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by

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ABSTRACT

An electrostatic precipitator based on charged water spray technology has been used in an underground uranium mine to control long-lived radioactive dust, and short-lived aerosol concentration, in a mine gallery where dust from a rock breaking/ore transportation operation was discharged. Two main sampling stations were established, one upstream of the dust precipitator, and one downstream. In addition, dust samplers were placed at different locations between the dust discharge and the end of the mine gallery. Long-lived radioactive dust was measured using cascade impactors and nylon cyclone dust samplers, and measurement of the radioactivity on the samples was carried out by conventional methods. Radon and thoron progeny were estimated using standard techniques. Experiments were conducted under a variety of air flow conditions. A gross radioactive dust reduction of about 40% at a ventilation rate of 0.61 m^3/sec was obtained. The dust reduction efficiency of the charged water spray decreased with increasing ventilation rate, i.e., decreasing air residence time, and hence, reduced dust cloud/charged water droplets mixing time.

Key words: Radioactive dust; Electrostatic precipitator; Charged water spray; Dust reduction.

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INTRODUCTION

Several techniques have been used to reduce dust emissions in mines. mills and other working environments. Effective dust control techniques include mechanical filtration, the use of wet scrubbers, electrostatic filtration employing filters with electret-like properties, hydraulic water sprays, electrostatic precipitation, and air 'curtains' using fans. More recently, the use of electrostatic fog techniques have been applied (1).

Water sprays are effective in removing respirable dust from working atmospheres, and also in producing dust stratification for dust avoidance (2). However, electrostatic fog techniques, e.g., charged water sprays, should in principle be more efficient at dust removal than traditional hydraulic water sprays. Unlike hydraulic sprays, however, charged water sprays require a minimum residence time for the charged water droplets and the dust particles to interact. Charged water sprays are most effective where air exchange and air velocities are low (3). The use of charged water sprays for dust control purposes has been reported by several authors (1,3,4).

In underground uranium mines and in mills, radon gas and its short-lived decay products are found in air in relatively high concentrations. These radioactive products attach themselves to particulate matter in the submicron range. Furthermore, long-lived radionuclides are found in respirable dust (1 to $\lesssim$10 μm) and coarse dust, generated in the course of mining and milling operations, particularly in rock crushing and ore transportation operations.

The long-lived radionuclides identified in airborne dust are formed by radioactive decay of uranium and thorium minerals present in the rock matrix. Included in these radionuclides are the parents of the natural radioactive decay chains, i.e., ^{238}U, ^{235}U and ^{232}Th.

Because of the association of radionuclides and airborne particulate matter, it is apparent that an effective dust control technique may also be a good radiation control method. With this in mind, a study using a commercial charged water spray was conducted in an underground uranium mine. A working location was chosen compatible with the potential application of the charged water spray, i.e., area of low air velocity, and hence, longest residence time and large dust production, such as crushing and ore transportation operations. The study was conducted in an area next to the dust discharge from a crusher/conveyor belt operation. A preliminary investigation using the Dustron system has been reported elsewhere (5).

THEORETICAL BACKGROUND

Under our experimental conditions, dust concentration is reduced mainly by the following physical mechanisms:

1. dilution by ventilation;
2. gravitational settling;
3. turbulent and Brownian diffusion with inertial impaction to mine walls:
4. scrubbing by the water spray; and
5. electrostatic forces.

The above removal mechanisms are linear effects, i.e., they depend on the instantaneous dust concentration. Other removal mechanisms such as coagulation are assumed not to be operative in our case because they require very high dust particle concentration, i.e., $>10^6/cm^3$.

The rate of removal of airborne dust by the above mechanisms can be expressed by the following equation:

$$V(dC/dt) = -C(Q + R) \qquad (1)$$

where, C is the dust concentration, e.g., Kg/m^3

V is the volume of the section of the mine under consideration, m^3

Q is the ventilation (air flow) rate, m^3/sec

R is a combined dust removal coefficient that takes into consideration the various dust removal mechanisms involved except for dilution by ventilation air, m^3/sec. Hence:

$$R = R_1 + R_2 + R_3 + \ldots = \Sigma_i R_i \tag{2}$$

where the subindices indicate the different removal mechanisms. It should be noted that the first term on the right hand side of Equation (1) represents the removal of dust by ventilation.

Integration of Equation (1) within the limits $C = C_o$ for $t = 0$, and $C = C$ for $t = t$ gives:

$$C = C_o e^{-((Q + R)/V)t} \tag{3}$$

Taking into consideration that V/Q represents the air residence time, t_R, in the mine volume V, Equation (3) shows that C decreases with increasing air residence time $t_R(= V/Q)$.

Under steady-state conditions it is possible to calculate the efficiency of the charged water spray for removing respirable dust. The removal efficiency, η, is defined by:

$$\eta = 1 - (C_{out}/C_{in}) \tag{4}$$

where C_{out} and C_{in} are, respectively, the dust concentration leaving and entering the volume V.

Defining now:

$$F_T = (Q + R_T)/V \tag{5}$$

and

$$F = (Q + R)/V \tag{6}$$

as the combined dust removal mechanism coefficient when the charged water spray is operating (Equation (5)), and the coefficient without the charged water spray (Equation (6)), it is easy to show that (3):

$$\eta = 1 - e^{-\Delta F . t_R} \tag{7}$$

where,

$$\Delta F = F_T - F$$

Equations (4) and (7) can be used to calculate the dust removal efficiency of the charged water spray used here.

THE CHARGED WATER SPRAY GENERATORS

The charged water spray generators used in the tests are manufactured by Keystone Dynamics (Villanova, PA., U.S.A.), and they are known under the commercial name Dustron Series 100.

The primary component of the system is the DUSTRON emitter. This unit uses compressed air to generate a finely atomized water mist. As the water is atomized, electrostatic charges are placed on the water droplets. The DUSTRON emitter must be supplied with pressure-controlled compressed air and clean water at a given constant flow-rate. The DUSTRON emitter unit requires a 24 V DC power supply to energize the charging system. Water droplets are charged by the field produced by a high voltage coil in an insulated enclosure system. A control panel is used to meter the water flow-rate to each emitter, and to control air pressure.

In addition to the DUSTRON emitter and the control panel, the charged water spray generator is provided with an electrical power supply cabinet to generate the required 24 V DC for the emitters from a regular 115 V AC 50-60 Hz source.

The compressed air pressure to the water spray atomizers was set at approximately 400 kPa. The water inlet was also set at about 400 kPa. The water flow-rate in each spray was in the range 0.076 to 0.30 L/min. However, different operating conditions were selected consistent with the specifications and range of operating values for the above variables suggested by the manufacturer.

No indicator was provided on the equipment to check the charge on water droplets. The charging performance of the system had to be checked externally by measuring the electrical current in the water mist produced. This was done by means of a 20 cm x 20 cm metal mesh (~1 mm spacing) mounted on an insulated teflon rod and connected to ground through a micro-ammeter. Under continuous operation the current measured was about 5 μA.

EXPERIMENTAL PROCEDURE

Experimental tests were conducted under three conditions:

a) no water spray:

b) uncharged water spray; and

c) charged water spray.

Under the above experimental conditions the following variables were measured:

i) dust (coarse and respirable);

ii) short-lived radon and thoron progeny associated with submicron particulate matter:

iii) long-lived radionuclides associated with dust.

Coarse and respirable dust data are reported elsewhere (6). Radon progeny were measured by grab-sampling using the Kusnetz method (7), two automated personal α-particle dosimeters (alpha-PRISM, from alpha-NUCLEAR, Toronto), and two Working Level (WL) continuous monitoring systems model RGA-400. manufactured by EDA Instruments (Toronto). Thoron progeny were measured using a modified version of the Rock method (8).

Long-lived radionuclides associated with respirable dust, i.e., Long-Lived Radioactive Dust (LLRD), were measured using 10 nylon cyclone dust samplers. Size distribution data were obtained by means of two 10-stage cascade impactors manufactured by Sierra Instruments (U.S.A.), model 210, operated at a flow-rate of about 13.3 L/min. Only 8 stages were used in each impactor. In addition, respirable dust was continuously monitored with an automated real-time dust monitor, model MiniRam PDM-3 from GCA (U.S.A.).

Two complete radiation sampling stations were established, one before the charged water spray system (i.e., upstream), and the other some distance away downstream, i.e., after the system. The radiation stations included instrumentation to measure radon and thoron progeny, and long-lived radionuclides (concentration and size distribution). In addition, dust samplers (nylon cyclones) for LLRD measurements were positioned at different locations before and after the water spray system, including the positions of the radiation sampling stations above.

Radon and thoron progeny data were collected every 20 min. Respirable dust data measured with the Mini-Ram were collected at a rate of one reading every 6 sec. Ten nylon cyclone samples were taken per day for respirable LLRD (and thoron progeny) analysis. Two sets of cascade impactor data were obtained daily for LLRD size distribution analysis and total LLRD concentration.

In order to investigate the effect of mine air residence time, t_R, on the removal of long-lived radionuclides by the charged water spray system, measurements were carried out under different air flow conditions. However, because of difficulties in controlling air flow under actual mine field conditions in a production area of the mine, only a limited range of ventilation rates and experiments at each flow (ventilation) rate are available. The range of air flow rate investigated was 0.61 to 1.64 m^3/sec.

Experiments were conducted in a 80 m long (~10 m^2 cross-section) mine gallery. The two sampling stations were located about 10 m and 52 m from the dust discharge and defined a 'control' mine volume of about 420 m^3(=V). The dust source was the outlet of a filter installed at the exhaust air system of a crusher/conveyor belt. The exhaust air ducting system discharged dust from the crusher/conveyor belt at 90^o relative to the axis of the test location. i.e., mine gallery. Figure 1 shows the experimental site.

Air residence time measurements were conducted: a) by estimating air velocity by anemometry, and b) by measuring (with the Mini-Ram) the time elapsed between the maximum dust concentration at the two sampling locations. Air residence time data are given in Tables 1 and 2.

The duration of the tests was two weeks. Two charged water spray units were used in close proximity and pointing slightly upward and upstream. In order to improve mixing of air, brattice curtains were hung in the test mine gallery defining a known 'mixing' volume of about 120 m^3 where the DUSTRON charged water spray system was located.

RESULTS AND DISCUSSION

The experimental data obtained have been summarized in Tables 1 and 2 and Figures 2 to 10.

Figures 2 to 4 show cascade impactor data. Figure 2 shows the percentage of Long-Lived Radioactive Dust (LLRD) activity accumulated in each impactor stage as a function of the impactor stage cut-off size before (upstream) and after (downstream) the DUSTRON,operating under normal conditions, for an air flow through the gallery of 0.61 m^3/sec.

Figure 2 shows that upstream of the DUSTRON, the dust size distribution spectrum is substantially broader than downstream. Futhermore, the dust size distribution after (downstream) the DUSTRON is shifted toward the smaller size range indicating the effect of the DUSTRON on the dust cloud.

Some of the effect observed is, however, due to gravitational settling and the scrubbing of dust by the water spray itself, even if uncharged.

Figure 3 shows the percentage cumulative LLRD activity versus the Equivalent Aerodynamic Diameter, EAD ($D_{P,50}$), upstream and downstream of the DUSTRON for several air flows through the gallery. The graphs of Figure 3 permit the estimation of the Activity Median Aerodynamic Diameter (AMAD) and the geometric standard deviation, σ_g, of the dust cloud (see Table 1). Figure 3 and Table 1 show that the DUSTRON is effective in reducing the AMAD, but this reduction is highly dependent on air flow conditions in the gallery. Maximum effect was obtained at lower air flows, i.e., longer residence times, as predicted by theory. Maximum AMAD reduction was obtained for an air flow Q = 0.61 m^3/sec, the lowest air flow achievable consistent with practical constraints and considerations in this particular production area of the mine. Data corresponding to the AMAD, σ_g, and AMAD reduction for several values of Q are given in Table 1.

Figure 4 shows the percentage cumulative LLRD activity versus EAD upstream and downstream of the DUSTRON for an air flow through the gallery of 0.61 m^3/sec when the DUSTRON is operated under normal conditions (i.e., water spray and charge), left figure, and with the DUSTRON off, right figure. Figure 4 shows that even with the DUSTRON off there is a reduction in AMAD between the location before and after the DUSTRON (see also Table 1). This is due, as indicated above, to gravitational settling and deposition mechanisms other than that by electrostatic means.

Complementary to Figures 3 and 4 are the data of Table 1 which show a greater AMAD reduction at Q = 0.61 m^3/sec when the DUSTRON was on (spray + charge) than when the DUSTRON was off. Again, a greater AMAD reduction was observed at Q = 1.02 m^3/sec when the DUSTRON was on (spray + charge) as compared with spray on but no charge. From the above data one may conclude that the DUSTRON had a significant effect on AMAD reduction, the effect being larger at lower airflow rates. Furthermore, from the limited data available, it seems that the AMAD reduction was larger with a charged spray than with the spray only. Unfortunately, not all desirable experimental conditions could be met in order to study all the cases of interest (see footnote of Table 1).

Figure 5 shows the percentage reduction in LLRD concentration, as obtained with the cascade impactors, as a function of the air flow in the gallery (see also Table 2). This figure shows that the percentage reduction in LLRD concentration decreases rapidly with increasing air flow in the mine gallery. This is to be expected from theory, as discussed above, because of the reduced mixing time of dust with the charged water spray at high air flows.

The values plotted in Figure 5 are total (percentage) dust reduction efficiency, e.g., ~40% for Q = 0.61 m^3/sec. The net reduction efficiency, i.e., due to electrostatic deposition mechanisms only, can be calculated from data reproduced in Table 2 and Equation 4. For example, using LLRD for Q = 0.61 m^3/sec when the DUSTRON is on and off, after concentration normalization, the dust removal efficiency of the DUSTRON is about 20%. Concentration normalization is necessary because dust production was not constant but varied substantially on a daily basis. The net LLRD reduction efficiency at a given Q can easily be calculated by subtracting the removal efficiency when the DUSTRON is off from the removal efficiency when the DUSTRON is on.

Equation 7 permits calculation of ΔF from the experimental data obtained. For Q = 0.61 m^3/sec, η = 0.2 (i.e., 20%), hence Equation 7 gives $\Delta F \simeq 1.46 \times 10^{-2}$ min^{-1}. The variable ΔF, i.e., the net removal mechanism coefficient, depends on air flow conditions.

Under the air flow conditions of the tests the LLRD at the dust discharge was in the range 200-400 mBq/m^3 (see Table 2), and the AMAD corresponding to the radioactive dust cloud was in the range 4.0 to 5.2 μm (see Table 1). As Tables 1 and 2 show, a net reduction in LLRD and AMAD of about 20% at Q = 0.61 m^3/sec was brought about by the DUSTRON. The average AMAD at the dust discharge was slightly larger than the Mass Median Aerodynamic Diameter (MMAD) of the dust carrier.

Figure 6 shows the LLRD concentration (actual and normalized), measured in samples taken with nylon cyclone dust samplers, as a function of distance from the dust discharge when the DUSTRON was operating, continuous line, and when the DUSTRON was not operating, short broken lines. (It should be noted that the longer broken lines are used to indicate average values for the LLRD concentration when the DUSTRON was off. The DUSTRON was located about 24 m from the dust discharge.) Figure 6 shows a rapid decline in LLRD concentration as the air approaches the operating DUSTRON and then a very slight increase thereafter. When the DUSTRON was not operated the LLRD concentration followed a far less well defined profile and there was a significant LLRD concentration increase as compared with the case when the DUSTRON was on.

Complementary to Figures 5 and 6 are the data of Table 2 which show a greater LLRD concentration reduction at Q = 0.61 m^3/sec when the DUSTRON was on (spray + charge) than when the DUSTRON was off. No comparison could be made at the same flow rate with the spray on, but no charge, for the reasons given in Table 2 (see footnote). However, data for Q = 0.82 m^3/sec show that the reduction in LLRD concentration is between the case with the DUSTRON on (spray + charge), and DUSTRON off at Q = 0.61 m^3/sec. One may speculate on the basis of these data, and data of Table 1, that the charge on water droplets may have some effect on LLRD concentration although it cannot be quantified in this instance because the actual effect (spray, no charge) is larger at 0.61 m^3/sec than at 0.82 m^3/sec. It may be concluded from the above data that a reduction in LLRD concentration is brought about by the operation of the DUSTRON, and that this reduction increases with decreasing airflow rate.

The total respirable dust concentration and the quartz respirable dust concentration measured by the nylon cyclones in the proximity of the dust discharge were in the range 1.17 to 1.77 mg/m^3 and 0.53 to 0.95 mg/m^3, respectively. Total dust measured by the cascade impactors at the same location was in the range 3.57 to 7.42 mg/m^3. Total dust concentration values estimated by the cascade impactors at the downstream sampling location were 1.94 to 3.80 mg/m^3.

Figures 7 to 9 show radon progeny data upstream and downstream of the DUSTRON for several air flows through the gallery. Also shown (by arrows) in the above Figures, are the times at which the crusher was operating and inactive (off). The radon progeny sampling stations were situated at about 10 m and 52 m from the dust discharge, respectively. These locations corresponded to ~15 m before (upstream) and 28 m after (downstream) of the DUSTRON, respectively. The radon progeny data shown correspond to the Working Level, WL(Rn), a measure of the radon progeny concentration in air; 1 WL = 20.53 μJ/m^3.

Figure 7 shows WL(Rn) versus time when the DUSTRON was off, and for Q = 0.61 m^3/sec. The Figure shows that the WL(Rn) was higher downstream than upstream of the DUSTRON. This is to be expected because of diffusion and transport of radon gas (^{222}Rn), from the decay of the uranium minerals, through mine walls. Hence, the total radon, and therefore radon progeny, concentration at a given location in the gallery is made up of two contributions, namely emanation from mine walls and the contribution carried by the flow of air from upstream locations. It should be noted that self-absorption effects may also play a role as indicated below (see also Figures 8 and 9).

Figure 8 shows WL(Rn) versus time for the two experimental sampling locations of interest, i.e., before (upstream) and after (downstream) the DUSTRON. The graphs show the effect of the DUSTRON on WL(Rn) for three different air flow conditions in the gallery, namely Q = 0.61, 1.02, and 1.64 m^3/sec. It is seen that for low air flows , i.e., Q = 0.61 m^3/sec. WL(Rn) after the DUSTRON is higher than before the DUSTRON (see also Figure 7). However, this situation reverses at higher air flows, i.e., Q = 1.64 m^3/sec. The transition between these two opposite conditions occurs, under our experimental conditions, at an air flow of about 1.0 m^3/sec.

The overall effect observed in Figure 8 is not clearly understood because of the different competing radioactivity removal mechanisms involved. The following should be considered in order to interpret the experimental data:

a) effect of air flow, i.e., ventilation rate;

b) effect of the water spray;

c) effect of charge on the water droplets; and

d) effect of location.

Assuming that the geological, geometrical and physical characteristics of the mine gallery are uniform, constant and isotropic (within the ore bearing rock mass), the following should be expected:

i) An increase in the ventilation rate, i.e., air flow, will bring about a decrease in the radon, thoron, and their progeny, level. The converse is equally true.

ii) Radon and thoron levels at locations downstream of the DUSTRON will be higher than upstream because of the radon and thoron contribution from mine walls by diffusion and transport mechanisms. However, because of plate-out phenomena of radon and thoron progeny on large surfaces. such as mine walls, the increase in radioactive gas levels indicated above may not strictly apply to the case of the decay products.

iii) The water spray will produce an increase of aerosol concentration in the area of variable size range according to experimental conditions. Aerosol concentration has no effect on radon and thoron levels. but it does affect their progeny concentration. In general, it is expected that the water spray will increase the radon and thoron progeny levels because plate-out mechanisms are reduced due to attachment of the decay products to aerosols, thereby decreasing their diffusivity.

iv) The effect of charged water droplets on radon and thoron progeny under our experimental conditions is not well understood.

Because of items a) to d), and i) to iv), it is difficult to predict the combined effect of air flow, charged water droplets, and location on radon and thoron progeny levels. However, an explanation for Figure 8, where the radon progeny concentration measured after the DUSTRON was higher than upstream of the DUSTRON for the lowest ventilation rate (0.61 m^3/sec), is filter self-absorption. This phenomenon consists of the attenuation or absorption of α-particles by dust deposited on the sampling filter. Self-absorption is more important upstream of the DUSTRON than downstream because of: a) higher total dust concentration; b) higher concentration of larger dust particles. With dust removal by the DUSTRON and gravitational settling, there will be fewer and smaller dust particles collected on downstream samples. and hence, less self-absorption in the sampling filters. Consequently, an apparently higher radon progeny concentration will be observed. This effect becomes important at low airflow rates, i.e., high dust concentrations. Filter self-absorption also affects LLRD concentration measurements by gross α-particle counting. Hence, the reduction in LLRD concentration by the DUSTRON may be higher than indicated by the experiments.

It should be noted that for Long-Lived Radioactive Dust the situation is considerably simpler because of the much larger size of the particles, i.e., 1 μm to >10 μm, for LLRD as opposed to <<1 μm for radon and thoron decay products. Radon and thoron progeny are found either unattached or combined with aerosol of submicron size. Hence, plate-out phenomena are not relevant for LLRD.

Figure 9 shows a similar effect to that indicated in Figure 8 when the DUSTRON is operated with the water spray only and no charge. This indicates that the water aerosol may have a similar effect on the radon and thoron progeny to that of charged water droplets. However, the net effect by either the water spray or the charged water spray could not be investigated in any detail because of the complexity of the underground environment. These effects are best investigated under strict laboratory-controlled conditions which were outside the scope of this field investigation.

Figure 10 shows the thoron progeny activity collected by nylon cyclone dust samplers versus distance from the dust discharge in the mine gallery. The Figure gives normalized activity relative to the activity measured by the dust sampler closest to the dust discharge. Measurements were carried out at different air flows and while the DUSTRON was on and off. Also shown in the graph is the location of the brattice curtains. The Figure shows that there was a significant decrease in thoron progeny activity in the region between the brattice curtains where the DUSTRON was located when the latter was operating. No such decrease was observed when the DUSTRON was off. The graphs also show that the effect was more noticeable at lower air flows than at high air flows.

The measurements presented in Figure 10, and other thoron progeny data (not shown) suggest a similarity between thoron progeny and radon progeny.

SUMMARY AND CONCLUSIONS

The main conclusions that can be derived from the present field study are the following:

a) The efficiency of the DUSTRON in removing Long-Lived Radioactive Dust (LLRD) depended on air flow conditions in the mine gallery. The removal efficiency, η, was higher at low ventilation rates, Q, than at high ventilation rates. Within the range of ventilation rates under which the field work was conducted, the DUSTRON was most efficient at air flows of about 0.61 m^3/sec (t_R ~15 min), the lowest ventilation rate consistent with practical considerations in the test mine production area. The removal efficiency decreased rapidly with increasing ventilation rate. For ventilation rates greater than 1.64 m^3/sec (t_R~4.5 min.), the removal efficiency was <5%, whereas for 0.61 m^3/sec, it was ~20%. It should be noted that the overall removal efficiency for LLRD when the DUSTRON was operating was significantly higher than the figures given above, i.e., ~41% for Q = 0.61 m^3/sec and ~23% for Q = 1.64 m^3/sec. This is because removal mechanisms other than that by electrostatic means, such as convective deposition and gravitational settling, also contribute to the removal of LLRD (see Table 1 and Figure 5).

b) The Activity Median Aerodynamic Diameter (AMAD) corresponding to the LLRD cloud was shifted toward the lower particle size range when the DUSTRON was on, in contrast to when the DUSTRON was not operating. The AMAD shift was largest at the lowest Q, and vice versa (see Figure 2). This shift decreased with increasing Q. A gross AMAD shift of ~2 μm at Q = 0.61 m^3/sec was observed as compared to 1 μm when the DUSTRON was off under the same ventilation conditions (see Figure 3). The shift observed in the latter case is assumed to be due mainly to gravitational settling. AMAD data are given in Table 1.

c) The DUSTRON affected radon progeny levels, WL(Rn), and thoron progeny levels, WL(Tn). Self-absorption effects are suspected to have played a role. However, when these effects are taken into consideration, a modest reduction in WL(Rn) and WL(Tn) by the DUSTRON may have resulted. However, the combined effect, and interplay, of the air flow, location, and charged and uncharged water droplets on radon and thoron progeny levels are not clearly understood. Unfortunately, because of practical considerations regarding mine production areas it was not possible to extend this study to a wider range of experimental conditions.

From the data presented here and data reported elsewhere (5), one may anticipate that radioactive dust removal efficiencies for the DUSTRON could be substantially improved by using more units and lower (<0.6 m^3/sec) ventilation rates (see Figure 5).

The data presented here for LLRD is consistent with theoretical expectations (3), and clearly indicate the important role of adequate dust mixing with water droplets. Hence, residence time (t_R) and, therefore, air flow (Q) are variables of paramount practical importance to ensure optimum performance of dust precipitators such as the DUSTRON as an effective and efficient dust and radioactive dust control method.

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Table 1 - Effect of the DUSTRON on the Activity Median Aerodynamic Diameter (AMAD) as a function of air flow rate.

Before AMAD μm	DUSTRON σ_g*	After AMAD μm	DUSTRON σ_g*	Air Flow Rate m^3/sec	Air Residence Time, t_R** min	DUSTRON Setting	%AMAD Reduction
4.30	3.1	3.20	2.5	0.61	15.30	Off	25.6
5.20	2.6	3.20	2.3	0.61	15.30	Spray & Charge	38.5
4.80	2.5	3.55	2.2	1.02	7.55	Spray, No Charge	26.0
4.35	3.1	2.85	2.4	1.02	7.55	Spray & Charge	34.5
4.00	2.5	3.50	2.3	1.64	4.45	Spray & Charge	12.5

*The symbol σ_g stands for geometric standard deviation.

**Average value obtained from direct air velocity measurements. and by measuring the time elapsed between maximum dust concentration (peak), obtained with the Mini-Ram, between the two sampling stations.

Note: Because the experimental work was conducted in a production area of the mine, airflow changes could not be implemented at will, but only when compatible with production needs, schedules, and health and safety regulations. Hence, it was not possible to reproduce Q = 0.61 m^3/sec with the DUSTRON on (spray, no charge), and Q = 1.02 m^3/sec with the DUSTRON off.

Table 2 - Effect of the DUSTRON on the Long-Lived Radioactive Dust concentration, [LLRD], as a function of the air flow rate

Before DUSTRON [LLRD] mBq/m^3	After DUSTRON [LLRD] mBq/m^3	Air Flow Rate m^3/sec	Air Residence Time, t_R* min	DUSTRON Setting	% [LLRD] Reduction
207.5	163.4	0.61	15.3	Off	21.3
408.0	242.1	0.61	15.3	Spray & Charge	40.7
223.0	150.0	0.82	8.28	Spray, No Charge	32.7
204.2	151.3	1.02	7.55	Spray & Charge	25.9
224.7	146.0	0.72-1.23	9.35	Spray & Charge	35.0
238.6	182.7	1.64	4.45	Spray & Charge	23.4

* Average value obtained from direct air velocity measurements, and by measuring the time elapsed between maximum dust concentration (peak), obtained with the Mini-Ram, between the two sampling stations.

Note: Because the experimental work was conducted in a production area of the mine, airflow changes could not be implemented at will, but only when compatible with production needs, schedules, and health and safety regulations. Hence it was not possible to reproduce $Q = 0.82\ m^3/sec$ with the DUSTRON on (spray + charge), and DUSTRON off; $Q = 0.61\ m^3/sec$ with DUSTRON on (spray, no charge), and other conditions.

LIST OF ILLUSTRATIONS

Figure 8--Radon progeny Working Level, WL(Rn), versus time during operation of the DUSTRON for several airflow conditions in the mine gallery.

Figure 9--Radon progeny Working Level, WL(Rn), versus time during operation of the DUSTRON (spray only) for two airflow conditions in the mine gallery.

Figure 10--Relative thoron progeny α-activity versus distance from the dust discharge site during operation of the DUSTRON for several airflow conditions, and with the DUSTRON off for an airflow of 0.61 m^3/sec.

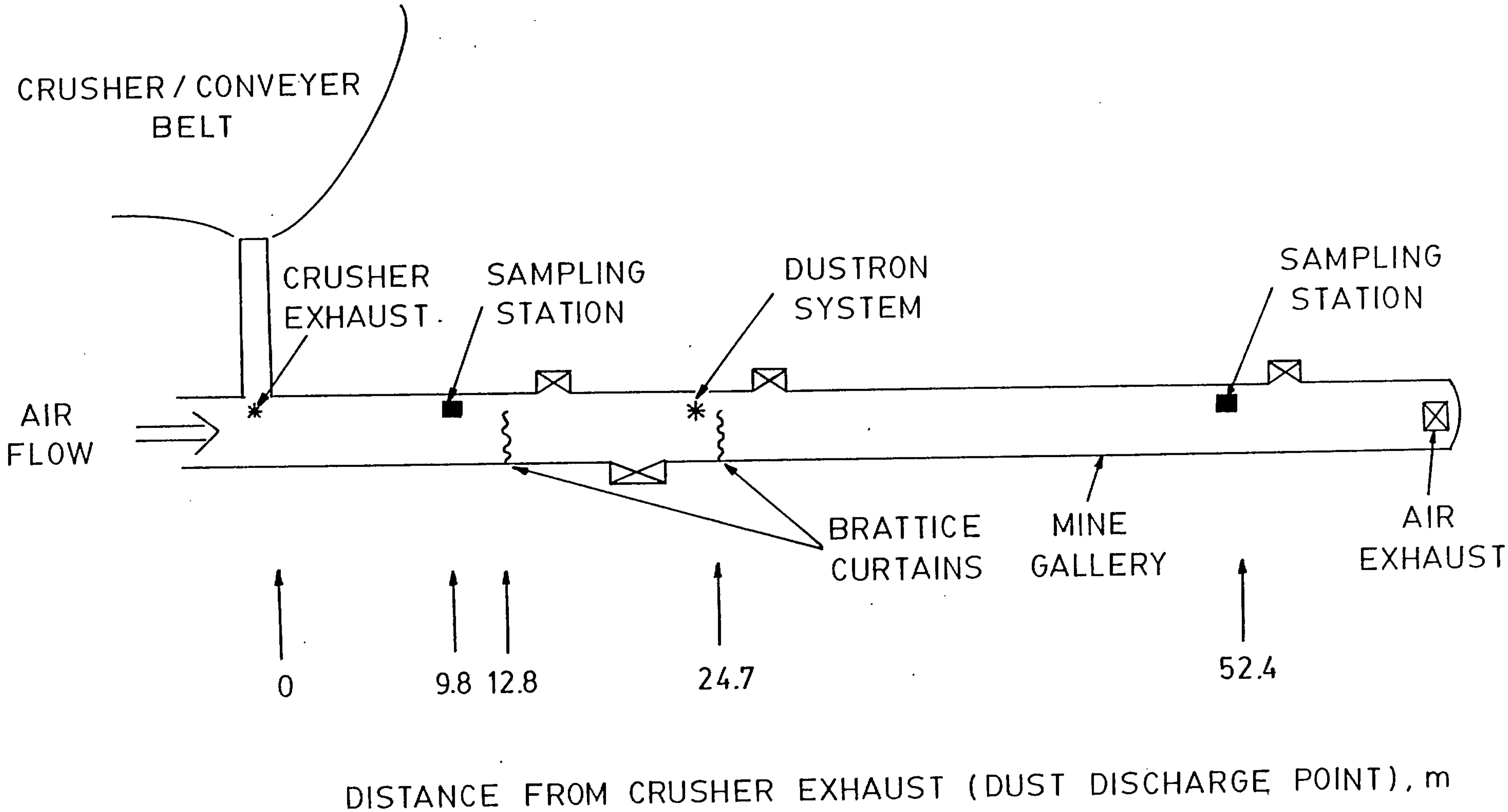

CRUSHER / CONVEYER BELT
CRUSHER EXHAUST
SAMPLING STATION
DUSTRON SYSTEM
SAMPLING STATION
AIR FLOW
BRATTICE CURTAINS
MINE GALLERY
AIR EXHAUST
0
9.8
12.8
24.7
52.4
DISTANCE FROM CRUSHER EXHAUST (DUST DISCHARGE POINT), m

Figure 1

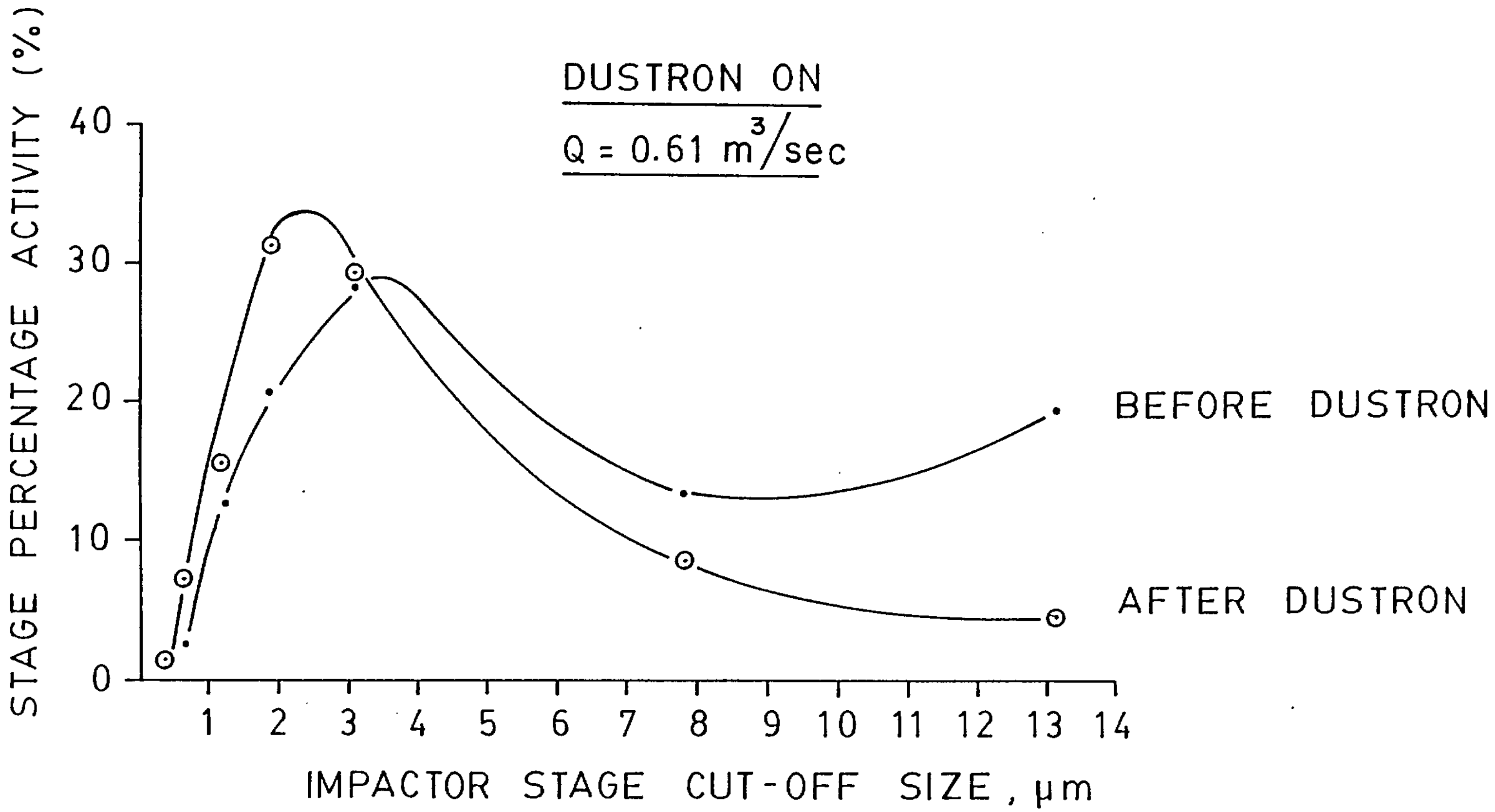

DUSTRON ON
Q = 0.61 m3/sec
STAGE PERCENTAGE ACTIVITY (%)
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14
IMPACTOR STAGE CUT-OFF SIZE, μm
BEFORE DUSTRON
AFTER DUSTRON

Figure 2

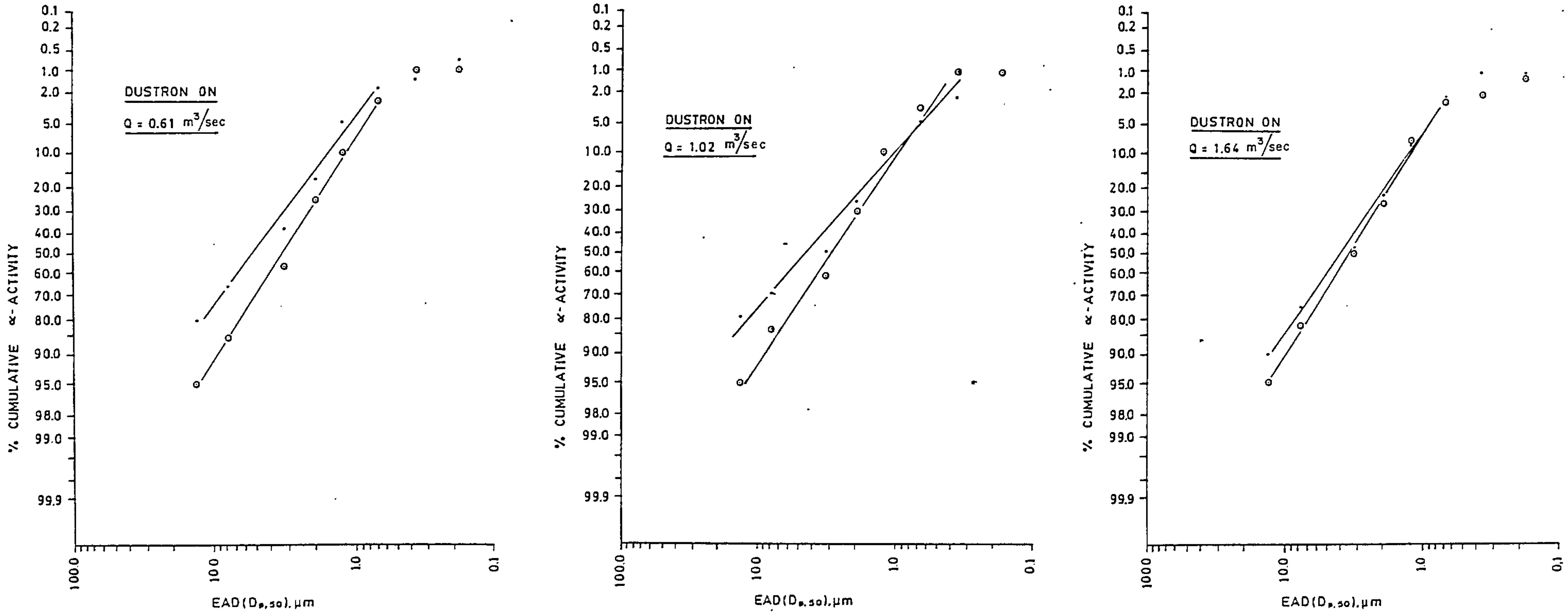
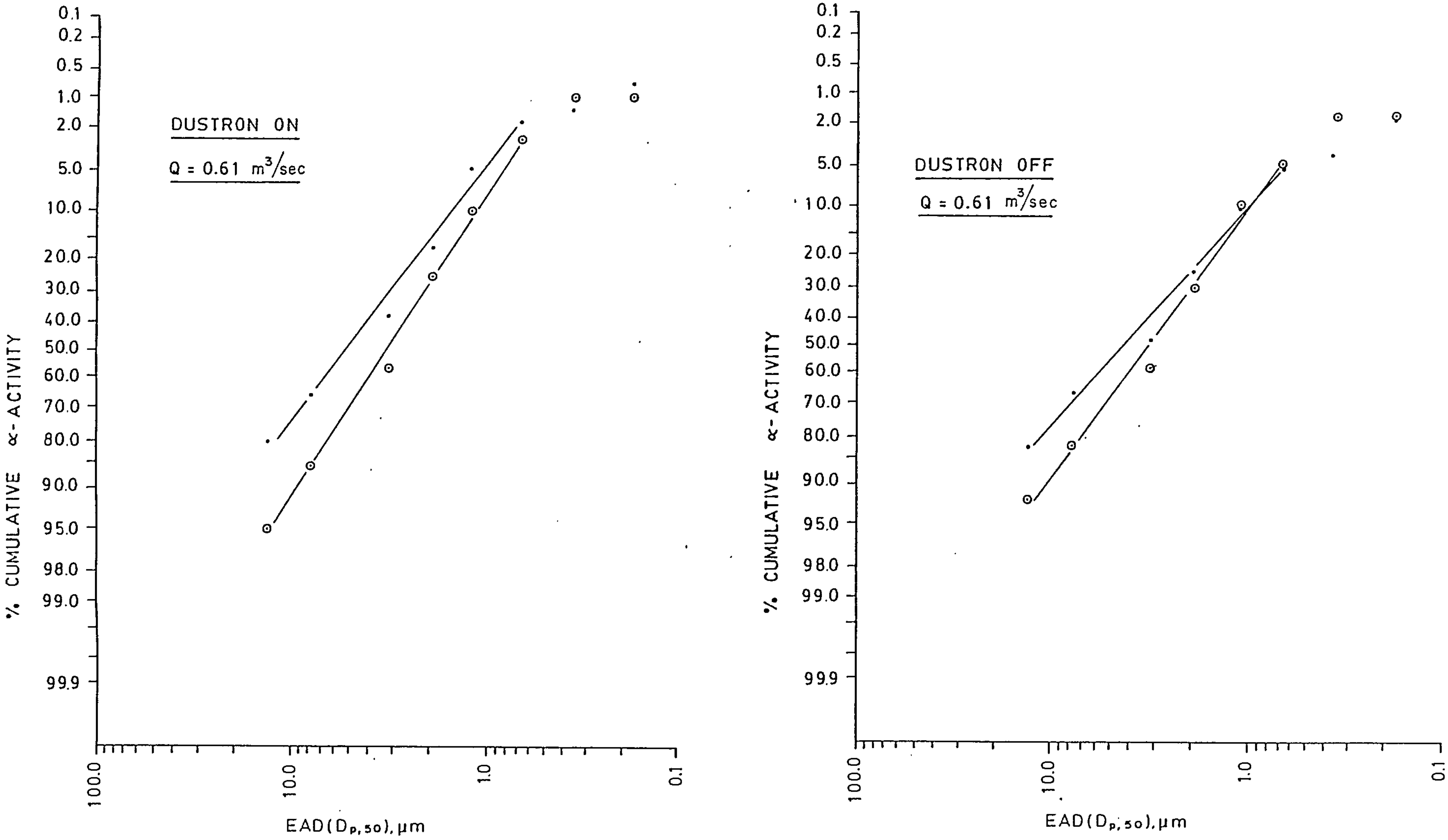

DUSTRON ON
Q = 0.61 m3/sec
DUSTRON ON
Q = 1.02 m3/sec
DUSTRON ON
Q = 1.64 m3/sec
% CUMULATIVE α-ACTIVITY
EAD(Dp,50),μm
0.1
0.2
0.5
1.0
2.0
5.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
95.0
98.0
99.0
99.9
100.0
10.0
1.0
0.1

Figure 3



DUSTRON ON
Q = 0.61 m3/sec
% CUMULATIVE α- ACTIVITY
EAD(Dp,50),μm
DUSTRON OFF
Q = 0.61 m3/sec
% CUMULATIVE α- ACTIVITY
EAD(Dp,50),μm

Figure 4

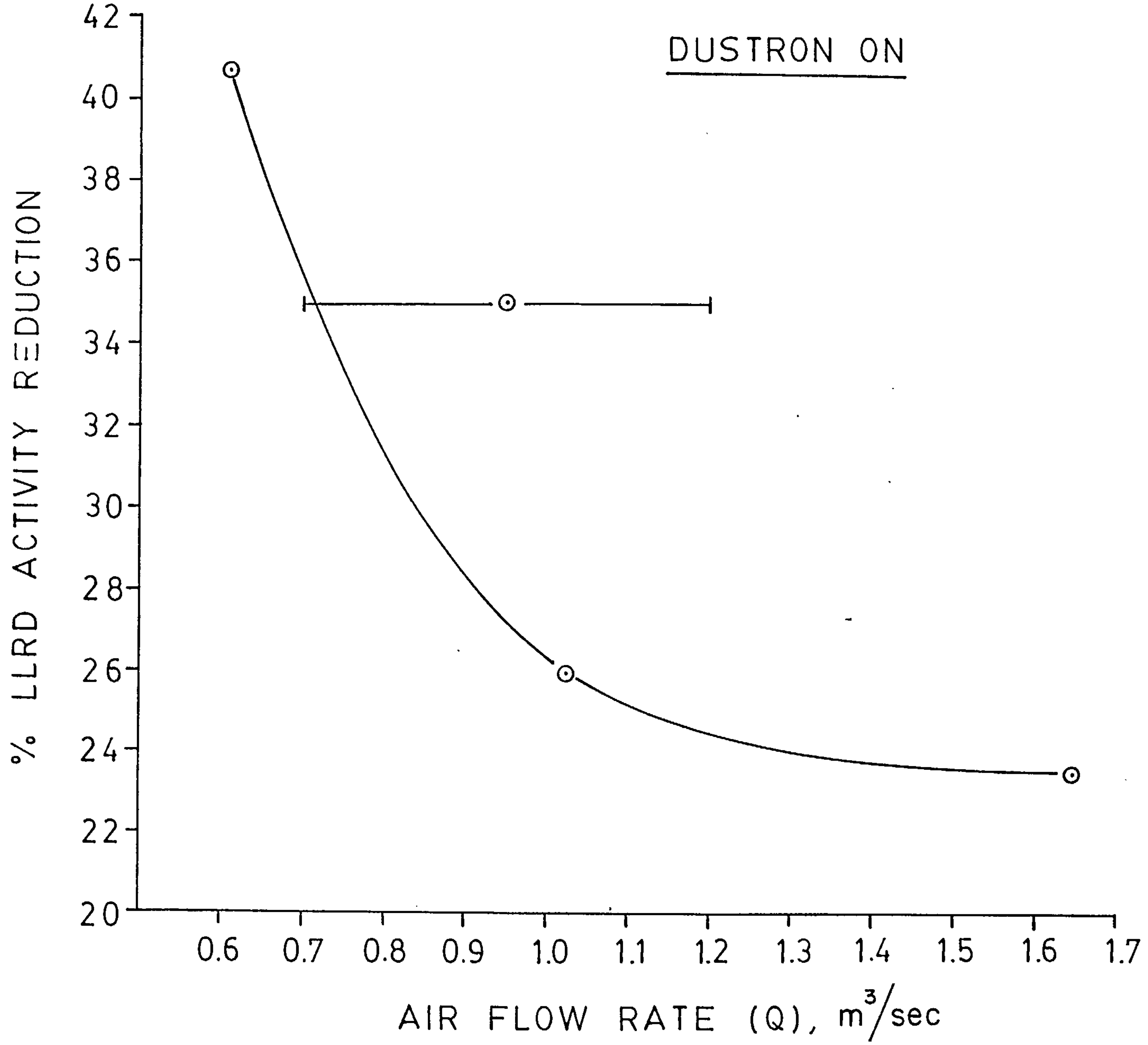
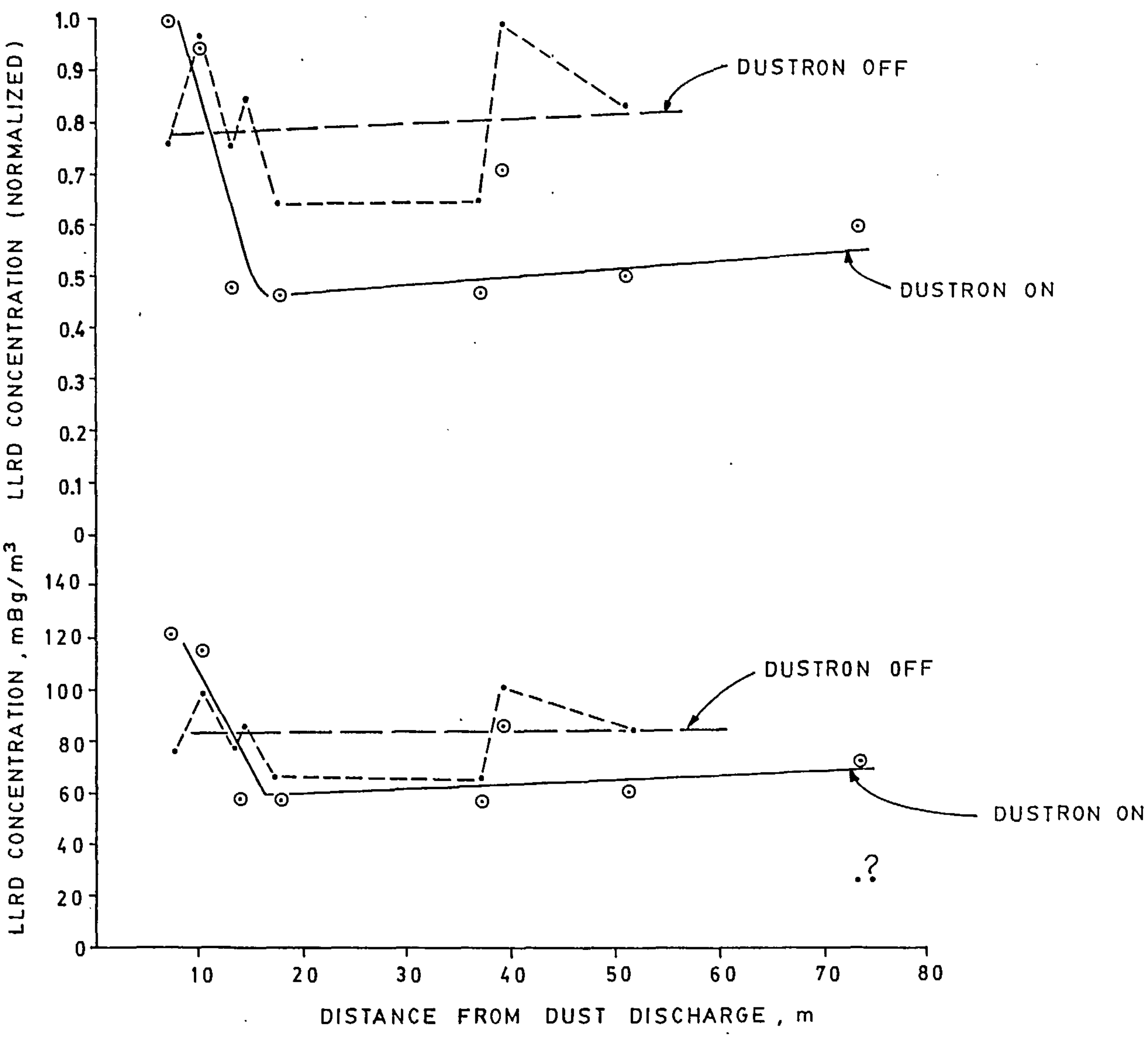
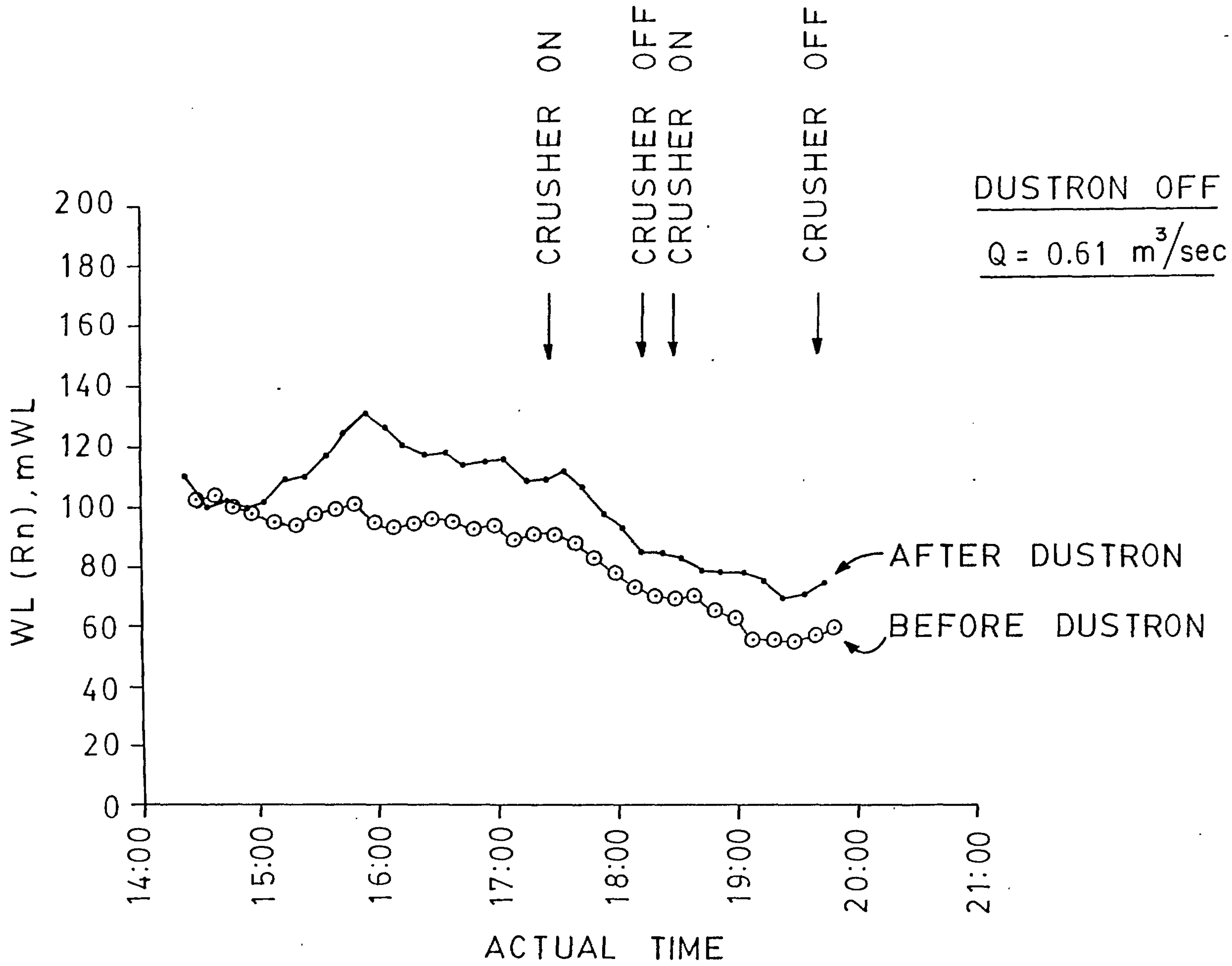

DUSTRON ON
% LLRD ACTIVITY REDUCTION
42
40
38
36
34
32
30
28
26
24
22
20
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
AIR FLOW RATE (Q), m3/sec

Figure 5



LLRD CONCENTRATION (NORMALIZED)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
DUSTRON OFF
DUSTRON ON
LLRD CONCENTRATION, mBg/m³
140
120
100
80
60
40
20
0
DUSTRON OFF
DUSTRON ON
?
10
20
30
40
50
60
70
80
DISTANCE FROM DUST DISCHARGE, m

Figure 6



CRUSHER ON
CRUSHER OFF
CRUSHER ON
CRUSHER OFF
DUSTRON OFF
Q = 0.61 m3/sec
200
180
160
140
120
100
80
60
40
20
0
WL (Rn), mWL
AFTER DUSTRON
BEFORE DUSTRON
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
ACTUAL TIME

Figure 7

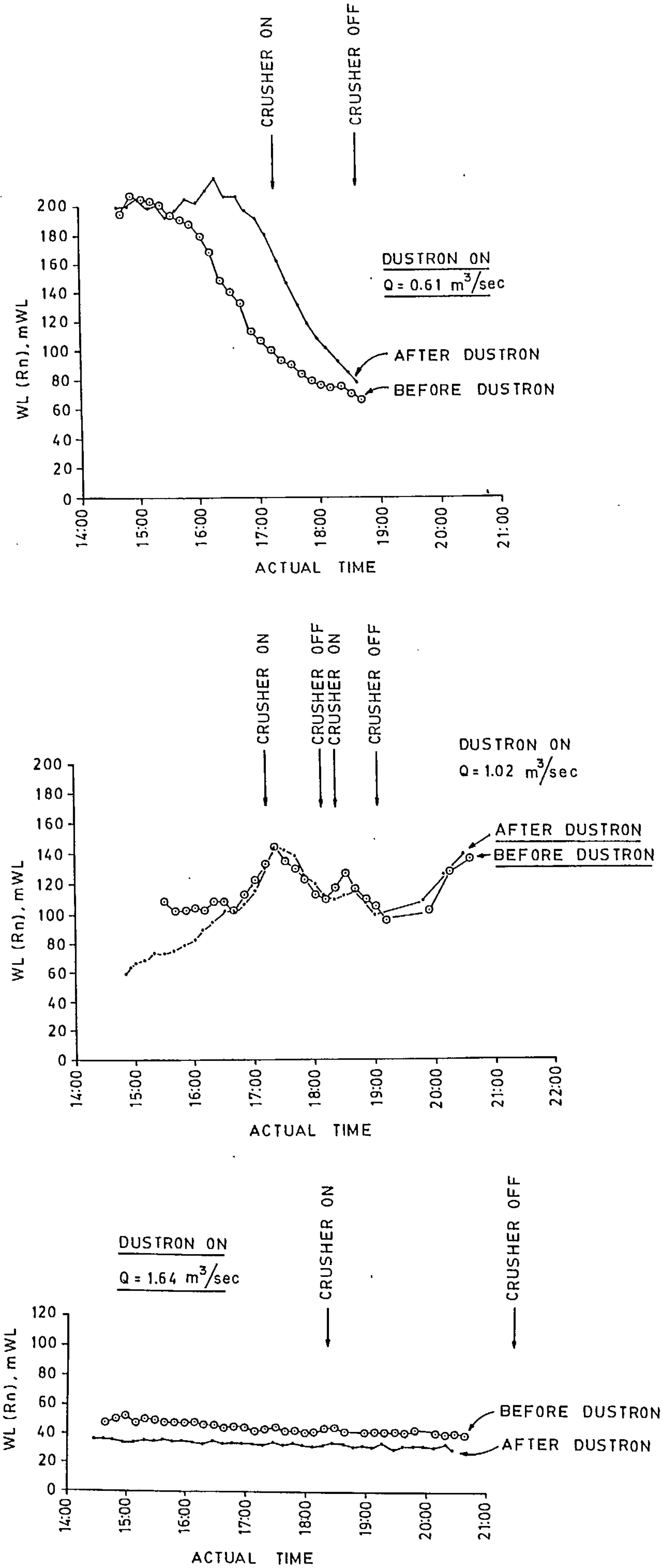
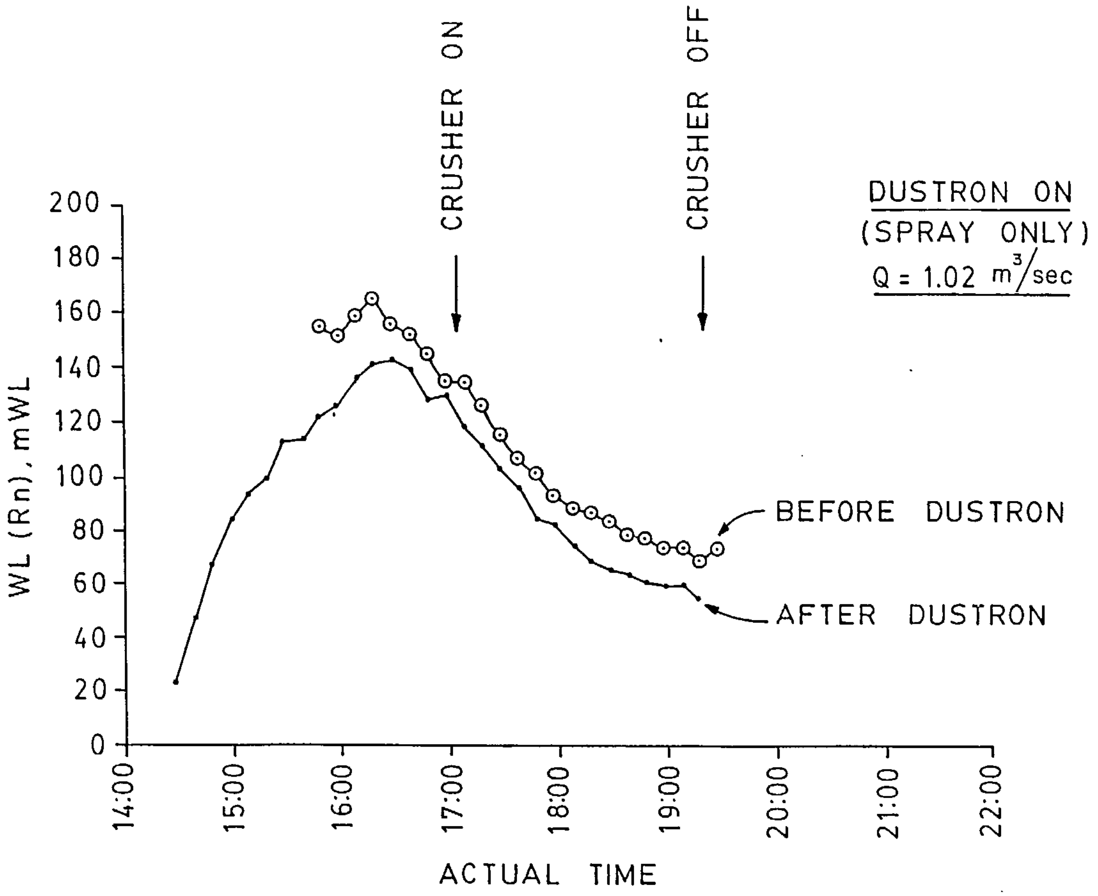
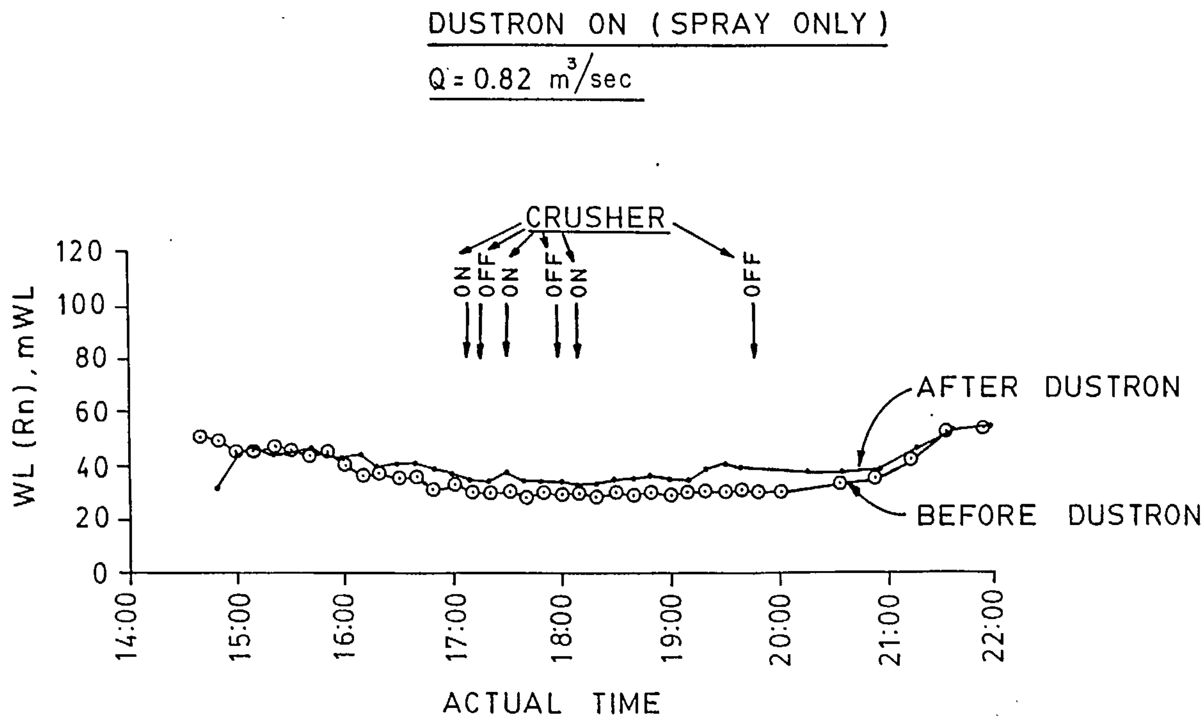

CRUSHER ON
CRUSHER OFF
DUSTRON ON
Q = 0.61 m3/sec
AFTER DUSTRON
BEFORE DUSTRON
WL (Rn), mWL
0
20
40
60
80
100
120
140
160
180
200
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
ACTUAL TIME
CRUSHER ON
CRUSHER OFF
CRUSHER ON
CRUSHER OFF
DUSTRON ON
Q = 1.02 m3/sec
AFTER DUSTRON
BEFORE DUSTRON
WL (Rn), mWL
0
20
40
60
80
100
120
140
160
180
200
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
ACTUAL TIME
DUSTRON ON
Q = 1.64 m3/sec
CRUSHER ON
CRUSHER OFF
BEFORE DUSTRON
AFTER DUSTRON
WL (Rn), mWL
0
20
40
60
80
100
120
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
ACTUAL TIME

Figure 8



CRUSHER ON
CRUSHER OFF
DUSTRON ON
(SPRAY ONLY)
Q = 1.02 m³/sec
200
180
160
140
120
100
80
60
40
20
0
WL (Rn), mWL
BEFORE DUSTRON
AFTER DUSTRON
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
ACTUAL TIME



DUSTRON ON (SPRAY ONLY)
Q = 0.82 m³/sec
CRUSHER
ON
OFF
ON
OFF
ON
OFF
120
100
80
60
40
20
0
WL (Rn), mWL
AFTER DUSTRON
BEFORE DUSTRON
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
ACTUAL TIME

Figure 9

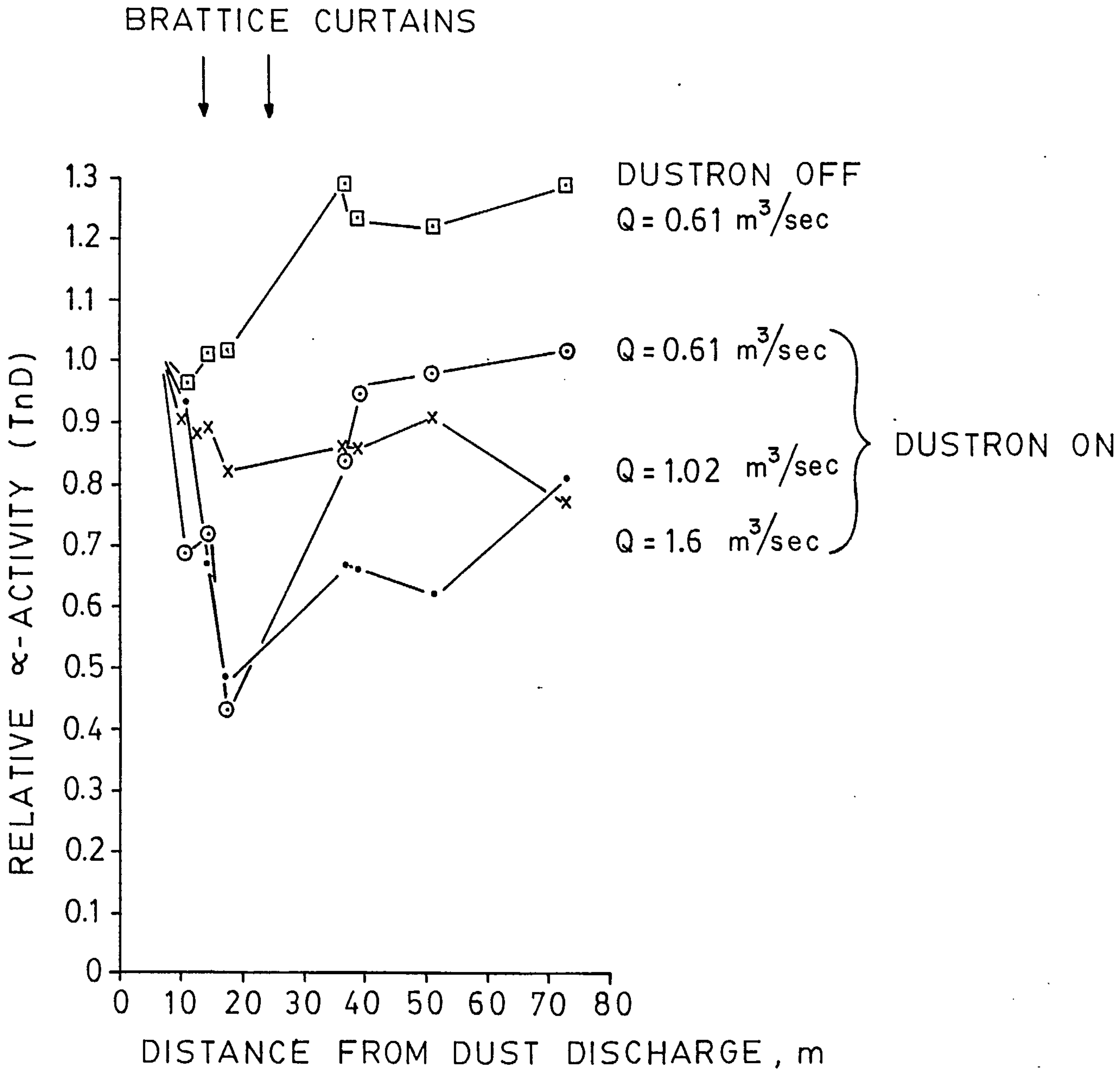

BRATTICE CURTAINS
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
RELATIVE ∝-ACTIVITY (TnD)
0 10 20 30 40 50 60 70 80
DISTANCE FROM DUST DISCHARGE, m
DUSTRON OFF
Q = 0.61 m3/sec
Q = 0.61 m3/sec
Q = 1.02 m3/sec
Q = 1.6 m3/sec
DUSTRON ON

Figure 10