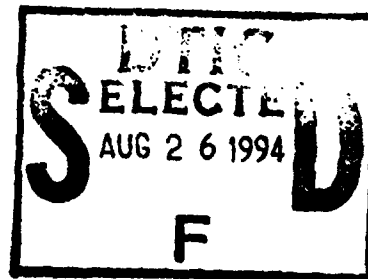


AD-A283 749



G

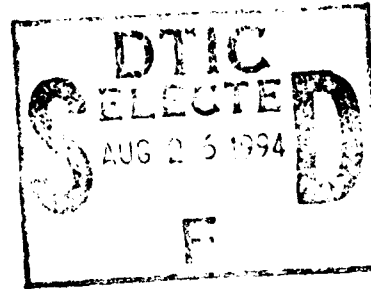


This document has been approved  
for public release and sale; its  
distribution is unlimited.

94 8 25 ' 176

8396 94-27371





# **RADON DETECTION AND REMEDIATION IN NAVY FAMILY HOUSING**

**BY**

**ROBERT N. MORRISON**

*NC0123-87-6-0549*

This document has been approved  
for public release and sale; its  
distribution is unlimited.

Accession For	
NTIS CRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By <i>form 50</i>	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
<i>A-1</i>	

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE  
DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

**UNIVERSITY OF FLORIDA**

**DTIC QUALITY INSPECTED 1**

**SUMMER 1994**

## TABLE OF CONTENTS

### LIST OF TABLES

### LIST OF FIGURES

INTRODUCTION .....	1
--------------------	---

DEFINITION OF RADON PROBLEM .....	3
-----------------------------------	---

Properties of Radon .....	3
Units of Measure .....	6
Indoor Radon .....	7
How Radon Enters .....	9
Soil Gas .....	9
Potable Water .....	12
Building Materials .....	13

RADON DETECTION METHODS .....	14
-------------------------------	----

General Issues in Radon Detection .....	14
Passive Devices .....	15
Charcoal Canister Detectors .....	16
Alpha Track Detectors .....	16
Charcoal Liquid Scintillation Detectors .....	17
Electret Ion Chamber Detectors .....	18
Active Devices .....	18
Continuous Radon Monitors .....	18
Continuous Working Level Monitors .....	19
EPA's Testing Checklist .....	20

RADON MITIGATION METHODS .....	21
--------------------------------	----

General Issues in Radon Reduction .....	21
Natural and Forced Air Ventilation .....	24
Forced Air Ventilation with Heat Recovery .....	26
Active Avoidance of Dwelling Depressurization .....	26
Sealing Radon Sources .....	27
Major Sources .....	28
Minor Sources .....	29
Drain Tile Soil Ventilation .....	30
Active Ventilation of Hollow-Block Basement Walls ..	33
Sub-Slab Depressurization System .....	36

RADON LEVELS IN NAVY FAMILY HOUSING UNITS .....	40
SAMPLE RADON MATION PROJECT DOCUMENTATION .....	43
CONCLUSION .....	48
APPENDIX A LISTING OF EXCESSIVE RADON LEVELS IN NAVY FAMILY HOUSING UNITS WORLDWIDE .....	49
REFERENCES .....	77

# LIST OF TABLES

Table 1	EPA Recommendations for Remedial Action .....	8
Table 2	Radium Content of Some Common Rocks and Building .. Materials .....	13

## LIST OF FIGURES

Figure 1	Radium-226 Decay Scheme .....	4
Figure 2	Major Radon Entry Routes .....	10
Figure 3	Effect of Ventilation on Indoor Radon Concentrations .....	23
Figure 4	Drain Tile Ventilation where Tile Drains to Sump .....	32
Figure 5	Drain Tile Ventilation Where Tile Drains to a Soakaway .....	34
Figure 6	Wall Ventilation with Individual Suction Points in each Wall .....	37
Figure 7	Wall Ventilation with Baseboard Duct .....	39
Figure 8	Sub-Slab Ventilation using Individual Suction ... Point Approach .....	41
Figure 9	Sample Radon Mitigation Project Documentation, DD Form 1391 .....	45
Figure 10	Sample Radon Mitigation Project Documentation, DD Form 1391c .....	46
Figure 11	Sample Radon Mitigation Project Documentation, .. NAVFAC Form 11013/7 .....	47

## INTRODUCTION

Radon is a radioactive gas, first discovered in the early 1900's, It is now widely recognized that indoor radon is the largest single source of exposure to ionizing radiation in the environment. The potential health risks associated with indoor radon concentrations in Navy Family Housing has become a growing concern for those individuals tasked with providing Navy Families a healthy, safe, and comfortable place to live.

All housing units will contain a certain amount of radon, the concentration of that radon depends upon many factors. A housing unit may act as accumulator by trapping and in some cases actually drawing radon gas from surrounding soils, while another housing unit may act as a barrier to all but the lowest background level of radon.

The vast inventory of Navy Family Housing, includes units of every shape and style located in every continent of the globe. This requires that the local Housing Facility Engineer become familiar with the radon concentration levels within the local inventory, and if necessary act upon reducing those levels.

Naval Facilities Engineering Command conducted an initial radon detection program which identified over 10,966 units that were over the Environmental Protection Agencies

"Action Level" of 4 pCi/L. This initial program provided only a sampling of the units in each area. The need for additional testing in these problem areas is recommended.

This report is provided as a guide to assist the Housing Facilities Engineer in understanding the radon problem, detection methods, and current mitigation methods.



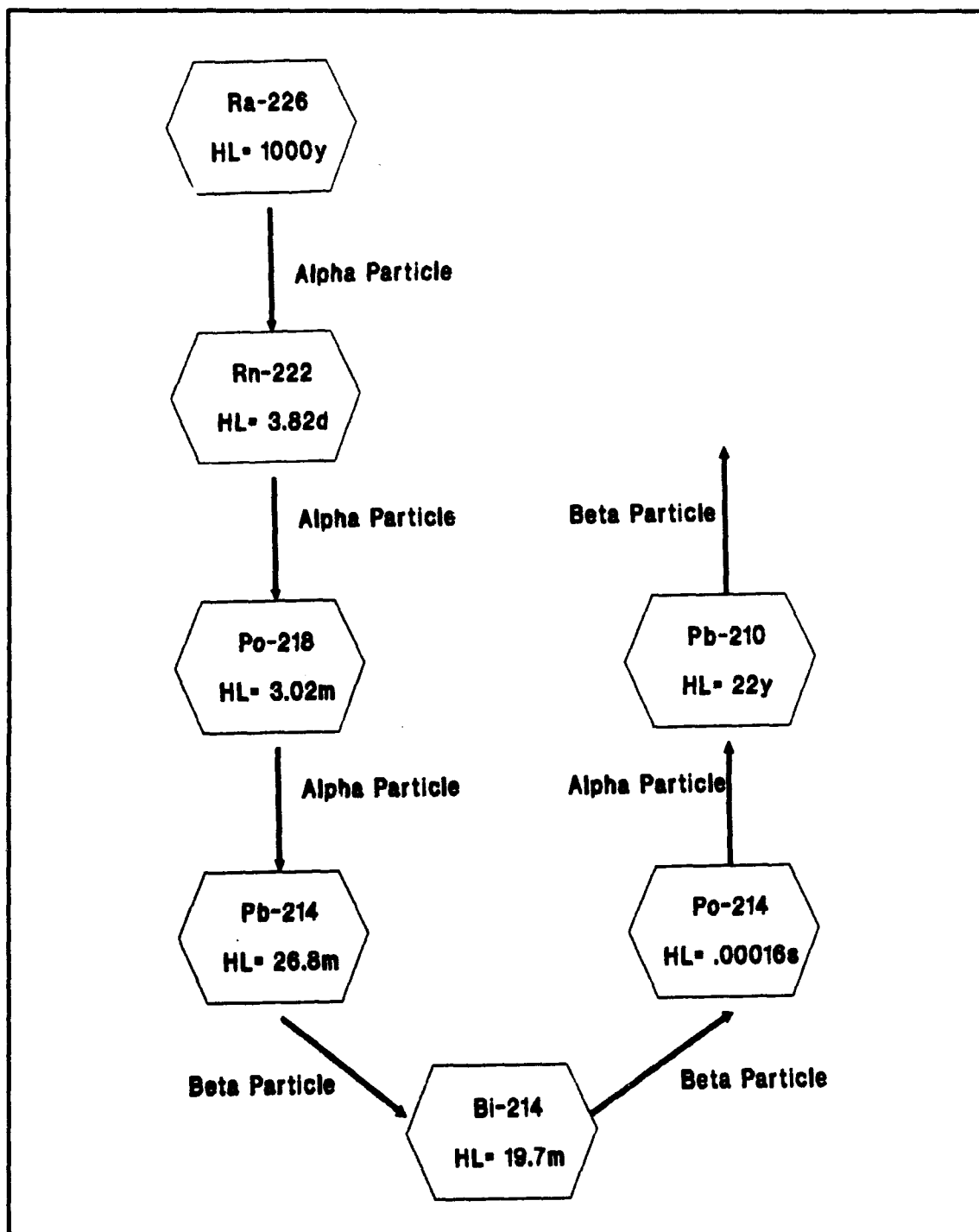
## DEFINITION OF RADON

### Properties of Radon

Radon is a radioactive gas, first discovered in the early 1900s. The most abundant of the several isotopes of radon is radon-222. Radon-222 is the direct product of the decay of the most prominent radium isotope, radium-226, which in turn is a product, several steps removed, of the decay of the most abundant uranium isotope, uranium-238 [Bodansky Et al. 1987, p.6] Other isotopes of radon exist, however because the half-lives of these isotopes are much shorter than that of radon-222 they are usually neglected.

Chemically, radon is a noble gas much like helium, argon, neon, krypton and xenon. These gases do not readily interact chemically with other elements under normal conditions. Like any other noble gas, radon is colorless, odorless and tasteless [Bodansky Et al. 1987, p.6] However, unlike the other noble gases, radon is radioactive with a half-life of 3.8 days and will further decay into radon progeny, which are themselves radioactive element with half-lives ranging from a fraction of a second to 22 years [Cole 1993, p.8] (see Figure 1).

The real problem is not the radon itself, radon gas flows quickly in and out of the lungs almost never lingering long enough to cause damage, but with the radon



**Figure 1 Radium-226 Decay Scheme (Source: NCRP No.78, p.8)**

progeny. These progeny, being solids, tend to lodge in the bronchial tree. Here they emit alpha particles, beta particles, and short wavelength gamma rays. Of the three kinds of emission, alpha particles are the most harmful; because of their greater electrical charge and relatively large mass, they can cause considerable damage to tissue [Cole 1993, p.9]. These progeny also are the key to the detection of radon.

Radon as a byproduct of the decomposition of uranium can be found everywhere. This is because uranium is found, in large concentrations, in granite, shale, and phosphate bearing formations and in smaller concentrations dispersed throughout the earth's crust [Cole 1993, p.8]. Since it is a gas, radon filters through cracks in the bedrock and soil before it eventually escapes into the atmosphere.

At the earth's surface atmosphere, the risk from radon or radon progeny is very slight. If, however, one builds a home or other dwelling, then the release of the radon to the atmosphere is blocked, and the radon accumulates in the dwelling [Brookins 1990, p.3]. Even in well ventilated dwellings, radon levels will be higher than in the open atmosphere. As we design dwellings for energy conservation, radon may accumulate to levels that constitute a health risk.

### Units of Measure

The Curie (Ci) is the traditional measure of radioactivity, equals 37 billion disintegrations per second of radioactive material. The Picocurie (pCi), one trillionths of one Curie, is more convenient for dealing with the amount of radioactivity given off by radon. Another unit being used in more recent references is the Becquerel (Bq), the standard international (SI) unit of activity. A Becquerel is defined as one disintegration per second of radioactive material.

Concentrations of radon are generally expressed in either Picocuries per gram (pCi/g), or Picocuries per liter (pCi/L).

A much older unit, the Working Level (WL) is a measure of the concentration of radon progeny. The unit was once used to represent the maximum concentration of radon progeny that uranium miners could safely be exposed. Today, the Working Level is sometimes used to express radon progeny levels in dwellings.

### Indoor Radon

As stated previously, the risk from radon and radon progeny at the earth's atmosphere is very slight. Radon concentrations decrease with an increase in altitude. As noted in several studies, radon concentration dropped by about a factor of two in the first meter, by another factor of two in 100 meters, and again by a factor of two in the next kilometer [Bodansky Et al. 1987, p.45].

However, in a closed atmosphere, such as a dwelling, radon and radon progeny levels may accumulate to levels that constitute a health risk. The Environmental Protection Agency has estimated lung cancer deaths per 100 people associated with the following indoor radon levels: 4 pCi/L, between 1 and 5 deaths; 20 pCi/L, between 6 and 21 deaths; and 200 pCi/L, between 44 and 77 deaths assuming 70 years in the dwelling with 70 to 80 percent of time indoors [Brookins 1990, p.17]. Based upon these levels the Environmental Protection Agency has provided recommendations for remedial action (see Table 1).

Table 1 EPA Recommendations for Remedial Action

---

Results higher than 200 pCi/L: "Exposures in this range are amount the highest observed in homes. Residents should undertake action to reduce levels as far below 200 pCi/L as possible. We recommend that you take action within several weeks. If this is not possible, you should determine, in consultation with appropriate state or local health or radiation officials, if temporary relocation is appropriate until the levels can be reduced."

Results from 20 to 200 pCi/L: "Exposures in this range are considered above average for residential structures. You should undertake action to reduce levels as far below 20 pCi/L as possible. We recommend that you take action within several months"

Results from 4 to 20 pCi/L: "Exposures in this range are considered above average for residential structures. You should undertake action to lower levels to about 4 pCi/L or below. We recommend that you take action within a few years, sooner if levels are at the upper end of this range."

Results about 4 pCi/L: "Exposures in this range are considered average or slightly above average for residential structures. Although exposures in this range do present some risk of lung cancer, reduction of levels this low may be difficult, and sometimes impossible, to achieve."

---

(Source: Brookins 1990, p.18)

### How Radon Enters

Radon gas can enter a dwelling by three principal routes: 1. soil gas, 2. potable water, and 3. building materials (see Figure 2) [EPA 1986, p.4].

#### Soil Gas

The rocks and soil over which dwellings are built are the primary source of most radon detected in homes [Brookins 1990, p.85]. Radon can enter the inner atmosphere through cracks, joints, and around sump pumps and plumbing penetrations. Since uranium and radium are found in wide distribution, the composition of the soil and rock will have to a large extent an impact on how much radon is present in the dwelling. The estimated radium content of the soil in the United States is approximately 1 pCi/g. Even though this may seem low, this amount of radium can produce from 200 to 1000 pCi/L of radon in a broad range of soil conditions [EPA 1987, p.10].

One of the most important physical characteristics of soil as it relates to indoor radon is its permeability. The permeability of soils can vary a great deal, permeability values course gravels down to homogeneous clays can span more than 10 orders of magnitude [Nazaroff Et al. 1988, p.61].

**Key to Major Radon Entry Routes**

**Soil Gas**

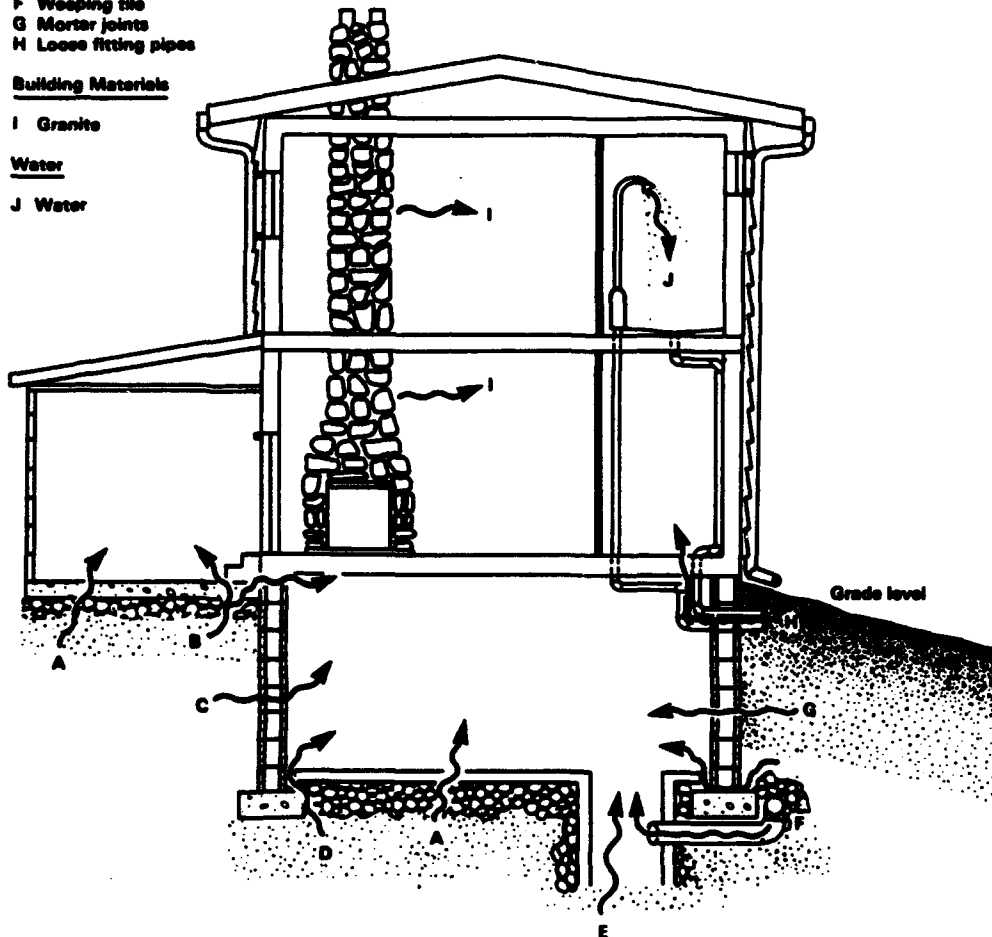
- A Cracks in concrete slab
- B Cracks between poured concrete (slab) and blocks
- C Pores and cracks in concrete blocks
- D Slab-footing joints
- E Exposed soil, as in sump
- F Weeping tile
- G Mortar joints
- H Loose fitting pipes

**Building Materials**

- I Granite

**Water**

- J Water



**Figure 2 Major Radon Entry Routes (Source: EPA 1986, p.4)**



p.8)Two important processes for permeability are diffusion and convective flow. Studies have shown that of the two processes, convective flow is the processes that accounts for most of the elevated levels of indoor radon in american housing.

Diffusion is the process by which a particular species moves along a constant pressure gradient. The movement is caused by the thermal action of individual molecules.

Convective flow means that a circulating system, such as a pressure differential, of fluid causes matter to migrate [Brookins 1990, p.88]. Because it uses a pressure differential for movement, convective flow is also known as pressure-driven flow. Where the pressure inside the dwelling is lower than that outside, radon gas can be drawn into the dwelling by pressure-driven flow.

These pressure differences need not be large. Pressure differences of only a few Pascal arise from winds and indoor-outdoor temperature differences are enough to drive small flows of gas that can significantly elevate radon levels in dwellings [Nazaroff Et al. 1988, p.20]. Other changes in indoor pressure can result from the use of items such as bathroom and kitchen exhaust fans, clothes dryer exhausts and even heating and air-conditioning systems. Even decreases in barometric pressure can result in elevated radon levels.

During the winter heating season pressure-driven flow can be increased by the "stack effect". The stack effect works much the same as a chimney, but instead of smoke, warm air rises in the house and will eventually flow out the attic through loose fitting windows, and any other openings it may find. This rising air tends to draw radon into the inner atmosphere through cracks, joints, and around the sump pumps and plumbing penetrations. Eliminating the effects of pressure-driven flow will become the main strategy of the radon mitigation process.

#### Potable water

The second most important route of entry for radon is the potable water service. Potable water service in the United States comes from surface sources (49.5 percent), public groundwater supplies (33.2 percent), and private wells (18.3 percent). Surface water have average radon concentrations of only 0.0005 pCi/L, groundwaters 0.009 pCi/L, and well waters 0.06 pCi/L [Brookins 1990, p.96]. While these average concentrations do not appear to be much of a problem, individual concentrations of up to 300,000 pCi/L have been found in some private wells. Radon is released by water on an average of about 0.1 pCi/L of radon in the air for every 1000 pCi/L of radon in water [Bodansky Et al. 1987, p.54].

Radon is soluble in water and can be easily released

when the water is heated. Typical avenues of entry for radon by potable water are dishwasher (95 percent), shower (66 percent), bath (42 percent), toilet (30 percent), laundry (92 percent), drinking and cleaning (34 percent) [Brookins 1990, p.96]. This shows clearly that any remediation program for potable water should concentrate around the water heating system.

### **Building Materials**

The third most important route of entry for radon are building materials used in the construction of the dwelling. Although not nearly as important a source as soil gas and potable water, certain building materials that are derived from minerals in the earth's crust may contribute to elevated radon levels (see Table 2). The amount of radon released by these building materials into the dwelling is relatively small. Approximate values include: concrete at 0.5 pCi/L, brick at 0.14 pCi/L, and by-product gypsum at 0.28 pCi/L [Brookins 1990, p.104].

**Table 2 Radium Content of Some Common Rocks & Building Materials**

Material	Radium Concentration (pCi/Kg)
Concrete	270 - 2,160
Brick	540 - 5,405
Granite	2,700 - 5,405
Gypsum Wall Board	13,510 - 54,050

---

(Source: Brookins 1990, p.103)

## **RADON DETECTION METHODS**

### **General Issues in Radon Detection**

The concentration of radon and radon progeny within a dwellings atmosphere vary with time, on both a daily cycle and an annual cycle. These fluxations are dependent upon atmospheric changes, seasonal changes and the usage of the dwelling by the occupants [Bodansky Et al. 1987, p.31]. A decision must be made whether to use a short-term or long-term testing period, based on the type of information desired and the time available.

Short-term testing provides the quickest way to determine radon levels. However, because radon levels vary on a daily and seasonal basis, the short-term testing period will not give an accurate assessment of the dwellings year-round average radon level. Short-term testing is useful however, in determining whether a significant radon problem exists and if long-term testing is indicated [EPA 1993, p.13]. Both passive and active detecting devices may be used to carry out a short-term test.

Long-term testing is useful in determining the dwellings year-round average radon level. The long-term test is

most useful in confirming initial short-term test results. Long-term tests are conducted for periods longer than 90 days [EPA 1993, p.13]. Because of the length of time involved with long-term testing, generally only passive detecting devices are used.

Radon testing should be conducted under closed-house conditions. This is especially true for short-term testing. When conducting a short-term test, windows and outside doors should be closed at least 12 hours prior to the start of the test. Normal use of door is permitted for entering and exiting, however. Long-term testing should be conducted during seasons when the dwelling is normally more sealed, such as winter months in the north and late summer months in the south [Brookins 1990, p. 111].

Radon detecting devices should be located in the lowest level of the dwelling suitable for occupancy. Devices should be placed 20 inches above the floor and in a location away from drafts, high heat, high humidity and exterior walls [EPA 1993, p.12, 15].

#### Passive Devices

Passive radon detecting devices do not require power to function. This makes passive detection devices inexpensive and ideal for both short-term and long-term testing ap-

plications. These devices normally include: charcoal canister detectors, alpha track detectors, charcoal liquid scintillation detectors and electret ion chamber detectors.

#### Charcoal Canister Detectors

Charcoal canister detectors consist of tightly sealed canisters of activated charcoal that will allow air to filter into them when unsealed. Radon is absorbed by the activated charcoal, this absorbed radon decays and deposits its progeny in the charcoal. Once the detector is resealed, it is sent to a laboratory where radon concentration is measured by counting the gamma emissions of the short lived radon progeny [Lao 1990, p.79].

The detector is useful in measuring indoor radon concentrations over a period of 2 to 7 days. Because the half-life of radon-222 is 3.8 days, it is essential to return the detector to the laboratory as soon as the testing is completed.

#### Alpha Track Detectors

Alpha track detectors utilize the fact that heavy atomic particles, such as alpha particles, leave a microscopic track of damage when passing through certain types of plastic emulsions. The tracks are en-

larged by developing them with a chemical etching solution and counted with a microscope. Radon concentration is proportional to the number of tracks per unit area.

An alpha track detector consists of a small piece of plastic emulsion enclosed in a container with a filter-covered opening. The filter allows radon to enter the container, but excludes radon progeny in the air. This allows only the radon within the container to decay into progeny [Lao 1990, p.78].

Alpha track detectors are long-term testing devices. They are most effective for testing periods of more than 3 months, and may be used for periods of up to a year.

#### Charcoal Liquid Scintillation Detectors

Charcoal liquid scintillation detectors are identical to charcoal canister detectors at the test site. The difference however is in the way radon concentrations are measured. Measuring the concentration of radon and radon progeny is accomplished by dissolving the charcoal in liquid scintillation fluid. This is followed by counting of the fluid in a liquid scintillation detector or by de-emanation of radon from the charcoal into a scintillation cell for alpha particle counting [Cothorn Et al. 1987, p.69].

### Electret Ion Chamber Detectors

The electret ion chamber detector is a fairly recent testing device. This device utilizes a electrostatically charged plastic disc, known as an electret, mounted in a canister isolated from particulates by a filter. Radon passes through the filter and induces a negative charge in the air near the positively charged electret. The negative ions in the air are attracted to the electret surface and a voltage is imparted. The voltage change is measured and is proportional to radon concentrations [Brookins 1990, p.116].

### Active Devices

Active radon detecting devices require power to function. They can be expensive and require operation by trained testers. They do provide continuous measuring and recording of radon or radon progeny in the air of the dwelling. Active devices normally include continuous radon monitors and continuous working level monitors.

### Continuous Radon Monitors

Continuous radon monitors test for radon by continuously pumping air into a scintillation cell. As with most



methods of testing, a filter is used to remove radioactive particulates and dust from the air. As the radon in the sample decays, alpha particle radon progeny strike the surface of the scintillation cell giving off a small burst of light. These bursts of light are recorded by a photomultiplier tube, and ultimately counted.

Continuous radon monitors are available as flow-through test units or periodic-fill test units. In flow-through units, air flows continuously through the scintillation cell and the counting is performed concurrently. Periodic-fill test units sample the air at preselected time intervals to perform counting [Lao 1990, p.82].

Continuous radon monitors are ideally suited for relatively short measurement periods, 6 hours for screening and 24 hours for follow-up measurements, but are highly expensive.

#### Continuous Working Level Monitors

Continuous working level monitors measure the radon progeny concentrations of the air. Continuous working level monitors dwelling air by drawing air through a filter cartridge at a low flow rate. The filter collects airborne particles and allows an alpha detector to count the alpha particles emitted by radon progeny. The detector is normally set to detect alpha energies between 2 to 8 MeV, corre-

sponding to alpha particles emitted by polonium-218 and polonium-214 [Lao 1990, p.83].

Continuous working level monitors are ideally suited for relatively short measurement periods, 6 hours for screening and 24 hours for follow-up measurements, but are highly expensive.

#### EPA's Testing Checklist

Radon testing is not a difficult process, however attention to detail is required to ensure that it is performed properly. To ensure the accuracy of test results the Environmental Protection Agency provides a checklist for testing agencies to follow. This checklist explains the conduct of all parties required before, during, and after the testing period. Copies of the checklist are available through the EPA. Testing consultants should be able to confirm that all the items in the checklist have been followed [EPA 1993, p.16].

## RADON MITIGATION METHODS

### General Issues in Radon Reduction

With reference to Figure 2, the principal methods of preventing radon entry into a dwelling are:

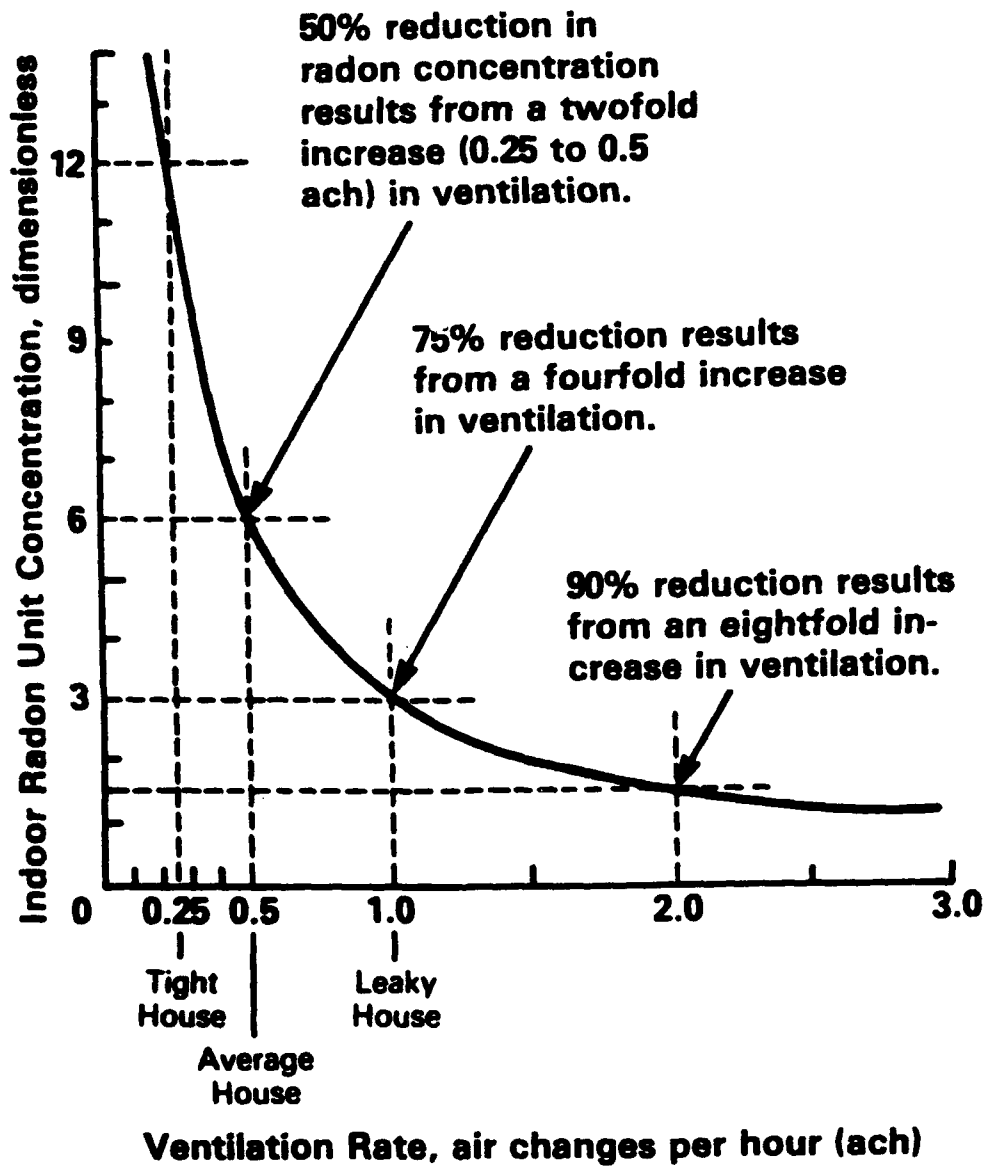
1. Sealing and closing of all pores, voids, utility penetrations, construction joints, and exposed earth that permit soil-gas to enter a dwelling.
2. Reversing the direction of soil-gas flow so that air movement is from the dwelling to the soil and outside air.
3. Avoiding the use of potable water supplies, principally individual wells, that are contaminated with radon or removing radon prior to use.
4. Avoiding the use of building materials that may contain radium and release radon.

Currently, the only effective method for removing radon after it has entered a dwelling is by ventilating the affected living space. Ventilation entails bringing outside air into the dwellings living areas, basement, or crawl space to displace and replace an equal volume of indoor air and to mix with undisplaced indoor air. The effect

of increasing ventilation rates for dwellings over a typical range of 0.2 to 2.0 air changes per hour (ach) is shown in Figure 3. This figure which shows four important characteristics associated with the use of ventilation for radon removal are discussed below [EPA 1986, pp.5-6]:

1. The use of ventilation for reducing indoor radon levels decreases with increased ventilation rates. Or said another way, ventilation is better suited and more cost effective for tight dwellings.
2. Increasing ventilation rates from 0.25 to 2.0 air changes per hour can reduce indoor radon levels by approximately 90 percent.
3. Ventilation, although helpful, can not reduce indoor radon levels below a finite level determined by radon source strength and entry rates.
4. While in theory ventilation can be utilized to effectively and efficiently reduce indoor radon concentrations, practical field experience has shown that it is difficult to operate ventilation systems so as not to induce pressure-driven flow.

There are a number of methods that can effectively reduce radon concentrations in dwellings. These methods either utilize dwelling ventilation/air exchange or control of radon at its source. It should be noted that while any one of these methods may be sufficient to lower radon concentrations in a given dwelling, higher concentration levels may be



**Figure 3** Effect of Ventilation on Indoor Radon Concentrations (Source: EPA 1986, p.5)

more economically dealt with by using a combination of several methods [EPA 1986, p.6].

### Natural and Forced Air Ventilation

Natural Ventilation is the exchange of indoor air for outdoor air that occurs due to natural forces. The major forces driving natural ventilation are wind, pressure, and temperature differences between the indoor and outdoor atmospheres. Natural ventilation in a dwelling takes place through all passageways that allow free communication of with the outside air. Typical examples, normally associated with weatherstripping, include: openings around windows and doors, switch and receptacle plates, and open joints in building materials.

Forced air or mechanical ventilation relies on the use of fans to induce an increase in dwelling air exchange rates by: 1. blowing in fresh outside air or 2. exhausting indoor air with the assurance that it will be replaced with cleaner outside air.

In most American dwellings under normal use, the average air exchange rate is approximately 1.0 air change per hour (ach). Newer dwellings, built to be more energy efficient, have air exchange rates as low as 0.1 ach, and older

dwellings may have air exchange rates as high as 2.0 ach [EPA 1986, p.10]. Again, dwellings with high air exchange rates are not suitable for the ventilation method of radon mitigation.

Both the natural and forced ventilation method reduce indoor radon concentrations by both the removal of radon-laden air and the dilution of the total indoor air volume with clean outdoor air.

The main drawback of natural and forced ventilation methods is the energy penalty imposed by the need to maintain human comfort conditions at potentially high ventilation rates. This drawback may be offset by closing off and limiting of these ventilation methods to areas such as basements. Natural ventilation of a basement can be accomplished if window around the perimeter are opened to allow cross ventilation. Forced ventilation can accomplish the same result by strategically locating two or three fans to provide for the cross ventilation.

Negligible installation costs are incurred with the natural ventilation method, while the forced ventilation method requires purchase of fans at a minimum. More sophisticated forced ventilation systems require new wiring, duct work, dampers, filters and smoke detectors. Operating costs, due to extra heat/cooling, can be expected if these methods are used during heating and cooling seasons.

### Forced Air Ventilation with Heat Recovery

Forced air ventilation with heat recovery is a technique that brings outside air into a dwelling, exhausting radon-laden air, and transferring and recovering heat energy from the exhaust air to the cleaner incoming air by means of a heat exchanger. This technique is similar to, but much superior than, the standard forced ventilation method. By transferring heat in the exhaust air to the incoming air ventilation as a radon mitigation method can be extended to a wider range of climatic conditions.

This application has the greatest potential in low-ventilation rate dwelling in cold climates. These conditions maximize the effectiveness of the ventilation and heat exchanger system [EPA 1986, p.11].

Installation costs will vary with the size and complexity of the system to be installed. A slight increase in operating cost will be seen, however, heat recovery rates of up to 70 percent are possible and should make this alternative more cost effective over extended periods.

### Active Avoidance of Dwelling Depressurization

The dwelling living space may be depressurized when



certain household appliances that use and exhaust inside air to the outside are used and when unbalanced natural or forced air ventilation is applied. Depressurization of a dwelling occurs naturally in the winter as a result of the "stack effect". The winter depressurization in the dwelling is believed to be the main cause of increased soil-gas radon entry [EPA 1986, p.12].

Reducing depressurization associated with household appliances is fairly straightforward. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has recommended the provision of outside makeup air for combustion appliances, such as furnaces, waterheaters, and clothes dryers since 1981 [EPA 1986, p.12]. Outside air duct work consisting of small dampered vents and flexible hose is relatively inexpensive and easy to install. Most modern combustion appliances come equipped from the factory with makeup air connections.

Installation costs for these modifications are very minor. Operation of these appliances with outside makeup air may increase efficiency and therefore provide a cost savings.

#### Sealing Radon Sources

Soil gas has been determined to have the largest impact on dwelling radon concentrations, since uranium and ra-

dium are found in wide distribution, the composition of the soil and rock will have to a large extent an impact on how much radon is present in the dwelling. It is reasonable to assume that a great benefit would be derived from sealing off this source of radon from the interior of dwellings. This mitigation method is best categorized by the size of the source, therefore major and minor sources will be dealt with separately.

### Major Sources

The existence of exposed soil and rock under, around, or within a dwelling can be a major source of radon entry. These areas should be closed or sealed to prevent radon laden soil gas from entering the dwelling. Areas with exposed earth, such as soil floored basements and water drainage sump areas should be excavated and covered with a concrete cap, or at least covered with an impermeable membrane, and forced air exhausting of any below grade air space such as sump cavities [EPA 1986, p.13].

Generally speaking, capping and sealing major potential sources of radon laden soil gas entry has a significant reduction benefit. It is cautioned however that the durability of this method is limited to the quality of the installation and materials used. Even imperceptible movements of a dwelling's understructure may create small imper-

fections that result in passageways for the entry of radon laden soil gas.

Sealing and exhausting the sump area can have a dual benefit. Although the immediate purpose is to exhaust the radon laden soil gas that enters the sump, Figure 4 show that suction produced by the exhaust fan may draw soil gas from the attached drain tile and diminish soil gas entry for some distance [EPA 1986, p.13].

Installation costs of sealing and capping will vary depending upon size and material used. Sump exhaust system installation costs also vary with the size and complexity of the system to be installed. However, annual operating costs of exhaust systems are quite reasonable.

#### Minor Sources

Entry of radon laden soil gas can be prevented by sealing cracks, openings, or other voids in the dwelling's envelope that may provide a passageway to the interior. These small passageways include: cracks, openings around utility services, and voids created by concrete form ties. This is often considered to be an initial radon reduction method, and is often utilized with other radon mitigation methods [EPA 1986, p.13].

Applicability of this method is generally limited by the knowledge of and access to all small soil gas entry routes. This is again complicated where the remodeling of

dwelling basements has occurred. The limited access is a major impediment to the sealing process. An occupant should not expect sealing of all noticeable cracks or openings to eliminate an indoor radon problem.

Installation costs can vary according to the size and condition of the area to be sealed. Additionally, if remodeling has occurred further expenses may be incurred for its removal and replacement.

#### Drain Tile Soil Ventilation

Dwellings utilizing surrounding perforated drain tiles next to the footings to drain moisture away from the foundation may also be used to draw radon laden soil gas away from the potential entry passageways through drain tile ventilation. Depending upon the permeability of the soil and of the aggregate beneath the slab, drain tile ventilation can also ventilate portions of the area underneath the slab and the soil well above the footing level [EPA 1986, p.15].

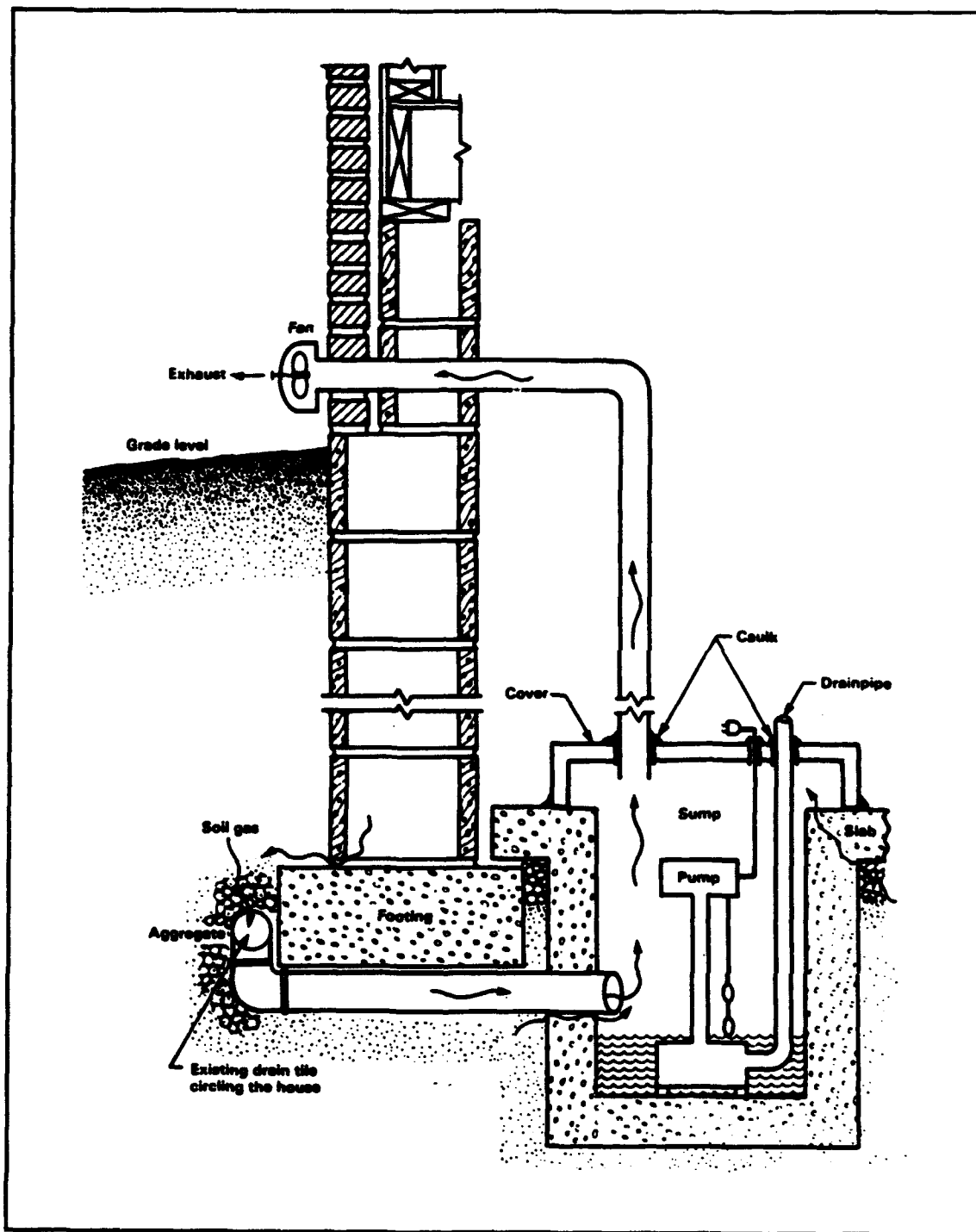
The advantage of drain tile ventilation is that it is the least expensive, for dwellings already having drain tiles, and least unobtrusive method of active soil ventilation. For dwellings without drain tiles other interior ventilation methods may prove to be more viable, unless concern for the appearance of a remodeled basement is a

concern.

Another concern is the condition and extent of the drain tile run. Drain tiles should encompass the entire perimeter of the dwellings footing and be free of blockages such as silt.

Two methods of drain tile ventilation exist. The sump ventilation method was illustrated in Figure 4. As discussed in the previous section, the sump ventilation methods immediate purpose is to exhaust the radon laden soil gas that enters the sump, however suction that is produced by the exhaust fan may draw soil gas from the attached drain tile and diminish soil gas entry for some distance. The other drain tile ventilation method, illustrated in Figure 5, is used where the tiles drain to an above ground soakaway. The ventilation system is connected to the existing line running to the soakaway and consists of: a trap, a set of risers, and a fan. The ventilation system can be install anywhere along the drain line as long as trap is sufficiently deep underground to keep the water from freezing [EPA 1986, p.17].

Due to the outside location of the ventilation system in the soakaway method, operating and maintenance requirements are greater than with the sump method. Regular inspections to ensure that the fan is operating properly, the trap is full of water, and that the exposed seals are in good condition should be conducted by the occupant of maintenance staff [EPA 1986, p.19].



**Figure 4** Drain Tile Ventilation Where Tile Drains to Sump  
(Source: EPA 1986, p.14)

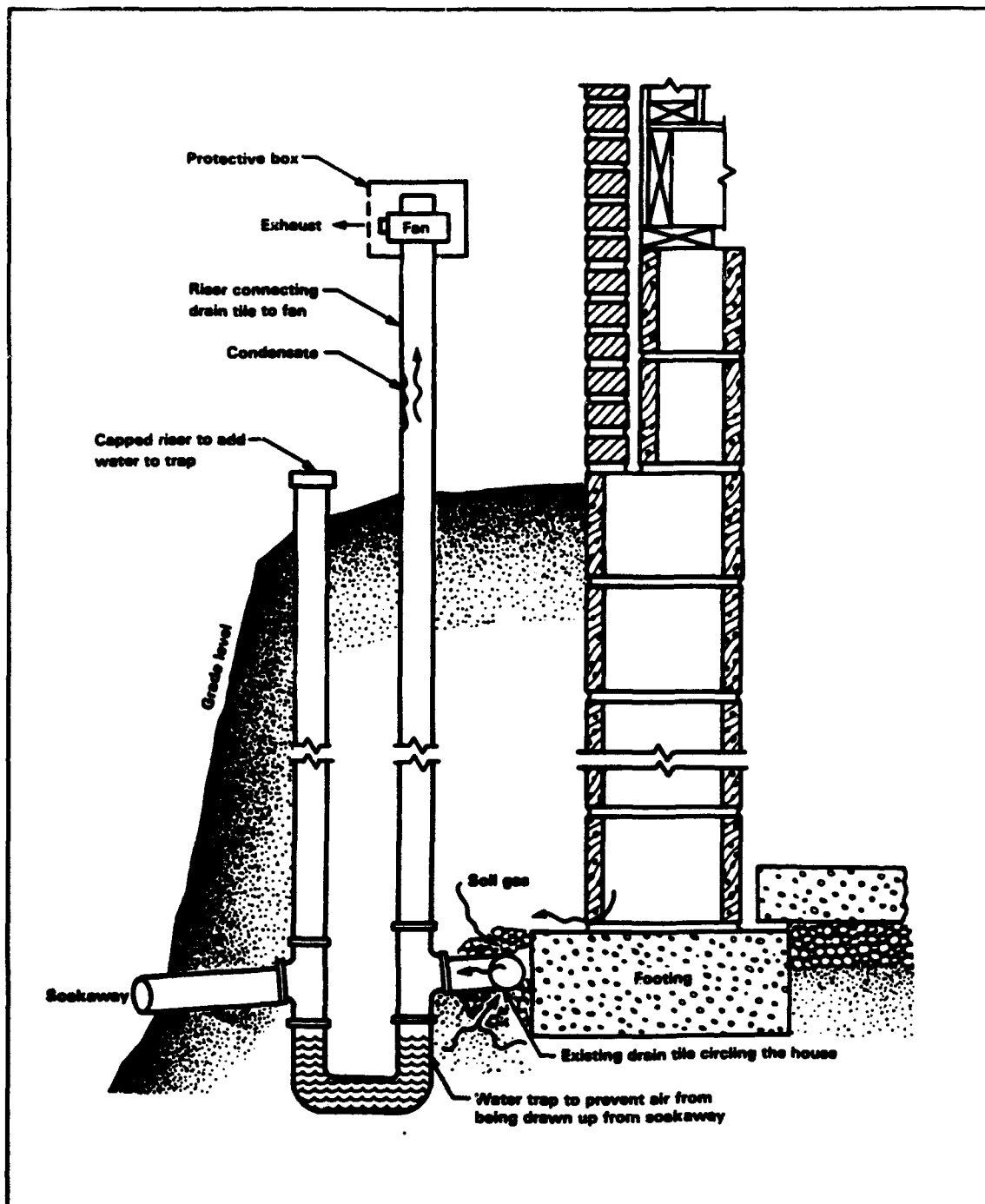
Installation cost will depend upon the choice of method for drain tile ventilation, and whether the installation is performed by contractors or occupants. Operating cost will include the electricity to run the fan, and perhaps a heating penalty due to the increased ventilation of the dwelling [EPA 1986, p.19].

#### Active Ventilation of Hollow-Block Basement Walls

Concrete Masonry Units (CMU) that are used to erect basement walls contain void spaces. These void spaces are generally interconnected both vertically and horizontally within a wall, thereby allowing soil gas that enters the wall through mortar joint cracks or pores to migrate throughout the wall, and ultimately enter the dwelling.

Active ventilation of hollow-block basement walls is used to sweep the soil gas from the voids by drawing a vacuum on the voids within a wall. By placing the voids at a lower pressure than the basement, soil gas is drawn through to outside face of the basement and vented to the outside atmosphere instead of into the basement [EPA 1986, p.19].

Two methods of active ventilation of hollow-block basement walls have been evaluated. The first method consists of inserting one or two pipes, connected to exhaust fans that draw the vacuum, into the void network of each basement wall



**Figure 5** Drain Tile Ventilation where Tile Drains to a Soakaway  
 (Source: EPA 1986, p.18)



(see Figure 6). The second method involves encircling the perimeter of the basement with a sheet metal baseboard duct, covering the joint between the wall and the slab. Holes are drilled into the block wall at intervals inside the baseboard duct, and the wall is ventilated by drawing a vacuum on the baseboard with exhaust fans (see Figure 7). The baseboard duct method is more effective at ventilating basement walls, but is more expensive than the individual pipe system. Additionally, the baseboard duct method to wall ventilation is especially useful in block basements having French drains around the inside perimeter of the basement wall for drainage. The baseboard duct covers the drain gap and not only draws soil gas from the block wall, but also the aggregate underneath the slab.

In order for either hollow-block ventilation method to be effective, the vacuum drawn on the wall void network requires that all major openings in the wall be closed. These major openings include: openings in the top layer of block, gaps between the concrete masonry units and the brick veneer, and utilities penetrations [EPA 1986, p.20].

Operation and maintenance of either wall system should include regular inspections by the occupant or maintenance staff to ensure that the fans are operating properly, and that all seals are in good condition.

Installation cost will depend upon the choice of

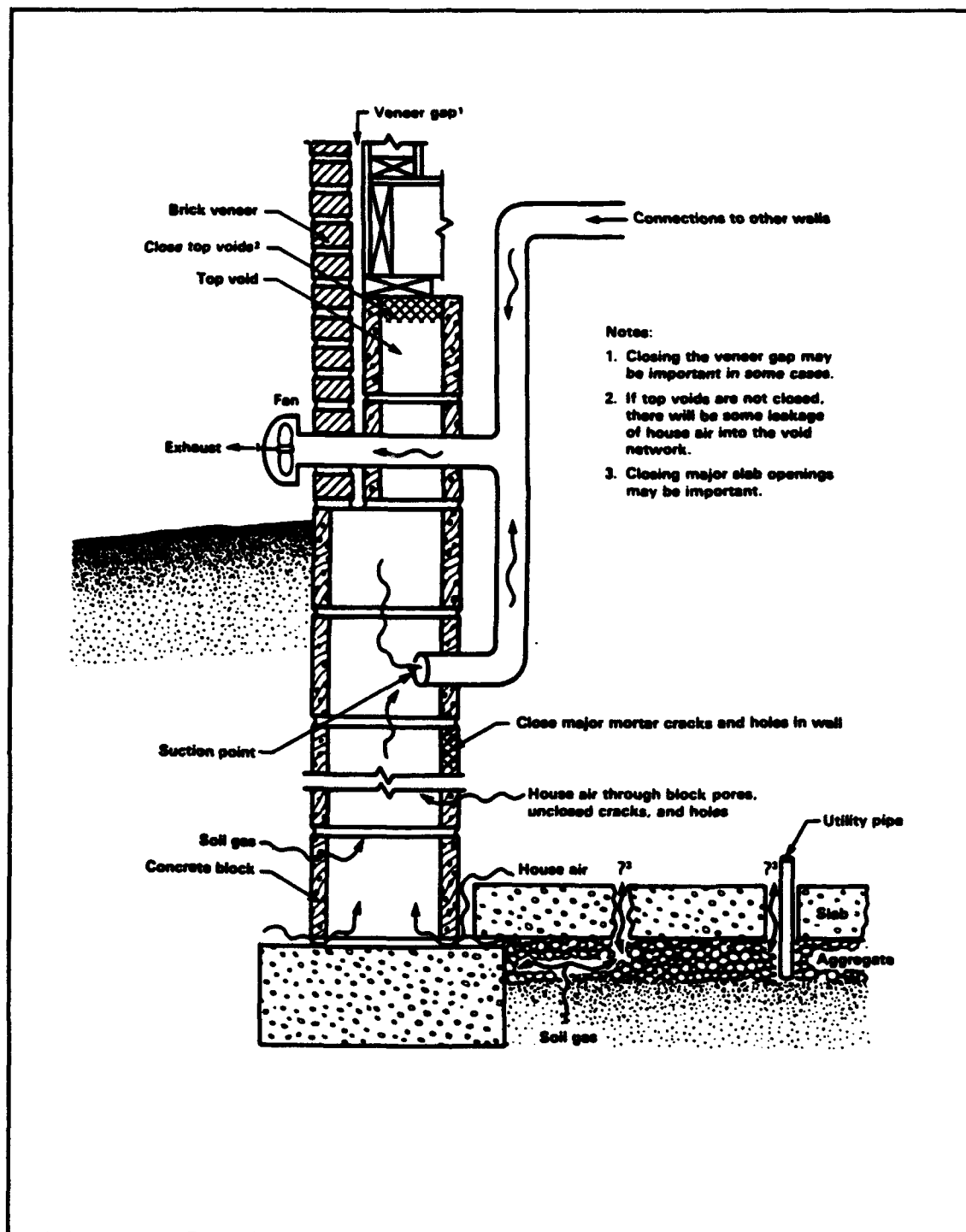
method for ventilation of hollow-block basement walls, and whether the installation is performed by contractors or occupants. As with any interior mitigation method, dealing with a remodeled basement will increase installation costs. Operating cost will include the electricity to run the fans, and perhaps a heating penalty due to the increased ventilation of the dwelling [EPA 1986, p.31].

#### Sub-Slab Depressurization System

Soil gas accumulates in the soil and aggregate that underlie concrete slabs in basements or on grade. This gas once accumulated can migrate into a dwelling through any openings such as: wall/floor joints, settling cracks, cold joints, or openings around utility penetrations.

Sub-slab depressurization uses a fan to create a vacuum within the soil and aggregate underlying the slab. By causing a vacuum within the soil and aggregate, any gas flow consists of cleaner indoor air flowing outward into the aggregate through the openings in the slab rather than soil gas flowing into the dwelling [EPA 1986, p.32].

Two methods of sub-slab depressurization have been evaluated. The first method consists of inserting two or

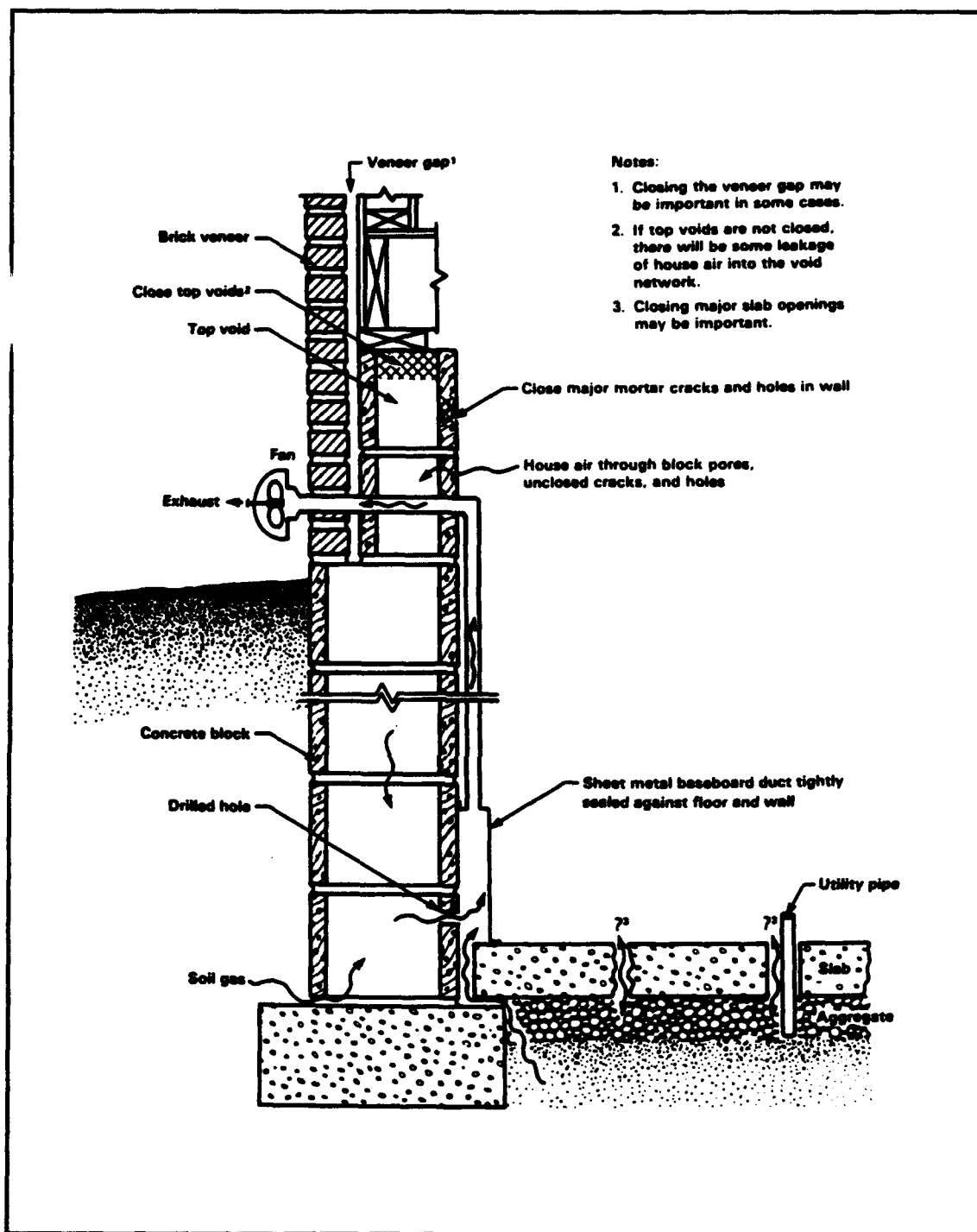


**Figure 6** Wall Ventilation with Individual Suction Points in each Wall (Source: EPA 1986, p.23)

more nonperforated pipes vertically down through the slab and into the aggregate and all ventilation is achieved by drawing a vacuum on these pipes with fans (see Figure 8). The second method, used more in Canada than the United States, consists of a network of horizontally laid perforated pipes underneath the slab. The network is connected to vertical risers which by means of fans produce a vacuum within the network. This second system is less dependant upon soil and aggregate permeability than the first.

Installation of a sub-soil depressurization system depends upon the dwelling situation. In new construction, use of the horizontally laid perforated pipe system should be considered for installation prior to slab placement. In some cases, newer dwellings have perforated pipe already installed beneath the slab for water drainage, this drainage network could be easily used as part of a sub-soil depressurization system. In retrofit applications, the vertical piping method seems to be the best alternative. Even in less permeable soil a small sump can be added to the system to create a void space for soil gas to accumulate. By careful placement of suction points, this type of system will ensure effective depressurization of the slab.

Operation and maintenance of either sub-soil depressurization system include regular inspections by the occupant or maintenance staff to ensure that the fans are operating prop



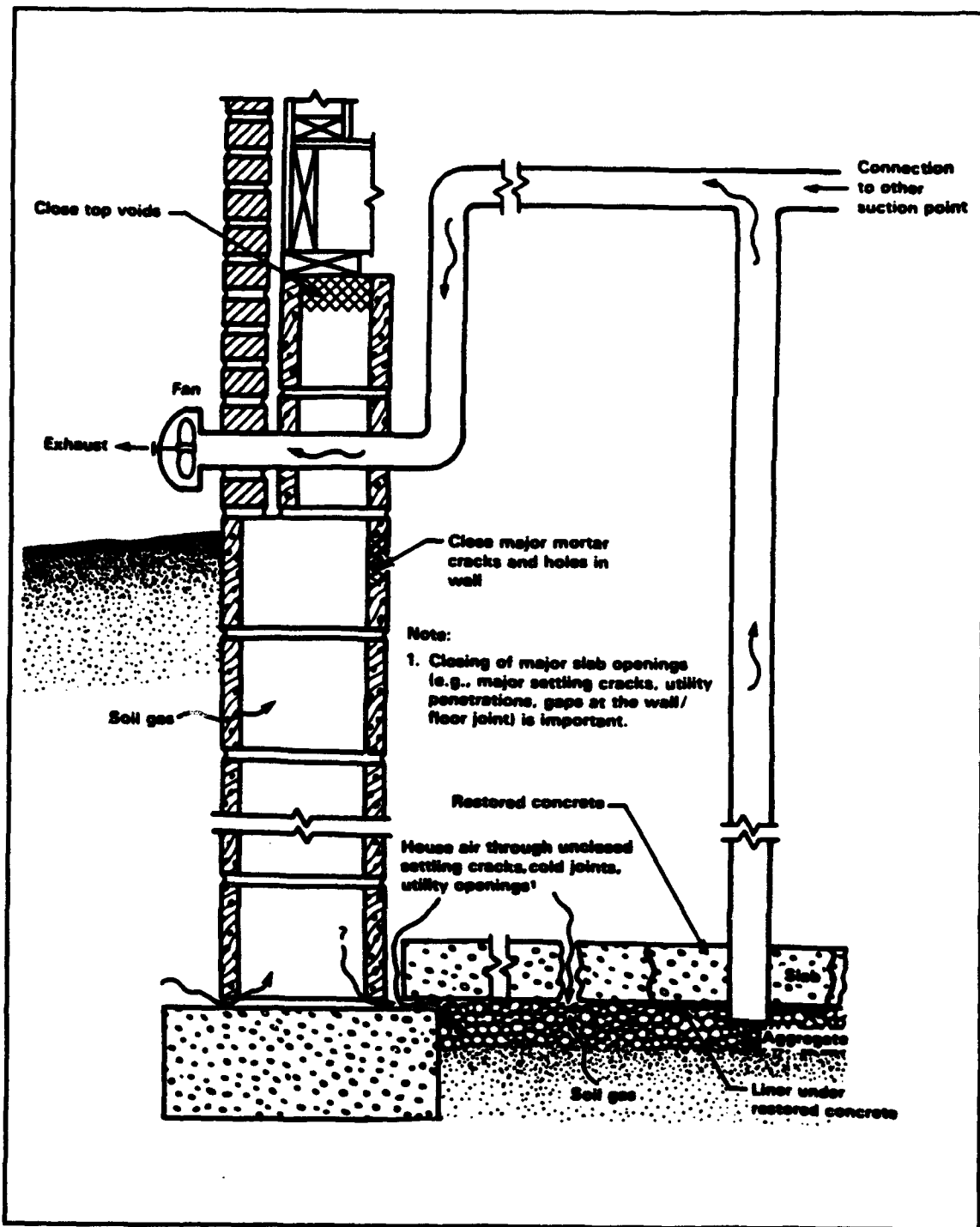
**Figure 7** Wall Ventilation with Baseboard Duct  
(Source: EPA 1986, p.29)

erly, that all seals are in good condition, and the new concrete remains intact.

Installation cost will depend upon the choice of method for sub-slab depressurization, and whether the installation is performed by contractors or occupants. Installation of a sub-slab depressurization system is not an easy do-it-yourself job, but some more knowledgeable occupant could save a considerable amount by performing the work themselves. As with any interior mitigation method, dealing with a remodeled basement will increase installation costs. Operating cost will include the electricity to run the fans, and perhaps a heating penalty due to the increased ventilation of the dwelling [EPA 1986, p.40].

#### **RADON LEVELS IN NAVY FAMILY HOUSING UNITS**

In 1989, the Naval Facilities Engineering Command undertook a study to determine radon concentrations in the worldwide inventory of Navy and Marine Corps Family Housing units. The study only included Family Housing because in 1989, Naval Facilities Engineering Command was responsible only for the Navy Family Housing Program, however, later the Secretary of the Navy and the Chief of Naval Operations transferred the responsibility for Bachelor Officer and Enlisted Quarters to Naval Facilities Engineering Command in



**Figure 8** Sub-Slab Ventilation using Individual Suction Point Approach (Source: EPA 1986, p.34)

1993 from Naval Supply Systems Command. Naval Facilities Engineering Command undertook a similar study for these bachelor quarters, and will be integrating the data in the near future.

The study was contracted out and was to be conducted during the winter heating season of 1989, however, due to scheduling problems, the contractor was unable to deliver detection devices to all Family Housing Areas in time for installation. Overseas areas received their detectors several months after the heating season began. On a complaint from this author, and several other Facilities Engineers, the program was extended to ensure accurate measurements were obtained for all units.

The study used passive charcoal canister and alpha track detectors to determine the minimum, maximum, and average radon concentrations in each type and location of Navy Family Housing. After training from Facilities Engineers, Housing Inspectors installed and recorded all pertinent information on the detector data sheets. As the study continued the contractor would recall certain detectors for testing. The inspectors would retrieve those detectors and complete the detector data sheets. These detectors would then be shipped back to the contractor for testing. This process continued until all detectors had been recalled.

Appendix A is a listing of all Navy Family Housing Units



worldwide, by type and location, in which excessive concentrations of radon have been detected. Over 10,966 units have been identified with maximum radon levels in excess of the 4 pCi/L "Action Level".

#### **SAMPLE RADON MITIGATION PROJECT DOCUMENTATION**

The Commander, Naval Facilities Engineering Command has established policies dictating that Field Activities are responsible for maintaining family housing facilities at a standard which provides adequate and habitable accommodations. The Field Activity Housing Manager, or Housing Facilities Engineer, is responsible for initiating necessary documentation and justification for all repair projects funded from the Family Housing Management Account, Defense [NAVFAC P-930 1983, p.20-2]. Repair projects are defined in the NAVFAC P-930 as:

"To restore a real property facility or system to such condition that it may be effectively used for its designated purpose and which does not increase the property account value. This includes the replacement of constituent parts or materials which have deteriorated by action of the elements or use and have not been corrected through maintenance."

Clearly radon mitigation programs fall within the scope of

this definition. Projects that safeguard the health of housing occupants are always considered repair projects. Recent examples include asbestos abatement projects and numerous structural projects.

The Environmental Protection Agency has established an "Action Level" for the mitigation process at 4 pCi/L [EPA 1993, p.11]. Thus any Navy Family Housing unit determined to have maximum or average radon concentrations of 4 pCi/L or higher should be programmed for radon mitigation repairs.

Funding for mitigation repairs must be requested utilizing: DD Form 1391 and DD Form 1391c, Military Construction Project Data Sheets (see Figures 9 and 10); and a NAVFAC 11013/7 Cost Estimating Form (see Figure 11). Sample project documentation was completed in accordance with NAVFAC P-930.

1. COMPONENT <b>NAVY</b>		FY 19-94 MILITARY CONSTRUCTION PROJECT DATA		2. DATE <b>15 JUL 1994</b>	
3. INSTALLATION AND LOCATION <b>Marine Corps Finance Center Kansas City, MO</b>			4. PROJECT TITLE <b>Repairs to 256 Capehart Family Housing Units</b>		
5. PROGRAM ELEMENT <b>AC</b>	6. CATEGORY CODE	7. PROJECT NUMBER <b>HR-1-94</b>	8. PROJECT COST (\$000) <b>\$1,031.3</b>		
<b>9. COST ESTIMATES</b>					
ITEM		U/M	QUANTITY	UNIT COST	COST (\$000)
Block ventilation system		UN	256	2,803	717.6
Engineering Estimate					717.6
Contractor's OH&P					179.3
Subtotal					896.9
Contingency (5%)					44.8
Total Contract Cost					941.8
SIOH (3.5%)					32.9
Design (6%)					56.7
Total Requested (FY 94 Dollars)					1,031.3
10. DESCRIPTION OF PROPOSED CONSTRUCTION This project encompasses all radon mitigation repairs required to officers and enlisted Capehart housing units at Marine Corps Finance Center, Kansas City, MO. Seal all suspected cracks, replace vapor barrier, and install active ventilation of hollow-block wall devices.					
11. REQUIREMENTS					
<b>PROJECT:</b> Correct hazardous radon exposure situation.					
<b>REQUIREMENT:</b> High radon gas concentration levels were indicated during the recent NAVFAC radon survey. Concentrations are significantly above the EPA action level.					
<b>CURRENT SITUATION:</b> Further analysis has determined that radon gas is entering housing units via hollow-block foundation walls.					
<b>IMPACT IF NOT PROVIDED:</b> Health risks to family housing occupants is unacceptable. Radon is linked to high rates of lung cancer. This is a severe morale problem. If repairs are not completed, these housing units will be removed from our inventory.					

**DD FORM 1391**  
1 DEC 76

PREVIOUS EDITIONS MAY BE USED INTERNALLY  
UNTIL EXHAUSTED

PAGE NO.

**Figure 9 Sample Radon Mitigation Project Documentation, DD Form 1391**

1. COMPONENT <b>NAVY</b>		FY 1994 MILITARY CONSTRUCTION PROJECT DATA		2. DATE 15 JUL 94																																	
3. INSTALLATION AND LOCATION Marine Corps Finance Center, Kansas City, MO																																					
4. PROJECT TITLE Repairs to 256 units of Capehart Family Housing Units				5. PROJECT NUMBER HR-1-94																																	
1. <u>UNIT COMPOSITION AND BILLET DESIGNATION</u>																																					
a. <table border="1"> <thead> <tr> <th>Units</th> <th>(Bldgs)</th> <th>Bldg Type</th> <th>(Stories)</th> <th>BR</th> <th>Bath</th> <th>Rank</th> <th>Cat-Code</th> </tr> </thead> <tbody> <tr> <td>215</td> <td>(215)</td> <td>Single</td> <td>(1)</td> <td>3</td> <td>1.5</td> <td>ENL</td> <td>711-25</td> </tr> <tr> <td>34</td> <td>(34)</td> <td>Single</td> <td>(1)</td> <td>3</td> <td>1.5</td> <td>OFF</td> <td>711-26</td> </tr> <tr> <td>7</td> <td>(7)</td> <td>Single</td> <td>(2)</td> <td>4</td> <td>2</td> <td>OFF</td> <td>711-26</td> </tr> </tbody> </table>						Units	(Bldgs)	Bldg Type	(Stories)	BR	Bath	Rank	Cat-Code	215	(215)	Single	(1)	3	1.5	ENL	711-25	34	(34)	Single	(1)	3	1.5	OFF	711-26	7	(7)	Single	(2)	4	2	OFF	711-26
Units	(Bldgs)	Bldg Type	(Stories)	BR	Bath	Rank	Cat-Code																														
215	(215)	Single	(1)	3	1.5	ENL	711-25																														
34	(34)	Single	(1)	3	1.5	OFF	711-26																														
7	(7)	Single	(2)	4	2	OFF	711-26																														
b. <table border="1"> <thead> <tr> <th>Units</th> <th>YR Built</th> <th>Acquired</th> <th>Life</th> <th>Type</th> <th>Const</th> </tr> </thead> <tbody> <tr> <td>256</td> <td>1961</td> <td>FY 60 Capehart</td> <td>25</td> <td>Frame</td> <td></td> </tr> </tbody> </table>						Units	YR Built	Acquired	Life	Type	Const	256	1961	FY 60 Capehart	25	Frame																					
Units	YR Built	Acquired	Life	Type	Const																																
256	1961	FY 60 Capehart	25	Frame																																	
c. N/A																																					
2. <u>REPAIR AND IMPROVEMENT PROJECTS (Last 5 Years)</u>																																					
<table border="1"> <thead> <tr> <th>Project No.</th> <th>Description</th> <th>Completed</th> <th>Cost</th> </tr> </thead> <tbody> <tr> <td>HR-8-89</td> <td>Replace Kitchen Fl. 09.91</td> <td></td> <td>\$ 57,000</td> </tr> </tbody> </table>						Project No.	Description	Completed	Cost	HR-8-89	Replace Kitchen Fl. 09.91		\$ 57,000																								
Project No.	Description	Completed	Cost																																		
HR-8-89	Replace Kitchen Fl. 09.91		\$ 57,000																																		
3. <u>PROPOSED METHOD OF ACCOMPLISHMENT</u>																																					
a. Contractor.																																					
b. No increments.																																					
4. <u>PHOTOGRAPHS</u> N/A																																					
5. <u>DRAWINGS</u> N/A																																					
6. <u>OTHER</u> N/A																																					
7. <u>REMAINING REPAIR &amp; IMPROVEMENT WORK REQUIRED</u>																																					
<table border="1"> <thead> <tr> <th>Proj. Class</th> <th>Work Required</th> <th>Est. Cost</th> </tr> </thead> <tbody> <tr> <td>AC</td> <td>Replace roofing &amp; furnaces</td> <td>\$3,030.3K</td> </tr> </tbody> </table>						Proj. Class	Work Required	Est. Cost	AC	Replace roofing & furnaces	\$3,030.3K																										
Proj. Class	Work Required	Est. Cost																																			
AC	Replace roofing & furnaces	\$3,030.3K																																			

DD FORM 1391c  
1 DEC 76  
GPO 5002-17-001-2015

PREVIOUS EDITIONS MAY BE USED INTERNALLY  
UNTIL EXHAUSTED

PAGE NO.

Figure 10 Sample Radon Mitigation Project Documentation, DD. Form 1391c

NAVFAC FORM 11013/7 (1-90) Supersedes NAVFACFORMS 2017 and 2011A		COST ESTIMATE				DATE PREPARED 15 JUL 94		SHEET 1 OF 1	
ACTIVITY AND LOCATION Marine Corps Finance Center Kansas City, MO				CONSTRUCTION CONTRACT NO.				IDENTIFICATION NUMBER HR-1-94	
PROJECT TITLE Radon Mitigation, Hollow-Block Wall Foundations - 256 Capehart Units				ESTIMATED BY R. N. Morrison				CATEGORY CODE NUMBER 711-25,711-26	
				STATUS OF DESIGN <input checked="" type="checkbox"/> PRE <input type="checkbox"/> SUB <input type="checkbox"/> HSB <input type="checkbox"/> FINAL <input type="checkbox"/> Other (Specify)				JOB ORDER NUMBER	
ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE		
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL	
Fan, Centrifugal 250 Cfm, 4" Opening	1	EA	200	200	59	59	259	259	
PVC, Schedule 40, 4" OD	120	LF	1.16	139.20	10.50	1260.00	11.66	1,399	
90° Elbow, PVC, Sch 40, 4" OD	12	EA	3.00	36.00	7.50	90.00	10.50	126	
Tee, PVC, Sch 40, 4" OD	3	EA	3.70	11.10	7.50	22.50	11.20	34	
Caulking, Butal Latex	200	LF	.17	34.00	1.59	318.00	1.76	352	
Electrical Cable, 3 Conductor	50	LF	.31	15.50	.45	22.50	.76	38	
Junction Box	1	EA	2.09	2.09	5.29	5.29	7.39	8	
Fill CMU Voids	140	LF	1.04	145.60	1.01	141.40	2.05	287	
Vapor Barrier	1200	SF	.03	36.00	.22	264.00	.25	300	
Engineering Estimate								2,803	
256 Units								717,568	
Contractors OH&P								179,392	
Subtotal								896,960	
Contingency (5%)								44,848	
Total Contract Cost								941,808	
SIOW (3.5%)								32,963	
Design (6%)								56,508	
Total Request								1,031,279	

Figure 11 Sample Radon Mitigation Project Documentation, ...  
NAVFAC Form 11013/7

## CONCLUSION

The purpose of this report was to understand the radon problem as it relates to Navy Family Housing Units. It is intended to be used as a guide for Housing Facilities Engineers who have never dealt with, and are facing radon problems within their own housing unit inventory. The Engineer is provided with a concise background on the: Definition of the Radon Problem, Radon Detection Methods, Radon Mitigation Methods, a Listing of Excessive Radon Levels in Navy Family Housing Units Worldwide, and a Sample of Radon Mitigation Project Documentation.

Because the Housing Facilities Engineer is tasked with the maintenance and repair of existing housing facilities, special emphasis was placed on providing information on current radon mitigation methods. This combined with the listing of excessive radon levels and the sample project documentation should provide the Housing Facilities Engineer with tools necessary to arrive at a sound engineering solution.

**APPENDIX A**

**LISTING OF EXCESSIVE RADON LEVELS**

**IN**

**NAVY FAMILY HOUSING UNITS**

**WORLDWIDE**

Page No. 1  
06/25/94

CITY ADAK NS  
STATE AK  
DESC 2 BEDROOM NEW ROBERTS  
BLDG 50 to 69  
UNITS 6  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 09/03/89  
STOP 05/21/90

CITY ADAK NS  
STATE AK  
DESC 4 BEDROOM KULUK  
BLDG 50 to 69  
UNITS 17  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 08/02/89  
STOP 05/02/90

CITY ALBANY MCLB  
STATE GA  
DESC CAPEHART HILL VILLAGE SG OFF  
BLDG CAPE  
UNITS 3  
MIN\_PCI\_L 3.07  
MAX\_PCI\_L 8.00  
AVG\_PCI\_L 6.00  
START 04/12/89  
STOP 11/13/89

CITY ALBANY MCLB  
STATE GA  
DESC DOD 10300 AREA HILL VILLAGE BRICK  
BLDG 50 to 69  
UNITS 11  
MIN\_PCI\_L 1.70  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 3.00  
START 04/13/89  
STOP 11/10/89

CITY ALBANY MCLB  
STATE GA  
DESC DOD HILL VILLAGE ENL BRICK  
BLDG 50 to 69  
UNITS 83  
MIN\_PCI\_L 1.43  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 4.00  
START 04/06/89  
STOP 11/09/89



Page No. 2  
06/25/94

CITY ANNAPOLIS NSRDC  
STATE MD  
DESC QTRS A-COMMAND  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 3.96  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 04/13/89  
STOP 03/22/90

CITY ANNAPOLIS NSRDC  
STATE MD  
DESC QUARTERS B  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 4.04  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 04/13/89  
STOP 03/21/90

CITY ANNAPOLIS NSRDC  
STATE MD  
DESC QUARTERS E  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 4.26  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 04/13/89  
STOP 03/21/90

CITY ANNAPOLIS USNA  
STATE MD  
DESC UPSHUR/RODGERS  
BLDG < 1950  
UNITS 22  
MIN\_PCI\_L 0.54  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 04/06/89  
STOP 03/23/90

CITY ANNAPOLIS USNA  
STATE MD  
DESC 51 COUNTY RD  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 5.87  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 6.00  
START 04/06/89  
STOP 03/22/90

Page No. 3  
06/25/94

CITY ANNAPOLIS USNA  
STATE MD  
DESC BUILDING DESCRIPTION -1950  
BLDG < 1950  
UNITS 10  
MIN\_PCI\_L 0.84  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 4.00  
START 04/11/89  
STOP 03/18/90

CITY ANNAPOLIS USNA  
STATE MD  
DESC DAIRY FARM QTRS  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 5.69  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 6.00  
START 04/06/89  
STOP 03/28/90

CITY ANNAPOLIS USNA  
STATE MD  
DESC HALLIGAN ROAD QTRS  
BLDG < 1950  
UNITS 6  
MIN\_PCI\_L 2.15  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 5.00  
START 04/11/89  
STOP 03/16/90

CITY ANNAPOLIS USNA  
STATE MD  
DESC WOOD RD  
BLDG < 1950  
UNITS 3  
MIN\_PCI\_L 3.57  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 04/04/89  
STOP 03/22/90

CITY BRUNSWICK NAS  
STATE ME  
DESC FLAG QTRS 904 + 905  
BLDG < 1950  
UNITS 2  
MIN\_PCI\_L 0.77  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 3.00  
START 04/16/89  
STOP 04/06/90

Page No. 4  
06/25/94

CITY BRUNSWICK NAS  
STATE ME  
DESC PUBLIC QUARTERS E-1,EA-EE  
BLDG 50 to 69  
UNITS 10  
MIN\_PCI\_L 0.99  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 04/09/89  
STOP 03/20/90

CITY CAMP LEJEUNE MCB  
STATE NC  
DESC CAPEHART 43 UNITS VINYL SIDED MCAS  
BLDG CAPE  
UNITS 43  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 04/12/89  
STOP 03/12/90

CITY CHESAPEAKE BEACH NRL  
STATE MD  
DESC QTRS D  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 5.06  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 5.00  
START 03/23/89  
STOP 01/24/90

CITY CHESAPEAKE BEACH NRL  
STATE MD  
DESC QUARTERS A,B,C  
BLDG < 1950  
UNITS 3  
MIN\_PCI\_L 3.98  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 4.00  
START 03/23/89  
STOP 01/24/90

CITY CRANE NWSC  
STATE IN  
DESC FARMHOUSE-1  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 4.38  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 05/11/89  
STOP 08/14/89

Page No. 5  
06/25/94

CITY CRANE NWSC  
STATE IN  
DESC FARMHOUSES 2 3+5  
BLDG < 1950  
UNITS 3  
MIN\_PCI\_L 2.21  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 4.00  
START 05/10/89  
STOP 08/14/89

CITY CRANE NWSC  
STATE IN  
DESC QTRS B,BB,C,D,E,F,G,H,I  
BLDG < 1950  
UNITS 9  
MIN\_PCI\_L 2.85  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 5.00  
START 01/10/89  
STOP 01/14/89

CITY CRANE NWSC  
STATE IN  
DESC QTRS J K L M N O P Q R S T U  
BLDG < 1950  
UNITS 12  
MIN\_PCI\_L 3.18  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 4.00  
START 05/09/89  
STOP 08/14/89

CITY CRANE NWSC  
STATE IN  
DESC QTRS W1+W2  
BLDG < 1950  
UNITS 2  
MIN\_PCI\_L 3.52  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 4.00  
START 05/10/89  
STOP 08/14/89

CITY CRANE NWSC  
STATE IN  
DESC QTRS X+Y  
BLDG < 1950  
UNITS 2  
MIN\_PCI\_L 3.15  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 3.00  
START 05/11/89  
STOP 08/14/89

Page No. 6  
06/25/94

CITY DALLAS NAS  
STATE TX  
DESC DUNCANVILLE ANNEX  
BLDG 50 to 69  
UNITS 9  
MIN\_PCI\_L 1.29  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 3.00  
START 03/13/89  
STOP 06/12/89

CITY DAVISVILLE CBC  
STATE RI  
DESC NAVAL CONSTRUCTION BATTALION CENTER  
BLDG < 1950  
UNITS 9  
MIN\_PCI\_L 0.91  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 5.00  
START 04/16/89  
STOP 03/19/90

CITY EDZELL NSGA  
STATE UK  
DESC BRECHIN LEASED HOUSING  
BLDG LEASE  
UNITS 102  
MIN\_PCI\_L 0.65  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 11/06/89  
STOP 03/21/90

CITY EDZELL NSGA  
STATE UK  
DESC RAF STYLE HOUSING  
BLDG < 1950  
UNITS 71  
MIN\_PCI\_L 1.64  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 11/07/89  
STOP 03/25/90

CITY FALLON NAS  
STATE NV  
DESC CAPEHART  
BLDG CAPE  
UNITS 106  
MIN\_PCI\_L 0.58  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 03/15/89  
STOP 12/13/89

Page No. 7  
06/25/94

CITY FOREST PARK NMCRC  
STATE IL  
DESC N&MCRC FOREST PARK  
BLDG < 1950  
UNITS 0  
MIN\_PCI\_L 2.33  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 5.00  
START 09/22/89  
STOP 02/14/90

CITY FORT CUSTER NRC  
STATE MI  
DESC BATTLE CREEK N&MCRC  
BLDG N/A  
UNITS 24  
MIN\_PCI\_L 2.39  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 3.00  
START 06/13/89  
STOP 05/06/90

CITY GLENVIEW NAS  
STATE IL  
DESC FARMHOUSES  
BLDG < 1950  
UNITS 7  
MIN\_PCI\_L 1.63  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 3.00  
START 03/21/89  
STOP 04/11/90

CITY GREAT LAKES PWC  
STATE IL  
DESC 100 UNITS OF WHERRY HOUSING  
BLDG WHERR  
UNITS 100  
MIN\_PCI\_L 0.89  
MAX\_PCI\_L 15.00  
AVG\_PCI\_L 3.00  
START 10/16/89  
STOP 03/06/90

CITY GREAT LAKES PWC  
STATE IL  
DESC 150 UNITS OF FUND HOUSING 1970 AND AFTER  
BLDG 1970 >  
UNITS 150  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 09/14/89  
STOP 03/17/90

Page No. 8  
06/25/94

CITY GREAT LAKES PWC  
STATE IL  
DESC 16 PRE-1950 FAMILY HOUSING UNITS  
BLDG < 1950  
UNITS 16  
MIN\_PCI\_L 0.61  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 07/21/89  
STOP 03/16/90

CITY GREAT LAKES PWC  
STATE IL  
DESC 30 PRE-1950 FAMILY HOUSING UNITS  
BLDG < 1950  
UNITS 30  
MIN\_PCI\_L 0.83  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 10/01/89  
STOP 03/24/90

CITY GREAT LAKES PWC  
STATE IL  
DESC 6 UNITS OF FUND HOUSING 50-69 2ND INC  
BLDG 50 to 69  
UNITS 6  
MIN\_PCI\_L 1.57  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 3.00  
START 10/10/89  
STOP 02/15/90

CITY GREAT LAKES PWC  
STATE IL  
DESC 750 UNITS OF WHERRY HOUSING  
BLDG WHERR  
UNITS 750  
MIN\_PCI\_L 0.92  
MAX\_PCI\_L 15.00  
AVG\_PCI\_L 5.00  
START 08/29/89  
STOP 03/06/90

CITY GREAT LAKES PWC  
STATE IL  
DESC FLAG QUARTERS AA  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 3.80  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 05/26/89  
STOP 04/26/90

Page No. 9  
06/25/94

CITY GREAT LAKES PWC  
STATE IL  
DESC HANNA CITY PEORIA N&NCRC  
BLDG < 1950  
UNITS 18  
MIN\_PCI\_L 2.09  
MAX\_PCI\_L 11.00  
AVG\_PCI\_L 5.00  
START 10/02/89  
STOP 05/03/90

CITY GUAM PWC  
STATE GU  
DESC APRA HEIGHTS  
BLDG 1970 >  
UNITS 60  
MIN\_PCI\_L 2.59  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 5.00  
START 09/11/89  
STOP 03/09/90

CITY GUAM PWC  
STATE GU  
DESC FAA HOUSING  
BLDG 50 to 69  
UNITS 89  
MIN\_PCI\_L 1.52  
MAX\_PCI\_L 17.00  
AVG\_PCI\_L 5.00  
START 09/19/89  
STOP 02/22/90

CITY GUAM PWC  
STATE GU  
DESC LOCKWOOD TERRACE  
BLDG 50 to 69  
UNITS 82  
MIN\_PCI\_L 1.26  
MAX\_PCI\_L 12.00  
AVG\_PCI\_L 3.00  
START 09/06/89  
STOP 03/02/90

CITY GUAM PWC  
STATE GU  
DESC NAS  
BLDG 50 to 69  
UNITS 52  
MIN\_PCI\_L 0.93  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 3.00  
START 10/06/89  
STOP 04/05/90



Page No. 10  
06/25/94

CITY GUAM PWC  
STATE GU  
DESC NAS  
BLDG 50 to 69  
UNITS 85  
MIN\_PCI\_L 1.36  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 09/18/89  
STOP 02/19/90

CITY GUAM PWC  
STATE GU  
DESC NAS  
BLDG 50 to 69  
UNITS 220  
MIN\_PCI\_L 0.71  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 09/17/89  
STOP 04/03/90

CITY GUAM PWC  
STATE GU  
DESC NAV HOSP  
BLDG 1970 >  
UNITS 4  
MIN\_PCI\_L 1.64  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 4.00  
START 09/13/89  
STOP 03/22/90

CITY GUAM PWC  
STATE GU  
DESC NEW APRA HEIGHTS  
BLDG 1970 >  
UNITS 56  
MIN\_PCI\_L 1.93  
MAX\_PCI\_L 11.00  
AVG\_PCI\_L 4.00  
START 09/13/89  
STOP 03/06/90

CITY GUAM PWC  
STATE GU  
DESC NEW APRA HEIGHTS  
BLDG 1970 >  
UNITS 114  
MIN\_PCI\_L 1.67  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 3.00  
START 09/08/89  
STOP 02/27/90

Page No. 11  
06/25/94

CITY GUAM PWC  
STATE GU  
DESC NIMITZ HILL-FLAG CIRCLE  
BLDG 50 to 69  
UNITS 64  
MIN\_PCI\_L 0.52  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 09/11/89  
STOP 02/26/90

CITY GUAM PWC  
STATE GU  
DESC NIMITZ HILL-FLAG CIRCLE  
BLDG < 1950  
UNITS 7  
MIN\_PCI\_L 1.26  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 3.00  
START 09/17/89  
STOP 03/06/90

CITY GUAM PWC  
STATE GU  
DESC SOUTH FINEGAYAN SECOND INCREMENT  
BLDG 1970 >  
UNITS 116  
MIN\_PCI\_L 1.46  
MAX\_PCI\_L 38.00  
AVG\_PCI\_L 13.00  
START 09/27/89  
STOP 03/30/90

CITY GUAM PWC  
STATE GU  
DESC SOUTH FINEGAYAN SECOND INCREMENT  
BLDG 1970 >  
UNITS 184  
MIN\_PCI\_L 1.55  
MAX\_PCI\_L 13.00  
AVG\_PCI\_L 8.00  
START 09/23/89  
STOP 02/11/90

CITY GUAM PWC  
STATE GU  
DESC SUMAY  
BLDG 50 to 69  
UNITS 132  
MIN\_PCI\_L 0.76  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 09/06/89  
STOP 02/20/90

Page No. 12  
06/25/94

CITY INDIAN HEAD NOS  
STATE MD  
DESC FUND QUARTERS - WOOD FRAMED  
BLDG < 1950  
UNITS 22  
MIN\_PCI\_L 0.63  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 09/19/89  
STOP 02/26/90

CITY IWAKUNI MCAS  
STATE JA  
DESC MIDRISE (6 STORY)  
BLDG FORN  
UNITS 164  
MIN\_PCI\_L 0.90  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 05/15/89  
STOP 11/13/89

CITY IWAKUNI MCAS  
STATE JA  
DESC TOWNHOUSE  
BLDG FORN  
UNITS 168  
MIN\_PCI\_L 0.89  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 05/15/89  
STOP 11/21/89

CITY KANSAS CITY MCFC  
STATE MO  
DESC CAPEH ENL  
BLDG CAPE  
UNITS 215  
MIN\_PCI\_L 2.53  
MAX\_PCI\_L 10.00  
AVG\_PCI\_L 6.00  
START 03/23/89  
STOP 03/01/90

CITY KANSAS CITY MCFC  
STATE MO  
DESC CAPEH OFF CG  
BLDG CAPE  
UNITS 14  
MIN\_PCI\_L 3.50  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 5.00  
START 03/22/89  
STOP 03/02/90

Page No. 13  
06/25/94

CITY KANSAS CITY MCFC  
STATE MO  
DESC CAPEH OFF FG  
BLDG CAPE  
UNITS 7  
MIN\_PCI\_L 2.93  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 6.00  
START 03/22/89  
STOP 03/02/90

CITY KANSAS CITY MCFC  
STATE MO  
DESC ENL 50-69  
BLDG 50 to 69  
UNITS 5  
MIN\_PCI\_L 3.10  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 4.00  
START 03/22/89  
STOP 03/02/90

CITY KEY WEST NAS  
STATE FL  
DESC WHERRY  
BLDG WHERR  
UNITS 188  
MIN\_PCI\_L 0.70  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 06/04/89  
STOP 01/12/90

CITY LAKEHURST NAEC  
STATE NJ  
DESC OFFICERS HOUSING  
BLDG < 1950  
UNITS 33  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 2.00  
START 10/14/89  
STOP 03/05/90

CITY LONDON NAVACTS  
STATE UK  
DESC 42/43 WIMPOLE ST FLAT 16  
BLDG N/A  
UNITS 1  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 06/09/89  
STOP 07/30/90

Page No. 14  
06/25/94

CITY LONDON NAVACTS  
STATE UK  
DESC BLDG 312  
BLDG LEASE  
UNITS 1  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 06/16/89  
STOP 07/13/90

CITY LONDON NAVACTS  
STATE UK  
DESC FAIR LIGHT - BUILDING 40  
BLDG LEASE  
UNITS 1  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 06/14/89  
STOP 07/16/90

CITY MECHANICSBURG NSPCC  
STATE PA  
DESC EDSON DRIVE OTHER QTRS X1 X2 Y1 Y2  
BLDG < 1950  
UNITS 4  
MIN\_PCI\_L 3.28  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 6.00  
START 03/15/89  
STOP 04/20/90

CITY MECHANICSBURG NSPCC  
STATE PA  
DESC EDSON DRIVE QTRS V  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 7.10  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 7.00  
START 03/13/89  
STOP 04/19/90

CITY MECHANICSBURG NSPCC  
STATE PA  
DESC EDSON DRIVE-QTRS  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 7.10  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 7.00  
START 10/03/89  
STOP 05/02/90

Page No. 15  
06/25/94

CITY MECHANICSBURG NSPCC  
STATE PA  
DESC SITES A&B-CATEGORY C  
BLDG 50 to 69  
UNITS 55  
MIN\_PCI\_L 2.40  
MAX\_PCI\_L 13.00  
AVG\_PCI\_L 7.00  
START 03/16/89  
STOP 03/09/90

CITY MECHANICSBURG NSPCC  
STATE PA  
DESC SITES A&B-CATEGORY C ANNEX  
BLDG 50 to 69  
UNITS 20  
MIN\_PCI\_L 1.83  
MAX\_PCI\_L 16.00  
AVG\_PCI\_L 7.00  
START 03/18/89  
STOP 02/16/90

CITY MECHANISBURGH NSPCC  
STATE PA  
DESC SITES A&B-CATEGORY C ANNEX-B  
BLDG 50 to 69  
UNITS 0  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 03/22/89  
STOP 04/15/90

CITY MIRAMAR NAS  
STATE CA  
DESC PUBLIC QUARTERS INCREMENT 2-6 UNITS  
BLDG 50 to 69  
UNITS 275  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 07/01/89  
STOP 06/01/90

CITY MONTEREY NPGS  
STATE CA  
DESC CAPEHART HOUSING  
BLDG CAPE  
UNITS 150  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 1.00  
START 05/08/89  
STOP 03/25/90

Page No. 16  
06/25/94

CITY MONTEREY NPGS  
STATE CA  
DESC POINT SUR FAMILY HOUSING  
BLDG CAPE  
UNITS 24  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 04/11/89  
STOP 03/05/90

CITY NAVS. ISLAND  
STATE CA  
DESC 100 TOWNHOUSES  
BLDG 50 to 69  
UNITS 100  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 0.00  
START 04/22/89  
STOP 03/11/90

CITY NAVSTA MARE ISLAND  
STATE CA  
DESC 17 BUNGALOW QUARTERS  
BLDG < 1950  
UNITS 17  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 2.00  
START 05/17/89  
STOP 03/20/90

CITY NAVSUPPACT HOLY LOCH  
STATE UK  
DESC GLADSWOOD VILLA  
BLDG N/A  
UNITS 1  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 01/18/89  
STOP 08/10/90

CITY NAVSUPPACT HOLY LOCH  
STATE UK  
DESC OFF HSG-EAGLE  
BLDG N/A  
UNITS 45  
MIN\_PCI\_L 2.49  
MAX\_PCI\_L 20.00  
AVG\_PCI\_L 9.00  
START 01/30/89  
STOP 07/28/90

Page No. 17  
06/25/94

CITY NEW LONDON NSB  
STATE CN  
DESC DODFH WESTOVER - CHICOPEE  
BLDG < 1950  
UNITS 5  
MIN\_PCI\_L 1.86  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 01/13/90  
STOP 04/20/90

CITY NEW LONDON NSB  
STATE CN  
DESC DODFH WESTOVER - CHICOPEE/DUPLEX  
BLDG CAPE  
UNITS 184  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 01/07/90  
STOP 04/14/90

CITY NEW LONDON NSB  
STATE CN  
DESC DODFH WESTOVER - CHICOPEE/MULTIPLES  
BLDG CAPE  
UNITS 124  
MIN\_PCI\_L 1.00  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 01/12/90  
STOP 04/01/90

CITY NEW LONDON NSB  
STATE CT  
DESC CONNING TOWERS GROTON  
BLDG 50 to 69  
UNITS 156  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 10/30/89  
STOP 03/23/90

CITY NEW LONDON NSB  
STATE CT  
DESC MCON ON BASE GROTON  
BLDG 50 to 69  
UNITS 40  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 2.00  
START 10/17/89  
STOP 03/13/90



Page No. 18  
06/25/94

CITY NEW LONDON NSB  
STATE CT  
DESC MOQ ON BASE GROTON  
BLDG < 1950  
UNITS 70  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 27.00  
AVG\_PCI\_L 3.00  
START 10/23/89  
STOP 03/21/90

CITY NEW LONDON NSB  
STATE CT  
DESC NAUTILUS PARK 1ST INCREMENT GROTON  
BLDG CAPE  
UNITS 500  
MIN\_PCI\_L 1.11  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 3.00  
START 10/25/89  
STOP 03/26/90

CITY NEW LONDON NSB  
STATE CT  
DESC NAUTILUS PARK 2ND INCREMENT GROTON  
BLDG CAPE  
UNITS 496  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 10/26/89  
STOP 03/14/90

CITY NEW LONDON NSB  
STATE CT  
DESC NAUTILUS PARK 3RD INCREMENT GROTON  
BLDG CAPE  
UNITS 250  
MIN\_PCI\_L 0.55  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 10/28/89  
STOP 03/19/90

CITY NEW LONDON NSB  
STATE CT  
DESC POLARIS PARK GROTON  
BLDG 1970 >  
UNITS 300  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 10/20/89  
STOP 03/15/90

Page No. 19  
06/25/94

CITY NEW ORLEANS NSA  
STATE LA  
DESC UNITS CONST FY75  
BLDG 1970 >  
UNITS 116  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 1.00  
START 06/20/89  
STOP 10/30/89

CITY NEWPORT NETC  
STATE RI  
DESC ANCHORAGE  
BLDG < 1950  
UNITS 180  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 1.00  
START 04/01/89  
STOP 03/04/90

CITY NEWPORT NETC  
STATE RI  
DESC FY71-72 400 UNITS FORTADAMS GREENELANE  
BLDG 1970 >  
UNITS 400  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 04/01/89  
STOP 02/27/90

CITY NORFOLK PWC  
STATE VA  
DESC WOODBRIDGE CROSSING (801)  
BLDG LEASE  
UNITS 300  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 07/27/89  
STOP 04/20/90

CITY ORLANDO NTC  
STATE FL  
DESC THIS PROJECT HAS 300 TOWNHOUSE UNITS  
BLDG 1970 >  
UNITS 300  
MIN\_PCI\_L 0.56  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 1.00  
START 03/27/89  
STOP 12/23/89

Page No. 20  
06/25/94

CITY PHILADELPHIA NRMC  
STATE PA  
DESC MAIN-LINE UNITS (BEFORE 1950)  
BLDG < 1950  
UNITS 0  
MIN\_PCI\_L 3.14  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 03/23/89  
STOP 03/21/90

CITY POINT MUGU PMTC  
STATE CA  
DESC CAPEHART I GRAVEL ROOF  
BLDG CAPE  
UNITS 153  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 10/27/89  
STOP 03/23/90

CITY POINT MUGU PMTC  
STATE CA  
DESC CAPEHART III SINGLE STORY DUPLEX CAMARIL  
BLDG CAPE  
UNITS 14  
MIN\_PCI\_L 0.63  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 10/19/89  
STOP 03/12/90

CITY POINT MUGU PMTC  
STATE CA  
DESC CAPEHART III TWO STORY DUPLEX CAMARILLO  
BLDG CAPE  
UNITS 26  
MIN\_PCI\_L 0.80  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 10/23/89  
STOP 03/15/90

CITY PORTSMOUTH NSY  
STATE NH  
DESC 200UNITSOFFAMILYHOUSINGADMIRALTYVILLAGE  
BLDG 1970 >  
UNITS 200  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 3.00  
START 03/13/89  
STOP 03/28/90

Page No. 21  
06/25/94

CITY PORTSMOUTH NSY  
STATE NH  
DESC ON BASE OFFICER UNITS  
BLDG < 1950  
UNITS 34  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 13.00  
AVG\_PCI\_L 5.00  
START 03/15/89  
STOP 04/05/90

CITY QUANTICO MCDEC  
STATE VA  
DESC 1100  
BLDG < 1950  
UNITS 9  
MIN\_PCI\_L 0.71  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 11/02/89  
STOP 01/24/90

CITY QUANTICO MCDEC  
STATE VA  
DESC CHAMBERLAIN  
BLDG < 1950  
UNITS 49  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 01/13/89  
STOP 01/10/90

CITY QUANTICO MCDEC  
STATE VA  
DESC GEIGER RIDGE  
BLDG < 1950  
UNITS 25  
MIN\_PCI\_L 0.58  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 01/07/89  
STOP / /

CITY QUANTICO MCDEC  
STATE VA  
DESC LUST 2700  
BLDG < 1950  
UNITS 54  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 2.00  
START 01/12/89  
STOP 01/24/90

Page No. 22  
06/25/94

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG < 1950  
UNITS 6  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 3.00  
START 01/17/89  
STOP 01/23/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 22  
MIN\_PCI\_L 0.81  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START / /  
STOP 01/18/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 22  
MIN\_PCI\_L 1.82  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 3.00  
START / /  
STOP 01/18/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 28  
MIN\_PCI\_L 0.66  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START / /  
STOP 01/18/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 34  
MIN\_PCI\_L 0.95  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 3.00  
START / /  
STOP 01/18/90

Page No. 23  
06/25/94

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 68  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 3.00  
START / /  
STOP 01/04/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 80  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 2.00  
START / /  
STOP 01/17/90

CITY QUANTICO MCDEC  
STATE VA  
DESC LYMAN PARK  
BLDG CAPE  
UNITS 109  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 3.00  
START / /  
STOP 01/01/90

CITY QUANTICO MCDEC  
STATE VA  
DESC Q-#6  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 3.52  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 4.00  
START 10/12/89  
STOP 01/23/90

CITY QUANTICO MCDEC  
STATE VA  
DESC Q-331,334,337,350,354,411,411 ~431  
BLDG < 1950  
UNITS 6  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 01/07/89  
STOP 01/12/90

Page No. 24  
06/25/94

CITY QUANTICO MCDEC  
STATE VA  
DESC SPLIT LEVEL 2700+2000  
BLDG 50 to 69  
UNITS 96  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 01/12/89  
STOP 01/23/90

CITY QUANTICO MCDEC  
STATE VA  
DESC SPLIT LEVEL 300  
BLDG 50 to 69  
UNITS 36  
MIN\_PCI\_L 1.04  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 01/10/89  
STOP 01/17/90

CITY QUANTICO MCDEC  
STATE VA  
DESC SPLIT LEVEL 300  
BLDG 50 to 69  
UNITS 39  
MIN\_PCI\_L 0.8  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 2.00  
START 01/13/89  
STOP 01/20/90

CITY SAN FRANCISCO PWC  
STATE CA  
DESC RAFAEL VILLAGE DODHF NOVATO  
BLDG WHERR  
UNITS 505  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 04/07/89  
STOP 04/29/90

CITY SASEBO COMFLEACTS  
STATE JA  
DESC DRAGON HEIGHTS APARTMENT  
BLDG FORN  
UNITS 18  
MIN\_PCI\_L 0.76  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 06/02/89  
STOP 05/16/90

Page No. 25  
06/25/94

CITY SASEBO COMFLEACTS  
STATE JA  
DESC DRAGON HEIGHTS/VALE HOUSING  
BLDG FORN  
UNITS 63  
MIN\_PCI\_L 0.76  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 05/25/89  
STOP 04/27/90

CITY SASEBO COMFLEACTS  
STATE JA  
DESC HARIO HOUSING AREA  
BLDG FORN  
UNITS 105  
MIN\_PCI\_L 0.76  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 05/12/89  
STOP 05/17/90

CITY SASEBO COMFLEACTS  
STATE JA  
DESC SAFURA TOWER  
BLDG FORN  
UNITS 28  
MIN\_PCI\_L 0.76  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 05/17/89  
STOP 04/10/90

CITY SIOUX CITY  
STATE IO  
DESC NAVY AND MARINE CORPS RESERVE CENTER  
BLDG < 1950  
UNITS 0  
MIN\_PCI\_L 2.75  
MAX\_PCI\_L 16.00  
AVG\_PCI\_L 6.00  
START 10/11/89  
STOP 04/18/90

CITY STOCKTON NCS  
STATE CA  
DESC WHERRY HOUSING FORRESTAL VILLAGE  
BLDG WHERR  
UNITS 40  
MIN\_PCI\_L 0.73  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 2.00  
START 03/21/89  
STOP 06/19/89



Page No. 26  
06/25/94

CITY SUGAR GROVE NRS-R  
STATE WV  
DESC NEW HOUSING CAT B  
BLDG 1970 >  
UNITS 10  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 7.00  
AVG\_PCI\_L 2.00  
START 05/19/89  
STOP 04/25/90

CITY WARMINSTER NADC  
STATE PA  
DESC QUARTER'S B  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 25.0  
MAX\_PCI\_L 25.00  
AVG\_PCI\_L 25.00  
START 03/29/89  
STOP 03/01/90

CITY WARMINSTER NADC  
STATE PA  
DESC QUARTERS A  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 6.22  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 6.00  
START 03/27/89  
STOP 03/06/90

CITY WATERLOO NMCRC  
STATE IA  
DESC NAVY AND MARINE CORPS RESERVE CENTER  
BLDG < 1950  
UNITS 23  
MIN\_PCI\_L 1.06  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 3.00  
START 04/13/89  
STOP 09/04/89

CITY WILLOW GROVE NAS  
STATE PA  
DESC SINGLE FAMILY HOMES OVER 40YRS OLD  
BLDG < 1950  
UNITS 1  
MIN\_PCI\_L 4.91  
MAX\_PCI\_L 5.00  
AVG\_PCI\_L 5.00  
START 05/04/89  
STOP 04/12/90

Page No. 27  
06/25/94

CITY WILLOW GROVE NAS  
STATE PA  
DESC SINGLE FAMILY HOMES OVER 40YRS OLD  
BLDG < 1950  
UNITS 5  
MIN\_PCI\_L 0.55  
MAX\_PCI\_L 9.00  
AVG\_PCI\_L 4.00  
START 05/04/89  
STOP 04/12/90

CITY YORKTOWN NWS  
STATE VA  
DESC MASON'S ROW A-G AND M&N  
BLDG < 1950  
UNITS 9  
MIN\_PCI\_L 1.38  
MAX\_PCI\_L 6.00  
AVG\_PCI\_L 3.00  
START 04/13/89  
STOP 03/19/90

CITY YORKTOWN NWS  
STATE VA  
DESC MOQ-MEMO KISKIAK/SKIFFES CREEK  
BLDG 50 to 69  
UNITS 100  
MIN\_PCI\_L <0.5  
MAX\_PCI\_L 4.00  
AVG\_PCI\_L 1.00  
START 04/12/89  
STOP 03/19/90

## REFERENCES

- Bodansky, David, Robkin, Maurice A., Stadler, David R., Indoor Radon and Its Hazards University of Washington Press, Seattle and London (1987), pp.6-54.
- Brookins, Douglas G., The Indoor Radon Problem Columbia University Press, New York (1990), pp.3-116.
- Cole, Leonard A., Element of Risk: The Politics of Radon AAAS Press (1993), pp.8-9.
- Cothorn, C. Richard, and James E. Smith, Jr., Environmental Radon, Plenum Press, New York (1987), p.69.
- Department of the Navy, Naval Facilities Engineering Command, Navy Family Housing Manual, NAVFAC P-930, Washington D.C. (1983), p.20-2.
- EPA, U.S. Environmental Protection Agency, Home Buyer's and Seller's Guide to Radon EPA/402/R/93/003, Washington D.C. (1993), pp.12-16.
- EPA, U.S. Environmental Protection Agency, Radon Reduction Techniques for Detached Houses EPA/625/5-86/019, Washington D.C. (1986), pp.4-40.
- EPA, U.S. Environmental Protection Agency, Radon Reference Manual, EPA/520/1-87-20, Washington D.C. (1987), p.10.
- Lao, Kenneth Q., Controlling Indoor Radon: Measurement, Mitigation, and Prevention Van Nostrand Reinhold, New York (1990), pp.78-83.
- Nazaroff, William W., and Anthony V. Nero, Jr., Radon and Its Decay Products in Indoor Air, Wiley, New York (1988), pp.20-61.



