., P.O. Box 76121, Atlanta,

r Air Pollution: An Emerging
, 1980.

Air Act, Summary of GAO
ng Reviews, (GAO CED 81-84)

tants, Washington, D.C.,

#952

Measurements of Radon Daughters in 12 000 Swedish Homes

Olov Hildingson, Research Engineer, National Testing Institute, Borås, Sweden

ABSTRACT

Three factors cause a high radon and radon daughter concentration in Swedish dwellings:

1. By energy-saving measures the ventilation rate has become low
2. 10 per cent of existing houses are built of light weight concrete with a high proportion of radium
3. Large regions have high radium content in the ground

One way of finding houses with possible high radon daughter level is to measure the gamma radiation from the outside. In gamma radiating houses at least two detectors are installed to monitor the radon daughter concentration. This passive detector (5 cm x 5 cm) is sensitive only to alpha radiation, such as that emitted by radon and its alpha-radioactive daughters. The detectors are mounted in the middle of the room. After exposure for three months the detectors are returned for processing and reading. An alternative method of measuring radon daughter concentrations is to use filter sampling and a modified Kusnetz method and at the same time determine the ventilation rate in the dwelling using a tracer gas technique.

Among so far investigated houses almost 15 per cent, measured with passive detectors, have a radon daughter concentration higher than 400 Bq/m^3 (10.8 pCi/ℓ).

INTRODUCTION

In this paper results from radon daughter (Rnd) measurements in 12 000 dwellings are presented. Two different methods were used, a modified Kusnetz method and a track etch method. With the first method the Rnd concentration and the ventilation rate are measured simultaneously at nine different locations in a dwelling. The measurements of Rnd concentration are based on air samples which are collected during ten minutes at each location. The ventilation rate is measured using the tracer gas technique. A complete test requires 2-4 hours. The second method uses track etch detectors from Terradex Corporation. Two detectors are placed in each home for three months.

Several factors are important when discussing radon levels in Swedish dwellings.

I Large regions have high radium content in the ground

II 10 per cent of existing houses are built of light weight concrete with a high radium content

III In some regions the radon exhalation from household water is very high

IV By energy-saving measures the ventilation rate has been reduced to a very low value.

In 1979 Sweden imposed a limit to the radon daughter (Rnd) concentration in dwellings. The limit is given as a mean value for a whole year. Depending on type of dwelling there are three different levels

I 70 Bq/m^3 in new dwellings

II 200 Bq/m^3 in rebuilt dwellings

III 400 Bq/m^3 in existing dwellings

RESULTS AND DISCUSSION

Most of the tested dwellings were chosen by local authorities. The criteria was to find dwellings with building materials based on alun shale or buildings built on radonexhalating ground. Therefore the results presented here are not typical for the average Swedish dwelling.

The mean radon daughter concentration for all dwellings tested in Sweden is 240 Bq/m^3. This number is based on measurements done with track etch detectors. In table 1 the results from the track etch detectors are shown for four intervals.

ach location. The ventilation
ique. A complete test requires
h detectors from Terradex Corpora-
for three months.

ng radon levels in Swedish

in the ground

lt of light weight concrete with

rom household water is very high

ion rate has been reduced to a

daughter (Rnd) concentration in
lue for a whole year. Depending
ent levels

y local authorities. The criteria
als based on alun shale or build-
efore the results presented here
elling.

all dwellings tested in Sweden is
ments done with track etch detec-
k etch detectors are shown for

Rnd (Bq/m^3)	Number of dwellings	Percentage of all measured dwellings
0 - 199	6326	52
200 - 399	4050	34
400 - 1000	1545	13
1000 <	162	1

Table 1. Radon Daughter (Rnd) Concentration for all Dwellings tested in Sweden.

Today almost 50 % of all dwellings in Sweden are one-family houses. However, more than half of all measured dwellings are one-family houses. In the following table the results have been divided into different types of dwellings (see table 2).

Type of dwelling	Number of dwellings	Mean value of Rnd (Bq/m^3)	Percentage of all measured dwellings in the group 0-199	200-399	400-1000	>1000
Dwelling in apartment house	2484	118	84	13	3	0
1 storey one-family house with basement	1131	287	39	42	17	2
1 storey one-family house without basement	4501	290	42	39	17	2
2 storey one-family house with basement	2013	242	48	38	13	1
2 storey one-family house without basement	1955	252	48	38	11	3
All houses	12084	240	52	34	13	1

Table 2. Radon Daughter (Rnd) Concentration for different Types of Dwellings

Radon exhalation from the ground is one reason why one-family houses have higher mean values than apartments. Another reason is that light-weight concrete is less common in apartments. Furthermore the ventilation rates in apartments are probably higher than in one-family houses.

Almost all new dwellings nowadays have mechanical ventilation for supplying fresh air but out of the measured dwellings only 5 per cent have mechanical ventilation. The results for one-family houses have been divided into two groups, dwellings with mechanical ventilation and dwellings with natural ventilation (see table 3).

Type of dwelling	Number of dwellings	Mean value of Rnd (Bq/m^3)	Percentage of all measured dwellings in the group 0-199	200-399	400-1000	>1000
Dwelling with natural ventilation	8311	272	43	40	16	1
Dwelling with mechanical ventilation	453	211	62	27	9	2

Table 3. Rnd Concentration for One-family Houses with natural Ventilation and for One-family Houses with mechanical Ventilation

One way of decreasing the Rnd concentration in dwellings is to increase the ventilation rate. This measure will only work in buildings with radon exhalation from building materials. When radon comes from the ground the situation can be different. If e.g. an exhaust fan is installed in a one-family house built on radon exhalating ground the fan causes a negative pressure in the basement, which creates a radon flux from the ground into the building through cracks in the foundation. This may be one reason why we got such a large number of dwellings with mechanical ventilation and a high radon daughter concentration.

In order to correlate radon daughter concentration and air infiltration, the Kusnetz method and the tracer gas technique were used in 92 dwellings (see fig. 1). The mean value of the radon daughter concentration and ventilation rate was 175 Bq/m^3 and 0.42 ach and the median value was 250 Bq/m^3 respectively 0.35 ach. For some dwellings the Rnd concentration is high although the ventilation rate is high. These buildings are probably built on a strong radon source.

It is useful to know how large a share of the Rnd concentration is caused by radon exhalation from building materials. At our laboratory measurements of the radon exhalation rates directly from building materials have been made by attaching a box to the surface of a wall.

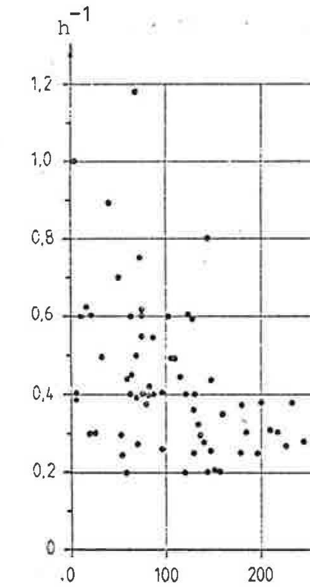


Figure 1. The Rnd Concentra

This box has one open side
of a test the increased rad
samples. The radon concentr
lowing formula if the radon
of a measurement is zero.

$$C_{Rn}(t) = \frac{E}{\lambda+\lambda_v} \cdot$$

where A/V is the ratio
λ is the decay
λ_v is the leakag
E is the radon
t is the time (

During the first half hour
tion of time. The slope of
halation.

houses have been divided into two
ation and dwellings with natural ven-

	Percentage of all measured dwellings in the group			
	0-199	200-399	400-1000	>1000
	43	40	16	1
	62	27	9	2

ly Houses with natural Ventilation and
entilation

tion in dwellings is to increase the
y work in buildings with radon exhala-
n comes from the ground the situation
n is installed in a one-family house
n causes a negative pressure in the
om the ground into the building through
ne reason why we got such a large num-
ation and a high radon daughter concen-

ncentration and air infiltration, the
ique were used in 92 dwellings (see
ughter concentration and ventilation
median value was 250 Bq/m^3 respecti-
nd concentration is high although the
gs are probably built on a strong ra-

of the Rnd concentration is caused
ials. At our laboratory measurements
from building materials have been
of a wall.

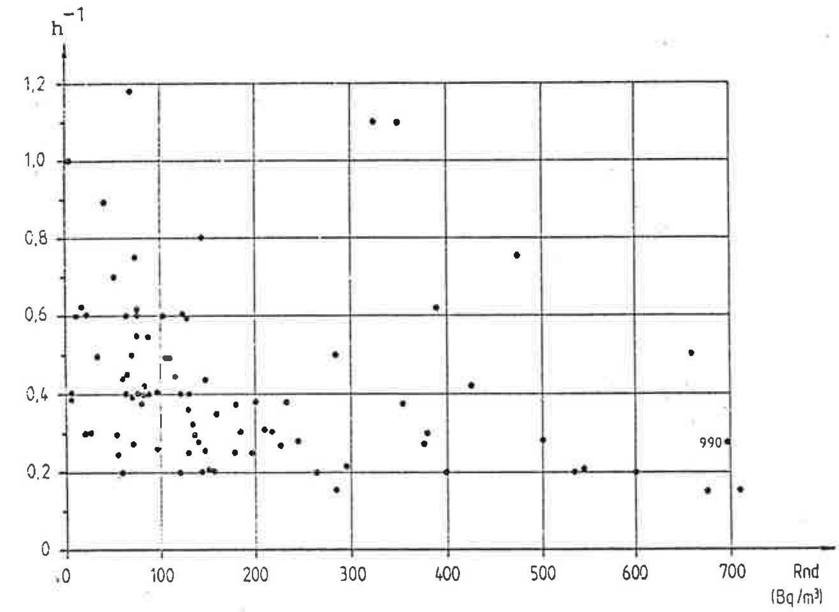


Figure 1. The Rnd Concentration vs. Ventilation Rate

This box has one open side which is facing the wall. During the first hour of a test the increased radon concentration is measured by collecting air samples. The radon concentration in the box increases according to the following formula if the radon concentration outside the box and at the beginning of a measurement is zero.

$$C_{Rn}(t) = \frac{E}{\lambda+\lambda_v} \cdot \frac{A}{V}\left(1-e^{-\lambda t}\right) \qquad (1)$$

where A/V is the ratio of the bottom area to the volume of the box (m^{-1})
λ is the decay constant of radon (s^{-1})
λ_v is the leakage factor in the container (s^{-1})
E is the radon exhalation rate ($Bq/m^2 \cdot s$) and
t is the time (s).

During the first half hour of a test the radon accumulation is a linear function of time. The slope of the curve of accumulation is the rate of radon exhalation.

We have measured the radon exhalation rates from 25 cm thick light weight concrete, with high radium content (~2500 Bq/kg) and for different surface treatments (see table 4).

Surface treatment	Radon exhalation rate ($Bq/m^2 \cdot s$)
Non-covered surface	$30 \cdot 10^{-3}$
Rendering + wall paper	$15 \cdot 10^{-3}$

(The inaccuracy in these measurements is large)

Table 4. Radon Exhalation Rate from Light Weight Concrete with high Radium Content

The radon exhalation rate can be used to calculate the radon concentration (C_{Rn}) in a room using the following formula

$$C_{Rn} = \frac{A}{V} \cdot \frac{E}{\lambda + n} \qquad (2)$$

where A is the radonexhalating areas of the room (m^2)

V is the volume of the room (m^3) and

h is the ventilation rate of the room (h^{-1}).

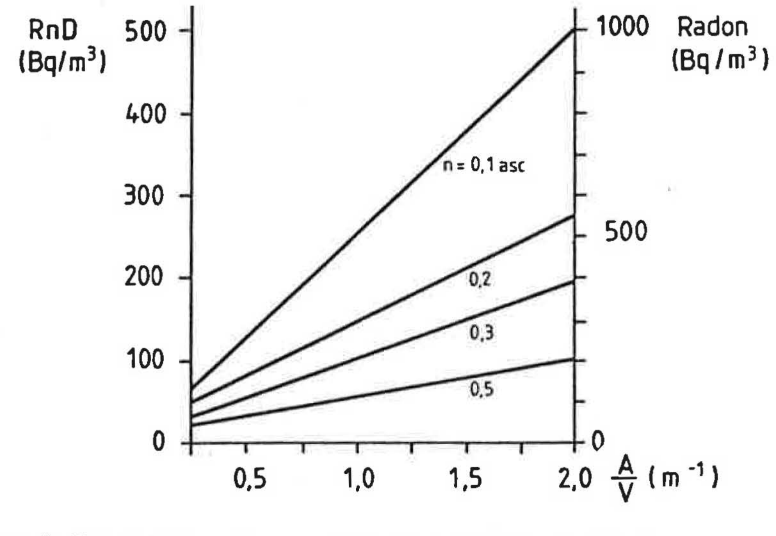


Figure 2. Rnd and Radon Concentration in a Room vs. Ventilation Rate and A/V Ratio for the Room for an Exhalation Rate of $1.5 \cdot 10^{-2}$ $Bq/m^2 \cdot s$.

In figure 2 the results fc
$Bq/m^2 \cdot s$ are shown. The Rr
radon concentration.

The results indicate that
only relying on radonexhal
ventilation rate is very l
tion must get additional r
source is the ground.

It is therefore not surpri
show a large variation. Tr
The radon problem is most
malies with high radium cc
houses built in areas with
400 bq/m^3 (see table 5). A
shows the importance of ra

	Number one-fa houses
All houses	9600
Houses on alun shale	655

(The last group doesn't i

Table 5. Rnd Concentratio

CONCLUSIONS

In the beginning of the r
of all buildings built of
have a Rnd concentration
far the number would be 5
concentration above 1000
years according to the Sw
if radon exhalation from

So far we have found that
we thought in the beginni

rates from 25 cm thick light weight con-
) Bq/kg) and for different surface treat-

	Radon exhalation rate ($Bq/m^2 \cdot s$)
	$30 \cdot 10^{-3}$
	$15 \cdot 10^{-3}$

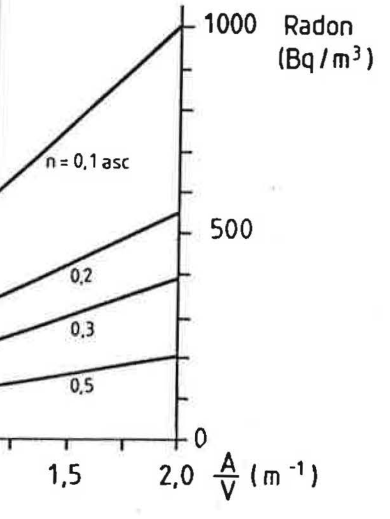
is large)

ight Weight Concrete with high Radium

to calculate the radon concentration
ormula

(2)

reas of the room (m^2)
m (m^3) and
of the room (h^{-1}).



n a Room vs. Ventilation Rate and
n Rate of $1.5 \cdot 10^{-2}$ $Bq/m^2 \cdot s$.

In figure 2 the results for a room with a radon exhalation rate of $1.5 \cdot 10^{-2}$ $Bq/m^2 \cdot s$ are shown. The Rnd concentration (EEC) is assumed to be half of the radon concentration.

The results indicate that it is difficult to arrive at high Rnd concentrations only relying on radonexhalating building materials. This is true even if the ventilation rate is very low. Therefore dwellings with high Rnd concentration must get additional radon from other sources. In most cases this other source is the ground.

It is therefore not surprising that the results from different parts of Sweden show a large variation. This is due to the varying radon flux from the ground. The radon problem is most accentuated in areas with alun shale or granite anomalies with high radium content in the ground. Almost 40 % of the one-family houses built in areas with alun shale in the ground have concentrations above 400 bq/m^3 (see table 5). A comparison with the results from all of Sweden shows the importance of radon exhalation from the ground.

	Number of one-family houses	Mean value (Bq/m^3)	Percentage of measured dwellings			
			0-199	200-399	400-999	>1000
All houses	9600	272	44	39	15	2
Houses on alun shale	655	476	25	38	30	7

(The last group doesn't include all buildings built on alun shale in Sweden)

Table 5. Rnd Concentration depending on Location for One-family Houses.

CONCLUSIONS

In the beginning of the research it was estimated that 15000 dwellings out of all buildings built of light weight concrete with high radium content would have a Rnd concentration above 400 Bq/m^3. Extrapolating from our results sofar the number would be 50000. One fifth of these dwellings would have Rnd concentration above 1000 Bq/m^3. These houses have to be rebuilt within two years according to the Swedish Building Code. The number will be still higher if radon exhalation from the ground is taken into account.

So far we have found that radon from the ground has a larger influence than we thought in the beginning. In the earlier stages of the radon investigation the local authorities concentrated on locating houses built with light weight concrete with high radium content, but now they have to find houses on radon exhalating ground. At this moment research is made to investigate radon exhalation from building materials and ground, and to investigate different methods of decreasing the Rnd concentration indoor.

REFERENCES

Hildingson, O. Radon in 5600 dwellings - Measurements with track-etch method and Kusnetz method. National Testing Institute, Borås, Sweden. 1981 (in Swedish).

The Development of a Small

Gordon Dixon, Principal Lec
Manchester Po

ABSTRACT

The work described in this p
field of small engine drive
theoretical modelling thr
operational test rig. An in
source to drive a vapour com
of the heat pump together wi
water heating. Attention is
study and to those likely to
heating system.

RESUME

Cette intervention traite
réalisé dans le domaine des
Les divers stades d'évolution
la mise au point et enfin à
source d'énergie est un m
différentes vitesses une pom
à chaleur associé à l'énerg
l'eau et de l'habitat. L'int
sont survenus pendant l'étud
de la production du prototyp