Natural Science Report, Ochanomizu University, Vol. 13, No. 1, 1962
お茶の水女子大学 自然科学報告 第 13 巻 第 1 号

On the Analyses of the Results of the Observations in the Windscale Accident

Jiro Sakagami (坂 上 治 郎)

Department of Physics, Faculty of Science,
Ochanomizu University

Introduction

Although several reports of the observed results in the Windscale accident which occurred in October 1957 have been published, there have been scarcely any reports in which the data were investigated in datail by adapting some diffusion formulae. In this paper, results reported by Booker[1] are analysed by using some diffusion formulae. After this report had been completed, the author read Martin and Doury's paper.[2] However, the way of analysis is different from that of the author, this report may have another significance.

General remarks

Among the results given in the Booker's paper, the most adequate one for quantitative investigations is the distribution of I^{131} in grass, because it includes the data in wider region, many measuring posts and wide range of observed values. (Fig. 1 and 2). In another paper, Crabtree reported the positions of smoke front of I^{131} in every 6 hours, which are shown in Fig. 3.[3] The suitable data to be analysed correspond to the portions being carried by the wind whose directions changed from NW to N and then to NE. So the line connecting the positions of the highest concentrations of the smoke is supposed to be the broken lines in Fig. 1 and 2. The data enclosed by brackets ( ) in Fig. 2 are the results correspond to another portion of the smoke, so they are excluded in this analysis.

The data of the sedimented amounts of I^{131} might be inadequate for the verification of the diffusion formulae. But the sedimented amounts have a relationship with the (space) concentration at the ground level (or at grass surface). Chamberlain[4] adopted a quantity 'sedimentation velocity' which connects the amount of sedimentation and the concentration, but the values of the sedimentation velocity are not always definite. However, if we assume that the condition of grass is uniform over the whole region, the value of sedimentation should be proportional to the concentration.

The effective source intensity and the period of emission for the diffusion which result the data being analysed in this paper were not obvious. Furthermore, though the stack height was reported as 120 m, the effective source height was unknown. These quantities are necessary for the calculation of the absolute values of sedimentation. Therefore, the object of these analyses is not to compare the absolute

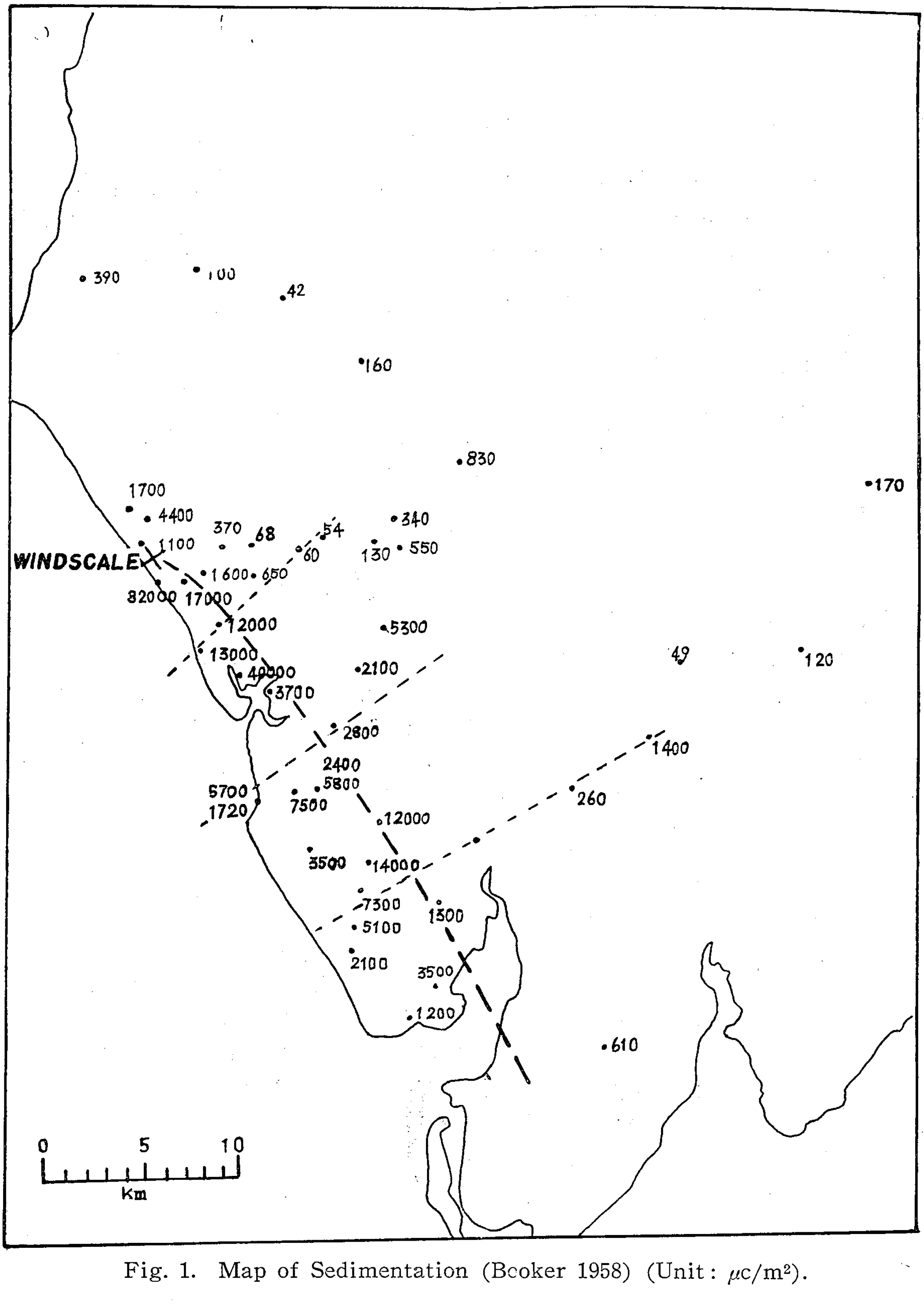

Fig. 1. Map of Sedimentation (Booker 1958) (Unit: $\mu c/m^2$).

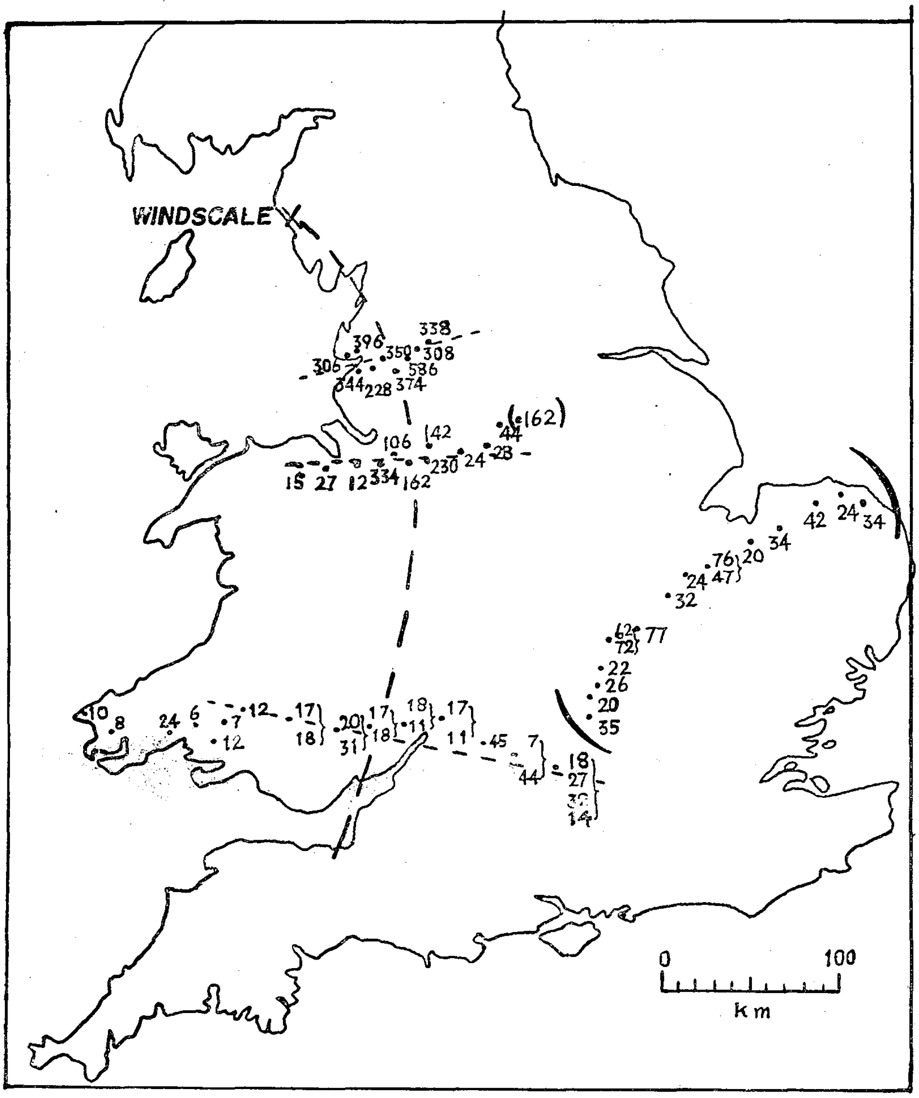

Fig. 2. Map of Sedimentation (Booker 1958) (Unit: $\mu c/m^2$).

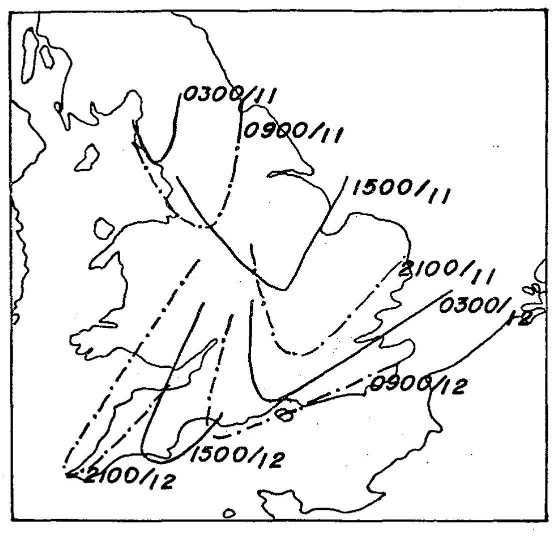

Fig. 3. Position of Smoke Front (Crabtree 1958).

values of sedimentation at each post with those obtained from the diffusion formulae, but to compare in detail the distribution of relative values with theoretical ones over the whole region.

Crosswind-ward distribution

We take x axis leeward, z axis vertically upward and y axis perpendicularly to them. Plotting the y-ward distributions for several leeward distances, we obtain Fig. 4. As Martin and Doury also remarked, y-ward distributions at farther distances are strongly affected by shifting of wind. We have considered that in such

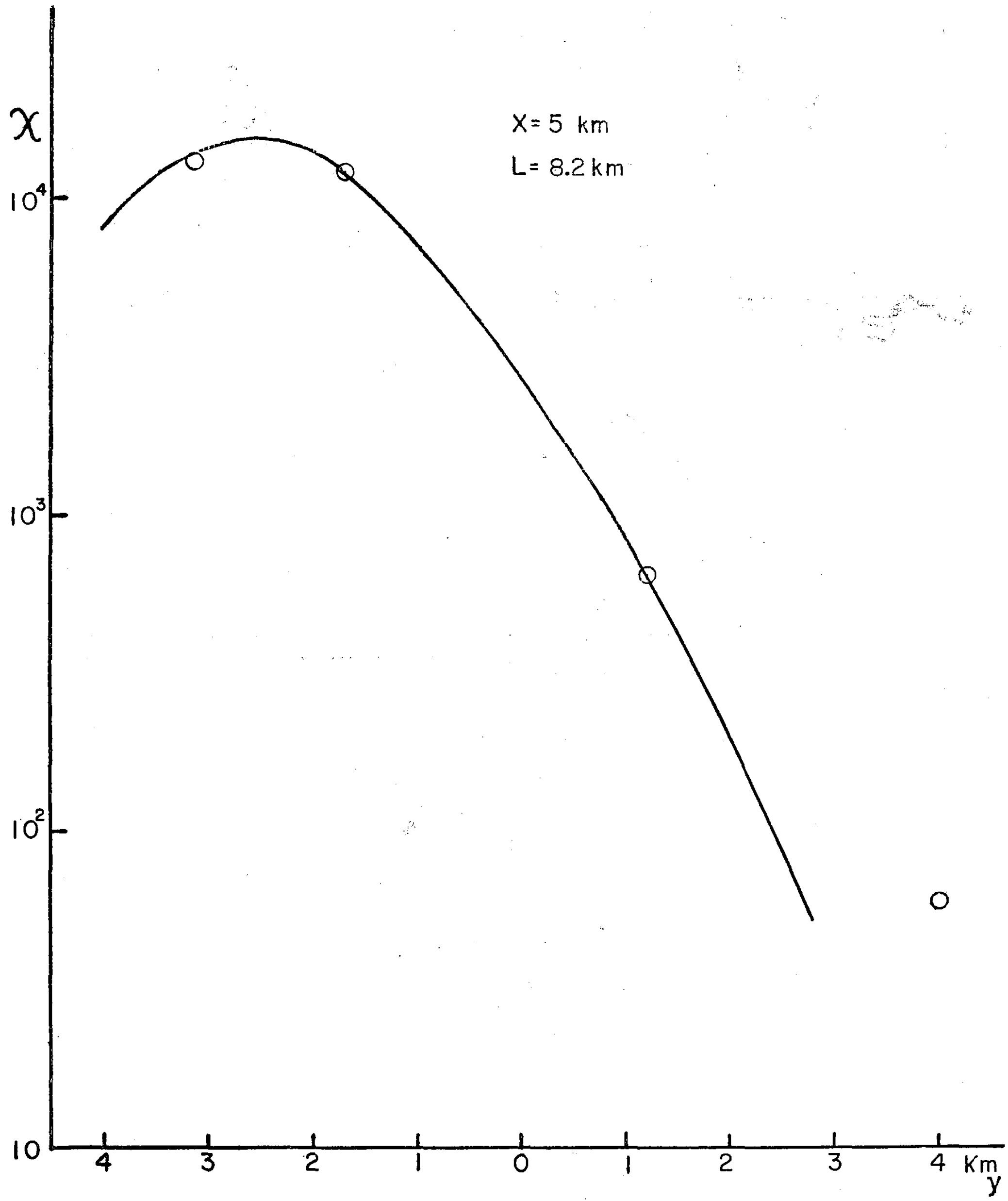

Fig. 4-1.

Fig. 4-1～4-6. y-ward distributions (Unit: $\mu c/m^2$).

distances, it is rather rigorous to assume the plateau type than to assume the normal distribution, and a quantity L is adopted which is defined by the distance between the positions where the concentration is 1/10 of the highest concentration.[5),6),7)] The values of L obtained from Fig. 4 are given in Table 1, and the curve of L versus x is shown in Fig. 5.*

In former papers,[5),6),7)] Lagrangian correlation was assumed as

$$R(\tau)=\exp(-\alpha\tau)\,, \tag{1}$$

and after some transformations, we got

$$L=\sqrt{q_A}(\exp(-\varphi_A x)+\varphi_A x-1)\,, \tag{2}$$

and it was verified from observed results that this functional form was adequate. Adapting eq. 2 to Fig. 5, we obtain the values of the parameters $\sqrt{q_A}$ and φ_A:

$$\begin{aligned}\sqrt{q_A}&=1.2\times10^3\\ \varphi_A&=2.27\times10^{-4}\,.\end{aligned} \tag{3}$$

These values are nearly equal to those obtained in the Tokai

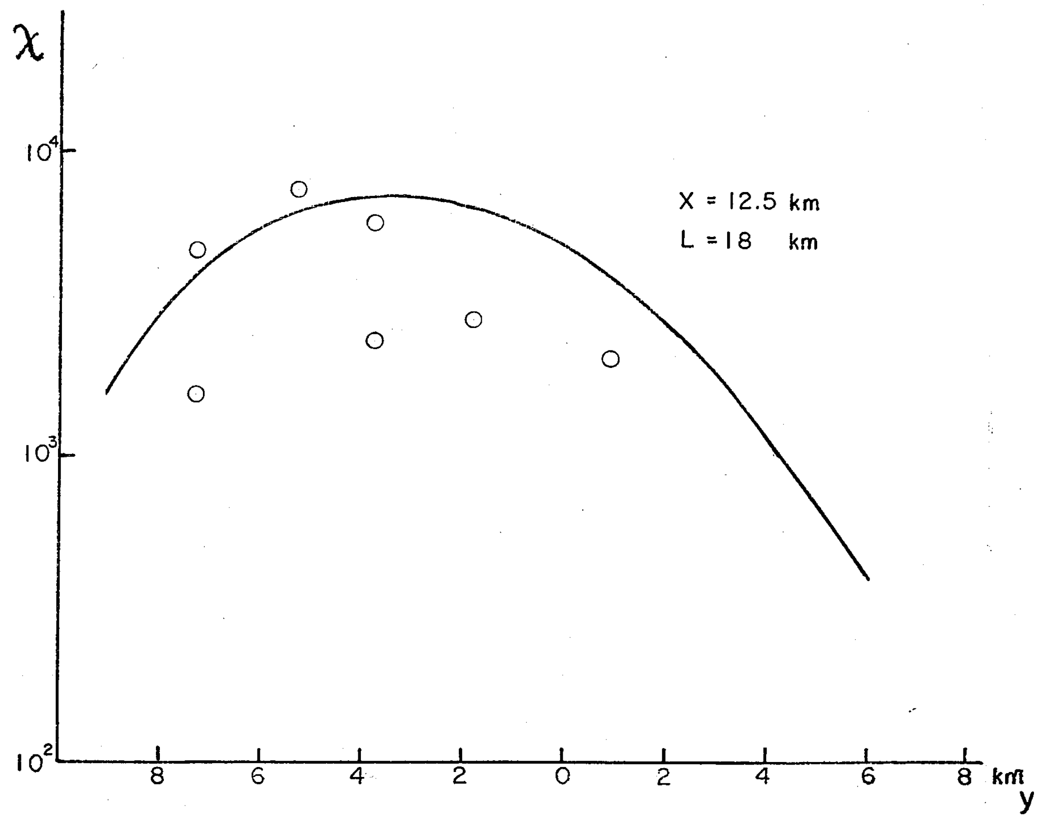

Fig. 4–2.

* Some posts are not on the given y-axis and the data diverged considerably, so there are some ambiguities in determining the values of L.

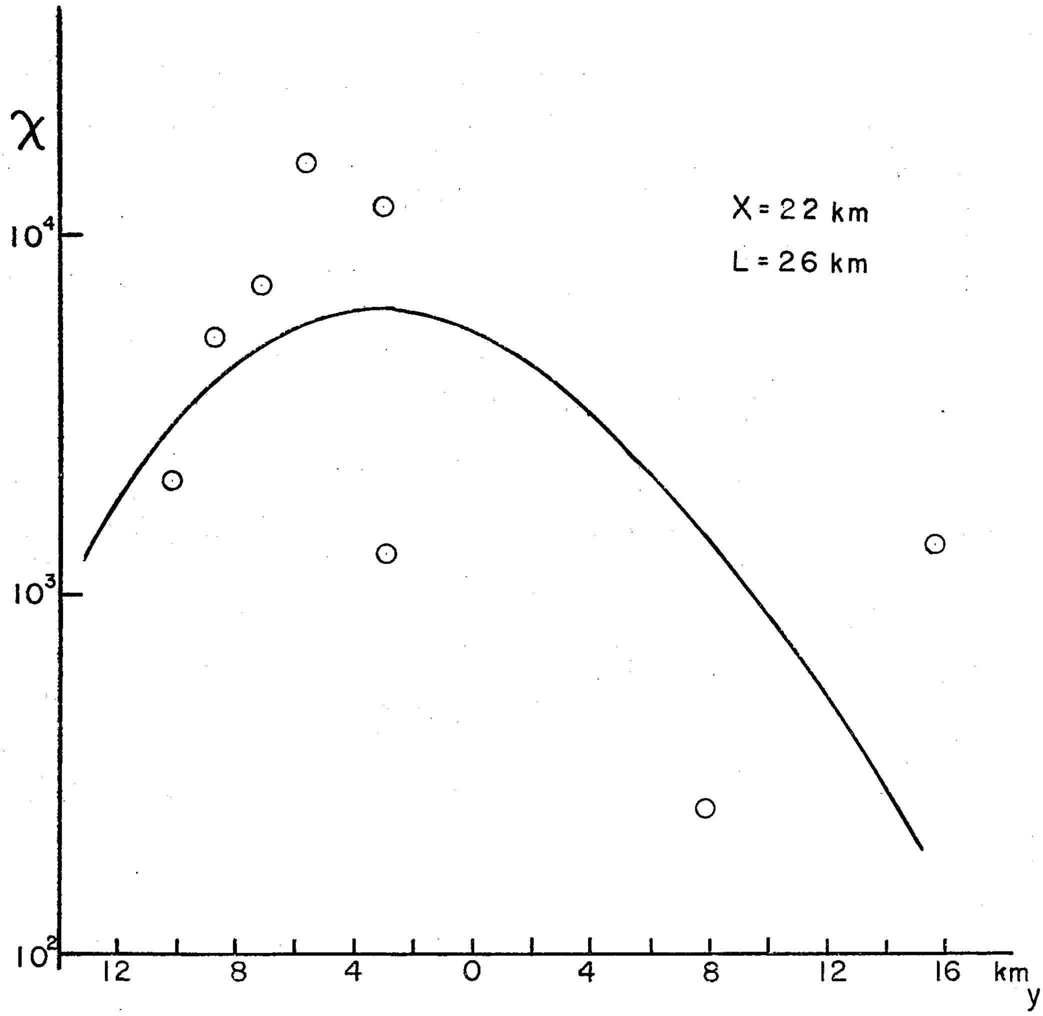
χ
10^4
10^3
10^2
X = 22 km
L = 26 km
12
8
4
0
4
8
12
16
km
y

Fig. 4-3.

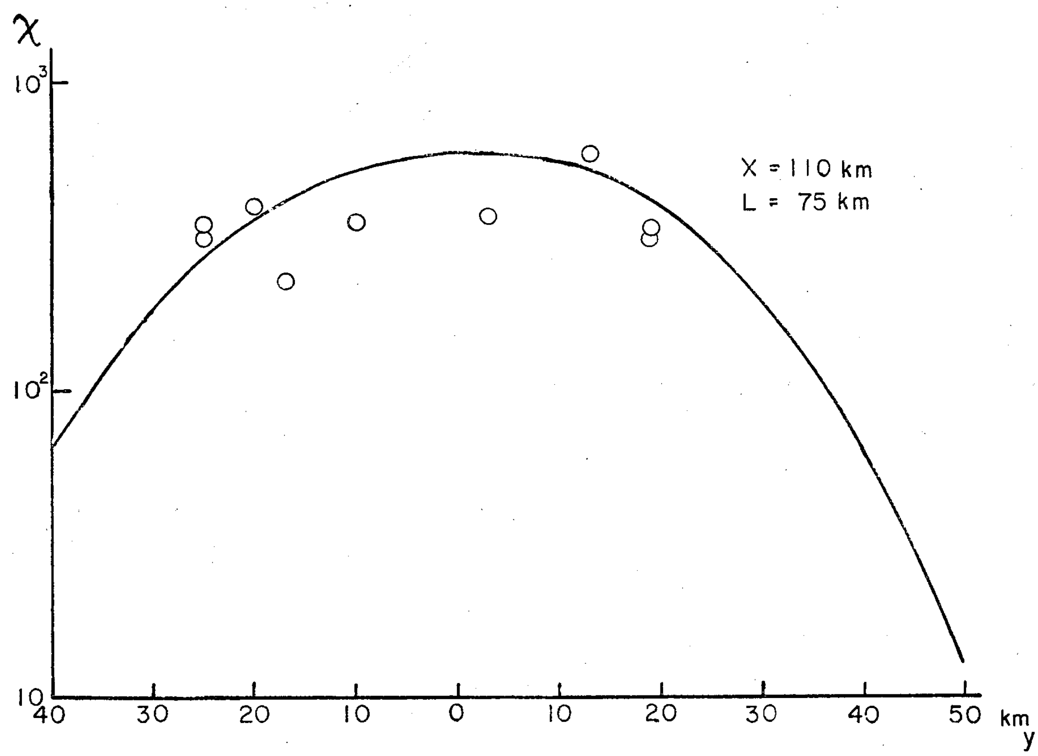
χ
10^3
10^2
10
X = 110 km
L = 75 km
40
30
20
10
0
10
20
30
40
50
km
y

Fig. 4-4.

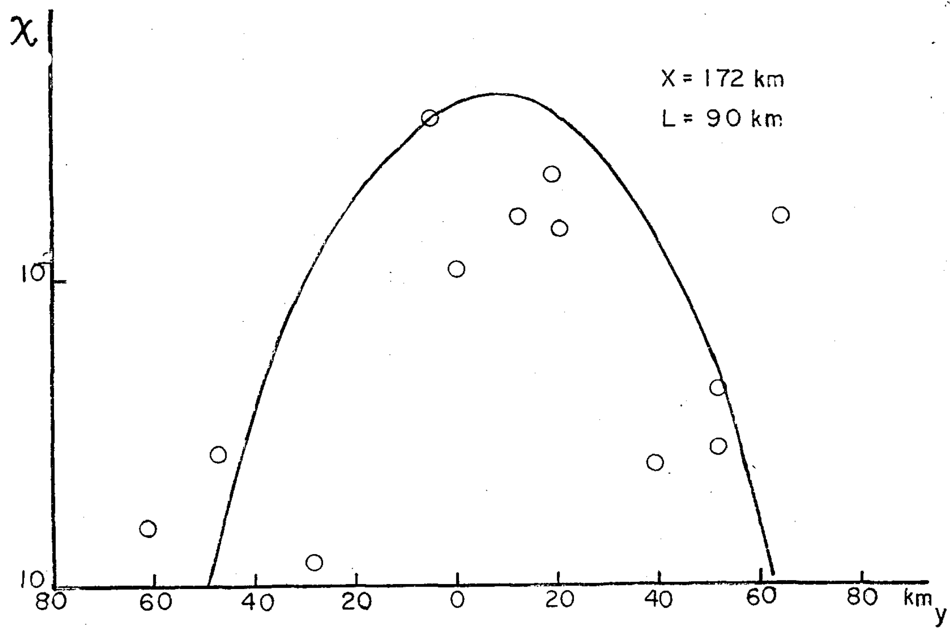

Fig. 4-5.

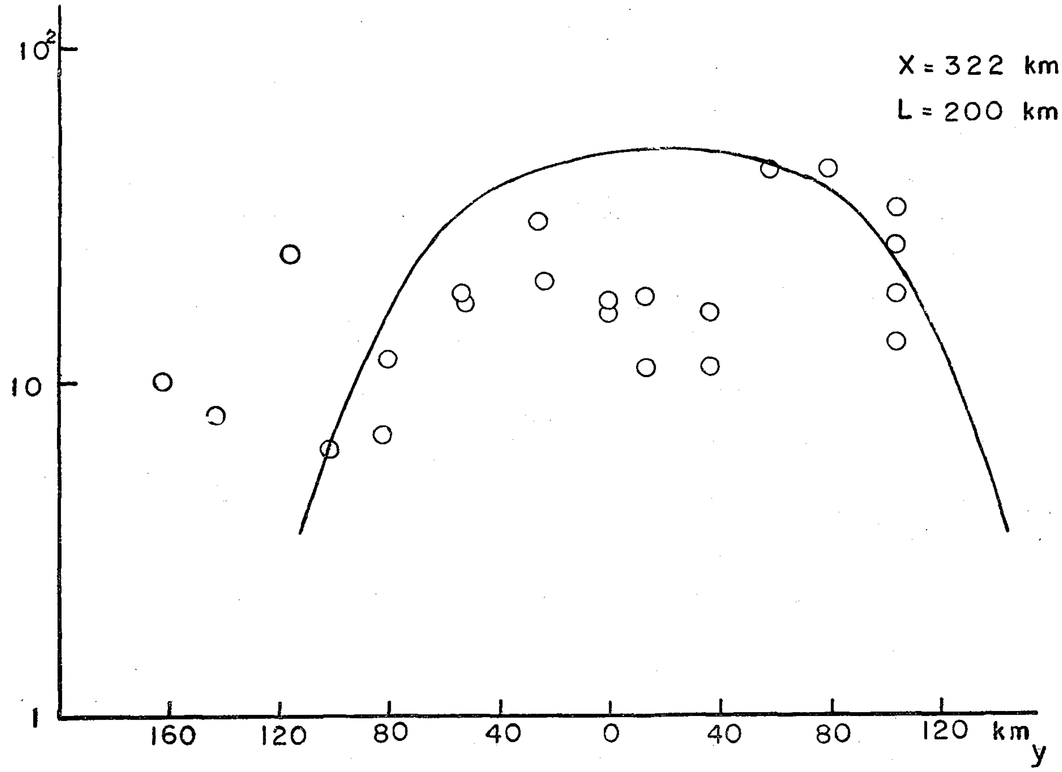

Fig. 4-6.

Table 1. Values of *L*.

x (km)	5	12.5	22	110	170	330
L (km)	8.2	18	26	75	90	200

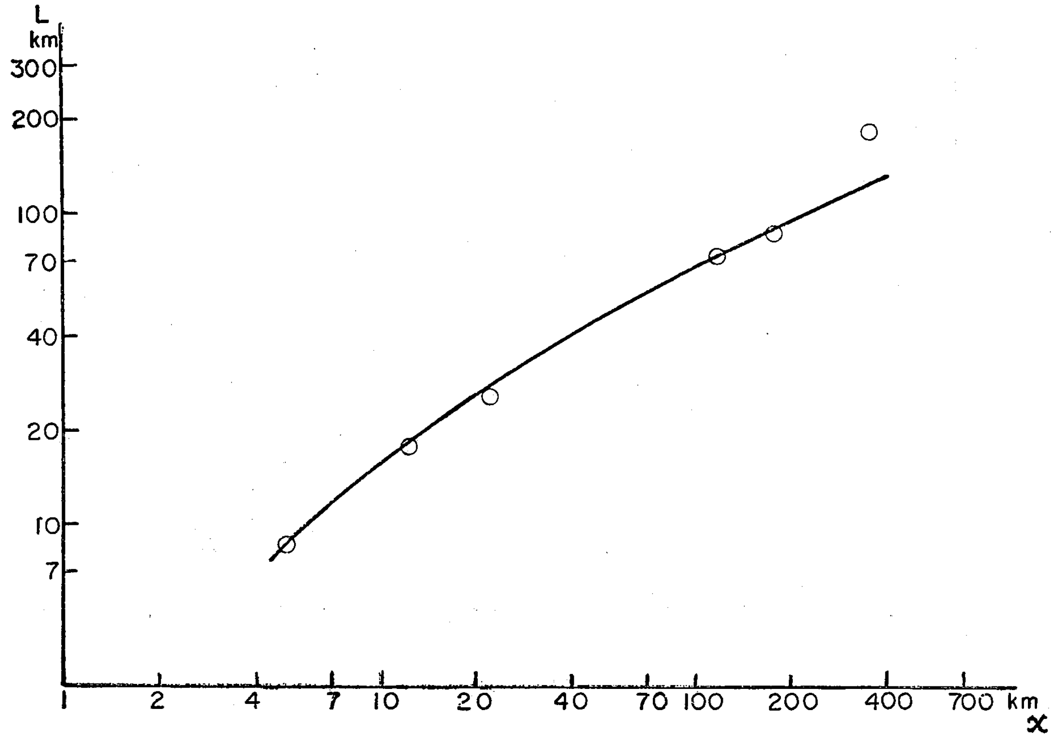

Fig. 5. Curve of L versus x.

experiments[6] in which the stack height was 65 m and the meteorological conditions were slightly unstable.*

Vertical diffusion

The data for the z-ward profile of concentration or sedimentation were not obtained. So we can only consider the vertical diffusion from the x-ward distribution of the crosswind-ward integrated concentrations:

$$\chi_{CIC}(x, 0)=\int_{-\infty}^{\infty}\chi(x, y, 0)dy\,. \tag{4}$$

The general form of χ_{CIC} is given from the author's formula:

$$\chi_{CIC}=\frac{q}{u}\frac{1}{B}\exp\left(-\frac{h+z}{B}\right)J_0\left(i\frac{2\sqrt{hz}}{B}\right), \tag{5}$$

where q is the source intensity, u is the mean wind speed, h is the stack height, $J_0(i\xi)$ is the 1st kind Bessel function of the order 0 with an imaginary argument $i\xi$ and B is given by

$$B=\sqrt{q_A}(\exp(-\varphi_A x)+\varphi_A x-1)\,. \tag{6}$$

In this case where $z=0$, eq. 6 becomes

$$\chi_{CIC}(x, 0)=\frac{q}{u}\frac{1}{B}\exp\left(-\frac{h}{B}\right). \tag{7}$$

* In the Tokai experiment, $\sqrt{q_A}=2\sim 8\times 10^3$ and $\varphi_A=8\sim 6\times 10^{-4}$.

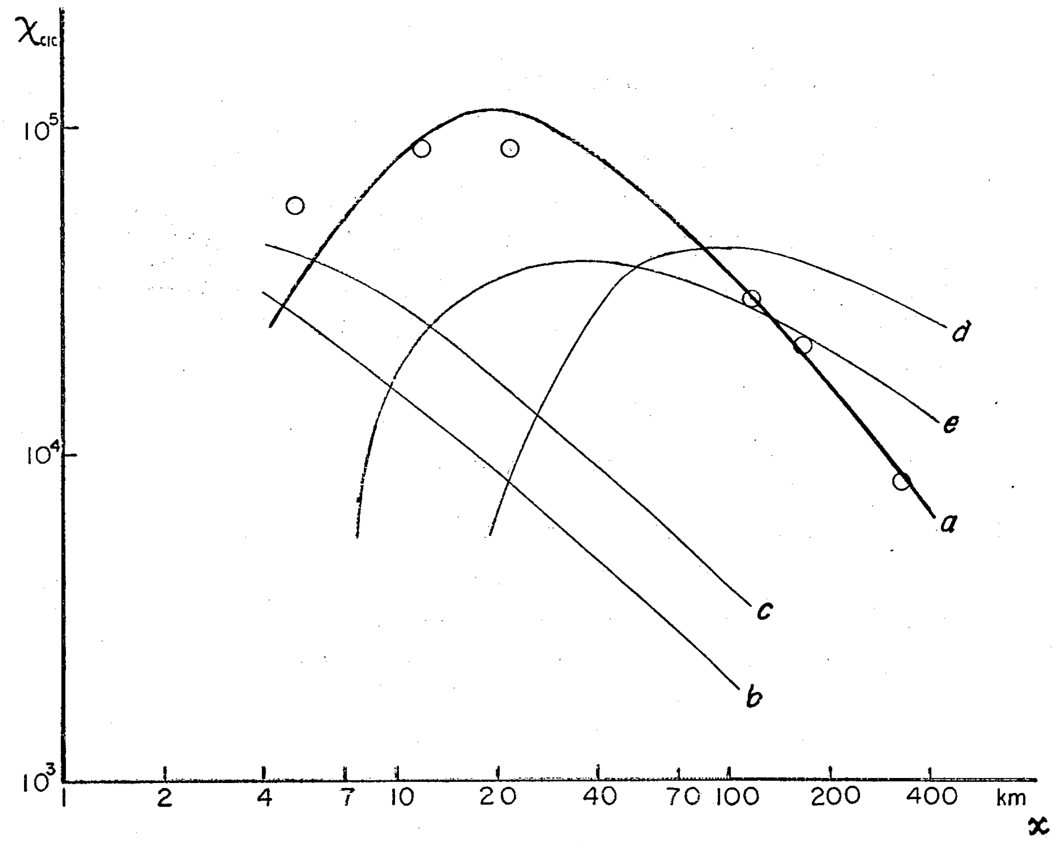

Fig. 6. Curve of χ_{CIC} versus x (Unit: μc/m).
(a) Sakagami: $\sqrt{q_B}=1.0$, $\varphi_B=1.2\times10^{-2}$
(b) Sutton: $n=0.25$, $C_z=0.40$
(c) Sutton: $n=0.25$, $C_z=0.20$
(d) Sutton: $n=0.73$, $C_z=0.20$
(e) Sutten: $n=0.73$, $C_z=0.40$

Table 2. Values of χ_{CIC}.

x (km)	5	12.5	22	110	170	330
χ_{CIC} (μc/m)	58,475	86,000	149,800	29,420	21,600	8,140

The values of χ_{CIC} are obtained from the results shown in Fig. 6 and they are given in Table 2.

In the former papers,[6),7)] it has been remarked that the diffusion parameters $\sqrt{q_A}$, $\sqrt{q_B}$, φ_A and φ_B depend not only on the meteorological conditions but also on the source height. The stack height of the Windscale pile is 120 m, but the effective source height might be more higher. The definite relationships between $\sqrt{q_B}$ or φ_B and the source height have not yet been obtained, so the values of these parameters are assumed as the same to those in the Tokai experiments which are comparable to the present case. Namely we adopt the following values:

$$\sqrt{q_B} = 1.0 \qquad \text{and} \qquad \varphi_B = 1.2 \times 10^{-2} .$$

According to eq. 7, the maximum value of χ_{CIC} appears at $h = B$. The values of χ_{CIC} in Fig. 6 show that the position of their maximum appears at about 15 km. The calculated value of B with the above values and $x = 15$ km becomes $h = 200$ m. This result is reasonable, so in the following calculation, we assume that $h = 200$ m. The calculated values of χ_{CIC} are given by the curve (a) in Fig. 6. This curve indicates that the formula and the adopted values of parameters are adequate.

Sutton's formula

If the y-ward distributions are assumed to be normal, the standard deviations $\overline{y^2}$ become proportional to L^2. According to Sutton's formula, the general inclination of the curve corresponds to $(2-n)/2$, where n is the parameter in the formula. The curve in Fig. 5 shows that the inclination is 0.63, so n is calculated as 0.73.

χ_{CIC} deduced from Sutton's equation is given by

$$\chi_{CIC} = \frac{2q}{u} \frac{1}{\sqrt{\pi B}} \exp\left(-\frac{h^2}{B} \right) , \tag{8}$$

where

$$B = c_z^2 x^{2-n} . \tag{9}$$

The value of B calculated from eq. 9 with $c_z = 0.40$ and $n = 0.25$, which were adopted by Chamberlain[3], gives the result that the position of the maximum χ_{CIC} does not appear within 4 km (curve (b) in Fig. 6). The result with $c_z = 0.20$ and $n = 0.25$, which were adopted in WASH 740[8], shows that the position is at about 4 km (curve (c) in Fig. 6), so they are very different from the observed result. If we calculate with $n = 0.73$, which is the result from the y-ward distributions in this paper, and $c_z = 0.20$ or 0.40, the obtained results (curve (d) and (e) in Fig. 6 respectively) are also different from the observed one, as it is evident from Fig. 6.

Conclusion

As some necessary quantities are unknown, the absolute values of sedimentation over the whole region cannot be calculated. However, the author's formulae with the values of parameters obtained in the Tokai experiments show fairly good agreements with the observed results of the relative distributions of the sedimentation to the extent shown in Fig. 4 and 6.

Literatures

1) Booker, D. V.: Physical measurements of activity in samples from Windscale, 1938, A. E. R. E. HP/R-2607.
2) Martin, J. J. and Doury, A.: A study of results of the Windscale accident (October 1957) and of the validity of Sutton's mathematical model of atmospheric diffusion, AEC-TR-4290.
3) Crabtree, J.: The travel and diffusion of the radioactive material emitted during the Windscale accident, 1958, Quart. J. Roy. Met. Soc., **85**, 362-370.
4) Chamberlain, A. C.: Aspects of travel and deposition of aerosol and vapour clouds, 1953, A. E. P. E. HP/R-1261.
5) Sakagami, J.: On the relations between the diffusion parameters and meteorological conditions, 1960, Natural Science Rep., Ochanomizu Univ., **11** (2), 127-159.
6) Sakagami, J.: On the Analyses of the data of the Tokai experiments, 1961, *ditto*, **12** (1), 7-27.
7) Sakagami, J.: Diffusion experiments using balloons, 1962, *ditto*, **12** (2), 1-24.
8) AEC: Theoretical possibilities and consequences of major accidents in large nuclear power plants.—A study of possible consequences if certain assumed accidents, theoretically possible but highly improbable, were to occur in large nuclear power plants, 1957, WASH-740.

(*Received March 31, 1962*)