although the tradeoff would be the additional cleaning maintenance and initial capital cost.

TABLE 3
AVERAGE COST PER PERCENT REDUCTION OF RADON DAUGHTER LEVELS

CONTROL MEASURE	ESTIMATED PERCENT RADON PROGENY REDUCTION	TOTAL COST (30–50 YRS)*	AVERAGE COST/PERCENT REDUCTION	RANK	
				FULL MEASURE**	LIMITED MEASURES
AIR CLEANERS:					
HEPA	40%	$1725–1925	$43–48($45)	–	5
ELECTRONIC	40%	800– 900	20–23($21)	–	2
ELECTRONIC & AIR EXCHANGE	60%	3000–3325	50–55($52)	5	6
VENTILATED CRAWL SPACE	80%+	450	6($ 6)	1	1
POLYMERIC SEALANT	80%	400–1300	5– 16($ 10)	2	3
EXCAVATION AND FILL					
(TO 10′ DEPTH):					
COMMERCIAL FILL RATE	80%	2100–3700	26– 46($ 36)	4	–
W/NOMINAL FILL COST	80%	1595–1850	20– 23($ 22)	3	–
(TO 5′ DEPTH):					
COMMERCIAL FILL RATE	40%	1100–1900	28– 48($ 38)	–	4
W/NOMINAL FILL COST	40%	800– 950	20– 24($ 22)	–	2
IMPROVED SLAB CONSTRUCTION	80%+	450	6($ 6)	1	1

*WITH 6% DISCOUNT RATE.
** MEASURES WITH ESTIMATED REDUCTION OF EFFICIENCIES OF 50% OR MORE.

difficult to project. With an electrical consumption rate of 50 watts over a one-year period (440 kwh) and an electrical cost of \$.03711/kwh (present rate charged in the Polk County area by Florida Power and Light Co. (30)), the annual cost would be approximately \$17. The total discounted cost thus comes to about \$800-\$900 over a 30-50 year period which results in a cost/percent reduction of \$21 (assuming a 40 percent efficiency).

An electronic air cleaner can be utilized in combination with an air exchange vent in order to obtain a substantial reduction in radon daughter activity (upwards of 60 percent at 25 percent air exchange). Because larger capacity air-conditioning units are necessary to handle the continuous influx of warm air, the capital cost largely would be the cost-differential between the normal 2-ton unit (24,000 BTU) and a 3-ton unit (36,000 BTU), which would be needed to compensate for the air exchange. As Table 2 shows, this cost is approximately \$500 (31) assuming that the cost of the exchange vent is minimal. The total capital cost is the sum of this value and the capital cost for the electronic air cleaner.

The annual electrical cost is estimated at \$120 using an electrical consumption differential of about 3000 kwh/yr between the 2-ton and 3-ton units and a charge of \$0.04/kwh (37). The total cost for electrical power shown is again, a combination of this value and that for the electronic air cleaner.

As it is probable that the maintenance and replacement costs associated with the use of the larger air-conditioning unit will not be significantly higher, the costs represented are those of the air cleaner alone. The "plus" beside the cost figure represents the additional capital cost which would be associated with the use of special dehumidifying equipment. Because an air exchanger of this magnitude will introduce a large moisture load on the air-conditioning system, the normal dehumidifying cycle may not be sufficient to treat the air. As electronic air cleaning efficiency decreases with an increase in humidity, such equipment would be necessary. No cost estimates were possible because such equipment is not normally applied to residential structures. However, such a unit because of its sophistication, would likely increase the capital and electrical power cost significantly.

Disregarding the dehumidifier cost, the total discounted cost for the application of this system is projected at \$3000-\$3325 for a 30-50 year period at a cost per percent reduction of \$52.

B. Cost for Ventilated Crawl Space Construction

The capital cost for constructing a crawl space of standard dimensions for a single story detached home is approximately \$450 over the cost for a slab-on-grade construction (32). The total cost of \$450 was derived from these projected costs which results in a \$6 per percent reduction (assuming 80 percent reduction).

C. Excavation Costs

The capital cost for the excavation and filling of a 14,260 cubic foot (46' x 31' x 10') pit on a 1000 square foot single home site (40' x 25') would consist of the following cost components:

Commercial Rates -

Excavation (32,33):	\$ 475 (\$0.90/yd³)
Hauling and fill cost (33):	
dirt/sand fill, or	1635 (\$3.10/yd³)
limerock fill	3225 (\$7.62/yd³)
TOTAL	≈ \$2100 or \$3700

W/Nominal Fill Cost -

Hauling and fill cost:	\$1100 - \$1375 (\$2.10-\$2.60/yd³)
TOTAL	≈ \$1575 - \$1850

The estimate of \$0.90/yd³ for excavation is taken from the 1974 HUD Regional Costs Data Handbook for Region IV (including Florida). This figure, although not adjusted for inflationary increases, does compare favorably with estimates of \$0.70/yd³ and \$1.00/yd³ from excavating contractors in the Polk County area. The cost of the replacement fill and the hauling needed to transport it to the site (assuming a 15-mile distance) was determined from estimates made by private contractors. The figure of \$3.10/yd³ for dirt/sand and \$7.62/yd³ for limerock were the lowest estimates received. Limerock is considerably cheaper due to its availability in the central Florida area while gravel must be shipped by rail from out-of-State. These two types of fill were used in making the cost estimate because they were found to be the least expensive. Their density and porosity characteristics have not been determined so that relaxation distances for radon diffusion could not be ascertained. If these fills should show relaxation distances less than 4.9 feet, then less excavation would be necessary. Of course, the reverse would also be true for longer relaxation distances. If less excavation is found to be necessary because of either less radon emanation at the site or use of fills with shorter relaxation distances for radon, total costs can be reduced considerably. Because basic costs are generally related to the volume excavated, transported, and filled, excavation to a depth of only five feet halves the cost while excavation of only three feet reduces the cost by a factor of about three.

As a properly excavated and filled pit should not require any later maintenance, the total cost would merely be the capital cost. Thus, with a total cost of \$2100-\$3700, the cost per percent reduction would be \$26-\$46 per percent (assuming 80 percent radon level reduction).

If the contractor has access to fill which can be obtained at a nominal cost, total costs can be reduced considerably. As no data is available on what the cost range would be in such a situation, \$2.10-\$2.60 was chosen as a representative range for the cost of the fill and the hauling involved (assuming a fill cost of \$0-\$0.50/yd^3). The total cost arrived at then, is \$1575-\$1850 leading to a cost per percent reduction of \$20-\$23.

D. Polymeric Sealant Cost

The cost range for polymeric sealants, \$400-\$1300, shown in Table 2, is based on a square footage cost range of \$0.40-\$1.30 assuming a 1000 square foot home. The upper range of this estimate is derived from field studies performed by Culot, et al. (22), at Colorado State University in 1972. In their study, Omnitech* epoxy sealant was utilized at a cost of $1.30 per square foot of multi-coat application (as described previously in this report).

As the CSU procedure applies to an existing structure, the actual cost should be less for a new structure as no flooring would have been built over the slab before sealing. The application process itself, should also be easier, not being hindered by any obstructions such as walls and woodwork. An "integral coverbase" is not included in this cost estimate, although it was in the original as many of the new polymers commercially available can be applied directly to a properly prepared slab. Although these factors would probably reduce the total cost to below a dollar a square foot, inflationary increases over the past four to five years would probably negate much of these savings. Thus, a cost of $1.30 per square foot has been retained as the upper limit for polymeric sealant use.

The Lawrence Livermore Laboratory (24) analysis of nine polymeric sealants being tested by the Bureau of Mines showed that Hydrepoxy 300, manufactured by the Acme Chemicals and Insulation Company, showed the best results in permeability, fire, and other laboratory tests. Communications with Acme (34) provided us with a cost estimate of approximately $\$0.41/ft.^2$ assuming application of three layers (.006" thickness)

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*Omnitech Industries, Inc.

of Hydrepoxy 300 with proper slab preparation and labor charge included as outlined below:

1. The application of two coats of Hydrepoxy 300 at .006" dry thickness each coat to most masonry surfaces will cost approximately $0.10 per square foot to the construction trade, and approximately $0.15 per square foot to the do-it-yourself homeowner. Application to rough or porous cement block can increase this cost by some 25 percent.

2. Preparation is generally done by wire brushing, sand-blasting, or acid etching to clean and rough up smooth surfaces.

3. A typical family house (assumed to be 1000 sq. ft. in area) would probably have the following requirements to coat a poured concrete slab:

a. Materials - assuming 1000 square feet of floor @ $0.15 for 3 coats = approximately $150.

b. Equipment - $25 (includes rollers, brushes, etc.).

c. Labor - Preparation - 5 to 10 hours
Application - 12 hours
Cleanup - 1 hour.

Total labor required = 18-23 hours at $10/hr.

Total labor cost = $18 - $230

Total cost = $350 - $400 ($0.35 - $0.40/sq. ft.).

This cost range of $0.40 - $1.30 square foot is also supported by estimates made in the 33rd Annual Edition for 1975 of "Building Construction Cost Data" (Robert Snow Means Co., Inc.). A range of $0.50 - $1.50 per square foot was ascribed to polymeric sealant application by the editors of this reference manual (35). Actual costs of materials and labor, however, will vary widely according to locality, polymer type, and manufacturer.

The costs for maintenance and replacement are listed as "undefined" because the durability and long-term effectiveness of polymeric sealants under normal residential usage has not yet been determined. Without proper protection, such as the use of a protective overcoat and substrate, the manufacturers of Hydrepoxy 300 project a minimal five-year life without cracking or peeling. In a number of homes, a monolithic (nonfooted) slab is utilized which tends, over the years, to settle and crack. Application of sealants over such surfaces will probably be only a temporary measure and reapplication will be necessary.

E. Cost of Improved Slab Construction

The cost for increasing the slab thickness of a 1000 square foot structure from 4 inches to 8 inches, listed as $450 in Table 2, is based on an estimated $1 cost per square foot (32). The differential between this figure and that for a conventional slab ($0.55 per square foot) results in a cost of $0.45 per square foot or $450 for a 1000 square foot structure. This cost includes the poured concrete (2500 lbs), reinforcement wire (6" x 6", #10) and trowel finish. With a projected radon daughter reduction efficiency of about 80 percent, a cost per percent reduction of $6 results, as Table 3 shows.

VI. MODEL FOR DECISION-MAKING

In order to address the implementation of the control measures discussed, a model for decision-making is presented. This model presumes the interaction of local and State health and housing agencies in the decision-making process. This situation, in fact, does not exist in the State of Florida, neither the State nor the counties involved having the authority to regulate construction on affected land at the present. However, notwithstanding the lack of governmental interaction, the decision-making process described could be of use to prospective developers in these areas.

In Figure 8, a flow diagram is presented which describes the options which would be available for a builder or developer when a potential radon diffusion problem is identified. The diagram is based on data in Tables 2 and 3, as well as survey experience from field studies. The outdoor gamma levels utilized in the decision process are based on the interim guidelines, issued by the Office of Radiation Programs, EPA, in January 1976 and amended in June 1976 for publication in the Federal Register (41FR26066) (36). These interim recommendations are subject to change at a later date through the development of more discriminating measurement techniques or through additional data collection.

A. Decision Process Summary

PICK HOMESITE - Prerogative of builder or developer.

FIGURE 8a

MODEL FOR DECISION MAKING FOR THE CONTROL OF INDOOR RADON DAUGHTER LEVELS IN NEW STRUCTURES DUE TO EMANATION THROUGH THE FOUNDATION

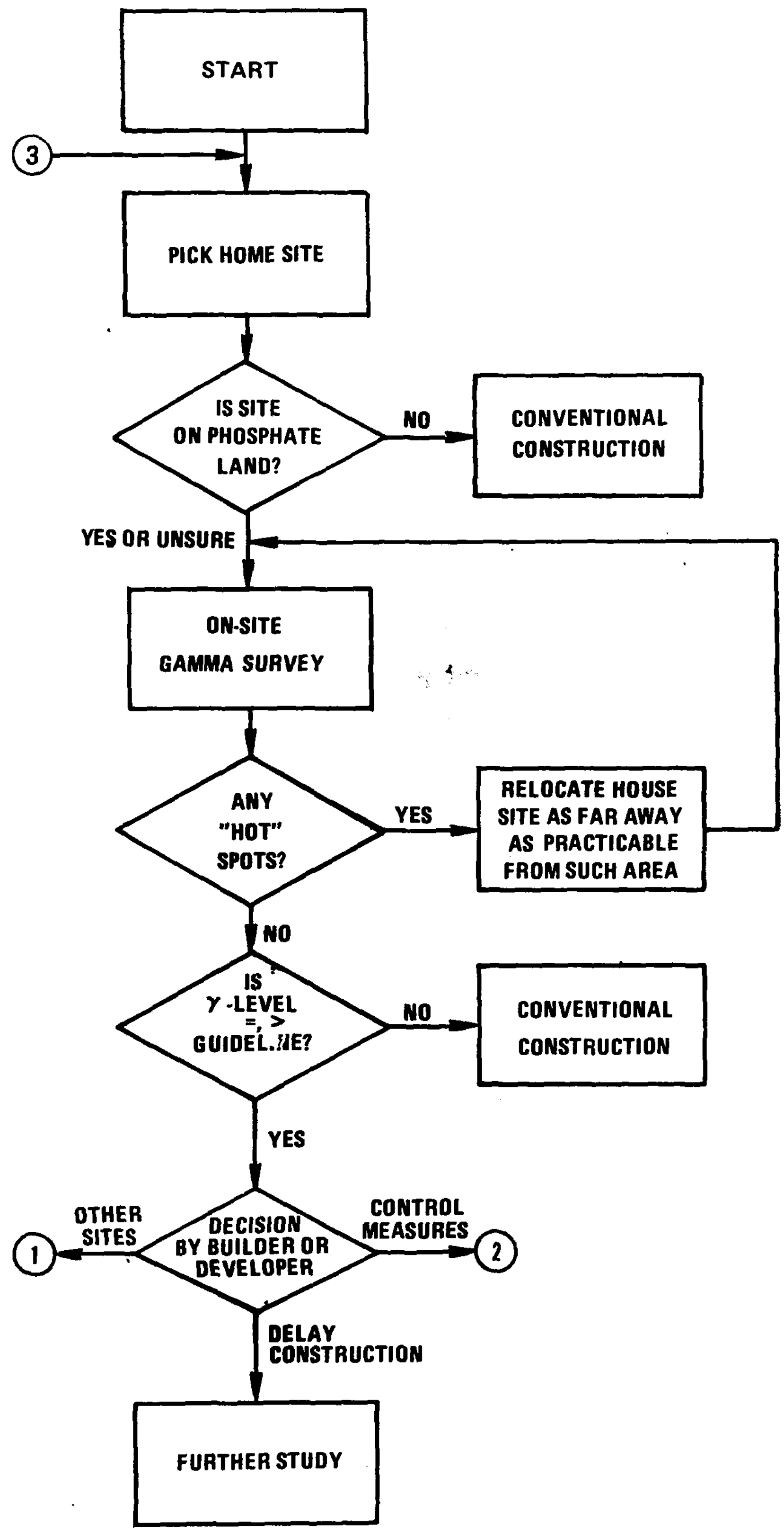
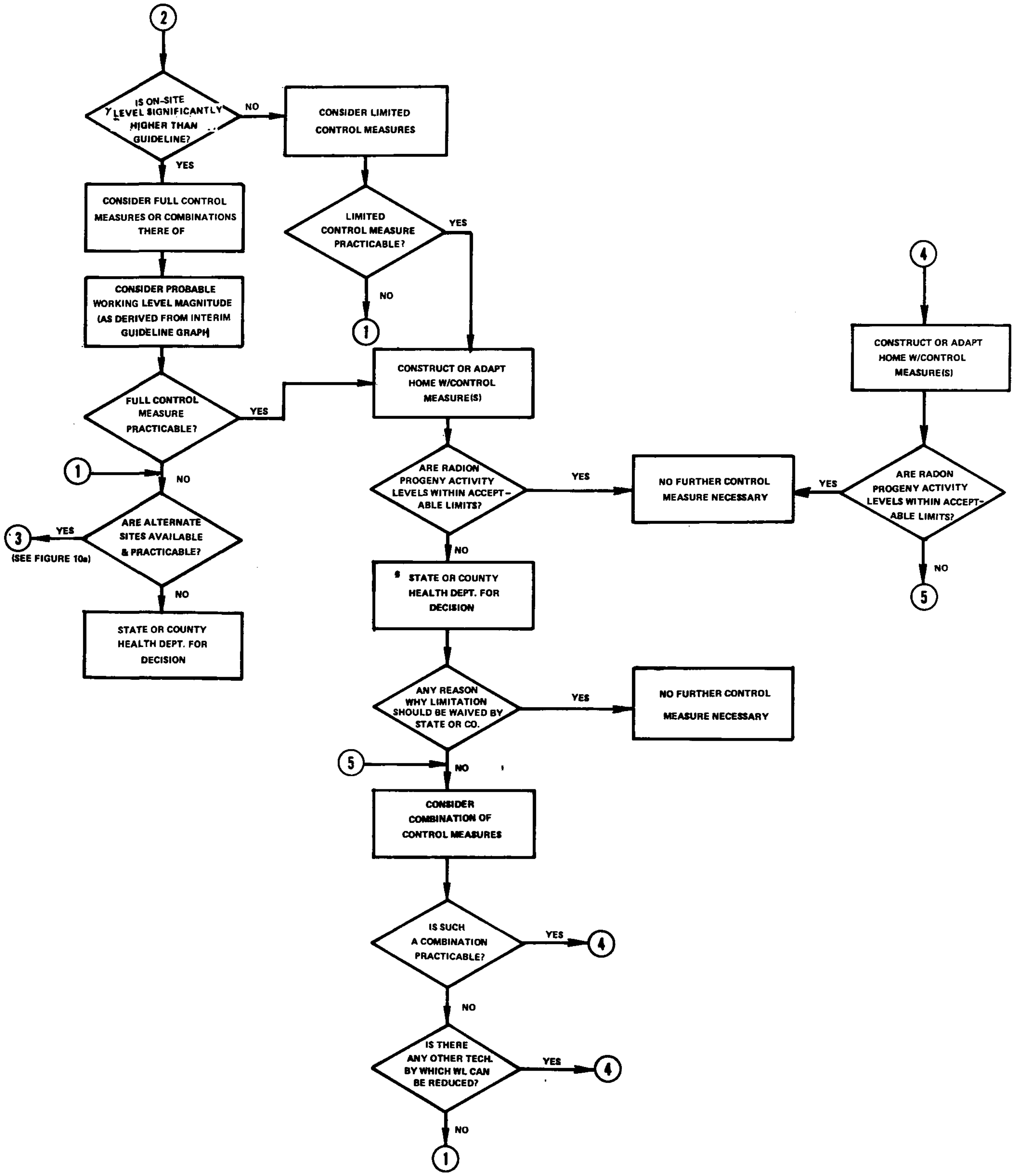


FIGURE 8b
MODEL FOR DECISION MAKING FOR THE CONTROL OF INDOOR RADON DAUGHTER LEVELS IN NEW STRUCTURES DUE TO EMANATION THROUGH THE FOUNDATION (CONT.)



*IS SITE ON PHOSPHATE LAND?** - This information should be obtained from State and county authorities. If the site is determined definitely not to be on phosphate land, normal construction can be initiated. If the site is on phosphate land or if there is any uncertainty (due to missing records, poor filing, etc.) as to this question, an on-site gamma radiation survey is recommended.

ON-SITE GAMMA SURVEY - To be performed as outlined in EPA's Interim Recommendations for Gamma Exposure Levels at New Structure Sites on Florida Phosphate Lands (36). (See Appendix B.)

ARE "HOT SPOTS" PRESENT? - This information would be obtained from the preceding gamma survey of the site. Because the interim guidelines are based on an average of the gamma levels measured on-site, anomalous elevated readings at a few points may raise the average reading so that it exceeds the recommended average gamma exposure level of 10 μR/hr. If such a situation does exist, the builder or developer should choose another site on the lot which would locate the proposed residence as far from these locations as practicable, or remove surface or near surface materials, such as phosphate slag, which may cause anomalous readings. The new or altered site would then be surveyed.

ARE OUTDOOR GAMMA EXPOSURE LEVELS AT THE SITE WITHIN ACCEPTABLE LIMITS? - If the average gamma exposure level is below the interim guideline of 10 μR/hr and no significant hot spots are present, conventional construction is suggested. Should the average level be equal to

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*For this report, phosphate land is defined as land which contains reclaimed mining overburden at or near the surface, and outcroppings of phosphate matrix material where it occurs.

or above this recommended guideline, the builder, developer, and/or appropriate county and State health agencies should decide whether: 1) control measures should be considered, 2) construction should be delayed pending further study, or 3) an alternate site should be found for construction. The first possibility, which this report addresses, is diagrammed fully in Figure 8b and is discussed further in the following section. It should be emphasized that the interim guidelines are subject to change as more data becomes available.

B. Control Measures

IS ON-SITE GAMMA LEVEL SIGNIFICANTLY HIGHER THAN GUIDELINE? - In order to introduce a degree of flexibility into the selection of control measures, an allowance needs to be made for the use of limited measures (efficiencies less than 50 percent). Because marginally elevated gamma readings (e.g., in the 10-20 mR/hr range) may be reduced effectively by these measures, their use could be justified. Conversely, with significantly elevated gamma readings, more efficient control measures are necessary to reduce potential indoor working levels to acceptable values. Such measures, termed full measures, have reduction efficiencies of at least 60 percent. With a working level approximation derived from the interim guidelines using outdoor gamma data, the prospective builder should first, determine what reduction efficiency he will need to reduce in-house radon daughter activities to acceptable levels, and second, what control measure or combination of control measures will provide this level of efficiency. Once such a decision has been made, a test home, incorporating these measures, should be built to allow for an actual survey. For single home construction, an acceptable in-house survey measurement would permit normal occupancy. Likewise, for multi-home construction, continued construction could be permitted if measured activities were low enough. If a survey still showed elevated levels, the responsible State or county agency would make the decision as to whether to grant a waiver or instruct the builder to institute an improved control program. There is also an option that allows the builder to develop innovative technologies by which radon working levels can be reduced in homes. Should acceptable daughter activities still be unattainable, an effort should be made to find another site for the structure(s). In the case of single home construction, a possible approach on the part of local government would be to allow the structure to be occupied pending further study of control measures. This type of flexibility on the part of the local government agencies is integrated into this decision process in order to allow them to be better able to handle cases on an individual basis. It is expected that situations will arise where such flexibility will serve to improve the performance and results of a control program such as this one.

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APPENDIX A

EFFECTIVENESS OF AIR CLEANING IN THE REMOVAL OF RADON DAUGHTER PARTICULATES: A MODEL

EFFECTIVENESS OF AIR CLEANING IN THE REMOVAL OF RADON DAUGHTER PARTICULATES: A MODEL

Because little experimental work has been performed on the effectiveness of radon daughter particulate removal by air cleaners in residential settings, modeling was chosen as a technique by which a rough approximation of effectiveness could be determined. These approximations of effectiveness are used in this report to compare relative working level reductions between various air cleaners and various ventilation rates. The function of the model is to determine what effect air cleaners will have on the equilibrium activity level of the daughter particulates. Air cleaning efficiencies approximating those found in HEPA filters and electronic air cleaners were used as they have been found to be critical for radon daughter particulates. The various parameters used, the assumptions made and the calculations performed are discussed in the following annotated calculations.

Determination of Radon Daughter Activities and Equilibrium Ratios With and Without Air Cleaners

Assumptions:

1. Natural air infiltration rate = 1 air change/hour.

2. Electronic and HEPA air cleaners 80 percent efficient for removal of radon daughter particulates with once-through cleaning.

3. The plateout factor, the fraction of the radon daughters removed by adhesion to macro-surfaces (walls, flooring, furniture, etc.), will be ignored in calculations as it has not been well-defined for residential situations and because it will be substantially the same for

structures with or without air cleaners. Evans (1) indicates that in mine shafts, a deposition factor of 0.7 h^{-1} was measured. He indicates, however, that lower deposition rates would be expected in structures due to lower air flow rates and lower particulate concentration (notwithstanding the possibility that this could be offset somewhat by electrostatic attraction for particles than the ribs, floors, and walls of a mine shaft).

Calculations:

1. To determine radon daughter activities and equilibrium ratios without air cleaners -

$$A_1 = \lambda_{d_1} N_{d_1} = \frac{A_R \lambda_{d_1}}{\lambda_{d_1} + \lambda_v}$$

where,

A_1 = Activity of RaA

A_R = Radon activity/structure volume (1.0 or unity)

N_d = Atoms of RaA in structures

λd_1 = Decay constant for RaA (3.85×10^{-3} s^{-1})

λ_v = Infiltration constant (2.8×10^{-4} s^{-1})

A_1 = 0.93

$$A_2 = \lambda_{d_2} N_{d_2} = \frac{A_1 \lambda_{d_2}}{d_2 + \lambda_v}$$

where,

A_2 = Activity of RaB

N_{d_2} = Atoms of RaB

λ_{d_2} = Decay constant for RaB ($4.27 \times 10^{-4}\ s^{-1}$)

A_2 = 0.56

$$A_3 = \lambda_{d_3} N_{d_3} = \frac{A_2 \lambda_{d_3}}{d_3 + \lambda_v}$$

where,

A_3 = Activity of RaC

N_{d_3} = Atoms of RaC

λ_{d_3} = Decay constant for RaC ($5.8 \times 10^{-4}\ s^{-1}$)

A_3 = 0.38

RADON:RADON
Daughter Activity Equilibrium Ratios

	Ratio Rn / Daughters	Ratio Rn / Daughters (Haque and Collison (2))
Radon	1	1
RaA	.93	.9
RaB	.56	.5
RaC	.38	.35

As the Table shows, the equilibrium ratios of the radon daughter activities to the radon activity for these calculations correspond to values calculated by Haque and Collison (2) for a structure with "adequate" ventilation. By determining these daughter/parent ratios for a structure with an air cleaner, a measure of the reduction in daughter product activity can be determined.

2. To determine radon daughter activities and equilibrium ratios with air cleaners:

$$A_1 = \lambda_{d_1} N_{d_1} = \frac{A_R \quad \lambda_{d_1}}{\lambda_{d_1} = \lambda_f = \lambda_v} \qquad (A_R = 1.0 \text{ or unity})$$

where for electronic and HEPA air cleaners,

λ_f = Filtration constant corresponding to an 80 percent efficiency for radon daughter particulates removal $(3.3x10^{-4} \cdot s^{-1})$

A_1 = 0.84

$$A_2 = \lambda_{d_2} N_{d_2} = \frac{A_1 \lambda_{d_2}}{d_2 + \lambda_f + \lambda_v}$$

A_2 = 0.34

$$A_3 = \lambda_{d_3} N_{d_3} = \frac{A_1 \quad \lambda_{d_3}}{d_3 + \lambda_f + \lambda_v}$$

A_3 = 0.17

Ratio of daughter activities to radon activity - 1: .84: .34:.17

Table A-1 provides calculations for determining working levels for daughter activities in structures with and without the use of air clearners.

Table A-1

Determination of Working Level
Reductions With and Without Air Cleaners*

Radionuclide	Air Cleaner	Concentrations pci/1	Concentrations Atoms/1	Alpha Energy per Atom (MeV)	Total Potential Alpha Energy per liter (MeV)
Rn	None	1	1.77×10^4	--	--
	Electronic & HEPA	1			
RaA	None	.93	9.08		124
	Electronic & HEPA	.84	8.20	13.68	112
RaB	None	.56	48.05		369
	Electronic & HEPA	.34	29.17	7.68	224
RaC	None	.38	24.86		190
	Electronic & HEPA	.17	11.12	7.68	85

<u>Total</u>	None	683 MeV
	Electronic & HEPA	421 MeV

As total alpha energy is directly proportional to working levels (1 WL defined as 1.3×10^5 MeV alpha/1) then:

% reduction w/electronic & HEPA air cleaners = $100\% - (\frac{421}{683} \times 100) = 38\%$

*Assuming attached and unattached ions are ventilated and removed at the same rate. For HEPA filters utilizing a high effective ventilation rate (>2-3 air changes/hr), though, an increased tracheo-bronchial dose would be realized from the elevated free ion fraction. For electronic air cleaners the opposite would be more likely with almost complete removal of RaA free ions to be expected in the electric field.

Utilization of Graphic Representation:

The curves in Figures A-1 and A-2 are derived from the preceding calculations. Figure A-1 provides a radon-222 "equilibrium value"* in pCi/m^2 for known emanation and ventilation rates. An equilibrium concentration (pCi/m^3) can be calculated for the structure assuming a known volume or height. The graph has primarily been utilized in this report to determine radon daughter reduction efficiencies, an example of which is provided at the end of this section.

Figure A-2 provides a measure of the radon daughter level (WL/100 pCi liter radon-222) as a function of effective ventilation rate. By comparing the working level measurement for a conventional residential situation against one with air cleaning equipment, a reduction efficiency for the air cleaner can be approximated. As an example, a reduction efficiency determination encompassing both graphs is provided below for the hypothetical utilization of a combination air exchanger and electronic air cleaner.

Determination of Radon Daughter Reduction Efficiency from Combined Electronic Air Cleaner and Outside Air Exchange System

Assumptions:

Air flow rate through ventilation system - 1.5 air changes/hr.
Percentage makeup air - 25 percent.
Efficiency of electronic air cleaner - 80 percent.
Natural air infiltration rate - 1.0 ac/h.
Air changes per hour - 1.4 (radon only).
Total effective air changes per hour - 2.3 (radon and daughters).

*In this case, the equilibrium value denotes the equilibrium concentration of radon-222 in the air volume of the structure overlying a square meter of floor space.

FIGURE A—1
EFFECT OF NATURAL VENTILATION ON RADON CONCENTRATION IN STRUCTURES (FOR RADON DIFFUSION RATES NOTED)

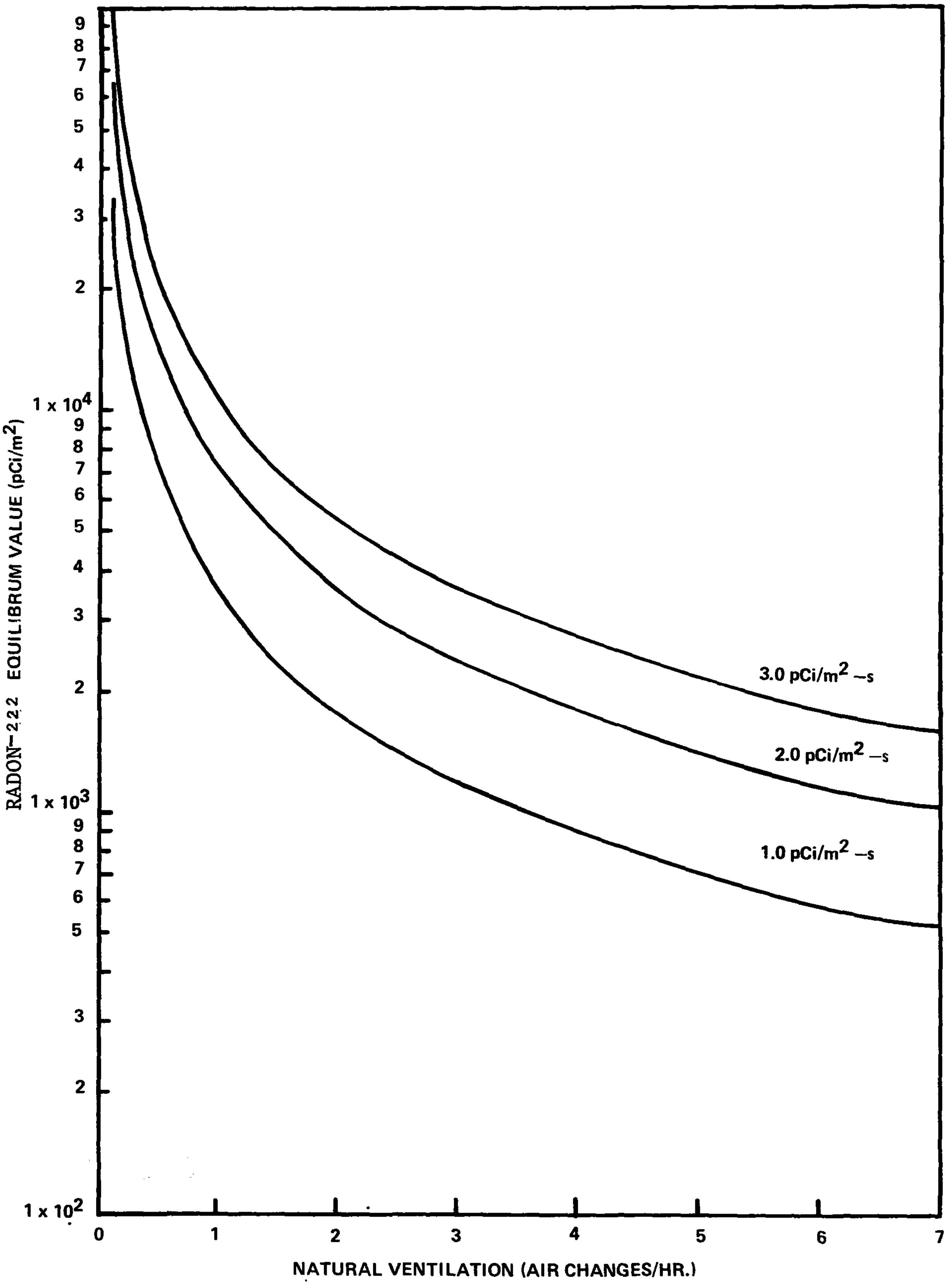
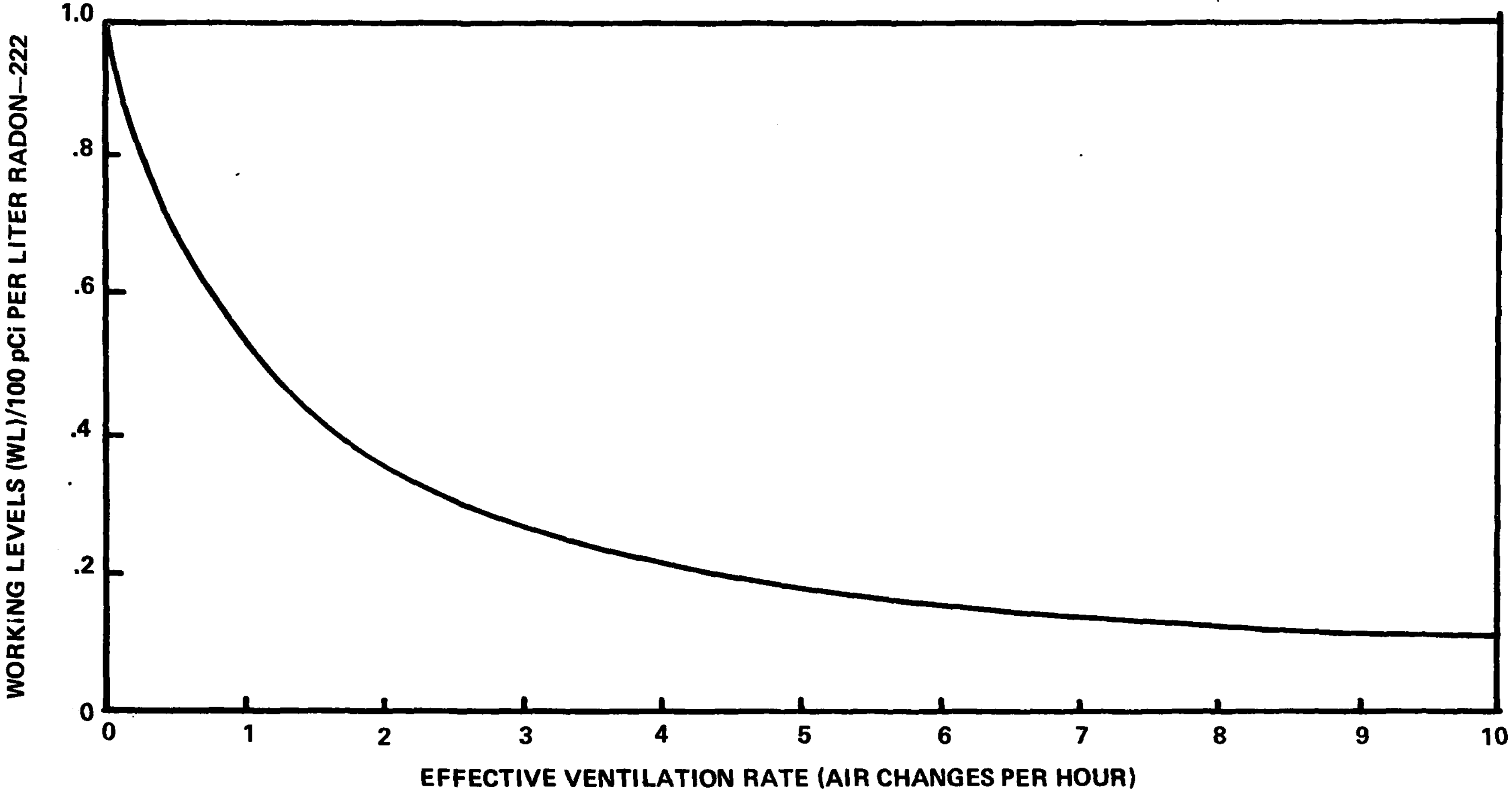


FIGURE A—2
WORKING LEVELS (WL) PER 100 pCi PER LITER OF RADON—222 VS EFFECTIVE VENTILATION RATE



From Figure A-2 an increase of 0.4 ac/hr from a total effective ventilation of 1.0 to 1.4 ac/yr gives an approximate reduction of 17 percent in the number of working levels per 100 pCi/l of radon-222. As Figure A-1 shows, 1.4 air changes per hour also leads to a radon source term reduction of 26 percent, using 1.0 ac/h, again, as a baseline. Because the radon source term reduction and the working level reduction are additive (Figure A-2 relates only to the effect of ventilation and air cleaning on radon daughters while Figure A-1 relates to the radon source term itself), a combined reduction in the working level of 43 percent is calculated for the air change system.

In order to determine the combined efficiency of the electronic air cleaner and an outside air exchange system, the effective ventilation rates of each are summed, and then added to the radon source term already calculated. From Figure A-2, a combined effective ventilation rate of approximately 2.3 ac/hr results in a 36 percent working level reduction which added to the 26 percent reduction of radon source term gives a total reduction of 62 percent.

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APPENDIX B

FLORIDA INDOOR RADON DAUGHTER LEVELS - FEBRUARY 1976

Table B1

Florida Indoor Radon Levels Data - February 1976

Location No.	ORP/CSD 75-4** Avg. WL	ORP/CSD 75-4** (No. of Measurements)	New Data Avg. WL	New Data (No. of Measurements)
98R	0.205	(2)	0.105	(4)
110R	0.111	(2)	0.075	(4)
107R	0.101	(1)	0.067	(2)
105R	0.051	(2)	0.037	(5)
94R	0.031	(3)	0.023	(5)
76R	0.030	(1)	0.058	(4)
172	0.025	(1)	0.027	(4)
103R	0.023	(1)	0.023	(4)
169	0.022	(1)	0.020	(4)
51R	0.011	(1)	0.013	(4)
118R (No A/C)	0.010	(1)	0.006	(4)
50R	0.007	(1)	0.006	(5)
170	0.006	(1)	0.005	(4)
175	0.005	(1)	0.002	(4)
84R (No A/C)	0.005	(1)	0.007	(2)
112R	0.004	(3)	0.002	(6)
134	0.004	(1)	0.001	(4)
176	0.004	(1)	0.003	(4)
180	0.004	(1)	0.002	(4)
135	0.0002	(1)	0.0002	(4)
136	0.0002	(1)	0.0005	(4)
137*			0.0006	(4)
200*			0.005	(4)
203*			0.003	(3)
204*			0.005	(4)

*Elemental Phosphorus facilities.

**Preliminary Findings Radon Daughter Levels in Structures Constructed on Reclaimed Florida Phosphate Land, Office of Radiation Programs, U.S. Environmental Protection Agency, Technical Note ORP/CSD-75-4 (Sept. 1975).

R -- Believed to be on reclaimed phosphate land.

APPENDIX C

NOTICE OF INTERIM RECOMMENDATIONS FOR RADIATION LEVELS ON FLORIDA PHOSPHATE LANDS

ENVIRONMENTAL PROTECTION AGENCY

FLORIDA PHOSPHATE LANDS

Interim Recommendations for Radiation Levels

In June 1975, the Environmental Protection Agency initiated a study to determine the radiological impact of living and working in structures constructed on reclaimed phosphate mine land in Central Florida. From data acquired by this study, the Environmental Protection Agency issued a report entitled, "Preliminary Findings Radon Daughter Levels in Structures Constructed on Reclaimed Florida Phosphate Land," (ORP/CSD 75-4, September 1975) showing elevated indoor radon daughter levels in some structures built on reclaimed lands as compared to structures built on unmined soil. On September 22, 1975, the Administrator of the Environmental Protection Agency informed the Governor of Florida by letter that a potential public health problem appears to exist due to exposure to elevated radon daughter concentrations in some of these structures. The primary public health consideration is the potential risk of increased lung cancer. As a result of these findings, the Administrator recommended to the Governor that "as a prudent interim measure that the start of construction of new buildings on land reclaimed from phosphate mining areas be discouraged."

Since this initial study, the Agency in cooperation with the Florida Department of Health and Rehabilitative Services, and the Polk County Health Department has been acquiring additional information necessary for the development of appropriate radiation protection guides. These guides will be used to determine the extent of any remedial action necessary to reduce radon daughter concentrations.

However, because of the Agency's caution to the State of Florida to discourage the start of construction of new buildings, some delays in new construction have resulted on land sites which do not represent a threat to health. Consequently, the Agency developed recommendations which would allow construction on such land areas with minimal risk of significant radiation exposure. By letter of January 22, 1976, the Agency provided the Director of the Florida Division of Health an interim recommendation to be used for screening of land sites for construction of new structures on Florida phosphate areas. The recommendations are considered not applicable for any situation other than the one specified.

The interim recommendations are based on the findings presented in the noted EPA report, additional radon daughter level data from the same structures identified in the report, information obtained from investigations of the potential hazard associated with the use of uranium mill tailings in several Western States, and consideration of the Surgeon General's Guidelines for remedial action in Grand Junction, Colorado (Code of Federal Regulations, Title 10, Part 12). While these recommendations do not constitute new formal Federal Radiation Protection Guidance on this subject under 42 USC 2021(h), they are consistent with the basic principles of present Federal guidance for radiation protection of the public (25 FR 4402, May 18, 1960).

The Agency believes that implementation of these recommendations would provide public health protection to the extent necessary to minimize the health risk to individuals or populations. The interim recommendations to the State of Florida are as follows:

INTERIM RECOMMENDATIONS FOR GAMMA EXPOSURE LEVELS AT NEW STRUCTURE SITES ON FLORIDA PHOSPHATE LANDS

Average External Gamma Radiation Level	*Recommendations*
Equal to or greater than 10 μR/hr.	Construction should be delayed pending additional study or acceptable control technology should be instituted to preclude indoor radon daughter problems.
Less than 10 μR/hr.	Construction may be initiated.

RATIONALE AND EXPLANATORY NOTES

1. The external gamma radiation level recommended includes background which varies throughout Central Florida but is generally 5 to 7 μR/hr in the regions of concern (ORP/CSD 75-4, September 1975).

2. The purpose of these interim recommendations is to limit radon daughter exposures in structures constructed on Florida phosphate lands in the absence of both an acceptable criterion for radon daughter exposures in the subject situation and a definitive radon daughter level to gamma exposure level correlation.

3. Figure 1 is a plot of indoor radon daughter levels as a function of outside average gamma levels for the structures sampled through January 1976. The curve represents a multiple regression fit to the data. The points identified by an "x" were not included in the fit because they are high ventilation locations which lowers radon daughter levels but does not effect gamma measurements. Although this data is limited in number and period of collection, it suggests a positive relationship between gamma levels and indoor radon daughter levels.

4. Based on uranium mill tailing experiences and the data presented in Figure 1, it is possible to observe indoor radon daughter levels two or more times the normal background level, which ranges from about .0002 WL to .005 WL in Central Florida, at gamma levels a few microroentgens per hour above the normal gamma background. However, differences in ventilation, construction, and use may create wide variations in the observed indoor radon daughter levels in structures constructed on land exhibiting the same gamma level.

5. At gamma radiation levels less than 10 μR/hr, the observed indoor radon daughter levels in structures constructed on this land should be substantially less than .05 WL (the upper limit of the Surgeon General's Guidelines for remedial action in Grand Junction, Colorado) and generally comparable to background.

6. A Working Level (WL) is the term used to describe radon daughter product activities in air. This term is defined as any combination of short-lived radon daughter products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. If 100 pCi of randon-222 per liter of air are present in equilibrium with its short-lived daughter products through RaC', the ultimate alpha energy released will be 1.3×10^5 MeV or one Working Level.

7. In evaluating proposed construction sites, gamma radiation level measurements should be made by a competent technician using properly calibrated equipment. The site external gamma radiation levels should be determined by averaging at least ten or more measurements made within a perimeter of two feet around the proposed structure as illustrated by Figure 2. All measurements should be made at a height of three feet above the ground surface.

8. If the exact proposed structure location on a building site is not known, then the entire area of the site suitable for structure construction should be evaluated with one measurement made within each 500 square feet. These measurements should be averaged to obtain an overall site value.

Any comments on these recommendations should be sent to the Director, Criteria & Standards Division, Office of Radiation Programs, Environmental Protection Agency (AW-460), 401 M Street, SW., Washington, D.C. 20460. Copies of the cited September 1975 EPA Report entitled, "Preliminary Findings Radon Daughter Levels in Structures Constructed on Reclaimed Florida Phosphate Land' are available at the above address.

Dated: June 16, 1976.

ROGER STRELOW,
Assistant Administrator for Air and Waste Manaegement.

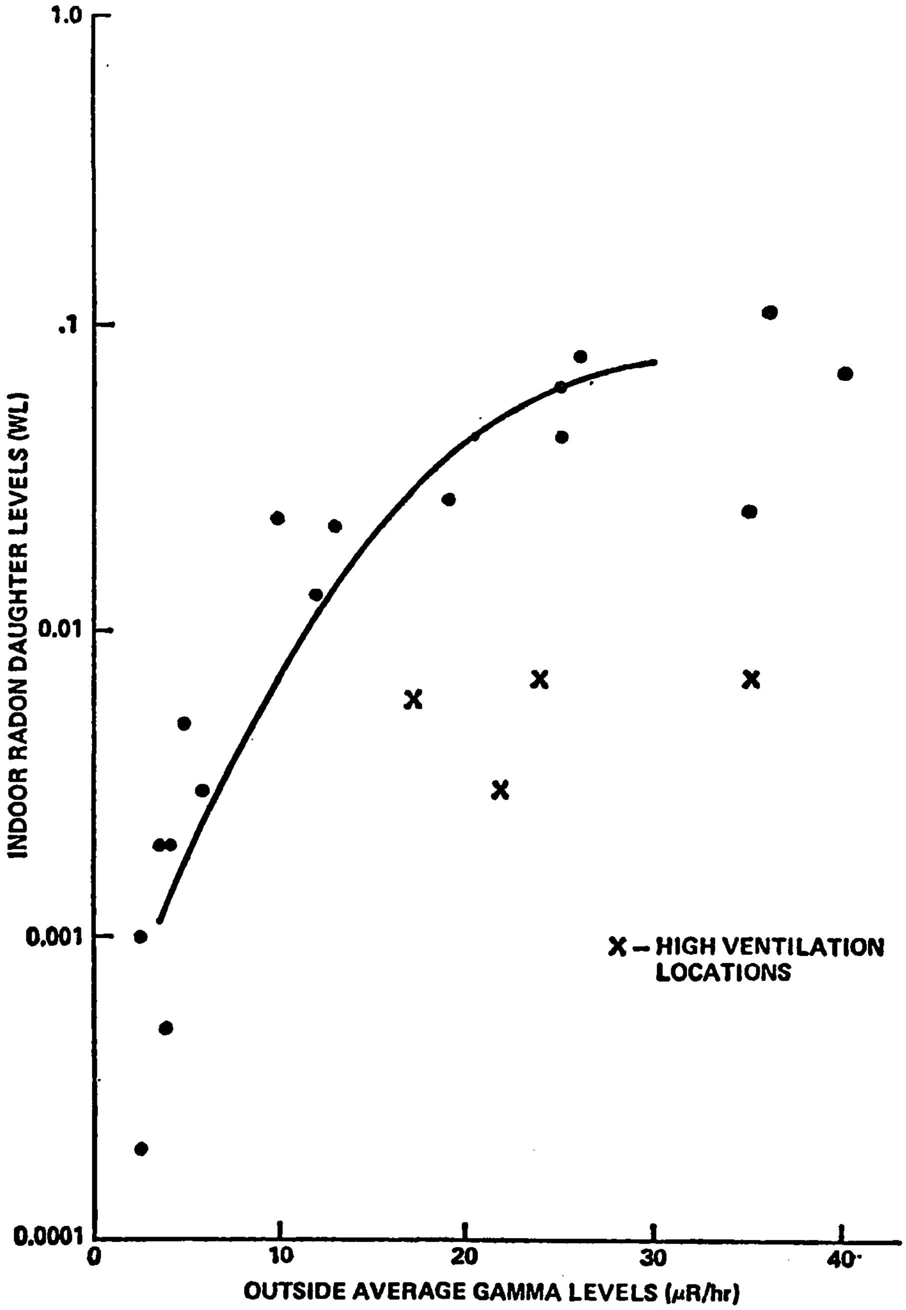
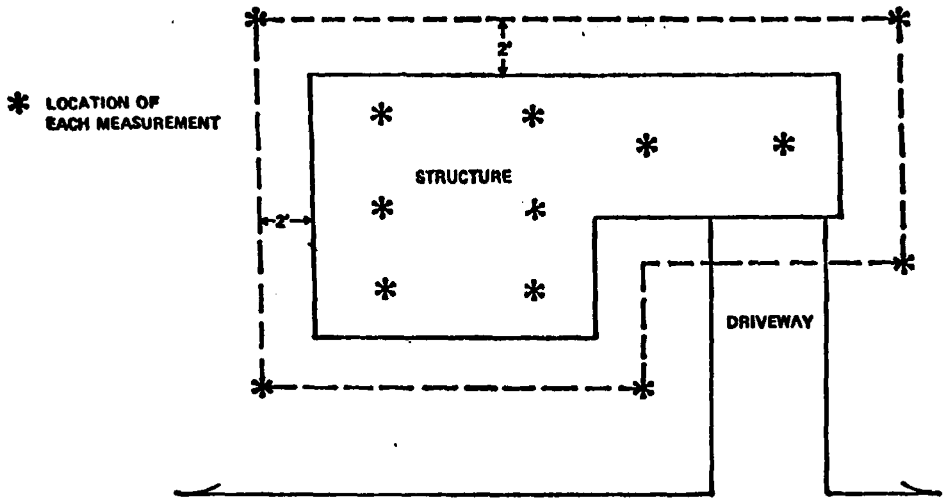


FIGURE 1 OBSERVED INDOOR RADON DAUGHTER LEVELS AS A FUNCTION OF OUTDOOR AVERAGE GAMMA RADIATION LEVELS FOR DATA COLLECTED AS OF FEBRUARY 1976.

Figure 2

TYPICAL SITE EVALUATION FOR A PROPOSED STRUCTURE



[FR Doc.76-18173 Filed 6-23-76;8:45 am]

APPENDIX D

EXPERIMENTAL EFFECTIVENESS OF SELECTED COMMERCIAL POLYMERIC SEALANTS IN STOPPING RADON DIFFUSION

EXPERIMENTAL EFFECTIVENESS OF SELECTED COMMERCIAL POLYMERIC SEALANTS IN STOPPING RADON DIFFUSION*

Table D-1 -- Various Coatings Tested in the Laboratory

Company	Product Identification	Effectiveness Percent
Acme Chemical	HydrEpoxy 101 water-base epoxy	38
Do	HydrEpoxy 260	4
Do	HydrEpoxy 156	94
Do	HydrEpoxy 300 (modified 1)	18
Do	HydrEpoxy 300 epoxy	87
American Cyanamid	Aerospray 52	0
Do	Reflecto-O-Seal	0
Do	Aerospray 70	99
BF Goodrich	Vinyl latex Geon 652	0
Callery	Urethane	56
Celanese Coatings Co.	EpiRez WD 510 epoxy	100
Do	EpiRez WE 3520	73
Devcon Corp.	Epoxy U.W.	73
Dev-Cote	Intumescent	82
Dow Chemical	Saran Resin F-310	0
Do	Saran Resin F-300	0
Do	Latex XD 4624	89
Do	Latex XD 7151	64
Do	Latex XD 7828	0
Essex Chemical Corp.	Unsaturated polyester	95
Do	Liquid Envelope 65-24	0
Fraley's modified system	Inorganic	0
Hercules	Chlorinated rubber	85
Morton Chemical	Serfene 432X	5
Do	Latex FR 103	0
Preserv-O-Paints	Polythane	71
Do	El-Stretch-O	0
Quaker Koat	Asphalt	0
Rustreat	Latex metal primer	44
Sika Chemical	Colma-Kote	99
Southwest Research	Sulfur	100
Staley Chemical	P-961	0
Do	P-930HT	0
Swift Co.	4517	0
Do	Adcote	0
Tra-Con	Tra-Bond 2106T	100
Do	Tra-Bond FS91	95

*From Franklin, J.C. and L.T. Nuzman, "Polymeric Materials for Sealing Radon Gas into the Walls of Uranium Mines," Spokane Mining Research Center, Washington, U.S. Bureau of Mines, RI 8036, HO-220006, and HO-230007 (1975).

Table D-1 -- CONTINUED

Company	Product Identification	Effectiveness Percent
United Paint	Butyl rubber	38
Do	-- do --	32
Do	Chlorinated rubber	11
Ventron Corp.	Resitron I furan resin	50
Do	Resitron II furan resin	97
Do	Resitron II modified 14,500 cp	91[1]
Do	Resitron II modified 7,800 cp	0
Michael Walters Ind.	Inorganic	0
Washington State University	Modified epoxy	100

[1]Three samples were widely scattered and will be recoated and retested. Figure given is for one of the three samples tested.

Table D-2 -- Two-Coat Systems Tested in the Laboratory

Prime Coat	Top Coat	Effectiveness Percent
HydrEpoxy 156[1]	HydrEpoxy 156	77
Do	HydrEpoxy 300	79
Resitron II	-- do --	70
Latex XD 4624	HydrEpoxy 156	95
HydrEpoxy 156[2]	-- do --	75
Latex XD 4624	HydrEpoxy 300	86
Resitron II	Resitron II, 14,500 cp	100
Do	Resitron II, 7,800 cp	100
Latex XD 4624	Unsaturated polyester	0
Resitron II[3]	Resitron II, 14,500 cp[3]	100
Do[3]	HydrEpoxy 156	100
Do	Unsaturated polyester	77
Do[3]	EpiRez WD 510	99
Do	Washington State University modified epoxy	65

[1]Diluted by 75 percent water.

[2]Diluted by 50 percent water.

[3]Diluted with water.

Development and Evaluation of Radon Sealants for Uranium Mines

by

H.G. Hammon, K. Ernst, J.R. Gaskill,
J.C. Newton, and C.J. Morris

(Excerpt from summary and conclusions)

Ranking of sealants studied:*

Name and Type	Comments
1. HydrEpoxy 300, pigmented water-dispersed epoxy	
2. Resitron II, furan (catalyzed furfuryl alcohol polymer)	Bad odor
3. Essex Polyester, pigmented one-component styrenated polyester	Flammable; contains styrene
4. Aerospray 70, plasticized polyvinyl acetate latex	Possible smoke problem
5. Saran XD-7151, vinylidene chloride copolymer	Liberates hydrogen chloride in possible fire
6. EpiRez WD-510/EpiCure 872, unpigmented water-dispersed epoxy	Possible smoke problem
7. WSU-118, modified epoxy	Possible smoke problem
8. Promulsion 200, unidentified composition	Possible smoke problem
9. Hydro Seal, acrylic emulsion	Possible smoke problem

*The authors note that the coatings ranked here only represent a few of such commercial coatings available, that other manufacturers may make similar coatings. The ranking gives little weight to permeability, as all of the sealants were adequate in stopping radon exhalation. Thus, much emphasis was placed on application and safety problems. They conclude that the selection of a suitable sealant should be based on cost/m^2, vapor toxicity during application and the ability to bind to surface without the formation of pinholes.