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BUILDINGS WITH ENHANCED RADIOACTIVITY IN SWEDEN

Gun Astri Swedjemark
National Institute of Radiation Protection

Enhanced radon/radon daughter concentrations indoors have been found in some houses in Sweden, especially in combination with low air exchange rates. The radon sources have been found to be some types of building materials, some types of filling materials, some types of ground and any combination of these sources. The radon source may also be radon-rich tap water. The same types of building materials also give an enhanced gamma radiation level.

The instruments used and estimations of the errors due to measurements have been described earlier (Sw 74, Sw 78). For momentary measurements of radon and radon daughters the inhabitants are asked not to air the house either by opening windows or by using the kitchen fan from 9 o'clock in the evening prior to the measurements. In all houses, both lower and higher concentrations of radon than the average levels given here have been found in individual rooms and with single measurements.

Building materials as the radon source

Most of the building and filling materials giving rise to enhanced radioactivity in Sweden today are based on alum shale. A minor but not negligible problem is presented by granites containing high levels of uranium and thorium used as filling materials or as ballast materials in concrete. It has been used to a lesser extent and generally it contains less uranium than the alum shale.

The most common of the alum shale based building materials is aerated concrete which contains about 1 300 Bq kg^{-1} (35 pCi g^{-1}) of radium-226 as weighted average for all the producers (Sw 79). This material was produced between 1930 and 1975. Wastes from the handling of alum shale for producing alum or burned lime have been used as filling materials around houses, in floor structures and as ballast materials in ordinary concrete. The waste material contains between 100 and 3 900 Bq kg^{-1}

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GS/LF 100 ex

(3 - 100 pCi g^{-1}) (Sw 79-2).

The radon concentrations indoors in houses almost entirely built of alum shale based aerated concrete were between 200 and 1 200 Bq m^{-3} (5 - 32 pCi l^{-1}) and the air exchange rates between 0.2 and 0.6 changes per hour as averages for the houses (Sw 80). This has been illustrated in Fig 1 a, where the radon concentrations have been plotted in a diagram together with the calculated steady state concentrations as a function of the air exchange rates. The curves have been adapted to observed levels in various types of houses (S-E 81). The absorbed dose rates in air from γ-radiation indoors were between 350 and 690 nGy h^{-1} (35 - 69 µrad h^{-1}) as averages of measurements in the middle of the rooms.

The alum shale based aerated concrete contains various activity concentrations, as mentioned above, and most houses containing this material are not entirely built of the material. This is the explanation of the fact that most houses built of alum shale based aerated concrete have average radon concentrations of about 200 Bq m^{-3} (5 pCi l^{-1}). The radon concentrations in some groups of apartment houses partly built of the material are illustrated in Fig 1 b.

In houses built of concrete with alum shale waste as ballast material, with the same material as filler around the foundations and with approximately .5 air exchanges per hour, the radon concentrations found were between 500 and 800 Bq m^{-3} (13 - 22 pCi l^{-1}).

It has been estimated that between 3 000 and 15 000 dwellings, 0.04 - 0.18 per cent, of the existing dwellings are built entirely of the alum shale based aerated concrete. It has been estimated that between 10 and 20 per cent are built of aerated concrete based on alum shale to a major extent. These estimates are confirmed by the results of the searches for houses with high radon concentrations made by the local health authorities (Wa 80).

The ground as radon source

The radon exhalation from the ground varies from place to place and in some areas the radon exhalation is higher than usual. These areas are mostly those with bedrocks of granites or alum shales.

Granites may contain high levels of uranium and thorium and alum shales contain high levels of uranium.

Radon in the air indoors passing through the building materials from the ground has been found in several countries (EPA 79, Gu 78, Le 78, Cu 73). In Sweden the extent of the problem was first recognized only a few years ago. In 1978 enhanced radon concentrations were found in houses built of normal materials on sites consisting of abandoned waste from alum shale mining. These houses had air exchange rates between 0.09 and 0.28 changes per hour. The average radon concentrations were found to be between 400 and 1 600 Bq m^{-3} (11 - 43 pCi l^{-1}) (Sw 80-2) illustrated in Fig 1 c. The average radon daughter concentrations were about 500 Bq m^{-3} (14 pCi l^{-1}). The γ-levels indoors were about the same as in most one-family houses built of normal building materials.

A long-term registration in the cellar of a house in a granitic region built of normal building materials and with natural ventilation and a kitchen fan is shown in Fig 2. The variations mostly depend on use of the kitchen fan or to airing by opening windows. The average radon concentration is around 500 Bq m^{-3} (15 pCi l^{-1}) which is about eight times the average level for Sweden.

It has been estimated that 200 to 2 000 houses in Sweden may be built on ground where the radon exhalation might give enhanced concentration of radon indoors compared with houses on "normal" ground.

In granitic regions where the radon exhalation from the ground is high the concentrations of radon and radium in the ground water also may be high. 1 000 Bq l^{-1} (25 nCi l^{-1}) of radon is not unusual in deep bored wells in such regions and in several wells concentrations of 4 000 Bq l^{-1} (100 nCi l^{-1}) have been found.

However, the problem with enhanced radon concentrations in houses built of materials with enhanced radium concentrations or on limited regions with higher radon exhalation from the ground than usual can be handled because of its limited extent. A more difficult problem is the collective dose to the population; this has doubled since the 1950s for various reasons (Sw 78). One reason is that all types of houses often contain more stone materials today. Another reason is that new techniques have made it possible to build houses more airtight and this is combined with the wish to decrease the air exchange rates to save energy. Futhermore, the radium concentration in the alum shale based aerated concrete has increased. For the collective dose to the population, more people live today in apartment houses, which mostly are built of stone materials and more houses built of aerated concrete based on alum shale is to be found in the existing buildings.

Countermeasures

When we found dwellings with enhanced radon concentrations the inhabitants were informed about simple measures which would increase the air exchange rate, for example opening the air ducts, removing sealing strips around the windows and regular airing of the house.

In 1979 the government formed a committee on measures against radiation hazards in buildings etc. A preliminary report was presented in May 1979 (SRC 79).

The proposals concerning research and provisional limits etc given in the report were the basis for a proposition from the Government in February 1980. Among other things this proposition commissioned the national authorities responsible for health and for building to propose provisional limits in concert with the National Institute of Radiation Protection. A provisional action limit for existing dwellings, 400 Bq m^{-3} (10 pCi l^{-1}), as an annual average of the equilibrium equivalent concentration of radon was established by the National Board of Health and Welfare and it has been in use since September 1980. Provisional limits for rebuilt and for new dwellings have been established by the National Board of Urban Planning in the Swedish Building Code of 1980 and come in use January 1st 1981.

Tests have been made of various technical solutions for reducing the radon/radon daughter concentrations and the results will be published, among others, by the Council of Building Research. Enhanced radon concentrations are often found because of a combination of bad ventilation and one or several radon sources with unusually high activity. One solution is therefore to instal mechanical ventilation systems with heat-exchangers. This has been tested in a single-family house with cellar where the ground has been the major radon source, but has not reduced the radon concentration to a sufficiently low level. There are also problems with noise and energy consumption when the air exchange rates must be kept over 0.5 - 1 h^{-1}. In houses built almost entirely of alum shale based aerated concrete, the installation of heat-exchangers decreased the radon concentrations to acceptable levels. In one house built on a crawl space a very good result was obtained by using the outlet air from the house ventilation to ventilate the crawl space.

For the houses where the filling around the ground was alum shale waste, the best effects were found when the material was replaced by filling materials with normal contents of radioactivity within four meters from the house. However, it is difficult to issue recommendations to the public in this case because if there is also active material under the house, the effect of removing the material around the house will be insufficient.

Tests have also been carried out on the effect of applying aluminium foil to the walls in existing houses and of plastic foils on the bottom slab in new built houses to prevent the radon coming from the ground, but the results have not yet been evaluated.

One problem when applying the provisional limits is the requirements on measurements and evaluation. They are beeing worked out by the National Institute for Testing and Metrology in concert with our Institute. Three methods are used today, α-sensitive film, passive radon monitors and momentary sampling of radon daughters. The integrating methods are preferable because of the varying radon levels indoors. However, at present the α-sensitive films give a large error in measurements at low levels. These errors are lower for the passive radon monitor, but when estimating the annual radon daughter concentration the deviation of the equilibrium factor (F-factor) must be taken into account. All these methods are also rather expensive. An inexpensive integrating detector for radon daughter measurements, simple to use, and sensitive enough to measure concentrations down to 70 Bq m^{-3} (2 pCi l^{-1}) during a resonable long time would be desirable.

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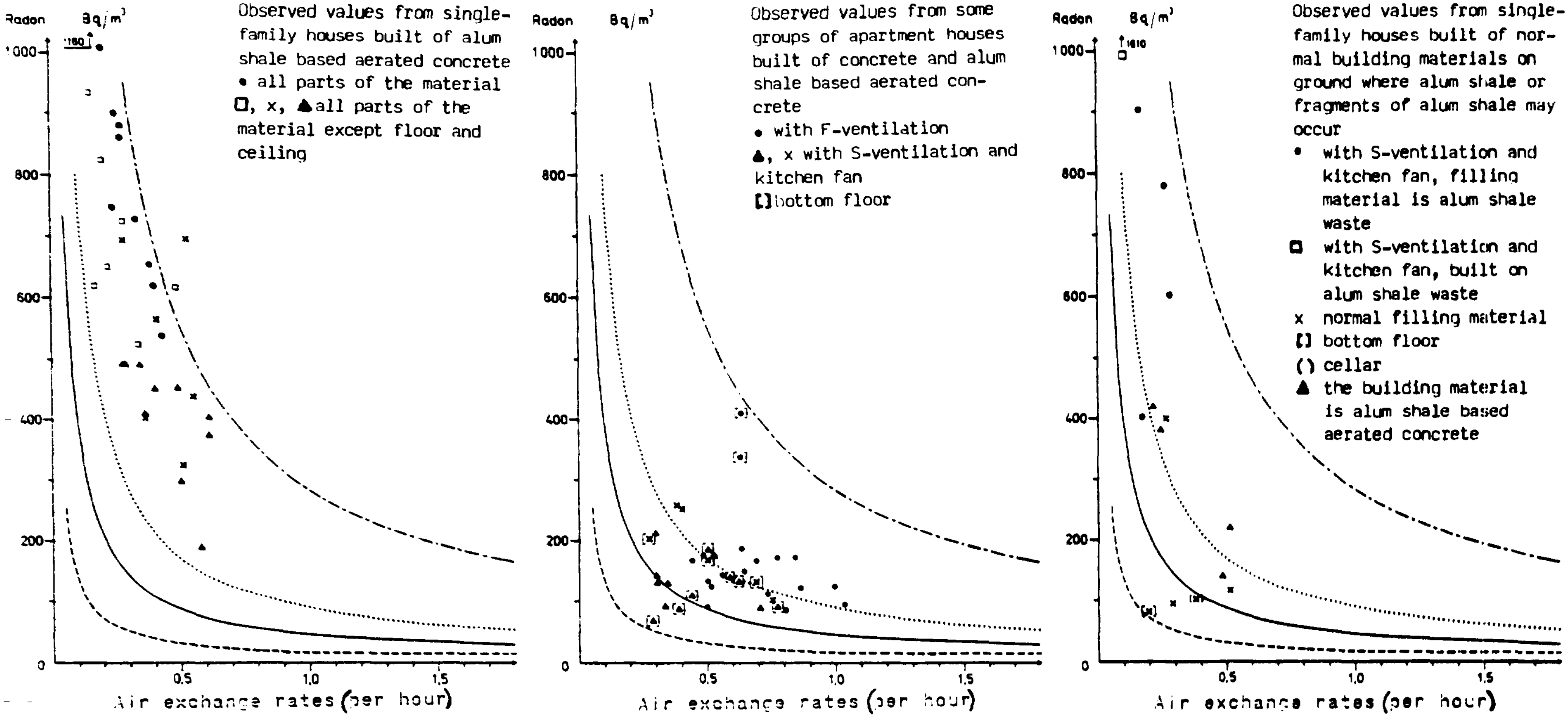


Fig 1. The steady state radon concentration as a function of the air exchange rate according to the equation $C = (C_{in} + G/V)(\ell + \lambda)^{-1}$, where C is the radon concentration at steady state, C_{in} is the radon concentration in the supply air, ℓ is the air exchange rate, λ is the disintegration constant for radon, G is the exhalation rate for radon in the dwelling and V is the volume of the dwelling. The curves have been adapted to experimental values for various types of houses on normal ground. - - - - - Wooden single-family houses without cellar, ———— Wooden single-family houses with cellar of concrete or granite or apartment houses of concrete or bricks, ········· Average for houses built of alum shale based aerated concrete, —·—·—·— Examples on a house with unusually high radon concentration.

Fig 2. The variation during a four week period of the radon concentration in a cellar in a single-family house with natural ventilation and a kitchen fan. The wind speed, outside temperature and air pressure are also given.

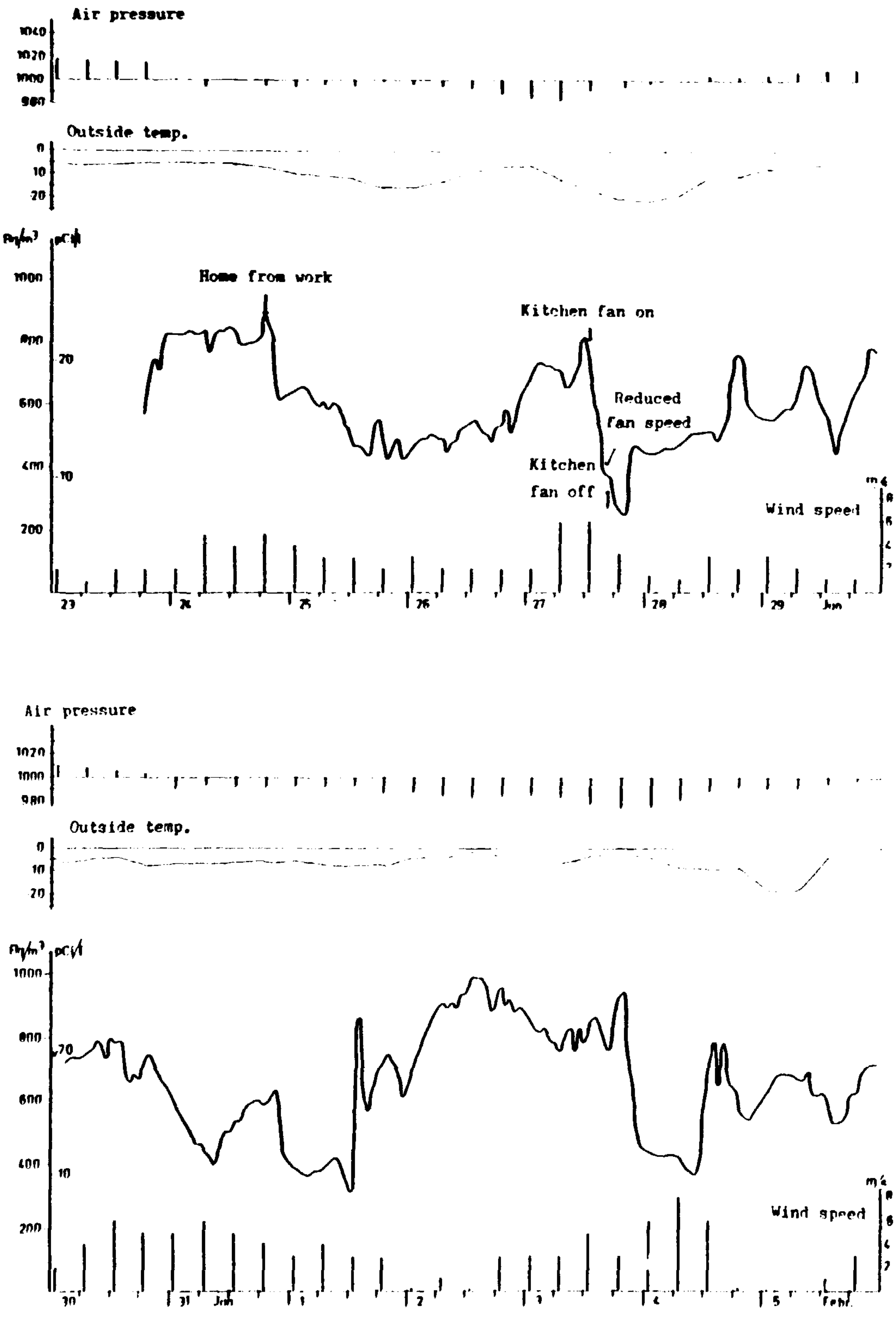
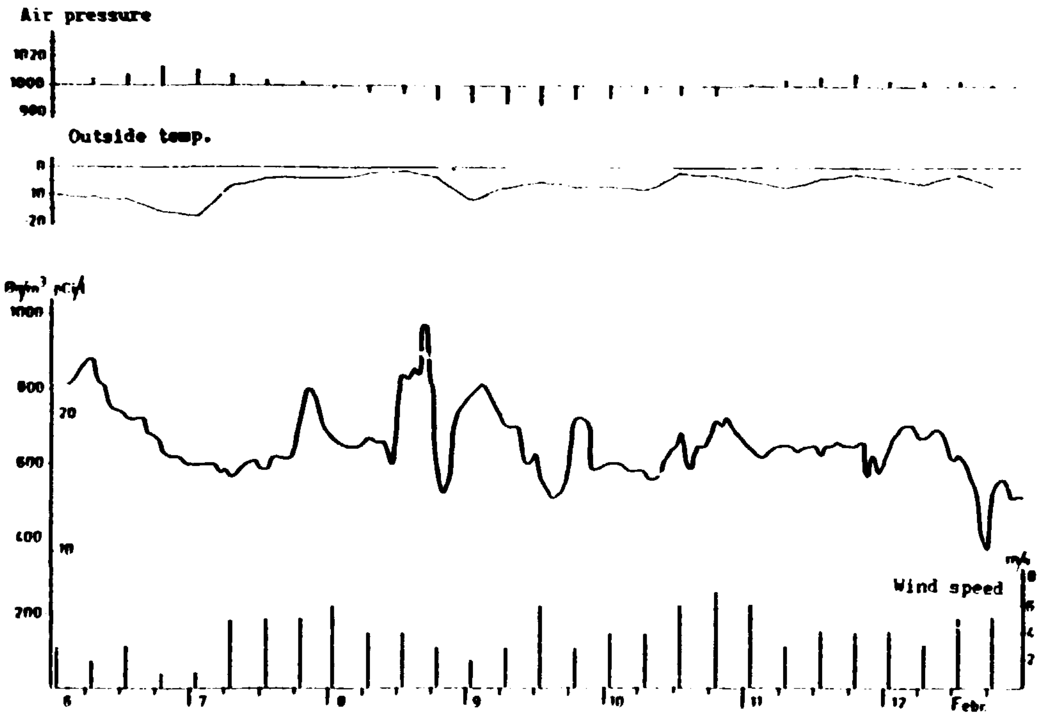
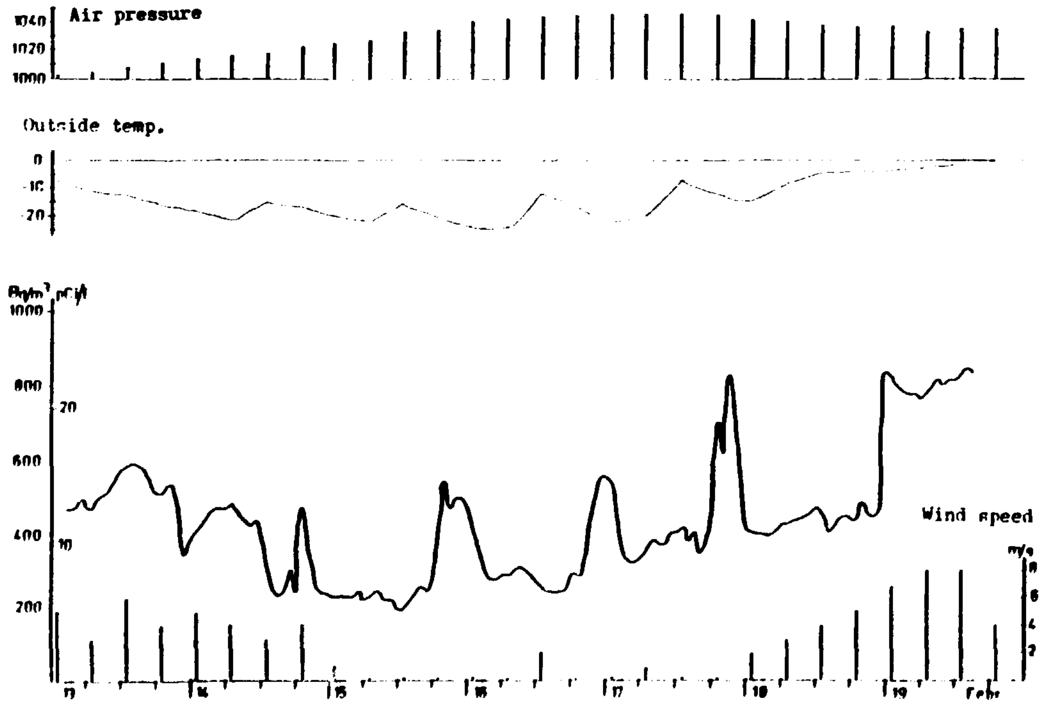


Fig 2 cont.



Air pressure
1020
1000
980
Outside temp.
0
-10
-20
Bq/m³ pCi/l
1000
800
20
600
400
10
200
m/s
Wind speed
8
6
4
2
6
7
8
9
10
11
12
Febr.



1040
Air pressure
1020
1000
Outside temp.
0
-10
-20
Bq/m³ pCi/l
1000
800
20
600
400
10
200
Wind speed
m/s
8
6
4
2
13
14
15
16
17
18
19
Febr.