＜ Reference ＞

November 19, 2011

Tokyo Electric Power Company

Fukushima Daiichi Nuclear Power Station Radiation Monitoring at the site

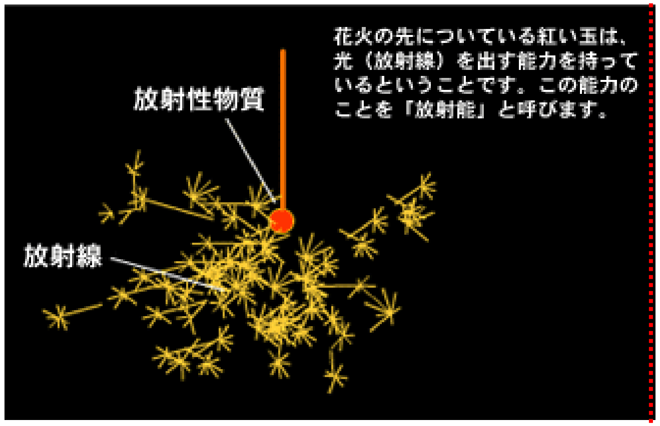
～measuring method～

Radiation and Radioactivity

- radiation：particle beam or electromagnetic ray released from radiological unstable atom which become stable.
- radioactivity：capability to release radiation.（radioactive material ）

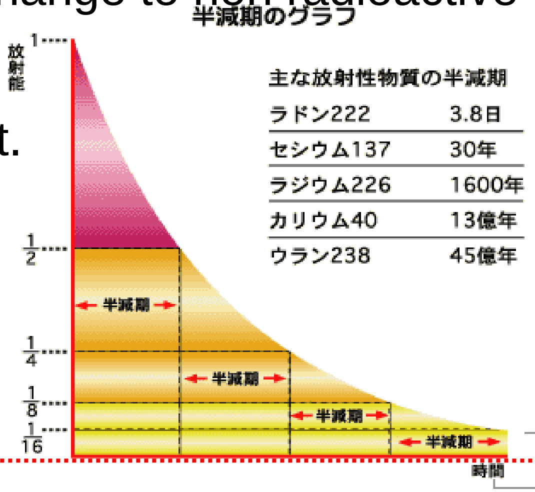
  example: sparkling firework

  - out coming fireworks ＝radiation
  - fireball at the tip of fireworks＝radioactive material
  - capacity to release fireworks＝radioactivity



花火の先についている紅い玉は、光（放射線）を出す能力を持っているということです。この能力のことを「放射能」と呼びます。

- radioactive material breakdown： radioactive material change to non radioactive material releasing radiation.
- half-life：the term until radioactivity become half amount.

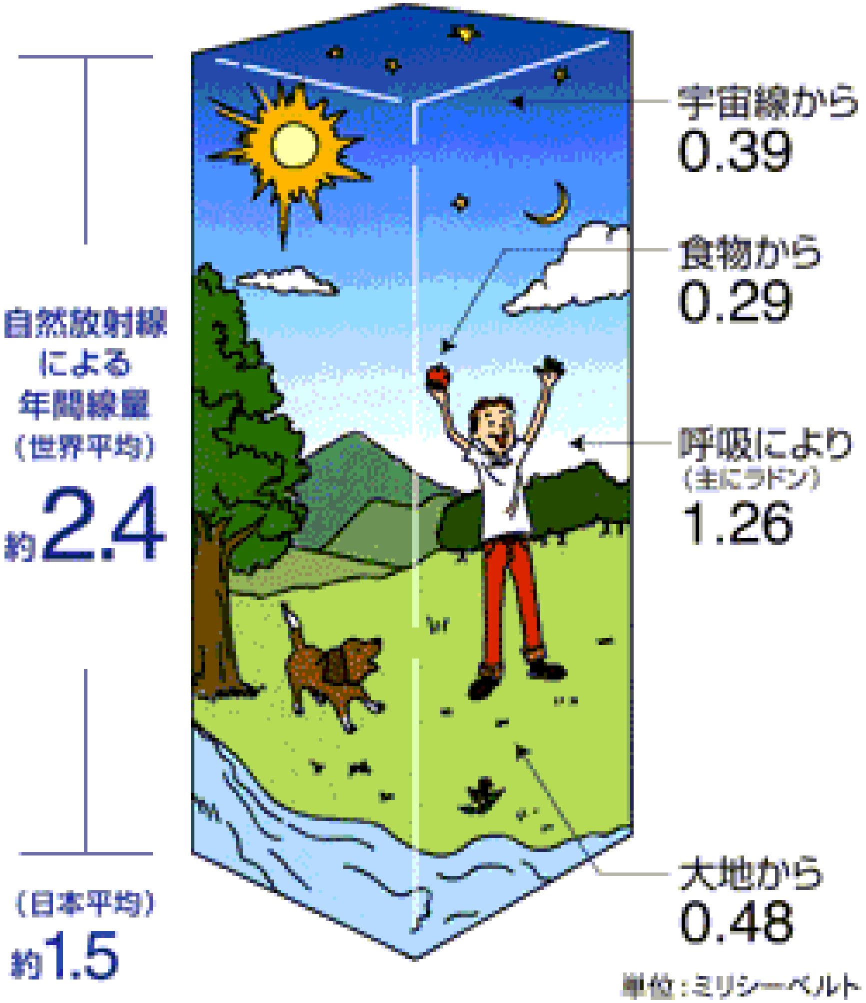


主な放射性物質の半減期

ラドン222	3.8日
セシウム137	30年
ラジウム226	1600年
カリウム40	13億年
ウラン238	45億年

Radiation around Us （1）

There is natural radiation around us. We usually take in it through a food and a breath. For example, 60 kg weighted japanese have 4,000 Bq of potassium 40

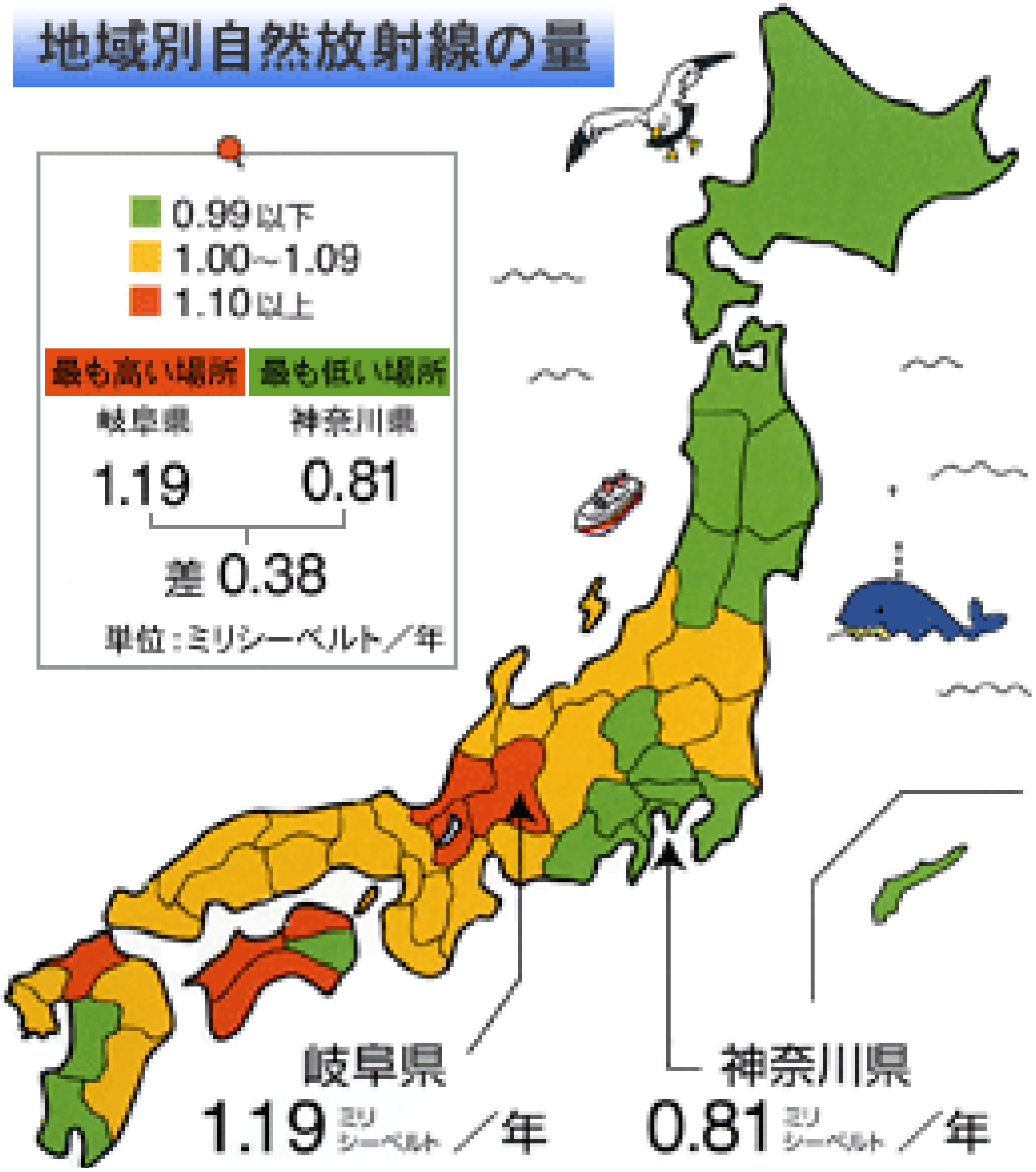


出典：当社資料

Radiation around Us （2）

Radiation from the space and the land depends on the area.

For example, radiation amount increase around granitoid area. Kanto area covered by kanto loamy layer have less radiation than kansai area. We receive 10mSv per year from the land at Guarapari in Brazil.

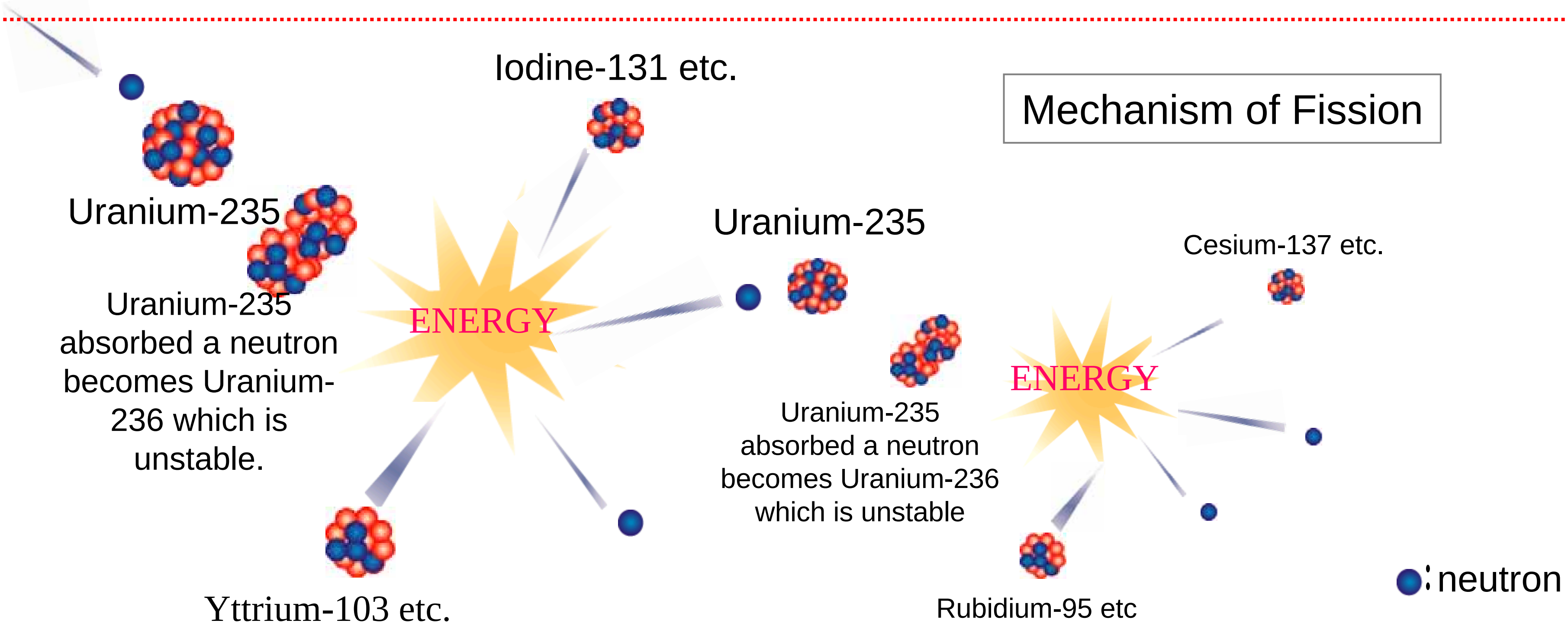


出典：当社資料

Mechanism of Radioactive Nuclides and Fission

The followings are the list of radioactive nuclides which come from the fission of uranium-235 and should be controlled at power plants.

iodine (I), cesium(Cs) :Important nuclides to control the exposure of gamma ray
Strontium (Sr), tritium (T) :Important nuclides to control the exposure of beta ray
Plutonium (Pu), americium (Am), curium (Cm): alpha nuclides which are derived from nuclear tests and accidents
Xenon (Xe), krypton (Kr): rare gas, Important nuclides to control the criticality



Mechanism of Fission

Uranium-235

Uranium-235 absorbed a neutron becomes Uranium-236 which is unstable.

ENERGY

Iodine-131 etc.

Yttrium-103 etc.

Uranium-235

Uranium-235 absorbed a neutron becomes Uranium-236 which is unstable

ENERGY

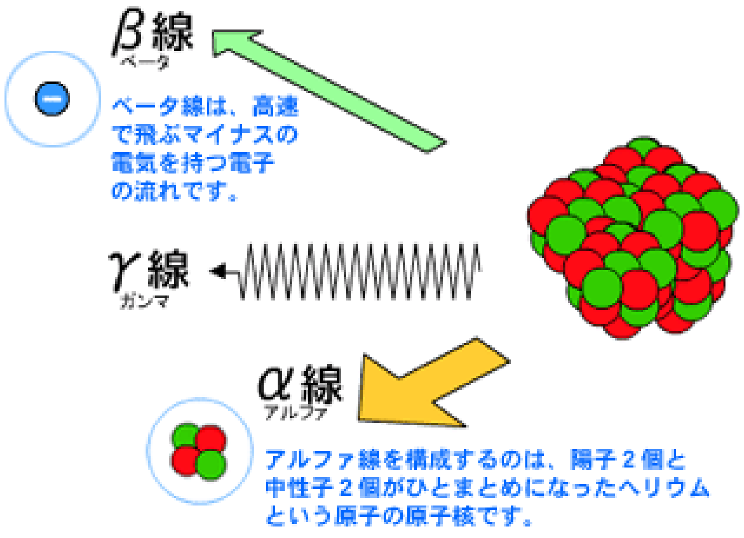
Cesium-137 etc.

Rubidium-95 etc

●: neutron

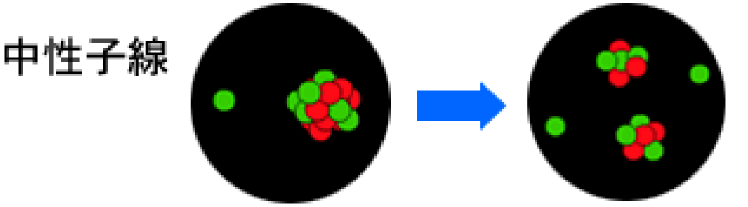
①Transuranic nuclides such as plutonium (Pu), americium (Am), curium (Cm), etc. are produced by uranium-238 which absorbs a neutron, increases the mass number, and then undergoes beta decay.
②Tritium is produced by deuterium in the water which absorbs a neutron.

Type and Characteristic of Radiation



ベータ線は、高速で飛ぶマイナスの電気を持つ電子の流れです。

アルファ線を構成するのは、陽子２個と中性子２個がひとまとめになったヘリウムという原子の原子核です。



ウランは外から中性子が当たると核分裂します。

このとき中性子が 2-3 個外へ飛び出していきますが、この中性子の流れが中性子線の正体なのです。

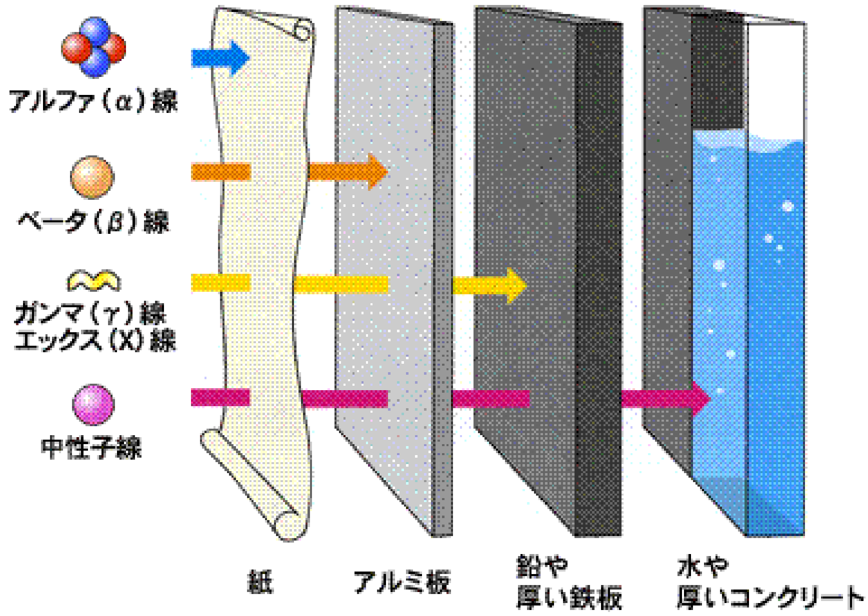


Table. Range of alpha particle and beta particle in the air(*)
(A case of 2MeV particle)

	エネルギー（MeV）	飛程（m）
α粒子	2	0.01
β粒子	2	8.5

Source: Alpha particle(Isotope Techo)
Beta particle(Nuclear Reactor Engineering 3rd Edition）

* Range；The distance to the point where the charged particle has lost all its kinetic energy.
(Gamma ray and neutron don’t carry electric charge. Therefore they decay by scattering instead of the distance.

Unit of Radiation and Radioactivity

ﾍﾞｸﾚﾙ Bq

放射能の強さ

放射性物質のもつ放射線を出す能力を表すもので、１秒間に壊変する原子の数で強さを表します。

Bq/cm^2＝床や物品の表面に付着している放射性物質の放射能の強さを表します

Bq/cm^3＝空気中や水中に含まれる放射性物質の放射能の強さを表します

ｼｰﾍﾞﾙﾄ Sv

人が受けた放射線の量（線量）

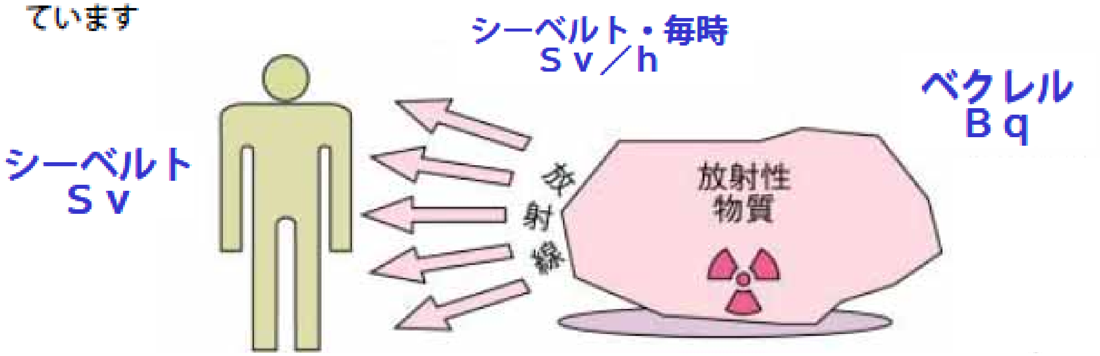
放射線が人体に与える影響の度合いを表す単位です。

この単位は大きいので通常は、１０００分の１のミリシーベルト・毎時（ｍＳｖ/ｈ）が使用されています

ｼｰﾍﾞﾙﾄ毎時 Sv/h

１時間当たりに受ける放射線の量（線量当量率）

この単位は大きいので通常は、１０００分の１のミリシーベルト・毎時（ｍＳｖ/ｈ）が使用されています



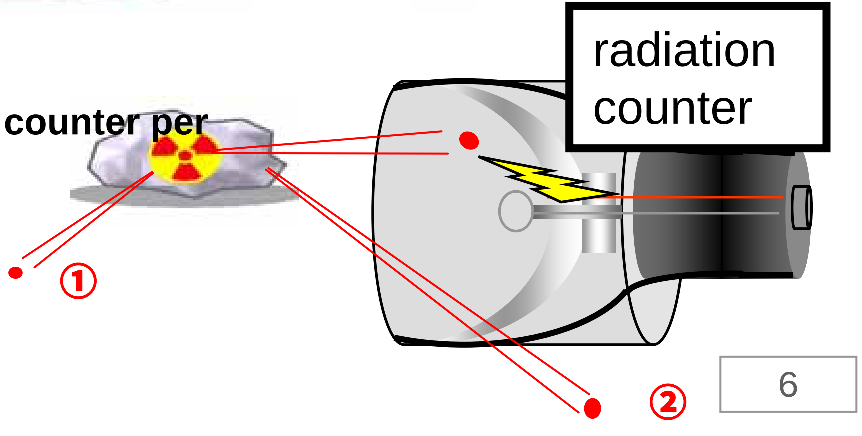
cpm（counts per minute）

= The number of radiations that are detected by radiation counter per unit time.

※Radiation counter doesn’t detect following radiations.

①which isn’t incident to the counter.

②which is incident to it but undetected.



Cpm and μSv/h

1. Conversion from cpm to Bq/cm^2

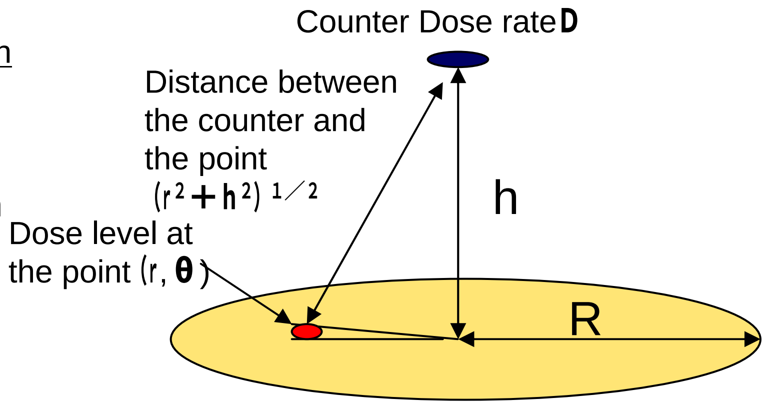
Usage of standard radiation source of which we have already known the radioactivitya(Bq/cm^2)

-Measure the counting rate X (cpm) by counter

-Compare a with X and calculate the conversion factor f (Bq/cm^2/ cpm) ｆ=a/X

2. Estimation of μSv/h from Bq/cm^2

-Conversion from Bq/cm2 to μSv/h varies from the condition of the expansion and distance of nuclide and radioactivity. However it is possible to calculate it by supposition.



Example) In the case that radioactive materials are distributed with uniformity.

a :Contamination density of radioactivity (Bq/m^2)

c :Constant of dose equivalent rate of radiation source (μSv･m^2/Bq･h)

Radiation source intensity of point (r, θ): a*dr*rdθ

Dose rate at the point(r, θ)

dD=c*a*dr*rdθ/(r^2+h^2)=c*a*r/(r^2+h^2)*dr*dθ

[r:0→R, θ：0→2θ]

Dose rate from counter(μSv/h)

D=π*c*a*ln{1+(R/h)^2}
D=π*c*X* f*ln{1+(R/h)^2}

In the case of Cs-137、contamination radius(40cm), Distance(1m):
13,000cpm=approx. 0.04μSv/h

Principle of Radiation Measurement

Radiation gives its energy to atoms which is located around the path. The followings are the typical effects:

①Ionization effect

Effect that changes gases to particles with positive or negative electrical charge.

(Examples) ionization chamber type survey meter, GM type survey meter

②Scintillation effect

Effect that materials such as sodium iodide emit light in response to the amount of radiation struck.

(Example) Scintillation survey meter

③Photoelectric effect

Effect that materials such as germanium emit photoelectron in response to the amount and energy of radiation struck.

(Example)Ge semiconductor detector, personal electronic dosimeter

④Mutual effect

Effect that materials emit alpha ray when neutrino hit it.

(Example)Rem counter

電離箱式サーベイメータ

GM管式サーベイメータ

シンチレーション式
サーベイメータ

レムカウンター
（中性子線測定器）

Actual Use of Meters　<Surface Contamination density Meter>

■ Radiation Meter for contamination measurement (GM Survey Meter)

- Measurement of surface contamination density
- Usage of GM counter (measurement range:0〜100kcpm)
- Frequency of calibration: Once/6 months
- Method of calibration：Calibrate by the proportion between beta ray emitted from standard radiation source(Co-60)and GM cpm

■ Radiation Meter for contamination measurement (Gate Monitor)

- Measurement of body surface contamination density
- Usage of 17 Plastic scintillation detectors
- Frequency of calibration: Once/6 months
- Method of calibration：Calibrate by the proportion between beta ray emitted from standard radiation source(Co-60)and GM cpm

Measures actually being used < measurement of air dose rate>

Ionization chamber type survey meter

- Used for γ ray measurement
- Simple structure
- Broad measurement range
- Uses "Ionization" within reciprocal action with radiation materials
- Measurement of dose equivalent rate within managed area
- Frequency of calibration: once a year
- Method of calibration: calibrated by γ ray dose equivalent rate, which is radiated from radiation measurement calibrator (Cs-137)

Rem counter (Neutron measurer)

- Used at works such as within PCVs, where there may be neutrons
- Neutrons have no electric charge, and has no direct ability to ionization
  →Measurement of neutrons are done by a combination of materials which are inclined to reciprocally act with neutrons, and detectors which detects secondary charged particles
- Uses 3He proportional counter as a detector
- Frequency of calibration: once a year (carried out at specialized institutes)
- Method of calibration: calibrated by neutron dose rate, which is radiated from radiation measurement calibrator (Am-Be)

Measures actually being used <measurement of individual exposure dose>

■ External exposure evaluation measure

[Electronic individual dose meter (γ・β APD)]

- For evaluation of external exposure
- Use of Si semi conductor detector
- Has high sensitivity, and easy to read accumulated dose (Range of measure (γ) ：0.01 ～999.9 mSv, (β)： 0.1 ～ 999.9mSv)
- Frequency of calibration: once every 6 months (β calibration is carried out at specialized institutes)
- Method of calibration: calibrated by γ(β) dose equivalent rate, which is radiated from radiation measurement calibrator (Cs-137(γ)、 ^{90}Sr-^{90}Y(β)) (carried out at specialized institutes)

■ Internal exposure evaluation measure (Whole body counter)

- For evaluation of internal exposure
- Use of plastic scintillation detector
- In case of nuclide analysis, Na I scintillator or germanium semi conductor detector is used
- Frequency of calibration: once a year
- Method of calibration: calibrate from ratio of the radioactivity amount (Bq) of phantom radiation source (Cs-137、Co-60), and number of counter (cpm) from the detector

Measures actually being used <measurement of individual exposure dose>

External exposure evaluation measure

[Electronic individual dose meter (glass patch)]

- For evaluation of external exposure
- Use fluorescent effect
- Measure one month accumulated dose (by specialized reading apparatus)

（Range of measure (γ) ：0.1 ～10000 mSv, (β)： 0.1 ～ 10000mSv ）

- Frequency of calibration: Subject to JIS, carried out at specialized institutes.
- Method of calibration: calibrated by γ (β) dose equivalent rate, which is radiated from radiation measurement calibrator (Cs-137(γ)、 ^{90}Sr-^{90}Y(β)) (carried out at specialized institutes)

External exposure evaluation measure

[For beta ray glass ring]

- Range of measure 0.1mSv～1Sv
- Measure one month accumulated dose (by specialized reading apparatus)
- Measure 70 μ m dose equivalent
- Beta ray exposure management on works such as works related to water
- Frequency of calibration: Subject to JIS, carried out at specialized institutes.
- Method of calibration: calibrated by β dose equivalent rate, which is radiated from radiation measurement calibrator (^{90}Sr-^{90}Y)(carried out at specialized institutes)

Alpha nuclide measurement (Plutonium)

External specialized institutes

	(Duration)
Transfer of sample	1day
Prior treatment **Separation and refinement of plutonium**	4days
Incineration at electro furnace⇒heat ⇒filtration⇒liquid concentration⇒boil⇒cool⇒filtration⇒elution by ion exchange⇒evapolation solidification⇒heat/melt⇒electrodeposition⇒bake	
Measure **Alpha ray spectrometry**	1day (22h)
Evaluation of the result	1day
Evaluation and confirmation of the result	1day

As alpha ray has low ability of material penetration, it is necessary to;

- remove impurities within sample, and create highly thin sample (to limit self absorption within the sample)
- measure within vacuum containers (to prevent absorption in air)
- make the detector window as thin as possible, or not make it

Low background α・β ray measurer

Due to amount of samples/data on the waiting list for measurement and final confirmation, the actual duration is longer than as stated above.

Beta nuclide measurement (Strontium)

t1

External specialized institutes

（duration）

Transfer of sample — **1day**

Prior treatment (1)

Separation and refinement of strontium — **4days**

Incineration at electro furnace⇒heat ⇒filtration⇒liquid concentration⇒boil⇒cool⇒filtration⇒elution by ion exchange⇒evapolation solidification⇒heat/melt⇒electrodeposition⇒bake

Prior treatment (2)

Y-90 milking — **7days**

Measure

Gamma ray spectrometry — **1day**

Evaluation of the result — **1day**

Evaluation and confirmation of the result — **1day**

- As beta ray has a continuous spectrum, it is difficult to identify and measure each sample which has several nuclides that dispatched beta ray. Therefore, similar to the alpha ray, decrease of ability to disintegrate by self absorption and external absorption, is to be taken care.
- For nuclides such as tritium, which dispatched low energy of beta ray, prior treatment id needed as liquid scintillation counter need to be used.

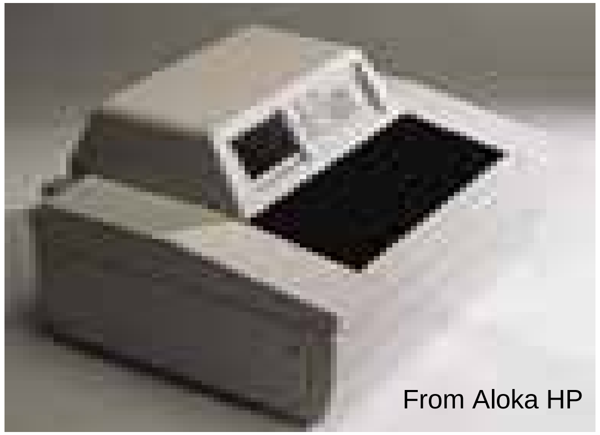
Low background α・β ray measurer

Due to amount of samples/data on the waiting list for measurement and final confirmation, the actual duration is longer than as stated above.

Beta nuclide measurement (Tritium)

	(duration)
Transfer of sample	1day
Prior treatment (1) **distillation**	2days
Prior treatment (2) **After removed into a low-potash-glass vial bottle,** **Liquid scintillator (9mL) added.**	1day
Measurement **Liquid scintillation measurer**	1day
Evaluation of the result	1day
Evaluation and confirmation of the result	1day

- As beta ray has a continuous spectrum, it is difficult to identify and measure each sample which has several nuclides that dispatched beta ray. Therefore, similar to the alpha ray, decrease of ability to disintegrate by self absorption and external absorption, is to be taken care.
- For nuclides such as tritium, which dispatched low energy of beta ray, prior treatment id needed as liquid scintillation counter need to be used.



From Aloka HP

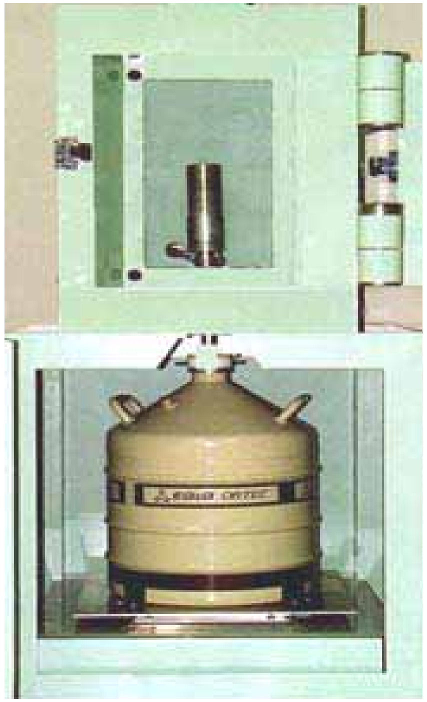
liquid scintillation counter

Due to amount of samples/data on the waiting list for measurement and final confirmation, the actual duration is longer than as stated above.

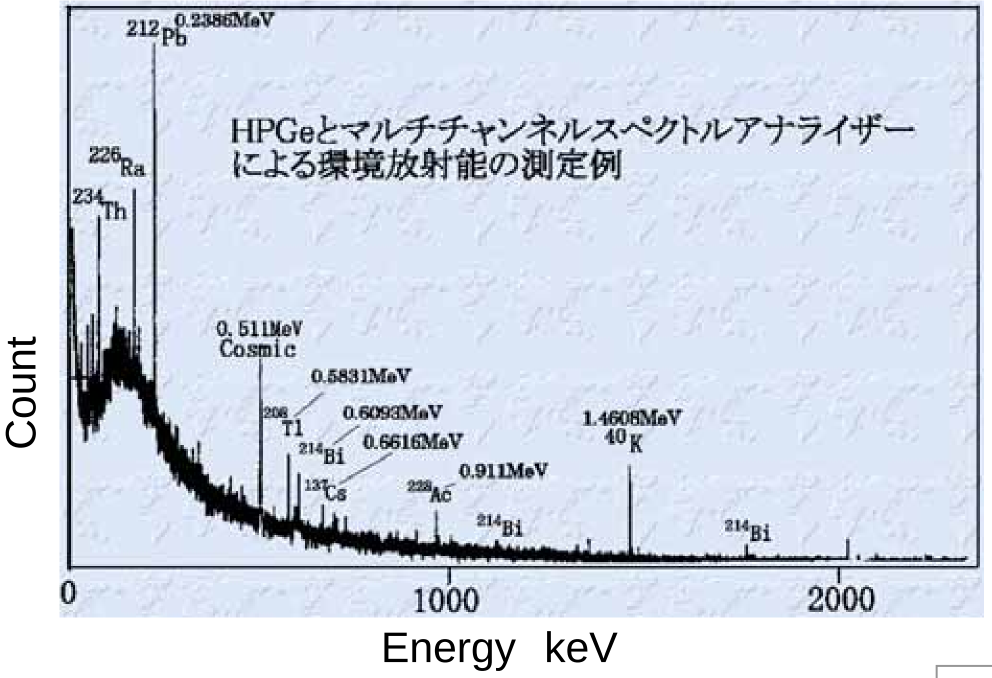
Gamma ray measurement

t2

- With γ ray, it is possible to identify radioactivity of each nuclide by monitoring energy measurements, as energy dispatched from each nuclides differs.
- As gamma ray measure has the following merits, it is / can be used in broader applications.
  - Many nuclides dispatches gamma ray
  - Gamma ray has high penetration and low in self absorption.
  - Treatment on sample before chemical analysis is not needed.



Germanium (Ge) semi conductor detector



Summary

As stated herein, monitoring order of radioactive material is organized, and the working environment of the site is appropriately observed.

Air dose rate at working sites and the amount of radioactive material in dust is especially being properly taken care, and by carefully managing individual exposure dose, we are working on the safety of workers.

Also, surface of humans and materials (including vehicles, etc) are being surveyed, and we are monitoring and taking care of radioactive materials from being taken outside the site.

By carefully implementing these measures, we would like to continuously proceed our work at site to stabilizing the situation.