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AEROSOL AND OZONE PRODUCTION IN TUNNEL OF THE TRISTAN ELECTRON-POSITRON BEAM COLLIDER

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ABSTRACT

Time variations of the concentration of aerosol particles and ozone produced by synchrotron radiation were measured in the main ring tunnel of the KEK TRISTAN accelerator. The maximum aerosol concentration of 3-5 x 10^5particles/cm^3 was observed after 8-9 minutes of beam operation, and these aerosol particles were found to have a lognormal distribution with a geometric mean radius of 0.00719 μm and a geometric standard deviation of 2.6. The highest ozone concentration of 45 ppb was measured during this experiment. The effective half-life of ozone including ventilation effect was 29 minutes and its production rate was estimated to be 0.147±0.003 ppb/min/mA at the beam energy of 26 GeV.

INTRODUCTION

Operation of the KEK 12 GeV proton synchrotron results in the production of many radioactive nuclides in the air of tunnel by the nuclear spallation reactions of high energy particles with oxygen and/or nitrogen, and argon atoms. Of these induced radioactive nuclides, ^{7}Be, ^{22}Na, ^{38}S have been revealed to be present in the form of aerosol particles with a geometric mean radius of 0.02-0.03 μm.[1,2] The formation mechanism of these radioactive aerosols could be adequately explained by the attachment of radioactive nuclides to ambient non-radioactive aerosols, which are considered to be sulfuric acid particles produced by radiolytic oxidation of SO_2 present in the air.

This paper is concerned with the production of non-radioactive aerosols in the high energy accelerator tunnels. As mentioned above, these aerosol particles play an important role in the formation of radioactive aerosols, and may also cause the corrosion of equipments because of containing sulfuric acid. We have measured the time variation of aerosol number concentration and their size distribution. In addition, the measurements of ozone concentration were also made. Noxious gases such as ozone and nitrogen oxides are well known to be produced by the ionizing of air in the high energy accelerator tunnels. Of these, ozone is the most toxic and may be produced in the greatest abundance.

EXPERIMENTAL

Sampling of the tunnel air

Air conditioning and ventilation system of the main ring tunnel of TRISTAN consists of 16 units. Namely, the tunnel is divided into 16 sections: 8 straight sections and 8 curved sections. Measurements were carried out for the air in one of the curved sections (the room volume: 5298 m^3). The air, of which temperature and relative humidity were controlled at 30°C and 50 % respectively, was circulated at a rate of 59000 m^3/h and ventilated at a rate of 4400 m^3/h.
Sample air was drawn through Tygon and Teflon tubings from the ventilation duct in the machine room outside of the tunnel.

Apparatus

The schematic diagram of measurements is shown in Fig. 1.
Total number concentration of the aerosol particles was continuously measured by a condensation nucleus counter (CNC: TSI model 3020). Measurements of the size distribution were made with a screen type diffusion battery coupled with a CNC. All the sampling lines for the aerosol measurements were made of Tygon tube and the flow rate was controlled by a mass flow controller. Ozone concentration was monitored by a UV absorption detecter (Dasibi model 1006-AHJ).

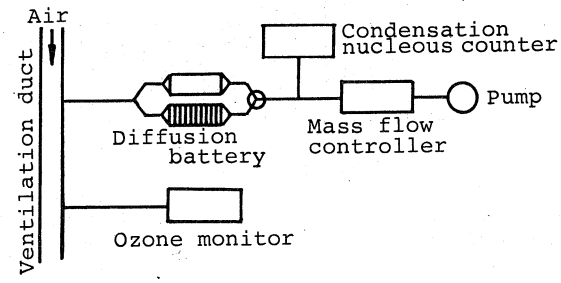

Fig. 1. Schematic diagram of Measurements

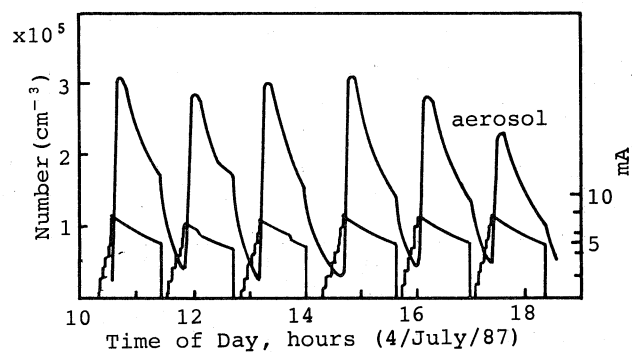

Fig. 2. Time profiles of aerosol number concentration and beam current

AEROSOL PARTICLE PRODUCTION

Fig. 2 shows the typical time profiles of the aerosol particle concentration and the beam current. Shortly after the electron and positron beams were accelerated to 26 GeV, typically 8-9 minutes, a sharp increase in number concentration from a background level of 3 x 10^3particles/cm^3 to a maximum level of 3-5 x 10^5 particles/cm^3 was observed. After the initial striking increase, the number concentration decreased continuously for the duration of beam operation and decreased rapidly when the beam was turned off.

The size distribution measurements were performed for the particles produced by synchrotron radiation and the background particles by using a screen type diffusion battery, which consists of multiple layers of very fine mesh wire screen.
Since the rate of diffusion of aerosol particles is a function of particle size, the particle loss in a battery can then be taken as a measure of particle size. Penetration of monodisperse aerosols through a screen type diffusion battery is given by Cheng and Yeh:[3,4]

$$P = (N/N_0) = \exp\{-K(Q/D)^{-\frac{2}{3}} Ns\} \quad (1)$$

where:
N_0,N = inlet and exit particle concentration (cm^3)
K = constant depending on the dimensions of a battery (205 for the battery used in this experiment)
Q = mass flow rate (l/min)
D = diffusion coefficient of particle (cm^2/sec)
Ns = number of screen

For polydisperse aerosols having a lognormal distribution, the penetration is given by

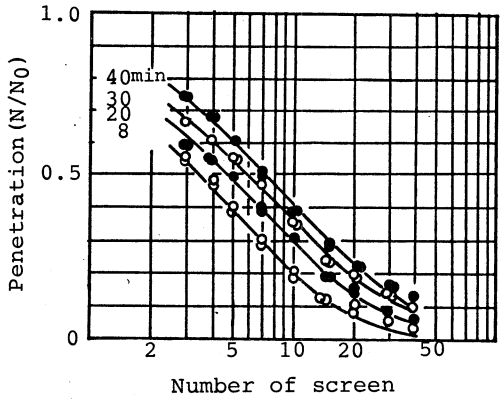

Fig. 3. Penetration of the aerosol particles produced by synchrotron radiation through the screen type diffusion battery

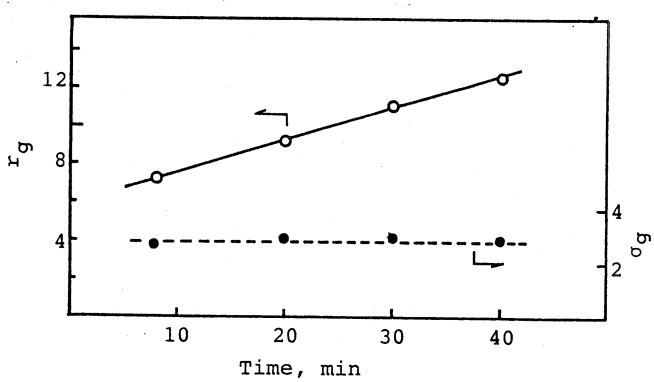

Fig. 4. Time variations of the geometric mean radius(r_g) and the geometric standard deviation(σ_g) of the aerosol particles

$$P = 1/(\sqrt{2\pi}\log\sigma_g)\int_{-\infty}^{+\infty}\exp\{-K(Q/D)^{-\frac{2}{3}}Ns\} \times \exp\{-(\log r-\log r_g)^2/2\log^2\sigma_g\}d\log r \qquad (2)$$

where r_g and σ_g are geometric mean radius and a geometric standard deviation, respectively.
From the relation between P and Ns experimentally obtained, the values of r_g and σ_g can be determined by means of a computer program of a least square fitting method.

The penetration was measured by varying the number of screen at a constant flow rate of 10 l/min at various times after the beam was accelerated to 26 GeV. The results were plotted in Fig. 3. The solid lines in Fig. 3 represent the least squares fit to the data.

Fig. 4 shows a plot of the geometric mean radii and the geometric standard deviations obtained from the data in Fig. 3 against the time after the beam was accelerated to 26 GeV. The particle growth was observed for the aerosol particles produced by synchrotron radiation. They were much smaller than the background particles, of which geometric mean radius was determined to be 0.047 μm.

OZONE PRODUCTION

When the beam was accelerated to 26 GeV, as shown in Fig. 5, the concentration of ozone built up over a period of 50 minutes until the equilibrium was reached. Equilibrium concentration continued for as long as the beam remains energized at a given energy. When the beam was turned off, ozone concentration diminished rapidly. The highest concentration measured during this experiment was approximately 45 ppb and its background level was 2-3 ppb.

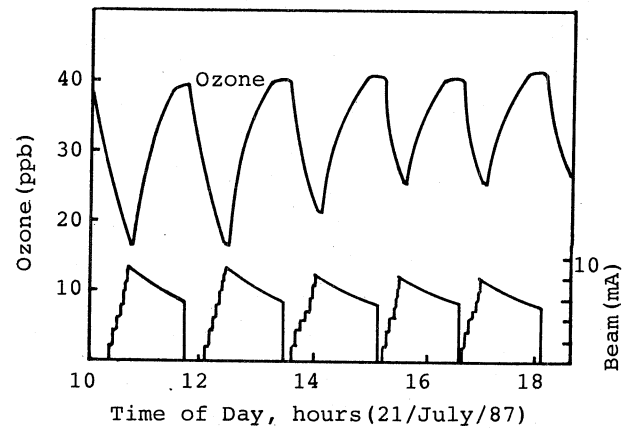

Fig. 5. Time profiles of ozone concentration and beam current

From the experimental data on build up and diminution of ozone concentration, the production rate of ozone was estimated.
The rate of change of ozone concentration in the tunnel would be given by

$$dC/dt = R\,i\exp(-\beta t) - (B+\alpha)C \qquad (3)$$

where:
- C = concentration of ozone (ppb)
- R = production rate of ozone per unit beam current (ppb/min/mA)
- i = initial beam current (mA)
- β = decay constant for beam current (min^{-1})
- B = ventilation rate divided by the tunnel volume (min^{-1})
- α = chemical decay constant for ozone (min^{-1})

The solution of this equation is

$$C = R\,i\{\exp(-\beta t) - \exp(-(B+\alpha)t)\}/\{(B+\alpha)-\beta\} \qquad (4)$$

In this experiment, the value of (B+α) was found to be 0.0239 min^{-1} which corresponds to a half-life of 29 min and the value of β was typically 0.0082 min^{-1}. From these values and ozone concentration measured at various times, a value of R = 0.147±0.003 ppb/min/mA was obtained at the beam energy of 26 GeV.

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