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# EVALUATION OF A FAN/FILTER SYSTEM TO REDUCE RADON (AND THORON) PROGENY IN UNDERGROUND URANIUM MINES

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# EVALUATION OF A FAN/FILTER SYSTEM TO REDUCE RADON (AND THORON) PROGENY IN UNDERGROUND URANIUM MINES

by

J. Bigu* and M. Grenier**

## ABSTRACT

The performance of a fan/filter system to reduce radiation levels in an underground uranium mine has been investigated. The fan was installed in a sill drivage where it provided ventilation air to an adjacent production stope. Radiation monitoring stations were located upstream of the fan intake, at the exhaust side of the ventilation ducting in the stope and at a location downstream of the junction of the sill drivage and the mouth of the stope. Measurements were conducted when the fan was operating, with and without the filtering system, and when the fan was off. When the fan was on and the filtering system was in place a reduction in the radon and thoron Working Levels of 10-17% was observed at the stope relative to the intake. Radiation levels at the stope increased substantially when the fan was turned off.

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Key words: Radon progeny; Uranium mines; Fans.

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# ÉVALUATION D'UN SYSTÈME DE VENTILATION ET DE FILTRATION POUR RÉDUIRE LES PRODUITS DE FILIATION DU RADON (ET DU THORON) DANS DES MINES D'URANIUM SOUTERRAINES

par

J. Bigu* et M. Grenier**

## RÉSUMÉ

Dans le présent rapport, on a évalué le rendement d'un système de ventilation et de filtration visant à réduire le niveau de rayonnement dans une mine d'uranium souterraine. Le ventilateur a été installé dans une galerie souterraine d'où il fournit de l'air à un chantier de production adjacent. Les stations de mesure du rayonnement étaient situées en amont de l'orifice d'entrée d'air du ventilateur, du côté de la sortie d'air des conduits de ventilation dans le chantier d'abattage et en aval du point de jonction de la galerie souterraine et du trou du chantier d'abattage. Les mesures ont été prises lorsque le ventilateur fonctionnait, avec et sans système de filtration, et lorsque le ventilateur était arrêté. Lorsque le ventilateur était en marche et que le système de filtration était en place, on a observé une réduction de 10 à 17 % des niveaux de travail du radon et du thoron dans le chantier d'abattage en ce qui a trait à l'entrée d'air. Les niveaux de rayonnement dans le chantier ont augmenté de façon importante lorsque le ventilateur était fermé.

Mots-clés : produits de filiation du radon, mines d'uranium, ventilateurs.

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# INTRODUCTION

Major air pollutants in underground uranium mines include radioactive aerosols, long-lived radionuclides associated with respirable dust, mineral dust in the respirable size range, and diesel particulates.

Radioactive aerosols consist mainly of the short-lived decay products (progeny) of radon and thoron attached to aerosols in the submicron range. In mine working environments, main aerosol contributions are from diesel particulates, mists, oils, and sprays.

A variety of methods have been developed to reduce and control atmospheric pollutants in underground mines. These methods include electrostatic precipitation, wet and dry scrubbing, air recirculation and mechanical filtration, to name but a few methods.

Air filtration is an effective and relatively cheap way of reducing atmospheric pollutants in working environments. In this paper the effect of an exhaust fan and an associated filtering system has been investigated as a means of reducing radon (thoron) progeny, and Long-Lived Radioactive Dust in an underground uranium mine (Stanleigh Mine, Rio Algom Ltd., Elliot Lake, Ont., Canada). The exhaust fan was used to provide ventilation air from a main mine drift to a production stope.

# EXPERIMENTAL SITE

The area of the mine selected for the study is shown in Figure 1. It consisted of a section of the sill drivage No. 36021, and the incline No. 36653. Radiation, dust, and meteorological sampling stations were located as follows:

a) nearby a refuge station (No. 36654) in sill drivage (No. 36021);

b) about 12 m from the junction of the sill drivage (No. 36021) and the incline (No. 36653) into the stope; and

c) approximately 18 m downstream the 36021/36653 junction (see item b).

The fan was installed in the sill drivage about 15 m downstream of the refuge station. The exhaust of the fan was coupled to flexible ventilation ducting leading about 28 m into the incline.

## DESCRIPTION OF THE FAN

The fan installed in sill drivage No. 36021 was designed and manufactured by the Compagnie Générale des Matières Nucléaires Établissement de Limoges (COGEMA) and will be referred to henceforth as the COGEMA fan. COGEMA fan model HCIA80/55 was used in the present study.

The COGEMA fan has an air capacity of about 12 $m^3\ s^{-1}$ and has been designed with noise reduction features that make it particularly suitable for frequently travelled working areas of the mine.

The COGEMA fan was equipped with a prefilter (AR 100 filtering agent) and a filter model SOREIS No. FCB 100 (thickness 15 mm).

## EXPERIMENTAL PROCEDURE

The following measurements were carried out in the sampling stations selected:

### A. METEOROLOGICAL VARIABLES

Meteorological data such as air temperature, air moisture content, barometric pressure and airflow (by anemometry) were obtained using grab-sampling techniques and conventional instrumentation.

### B. DUST

Dust concentration was measured by means of nylon cyclone dust samplers. Dust size distribution was estimated by means of cascade impactors. Dust measurements are described in detail elsewhere (1).

## C. RADIOACTIVITY

The following radiation variables were monitored:

a) radon progeny concentration such as radon progeny Working Level, WL(Rn), [$^{218}$Po], [$^{214}$Pb], and [$^{214}$Bi]. (Square brackets are used to indicate activity concentration.);

b) thoron progeny Working Level, WL(Tn);

c) thoron progeny on nylon cyclone and cascade impactor dust samples; and

d) Long-Lived Radioactive Dust (LLRD), i.e., long-lived radionuclides associated with respirable mineral dust, in nylon cyclone and cascade impactor dust samples.

Radon progeny concentrations were determined by the Thomas-Tsivoglou method (2), the Kusnetz method (3), and by means of radon progeny/thoron progeny continuous monitoring systems, models RGA-400, manufactured by EDA Instruments (Toronto, Canada), and $\alpha$-PRISM, manufactured by $\alpha$-NUCLEAR (Toronto, Canada).

Thoron progeny Working Levels, WL(Tn), were determined by grab-sampling using the Rock method (4).

Long-lived radionuclide activity was estimated by gross $\alpha$-particle counting. Thoron progeny activity on nylon cyclone and cascade impactor samples were also measured by gross $\alpha$-particle counting.

Measurements were conducted with the fan on and off. Furthermore, the fan was operated with and without the pre-filter and filter, and hereafter referred to as the filtering system. The reason for this experimental procedure was threefold:

a) To determine the effect of the fan on radioactivity levels when the fan was off as opposed to the situation where the fan was operated without the filtering system;

b) To investigate the filtration characteristics, and removal efficiency of the fan for radon progeny, thoron progeny and Long-Lived Radioactive Dust when the fan was operated with the filtering system in place; and

c) to study plate-out effects on the fan blades when the fan was operated without the filtering system.

The duration of the underground measurements was 9 days, and the schedule indicated in Table 1 was followed for measurement purposes.

## EXPERIMENTAL RESULTS AND DISCUSSION

The experimental data have been summarized in Tables 2 to 6 and Figures 2 to 6.

Table 2 and Figure 2 show grab-sampling data taken at the intake, exhaust and sill drift during the regular work-day shift. Daily average values for the radon and thoron progeny Working Levels, and the ratio WL(Tn)/WL(Rn), are shown in Table 3.

Examination of Tables 2 and 3 show the following interesting features (see also Figure 2):

a) WL(Rn) and WL(Tn) were on average slightly higher at the sill drift than at the intake;

b) WL(Rn) and WL(Tn) were higher at the exhaust than at the intake when the fan was off. This is to be expected because of lack of ventilation at the exhaust;

c) when the fan was on and the filters in place, WL(Rn) and WL(Tn) were slightly lower (~10%) at the exhaust than at the intake. This difference can be ascribed to the effect of the filter on the radon and thoron progenies. It also shows that the efficiency of the filter in removing the short-lived decay products of radon and thoron was rather low and not particularly designed for this type of operations;

d) the daily average values for the 'disequilibrium' ratios $[^{214}Pb]/[^{218}Po]$

and $[^{214}Bi]/[^{218}Po]$ for the intake and the sill drift were not significantly different: (0.46, 0.29) to (0.65, 0.47) for the intake, and (0.46, 0.23) to (0.57, 0.40) for the sill drift. (Square brackets are used to indicate activity concentration. The values in round brackets separated by a comma indicate the ratios $[^{214}Pb]/[^{218}Po]$ and $[^{214}Bi]/^{218}Po]$, respectively.

For the exhaust, the disequilibrium ratios were dependent on whether the fan was operated or was turned off. As predicted by theory (5), these ratios were lower when the fan was operating than when the fan was off. It should be noted that the disequilibrium ratios are a measure of the age of mine air, i.e., air residence time. A low value for these ratios indicate young mine air conditions corresponding to a high ventilation rate. The converse is equally true. The highest values measured at the exhaust under no air flow conditions were $[^{214}Pb]/[^{218}Po] = 0.75$ and $[^{214}Bi]/[^{218}Po] = 0.58$, whereas the lowest average values were 0.46 and 0.28, respectively.

e) At the exhaust, the ratio WL(Tn)/WL(Rn) increased substantially when the fan was operating as compared with the case where the fan was off, the converse being equally true. Although to a lesser degree, the same held true at the intake. At the sill drift the situation was, however, somewhat more complicated because conditions at this location are affected by conditions at the intake and the exhaust. Table 2, and to a lesser extent, Table 3, show the effect of the fan on the ratio WL(Tn)/WL(Rn).

As discussed elsewhere (5), the ratio WL(Tn)/WL(Rn) is a good indicator of airflow conditions in an underground uranium mine. The experimental data obtained at the exhaust, are therefore, qualitatively consistent with theoretical predictions. The data at the intake are also to be expected because of the high air flow rate of the fan that creates a noticeable increase in airflow conditions in the area near the fan where the intake sampling location was situated.

f) Although a decrease in WL(Rn), and sometimes WL(Tn), was observed when the fan was operated (with and without the filter system), losses by plate-out on the fan blades could not be substantiated because the effect was also evident at the intake, and hence, before the air stream entered the fan.

g) The ratio WL(Tn)/WL(Rn) was in the range 0.15 to 0.7, but most of the values were less than 0.4. This is a value significantly lower than that measured in other uranium mines in the Elliot Lake area. Since the rock formation and the strata characteristics are quite similar to the other mines in the area, the low value for the above ratio seems to suggest a lower gram ratio $^{232}Th/^{238}U$.

Figures 3 to 6 show WL(Rn) versus time at the intake, exhaust and sill drift as measured by several radon progeny continuous monitoring systems, and also by grab-sampling. These Figures show:

a) Good agreement between grab-sampling and continuous monitoring;

b) WL(Rn) is 'modulated' at the three locations by substantial increases between 6-7 h and 18-20 h caused by the central blasting during which ventilation fans were turned off. Radiation levels decreased again back to 'normal' when ventilation fan operation was reestablished;

c) As expected, turning the fan off caused a sharp increase in WL(Rn) at the exhaust. The converse was equally true;

d) WL(Rn) at the intake and the sill drift was also somewhat affected by the operation of the fan. The reason for this is the large volume of air drawn by the fan at the intake location which affects conditions at the sampling location. Furthermore, conditions at the intake and exhaust affect conditions at the sill drift; and

e) Items c) and d) agree with data, and discussion, of Tables 2 and 3 and Figure 2.

Table 4 shows the thoron progeny $\alpha$-particle activity concentration measured on samples taken with nylon cyclones. The data in this Table show that a reduction in thoron progeny concentration is brought about by the operation of the fan with the filters in place. The average reduction was about 17% (10.1% for June 17, 25.5% for June 18, and 15.7% for June 19).

The reduction in thoron progeny concentration measured in samples taken with the cascade impactor was about 14%.

Table 4 also shows that the thoron progeny concentration at the exhaust and the sill drift when the fan was on and the filters in place was essentially the same.

Tables 5 and 6 present Long-Lived Radioactive Dust (LLRD) data (activity concentration) measured with nylon cyclones (Table 5) and cascade impactors (Table 6). Two sets of data are shown, namely corrected, and non-corrected, for 'background'.

Long-Lived Radioactive Dust is associated with mineral dust in the respirable range. Unfortunately, little mineral dust was generated in the nearby production stopes during the COGEMA fan testing period. As a consequence, very little long-lived radionuclide activity was collected on the filters. Negative values for the corrected LLRD activity concentration reflect the poor statistics of counting. It is, therefore, not possible to draw any conclusion regarding the efficiency of the filter system for LLRD from cascade impactor data or nylon cyclone data.

## CONCLUSIONS

From the data examined thus far, the following main conclusions can be drawn:

1. When the fan was operating and the filters were in place, WL(Rn) and WL(Tn) were lower (10-17%) at the exhaust than at the intake. When the

fan was off, the converse was equally true;

2. At the exhaust, the radon progeny disequilibrium ratios and the ratio WL(Tn)/WL(Rn) depended on whether the fan was on or off in accordance with theoretical (qualitative) predictions;
3. Because of low mineral dust concentrations in the area where the fan was located, and hence poor statistics of counting, a reduction in Long-Lived Radioactive Dust attributed to the fan could not be ascertained.

In summary, and as expected, radiation levels at the exhaust were lower during the operation of the fan. A reduction in WL(Rn) and WL(Tn) at the exhaust, as compared with the intake, of less than 20% was brought about by the operation of the fan.

## ACKNOWLEDGEMENTS

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Table 1 - COGEMA fan working schedule

| Date | Fan | Filter System | Remarks |
|---|---|---|---|
| June 15/87 | On | No | - |
| June 16/87 | Off | No | Fan off at 9:20 |
| June 17/87* | On | Yes | |
| June 18/87 | Off/on | Yes | Fan off at 9:04; fan on at 9:13; fan off at 14:00 |
| June 19/87 | On/off | Yes | Fan on at 11:24; fan off at 14:13 |
| June 20/87 | Off | Yes | - |
| June 21/87 | Off | Yes | - |
| June 22/87 | Off | Yes | - |
| June 23/87 | On/off | Yes | Fan on at 8:55; fan off at 13:20 |

*Fan automatically shut-off for blasting from 16:00 to 17:52 (June 17), and from 3:00 to 5:50 (June 18).

Table 2 - Radon progeny and thoron progeny data by grab-sampling

| Date | Time | Location | $[^{218}Po]$ $pCiL^{-1}$ | $[^{214}Pb]$ $pCiL^{-1}$ | $[^{214}Bi]$ $pCiL^{-1}$ | $\frac{[^{214}Pb]}{[^{218}Po]}$ | $\frac{[^{214}Bi]}{[^{218}Po]}$ | WL(Rn) | WL(Tn) | $\frac{WL(Tn)}{WL(Rn)}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 15/87 | 10:20 | Intake | 49.3 | 31.3 | 21.9 | 0.634 | 0.444 | 0.291 | 0.062 | 0.212 | |
| | 11:00 | " | 55.6 | 35.4 | 29.6 | 0.636 | 0.532 | 0.347 | 0.068 | 0.197 | |
| | 11:40 | " | 50.8 | 34.8 | 22.9 | 0.685 | 0.451 | 0.315 | 0.070 | 0.222 | Fan on, no filters |
| | 12:20 | " | 38.2 | 24.8 | 21.2 | 0.649 | 0.555 | 0.245 | 0.065 | 0.263 | |
| | 13:00 | " | 34.6 | 22.36 | 15.6 | 0.646 | 0.451 | 0.207 | 0.069 | 0.332 | |
| | 13:40 | " | 33.6 | 21.21 | 14.08 | 0.631 | 0.419 | 0.195 | 0.065 | 0.335 | |
| June 16/87 | 9:00 | Intake | 47.1 | 23.78 | 14.66 | 0.505 | 0.311 | 0.224 | 0.082 | 0.365 | Fan on, no filters |
| | 10:00 | " | 39.88 | 20.67 | 13.32 | 0.518 | 0.334 | 0.196 | 0.076 | 0.390 | |
| | 10:40 | " | 39.22 | 20.61 | 12.82 | 0.525 | 0.327 | 0.193 | 0.073 | 0.379 | |
| | 11:20 | " | 32.8 | 16.57 | 10.49 | 0.505 | 0.319 | 0.157 | 0.069 | 0.438 | Fan off, no filters |
| | 12:00 | " | 28.1 | 14.67 | 8.22 | 0.522 | 0.292 | 0.134 | 0.057 | 0.426 | |
| | 12:40 | " | 26.3 | 14.6 | 11.4 | 0.555 | 0.433 | 0.144 | 0.050 | 0.346 | |
| | 13:20 | " | 29.1 | 14.1 | 8.16 | 0.485 | 0.280 | 0.132 | 0.059 | 0.448 | |
| June 17/87 | 9:20 | Intake | 43.0 | 21.6 | 10.39 | 0.502 | 0.241 | 0.193 | 0.073 | 0.380 | Fan off, filters in place |
| | 10:00 | " | 39.8 | 16.8 | 5.8 | 0.422 | 0.146 | 0.148 | 0.047 | 0.319 | |
| | 10:40 | " | 34.9 | 14.8 | 6.13 | 0.424 | 0.176 | 0.134 | 0.058 | 0.433 | |
| | 11:20 | " | 21.77 | 10.4 | 11.97 | 0.477 | 0.549 | 0.120 | 0.051 | 0.425 | Fan on, filters in place |
| | 12:00 | " | 26.3 | 11.55 | 7.44 | 0.439 | 0.283 | 0.114 | 0.057 | 0.498 | |
| | 12:40 | " | 29.5 | 14.04 | 8.19 | 0.475 | 0.278 | 0.132 | 0.051 | 0.389 | |
| | 13:20 | " | 28.19 | 13.6 | 9.66 | 0.482 | 0.343 | 0.134 | 0.066 | 0.493 | |
| June 18/87 | 9:21 | Intake | 33.5 | 27.5 | 24.7 | 0.821 | 0.737 | 0.267 | 0.080 | 0.301 | |
| | 10:00 | " | 29.6 | 20.6 | 17.4 | 0.696 | 0.587 | 0.201 | 0.074 | 0.371 | |
| | 10:40 | " | 29.2 | 15.8 | 7.41 | 0.541 | 0.254 | 0.138 | 0.061 | 0.439 | |
| | 11:20 | " | - | - | - | - | - | 0.126 | 0.061 | 0.482 | Fan on, filters in place |
| | 12:00 | " | 22.1 | 12.2 | 10.2 | 0.552 | 0.461 | 0.123 | 0.061 | 0.494 | |
| | 12:40 | " | 36.8 | 17.19 | 3.76 | 0.467 | 0.102 | 0.139 | 0.052 | 0.376 | |
| | 13:00 | " | 32.19 | 15.6 | 7.25 | 0.484 | 0.225 | 0.140 | 0.055 | 0.391 | |
| June 19/87 | 8:59 | Intake | 42.9 | 23.4 | 14.2 | 0.545 | 0.331 | 0.216 | 0.084 | 0.390 | |
| | 9:40 | " | 25.1 | 14.86 | 10.05 | 0.589 | 0.400 | 0.139 | 0.071 | 0.515 | Fan off, filters in place |
| | 10:40 | " | 33.8 | 14.6 | 4.73 | 0.432 | 0.139 | 0.127 | 0.069 | 0.548 | |
| | 11:20 | " | 26.6 | 12.5 | 6.98 | 0.470 | 0.262 | 0.117 | 0.061 | 0.523 | |
| | 12:00 | " | 33.6 | 15.3 | 5.25 | 0.455 | 0.156 | 0.132 | 0.058 | 0.441 | |
| | 12:40 | " | 29.8 | 12.8 | 6.79 | 0.429 | 0.228 | 0.121 | 0.075 | 0.623 | Fan on, filters in place |
| | 13:20 | " | 26.1 | 12.6 | 8.71 | 0.482 | 0.333 | 0.102 | 0.072 | 0.703 | |

Table 2 cont. overleaf

Table 2 Cont.

| Date | Time | Location | $[^{218}Po]$ $pCiL^{-1}$ | $[^{214}Pb]$ $pCiL^{-1}$ | $[^{214}Bi]$ $pCiL^{-1}$ | $\frac{[^{214}Pb]}{[^{218}Po]}$ | $\frac{[^{214}Bi]}{[^{218}Po]}$ | WL(Rn) | WL(Tn) | $\frac{WL(Tn)}{WL(Rn)}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 15/87 | 9:37 | Exhaust | 90.6 | 60.6 | 50.9 | 0.669 | 0.562 | 0.591 | 0.090 | 0.153 | |
| | 10:20 | " | 43.0 | 28.8 | 28.8 | 0.669 | 0.669 | 0.308 | 0.070 | 0.230 | |
| | 11:00 | " | 56.1 | 34.5 | 27.1 | 0.615 | 0.483 | 0.334 | 0.068 | 0.203 | |
| | 11:40 | " | 48.7 | 29.8 | 25.4 | 0.612 | 0.522 | 0.297 | 0.063 | 0.213 | Fan on, no filters |
| | 12:20 | " | 61.6 | 35.5 | 13.2 | 0.576 | 0.214 | 0.308 | 0.066 | 0.221 | |
| | 13:00 | " | 35.9 | 21.0 | 15.1 | 0.585 | 0.420 | 0.200 | 0.065 | 0.322 | |
| | 13:40 | " | 26.2 | 18.4 | 15.6 | 0.702 | 0.595 | 0.180 | 0.070 | 0.389 | |
| June 16/87 | 9:02 | Exhaust | 41.8 | 24.6 | 16.1 | 0.588 | 0.385 | 0.228 | 0.082 | 0.357 | Fan on, no filters |
| | 10:00 | " | 46.0 | 33.6 | 24.2 | 0.730 | 0.526 | 0.309 | 0.085 | 0.276 | |
| | 10:40 | " | 44.5 | 37.2 | 33.3 | 0.836 | 0.748 | 0.359 | 0.082 | 0.229 | |
| | 11:20 | " | 59.6 | 41.1 | 29.1 | 0.689 | 0.488 | 0.379 | 0.086 | 0.227 | Fan off, no filters |
| | 12:00 | " | 61.5 | 46.9 | 33.2 | 0.762 | 0.540 | 0.426 | 0.089 | 0.210 | |
| | 12:40 | " | 50.3 | 41.0 | 35.0 | 0.815 | 0.696 | 0.391 | 0.096 | 0.246 | |
| | 13:20 | " | 54.2 | 36.7 | 24.8 | 0.677 | 0.458 | 0.335 | 0.069 | 0.207 | |
| June 17/87 | 9:00 | Exhaust | 79.2 | 56.1 | 44.9 | 0.708 | 0.567 | 0.534 | 0.087 | 0.163 | Fan off, filters in place |
| | 10:00 | " | 30.4 | 13.9 | 9.41 | 0.457 | 0.309 | 0.137 | 0.069 | 0.501 | |
| | 10:40 | " | 25.7 | 11.29 | 9.18 | 0.439 | 0.357 | 0.118 | 0.059 | 0.502 | |
| | 11:20 | " | 22.2 | 12.5 | 9.43 | 0.563 | 0.425 | 0.122 | 0.053 | 0.433 | Fan on, filters in place |
| | 12:00 | " | 27.0 | 11.8 | 6.57 | 0.437 | 0.243 | 0.112 | 0.049 | 0.436 | |
| | 12:40 | " | 23.7 | 13.96 | 8.45 | 0.589 | 0.356 | 0.127 | 0.053 | 0.417 | |
| | 13:20 | " | 30.4 | 14.6 | 7.35 | 0.480 | 0.242 | 0.133 | 0.052 | 0.389 | |
| June 18/87 | 9:20 | Exhaust | 36.7 | 22.8 | 18.3 | 0.621 | 0.499 | 0.222 | 0.081 | 0.365 | |
| | 10:00 | " | 30.8 | 20.1 | 14.5 | 0.652 | 0.471 | 0.188 | 0.063 | 0.335 | |
| | 10:40 | " | 23.6 | 12.0 | 10.0 | 0.508 | 0.423 | 0.123 | 0.054 | 0.441 | |
| | 11:20 | " | 23.5 | 12.1 | 7.8 | 0.515 | 0.332 | 0.115 | 0.060 | 0.518 | Fan on, filters in place |
| | 12:00 | " | 24.1 | 12.72 | 8.2 | 0.528 | 0.340 | 0.120 | 0.052 | 0.434 | |
| | 12:40 | " | 27.4 | 11.7 | 8.1 | 0.427 | 0.296 | 0.118 | 0.048 | 0.410 | |
| | 13:20 | " | 27.2 | 13.3 | 7.59 | 0.489 | 0.279 | 0.124 | 0.048 | 0.385 | |
| June 19/87 | 9:26 | Exhaust | 47.5 | 37.3 | 27.9 | 0.816 | 0.611 | 0.350 | 0.074 | 0.211 | |
| | 10:05 | " | 41.1 | 27.9 | 19.4 | 0.679 | 0.472 | 0.260 | 0.087 | 0.335 | Fan off, filters in place |
| | 10:42 | " | 27.7 | 16.9 | 11.2 | 0.610 | 0.404 | 0.160 | 0.075 | 0.469 | |
| | 11:26 | " | 23.6 | 11.9 | 7.5 | 0.504 | 0.318 | 0.120 | 0.061 | 0.508 | |
| | 12:01 | " | 25.5 | 9.6 | 8.5 | 0.376 | 0.333 | 0.110 | 0.061 | 0.554 | Fan on filters in place |
| | 12:40 | " | 27.6 | 13.7 | 5.3 | 0.496 | 0.192 | 0.120 | 0.049 | 0.408 | |
| | 13:20 | " | 25.5 | 12.2 | 6.9 | 0.478 | 0.271 | 0.120 | 0.074 | 0.617 | |

Table 2 cont. overleaf

Table 2 Cont.

| Date | Time | Location | $[^{218}Po]$ pCiL$^{-1}$ | $[^{214}Pb]$ pCiL$^{-1}$ | $[^{214}Bi]$ pCiL$^{-1}$ | $\frac{[^{214}Pb]}{[^{218}Po]}$ | $\frac{[^{214}Bi]}{[^{218}Po]}$ | WL(Rn) | WL(Tn) | $\frac{WL(Tn)}{WL(Rn)}$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 15/87 | 11:00 | Sill drift | 49.9 | 30.7 | 25.4 | 0.615 | 0.510 | 0.310 | 0.074 | 0.239 | |
| | 11:40 | " " | 49.6 | 28.7 | 25.2 | 0.578 | 0.508 | 0.300 | 0.072 | 0.240 | |
| | 12:20 | " " | 53.9 | 27.7 | 16.1 | 0.514 | 0.298 | 0.260 | 0.060 | 0.231 | Fan on, no filters |
| | 13:00 | " " | 47.1 | 21.8 | 11.0 | 0.463 | 0.233 | 0.210 | 0.051 | 0.243 | |
| | 13:40 | " " | 39.3 | 20.9 | 10.4 | 0.532 | 0.264 | 0.190 | 0.064 | 0.337 | |
| June 16/87 | 9:10 | Sill drift | 18.3 | 15.3 | 22.1 | 0.836 | 1.208 | 0.180 | 0.061 | 0.339 | Fan on, no filters |
| | 10:00 | " " | 35.7 | 21.5 | 13.9 | 0.602 | 0.389 | 0.200 | 0.067 | 0.335 | |
| | 10:40 | " " | 40.6 | 19.0 | 14.2 | 0.468 | 0.350 | 0.200 | 0.094 | 0.470 | |
| | 11:20 | " " | 22.9 | 16.0 | 13.7 | 0.699 | 0.598 | 0.160 | 0.071 | 0.441 | Fan off, no filters |
| | 12:00 | " " | 24.1 | 15.8 | 10.6 | 0.656 | 0.439 | 0.150 | 0.073 | 0.487 | |
| | 12:40 | " " | 38.0 | 16.7 | 8.7 | 0.439 | 0.229 | 0.160 | 0.068 | 0.425 | |
| | 13:20 | " " | 25.9 | 14.4 | 9.7 | 0.556 | 0.374 | 0.140 | 0.086 | 0.614 | |
| June 17/87 | 9:10 | Sill drift | 46.5 | 23.1 | 9.30 | 0.497 | 0.200 | 0.210 | 0.054 | 0.257 | Fan off, filters in place |
| | 10:00 | " " | 39.8 | 16.7 | 5.03 | 0.419 | 0.126 | 0.150 | 0.065 | 0.433 | |
| | 10:40 | " " | 28.6 | 13.0 | 7.27 | 0.454 | 0.254 | 0.130 | 0.053 | 0.408 | |
| | 11:20 | " " | 31.7 | 13.3 | 7.59 | 0.419 | 0.239 | 0.130 | 0.056 | 0.431 | Fan on, filters in place |
| | 12:00 | " " | 31.5 | 12.4 | 5.68 | 0.394 | 0.180 | 0.120 | 0.061 | 0.508 | |
| | 12:40 | " " | 24.9 | 13.7 | 9.13 | 0.550 | 0.367 | 0.130 | 0.079 | 0.608 | |
| | 13:20 | " " | 29.1 | 14.2 | 7.66 | 0.488 | 0.263 | 0.130 | 0.056 | 0.431 | |
| June 18/87 | 9:20 | Sill drift | | | | | | 0.220 | | | |
| | 10:00 | " " | | | | | | 0.220 | | | |
| | 10:40 | " " | | | | | | 0.140 | | | |
| | 11:20 | " " | | | | | | 0.140 | | | Fan on, filters in place |
| | 12:00 | " " | | | | | | 0.130 | | | |
| | 12:40 | " " | | | | | | 0.120 | | | |
| | 13:20 | " " | | | | | | 0.150 | | | |
| June 19/87 | 9:00 | Sill drift | | | | | | 0.270 | | | |
| | 10:00 | " " | | | | | | 0.170 | | | Fan off, filters in place |
| | 11:00 | " " | | | | | | 0.160 | ---------- | ---------- | |
| | 12:00 | " " | | | | | | 0.150 | | | Fan on, filters in place |
| | 13:00 | " " | | | | | | 0.130 | | | |

Table 3 - Radon progeny and thoron progeny Working Levels by grab-sampling. (Average values under 'steady-state' conditions.)

| Date | Location | $\overline{WL(Rn)}$ | $\overline{WL(Tn)}$ | $\frac{\overline{WL(Tn)}}{\overline{WL(Rn)}}$ | Remarks |
|---|---|---|---|---|---|
| June 15/87 | Intake | 0.267 | 0.066 | 0.247 | ) Fan on; |
| | Exhaust | 0.268 | 0.067 | 0.250 | ) no filters |
| | Sill drift | 0.254 | 0.064 | 0.252 | ) |
| June 16/87 | Intake | 0.168 | 0.066 | 0.393 | ) Fan off; |
| | Exhaust | 0.347 | 0.084 | 0.242 | ) no filters |
| | Sill drift | 0.170 | 0.074 | 0.435 | ) |
| June 17/87 | Intake | 0.139 | 0.058 | 0.417 | ) Fan on; |
| | Exhaust | 0.125 | 0.056 | 0.448 | ) filters in place |
| | Sill drift | 0.143 | 0.061 | 0.426 | ) |
| June 18/87 | Intake | 0.156 | 0.063 | 0.404 | )Fan on; |
| | Exhaust | 0.144 | 0.058 | 0.403 | ) filters in place |
| | Sill drift | 0.160* | - | - | ) |
| June 19/87 | Intake | 0.136 | 0.070 | 0.515 | ) Fan off until ~11:20; |
| | Exhaust | 0.177 | 0.069 | 0.390 | ) fan on at ~11:20; |
| | Sill drift | 0.176* | - | - | ) filters in place |

*Estimated by means of an 'Instant Working Level Meter' Model MIMIL manufactured by CEA (France).

Table 4 - Thoron activity concentration on samples taken with nylon cyclones.

| Date | Location | Activity Concentration cpm $m^{-3}$ | Reduction % | Operating Conditions |
|---|---|---|---|---|
| June 15/87 | Intake | 107.4 | | ) Fan on, |
| | Exhaust | 105.4 | 1.9 | ) no filters |
| | Sill drift | 81.7 | | ) |
| June 16/87 | Intake | 46.8 | | ) Fan off, |
| | Exhaust | 55.9 | -19.0 | ) no filters |
| | Sill drift | 51.8 | | ) |
| June 17/87 | Intake | 164.8 | | ) Fan on, |
| | Exhaust | 148.1 | 10.1 | ) filters in place |
| | Sill drift | 143.0 | | ) |
| June 18/87 | Intake | 118.5 | | ) Fan on, |
| | Exhaust | 88.3 | 25.5 | ) filters in place |
| | Sill drift | 94.6 | | ) |
| June 19/87 | Intake | 204.1 | | ) Fan off until ~11:20; |
| | Exhaust | 172.0 | 15.7 | ) fan on at ~11:20; |
| | Sill drift | 169.2 | | ) filters in place |

Note: cpm stands for $\alpha$-particle count rate in counts per minute.

Table 5 - Long-Lived Radioactive Dust (activity concentration) from nylon cyclone samples.

| Date | Location | Activity concentration Non-Corr. (cpm $m^{-3}$) | Activity concentration Corr. (cpm $m^{-3}$) |
|---|---|---|---|
| June 15/87 | Intake | 0.526 | 0.018 |
| | Exhaust | 0.336 | -0.136 |
| | Sill drift | 0.435 | -0.002 |
| June 16/87 | Intake | 0.370 | -0.007 |
| | Exhaust | 0.421 | 0.048 |
| | Sill drift | 0.574 | 0.154 |
| June 17/87 | Intake | 0.296 | -0.064 |
| | Exhaust | 0.240 | -0.118 |
| | Sill drift | 0.234 | 0.049 |
| June 18/87 | Intake | 0.424 | 0.102 |
| | Exhaust | 0.233 | -0.088 |
| | Sill drift | 0.393 | -0.066 |
| June 19/87 | Intake | 0.560 | -0.034 |
| | Exhaust | 0.563 | -0.008 |
| | Sill drift | 0.460 | -0.427 |
| June 23/87 | Intake | 0.366 | 0.003 |
| | Exhaust | 0.319 | -0.036 |
| | Sill drift | 0.244 | -0.190 |

Note: cpm stands for $\alpha$-particle count rate in counts per minute.

Table 6 - Long-Lived Radioactive Dust (activity concentration) from cascade impactors.

| Date | Location | Activity concentration Non-Corr. (cpm $m^{-3}$) | Activity concentration Corr. (cpm $m^{-3}$) |
|---|---|---|---|
| June 15/87 | Intake | 0.983 | 0.572 |
| | Exhaust | 0.736 | 0.208 |
| June 17/87 | Intake | 0.587 | 0.206 |
| | Exhaust | 0.351 | -0.028 |
| June 23/87 | Intake | 0.561 | 0.257 |
| | Exhaust | 0.588 | -0.025 |

Note: cpm stands for $\alpha$-particle count in counts per minute.

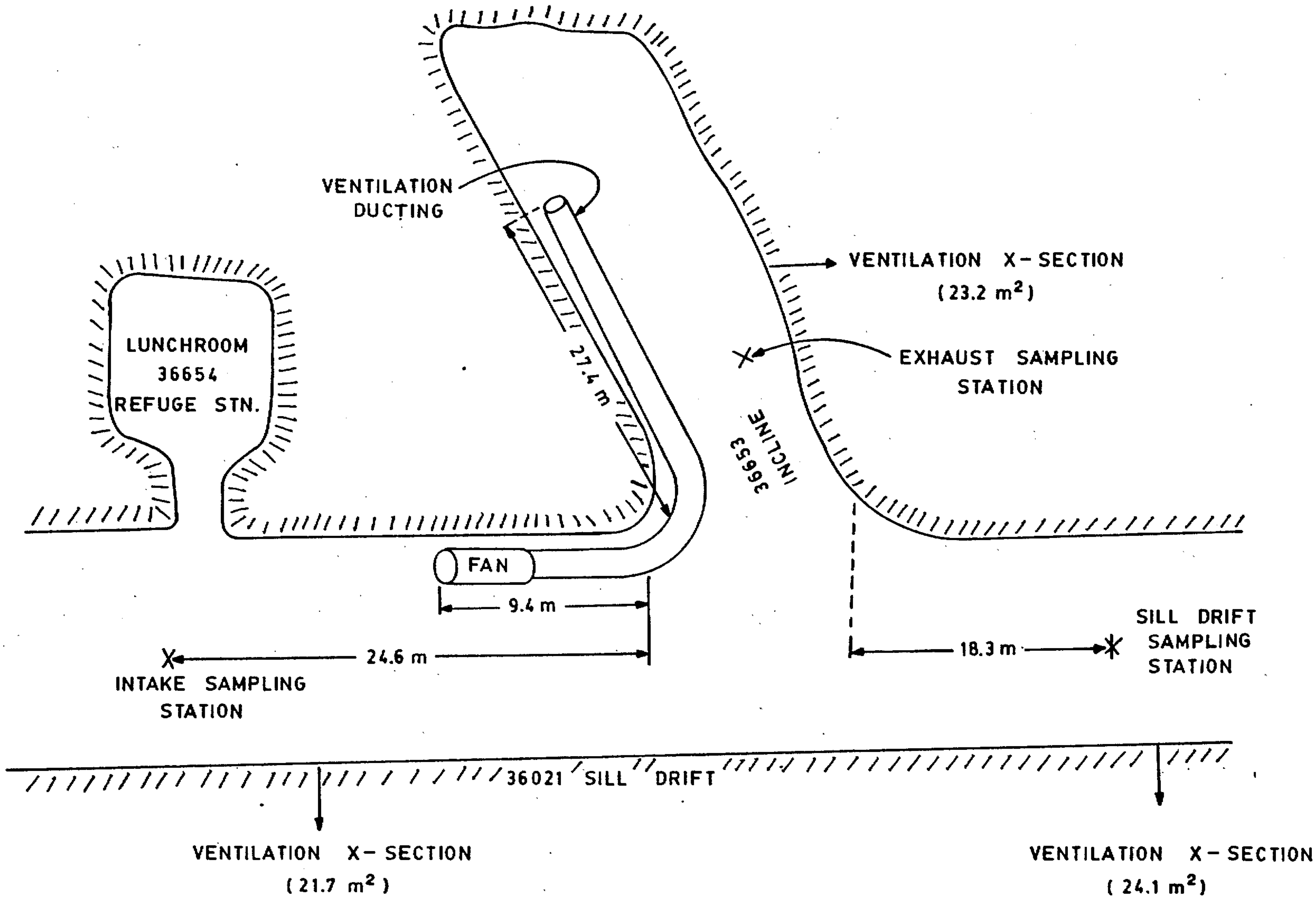


Fig. 1 - Experimental site.

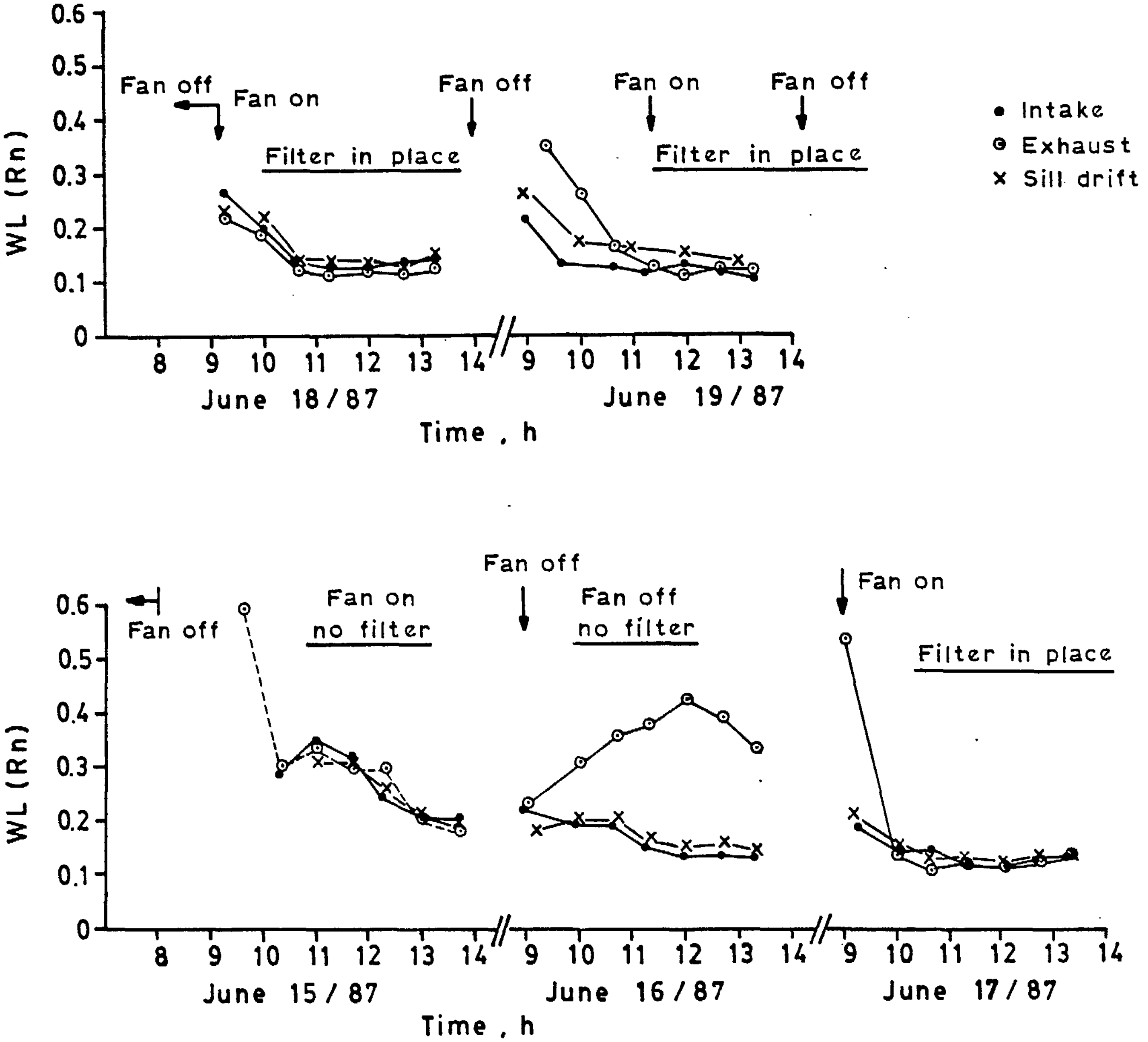


Fig. 2 - Radon progeny Working Level data (grab-sampling) versus time for several locations and fan/filter conditions.

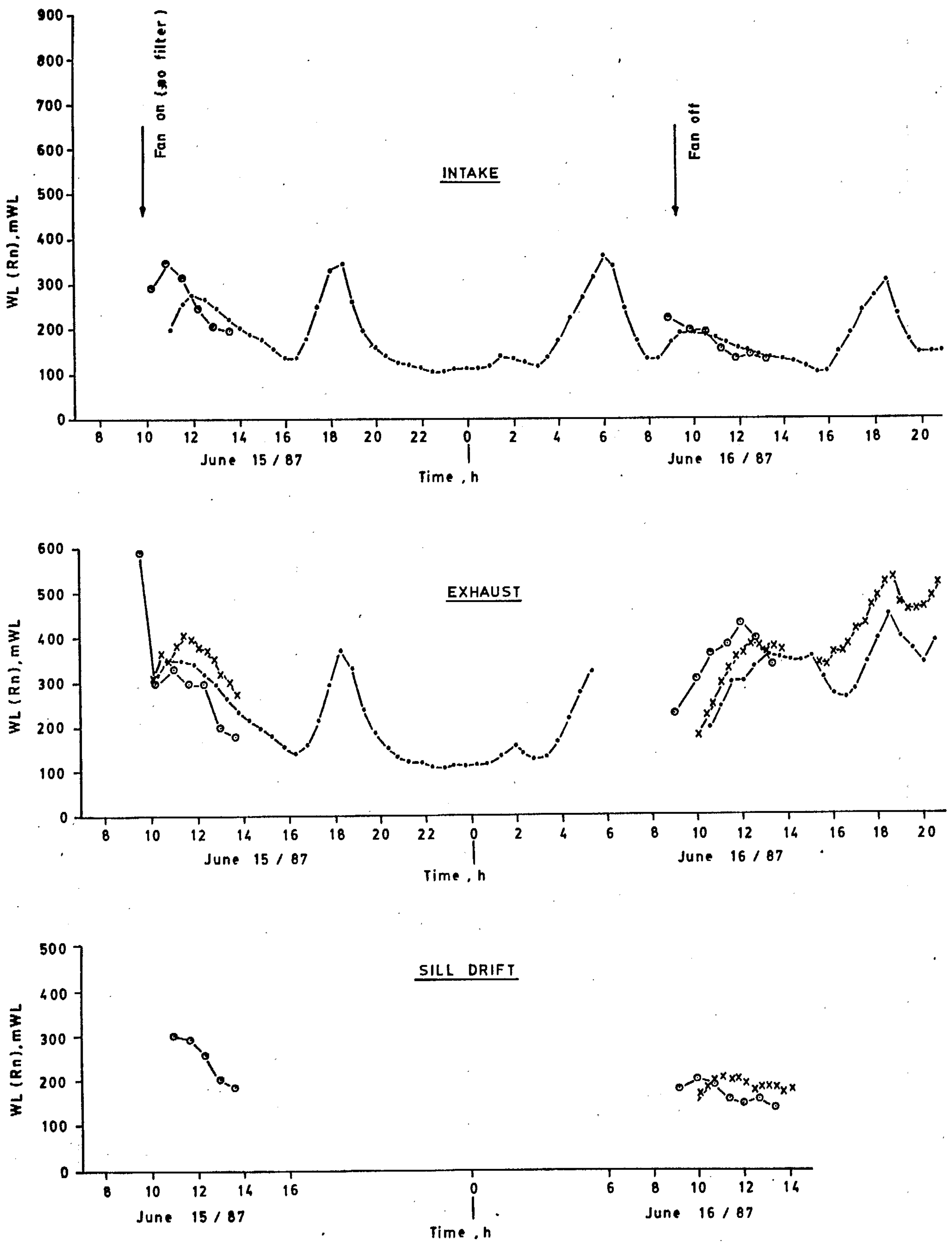


Fig. 3 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

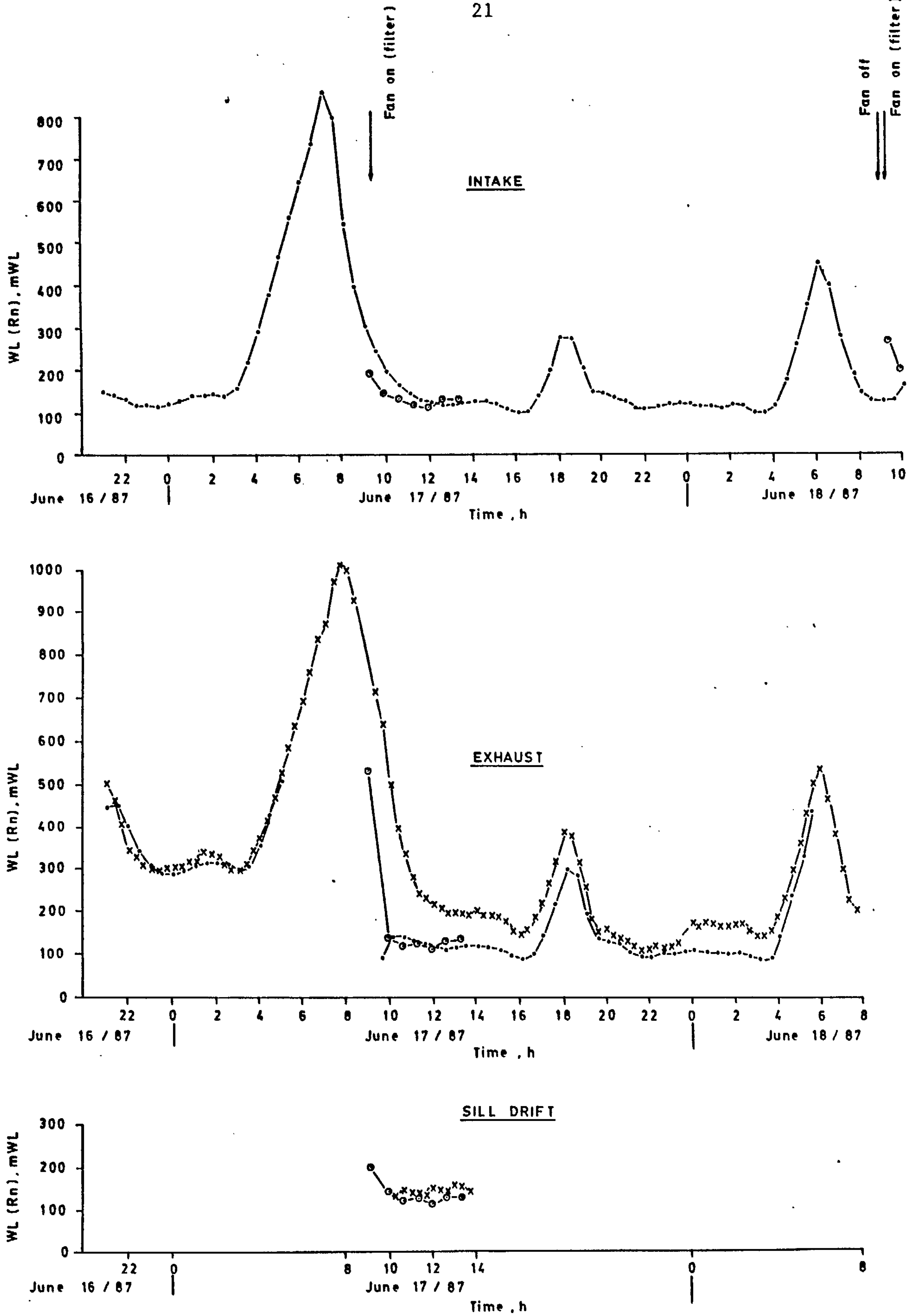


Fig. 4 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

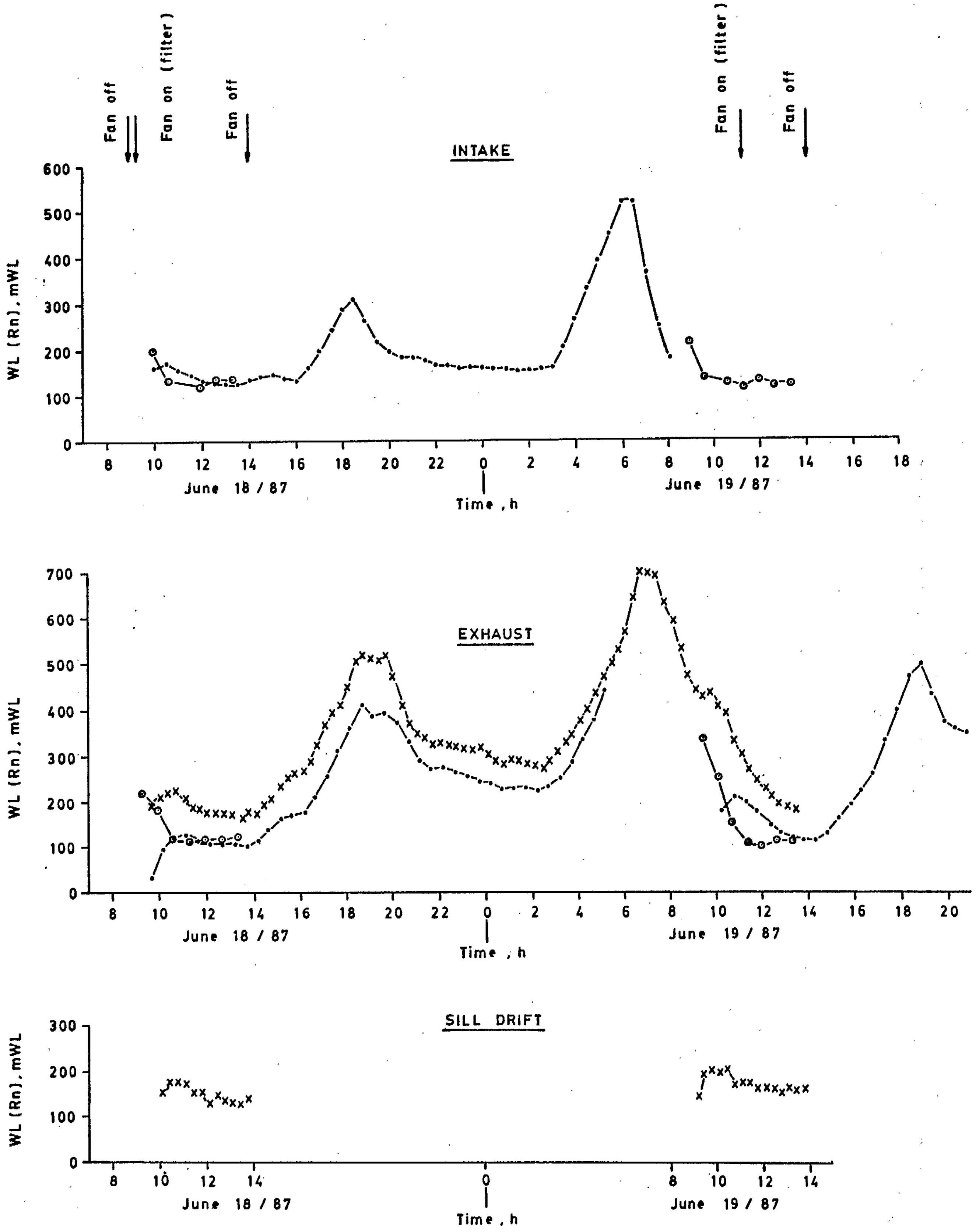


Fig. 5 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

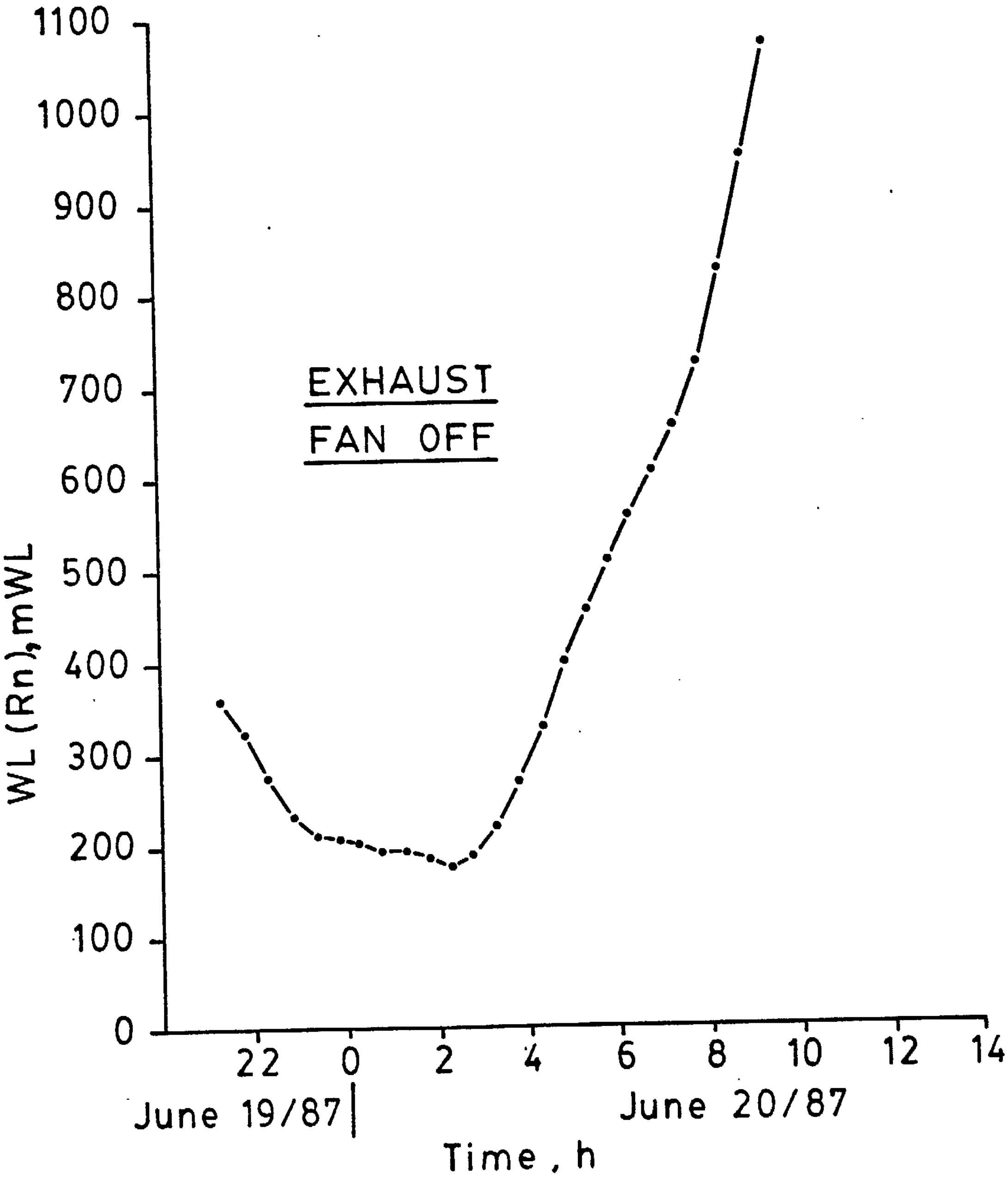


Fig. 6 - Radon progeny Working Level by continuous monitoring versus time for the exhaust with the fan off.