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PERFORMANCE OF A FAN/FILTER VENTILATION SYSTEM FOR REDUCING RADON (THORON) PROGENY AND RESPIRABLE DUST IN AN UNDERGROUND URANIUM MINE

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by

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ABSTRACT

The performance of a fan/filter system, model HCI 80/F80 manufactured by COGEMA (France) to reduce radiation and dust 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. Dust and 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. Furthermore, the fan/filter system was 10-30% efficient for dust particles in the size range 0.2 to 2.0 μm.

Key words: Radon progeny; Thoron progeny; Respirable dust; Uranium mines; Fans.

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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, for example, electrostatic precipitation, wet and dry scrubbing, air recirculation and mechanical filtration.

Air filtration is an effective and relatively cheap way of reducing atmospheric pollutants in working environments (1). 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, respirable dust, 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 the 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.

The air flow rate in the sill drift was 19.6 m^3/s whereas that corresponding to the incline was about 16 m^3/s.

DESCRIPTION OF THE FAN

The fan installed in sill drivage No. 36021 was designed and manufactured by the Compagnie Generale des Matieres Nucleaires Etablissement de Limoges (COGEMA) and will be referred to henceforth as the COGEMA fan. COGEMA fan model HCI 80/F80 was used in the present study.

The COGEMA fan has an air capacity of about 16 m^3/s and has been designed with noise reduction features using silencers that make it particularly suitable for frequently travelled working areas of the mine. It was later found that the efficiency of the sound proofing mechamism decreased markedly as dust accumulated on the sound damping material. In order to remedy this problem, the manufacturer designed a filter cage at the fan intake. This also helped prevent damage or imbalance to revolving mechanical parts of the fan.

The unit tested (COGEMA HCI-80 with F80 filter element) is a compact design made up of a fan with an integrated diffuser-silencer unit. The intake to the fan is fitted with a squirrel cage type frame designed to receive the fan-folded filtering element. The HCI-80 Insulated Compact Helicoid fan is shown in Figure 2.

The manufacturer claims a total filtering surface of 9 m^2 for the HCI-80 model. The filtering material is made of a coarse synthetic fiber material held between a folded metal mesh. This filter comes in four sections that are easily installed or removed. In order to extend the life of the filter, a pre-filter material (Agent AR100) and a filter model SOREIS No. FCB 100 (15 mm thickness) are used in front of the filter and held in place by fan suction.

EXPERIMENTAL PROCEDURE

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

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.

DUST

Three types of instruments were used to evaluate the COGEMA fan. These were 10 mm nylon cyclones for the determination of respirable dust concentration. The cyclones were operated with self-regulated sampling pumps which were calibrated daily on site. Eight-stage cascade impactors (Sierra Instruments Ltd.) operated at a flow rate of 13.4 L/min, helped determine the dust size distribution in various areas as well as the filtration efficiency of the fan as a function of dust particle size. A continuous dust monitor was also used to measure airborne dust concentrations on a continuous basis close to the fan intake.

Four nylon cyclones were located in an area approximately 15 m from the intake to the fan (25 m from the incline). Four more cyclones were placed in the incline to monitor the fan exhaust. Two cyclones were used in the sill drift, down from the incline.

Two cascade impactors were used to monitor the intake and exhaust areas. During most of the evaluation these were used to determine the airborne dust size distribution at the fan intake (sill drift) and the exhaust area (incline). On two occasions, the impactors were sampling the fan intake and exhaust directly. In this configuration the intake impactor was sampling inside a specially designed enclosure (1.8 m in diameter and 3 m in length). The exhaust impactor was sampling on the ventilation duct (see Figure 1). Sampling in high velocity air streams requires that special sampling probes be designed in order that duct air velocities be matched to air entry velocities in the probes (isokinetic sampling conditions). Two such probes were built taking intake and exhaust air velocity into account.

A total of five tests were conducted. On one of these tests, the fan was operated without the F80 filter element. Four tests were conducted while the fan operated with the filter element. During two of these tests, the special enclosure mentioned above was not used and area sampling was conducted. For the remaining two tests, the enclosure was installed and impactors were used directly on the fan system as previously described.

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 α-PRISM. manufactured by α-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 α-particle counting. Thoron progeny activity on nylon cyclone and cascade impactor samples was also measured by gross α-particle counting.

Measurements were conducted with the fan on and off. Furthermore, the fan was operated with and without the pre-filter and filter, 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 radiation measurements was 9 days, and the schedule indicated in Table 1 was followed for measurement purposes. The radiation sampling locations (stations) were the same as those used for dust sampling.

EXPERIMENTAL RESULTS AND DISCUSSION

A. RADIOACTIVITY

The experimental radiation data have been summarized in Tables 2 to 6 and Figures 3 to 7.

Table 2 and Figure 3 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 3):

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 indicates 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 4 to 7 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 3.

Table 4 shows the thoron progeny α-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, corrected and uncorrected, 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 fan/filter system for LLRD from cascade impactor data or nylon cyclone data.

B. DUST

Table 7 shows data gathered by cascade impactors sampling the general areas at the fan intake and exhaust. Two parameters are used to determine the dust cloud size distribution, namely the mass-median aerodynamic diameter (MMAD), which defines the median dust particle size, and the geometric standard deviation (GSD), which gives the degree of spread of the distribution. Also shown in Table 7 is the percentage difference in MMAD between the intake and exhaust areas.

Data in Table 7 show very low MMAD values indicating that diesel soot forms a large portion of the airborne dust mass. Typically MMAD values are in the 2 to 3 μm range in production areas and higher close to rock breaking operations in these mines. On the day when the filter element was not installed a 35% reduction in MMAD was measured. When the filter was installed this reduction was measured on two occasions at 31 and 42%. On the basis of these data there is no statistical evidence to show that the filter system significantly altered the airborne dust size distribution.

The graph in Figure 8 shows the dust removal efficiency of the filter element as a function of dust particle size when the impactors were installed on the ventilation system. The efficiency is given in the size range between 0 and 2 μm. Not enough mass was gathered on upper stages of the impactor to allow the filtering efficiency to be established for larger dust sizes. The fact that most of the airborne dust was small in diameter allowed the efficiency of removal of small dust particles to be determined more accurately. According to Figure 8, the filter efficiency increases as a function of size with a value of 12% at 0.3 μm, and 30% at 1.5 μm. The solid curves are the results obtained from two different tests with the average being shown by the broken line.

Although it has been expected that the filter might be more efficient for larger particle sizes, the efficiency seems to be peaking between 1 and 1.5 μm. This seems to indicate that under the testing conditions encountered, the maximum filtering efficiency is in the range between 30 and 40% for any size of airborne dust particles. This is also supported by the fact that in fibrous filter media large diameter particles (>5 μm) may not be trapped by the filter when gas velocities exceed 0.35 m/s. Table 8 gives some specifications for the COGEMA family of fan/filter assemblies. Shown are the filtering surfaces of the filter and pre-filter elements as well as air volumes and air velocities through the filter system. In every case, the air velocity is in excess of 0.35 m/s, ranging between 0.66 and 1.70 m/s for the main filter element which offers a greater filtering surface due to the folded design and between 1.45 and 5.65 m/s for the pre-filter which is simply laid over the filter. For the model tested, the air velocity through the filter and pre-filter are estimated to be 1.51 and 4.74 m/s, respectively.

Table 9 lists respirable dust data gathered using nylon cyclones. Shown are the average respirable dust concentrations (mg/m^3) measured at the intake and the exhaust. The percentage difference between the intake and exhaust concentrations is also shown along with the MMAD measured by the impactor located at the intake on each day. During test 1, the filter element was not installed and a decrease of 11.6% was measured in respirable airborne dust concentration. This decrease is probably caused by inertial impaction of dust on fan blades, silencer walls and ventilation duct inner walls and elbows. When examining the MMAD values obtained for days when the filter element was installed, it is noticed that the respirable dust reduction varies between 18.7 and 32.4% and increases with the MMAD value. This is expected and is in agreement with the data shown earlier for the efficiency of dust removal of the filter as a function of size. The percentage decrease in respirable dust as a function of measured MMAD at the intake is graphically shown in Figure 9. The reduction is seen to increase linearly in the MMAD range between 0.1 and 0.3 µm.

CONCLUSIONS

The evaluation conducted shows no evidence that the filter significantly altered the aerosol size distribution in the area tested. Decreases in MMAD ranging between 31 and 42% were measured whether the filter unit was installed or removed. The filtering efficiency of the unit ranged between 10 and 30% for particles in the 0.2 to 2.0 µm range. It is possible that the filter might operate more efficiently at larger dust particle sizes.

Reductions in respirable dust concentration ranged between 18 and 32% when the filter was in place. It is conceivable, although it could not be proven here, that reductions higher than 32% may be achieved for dust clouds where the MMAD is larger than those measured here.

Furthermore, from the radiation data examined, the following conclusions may 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, airborne respirable dust concentration and radiation levels were somewhat reduced during the operation of the COGEMA fan/filter system. It should be clear, however, that the filtering system was primarily designed for the purpose of extending the life of the sound damping materials of the silencer. The present investigation was only prompted by the suggestion, and claim, by the manufacturer that the fan/filter system tested here was potentially capable of reducing radon daughter and dust concentration significantly.

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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	Fan on, no filters
	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	
	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	Fan off, no filters
	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	
	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	Fan on, filters in place
	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	
	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	Fan on, filters in place
	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	
	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	Fan off, filters in place
	9:40	"	25.1	14.86	10.05	0.589	0.400	0.139	0.071	0.515	
	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	Fan on, filters in place
	12:40	"	29.8	12.8	6.79	0.429	0.228	0.121	0.075	0.623	
	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	Fan on, no filters
	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	
	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	Fan off, no filters
	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	
	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	Fan on, filters in place
	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	
	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	Fan on, filters in place
	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	
	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	Fan off, filters in place
	10:05	"	41.1	27.9	19.4	0.679	0.472	0.260	0.087	0.335	
	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	Fan on filters in place
	12:01	"	25.5	9.6	8.5	0.376	0.333	0.110	0.061	0.554	
	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	Fan on, no filters
	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	
	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	Fan off, no filters
	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	
	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	Fan on, filters in place
	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	
	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			Fan on, filters in place
	10:00	" "						0.220			
	10:40	" "						0.140			
	11:20	" "						0.140			
	12:00	" "						0.130			
	12:40	" "						0.120			
	13:20	" "						0.150			
June 19/87	9:00	Sill drift						0.270			Fan off, filters in place
	10:00	" "						0.170	------------------		
	11:00	" "						0.160			Fan on, filters in place
	12:00	" "						0.150			
	13:00	" "						0.130			

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

Date	Location	$\overline{\mathrm{WL(Rn)}}$	$\overline{\mathrm{WL(Tn)}}$	$\dfrac{\overline{\mathrm{WL(Tn)}}}{\overline{\mathrm{WL(Rn)}}}$	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 α-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.	 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 α-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}	Corr.
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 α-particle count in counts per minute.

Table 7 - Airborne dust size distribution in intake and exhaust areas.

Test	Filter	Intake Area MMAD (μm)	GSD (μm)	Exhaust Area MMAD (μm)	GSD (μm)	Decrease in MMAD %
1	Off	0.20	6.84	0.13	4.22	35
2	On	0.16	8.71	0.11	7.34	31
3	On	0.31	8.32	0.18	12.31	42

Table 8 - COGEMA model HCI fan specifications and air velocity through filter and pre-filter elements (6).

Model	Air Volume (m^3/s)	Filtering Surface (m^2) Pre-Filter	Filtering Surface (m^2) Filter	Air Velocity Through Element (m/s) Pre-Filter	Air Velocity Through Element (m/s) Filter
HCI40/F40	1.6	1.11	1.52	1.45	1.05
HCI45/F45	2.0	1.18	3.01	1.69	0.66
HCI50/F50	3.2	1.26	3.01	2.57	1.08
HCI56/F56	3.8	1.36	3.01	2.79	1.26
HCI63/F63	6.3	1.45	4.51	4.34	1.40
HCI71/F71	9.3	2.59	6.72	3.59	1.38
HCI80/F80	13.5	2.85	8.96	4.74	1.51
HCI90/F90	19.0	3.36	11.19	5.65	1.70

Table 9 - Respirable dust concentration and reduction data.

Test	Filter	Respirable Dust Conc. (mg/m^3) Intake	Respirable Dust Conc. (mg/m^3) Exhaust	% Difference Intake-Exhaust	MMAD at Intake (μm)
1	Off	0.95	0.84	11.6	-
2	On	0.75	0.61	18.7	0.16
3	On	0.34	0.23	32.4	0.31
4	On	1.02	0.81	20.6	0.18

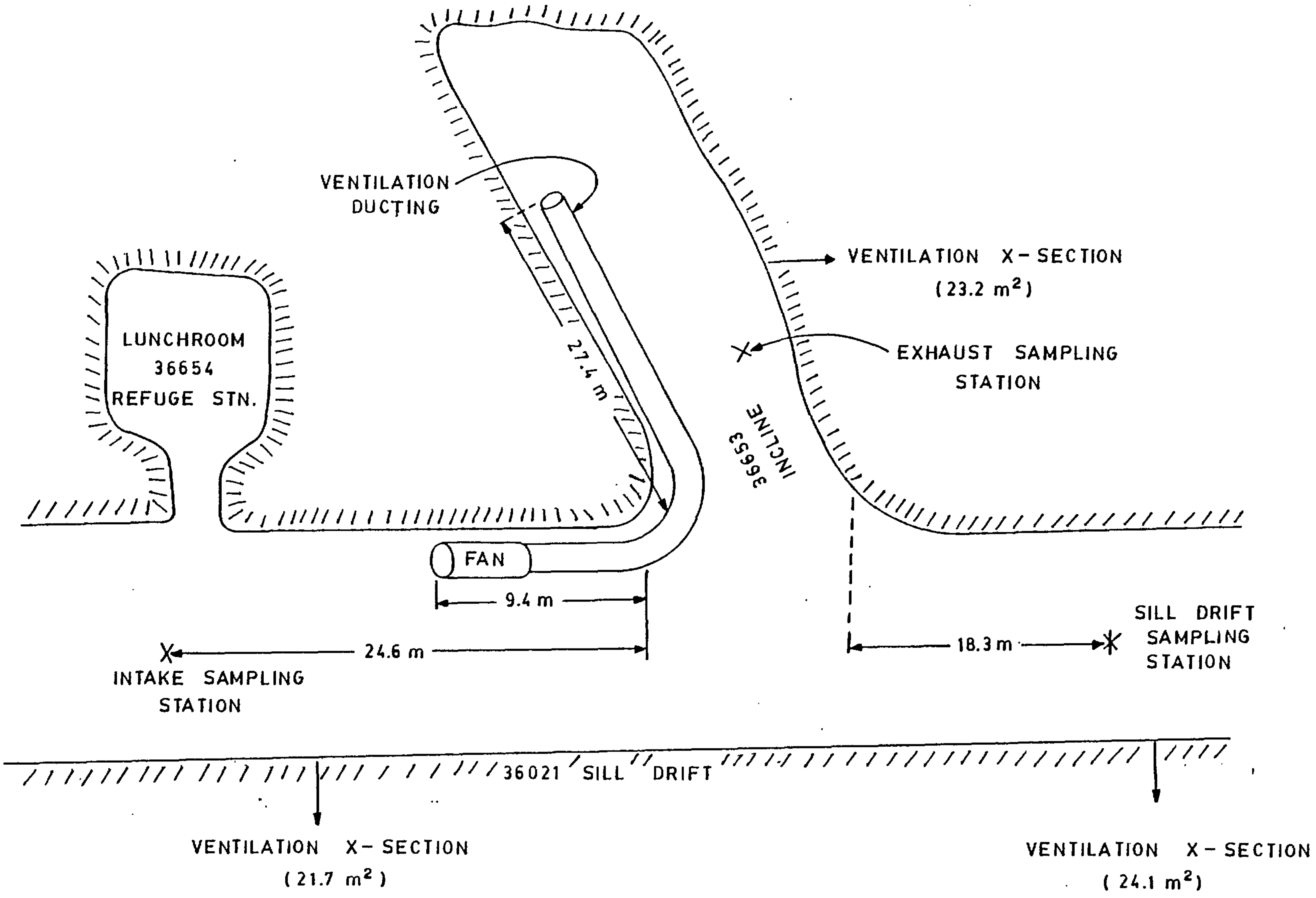

Fig. 1 - Experimental site.

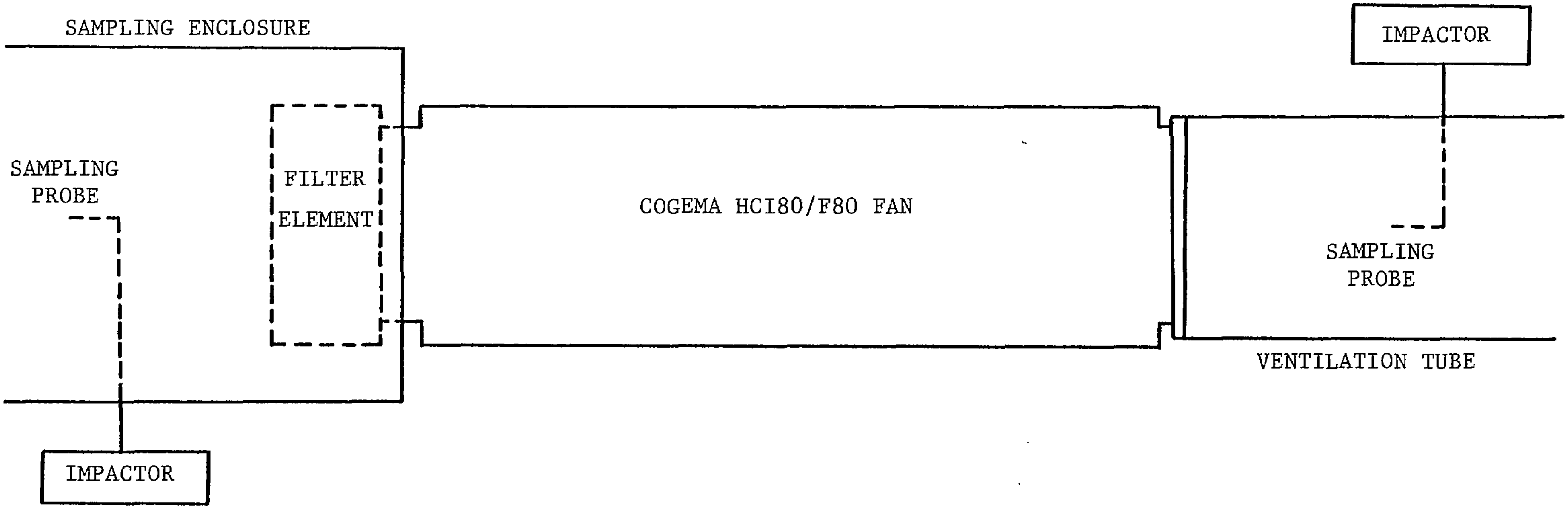

Fig. 2 - Schematic diagram showing the COGEMA fan/filter system and the sampling apparatus used to determine the filter's efficiency as a function of dust particle size.

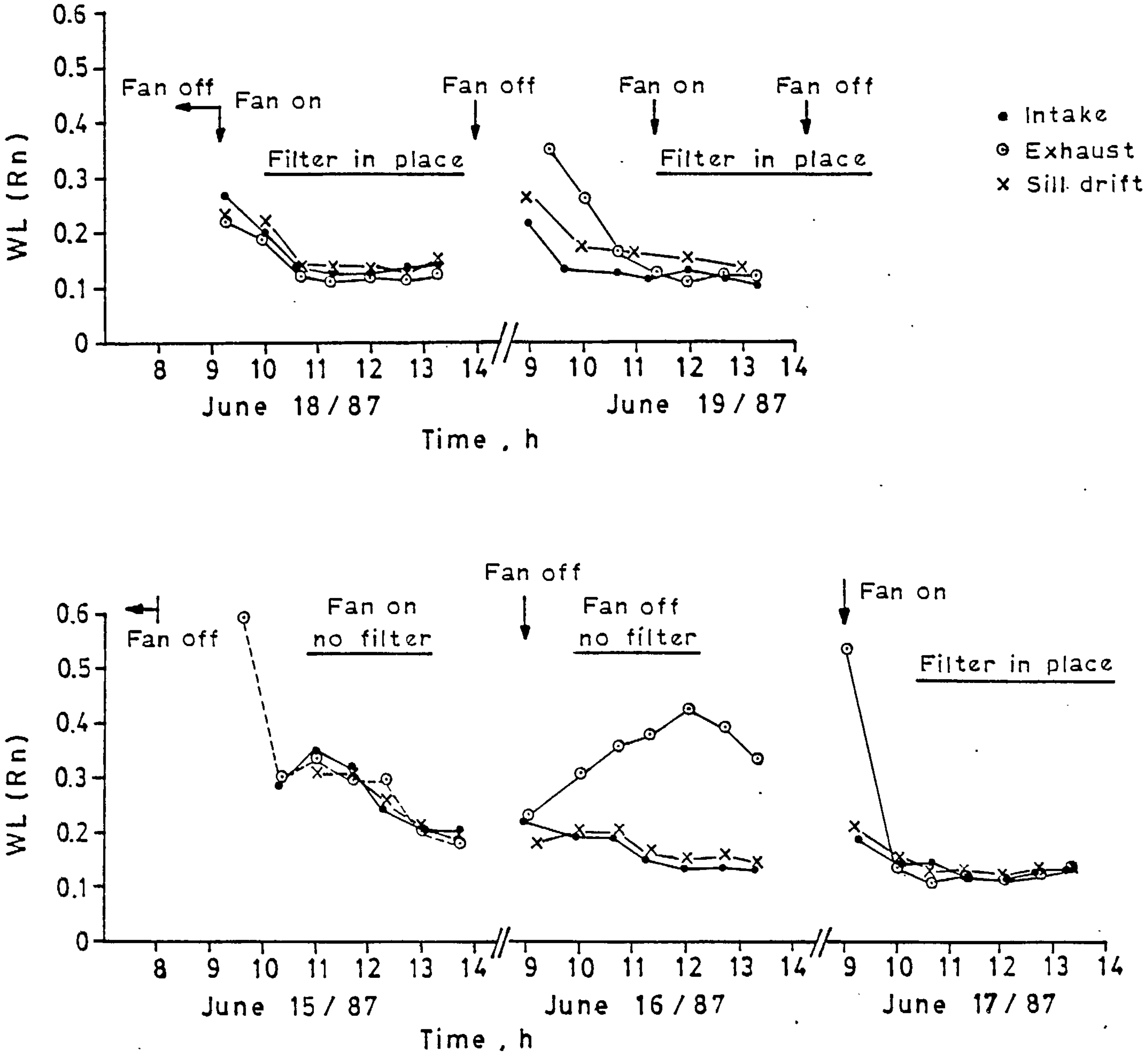

Fig. 3 - Radon progeny Working Level data (grab-sampling) versus time for several locations and fan/filter conditions.

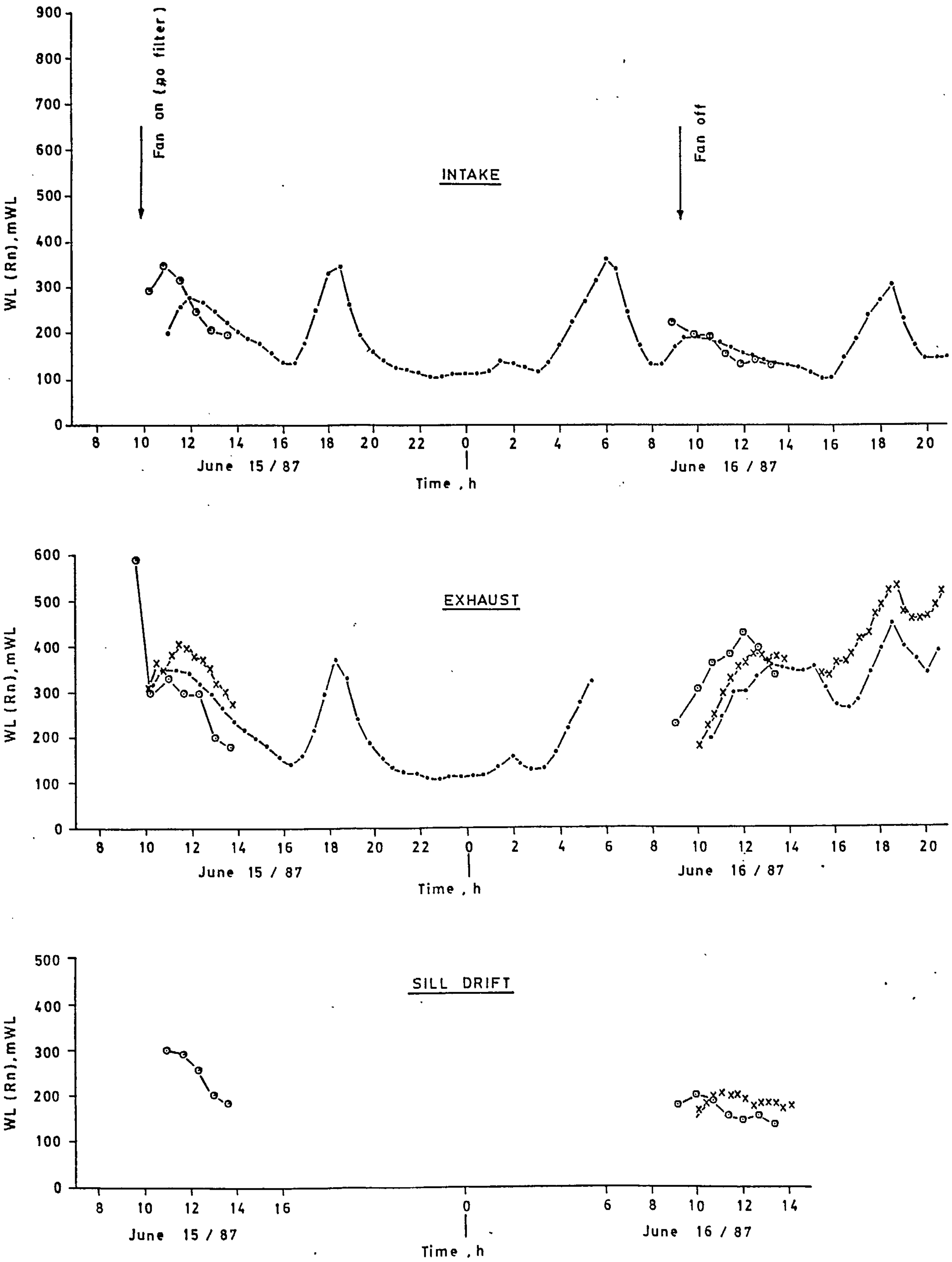

Fig. 4 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

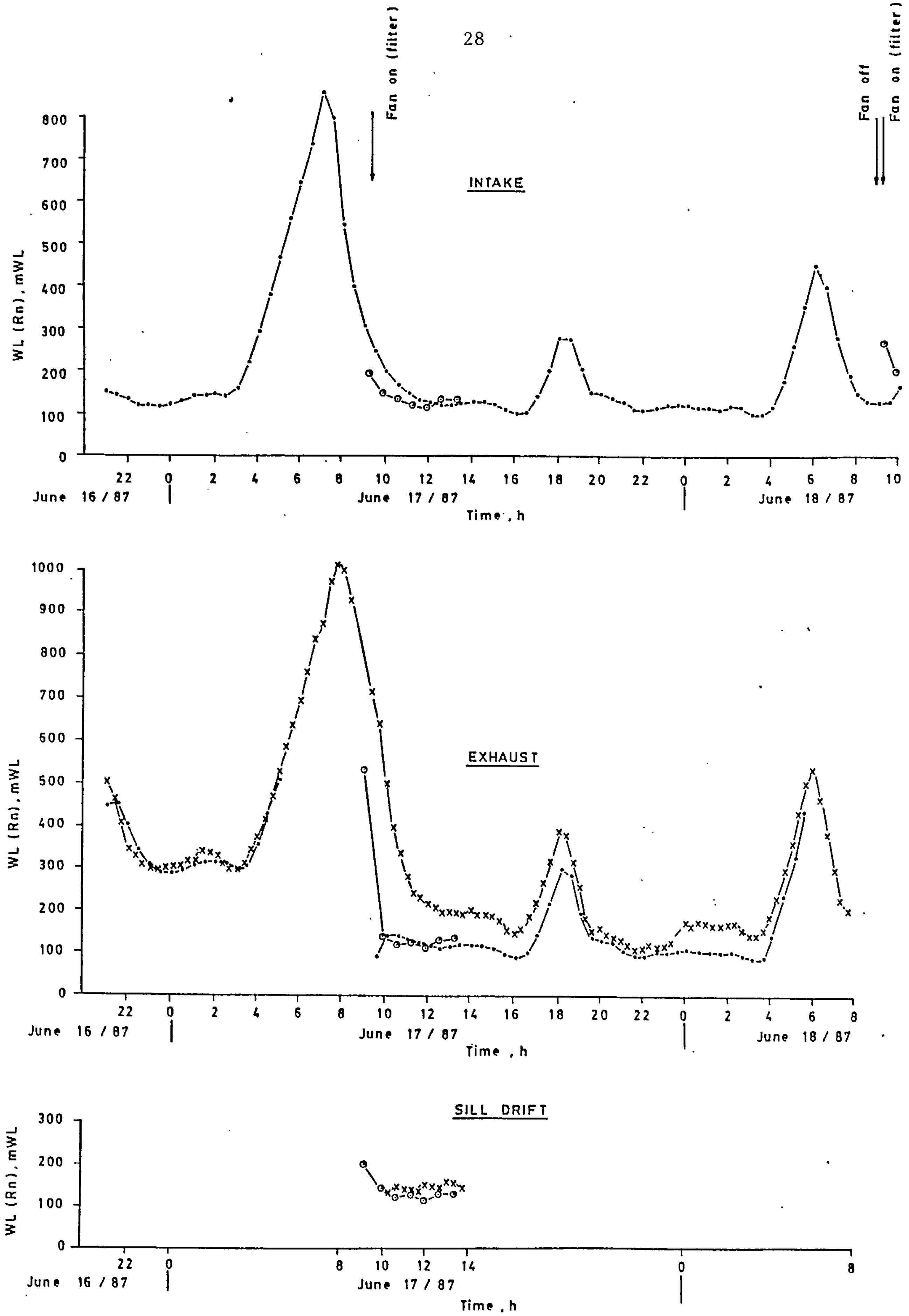

Fig. 5 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

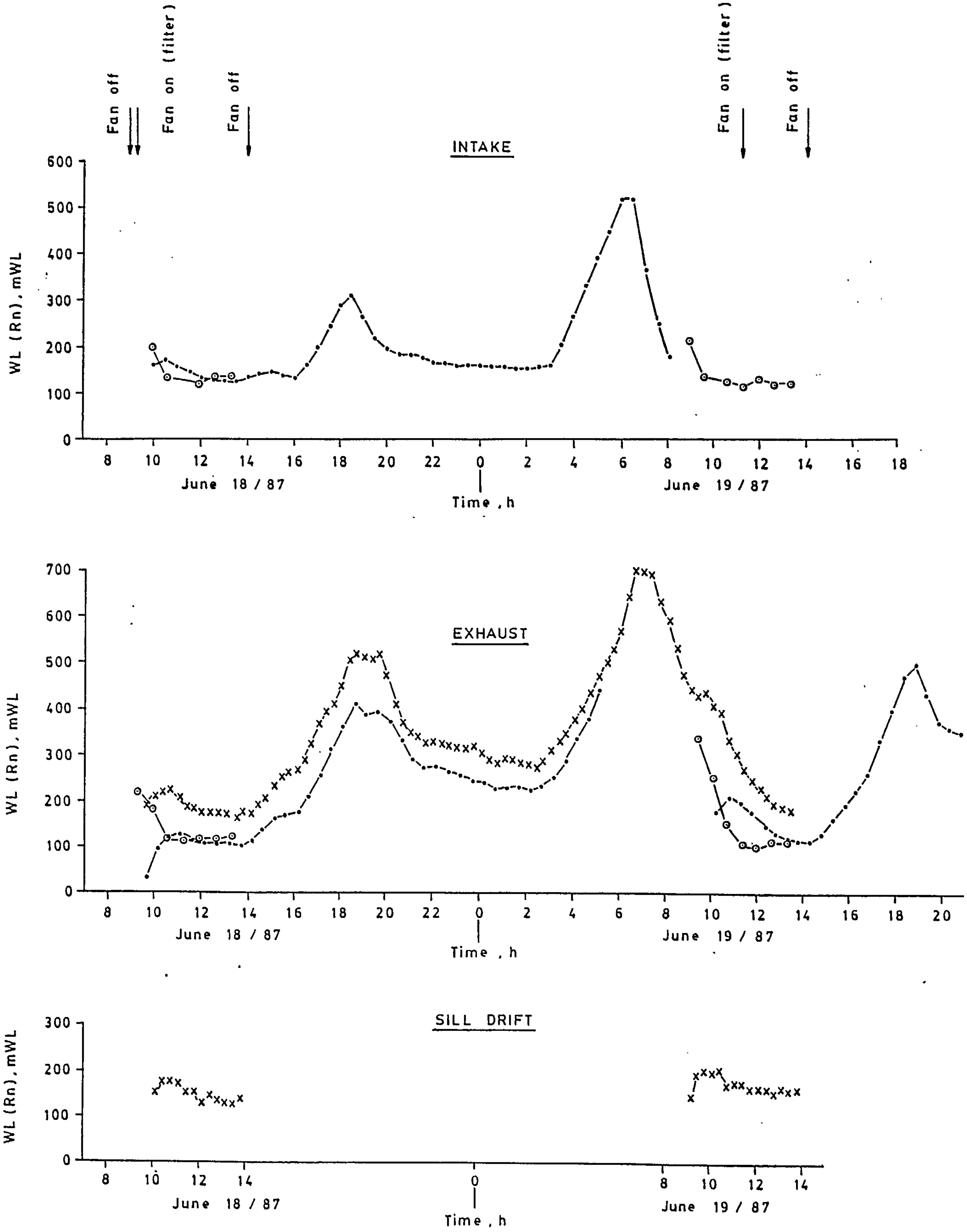

Fig. 6 - Radon progeny Working Level by continuous monitoring and by grab-sampling (daily shift) versus time for several locations and fan/filter conditions.

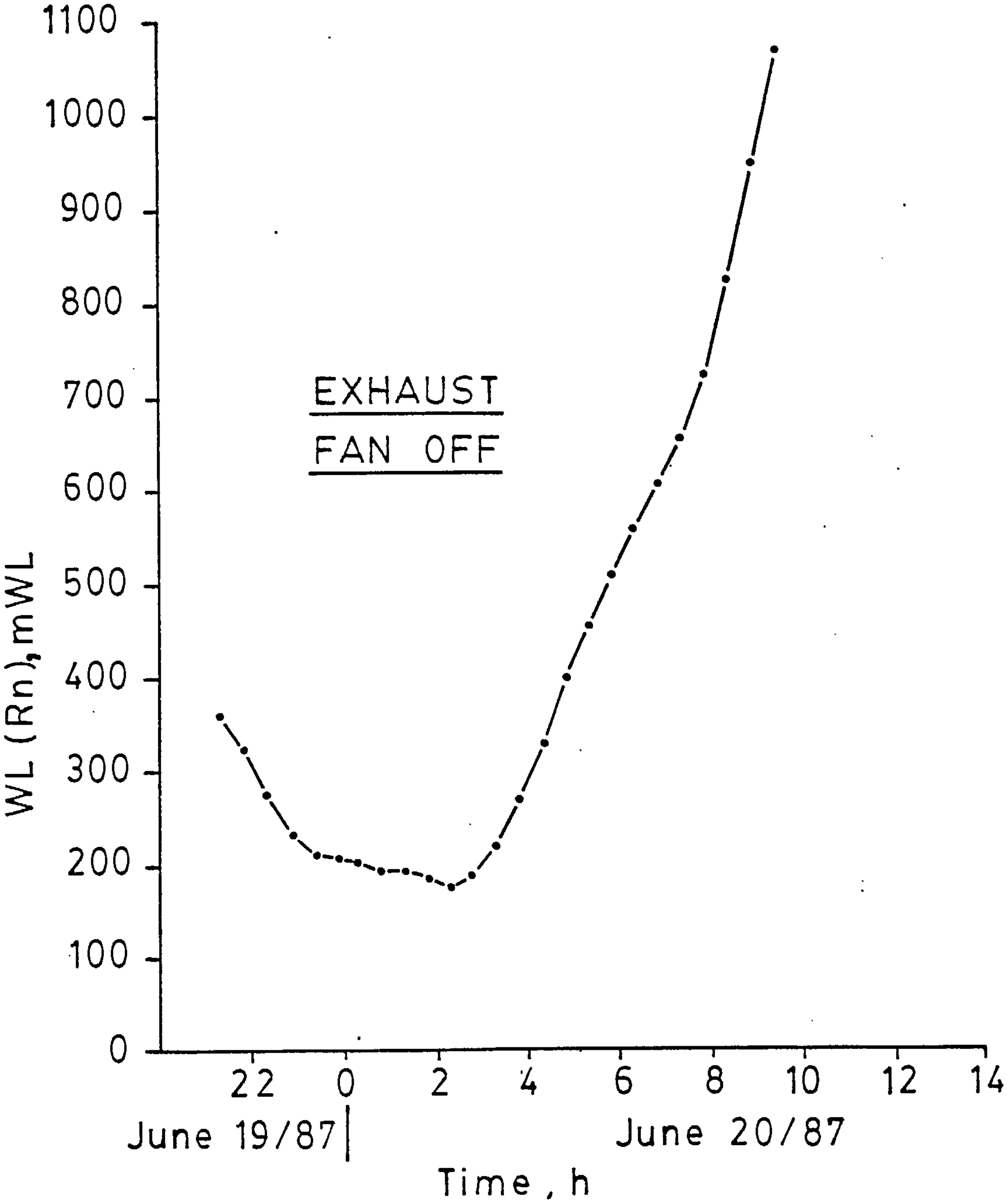

Fig. 7 - Radon progeny Working Level by continuous monitoring versus time for the exhaust with the fan off.

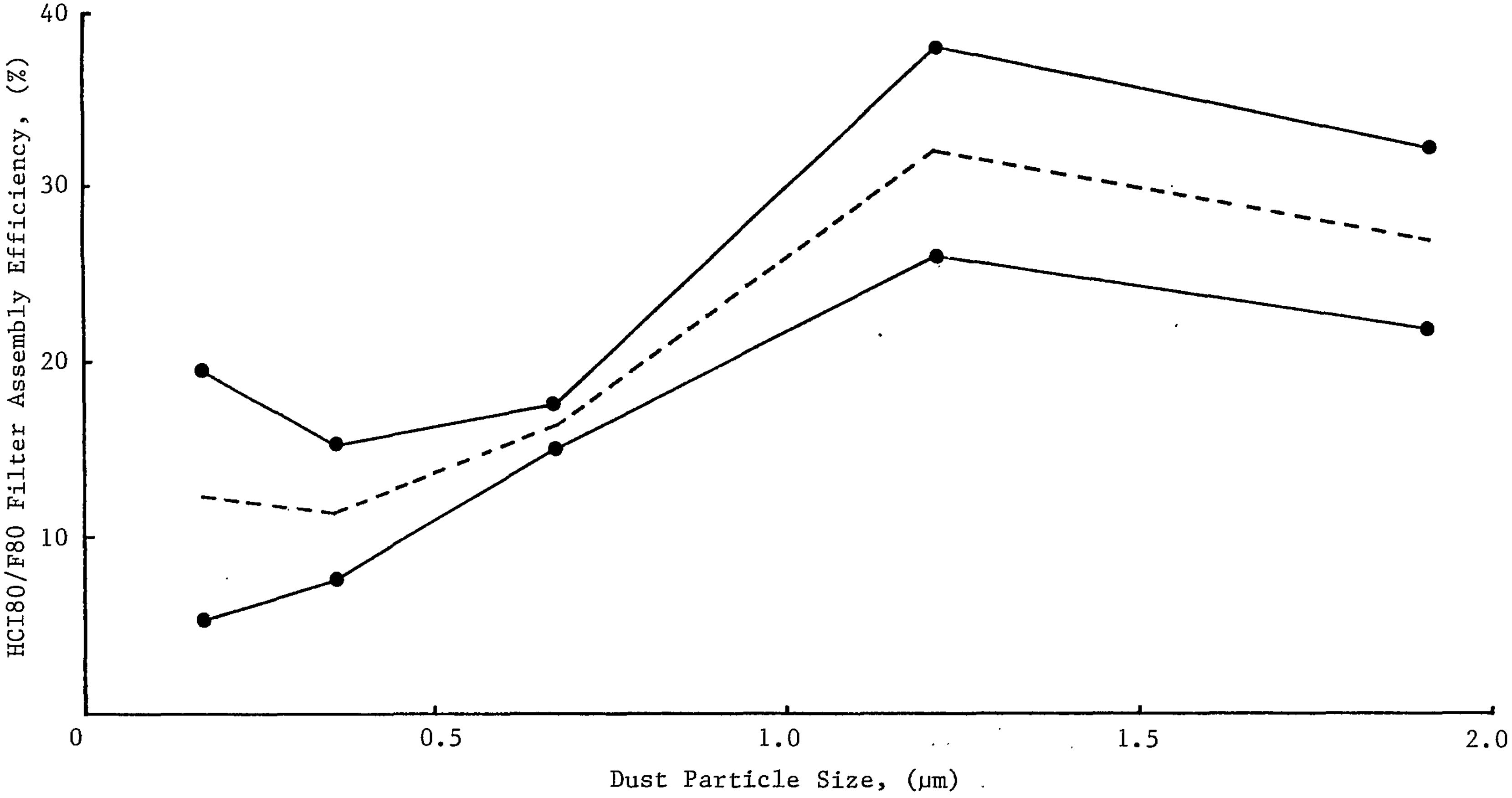

Fig. 8 - HCI80/F80 filter/fan efficiency as a function of particle size. Two separate tests are shown as well as the average of both tests.

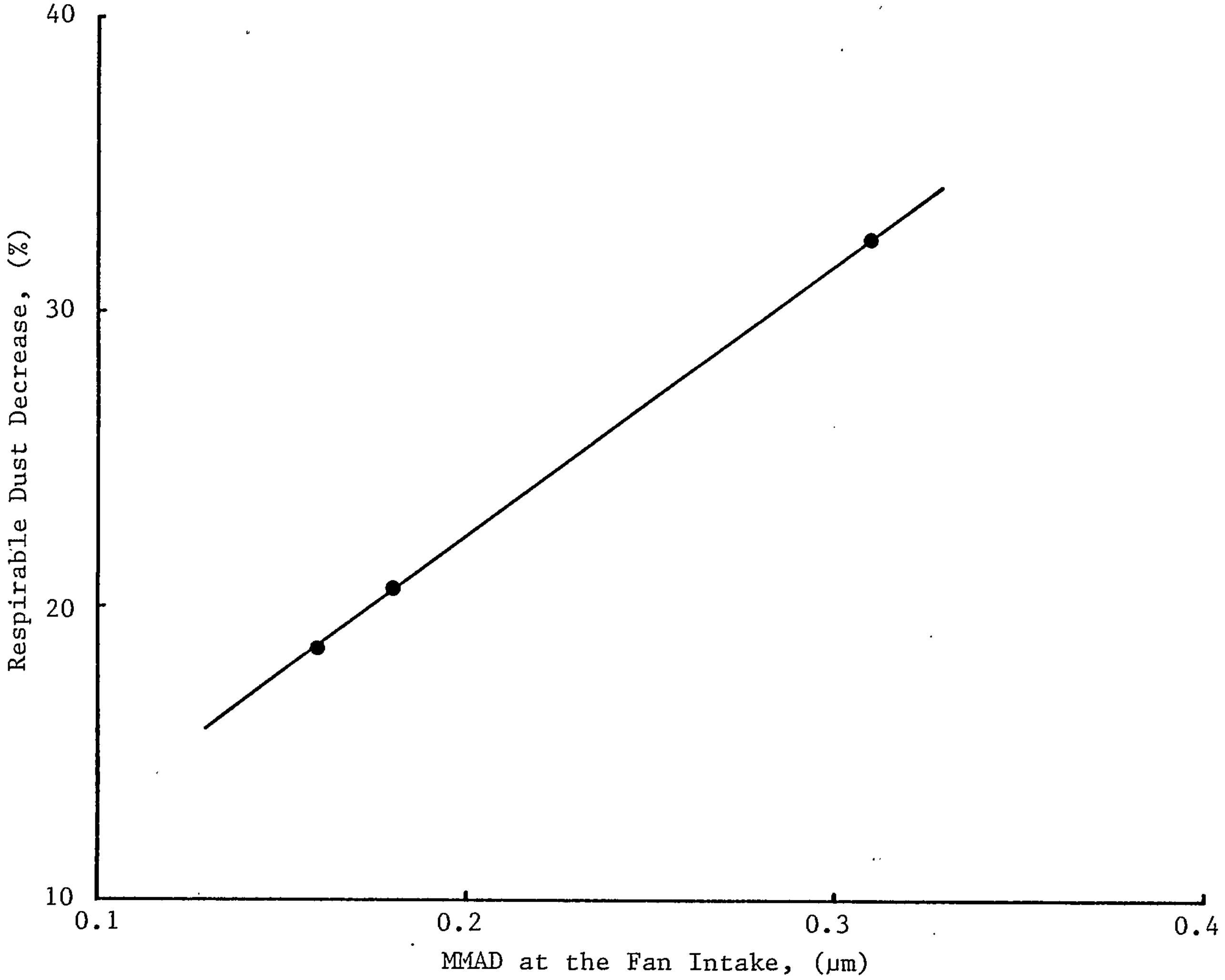

Fig. 9 - Percent respirable dust decrease measured between areas at the fan intake and exhaust as a function of MMAD measured at the intake.