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AEROSOL DENSITY OF SODIUM OXIDE, URANIUM OXIDE AND THEIR MIXED AEROSOL

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Aerosol Density of Sodium Oxide, Uranium oxide and Their Mixed Aerosol

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In the hypothetical accident of LMFBR, it is assumed that nuclear aerosol, mainly sodium oxide aerosol containing fuel material, is dispersed in the reactor containment vessels. Decrease of the aerosol concentration in the containment may be governed by settling of the aerosol. In analysis of the aerosol behavior, the density of aerosol particles is important together with the particle size distribution. The value of density of nuclear aerosol is not available yet. The present work was undertaken to obtain the average apparent densities of sodium oxide, uranium oxide and their mixed aerosol, using the measurements of settling velocity and size distribution.

Keywords: Fast Breeder Reactor, Hypothetical Accident, Nuclear Aerosol, Containment Vessel, Aerosol Density, Aerosol Settling, Size Distribution, Environmental Safety, Sodium Oxide Aerosol

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核燃料エアロゾルの密度に関する研究
（酸化ナトリウム，酸化ウラン，混合エアロゾル）

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高速増殖炉の仮想事故時において，原子炉格納容器内には核燃料物質を含む酸化ナトリウムエアロゾルが分散する。格納容器内のエアロゾルの減衰は沈降現象によって支配されるが，その重要な因子である核燃料エアロゾルの密度，およびエアロゾル粒度分布は未だ明らかになっていない。

この研究は，エアロゾルの沈降速度と粒度分布を測定することにより，核燃料エアロゾルである酸化ウラン，高速炉の冷却材であるナトリウムエアロゾル，そしてその混合エアロゾルの見掛の密度を測定したものである。

本報告書は，日本原子力研究所が動力炉・核燃料開発事業団の委託により実施した研究の成果である。

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1. Introduction

As a fast breeder reactor uses plutonium fuel, the behavior of plutonium aerosol in the event of an accident constitutes quite an important factor in the safety analysis of the fast breeder reactor. Assuming that in the case of a hypothetical accident of an FBR, aerosol materials (nuclear fuel materials, sodium coolant, structural materials, etc.) disperse into the reactor containment, evaluation of its concentration by the lapse of time is highly important for the evaluation of its leakage into the environment.

The velocity of aerosol concentration decrease in the reactor containment is largely dominated by the settling phenomenon of the coagulated particles produced by the collision effect. Especially, as to the apparent density of the mixed aerosol of nuclear fuel and sodium oxide, though is closely related with the decrease of aerosol concentration by its settling, there has been yet undertaken no experiment to determine the data of its apparent density. Even the literature relating to the measured data of aerosol particle density is relatively scarce, except those measured by use of MILLIKAN cell.[1] Generally, the density of aerosol particles is affected by frequency of collision agglomeration. However, it can be seen that in the collision above 10 particles, its density becomes constant with 0.63 relative density (apparent density/ theoretical density) in the case of spherical mono-dispersed aerosol (stylene particle aerosol), but in dispersed aerosol, its agglomeration is rough and its relative density is extremely small.[2] Generally, the relative density of chain like aerosol particles is considered to be 1/10 for the theoretical density of its material.

The present experiment obtained the data of the average apparent

density of aerosol particles of such sodium oxide and the mixture of uranium oxide and sodium oxide which are the poly-dispersed aerosol by Stokes' formula of sedimentation. The measured values can be used as the input data of the computer code (ABC Code) to calculate the release of nuclear fuel aerosol from the reactor containments into the environment under a hypothetical accident of FBRs.

2. Procedure of Experiments

The vessel which was used as the test apparatus in this experiment is two meters in height and 0.8 meters in inner diameter. The total capacity of this vessel is about 1 m^3. Its inner wall surface is of mirror-finish. Installed inside the vessel are a burning pot type electric furnace to generate sodium oxide aerosol and an arc-melting unit to produce uranium oxide aerosol. There is provided a sampling hole at the bottom of the vessel for collection of settled aerosol particles.

The experiment was conducted by blowing air to metallic sodium, and by arc-melting metallic uranium in argon atmosphere and burning the produced vapor in air to produce Na_2O and U_3O_8aerosols. The mixed aerosol was produced simultaneously by changing the combustion rate of both substances, and aerosol was sampled when both kinds of aerosol were sufficiently agglomerated. The relative humidity inside the vessel was decreased from 62.6 % (26.5°C)(absolute humidity 25.1mg-H_2O/liter) to 32.7 % (23°C) during this time. Filters were used for the sampling of aerosol in gas phase, and for collecting of settling particles which were placed at the lid of the sampling hole by opening it to correct the settling particles. For the settling particle, there is placed an electron-microscopic measuring grid onto the filters. The particle size distribution

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was measured by the electron-microscopic method which counted the number of aerosol particles settled on the filters. The measurement of particle size was performed by use of a Carl Zeiss particle analyzer, by which the photograph of aerosol particles taken by the electronmicroscopic camera is projected by circular spot light, so that the particle diameters are measured as equivalent to the projected area of spot. The measurement of particle size was conducted on 1,000 aerosol particles by two persons, each person measuring 500 aerosol particles, in order to reduce personal errors to the minimum. For the chemical analysis of the mixed aerosol, the atomic adsorption method was employed for sodium oxide and the photo-electric calorimetry of arsenazo-III was used for uranium oxide.

3. Calculation of Average Apparent Density of Aerosol Particles

The gas inside the experimental vessel is uniformly mixed at the time of aerosol generation, and both kinds of aerosol of uranium oxide and sodium oxide may be assumed to have collision and agglomeration of more than 10 particles, and that the mixed aerosol may settle down in the form of log normal distribution in gas phase. Assuming also that the large size aerosol particles produced by agglomeration may sediment at the velocity of $v_s(r_k)$, the weight per unit area A of aerosol sedimented on the filter during the time Δt is calculated by;

$$W = \rho_o A \sum_{k=1}^{\infty} \{ \frac{4}{3} \pi r_k^3 N_k(t) V_s(r_k) \} \Delta t + \rho_o A \sum_{k=1}^{\infty} \{ \frac{4}{3} \pi r_k^3 N_k(t) \frac{D_k}{\delta_d} \} \Delta t \quad (1)$$

Here, ρ_o is the average apparent density of aerosol particles; r_k is the radius of the k-th class particle, and $N_k(t)$ represents the number of

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Here, ρ_o is the average apparent density of aerosol particles; r_k is the radius of the k-th class particle, and $N_k(t)$ represents the number of

airborne aerosol particles per unit volume at time t in the vessel. While D_k is the diffusion coefficient of the k-th class particle, and δ_d represents the thickness of its diffusion-boundary layer.

The effect of the diffusional plating of the 2nd term of Eq.(1) is dominant to micro-fine particles, and has no such large effect as its sedimentation effect, and thus the term of diffusional plating can be ignored. However, if the diffusion-boundary layer is assumed as δ_d = 1,000 μm, the apparent density becomes somewhat smaller value (at a few % level) than the average apparent density considering gravitational sedimentation alone. In order to obtain the average apparent density assuming Eq.(1) has the gravitational sedimentation effect alone, the value of particle number concentration N_k becomes necessary. The value of N_k may be obtained by the following equation assuming aerosol has distributed in log-normal distribution:

$$N_k(t) = \frac{N_T(t)}{3\sqrt{2}\ \ell n\sigma_g} \exp\{-\frac{\ell n^2(r_k/r_g(t))}{2\ell n\ \sigma_g^2(t)}\} \frac{\Delta v}{v_k} \qquad (2)$$

Here, $N_T(t)$ is the number of the total aerosol particles floating per unit volume at time inside the vessel, and $r_g(t)$, $\sigma_g(t)$ represent respectively a logarithmic mean particle radius and a geometric standard deviation of aerosol at time t. Δv represents the minimum unit for dividing the volume of aerosol particles.

When the aerosol particle distribution is log-normal, the total particle number $N_T(t)$ floating per unit volume is established in the relation with aerosol concentration C(t) in gas phase by the following equation:

$$N_T(t) = \frac{C(t)}{\frac{4}{3}\pi r_g^3(t)\rho_o\ \exp(4.5\ell n^2\sigma_g(t))} \qquad (3)$$

Here, $r_g(t)$, $\sigma_g(t)$ and $C(t)$ are the actually measured values, and the value of $N_T(t)$ is introduced from Eq.(3) and substituted into Eq.(2) to determine the value of $N_k(t)$.

Considering the sedimentation of aerosol particles depend on the equation of Stokes, the sedimenting velocity of aerosol particles follows the following formula:

$$v_s(r_k) = \frac{2\rho_o g}{9\mu} r_k^2 \left(1 + \frac{A_k \lambda}{r_k} \right) \tag{4}$$

Here, $v_s(r_k)$ is the sedimenting velocity of aerosol particles, g represents the gravitational constant, μ the air viscosity, λ the mean free path and A_k a Cunningham's constant. By substituting Eq.(2) - Eq.(4) into Eq.(1), the average apparent density of aerosol particles ρ_o is calculated by;

$$\rho_o = W/A\Delta t \sum_{k=1}^{10000} r_k^3(t) \frac{\frac{2g}{9\mu} r_k^2(t)(1 + \frac{A_k}{r_k})C(t) \exp\{- \frac{\ell n^2(r_k/r_g(t))}{2\ell n^2\sigma_g(t)}\}}{3\sqrt{2\pi}\ \ell n\sigma_g r_g^3(t) \exp(4.5\ \ell n^2\sigma_g(t))} \frac{\Delta r^3}{r_k^3} \tag{5}$$

where, Δr : radius of the minimum unit

Δt : opened time of sampling hole.

If gas phase aerosol concentration $C(t)$ at any time, the weight flux $(W/A\Delta t)$ of the aerosol particles settled on the filter, and the aerosol particle size $r_g(t)$, $\sigma_g(t)$ are determined from this experiment, then the value of average apparent density is calculated from Eq.(5). The integration of Eq.(5) was performed by dividing into 10,000 particles from k = 1 in order to minimize calculation errors.

4. Sphericity of Aerosol Particles

The measurement of aerosol particle diameter is performed by use of the radius of a circle which has the equivalent area as that of the projected particle area. This particle diameter measuring method is frequently used and is called Heywood diameter. Wadel (1933) thought that two particles having equivalent surface area and equivalent volume have the same spherical configuration, and defined the following formula of degree of sphericity:

$$\Psi_W = \frac{\text{Surface area of the volume equivalent sphere to the volume of the actual particle}}{\text{Surface area of the actual particle}}$$

$$\simeq \frac{\text{Diameter of a circle equivalent to projected area of particle}}{\text{Diameter of the smallest circle circumscribed with the projected area of particle}} \qquad (6)$$

The configuration of aerosol particles of uranium oxide is in the form of chain, but as mixed with sodium oxide, it changes into near spherical form (refer to photograph). Generally, the settling velocity of non-spherical aerosol particles is slower than the sedimenting velocity by Stokes formula of Eq.(4). Here assuming that Stokes velocity as v_s, and that the actual measured settling velocity of particle as v_c, the correction factor is given by $K = v_c/v_s$. Consequently, the settling velocity of non-spherical aerosol is given by the following formula:

$$v_c = Kv_s = \frac{2K\rho g}{9\mu} r^2 \left(1 + \frac{A\lambda}{r} \right) \qquad (7)$$

Here, it was defined as $\rho_o = K\rho$. Pettyjohn (1948)[3] actually measured the settling velocity of various fine particles in water and discovered that the following empirical equation can be used in the laminar flow

region (Re < 0.05) between Wadell's degree of sphericity and correction factor K:

$$K = 0.843 \log \frac{\Psi_w}{0.065} \tag{8}$$

Here, if particles are in perfect sphere, it is $\Psi_w = 1.0$, and the value of K naturally becomes 1.0, thus showing good agreement with Stokes settling velocity.

The degree of sphericity of uranium oxide and sodium oxide aerosols as well as the mixed aerosol is expressed by the ratio between the projected equivalent diameter of particles and the circumscribed circle diameter of particles as shown by Eq.(6). The degree of sphericity Ψ_w of aerosol was obtained by double counts of 50 particles for each circular equivalent diameter and the circumscribed circle diameter of the dispersed aerosol obtained by microscopic photographing.

5. Results of Experiment

This experiment to measure the average apparent density ρ_o of sodium oxide (Na_2O) aerosol was undertaken by reiterating four tests (Run 1-4) by changing the combustion degree of metallic sodium inside the experimental vessel. Fig.1 shows the rate of Na_2O aerosol concentration decrease floating in the experimental vessel. From this diagram, the value of aerosol concentration C(t) was obtained for computation of average apparent density. Fig.2 represents the sedimentation rate of aerosol deposited on the filter with an area of A = 13.1 cm^2 at the sampling hole of bottom in the vessel. From the values given in Fig.2, the settling flux ($W/A\Delta t$) of aerosol was obtained in terms of its values. Fig.3 and 4 show the measurement of particle distribution by sampling the

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the sodium oxide aerosol deposited on the electron-microscopic grid installed on the filter. As the result, the values of $r_g(t)$ and $\sigma_g(t)$ were obtained.

By the above means, all the values of the gas phase concentration C(t) at the time of the aerosol sampling, the deposited flux ($W/A\Delta t$) on the filter, logarithmic mean radius of particles $r_g(t)$, geometrical standard deviation $\sigma_g(t)$, etc. were determined and thus by use of Eq.(5), the value of their average apparent density was obtained.

Fig.5 shows in the same diagram simultaneously the concentration decrease rate inside the experimental vessel for the chain like aerosol of uranium oxide (U_3O_8) and the sedimentation rate of uranium oxide aerosol deposited on the filter installed at the bottom of the vessel. Fig.6 and 7 similarly show the aerosol particle size distributions of chain like uranium oxide aerosol. The dotted plots in the figure represent the cumulative percentage of aerosol vs. particle diameter measured by the projected circle equivalent diameter up to 0.2 μm. The circle plots represent the cumulative percentage of aerosol vs. particle diameter eliminating those below 0.2 μm. The values of $r_g(t)$ and $\sigma_g(t)$ obtained by both straight lines are somewhat different from each other, and this difference presents a considerably large fluctuation gap for the value of the average apparent density (refer to Table 1-(b)).

Fig.8 shows the decrease of aerosol concentration in the case of uranium oxide and sodium oxide mixed aerosol (85 wt.% in terms of U_3O_8 converted weight percent), and the plot ○ represents sodium oxide aerosol and ● plots are uranium oxide aerosol, while the plot Δ represents the total C(t) of the concentration of both aerosols. Fig.9 shows the sedimentation rate of each type of aerosol deposited on the sampling filter. Fig.10 shows the particle size distribution of the mixed aerosol in the

case of U_3O_8 weight percentage being 85 wt.%. Each of them is compatible with the log-normal distribution.

Fig.11 also shows the concentration decrease of sodium oxide and uranium oxide in the gas phase for mixed aerosol. Run 8 shows the uranium oxide (U_3O_8 converted) weight percentage is 21 wt.% against sodium oxide, and Run 7 shows it is 6.7 wt.%. Similarly, Fig.12 shows settling sodium oxide and uranium oxide deposited on the filter in the case of Run 7 and Run 8 respectively. The particle size distribution of the mixed aerosol deposited on the grid in the case of Run 7 maintained log-normal distribution as shown in Fig.13. But the particle size distribution shown in Run 8 was not compatible with straight lineality as shown in Fig.14. The reason is considered that either the aerosol particles deposited on the electron-microscopic grid installed on the filter failed to sample the mother group of the accurate particle size distribution, or it might be that the coagulation of sodium oxide aerosol and the uranium oxide aerosol had not progressed well. Consequently, the average apparent density values obtained by Run 8 fluctuated so largely that no constant value was obtained.

6. Discussion

The photographs show the aerosol particles sedimented on the electron-microscopic grid installed on the sampling filter at the bottom of the vessel, and respectively represent the deposited particles of Na_2O aerosol, mixed aerosol and U_3O_8 aerosol. U_3O_8 aerosol indicated a trend to become spherical as increased the mixing percentage of Na_2O aerosol. There is a case that the height of the deposition of aerosol particles on the grid has been measured by a shadow method.[4] It is thought that even

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the measurement of particle size by the projected area technique may present no much errors.

The value of degree of sphericity Ψ_w of aerosol is $\Psi_w = 0.833$ for Na_2O aerosol and $\Psi_w = 0.659$ for U_3O_8 aerosol in the form of chain, while their mixed aerosol takes the intermedium value. The value of Ψ_w is necessary for improving the accuracy of the average apparent density of aerosol.

Table 1 lists the settling flux ($W/A\Delta t$) in respect of aerosol particles as shown in photographs, aerosol concentration $C(t)$, $r_g(t)$, $\sigma_g(t)$, and the lapse of sampling time Δt as well as the values of average apparent density obtained by calculation of Eq.(5). At the same time, the values for degree of sphericity of aerosol particles Ψ_w of each composition are also listed. The fluctuation of the average apparent density ρ_o as given in Table 1 pursued the following statistical processing procedures.

Firstly, (1) the arithmetic mean value ($\bar{x}$) of the average apparent density was obtained, (2) the standard deviation σ of each density (mean square errors) was obtained, (3) then the maximum error $\Delta = 3\sigma$ of each individual density was obtained, and confirming that they are not deviate more than Δ from the value of $(\bar{x} - x_i)$, and (4) the standard deviation σ_o of the sample average was obtained. The aerosol particles of average apparent density ρ corrected by use of Eq.(8) have of course substantial voids or crevices in the particles, and in the case of the chain like U_3O_8 aerosol, the value of its relative density (apparent density/true density) was about 1/10. It must be noted in the case of 85 wt.% (28.9 mole %) of U_3O_8 that the value of average apparent density has become considerably large. The reason for this is considered that the chain like U_3O_8 aerosol has shrunk with the presence of Na_2O aerosol.

Generally, many of the aerosol density measuring methods use MILLIKAN

cell. The values obtained by the present experiment are lower in measurement accuracy compared with those obtained by use of MILLIKAN cell. But no high experimental technique is required in the former case, and even the fluctuation of obtained values is relatively small. However, the value of the average apparent density ρ_o is substantially affected by the values of $r_g(t)$, $\sigma_g(t)$. Therefore, sufficient caution must be taken in determining the particle size distribution.

Considering the deviation from the log-normal distribution as shown in Fig.14 has happened only in the case of the experiment of mixed aerosol, it is assumable that, at the time of aerosol sampling, both types of aerosol in gas phase have not completed satisfactory because of coagulation yet.

The theoretical density of Na_2O is 2.27 g/cm^2, and that of U_3O_8 is 7.31 g/cm^2. Consequently, their relative density is 1/6 for Na_2O and 1/10 for U_3O_8 aerosol. The value of this relative density of Na_2O aerosol is smaller than the expected value of the average apparent density. In respect to U_3O_8 aerosol, it has agreed well with the apparent density of 1/10 of the chain like aerosol as generally accepted.

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Table 1(a) Data on density of aerosol particles

Sodium oxide aerosol (Na_2O) U_3O_8 wt.% = 0 Ψ_w = 0.833

Settling flux (g/cm^2sec)	Airbone conc. (g/cc)	r_g (μm)	σ_g (—)	Sampling time (min.)	ρ_o (g/cm^3)
3.26×10^{-9}	6.90×10^{-7}	0.46	1.45	8.5	0.58
3.48×10^{-9}	5.60×10^{-7}	0.42	1.78	25.0	0.20
3.85×10^{-9}	2.80×10^{-7}	0.71	1.77	302.5	0.17
1.47×10^{-9}	5.50×10^{-8}	0.78	1.66	232.0	0.47
5.03×10^{-9}	5.60×10^{-7}	0.39	1.76	7.5	0.34
4.95×10^{-9}	4.96×10^{-7}	0.44	1.61	31.0	0.68
4.63×10^{-9}	3.05×10^{-7}	0.58	1.76	102.5	0.29
3.67×10^{-9}	1.29×10^{-7}	0.80	1.81	234.5	0.24
3.97×10^{-9}	1.17×10^{-6}	0.93	1.73	33.5	0.31
3.40×10^{-9}	9.60×10^{-7}	0.83	1.82	51.0	0.27

Mixed sodium oxide (Na_2O) aerosol containing uranium oxide (U_3O_8) particles

U_3O_8 wt.% = 6.7 Ψ_w = 0.820

8.15×10^{-9}	4.95×10^{-7}	0.62	1.81	38.0	0.22
7.50×10^{-9}	2.81×10^{-7}	0.67	1.83	103.0	0.28
4.75×10^{-9}	1.74×10^{-7}	0.67	1.88	160.0	0.24
3.05×10^{-9}	0.89×10^{-7}	0.63	1.78	244.0	0.51

Table 1(b) Data on density of aerosol particles

Mixed sodium oxide (Na_2O) aerosol containing uranium oxide (U_3O_8) aerosol

U_3O_8 wt.% = 85.0 Ψ_w = 0.810

Settling flux (g/cm^2sec)	Airborne conc. (g/cc)	r_g (μm)	σ_g (—)	Sampling time (min.)	ρ_o (g/cm^3)
5.79×10^{-9}	4.85×10^{-7}	0.18	1.78	25.0	2.17
5.12×10^{-9}	2.90×10^{-7}	0.24	1.77	72.0	1.84
3.78×10^{-9}	1.53×10^{-7}	0.26	1.70	186.0	3.13
3.10×10^{-9}	1.07×10^{-7}	0.32	1.61	249.0	3.72

Uranium oxide (U_3O_8) aerosol U_3O_8 wt.% = 100 Ψ_w = 0.659

6.83×10^{-10}	2.05×10^{-7}	0.28	1.60	50.0	0.34
6.83×10^{-10}	2.05×10^{-7}	0.27	1.86	50.0	0.57
7.97×10^{-10}	1.78×10^{-7}	0.29	1.68	126.0	0.59
7.97×10^{-10}	1.78×10^{-7}	0.34	2.18	126.0	0.60
8.97×10^{-10}	1.37×10^{-7}	0.27	2.04	238.0	0.68
8.97×10^{-10}	1.37×10^{-7}	0.27	2.04	238.0	0.94

Table 2 Average aerosol densities and its atandard deviation

	Arithmetic average (g/cm^3) $\bar{x} = \frac{\Sigma x_i}{x}$	Standard deviation (σ) $\sigma = \sqrt{\frac{\Sigma(\bar{x} - x_i)^2}{n - 1}}$	3σ	Standard deviation of the average (σ_o) $\sigma_o = \sqrt{\frac{\Sigma(\bar{x} - x_1)^2}{n(n - 1)}}$	Apparent density of aerosol (g/cm^3) ρ_o	ρ
Na_2O (0 wt.%)	0.349 (n = 10)	0.16	0.48	0.05	0.35 ± 0.05	0.375 ± 0.094
$Na_2O + U_3O_8$ (6.7 wt.%)	0.313 (n = 4)	0.134	0.402	0.07	0.31 ± 0.07	0.334 ± 0.07
$Na_2O + U_3O_8$ (85.0 wt.%)	2.715 (n = 4)	0.865	2.595	0.48	2.70 ± 0.4	2.92 ± 0.433
U_3O_8 (100 wt.%)	0.62 (n = 6)	0.274	0.822	0.08	0.62 ± 0.08	0.738 ± 0.08

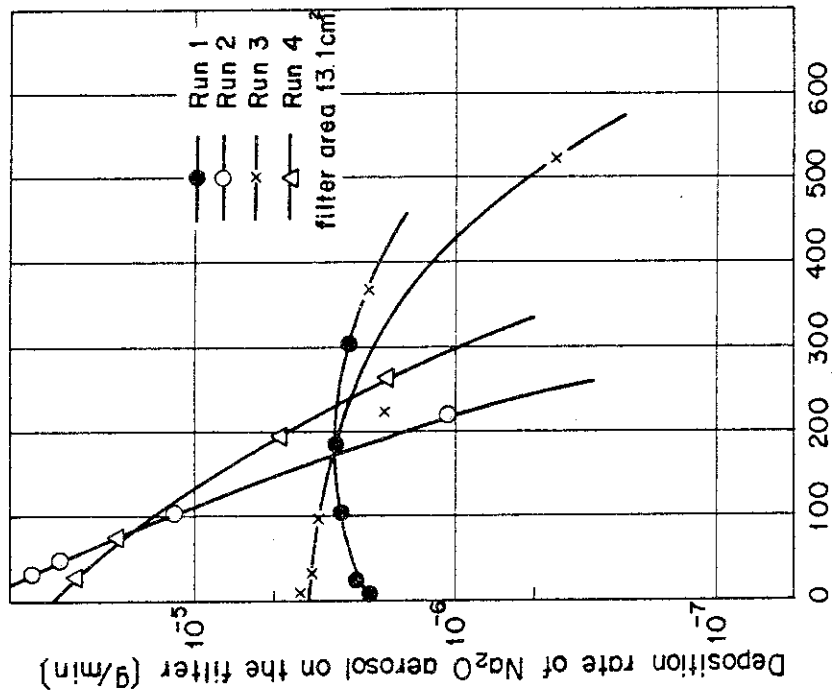


Fig.2 Rate of the deposition for Na_2O aerosol settled on the sampling filter in the chamber

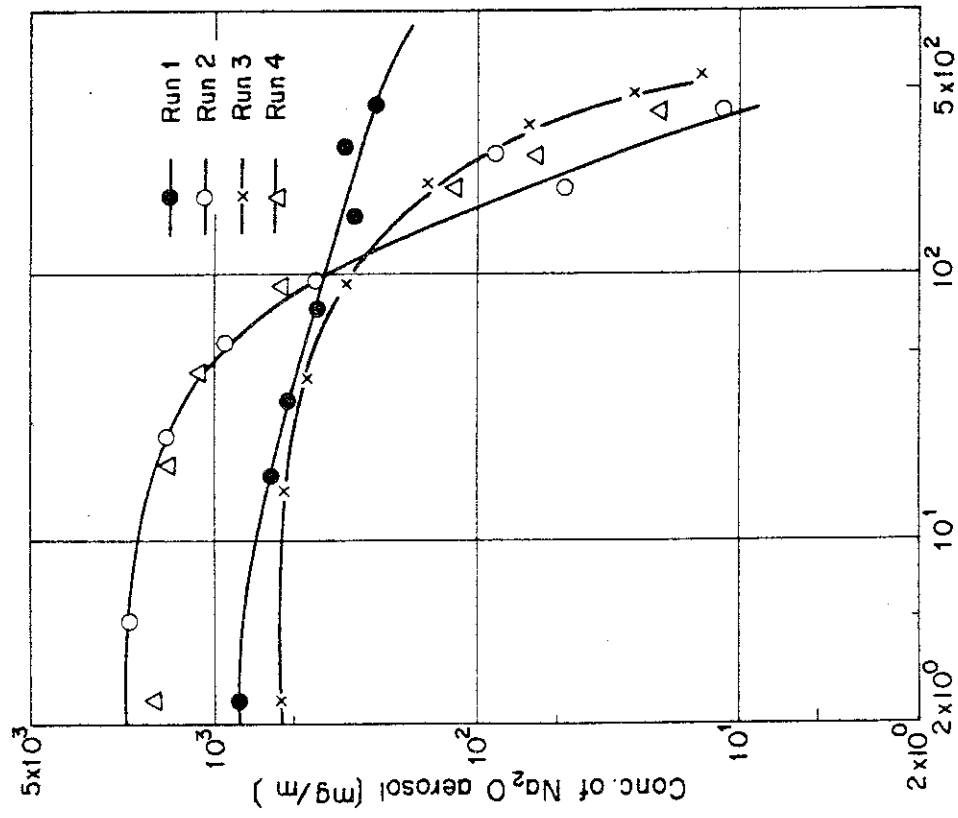


Fig. 1 Concentration decreases of sodiun oxide (Na_2O) aerosol in the experimental chamber

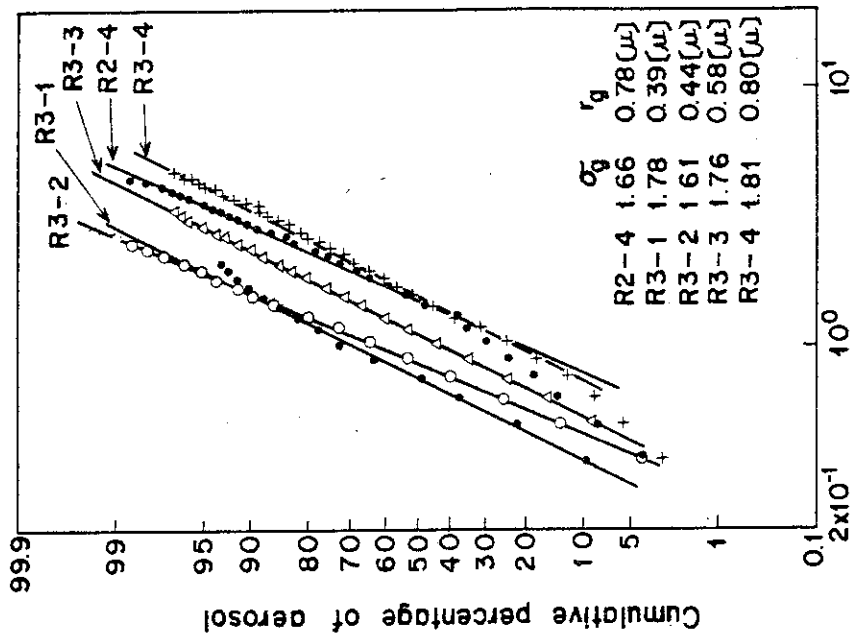


Fig.4 Particle size distributions of sodium oxide (Na_2O) aerosol

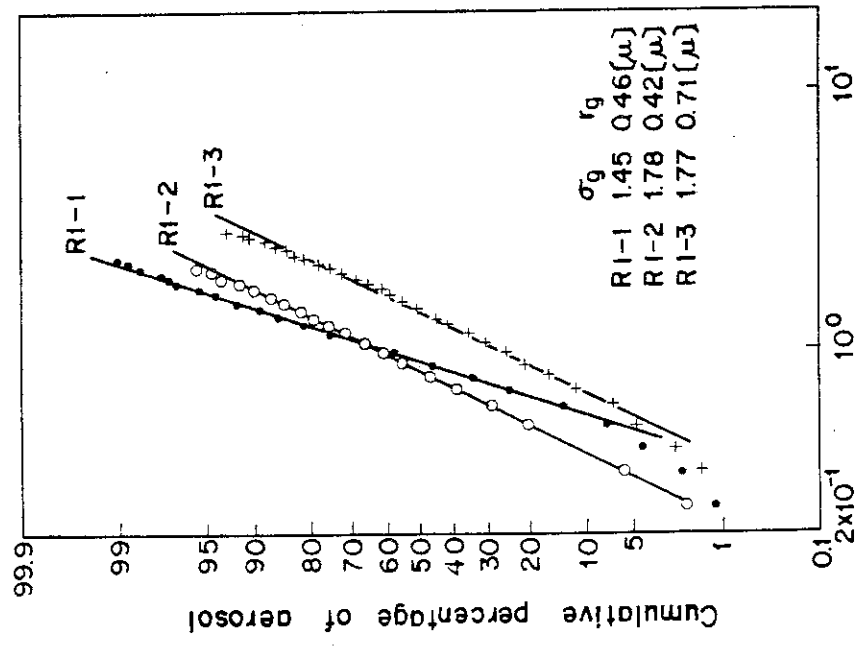


Fig.3 Particle size distribution of sodium oxide (Na_2O) aerosol

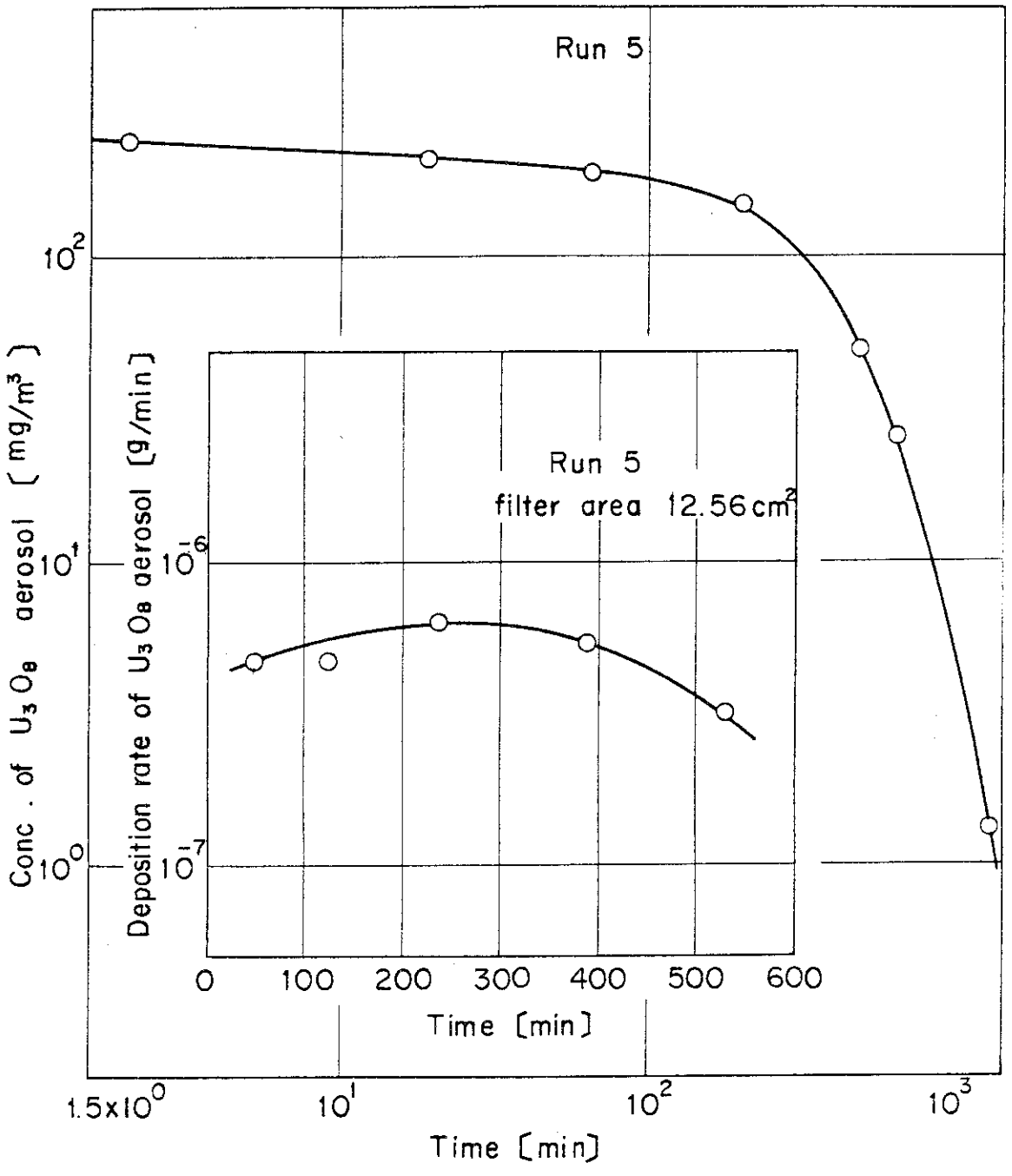


Fig.5 Concentration decrease of uranium oxide (U_3O_8) aerosol and its deposition rate on the sampling filter in the chamber

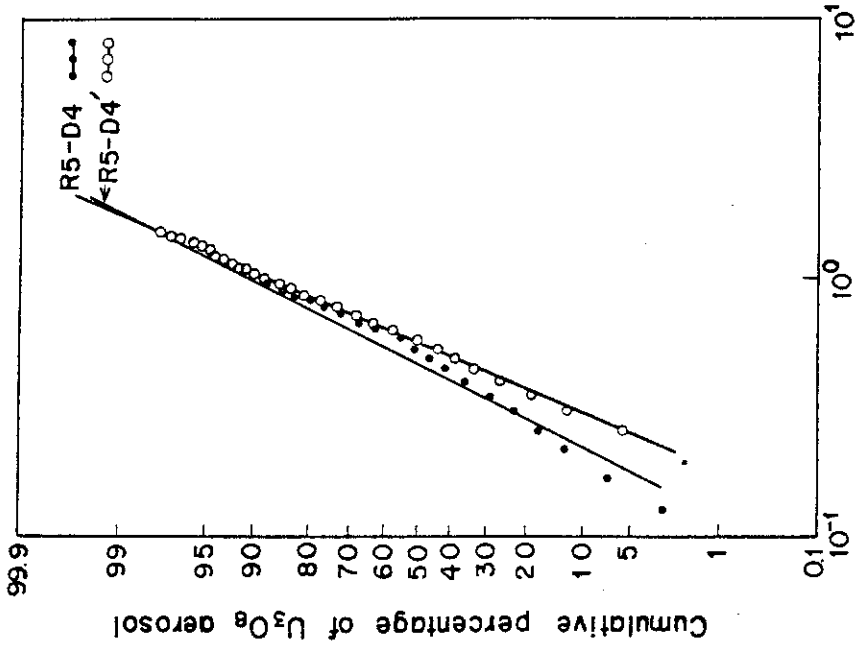


Fig.7 Particle size distribution of uranium oxide (U_3O_8) aerosol

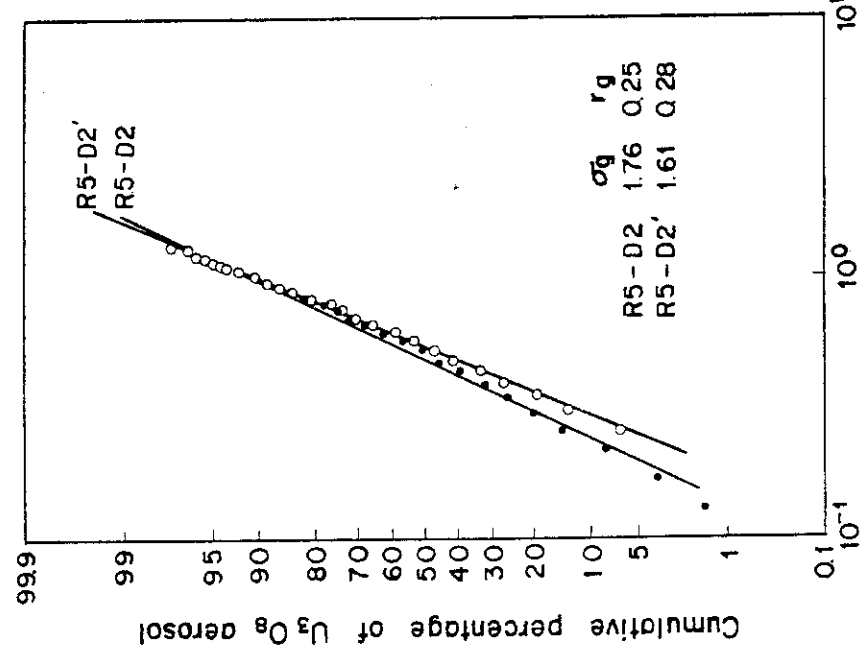


Fig.6 Particle size distribution of uranium oxide (U_3O_8) aerosol

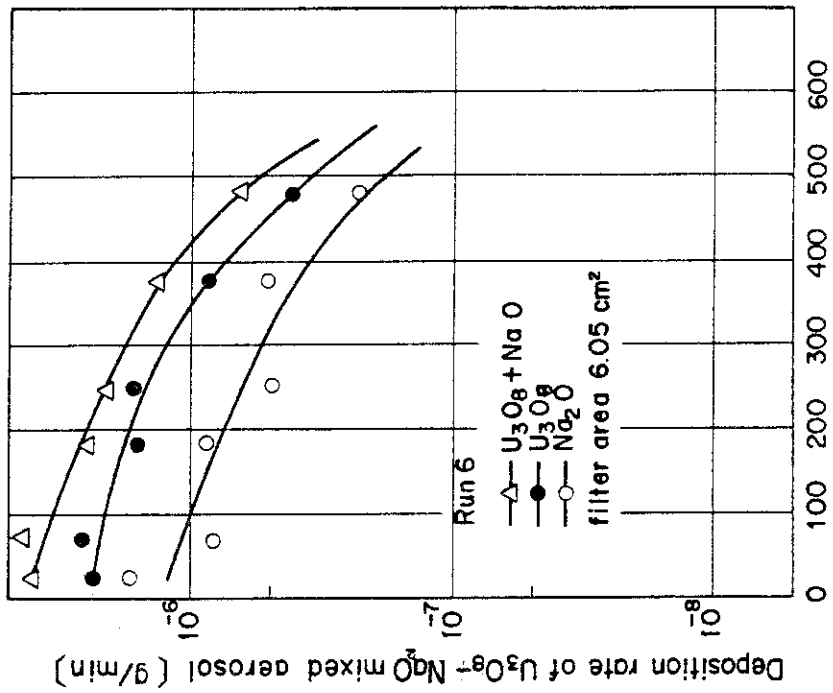


Fig.9 Rete of the deposition for mixed Na_2O-U_3O_8 aerosol settled on the sampling filter in the case of U_3O_8 content of 85.0 wt% in the chamber

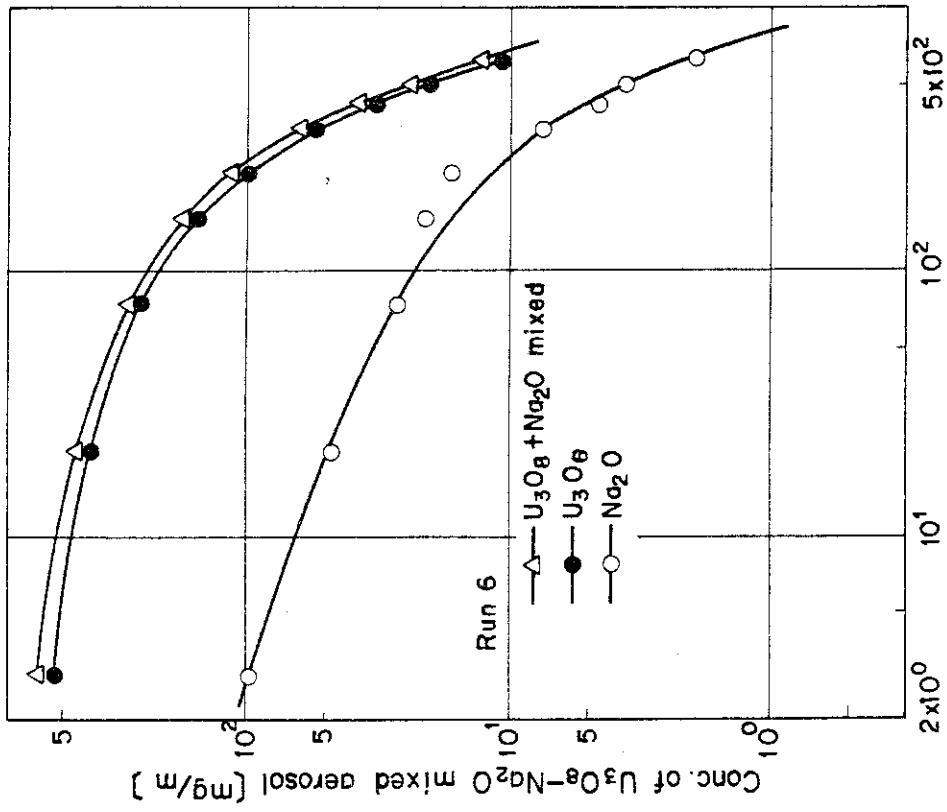


Fig.8 Concentration decreases of mixed Na_2O-U_3O_8 aerosol in the case of U_3O_8 contents of 85.0 wt% in the chamber

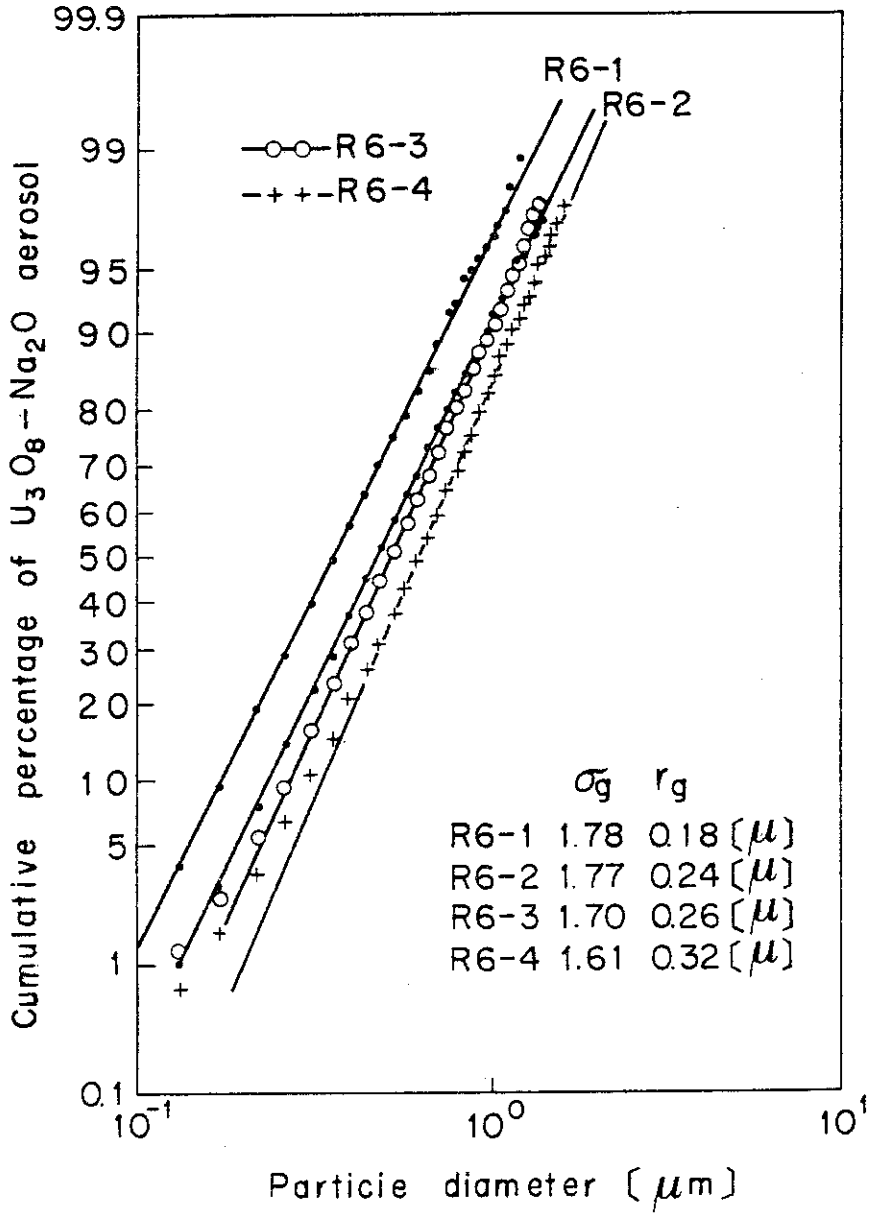


Fig. 10 Particle size distributions of mixed Na_2O-U_3O_8 aerosol in the case of U_3O_8 content of 85.0 wt.% in the chamber.

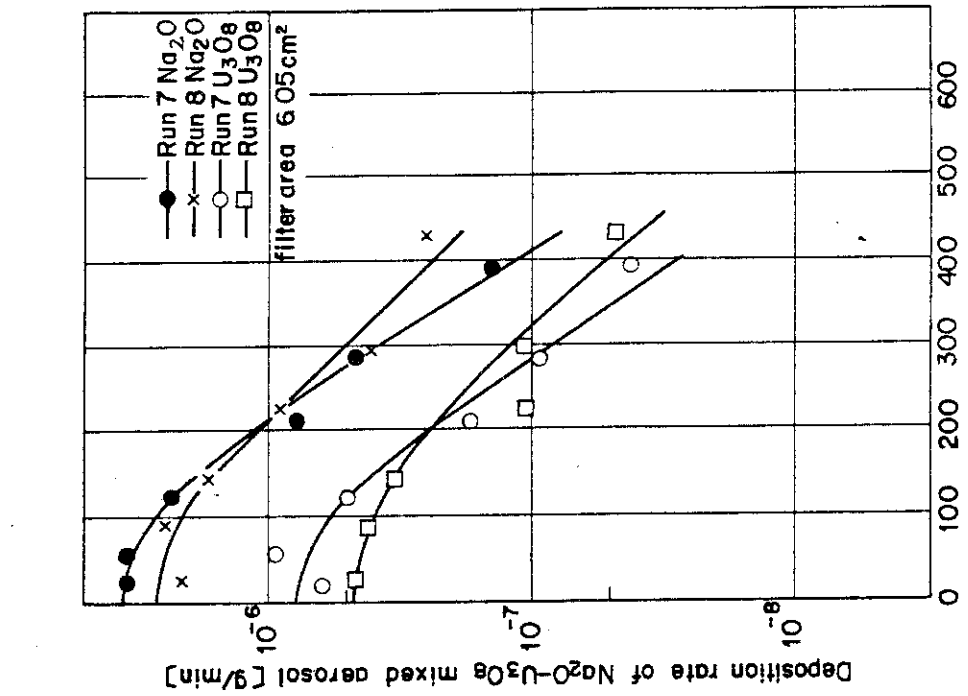


Fig. 12 Rate of the deposition for mixed $Na_2O-U_3O_8$ aerosols settled on the sampling filter in the case of U_3O_8 contents of 6.7 wt.% and 21.0 wt.% in the chamber

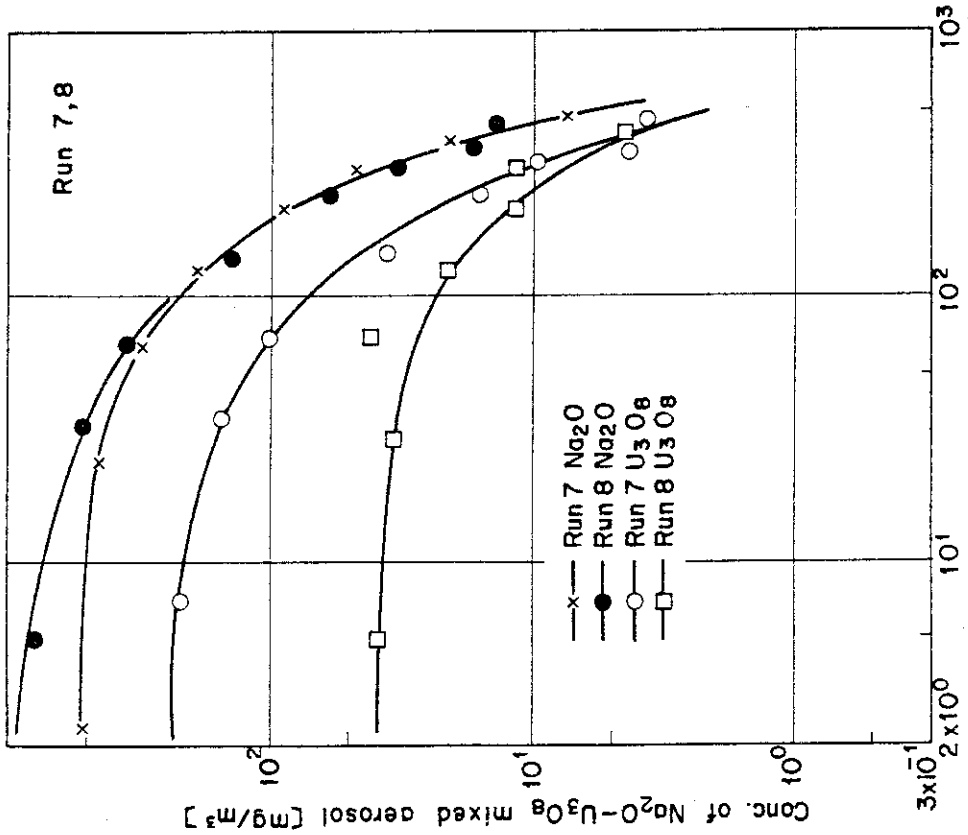


Fig. 11 Concentration decreases of mixed $Na_2O-U_3O_8$ aerosol in the case of U_3O_8 contents of 6.7 wt.% in Run 7 and 21.0 wt.% in Run 8 in the chamber

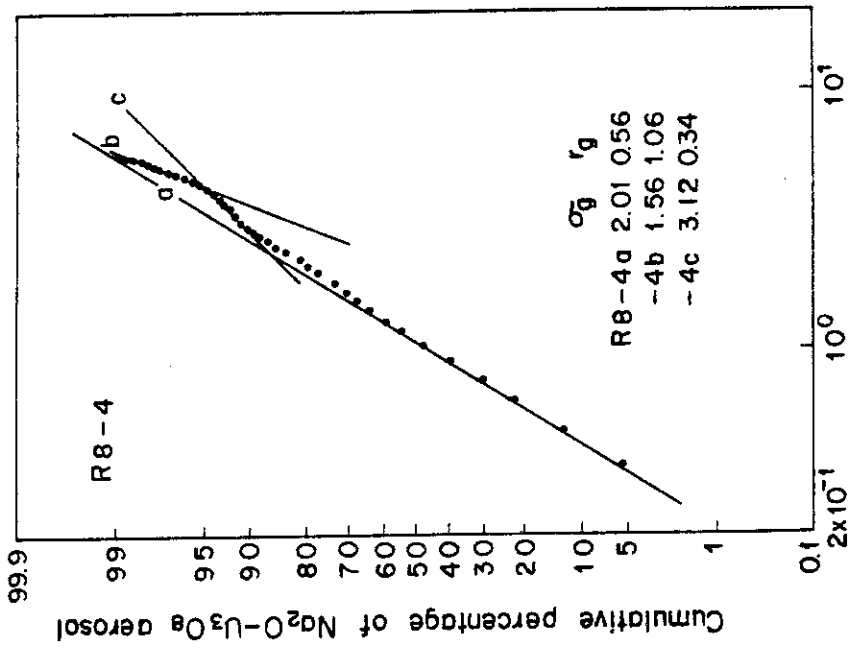


Fig.14 Particle size distribution of mixed Na_2O-U_3O_8 aerosol in the case of U_3O_8 content of 21.0 wt% in the chamber

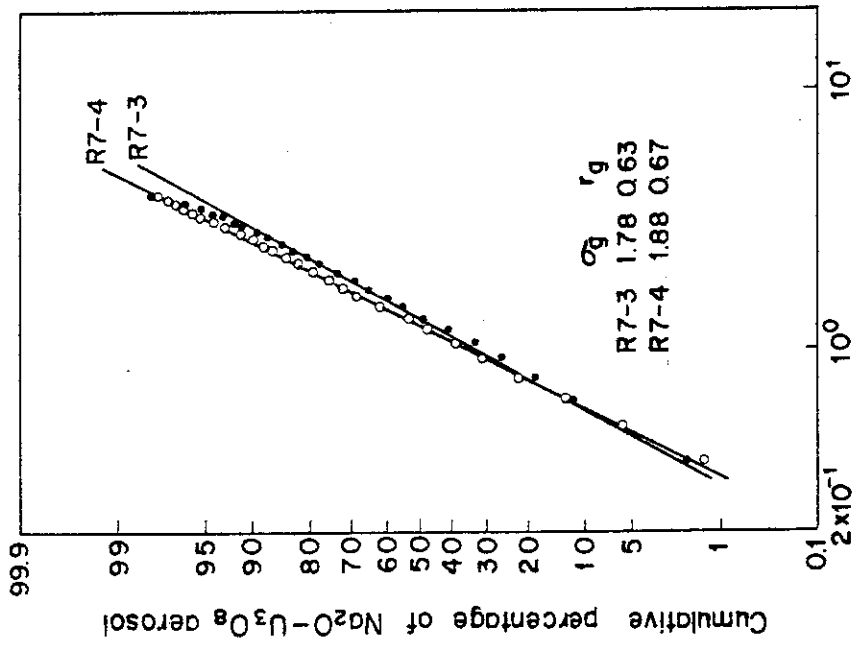
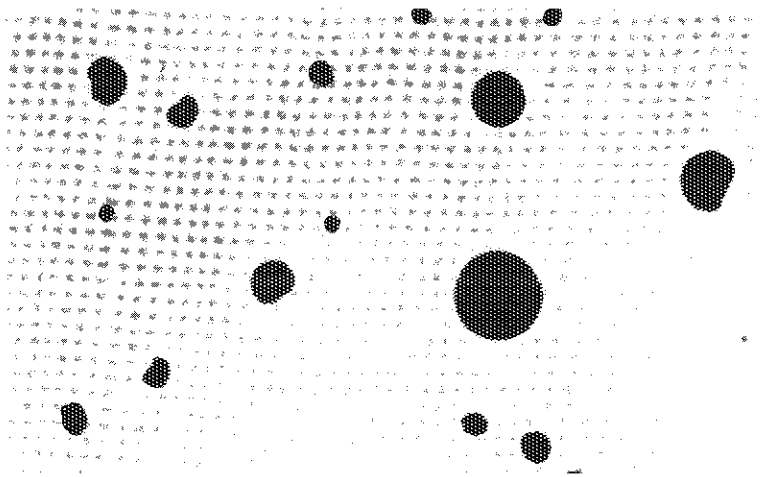
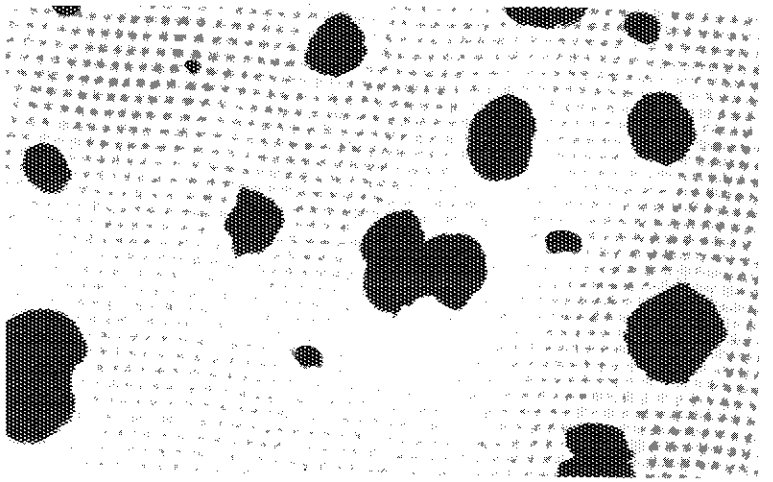


Fig.13 Particle size distribution of mixed Na_2O-U_3O_8 aerosol in the case of U_3O_8 content of 6.7 wt.% in the chamber

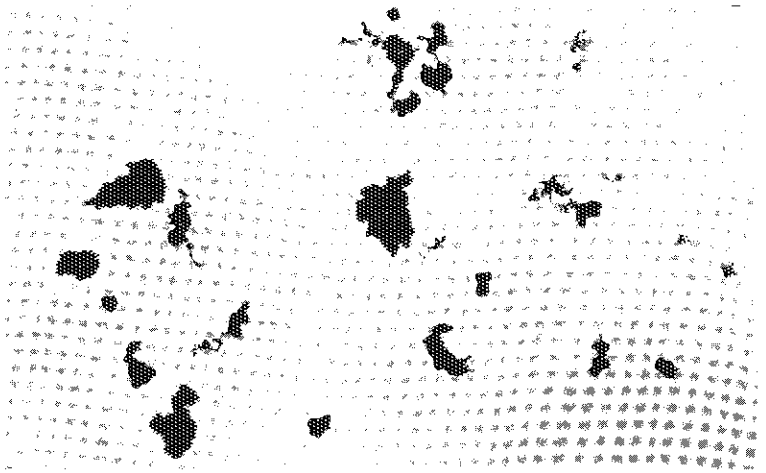
photo. Aerosol particles deposited on the grid in the U_3O_8 wt.% of 0 ~100 wt.% (x 4000)



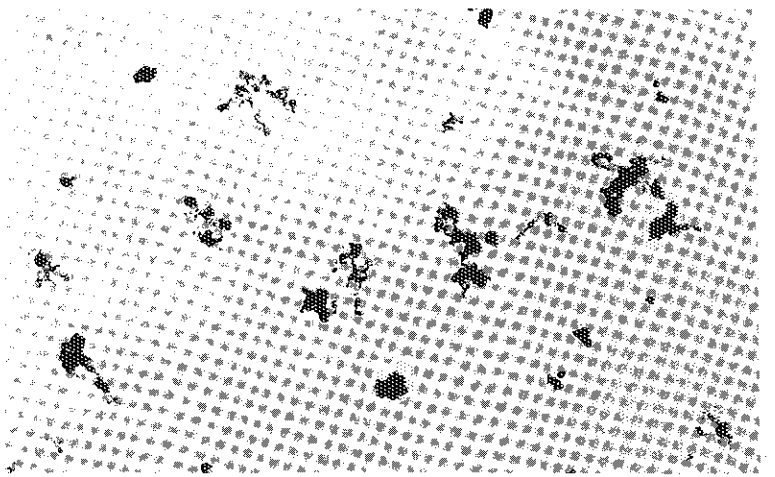
Sodium oxide (Na_2O) aerosol



Sodium oxide aerosol containing U_3O_8 particles (U_3O_8 weight % 6.7 wt.%)



Sodium oxide aerosol containing U_3O_8 particles (U_3O_8 weight % 85.0 %)



Uranium oxide (U_3O_8) aerosol