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The second Dutch national survey on radon in dwellings: set-up of the project

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SUMMARY

In 1994 the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) commissioned RIVM to carry out a national survey on radon in dwellings, the set-up of which is described in this report. The goals of the survey were:

1. To determine the average and the range of the radon (^{222}Rn) concentration in Dutch dwellings built since concluding the previous survey in 1984. These data will serve as a reference for evaluating the effectiveness of final regulations on radon in new dwellings.
2. To quantify the relative contribution of radon from the building materials and from the soil to the indoor radon level in dwellings built in the course of the last decade. These data will be used for the selection of possible counter-measures.

Two separate random samples from the Dutch housing stock were taken to answer these questions. A sample of about 1000 dwellings built between 1985 and 1993 in 52 municipalities was taken to answer the first question. The composition of the sample differs from the Dutch housing stock for a number of characteristics, the most obvious of which is the over-representation of single-family and private homes.

A sample of about 450 single-family dwellings built in 14 municipalities on different soil types was taken to answer the second question. Two groups of municipalities were distinguished because of geographic differences in building practices: those where town houses predominate and those with mainly detached and semi-detached houses.

Information on radon and its sources was collected through placement of alpha track detectors, installation of so-called PFT sources and passive samplers for air infiltration measurement, collection of soil samples and completion of a questionnaire on building and ventilation characteristics.

The results of the study are dealt with in RIVM report no. 610058006.

SAMENVATTING

In 1994 verleende het Ministerie voor Volkshuisvesting, Ruimtelijke Ordening en Milieu (VROM) aan RIVM de opdracht tot het uitvoeren van een landelijk onderzoek naar radon in woningen. De opzet van dit landelijke onderzoek vormt het onderwerp van dit rapport. De doelstellingen van het onderzoek waren:

1. Bepalen van de gemiddelde radonconcentratie (^{222}Rn) en de spreiding daarin voor woningen gebouwd na het afsluiten van een vergelijkbaar onderzoek in 1984. Deze gegevens zullen gebruikt worden als referentiepunt bij het evalueren van de effectiviteit van de regelgeving op het gebied van radon in nieuwbouwwoningen.
2. Vaststellen wat de relatieve bijdrage is van bodem en bouwmaterialen aan de radonconcentratie in recent gebouwde woningen. Deze gegevens zullen worden gebruikt bij het selecteren van mogelijke tegenmaatregelen.

Voor ieder van beide te beantwoorden vragen werd een afzonderlijke steekproef uit het Nederlandse woningbestand genomen. De eerste vraag werd beantwoord aan de hand van een steekproef van circa 1000 woningen, die in de periode 1985 tot 1993 zijn gebouwd in 52 gemeenten. De samenstelling van de steekproef wijkt voor een aantal kenmerken af van het Nederlandse woningbestand. Het meest opvallend is de oververtegenwoordiging van eengezins- en eigen woningen.

De tweede vraag werd beantwoord middels een onderzoek in ongeveer 450 eengezinswoningen verdeeld over 14 gemeenten en gebouwd op uiteenlopende bodems. Geografische verschillen in bouwwijze leidden tot het onderscheiden van twee groepen gemeenten: gemeenten met hoofdzakelijk tussenwoningen en gemeenten met vooral halfvrijstaande en vrijstaande woningen.

Gegevens over radon en bronnen van radon werden verzameld met radon-meetbekers, door het plaatsen van zogenaamde PFT-bronnen en -adsorbers voor het meten van luchtstromen, het bemonsteren van grond en het invullen van een vragenlijst over bouwkundige kenmerken en ventilatiegedrag.

De onderzoeksresultaten worden behandeld in RIVM rapport 610058006.

1. INTRODUCTION

1.1 Background

In 1982, the Dutch government started a programme (called 'SAWORA'[i]) to investigate the contribution of different sources of natural radiation to the exposure of the Dutch population. The average and range of radon concentrations in dwellings were determined in the part of the programme dealing with radiation aspects of the indoor environment.

In this survey, carried out by KVI[ii] in 1984, 894 dwellings were investigated with the voluntary participation of the occupants. The yearly averaged radon concentration in living-rooms was found to range from 8 to 120 Bq m^{-3}. The mean concentration was 29 Bq m^{-3}. Radon concentrations in dwellings built over the period 1970–1983 were 5–10 Bq m^{-3} higher than in those built before 1970. Possible explanations are the increased use of concrete as building material and reduced ventilation due to energy conservation measures [1].

The research programme SAWORA was followed by the RENA[iii] programme (1986–1991) on controllable forms of natural background radiation and the STRATEGO[iv] programme (1991-1997), in which the effectiveness of risk-reducing measures is being investigated. In 1991 RIVM published the 'Integrated Criteria Document Radon' [2], summarizing the knowledge on sources, emissions, dispersion and risks of radon. The Health Council published an assessment of this document in 1993 [3]. Both publications have been an important basis for the planning of the STRATEGO programme and the Dutch policy on radon.

The Dutch government has set three goals for indoor radon [4]:

1. An average radon concentration in new dwellings of at most 20 Bq m^{-3} to be realized after adjustments in present building practices;
2. Reduction with the use of remedial techniques of the average radon concentrations in existing dwellings to 20 Bq m^{-3};
3. Prevention of an increase in the average contribution of building materials to the indoor radiation risk (stand-still principle).

In order to verify whether these goals will be reached, it is necessary to regularly monitor the indoor radon concentration, a task which has been commissioned to RIVM by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM). Questions to be answered during monitoring pertain to the distribution of radon concentrations in dwellings built over the past decade, and to the relative importance of radon originating from soil, building materials and outdoors for the indoor concentration level. The set-up of the survey launched to answer these questions will be described in this report.

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[i] StralingsAspecten van WOonhygiëne en verwante RAdioecologische problemen

[ii] Kernfysisch Versneller Instituut, University of Groningen

[iii] REguleerbare vormen van Natuurlijke Achtergrondstraling

[iv] STRAling Ten aanzien van de GEbouwde Omgeving

The Ministry of VROM has recently announced its intention to issue in 1997 a document on its policy implementation with respect to indoor radon. In this policy document the goals, regulations and necessary measures will be worked out using, for example, the results of the successive national research programmes and the RIVM survey.

1.2 Aim of the survey

To properly deal with each of the questions raised by the Ministry of VROM (see 1.1), two separate samples were taken from the Dutch housing stock. The second Dutch national survey is considered to reflect the combination of the samples.

The first sample was taken to determine the distribution of the radon concentration in dwellings built in the period 1985 to 1993. It can be seen as a sequel to the survey of 1984. In combination with this survey it should be considered as a check on the postulated trend of the indoor radon concentration [5]. As proposed regulations for new dwellings[v] are of a more binding character than those for existing ones[vi], this survey is specifically also a reference point for the evaluation of the effectiveness of final regulations on radon for new dwellings. *This sample will be referred to as SAMPLE N.*

The second question pertains to the relative importance of the major sources, soil and building materials, of radon in dwellings. Since soil was estimated to be the most important source [2, 6], reducing the entry of radon from the soil was supposed to be potentially most effective. Theoretically, the intended limit of 20 Bq m^{-3} for new dwellings would be reached by enhancing the ventilation of the crawl space and reducing the permeability of the ground floor [5, 6]. This reduction could be realized, assuming no increase in the contribution from building materials.

The starting points of these calculations, however, need a further check before control measures can be definitely prescribed. A second sample was taken to specifically investigate the importance of the soil as a source of radon in dwellings. The sample consists of a large group of typical single-family dwellings of about the same age and built on various soil types. The outcome of radon measurements will be described as a function of soil characteristics such as radium content and grain-size fractions. The results for this second sample also support the further elaboration of environmental quality objectives for the soil with respect to ^{226}Ra [7]. That is why this part of the study has been combined with ongoing research in the Rijnmond area. In this area radon infiltration is studied in dwellings which have been built on harbour sludges from the Rotterdam harbours, in which radium levels are enhanced [8, 9, 10, 11]. *This sample will be referred to as SAMPLE R.*

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[v] The proposed limit of 20 Bq m^{-3} for new dwellings is the compulsory level.

[vi] The proposed limit of 20 Bq m^{-3} for existing dwellings is the target level.

The report will be discussed under context and time schedule of the survey, followed by applied measurement techniques, aspects of communication with persons and parties concerned and the structure of the samples.

2. PLANNING AND ORGANIZATION

The planning of the project is briefly outlined in Table 2-1.

Table 2-1 Planning of the project

Period		Activity
04/94	08/94	Description of the research programme in consultation with the Ministry of VROM.
09/94	02/95	Selection of a database of addresses and creation of mailing lists. Selection of measuring techniques and equipment.
11/94	03/95	Preparation of agreements with subcontractors. Placement of orders.
01/95	03/95	Construction of the sample: mailings to and phoning of potential participants. Preparation of instructions and equipment for fieldworkers.
04/95		Distribution of the sampling equipment.
04/95	12/95	Soil sampling.
08/95		Collection of sampling equipment in Schiedam and part of the Maassluis location.
11/95	04/96	Completion of the questionnaires.
04/96		Collection of sampling equipment.
06/95	06/96	Gammaspectrometric analysis of soil samples.
05/96	10/96	Analysis of the alpha track detectors.
05/96	11/96	Analysis of the sampling tubes for air-flow measurement.
12/96	01/97	Calculation of air flows, set-up of databases.
11/96	03/97	Analysis of results.
03/97		First report to VROM and letter to participants.

For the execution of the project RIVM was supported by a number of other organizations. FzK[vii] supplied and analysed the alpha track detectors (see 3.1) and BNL[viii] did the same for the equipment to measure air flows between crawl space and living-room (see 3.2). As the configuration of the alpha track detectors of FzK differs from that used in the survey of 1984 and in some of the projects of the STRATEGO programme (see 1.1), KVI did a number of comparative measurements with the type of alpha track detectors used in all of these projects. LB&P[ix], as intermediary for RIVM and BNL, has taken care of a correct interpretation of the chemical analyses reported by BNL. Soil samples were taken by IWACO BV (Rotterdam) (see 3.3). Randstad Uitzendbureau took responsibility for the distribution and collection of sampling equipment and for filling out the questionnaires (see 3.5).

[vii] Forschungszentrum Karlsruhe, Karlsruhe, Germany
[viii] Brookhaven National Laboratory, New York, USA
[ix] Lichtveld, Buis & Partners BV, Utrecht

Last but not least, RIVM was responsible for the coordination and planning of the project, construction of the samples, the full administration of all equipment, the gammaspectrometric analysis of soil samples (see 3.4), and evaluation and reporting.

3. METHODS

A variable combination of the following measurements was made for each dwelling:

1. the yearly averaged effective air flow between crawl space and living-room, and the yearly averaged effective ventilation of the crawl space and living-room,
2. the radium content of the soil,
3. the $CaCO_3$ and organic matter content of the soil, and the distribution of the soil's mineral content over three grain-size fractions,
4. the yearly averaged radon concentration in the crawl space, living-room, one of the bedrooms and outdoors.

Each of these measurements will be discussed in this chapter. When and how they were applied is summarized in Table 3-1. Matters relating to calibration, detection limits, etc. will be discussed when reporting on the results of the survey.

Table 3-1 Measurement scheme for SAMPLES N and R**

	^{222}Rn		^{226}Ra in soil		Air flow	
SAMPLE	*N*	*R*	*N*	*R*	*N*	*R*
Outdoors	8 per municipality		–	+	–	–
Living-room	+	+	–	–	+	+
Crawl space	+	+	–	–	+	+
Bedroom	–	+	–	–	–	–

* for a definition of *SAMPLE N* and *SAMPLE R* see 1.2

3.1 Radon

Passive radon dosemeters or alpha track detectors were used (Figure 3-1). These are time-integrating instruments [12]: α-particles impinging on the surface of a polycarbonate foil give rise to damage ('tracks'). Electro-chemical etching of the foil makes the tracks visible. The separation of radon and radon progeny present in the ambient air is realized by enclosing the foil in a cup fitted with a filter. As a result, the number of tracks per unit area is proportional to the measurement time and the radon concentration in the measurement room. Two different detectors, both developed by FzK, were used. The one actually in use at FzK (see Figure 3-1) was installed at all research locations. The other, older type is still in use at KVI and has been applied in most previous Dutch studies making use of alpha track detectors. It was installed for comparative purposes in 12 dwellings, next to the new detectors of FzK. The FzK detector differs from the one supplied by KVI in geometry, and in size and position of its foil.

RIVM technicians assembled the detectors of FzK from materials supplied by FzK. They vacuum-sealed the detectors in polyethylene bags in sets of two or three pieces. KVI supplied unpacked, ready-for-use detectors at the time of installation of the equipment.

Fieldworkers trained by RIVM installed the detectors (see 3.6). They kept all detectors outdoors until being installed. The KVI detectors were installed in the first few days of the month during which sampling equipment was distributed. The detectors of FzK were unpacked on site.

Twelve months later the fieldworkers collecting the detectors returned the FzK detectors to RIVM and the others to KVI. In most cases the delay between collection of a detector and its receipt by RIVM or KVI was less than 48 hours. The detectors delivered to RIVM were disassembled and the foils were vacuum-sealed in polyethylene and aluminium/polyethylene bags upon receipt. The bags were sent to FzK for analysis. Foils and detectors received by FzK and KVI were processed using standard procedures.

A FzK alpha track detector was installed in all living-rooms and -- when present and accessible -- in the crawl space. If possible it was placed next to the PFT sampling tube (see 3.2). The nearest distance between the measuring device and the walls or floor was 30 cm. To gain insight into the homogeneity of the radon concentration in the above-ground part of the dwellings, all *SAMPLE R* dwellings were equipped with a radon meter in a bedroom in regular use.

Figure 3-1 Foil with aluminum coating, open detector with etched foil and assembled alpha track detector of FzK (scale 1:0.9)

In each municipality (listed in Appendices 3 and 4) four houses were additionally equipped with two outdoor detectors to determine the ambient radon level. To protect them from the rain they were suspended from trees or wooden fences, and enclosed in a plastic flask of which the bottom had been cut out.

Detectors of KVI were installed in 12 fully equipped *SAMPLE R* dwellings, i.e. with detectors of FzK outdoors, in the crawl space, the living-room and in a bedroom. Both types of detector were installed at the same time and next to each other.

At the time RIVM launched the project, soil remediation programmes were envisaged in two city quarters studied in the Rijnmond area (see 1.2): Steendijkpolder-Zuid in Maassluis (code 556 in Appendix 4) and Woudhoek in Schiedam (code 606). Remediation activities would probably interfere with the measurements if started during the monitoring period. To allow for an intercomparison of all dwellings in the Rijnmond area and a comparison of these dwellings with the rest of *SAMPLE R*, some of the dwellings in Rijnmond were equipped with duplicate alpha track detectors. Duplicate equipment was provided for dwellings in Maassluis where, according to the draft plan of work, initiation of groundworks in the course of the monitoring period was most improbable. At the beginning of the remediation programme a complete set of detectors would be collected in each dwelling in Rijnmond, leaving some of them with another set for comparison with the rest of *SAMPLE R*. In the end the sanitation programme was started in Woudhoek as early as August 1995.

The measurements of the outdoor radon level in the survey at issue were linked to the long-term measurements with aerosol monitors of the national monitoring network [13, 14]. This link was realized by measuring the yearly averaged radon level with 16 alpha track detectors of FzK at each of 11 locations of the network and with 2 detectors of KVI at one location. The link is to be considered as an additional check on the monitoring technique for radon and offers supplementary information for interpreting time- and location-dependent changes in indoor radon levels.

3.2 Radon transport

A tracer technique for air infiltration measurements was used to quantify radon transport [15, 16]. The method uses small perfluorcarbon tracer (PFT) sources, emitting vapors at a constant rate, and miniature passive samplers adsorbing the tracer gas (Figure 3-2). By using a different tracer in each room of a dwelling, mutual transport can be quantified. Conditions for the use of this technique for radon transport measurement are:

1. Radon and the tracer will mix in the same way in the room in which they are set free;
2. There is no significant loss of either compound e.g. as a result of sorption;
3. The number of radon sources and their locations equals the number and locations of PFT sources.

In the present survey, sources with different tracers were placed in the crawl space (one source of perfluor*di*methylcyclohexane against each of the inner walls) and living-room (a source of perfluormethylcyclohexane in each of two opposite corners). Sampling tubes were placed in the middle of the living-room and the crawl space. Because other rooms and thus other radon sources than living-room and crawl space are present, the third condition is not fulfilled. As a result, the air,

and thus radon, from the crawl space contributing to that of the living-room is the only parameter which can be properly quantified. The flows averaged over one year were measured. In each dwelling the PFT equipment was installed and removed together with the alpha track detectors. At the end of the monitoring period the sorbed gas is quantified by means of ECD gaschromatography.

Figure 3-2 PFT sources and passive sampler (scale 1:0.85)

3.3 Soil characteristics

Soil samples were taken close to each dwelling of *SAMPLE R* [17]: two samples in front of the house and two at the back, at 1.5 meter distance from the outer walls and at 1/4 and 3/4 of the width of the house (see Figure 3-3). Each sample represented a soil column of 100 cm, starting 30 cm above the floor of the crawl space (see Figure 3-4). If there is no crawl space, the top 100 cm of soil was sampled. The four drillings were combined in the field, resulting in a sample of about 5L.

The samples were homogenized, dried (40 °C), sieved (< 4 mm) and mixed. The applied methods have been described in [17]. A subsample of 1L was transferred to RIVM for gamma spectrometric analysis (see 3.4).

Lime, organic matter and the mineral grain-size fractions < 2 µm, 2-50 µm and > 50 µm were determined for all samples from Maassluis (one of the municipalities in the Rijnmond area) and for 44 other samples (4 per municipality or group of municipalities (see 5.3.2)). The applied methods have been described in [17].

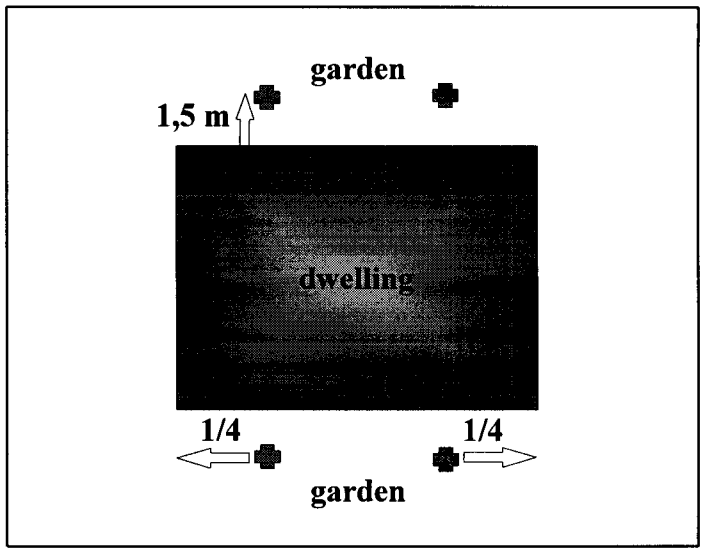


Figure 3-3 Soil sampling: sampling locations

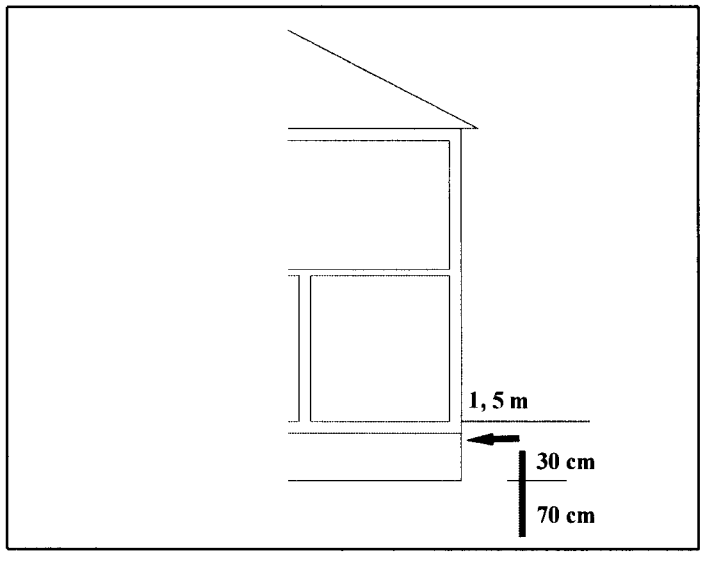


Figure 3-4 Soil sampling: position and depth

3.4 Radium

Soil samples collected close to each house of *SAMPLE R* and pretreated by IWACO B.V. (see 3.3) were analysed for ^{226}Ra. Its concentration was derived from the γ-radiations of ^{214}Pb and ^{214}Bi by means of a high purity Ge-detector. Measurements were made in duplicate on hermetically sealed samples of 300 mL. As the measurements are based on the analysis of the gamma radiations of the radon progeny, the time lag between sealing and analysis was at least three weeks.

3.5 The questionnaire

In the course of the monitoring period each house was visited in order to check the measuring equipment and to fill out a questionnaire. This questionnaire, developed by KVI [18] in the context of the STRATEGO programme (see 1.1), has been used in a number of other Dutch studies on radon. The questions pertain to parameters which are relevant for the characterisation of the sources of radon and its transport in houses, i.e.: constructional characteristics (such as dominant building materials and dimensions of the dwelling as a whole and of the rooms under investigation), means of ventilation and behavioural patterns affecting ventilation. A computerized version of the list was used [19].

The seven temporary employees filling out the questionnaires were given a two-day training at RIVM. This included use of the computerized list for three test locations. These employees received additional advice during on-site visits of a RIVM staff member and by checking their regularly submitted data.

3.6 Surveillance of activities and checks on measurements

The 27 temporary employees responsible for the installation of the measuring equipment were given a one-day training on the goals of the survey, handling the detectors, criteria for selection of proper measurement locations and communication with the participants. All employees also received a written instruction. They filled out a standard form for each house, giving identification codes of installed detectors and their position in each of the rooms (see Appendix 1). In the course of the installation period the completed forms of two randomly selected houses per employee were verified. Limited additional advice was given on the basis of observed anomalies.

The 14 employees collecting the detectors were trained in a half-day session. In addition, they received a written instruction and the layouts made at the start, however, without the identification code of the detectors. They reported their observations and identification codes on a standard form. An address label was attached to each detector before returning it to RIVM.

A number of checks on the alpha track detection technique, as for example in [20], were applied. Measurements of FzK were compared with parallel measurements of KVI and of the National Monitoring network for Radioactivity. Futhermore, from each lot supplied by FzK, unexposed foils were analysed. Leakage of packaging material was checked by analysing foils of packed and unpacked detectors simultaneously exposed in the lab.

Both unexposed and 'overexposed' PFT sampling tubes were added to the detectors to be analysed by BNL to check the reproducibility of the measurements and the registration of the samples.

3.7 Data processing

In the context of the STRATEGO programme (see 1.1) RIVM has developed a database application, called RAGE, to store data related to indoor radon [19]. The address files were created in MS-ACCESS format to facilitate export to RAGE, which has also been implemented in MS-ACCESS.

4. COMMUNICATION

4.1 Participants

The occupants of dwellings sampled from the CBS[x] database (see 5.2.3 and 5.3.3) received a letter from RIVM inviting them to participate in the survey, together with a leaflet from the Ministry of VROM, in which the background and goals of the survey are explained. After a couple of days they were contacted by phone to probe their interest and to check a number of general characteristics of their own house such as year of construction, whether removal was planned in the short term and type of dwelling. Occupants were approached both by mail and by phone to reduce non-responses and thus to increase representativeness of the samples. In order not to lose the fraction of sparsely occupied dwellings up to ten attempts were made to contact selected occupants. The calls were spread over a period of several weeks and made both during working hours and in the evening six days of the week Sundays excluded.

Based on the information collected during the phone calls, a final selection of participants was made. About one month before the start of the monitoring period occupants of selected dwellings received a second letter confirming their selection and describing planned actions. Volunteers who were not selected and people who could not be reached for one reason or another in the course of the selection procedure or in the period when equipment was installed, were sent a letter explaining their dropping-out. Its was undertaken to inform each participant on the general conclusion of the survey and on the results of his/her own house.

Throughout the monitoring period inquiries about the research could be made via a special RIVM phone number. The phone number of the Ministry of VROM contact person was given on their leaflet.

All participants were visited by a fieldworker who installed the equipment and filled out the questionnaire (see 3.5). Where no equipment was installed in the crawl space, the RIVM fieldworker has examined the preparedness of the participant to return equipment based on a written instruction, an example of which is given in Appendix 2. Those prepared to do so, received a letter and packing material at the beginning of April 1996. All others were visited in order to collect the equipment.

4.2 Local authorities

The samples were drawn from a VROM database on the Dutch housing stock. It is a copy of a database composed by CBS and based on data supplied by the local authorities. Each year they report on completed housing projects to CBS. In principle this database is solely meant for statistical analysis and not for directed sampling. As a result, the authorities of selected municipalities had to be asked for

[x] Central Bureau of Statistics

permission. They were sent a letter from RIVM, together with the leaflet of the Ministry of VROM on the background of the survey, a letter from CBS and a replication form. All local authorities granted RIVM permission to take a sample from the file.

4.3 Housing corporations

The housing corporations were informed on the survey via their respective umbrella organizations, i.e. the 'NCIV Koepel voor Woningcorporaties' and 'Nationale Woningraad'. Both organizations have a contact person for radon. The goals of the research, its set-up and potential limitations with respect to studying dwellings owned by the corporations was discussed with each of them. They were supplied with a written summary on the project for publication in the periodical of their organization.

4.4 Maassluis and Schiedam

Since the dwellings which have been studied in Maassluis and Schiedam were built on polluted soil, special attention was given to communication with these local authorities. On several occasions the project was thoroughly discussed with the responsible aldermen, municipal officials, representatives of the inhabitants and 'DCMR Milieudienst Rijnmond' (the Rijnmond Environmental Protection Agency). The planned surveys were announced in the subscription-free local papers.

5. DESIGN OF THE SAMPLE

5.1 Introduction

Just as the goals of both samples (see 1.2) are different, so is their design. The sample size, sampling strategy and the actual compilation of the sample in succession will be described for *SAMPLES N* and *R*.

5.2 Sample N

5.2.1 Sample size

As the trend in the indoor radon concentration had to be demonstrated, the number of dwellings to be studied depended on the size of the change in concentration to be detected and on the desired reliability. The estimated increase in the average radon concentration of the entire housing stock over the period 1985–2015 was 4–5 Bq m^{-3} [5]. At least half of this increase had to be detected with sufficient accuracy. Table 5-1 summarizes how many measurements have to be made to detect, with a given certainty, a difference of 2 Bq m^{-3} between two successive samples at several levels of significance. The numbers have been calculated on the basis of formulas in [21]. The geometric standard deviation of the samples was assumed to be equal to that of the survey of 1984, i.e. σ_g=1.6. A difference of 2 Bq m^{-3} can be detected with >95% certainty (P) at a level of significance of <5% (α) -- considered as minimum requirements -- with a sample size of about 1000 dwellings.

Table 5-1 Number of measurements required to detect a difference of 2 Bq m^{-3} means

α*\P†	0.90	0.95	0.99
0.10	514	670	1018
0.05	670	846	1233
0.01	1018	1233	1692

* Level of significance

† Desired probability that a difference will be found to be significant or 'intended power of the test'

5.2.2 Strategy

Out of the five different sampling strategies proposed by KVI [22], RIVM chose a two-stage strategy: in succession municipalities and addresses within each of these municipalities were selected. This approach was chosen for practical reasons, i.e. to limit the number of contacts with the local authorities and to cut down travelling distances. Furthermore, the municipalities of this sample could be used to select the locations for *SAMPLE R* (see 5.3.2).

As the sample should represent the housing stock built over the past decade, the probability of selection of a municipality was proportional to the number of dwellings built there between 1985 and 1993. The year 1985 was chosen as the

start of the study period, since sufficiently detailed, computerized data on the Dutch housing stock were available from that point onwards. This choice thus allowed for a uniform selection procedure for the study period as a whole. The year 1993 was the most recent, fully documented year at the moment of sampling.

It was decided to make 64 selections resulting at most in an equal number of municipalities, i.e. 10% out of a total of 636 [23]. A fixed number of addresses per selection had to be found. Each selection corresponds to at least 17 dwellings, taking into account an estimated drop-out rate of about 10% in the course of the monitoring period and a necessary sample size of about 1000 dwellings. Because some municipalities were randomly sampled more than once, 52 municipalities were eventually selected (see Appendices 3 and 4).

For the sample as a whole, the total number of houses per year of construction had to be constant, since the analysis of a time trend in the radon concentration was one of the goals. No further stratification was carried out because detecting a trend in the average radon level and representativeness for the total housing stock were considered far more important than, for example, a description of the geographic variation in radon concentration.

5.2.3 Selection of addresses

Addresses were selected by the Ministry of VROM from the CBS database. The files of CBS give: local authority code, number of rooms, multi/single-family home, owned/rented home and year of construction.

For *SAMPLE N*, ten addresses were randomly selected per municipality and per year over the period 1985-1993. If less than ten dwellings were built in a given year, all of them were selected. In all, 5510 addresses were sampled. PTT added names and phone numbers to the addresses. In 78% of the cases a name and phone number could be found. A delay in the incorporation of changes of address and the absence of a telephone explain a small percentage of the loss. The larger part of the loss in this phase of the selection, however, consisted of addresses with unlisted telephone numbers, which occurred more often in the big cities. As it is unknown whether this relates to a part of the housing stock differing from the overall stock in some of its characteristics, it is not possible to correct the resulting data for this loss. A total number of 1897 occupants, again randomly selected from the about 4300 addresses with phone number, were approached by mail (see 4.1).

Table 5-2 and Table 5-3 show the response rates. The total percentage of non-responses, P_N, as defined in [24], is derived from the fraction lost when linking address and phone number, the refusals (see Table 5-3) and the fraction not reached by phone (see Table 5-2) as follows:

$$P_N = 100 * [Q + (1-Q)* (A - B + G) / A] = 50\%$$

in which Q equals the fraction lost when linking address and phone number and A, B and G, the number of addresses as given in Table 5-2 and Table 5-3. Half the loss is related to the procedure chosen to select addresses and half of it occurred whilst approaching the potential participants. The non-response in studies based on contact by mail only [25, 26] was larger than 60% and 24% in a study based on a door-to-door approach of participants [24].

Table 5-2 Response to SAMPLE N

	No.	%	% of
A. Approached by mail	1897		
B. Reached by phone	1581	83	A.
C. Positive response*	1020	65	B.
D. Negative response†	561	35	B.
E. Selected for measurements	1020	100	C.
F. Successfully completed‡	992	97	E.

* A positive response means that the person was reached by phone and was willing to participate in the survey.

†A negative response means the person was reached by phone, but either refused to participate, had plans to move in the near future, had a house built before 1985 or could not be reached after the first phone call (see Table 5-3).

‡Alpha track detector of either living-room, bedroom or crawl space returned during (e.g. because of moving) or at the end of the survey period.

Table 5-3 Breakdown of negative responses for SAMPLE N

	No.	% of those reached by phone
G. Refusals	363	23
H. Planning to move	90	6
I. Built before 1985*	11	1
J. Contact broken off†	97	5
D. Total	561	35

* Dwellings were selected from files with year of construction from 1985 to 1993. However, according to 11 occupants, their home had been built before 1985.

† Occupants prepared to participate in the survey, but could not be reached to make an appointment to install the equipment.

5.2.4 Representativeness

In [27] criteria are given for 'a satisfactory national survey': measurements of adequate quality were to be made over a period of a year in the living- and bedrooms of a stratified sample of at least 1 in 10,000 of the housing stock. With *SAMPLE N* more than 1 in 1000 houses, however, in a specific segment of the national housing stock was studied. Furthermore, no measurements were made in bedrooms, contrary to *SAMPLE R* (see 3 and 5.3). Given these characteristics, *SAMPLE N* cannot be considered as a survey allowing for a comparison of the average level of radon in the Dutch housing stock with that of other countries.

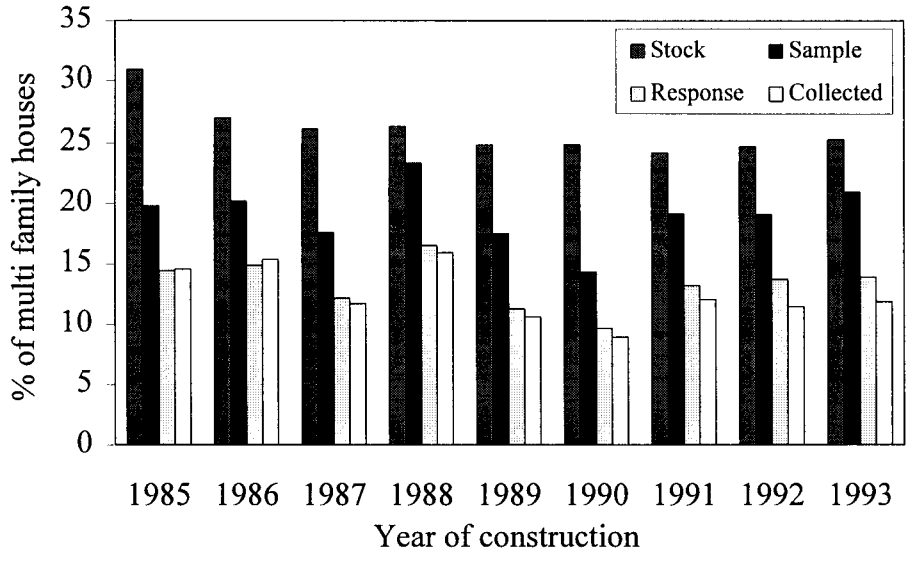


Figure 5-1 Percentage of multi-family dwellings in the Dutch housing stock (Stock), in the original sample of addresses (Sample) , for the houses participating in SAMPLE N (Response) and for those where the monitoring period was completed successfully (Collected).

Much attention was given to the approach of the occupants, which is essential to prevent the loss of information on specific fractions of the housing stock (see 4.1). The resulting selection, however, differed from the original stock for some of its characteristics, a number of which are discussed in this section.

The percentage of multi-family dwellings in the sample was compared to that in the Dutch housing stock. It is smaller in the sample of addresses than in the stock. For the selection participating in the study it was again smaller than for the sample of addresses (Figure 5-1). However, the percentage of multi-family dwellings in the selected municipalities (19.5%), as derived from data of CBS [28, 29], is comparable to that of the sample of addresses (20.9%). The sample of local authorities is thus not entirely representative for this characteristic of the Dutch housing stock.

The teleteam reported that a substantial but unquantified number of the elderly people were not prepared to take part in the project. Old people's flats are thus supposedly insufficiently represented in the sample.

According to data of CBS 57% of the houses built over the period 1985-1993 are private property, as opposed to 66% in the sample of addresses. In the final selection the deviation from the stock with respect to this characteristic is even larger (74% private property).

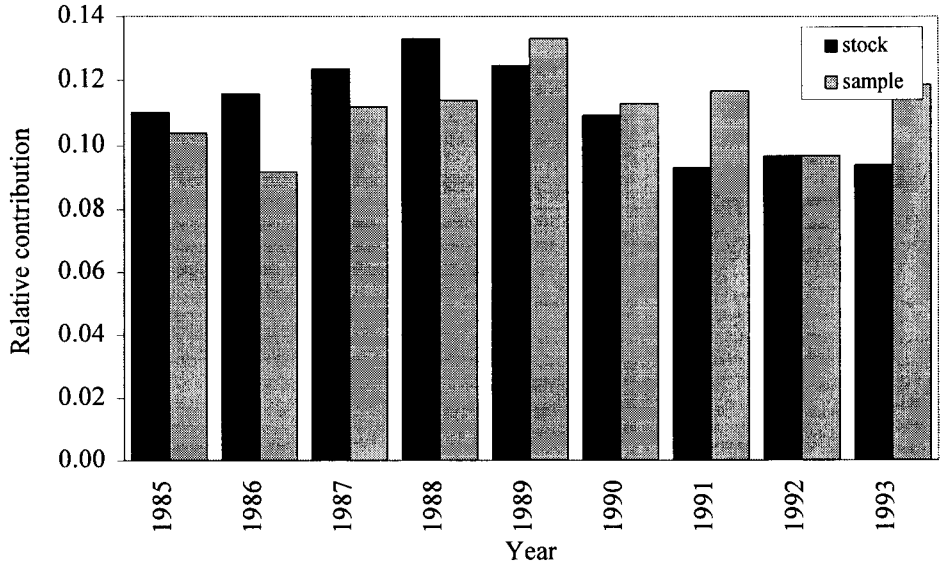


Figure 5-2 Relative contribution per year of the stock and the sample to the total number of houses built over the period 1985–1993 and the total number studied, respectively.

Over the period 1985–1993, the largest number of houses was built in 1988, that is 119,000. In 1991 building activity was lowest: 83,000 houses were completed or 30% less than in 1988. The representation of each year in the sample, however, differs from that in the stock because the sampling strategy aimed at a selection of a constant number of houses per year of construction and because of drop-outs during selection. The deviation of the sample from the stock per year is at most 30% (Figure 5-2). The first half of the period is slightly under-represented and the second half over-represented in comparison with the stock.

Table 5-4 Necessary sample size to detect a certain concentration ratio C_1/C_2 between two locations

C_1/C_2	Sample size	
	α=0.01*, P=0.99†	α=0.05*, P=0.95†
1.5	71	35
2	24	12
3	11	6

* and † see Table 5-1.

5.3 Sample R

5.3.1 Sample size

In [9] the necessary sample size to demonstrate concentration differences of up to a factor of three between two subsamples is calculated. The results summarized in Table 5-4 were calculated assuming that the geometric standard deviation for each subsample of *SAMPLE R* is equal to that of the survey reported on in 1984, i.e. σ_g=1.6. The sample size was set at 40 houses, i.e. a difference of a factor of 1.5 can be detected with a certainty of 95% (P) at a level of significance of 5% (α).

5.3.2 Strategy

A subset of 10 municipalities or groups of municipalities was chosen from the selection for *SAMPLE N* (Table 5-5). The criteria for selection were:

1. There is a sufficient number of typical single-family dwellings of about the same age.
2. The municipality is predominantly built on and surrounded by one kind of soil type.
3. The soil is one of the major soil types present in the Netherlands[xi].
4. Neighbouring municipalities could be combined to fulfill the first criterion if built on the same type of soil.

Furthermore, a city quarter in the municipality of Maassluis (Steendijkpolder-Zuid) and one in Schiedam (Woudhoek-Noord), which have been built on harbour sludge, have been selected. In Woudhoek-Noord the sludge layer was covered with a layer of sand before houses were built, in Steendijkpolder-Zuid it was not.

Table 5-5 Selected municipalities for SAMPLE R

No.	Code	Municipality	Soil type	Combined with municipality
1	0034	Almere	clay	
2	0200	Apeldoorn	sand	
3	0743	Asten	sand	
4	0385	Edam-Volendam	peat	50/50 Landsmeer/Oostzaan
5	0226	Duiven	clay	
6	0357	Egmond	sand	
7	0237	Gendringen	clay	
8	0415	Landsmeer	peat	
9	0556	Maassluis	harbour sludge	
10	0356	Nieuwegein	clay	
11	0431	Oostzaan	peat	
12	0606	Schiedam	harbour sludge	
13	0986	Voerendaal	loam	
14	0295	Wisch	clay	Gendringen

[xi] Derived from the STIBOKA soil map of the Netherlands (1:250.000) dating back to 1985.

5.3.3 Selection of addresses

Before composing *SAMPLE R*, selection criteria were formulated. As many parameters as possible, which may affect the indoor radon concentration (apart from the soil type), should be constant. The following pre-selection was made for each municipality, with the exception of Maassluis and Schiedam[xii].

From the CBS files single-family dwellings with four rooms were selected, the number most common for Dutch dwellings built over the past decade [30, 31]. The dwellings had to be completed in 1988 or 1989. Two years of construction were chosen, since an insufficient number was found in all municipalities for each single year out of the period 1985-1993.

About three addresses meeting these criteria were selected from the CBS files for each dwelling to be studied. About 80% of the selected addresses could be coupled by PTT to a name and telephone number. Information on the response rates is summarized in Table 5-6 and Table 5-7. The total percentage of non-responses as derived with the formula given in section 5.2.3 is 43%.

Table 5-6 Response to SAMPLE R✧

	No.	%	% of
A. Approached by mail	1151		
B. Reached by phone	1046	91	A.
C. Positive response*	754	72	B.
D. Negative response†	292	28	B.
E. Selected for measurements¶	484	64	C.
F. Successfully completed‡	467	96	E.

✧ Including Maassluis and Schiedam

*, † and ‡: see Table 5-2

¶ All detached houses, for example, have been removed from the selection.

Table 5-7 Breakdown of negative responses for SAMPLE R✧

	No.	% of selection
G. Refusals	221	21
H. Planning to move	55	5
I. Not built in 1988 or 1989*	2	0
J.Contact broken off†	14	1
D. Total	292	27

✧ Including Maassluis and Schiedam

* Dwellings were selected from files with 1988 and 1989 as year of construction. However, according to 2 occupants, their home had not been built in that period.

†: see Table 5-3

[xii] To be discussed at the end of this section

The type of dwelling was an additional criterion for selection. The 'enclosed town house', the most commonly built dwelling in the Netherlands over the period 1985-1993, was chosen[xiii]. The various types are not equally represented in each municipality. In some municipalities mostly detached and semi-detached houses were built (Figure 5-3).

It appeared to be impossible to obtain a sample of only enclosed town houses in all municipalities via the above-mentioned selection procedure. Finally, two groups of municipalities were defined: one with predominantly detached and semi-detached houses, i.e. Gendringen/Wisch, Asten and Voerendaal, and one with mostly enclosed town houses, i.e. all other municipalities. Locations built on clay and on sand are present in both groups. A comparable representation of the different types of dwellings in all municipalities of a given group was aimed at. Figure 5-4 shows the distributions that were actually realised.

In Maassluis (Steendijkpolder-Zuid) soil samples were taken from gardens of 120 single-family dwellings in August 1994 in the context of previous studies on artificially enhanced levels of ^{226}Ra [10, 11]. Out of this group, 80 houses of a limited type were chosen for *SAMPLE R*. Eleven of the occupants, however, refused further participation. The remaining 69 houses were subdivided into two groups: those with an average level of ^{226}Ra in the top 2.5 m of soil below 40 Bq kg^{-1}, and those above this level. The group with the higher level of ^{226}Ra coincides with the group where duplicate equipment was provided (see 3.1). All of the houses were built in the period 1976-1978.

In Schiedam (Woudhoek-Noord) soil samples were taken in public gardens in August 1994 [11]. Forty-six enclosed town houses were selected for *SAMPLE R*. The selection was limited to two out of twelve sectors of the city quarter demarcated in the study of 1994. All of these houses were built in the period 1983-1985.

[xiii] During the phone call following the introductory letter, the type of dwelling was asked. Of the group contacted for *SURVEY N* who lived in a single-familiy dwelling, 25% appeared to live in a detached house, 26% in a semi-detached house, 32% in an enclosed town house and 17% in a town houses on the corner.

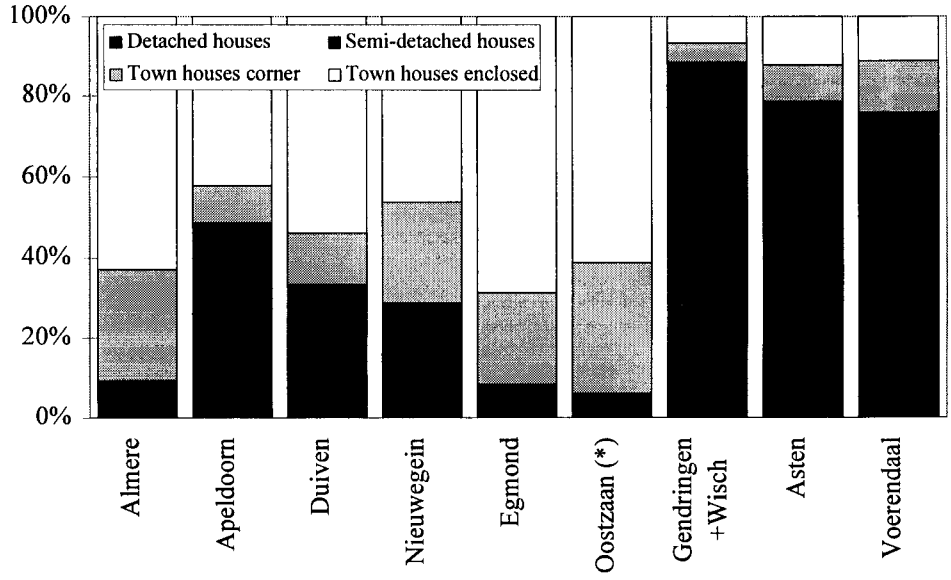


Figure 5-3 Relative importance of four kinds of single-family dwellings in each of the municipalities of SAMPLE R, except Schiedam and Maassluis. (*)= Oostzaan+Landsmeer+Edam+Volendam

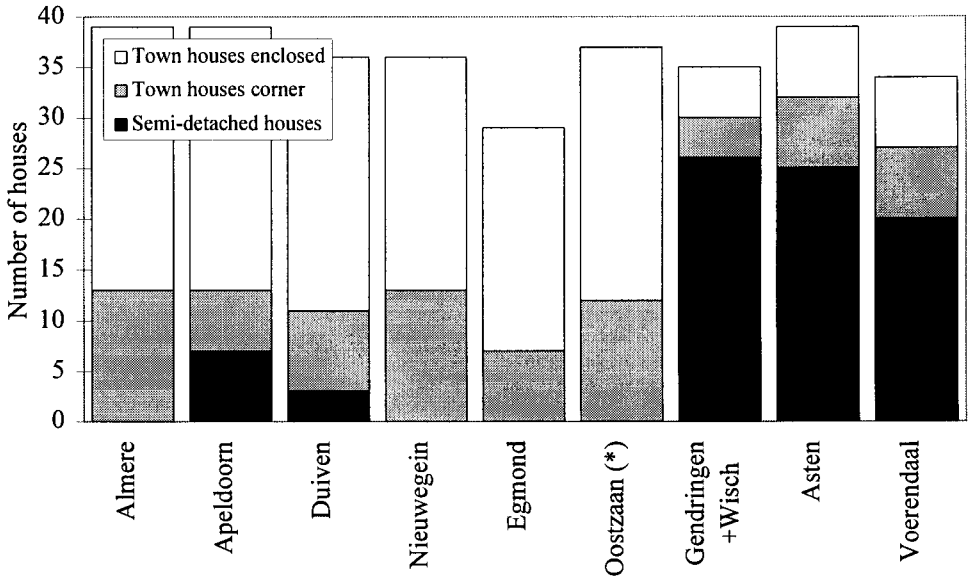


Figure 5-4 Number of dwellings per category which were eventually selected in each municipality of SAMPLE R, except Schiedam and Maassluis. (*)= Oostzaan+Landsmeer+Edam+Volendam

6. CONCLUSIONS

We have presented the set-up of a nationwide survey on radon carried out during 1995 and 1996. The survey was meant to provide: a) the frequency distribution of the annual average radon concentration in Dutch dwellings built over the past decade and b) information on the relative importance of the dominant sources of radon, i.e. soil and building materials. Two separate samples from the housing stock were taken to answer these questions.

The sample of houses selected to answer the first question differs from the original stock for a number of characteristics, the most obvious of which is the over-representation of single-family and private homes. The resulting data will have to be corrected for quantified deviations from the original stock.

The sample selected to answer the second question did not result in comparable subsamples for each of the study locations. Two groups of locations had to be distinguished: those where town houses predominate and those with mainly detached and semi-detached houses.

Information on radon and its sources was collected for about 1450 houses through placement of alpha track detectors, installation of PFT sources and passive samplers for air infiltration measurement, along with interviews with the residents. Soil samples were taken near to about one third of the houses. The study was carried out as planned. Key information was lost for about 4% of the dwellings in the course of the monitoring period.

The results of the study are dealt with in RIVM report no. 610058006, "The second Dutch national survey on radon in dwellings: results".

APPENDIX 1 - REGISTRATION FORM

CHECKLIST / REGISTRATIEFORMULIER R

☐ : Hokjes direct na uitvoeren actie markeren.
/* : Doorhalen wat niet van toepassing is.

Woning <**Straat + huisnummer**> (voorgedrukt)
<**Postcode + plaatsnaam**> (voorgedrukt)
<**Naam bewoner**> (voorgedrukt) Telefoon _____ (overdag), _____('savonds en weekend)
Bewoners bereikbaar: overdag */ 'savonds */ weekend (voorgedrukt)

Plaatsing Naam plaatser :

Datum (dag) :____ april 1995. Tijd van aankomst (uren.minuten) :____.____ voormiddag* namiddag.

1 ☐Zoek een luik naar de kruipruimte. Open dit zo mogelijk, kijk er in en sluit het weer.

Als de kruipruimte niet toegankelijk is, markeer dan dit hokje en vermeld hieronder de reden: ☐

Woonkamer

2 ☐ Haal buiten twee *rode* bronnen uit de pot.
3 ☐ Plaats deze bronnen in de woonkamer.
4 ☐ Haal het dopje van de genummerde zijde van een adsorber. Stop dit terug in de pot en sluit de pot. Noteer het nummer hier:

Adsorber woonkamer:nummer ....
5 ☐ Pak een radonmeter en noteer hier het nummer:

Radonmeter woonkamer:nummer ....
6 ☐ Plaats adsorber en radonmeter in de woonkamer.
7 ☐ Schets op de achterkant van dit formulier de woonkamer. Geef de plaats aan van de belangrijkste meubels, deuren, ramen, de *rode* bronnen, de adsorber en de radonmeter.

Slaapkamer

8 ☐ Pak een radonmeter en noteer hier het nummer:

Radonmeter slaapkamernummer:..... .....
9 ☐ Plaats deze radonmeter in de grootste slaapkamer.

Deze ligt op de: begane grond */ ____e verdieping.

Buitenmetingen (flessen)

10 ☐ Beoordeel of de woning in aanmerking komt voor een buitenmeting (boom in de tuin, bewoners gaan accoord). Als u hier een fles met twee radonmeters plaatst, vul dan de nummers in op de achterkant van dit formulier en markeer dit hokje☐

Als de kruipruimte niet toegankelijk is (zie 1) sla dan acties 11 t/m 21 over en ga door naar 22 (rechter kolom).

Grote radonbekers

11 ☐ Als u bij deze woning een fles voor buitenmeting plaatst (10) en *tevens* vijf grote radonmeters, notee dan de vijf nummers op de achterkant van dit formulier en markeer dit hokje: ☐

Kruipruimte

12 ☐ Haal een adsorber uit de pot. Sluit de pot en notee het nummer:

Adsorber kruipruimte:nummer .....
13 ☐ Pak een radonmeter en noteer het nummer:

Radonmeter kruipruimte:nummer .....
14 ☐ Maak de adsorber zonder het dopje er af te halen vast aan een stukje draad en leg deze naast het kruipruimte-luik.
15 ☐ Doe hetzelfde met de radonmeter. Zet de pot met adsorbers er naast. Open het luik.
16 ☐ Neem de pot met de *oranje/gouden* bronnen, de tang, de schaar en de tape mee naar buiten. Haal twee bronnen uit de pot uit en sluit de pot. Maak aan elke bron een stuk draad vast.
17 ☐ Doe beschermende kleding aan en plaats de *oranje/gouden* bronnen in de kruipruimte.
18 ☐ Ga terug naar het luik, haal nu het dopje van de adsorber, stop dit in de pot en sluit de pot. Plaats adsorber en radonmeter in de kruipruimte.
19 ☐ Schat de hoogte van de kruipruimte:
Hoogte kruipruimte: _____ cm.
20 ☐ Schets op de achterkant van dit formulier de situatie in de kruipruimte. Geef op deze schets de plaats weer van de bronnen, adsorber en radonmeter.
21 ☐ Trek de beschermende kleding uit en sluit de kruipruimte.

22 ☐ Laat de woning schoon achter.

Woonkamer

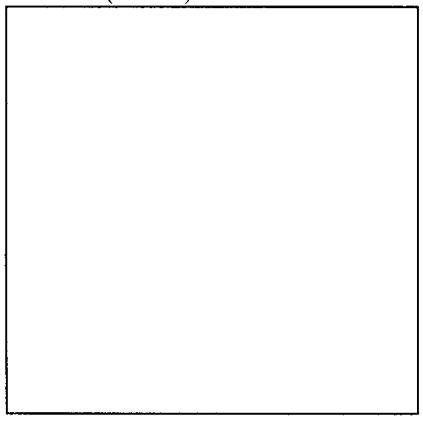
B Bron +++ raam
A Adsorber ooo deur
R Radonmeter

Schets de belangrijkste meubels. Zorg dat de voorkant van het huis (voordeur) boven zit.

Slaapkamer

B Bron +++ raam
A Adsorber ooo deur
R Radonmeter

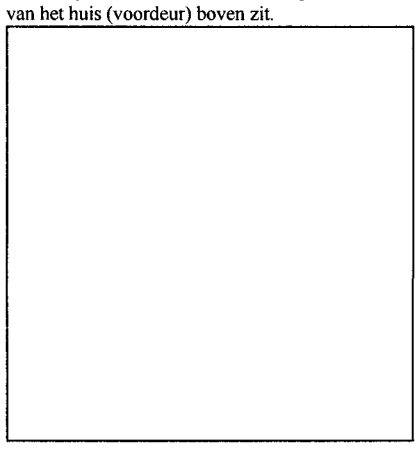
Schets de belangrijkste meubels. Zorg dat de voorkant van het huis (voordeur) boven zit.



Kruipruimte

B Bron ═══ binnenmuur
A Adsorber
R Radonmeter

Geef de plaats van het luik aan. Zorg dat de voorkant van het huis (voordeur) boven zit.



Als bij deze woning ook een **buitenmeting** plaatsvindt, noteer dan hier de nummers van de twee radonmeters in de fles:

Radonmeter 1 in fles buiten nr. .....

Radonmeter 2 in fles buiten nr. .....

Als bij deze woning een buitenmeting plaatsvindt en er ook nog vijf **grote radonbekers** zijn geplaatst, vermeldt dan hier de nummers:

Grote radonmeter kruipruimte nr. .....

Grote radonmeter woonkamer nr. .....

Grote radonmeter slaapkamer nr. .....

Grote radonmeter onderin nestkast nr. .....

Grote radonmeter bovenin nestkast nr. .....

APPENDIX 2 - INSTRUCTION FOR PARTICIPANTS

Registratieformulier **W/S/B**

Naam
Straat + huisnummer
Postcode + plaats

Voer de acties (1.) tot en met (4.) uit in de periode tussen 8 en 19 april.

1. Zoek de adsorber in de woonkamer. Deze is met **A** aangegeven op de schets. Het is een glazen buisje met, als het goed is, aan één zijde een zwart dopje. Aan de andere zijde is het buisje open.
   *Vraag: alleen op de ONgenummerde zijde van het buisje zit een dopje? Ja / Neen**
   In de enveloppe met het RIVM antwoordnummer (3205) zit een plastic zakje en een kokertje. In het kokertje zit een zwart dopje. Sluit met het dopje de open zijde van de adsorber af.

2. Schuif het glazen buisje in het kokertje en stop het geheel in het plastic zakje.

3. Zoek de radonmeter in de woonkamer. De radonmeter is een zwart, rond doosje en is met **R** aangegeven op de schets.
   *Vraag: de meter staat/hangt zó dat de ronde gleuf waaronder zich een wit filter bevindt, zichtbaar is? Ja / Neen** *Het nummer op de meter is:* .....
   Zoek de radonmeter in de slaapkamer.
   *Vraag: de meter staat/hangt zó dat de ronde gleuf waaronder zich een wit filter bevindt, zichtbaar is? Ja / Neen** *Het nummer op de meter is:* .....
   Zoek de twee radonmeters die buiten zijn opgehangen.
   De nummers op de meters zijn: ....

   Stop de radonmeters in hetzelfde zakje als de adsorber. Knoop het zakje dicht en stop het in de enveloppe met het RIVM antwoordnummer (3205).

4. Sluit de enveloppe goed af, vermeld postcode en huisnummer in de linker bovenhoek en post ze nog dezelfde dag.
   Vraag: de adsorber en de radonmeters zijn weggehaald en verzonden op ..... (datum invullen).

Voer de acties (5.) en (6.) uit in de periode tussen 29 april en 3 mei.

5. Zoek de twee bronnen in de woonkamer. De bronnen zijn gekleurde aluminium capsules (oranje of rood) en zijn met **B** aangegeven op de schets.

6. Stop de bronnen in het plastic zakje dat u vindt in de enveloppe met het VROM antwoordnummer (10907). Knoop het zakje dicht. Stop het zakje en ook dit registratieformulier in deze enveloppe. Sluit ze goed af en vermeld postcode en huisnummer in de linker bovenhoek. Verzend deze tweede enveloppe tussen 29 april en 3 mei.

Samen verpakken van de adsorber en de bronnen maakt de metingen onbruikbaar! Hetzelfde geldt voor het samen verzenden van beide enveloppen!

HARTELIJK DANK VOOR UW MEDEWERKING

* Doorhalen wat niet van toepassing is

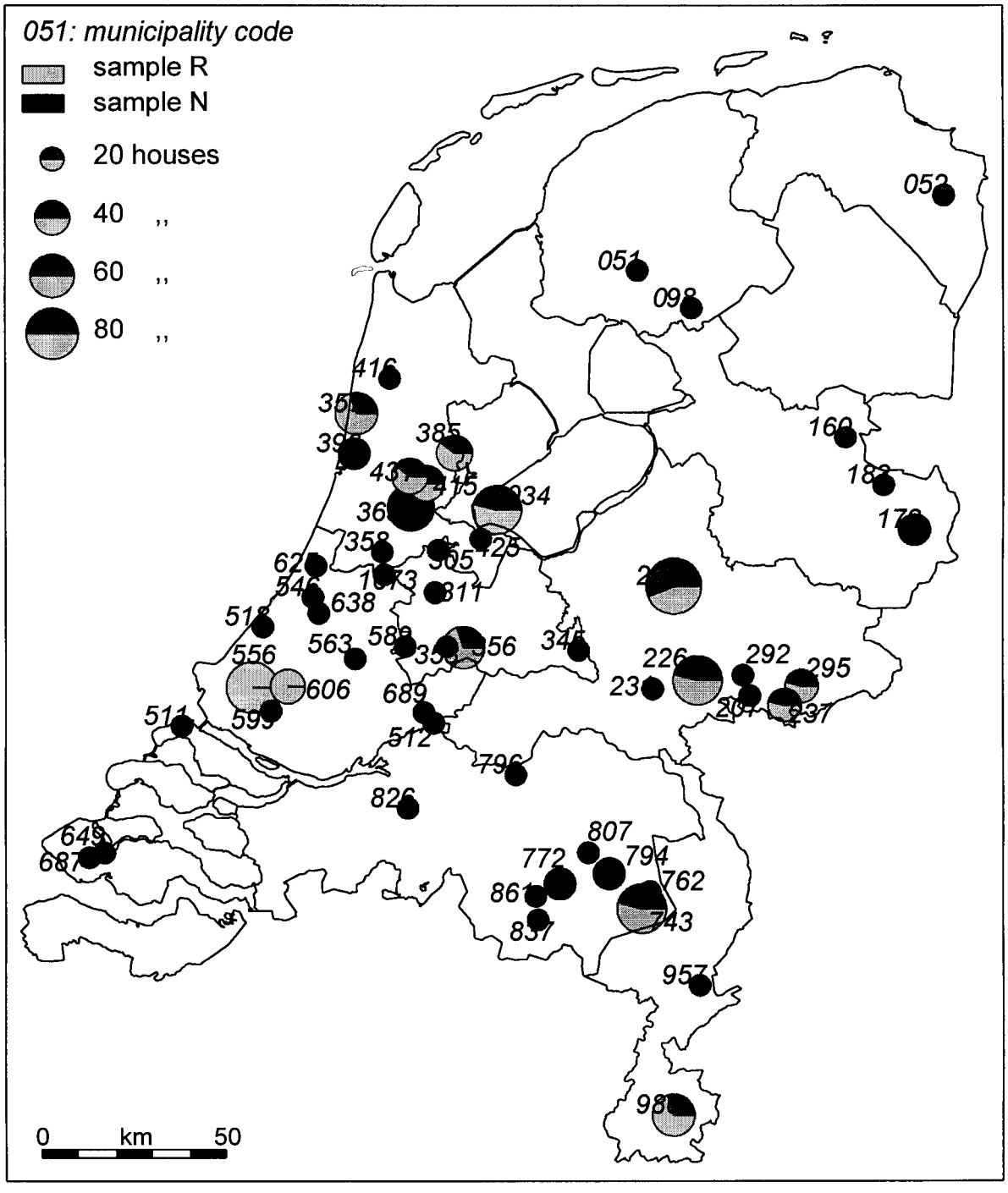
APPENDIX 3 - MUNICIPALITIES OF SAMPLE N

No.	Code	Municipality	No. selections	Urbani-zation†	Inhabitants*	Housing stock*	Province
1	0358	Aalsmeer	1	4	21902	8069	NH
2	0305	Abcoude	1	4	7992	3164	U
3	0034	Almere	2	3	98444	37890	Fl
4	0363	Amsterdam	4	1	724096	350214	NH
5	0200	Apeldoorn	3	3	149449	56977	Gld
6	0649	Arnemuiden	1	5	4921	1742	Z
7	0743	Asten	2	4	15772	5376	NB
8	0207	Bergh	1	5	17830	6453	Gld
9	0311	Breukelen	1	4	13746	5182	U
10	0762	Deurne	1	4	30611	10800	NB
11	0226	Duiven	2	4	22395	8604	Gld
12	0385	Edam-Volendam	1	3	25640	9492	NH
13	0357	Egmond	1	4	11518	4609	NH
14	0772	Eindhoven	2	2	196130	84299	NB
15	0231	Elst	1	4	18470	7039	Gld
16	0237	Gendringen	1	4	20547	7469	Gld
17	0689	Giessenlanden	1	5	14215	5055	ZH
18	0511	Goedereede	1	5	10848	4017	ZH
19	0512	Gorinchem	1	2	31090	13267	ZH
20	0518	's-Gravenhage	1	1	445279	202653	ZH
21	0160	Hardenberg	1	5	33463	10815	O
22	0396	Heemskerk	2	2	34555	13461	NH
23	0794	Helmond	2	3	72293	29483	NB
24	0796	's-Hertogenbosch	1	2	95448	40467	NB
25	0415	Landsmeer	1	4	10445	4080	NH
26	0416	Langedijk	1	4	22236	7742	NH
27	0546	Leiden	1	1	114892	47387	ZH
28	0807	Lieshout	1	5	6137	2115	NB
29	0687	Middelburg (Z.)	1	2	40118	16824	Z
30	0563	Moordrecht	1	4	7277	2529	ZH
31	0425	Naarden	1	4	16570	6942	NH
32	0356	Nieuwegein	1	2	58340	22127	U
33	1673	Nieuwveen	1	5	6928	2217	ZH
34	0173	Oldenzaal	2	3	21690	6616	O
35	0826	Oosterhout	1	3	50038	19454	NB
36	0431	Oostzaan	1	4	8047	3248	NH
37	0589	Oudewater	1	4	8284	2981	U
38	0837	Riethoven	1	5	2278	807	NB
39	0957	Roermond	1	3	43110	17980	L
40	0599	Rotterdam	1	1	598521	278419	ZH
41	0051	Skarsterlan	1	5	12571	4335	F
42	0183	Tubbergen	1	5	19182	5739	O
43	0345	Veenendaal	1	2	53045	19594	U
44	0861	Veldhoven	1	3	39817	14986	NB
45	0986	Voerendaal	1	5	13178	4879	L
46	0625	Voorhout	1	4	11185	3978	ZH
47	0292	Wehl	1	5	6609	2123	Gld
48	0098	Weststellingwerf	1	5	13780	5434	F
49	0052	Winschoten	1	3	18771	8422	Gr
50	0295	Wisch	1	5	19873	7411	Gld
51	0353	IJsselstein	1	3	22527	8594	U
52	0638	Zoeterwoude	1	4	8544	2901	ZH

* Source [23]

† Urbanization: 1: very heavily urbanized, 2: heavily urbanized, 3: moderately urbanized, 4: little urbanized, 5: non-urbanized

APPENDIX 4 - GEOGRAPHIC PRESENTATION OF RESEARCH LOCATIONS



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