A large-scale study of a measure against soil gas radon (*)

E. R. VAN DER GRAAF and R. J. DE MEIJER
Kernfysisch Versneller Instituut, University of Groningen
Zernikelaan 25, 9747 AA, Groningen, The Netherlands

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Summary. — This paper presents the results of a large-scale study (50 single family houses with a crawl space) on the effectiveness of using a foil on the crawl space floor in combination with a Sub-Foil Air Removal (SFAR) system as a measure for reducing indoor radon concentrations. Radon measurements in both crawl spaces and living room of houses with and without the measure show a significant reduction with a factor of 2.5 in the crawl space and 1.35 in the living room.

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1. – Introduction

In 1994 the Dutch Government announced the intention to develop a policy for reducing the annual average radon concentration in the Netherlands from 30 to 20 Bq m^{-3}. Previous research had shown that such a reduction was feasible by implementing measures against radon entry from the soil (then believed to contribute about 70% to the indoor concentration).

One of the contemplated measures was using a foil on the crawl space floor in combination with a sub-foil air removal system ("SFAR"-system). In experiments in the KVI test house [1] this measure was found to reduce the crawl space radon concentration by about 70%.

Early in 1993 the KVI proposed a large-scale study in order to validate the effectiveness of a "SFAR"-system. To minimize the costs of the project it was decided to implement the measure during the construction phase of new housing estates. The developers (contractor, architect, geotechnician, housing association, local government) of these housing estates were asked to participate and an appropriate SFAR system was designed, in collaboration.

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2. – Materials and methods

2·1. *SFAR-system.* – The "SFAR"-system (fig. 1) consists of: a robust groundwater drainage system of two parallel water drainage tubes instead of the usually used single tube (to avoid groundwater entering the system); an air ventilation tube (30 m) lying in zigzag fashion on the crawl space floor and covered with a polyethylene foil that is sealed against the crawl space wall; a vertical ventilation shaft connected to the middle of the tubing on the crawl space floor and extending to the roof; and a continuously working mechanical ventilation system (fan) that removes the radon-rich sub-foil air. This fan is also used for removing air from the kitchen and the bathroom.

2·2. *Houses.* – The construction of the houses that participated in this study was completed in June-September 1995. The houses are located in two housing estates situated in the northeastern part of the city of Groningen, namely "Waterland" (26 identical houses owned by a housing corporation) and "Zonland" (24 somewhat larger, privately owned houses, all identical). The "SFAR"-system was installed in 25 houses (13 in "Waterland" and 12 in "Zonland"), in the other 25 houses no system was installed and these were appointed to serve as "controls". The "control"-houses were similar in orientation and position with respect to the "SFAR"-houses and also had the robust groundwater system installed to avoid variations due to differences in water table.

2·3. *Radon measurements.* – At the end of November 1995, passive radon concentration monitors [2] were installed in both the living rooms and the crawl spaces of all 50 houses. Monitors in the crawl spaces were replaced in June 1996 (to avoid overexposure of the track-etch detectors) and all monitors were collected after 12 months (November 1996). The measurement periods will be designated as period 1 (Nov95-Jun96), period 2 (Jun96-Nov96) and period 1 + 2 (Nov95-Nov96).

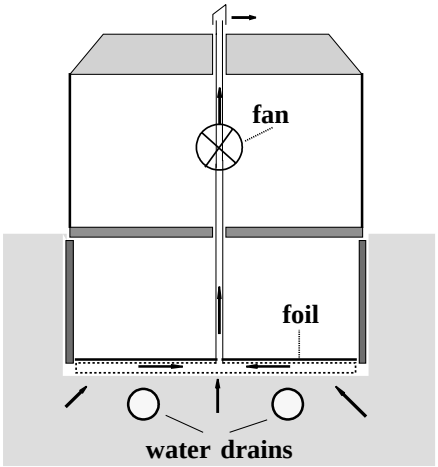

Fig. 1. – Schematic drawing of the SFAR-system.

3. – Results

Radon concentrations are often found to follow a log-normal distribution [3]. For this, the cumulative percentages (probability axis) of the radon concentrations measured in "Waterland" and "Zonland" during the three periods were plotted (see fig. 2) against the concentrations (logarithmic axis). Ideal log-normal distributions would result in straight lines.

A W-test [4] showed that in all cases the radon concentration distribution did not significantly differ (5%-level) from a log-normal distribution except for the living rooms in "Zonland" of which the highest value of the "SFAR"-group tested as an outlier and was discarded in the further analysis.

For all sub-groups geometric average radon concentrations (table I) were calculated and from these the reduction factors (defined as the ratio of the geometric average concentrations of the "control"- and "SFAR"-group) were deduced (see table II). As in all sub-groups the radon concentrations were log-normally distributed,

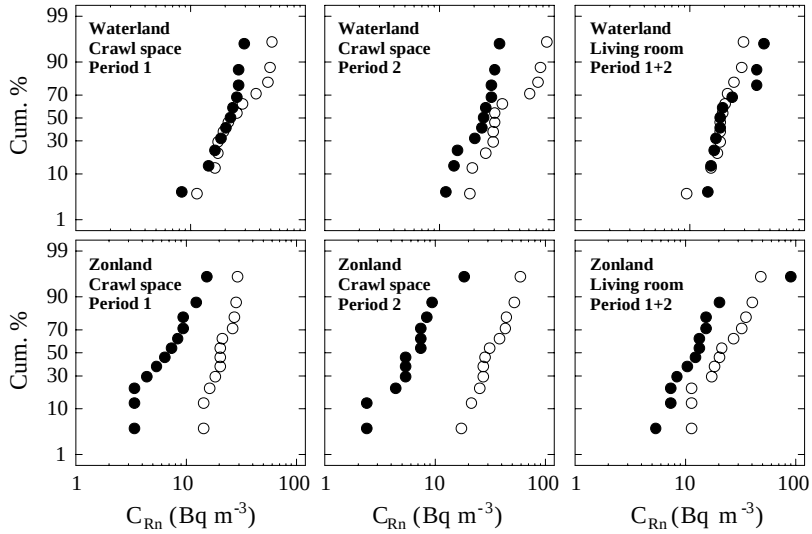

Fig. 2. – Cumulative percentages (vertical probability axis) of the radon concentrations in crawl spaces and living rooms in "Waterland" (top) and "Zonland" (bottom) as a function of the radon concentration (horizontal logaritmic axis); ○ "controls"; ● "SFAR"-houses.

TABLE I. – *Geometric means and standard deviations (in parenthesis) of radon concentrations* (Bq m^{-3}) *for different groups and periods; n: number of dwelling in group.*

	Location	Period	Control	*n*	Measure	*n*	Significant
Waterland	crawl space	1	25.5(1.6)	12	20.0(1.4)	11	no
	crawl space	2	37.4(1.7)	12	21.8(1.4)	11	yes
	living room	1 + 2	20.2(1.4)	13	22.1(1.5)	12	no
Zonland	crawl space	1	20.9(1.3)	12	6.6(1.7)	12	yes
	crawl space	2	32.6(1.5)	12	6.0(1.8)	12	yes
	living room	1 + 2	22.0(1.7)	12	11.0(1.5)	11	yes

TABLE II. – *Reduction factors in Waterland and Zonland; 1σ uncertainty is given in parenthesis.*

Location	Period	Waterland	Zonland	All dwellings
crawl space	1	1.28(0.12)	3.2(0.9)	2.1(0.4)
crawl space	2	1.71(0.14)	5.4(1.6)	3.1(0.6)
living room	1 + 2	0.91(0.09)	2.0(0.3)	1.35(0.18)

t-tests [5] were used to determine if the differences between "control"- and "SFAR"-groups were significant (see table I, all tests at 5%-level).

4. – Discussion and conclusions

The "SFAR"-system reduced the crawl space concentration with a mean factor of 1.5 in "Waterland" and of about 4 in "Zonland". It is speculated that the lower reduction in "Waterland" is due to the somewhat smaller capacity of the installed suction fans. This smaller reduction is probably also the reason why in "Waterland" no significant reduction is effectuated in the living rooms as is the case in "Zonland".

In a recent indoor radon survey [6] (sample representative for the Dutch building stock of 1985-1994) it was found that the average concentration was 28 Bq m^{-3} and the largest contribution was due to building materials (70%). In the light of this last finding it is surprising to find a significant (5%-level) overall reduction (factor 1.35) in the living rooms of both housing estates, probably indicating that the relative source strength of soil and building materials may differ dramatically between different types of houses.

In conclusion, this study demonstrates that the application of a "SFAR"-system can significantly reduce indoor radon concentrations even in houses with low pre-mitigative values. Taking the overall reduction of 1.35 as representative for new Dutch houses, the application of a "SFAR"-system could reduce the present average living-room radon concentrations of 28 Bq m^{-3} to 21 Bq m^{-3}.

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