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Tokyo Electric Power Company

Evaluation of Exposure Dose Based on the Density of Detected Radioactive Materials

1. Discharge rate equivalent of the current density of the radioactive materials in the air

Using the diffusion graph developed (by unit radioactivity and atmospheric stability) based on the Gauss Diffusion Model (see Exposition 1 below), we identified the density at the evaluation points and compared them with current value measured around the site.

(Conditions of Diffusion Graph)

[Weather] Wind Direction: Leeward by 1 azimuth direction,

Wind Velocity: 1.0m/sec, Atmospheric Stability: D

[Discharge Rate] 1Bq/sec

[Discharge Point] Ground Height

Based on the diffusion graph (see Figure "Density Diffusion of Radioactivity in the Aire"), the density at 1km with atmospheric stability D can be identified as approx. 7E-5Bq/m3 and consequently the density per 1 Bq/sec discharge rate comes to be approx. 7E-11 Bq/cm3.

Conservatively assuming that all of the radioactive materials currently detected in the air around West Gate (1km west of Reactor Building) originated from the power station, <u>the discharge rate (total of the reactor buildings, Unit 1, 2 and 3) corresponding to the measured value 1E-5 Bq/cm3 of Cs-137 is identified as 1.4E+5 Bq/sec</u> by the following calculation.

1E-5(Bq/cm3) / 7E-11(Bq/cm3*(Bq/sec)) = 1.4E+5(Bq/sec)

<Exposition 1>

Gauss Diffusion Model

(Formula)

The formula of Gauss Diffusion Model represents the steady-state density diffusion of materials steadily discharged under the condition that atmosphere is constant and geological formation is flat. The formula is a standard diffusion formula adopted in the safety evaluation of nuclear power plants (see Note 1). Also this formula assumes that the discharged materials fully reflect at ground surface.

$$\chi(x,y,z) = \frac{Q}{2\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \cdot \left[\exp\left\{-\frac{(z-H)^2}{2\sigma_z^2}\right\} + \exp\left\{-\frac{(z+H)^2}{2\sigma_z^2}\right\}\right]$$

χ : Density at point (x, y, z) **(Bq/m³)**

Q : **Discharge rate(Bq/sec)**

U : **Wind velocity(m/sec)**

σ_y : Parameter of density diffusion to y direction **(m)**

σ_z : Parameter of density diffusion to z direction **(m)**

H : Height of discharge point **(m)**

(Calculation condition to develop the diffusion graph)

Q = **1 Bq/sec**

U = **1 m/sec**

σ_{y0} = **(1/3.0) × Length of Reactor Building(80m)**

σ_{z0} = **(1/2.15) × Height of Reactor Building(60m)**

H =**0 m**

Atmospheric Stability D

2. Evaluation of exposure dose based on the discharge rate estimated by the current density of radioactive materials

Radiation dose at south boundary of the site (, where the highest value of the exposure dose is recognized in the safety examination,) has been figured out, assuming that the discharge rate above is worked out under the condition that there are neither radioactive materials discharged immediately after the accident nor refloat of materials (see Exposition 2 below).

(Conditions)

[Weather] Wind Direction, Wind Velocity, and Atmospheric Stability: annual average (April 1979 - March 1980, Height of measuring point 10m)

[Discharge Rate] 1Bq/sec (effective energy 1MeV)

[Discharge Point] Ground Surface

[Evaluation Point] 1.35 km - 1.13 km from Reactor Buildings of Unit 1, 2 and 3 (south boundary of the site)

By summing up the exposure dose from the following categories total annual exposure dose has been calculated, based on the unit annual exposure dose and annual average density that have been figured out with the conditions above and calculation formula in the guideline.

(See Attachment: Evaluation of Exposure Dose)

(1) External whole-body exposure dose (effective dose) by radioactive cloud

(2) External whole-body exposure dose (effective dose) by radioactive material settling at ground surface

(3) Internal exposure dose (committed effective dose) by inhalation and intake

Assuming that the total discharge rate of Cs-134 and Cs-137 is the doubled value

of section 1, namely 2.8E+5 Bq/sec(1.0E+9 Bq/hr), the annual exposure dose under the average weather condition of the safety evaluation comes to be 1.7E+0 mSv/year. Annual exposure dose at 5km, 10km, 15km, 20km and 30 km away from the reactors in north, northwest, west, southwest and south direction are also figured out. (See Attachment: Evaluation of Exposure Dose)

<Exposition 2>

Calculation of annual exposure dose and annual average density per unit amount of discharge

(1) Calculation of density in the air (see Note 1)

The density of radioactive material in the air is calculated based on the formula that assumes normal distribution in horizontal and vertical direction as to the distribution of the density of the radioactive materials in the air under that conditions that wind direction, wind velocity and other weather conditions are all constant, the radioactive materials are steadily discharged and geological formation is flat.

The original point, x, y and z axes of coordinate are set out at the ground surface immediately under the discharging point, leeward direction, right angle direction to leeward direction and vertical direction respectively.

The radiation density in the air, used for radiation dose calculation, is figured out based on the following formula.

$$\chi(x,y,0) = \frac{Q}{\pi \cdot \sigma_y \cdot \sigma_z \cdot U} \cdot \exp(-\frac{y^2}{2\sigma_y{}^2}) \cdot \exp(-\frac{H^2}{2\sigma_z{}^2})$$

X(x,y,0) : Density of radioactive material at point(x,y,0)(Bq/m^3)

Q : Discharge rate(Bq/sec)

U : Wind velocity(m/sec)

σ_y : Parameter of density diffusion to y direction (m)

σ_z : Parameter of density diffusion to z direction (m)

H : Height of discharge point (m)

(2) Calculation of annual average density (see Note 1)

a. Sum up the contributions toward/around the evaluation point
b. Use the total of inverse of wind velocity by wind direction and level of atmospheric stability
c. Average the density assuming that wind direction varies within 1 azimuth direction

(3) Calculation of annual exposure dose (see Note 2)

Effective dose is calculated based on the following formula.

a. Calculation of Air Kerma Rate at evaluation points

$$D = K_1 \cdot E \cdot \mu_{en} \int_0^{\infty} \int_{-\infty}^{\infty} \int_0^{\infty} \frac{e^{-\mu r}}{4\pi r^2} B(\mu r) x(x', y', z') dx' dy' dz'$$

D : Air Kerma Rate at calculated point (x,y,0)(uGy/h)

Air Kerma Rate : Value obtained by dividing total of motion energy of charged particles discharged by the interaction between charged particles(photon, neutron etc.) and air by mass of air (approximately equal to absorbed dose)

K_1 : Conversion factor to Air Kerma Rate(dis・m^3・μGy)/(MeV・Bq・h)

E : Effective energy of gamma ray(MeV/dis)

μen : Linear energy absorption coefficient of gamma ray to air (m-1)

μ : Linear attenuation coefficient of gamma ray to air(m-1)

r : Distance from point(x',y',z') in radioactive cloud to calculation point(x,y,0)(m)

B(μr) : Regeneration factor of gamma ray to air

X(x',y',z') : Density at point(x',y',z') in radioactive cloud(Bq/m^3)

b. Calculation of Effective Dose at evaluation points

Annual effective dose at evaluation points are obtained by integrating the air kerma from gamma ray of radioactive cloud toward the evaluation points by taking into account the distribution of wind direction and wind velocity by atmospheric stability.

$$H_r = K_2 \cdot f_h \cdot f_0 (\overline{D}L + \overline{D}L_{-1} + \overline{D}L_{+1})$$

Hr : Effective dose at calculation point(μSv/y)

K_2 : Conversion factor from air kerma to effective dose (μSv/μGy)

f_h : Shielding factor of houses (=1)

f_0 : Housing factor(=1)

$\overline{D}L$、$\overline{D}L_{-1}$、$\overline{D}L_{+1}$: Annual average of air kerma from the gamma ray of radioactive cloud toward calculation point (L) or near place (μGy/y)

Note 1: Nuclear Safety Commission of Japan "Guideline of weather regarding safety analysis of reactor nuclear plant"

Note 2: Nuclear Safety Commission of Japan " Evaluation guideline for target dose around light-water reactor nuclear plant"

End

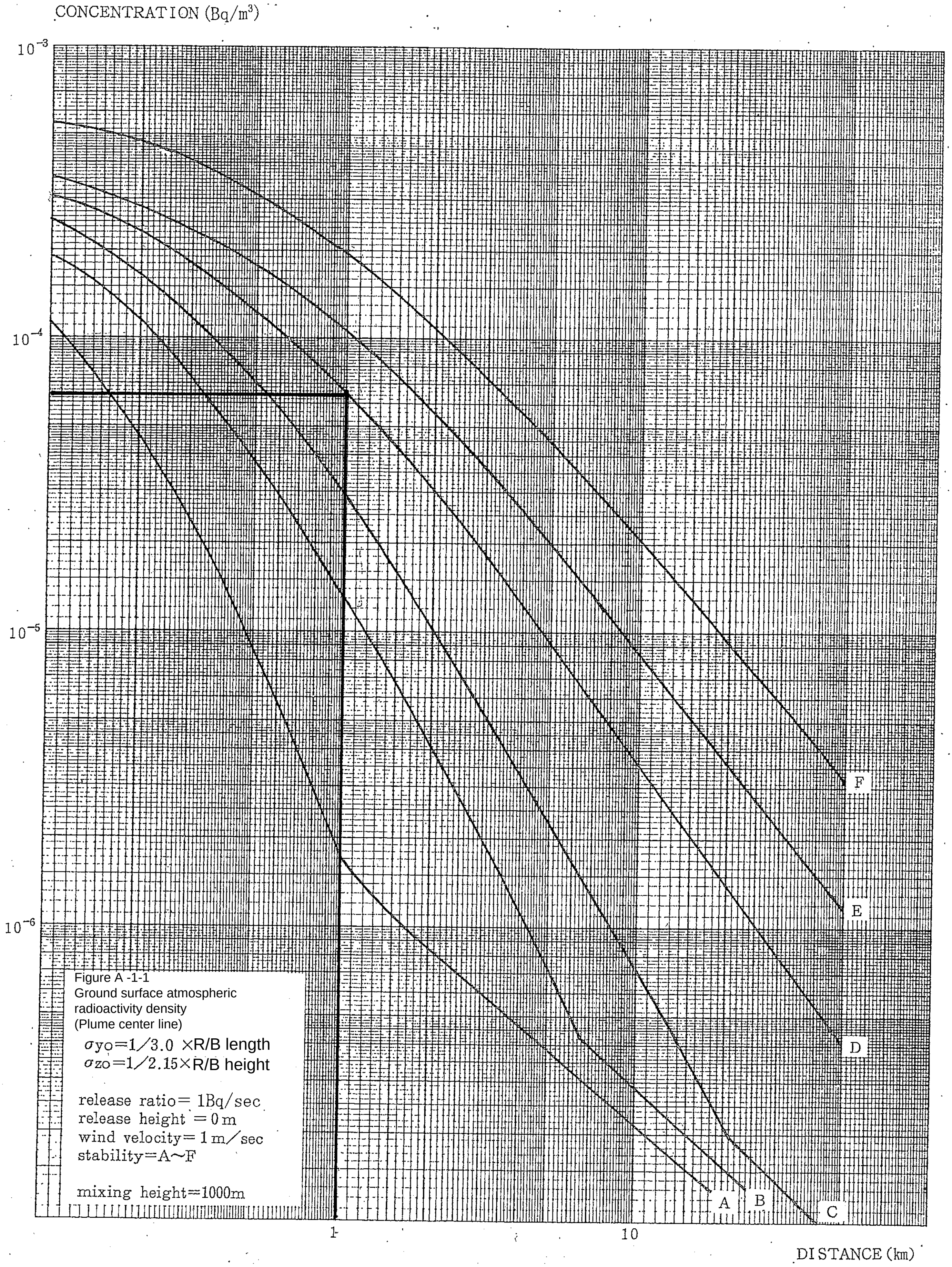

Figure Ground surface atmospheric radioactivity density distribution

Attachment

Evaluation of Exposure Dose

Using annual average weather data regarding safety audit, we calculated the annual exposure dose (provisional) in public by ground discharge, following the audit guideline, as follows.

1. Annual exposure dose per unit discharged, Calculation of annual average density

Dose/density per unit discharged, calculated based on the following condition

	Annual exposure dose(μSv/y)	Annual average density (Bq/cm^3)
Unit 1	5.2E-7	8.8E-13
Unit 2	5.8E-7	1.0E-12
Unit 3	6.7E-7	1.2E-12

Calculation condition

Weather: Wind direction, Wind velocity, atmospheric stability annual average（1979/4～1980/3 Monitored height 10m）

Discharge rate： 1 Bq/sec（Effective energy 1MeV）

Discharge point： Ground surface

Evaluation point： 1.35km～1.13km from 1,2,3 R/B（South of the site periphery）

2. Calculation of annual exposure dose (provisional)

(1)External whole-body exposure dose (effective dose) by radioactive cloud

Calculation method

Discharge rate × annual exposure dose (per unit discharge rate)

(2) External whole-body exposure dose (effective dose) by radioactive material settling at ground surface

Calculation method

Discharge rate × annual average density (per unit discharge rate) × settling speed × 365days × residual rate × conversion factor × 365days

Settling speed *1: 1 cm/sec

Residual rate *1： 0.5

Conversion factor *2: Cs-134 1.5E-15 (Sv/sec)/(Bq/m^2)

Cs-137 5.8E-16

(Source)
*1：Dose Evaluation of the Public under Safety Audit regarding Light-Water Reactor Facility for Generation
*2：Federal Guidance Report No.12 (EPA-402-R-93-081)

(3)Internal exposure dose (committed effective dose) by inhalation a

Calculation method

Discharge rate × annual average density (per unit discharge rate) × breathing rate × 365days× effective dose factor (inhalation and intake)

Breathing rate*3: 2.22E+7 cm^3/day (Adult)

Effective dose factor*4: Cs-134 2.0E-5 mSv/Bq

Cs-137 3.9E-5

(Source)
*3：Emergency Environmental Radioactivity Monitoring Guideline (ICRP Publication 71)
*4：Guideline for Environmental Radioactivity Guideline (ICRP Publication 72)

(4)Discharge rate（provisional） Unit: Bq/sec

	Cs-134	Cs-137	Total
Unit 1	7.0E+2	7.0E+2	1.4E+3
Unit 2	7.0E+4	7.0E+4	1.4E+5
Unit 3	7.0E+4	7.0E+4	1.4E+5
Total	1.4E+5	1.4E+5	2.8E+5

3. Result of the calculation by units

3－1. Dose at evaluation point (South of the site periphery) under safety audit

(1) External whole-body exposure dose (effective dose) by radioactive cloud

Unit：mSv/y

	Cs-134	Cs-137	Total
Unit 1	3.7E-7	3.7E-7	7.4E-7
Unit 2	4.1E-5	4.1E-5	8.2E-5
Unit 3	4.7E-5	4.7E-5	9.4E-5
Total	8.9E-5	8.9E-5	1.8E-4

(2) External whole-body exposure dose (effective dose) by radioactive material settling at ground surface

Unit：mSv/y

	Cs-134	Cs-137	Total
Unit 1	4.6E-3	1.8E-3	6.4E-3
Unit 2	5.2E-1	2.0E-1	7.3E-1
Unit 3	6.2E-1	2.4E-1	8.6E-1
Total	1.1E+0	4.5E-1	1.6E+0

(3) Internal exposure dose (committed effective dose) by inhalation and intake

Unit：mSv/y

	Cs-134	Cs-137	Total
Unit 1	1.0E-4	1.9E-4	2.9E-4
Unit 2	1.1E-2	2.2E-2	3.4E-2
Unit 3	1.4E-2	2.6E-2	4.0E-2
Total	2.5E-2	4.9E-2	7.4E-2

(4)Total dose（Effective dose） Unit：mSv/y

	Cs-134	Cs-137	Total
Unit 1	4.7E-3	2.0E-3	6.7E-3
Unit 2	5.4E-1	2.2E-1	7.6E-1
Unit 3	6.4E-1	2.7E-1	9.0E-1
Total	1.2E+0	4.9E-1	1.7E+0

3－2. Exposure dose at each point

We calculated annual exposure dose at each of the points at 5km～30km

Unit：mSv/y

	Site periphery*2	5km	10km	15km	20km*3	30km*3
North	－(approx.1.9km)	2.6E-1	9.1E-2	5.1E-2	3.2E-2	1.8E-2
Northwest	－(approx. 0.9km)	5.2E-2	1.8E-2	1.0E-2	6.5E-3	3.6E-3
West	－(approx. 1.2km)	3.5E-2	1.7E-2	9.8E-3	6.2E-3	3.4E-3
Southwest	－(approx.1.0km)	3.8E-2	1.3E-2	7.3E-3	4.6E-3	2.6E-3
South*1	1.7E+0(approx.1.3km)	1.6E-1	5.4E-2	3.0E-2	1.9E-2	1.1E-2

*1：Direction of which recorded highest at site periphery under safety audit
*2：Brackets show the distance the reactor
*3：We derived the result for 20km～30km, by using 5km～15km, site periphery results.