A NEW APPROACH TO THE REDUCTION OF INHALATION DOSE IN WORKING AREAS USING MOBILE ELECTROSTATIC PRECIPITATORS

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Abstract—A system for the rapid continuous decontamination of air has been investigated for reducing the inhalation dose in working areas where continuous small releases of radioactive contaminants in the air are unavoidable due to the nature of the operations involved. Continuous replacement of conditioned air used in such areas with the atmospheric air is generally not feasible due to large differences between the temperature of the conditioned air and the atmospheric air. Consequently recirculation has to be employed. Recirculation through the filters in the air conditioning system generally does not remove a large fraction of the submicron particles which are mainly responsible for the dose to the lung. The system described in this paper is based on a mobile electrostatic precipitator which can remove the particulate matter from the air down to the submicron size range at large flow rates. A description of the electrostatic precipitator used for continuous decontamination of the air, and studies carried out with the system in a test room and in typical working areas are presented.

1. INTRODUCTION

Inhalation dose in nuclear energy operations and handling and processing of radioactive materials is mainly caused by the deposition of submicron sized radioactive particles in the lower respiratory system. The total bulk of solid matter responsible for this dose is generally very small. Therefore, the problem of filtration of radioactive particulate matter from the air in nuclear energy plants and laboratories has to be treated differently from the problem of normal air cleaning, where large dust loads have to be handled. This is particularly so because these areas are normally fed with dust free conditioned air and the problem is essentially that of removal of radioactive and other particulate matter generated within the plant or laboratory. The radiotoxic particulate matter in the air is generally in the form of submicron particles. To remove such particles from the air effectively it is necessary to have a special filtering system. Mechanical filtration with absolute filters for efficient removal of these particles generally gives large pressure drops across the filters and it is very expensive to treat large volumes of air with such filters in most working areas.

In this paper we have described a recirculating system for high efficiency filtration of large volumes of air in working areas by electrostatic precipitation. The important features of this system are, (a) large volumes of air can be cleaned without excessive pressure drop across the filtering system, (b) filtering efficiency is particularly high for submicron particles in which we are mainly interested, (c) running power required is less than that for mechanical filters by more than an order of magnitude, (d) the filtering system can be made mobile and (e) the normal conditioned air supplied to the laboratory is adequate for the filtering system.

2. INHALATION DOSE AND AIR ACTIVITY

The concept of inhalation dose has been recently reconsidered by the ICRP on the basis of a new lung model.[1] This model recognises the importance of particle size distribution and takes into consideration the mass median diameter of the particles for pulmonary deposition mainly responsible for dose to the lung. The highly retained dust particles with mass median diameters in the range of 0.1 to 1 micron give pulmonary deposition of 20 to 50% of that inhaled (although pulmonary deposition for particles below 0.1 micron is higher, their diffusion coefficients are so large that they are retained in the upper respiratory tract). Considerable reduction in the dose to the lung could therefore be achieved by the removal of submicron particles.

The fraction of the inhaled particles deposited in the lung can be reduced by 3 to 4 orders of magnitude by the removal of submicron particles from the air with an efficiency of 99.99% and higher. A recirculating filtering system can attain a very high efficiency for the removal of submicron aerosols from the air in working areas. Therefore in the present paper we have laid emphasis on this system of air cleaning for achieving very large decontamination factors.

In a recirculating system the rate of decrease in the concentration of particulate matter in the air would depend on the total volume of the room and the volume of air decontaminated per unit time. If C_0 is the initial concentration and C' the concentration after time t, the reduction factor is given by

$$\frac{C_0}{C'} = e^{kt}$$

where k is the constant (i.e. fraction removed per unit time) given by

$$k = \frac{v\text{ (volume filtered per unit time)} \times \text{efficiency}}{V\text{ (volume of the room)}}$$

The efficiency term would account for filtering efficiency and the efficiency of mixing in the room.

If there is a constant supply of the radioactive aerosol in a room at a rate of N particles per unit time, the following equations give the number of particles N' in the room at any time t after the start of the filter

$$\frac{dN'}{dt} = N - kN'$$

$$N' = \frac{N}{k}(1 - e^{-kt})$$

For t much larger than the decontamination half time ($0.693/k$), $N' = \frac{N}{k}$. The reduced concentration C' is given by

$$C' = \frac{N'}{V} = \frac{N}{V}\cdot\frac{1}{k}$$

This shows that the concentration of aerosols can be maintained at the supply level as k approaches unity, and the build up of radioactive atoms attached to aerosols is prevented. In the case of radioactive aerosol contamination in the air the supply level is generally small and the build up of activity in the air with time is an important consideration.

3. DESCRIPTION OF THE FILTERING SYSTEM

The filtering system which is based on the conventional two stage electrostatic precipitator has been designed to meet the special requirements of working areas where the normal dust load is small and the supply of conditioned air has to be conserved. The special design features are, (a) free flowing decontaminated air at the breathing level, (b) low consumption of corona power, (c) extremely small production of ozone, (d) large collecting surface to handle significant loads of submicron particles and (e) high efficiency for submicron particles.

Figure 1 gives the schematic illustrating the main components of the precipitator. The overall dimensions of the unit are 34 × 34 × 72 in. (high). The clean air outlet is provided on all four sides of the cabinet with the main flow at a height of 3.5 ft from the ground. A 24 in. propeller fan is used for drawing the air through the filtering system located on the top of the cabinet as illustrated in the sketch in Fig. 1. The integrated flow rate at the outlet is 3500 ft^3/min.

The dimensions of the precipitator inlet are 31 × 31 in. The ionizer consists of 30 parallel wires. The collection surface is provided partly by the perforated plates on either side of the ionizer and partly by 30 parallel collecting plates placed after the ionizer. The charging and collecting potentials are adjusted to give nearly 100% efficiency for submicron particles. The high voltage supply consisting of a voltage tripler is placed in the bottom compartment of the cabinet. The ionizer and collecting plate assemblies are made readily removable for cleaning.

A dacron fibre pre-filter is placed at the inlet

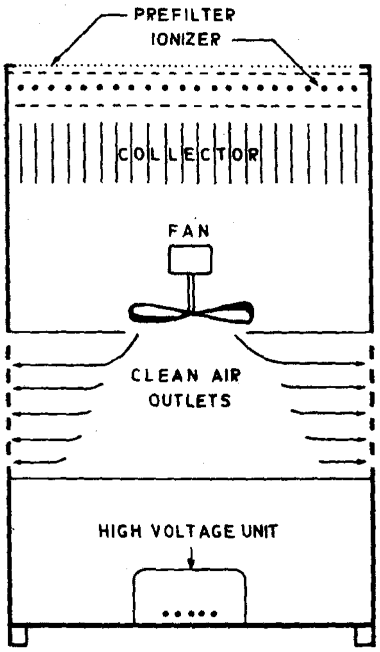

FIG. 1. Schematic illustrating the main components of the precipitator.

to remove fibrous material and large particles from the air. The present filtering unit was fabricated as a "test model" for initial studies.

4. EXPERIMENTS

(a) *Studies in the test room with a thoron generator*

The first study with the filtering system was made in a small test room having a total volume of about 2000 ft^3. This room was fitted with a normal air conditioning unit which maintained the temperature in the room at 25°C. Thoron gas was generated in the room from a thoron generator consisting of a specially designed bubbler containing thorium nitrate solution. A continuous air monitor with a moving filter paper and a strip chart recorder was installed in the test room to record the levels of thoron daughter activity continuously. The initial equilibrium concentration of thoron daughter activity with the bubbler was attained in about 3–4 hr. After the equilibrium was attained, thoron daughter activity showed almost a steady level with the thoron generator in operation. The electrostatic filter was then switched on. The airborne activity in the room decreased with time with the electrostatic filter in operation and with the thoron generator continuously running. After the filter was in operation for about 50 min, the airborne activity in the room shown by the continuous air monitor was even lower than the normal background air activity in the room.

(b) *Studies at the laboratory room attached to Apsara Hall*

The airborne radioactivity in the swimming pool reactor area is mainly due to ^{88}Kr and ^{138}Xe daughters, present during the normal operation.[2, 3] For our studies we selected a large enclosed laboratory room attached to the main hall of the swimming pool reactor Apsara at Trombay. A moving filter-paper type of continuous air monitor was first placed in the room to find the normal level of activity with the reactor in operation. This showed an initial build-up of activity on the filter paper (paper speed 2 in./hr) for about 20 min, before attaining a steady value. When the electrostatic filter was started in the room the airborne activity started decreasing and came down to the normal background value (the reactor was running at its normal power). Figure 2 shows the decrease in activity caused by the electrostatic filter. The room volume is about 7000 ft^3 and a

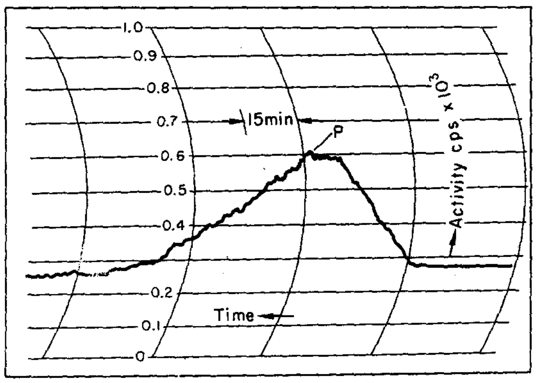

FIG. 2. Continuous air monitor trace showing decontamination of the air attained with the electrostatic filter operated in the laboratory room in the Apsara Reactor Building. Filter started at point *P*.

volume of air equivalent to the volume of the room passed through the filter in about 2 min. Although complete decontamination of the room air would be expected after 4 to 5 air passages through the recirculating filter, the longer time shown by the air monitor was due to the movement of the filter paper being slower compared to the speed of decontamination.

In both of the above experiments an additional indication of the cleanliness of decontaminated rooms was provided by the appearance of a completely unstained filter paper in the air monitor after the precipitator had run long enough to give a few air circulations through the filter.

(c) *Studies at the Thorium Plant at Trombay*

The packing room attached to the crushing room of the Thorium Plant at Trombay was selected for studies on decontamination of the air in a plant area. This room is fed by a supply line of conditioned air at a small flow-rate and is kept closed to prevent direct spray of thorium nitrate from the crushing room. The room had an equilibrium concentration of thorium (B+C). The continuous air monitor showed a steady level after nearly 25 min. of operation. Figure 3 shows a typical trace indicating a decrease in activity with operation of the electrostatic filter. It is interesting to note that in spite of high initial levels of activity, the degree of decontamination was so large that the air monitor showed negligible air activity after the initial operation of the filter for 30–40 min (as in the previous case, actual time of decontamination would be smaller). Nearly all the particulate airborne activity in the room was due to build-up of thorium (B+C) which could be controlled by rapid decontamination of the air.

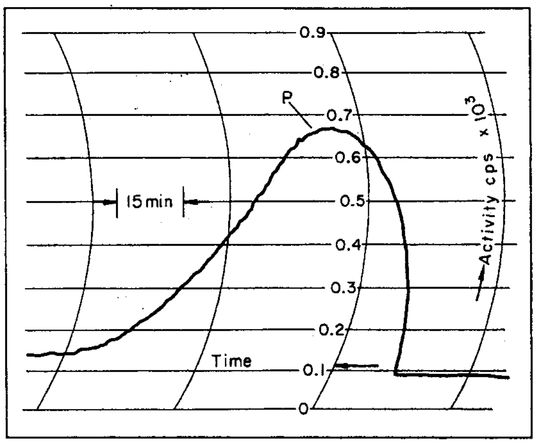

FIG. 3. Continuous air monitor trace showing decontamination of the air attained with the electrostatic filter installed in the packing room of the Thorium Plant. Filter started at point *P* (Equilibrium case).

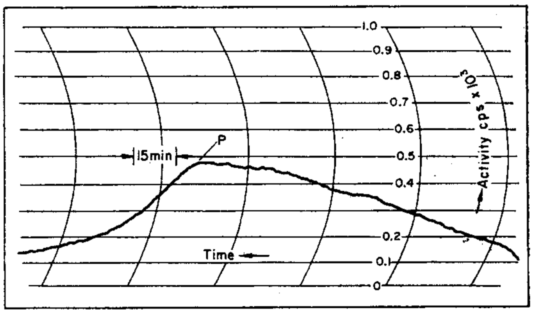

FIG. 4. Continuous air monitor trace showing decontamination of the air attained with the electrostatic filter operated in the packing room of the Thorium Plant. Filter started at point *P* (Non-equilibrium case).

Figure 4 gives the trace from the continuous air monitor showing the building-up of air activity in the room when the electrostatic filter was switched off. The filter was restarted at time corresponding to point *P* in the figure, and the trace also shows the decrease in air activity. The longer time of build-up in this case was due to growth of thorium-B and thorium-C in the room air (from the decay of thoron continuously produced in the room).

5. DISCUSSION

On the basis of the experiments carried out with the present system we can define the situations in nuclear energy operations where electrostatic filters of the present design can be applied with great advantage. Our suggested approach using mobile electrostatic filters has taken into consideration the adverse experiences of installed electrostatic filters[4] where the initial costs and maintenance problems have been the limiting factors and absolute filters with asbestos and glass fibre have been extensively used.

The working areas involving small unavoidable releases of radioactive materials in the form of fine particles from the processes can be ideally protected by using the suggested recirculating type of electrostatic filters. Although the normal concentration of contaminants in the air in these areas may be less than the maximum permissible concentration in the air by one or two orders of magnitude, it may be desirable to reduce the inhalation dose for maintaining higher standards of radiation hygiene in these areas.

A recirculating electrostatic filter, installed in an air-conditioned room, passing one volume of the room air through it per minute is equivalent in performance to the supply of one air change in the room per minute through absolute filters and conditioning unit. Whereas for most working areas the latter would be prohibitively expensive in initial cost and running expenditure, the former could be installed at moderate initial investment and very small running expenditure.

From the limited operational experience, the suggested areas for use of the proposed filtering system are the working areas in uranium and thorium processing plants where major contamination is due to radon and thoron daughter products, working areas in the swimming pool type of reactors where the contamination is caused by the daughter products of gaseous fission products ^{88}Kr and ^{138}Xe, chemical laboratories attached to isotope production plants and chemical control laboratories attached to fuel processing plants where the hazard is primarily due to airborne plutonium.

Several minor radiochemical operations normally carried out in glove boxes can be carried out more freely in open laboratories with the protection from air contamination provided by mobile electrostatic filters. This would increase the production efficiency considerably. This filtering system would be particularly useful in sterile areas for the preparation of labelled compounds for medical uses.

The obvious limitation to the suggested system for use in areas of higher contamination is the build-up of radioactivity on the collecting plates giving rise to higher radiation dose in the vicinity of the filtering unit. For this purpose it is proposed to incorporate a gamma radiation dosimeter in the filtering unit to provide a warning of the need for decontamination of the filter plates.

Further investigations on the applications of the proposed filtering system are in progress.

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