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Spectrum estimation of low-energy X-rays radiated from Crookes tube using Peltie type cloud chamber

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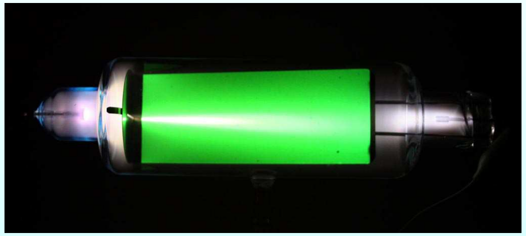
How to Establish Safty Management for Crookes tube?

Crookes tube has been used in junior-high science classes in Japan, and the primary purpose is to teach the characteristics of electrons and current, not for radiological education. Therefore, some teachers are not recognizing the radiation of X-ray from Crookes tube, and most of them have no information of the dose. However, it is possible to expose high dose of X-ray to students using a Crookes tube, where Hp(0.07) reaches 200mSv/h at a distance of 15cm.

Some discharge tube that use hot cathode is operated with only several 100V, and even with cold cathode, some equipment can be operated at about 5kV. With this low voltage, radiated X-ray is shielded completely by the glass wall.



A Crookes tube operated by 5kV
(Horizon Co. VT-7010)

5kV CW high voltage unit
driven by 9V battery

Junior-high school in Japan have quite limited budget!

Basic Plan

By using low voltage type equipment, teachers never required to consider the radiation and students can observe electron beam very safely.

The problem is resolved completely!

Advanced Plan

1) Cannot replace legacy devices with economical reason
2) Advenced education program that utilize X-rays radiated from Crookes tube

Anyway, radiation safty guide line to limit X-rays dose is required.

Problems on Estimation of X-rays from Crookes Tube

Low Energy X-Rays (arround 20keV)

Not only conventional survey meters for public use, but also reliable NaI survey meters for general radiological management are useless for low energy X−rays from Crookes tube.
(below 50keV pulse is ignored by conventioal NaI surver meters)

Radiated in Sharp Pulse

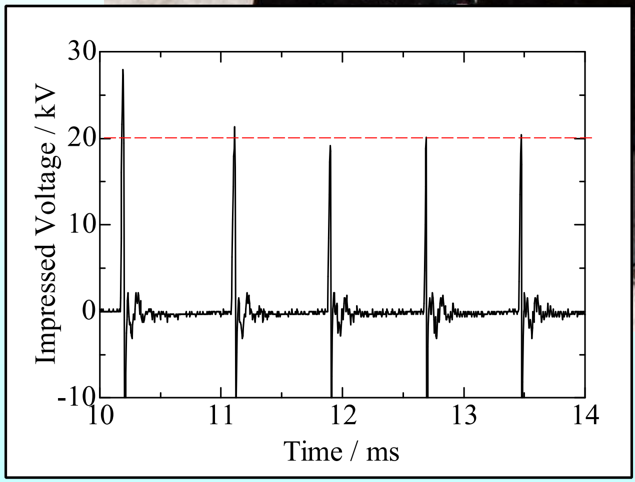
Even using detector with Be window for low energy X−rays measurement, radiation in sharp pulse give pile up and dose is estimated as very small value. Only ionization chamber that measure averaged current or solid detector that integrate the absorbed dose is useful.

Instability of Induction Coil and Applied Voltage

Induction coil generate high voltage pulse mechanically, that is affected by conditions such as temperature, and firing voltage between discharge electrodes is also affected by temperature or humidity. For systematic measurement, some physical parameter is required to compare results.

High Voltage Applied by a Induction Coil

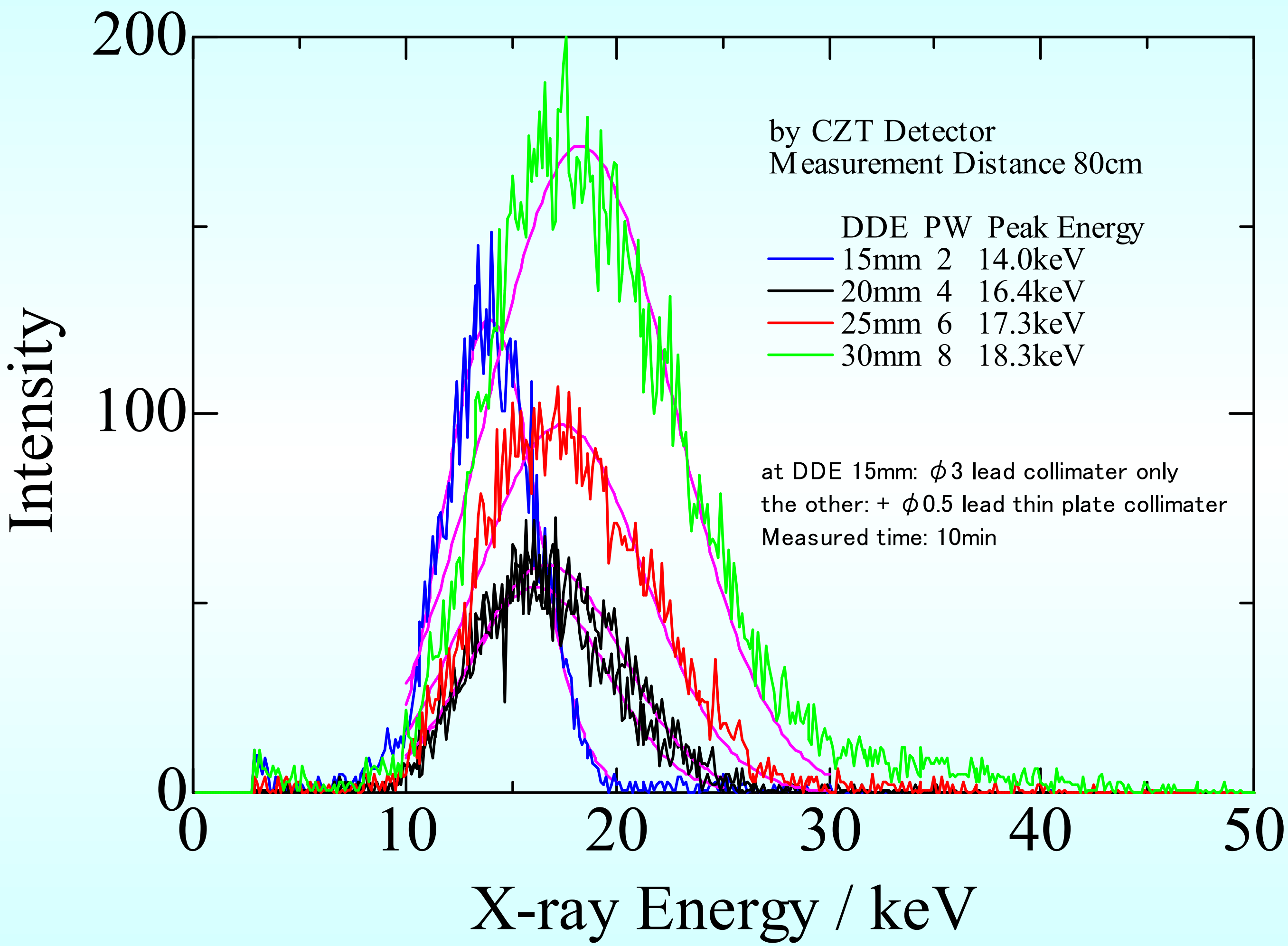
Output power dial changing the voltage impressed to the primary side of a transformer, and that control output voltage continuously.
Since the dielectric breakdown voltage in the air is about 1 mm for 1 kV, the distance of discharge electrodes can limit the maximum voltage. If the distance is settled to 20mm, the maximum voltage impressed to a Crookes tube was limited to 20keV, therefore it work as a safety device.



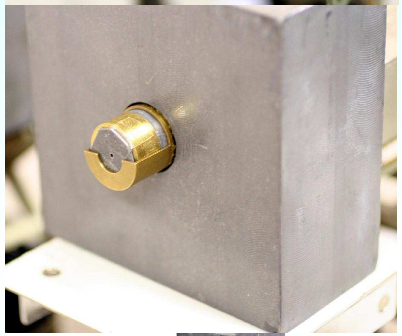
Distance of discharge electrodes 20mm,
Output power 4, Averaged current 80 μA

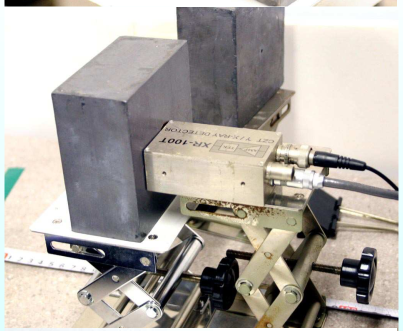
To measure high voltage pulse, voltage divider that use a large registor (< 100MΩ) and a small resister (about 100kΩ) is used to protect a oscilloscope.
In the most case, an induction coil is not connected to the ground. In such case, the electric potential is floating and must be used 2 divider and 2 probe to take difference between anode and cathode.

Spectrum Measurement by a CZT Detector



Amptek XR-100T-CZT
CZT(Cd0.9Zn0.1Te)
detector with Be window,
cooled by Peltier device





Collimaters
ϕ0.5 lead thin plate
ϕ1.0 lead thin plate
ϕ2 co-axial brass
ϕ3 co-axial lead

ϕ0.5mm lead collimater can reduce count rate to several cps that avoid pile up in the spectrum

Peltier-cooling-type High Performance Cloud Chamber

Web Site (Japanese)
http://bigbird.riast.osakafu-u.ac.jp
/~akiyoshi/Works/CloudChamber.htm

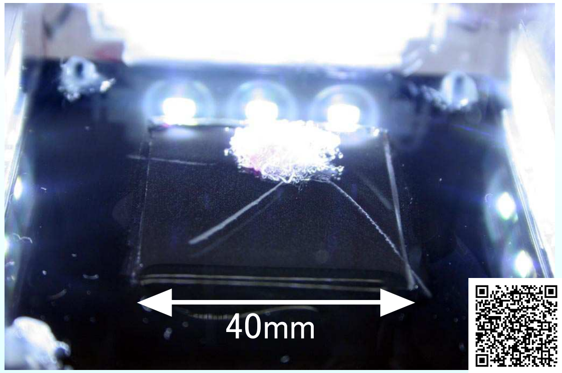
Features of this products

- Dry-ice Free!
- Clear track observation and Stable long time
(hole day operation with no support is abailable)
- Oservation of not only Alpha-rays tracks, but also Beta-rays tracks, and furthermore, photoelectron tracks by Gamma-rays or X-rays.

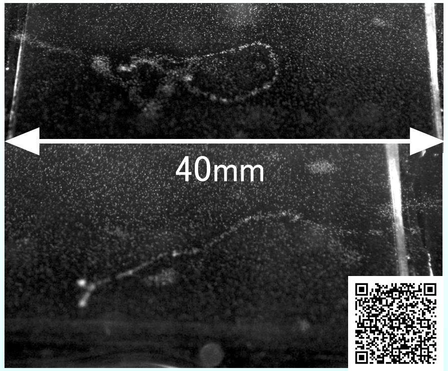
→ Intuitively radiological education of the difference in interaction with materials from a kind of radiation-rays

- Quite Cheap Price! Most parts are common consumer items.

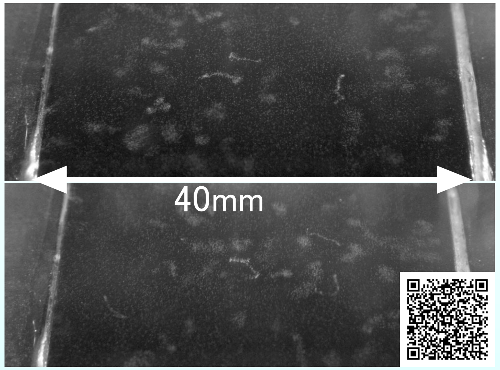
Observation of radiations using conventional cloud chambers were limited to only alpha-ray tracks and had many restrictions. While this Peltier-cooling-type high performance cloud chamber enable us to observe **very clear radiation tracks** in a few tens of seconds after a power supply even under a bad weather condition, of cause **without dry ices**. The technical features such as clearing assorted ions in air using HV-unit, high-intensity LED illuminations and the fabric of the chamber enable us to **observe beta-ray tracks**. Not only simple observation of alpha-ray tracks, but also compare with beta-rays track or a **delta-ray tracks arisen from gamma rays** enables us to perform far deep radiological education related to interactions of radiations and materials.



Alpha-rays



Beta-rays / Gamma-rays
(Photo electrons)



X-rays from Crookes Tube
(Photo electrons)

Main unit of standard type (SD)
Peltier-cooling cloud chamber.

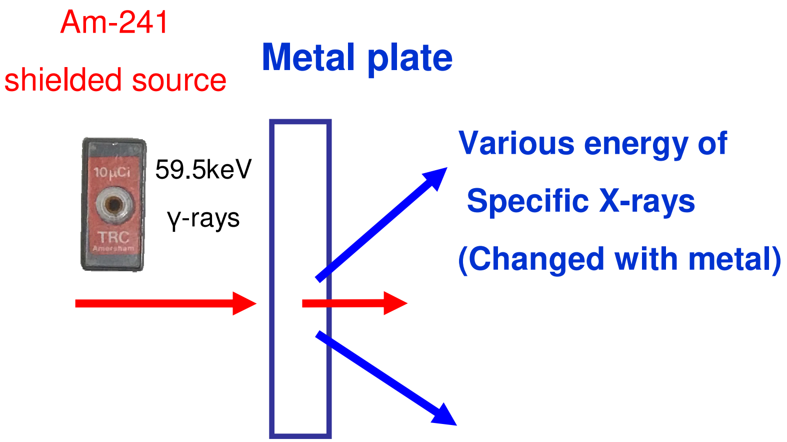
With the new EX-type, observation area is enlarged to 60mm x 60mm. Large cylindrical chamber enable multi-people observation, and very high efficiency enable observation of natural-radiation .

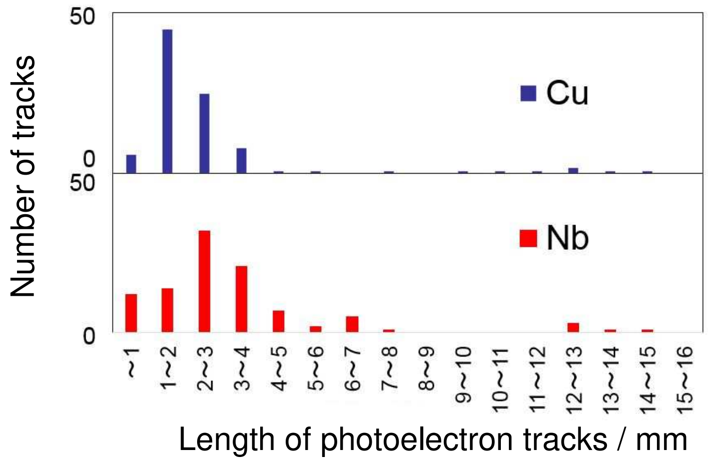
A Cockcroft high voltage unit supply up to 2kV tension. It sweep motley ions in air that achieve high efficiency and all weather operation.

You can watch radiation track movies using these QR code!

natural radiations

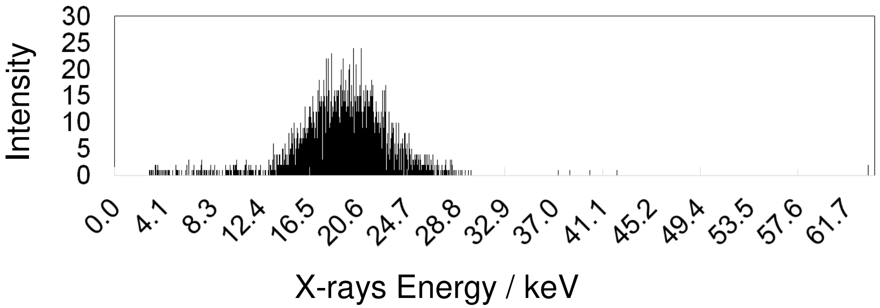
Measurement of photoelectron track length

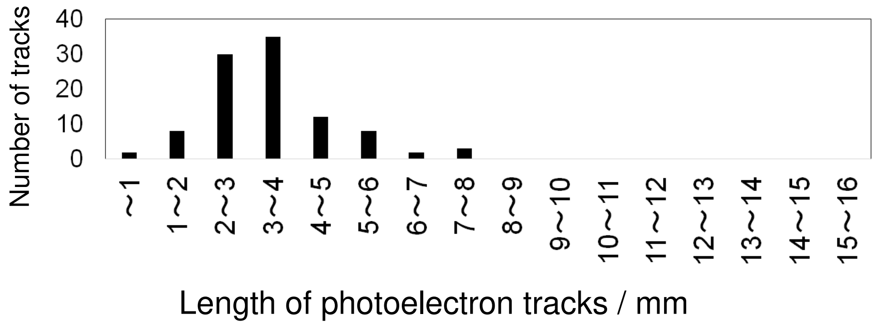


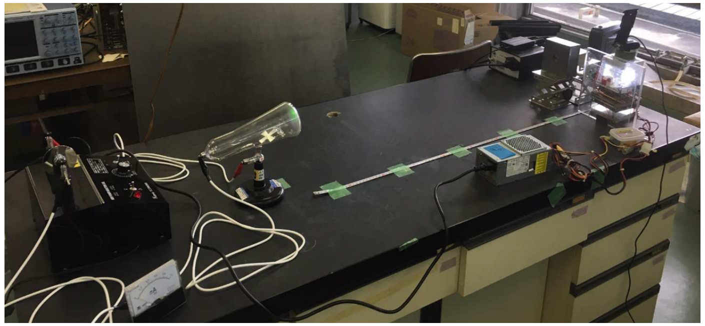


Cu K$_\alpha$8.0keV、Lenge of photoelectron **1.8mm**
Nb K$_\alpha$線 16.5keV Lenge of photoelectron **5.2mm**

Spectrum of X-rays from a Crookes tube







Very simple system enable energy estimation.
Further study using image analysis with AI is required for statistical enough counting.

Measurement at Real Education Field

Setting of induction coil were same as their usually.

Measurements of leaked X-rays from 37 Crookes tubes at junior-high school in Japan were performed using radiophotoluminescence dosimeters by science teachers.

The dosimeter were sticked on 2L PET bottle and put from distances of 15, 30, 50cm and irradiated during 10min for each. The radiophotoluminescence dosimeter was Glass Badge type FX (Chiyoda Technol) that can estimate effective energy and can estimate back ground radiation with Sn shielded element.

In the 37 Crookes tubes, Hp(0.07) with 10min exposure was;

25 tubes ＜ 50 μ Sv @ 1m (extrapolated)

18 tubes ＜ 50 μ Sv @ 15cm (detection limit)

One tube radiate 600 μ Sv in 10min at 1m with minimum output power.

The tube showed intermittent beam and lookes current was small.

Minimum power、at a distance of 30cm

DDE 30mm: 2mSv/h
DDE 50mm: 30mSv/h

→

DDE 20mm: 40 μ Sv/h

at 1m、10min radiation gives only 0.6 μ Sv exposure

To Reduce the Dose from Crookes tube

First of all

Replace to low voltage equipment

10,000 Junior-High School × 400USD / ea. = 4Million USD is required in Japan
But Crookes tube is used at just a 1 lecture in 3 year.

Inherent Safety
No concern is required

With Economic Factor, Safety Guideline for Conventional Crookes tube is Required

1) Applied Voltage
2) Beam Current

Reduce Radiated X-rays

3) Diatance
4) Shielding
5) Time

Radiation Protection Three Principles

Reduce applied voltage gives low transmission of X-rays to the glass wall drastically.
When we shielding, acrylic is not effective but thin glass is enough effective.
To take distane is most easy way to reduce dose.

Provisional Guideline with our study

Is it enough?
Substantiate study is required.

- **Set output power as low as possible**
- **Never remove discharge electrodes and set the distance smaller than 20mm**
- **Take distance as far as possible. For student, more than 1m is recommended.**
- **Keep the display time shorter than 10min.**

Problems on management of X-rays from Crookes tube

Dose Constraint for Education Field is not Discussed well

Dose limit for general public have been proposed by ICRP Pub1990/2007 as 1mSv/y, but it is for all additional exposure. ICRP Pub 36 is the only instance for the teaching of science (in effective dose equivalent, 0.5mSv/y and 0.05mSv for each class).

Definition of X-ray Device is not Clear

In Japanese domestic low, \`X-ray device' is not defined strictly. There is no exemption level that gives a confusion to safety management of X-rays in many fields.

IAEA GSR Part gives exemption level as; in normal operating conditions cause an ambient dose equivalent rate or a directional dose equivalent rate, as appropriate, exceeding 1 ìSv/h at a distance of 0.1 m from any accessible surface of the equipment or the maximum energy of the radiation generated is no greater than 5 keV.

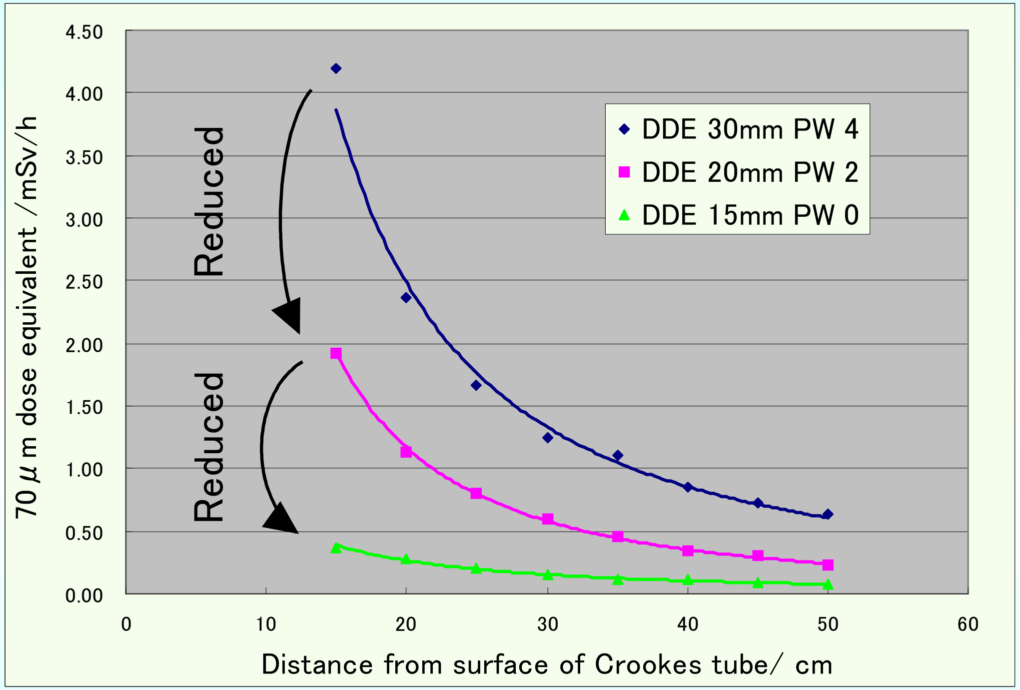
Difficult Estimation of Effective Dose

For 20keV X-rays, the half value layer is about 1cm in human body. The absorbance dose to tissues in body depends on its depth from the surface. The transmittance is changed with energy of X-ray drastically around this energy range and the X-rays have broad spectrum.

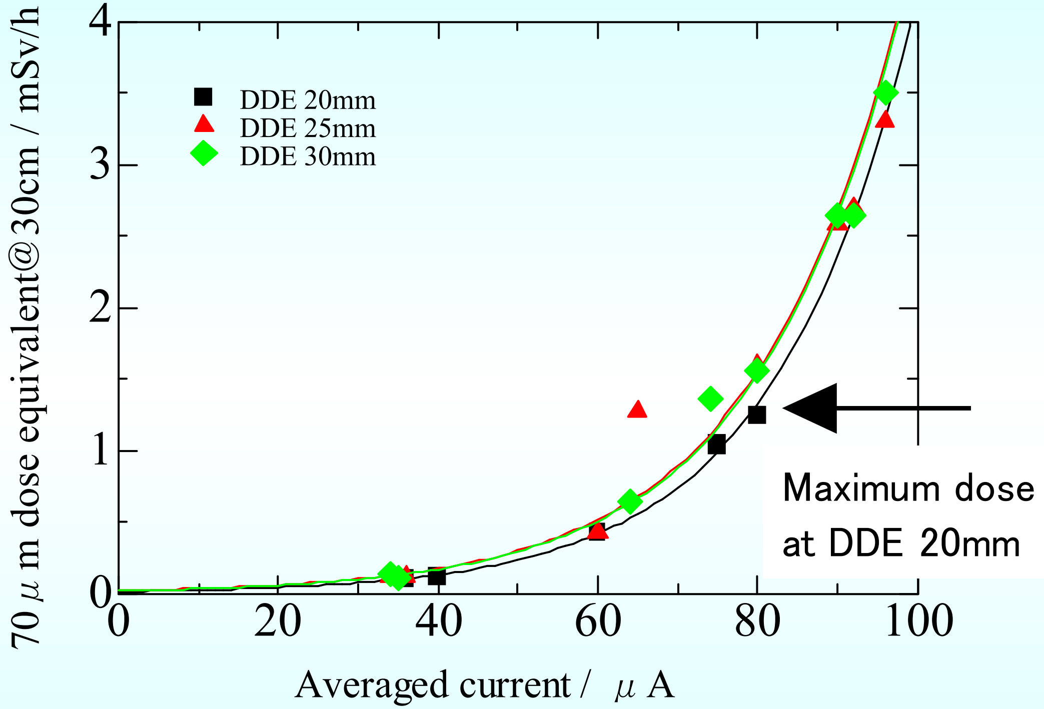
Further more, dose distribution in horizontal plane is not uniform. Therefore we cannot assume aligned and expanded radiation field, and we cannot use 1cm dose equivalent as approximation of effective dose.

Dose Control

Distance of discharge electrodes: 30, 20, 15mm
Output power was set to the just firing voltage.



Averaged current was changed with output power.
The averaged current was measured by simple analog current meter.



·Dose is reduced drastically with the voltage limitation

Distance of discharge electrodes must be shorter than 20mm

·Dose is changed with distance as the inverse square law

At a distance of 1m, dose is reduced to 1/100 from that of 10cm.

·Increasing current rising dose exponentially

The output power increase current and also voltage. The voltage changes the energy of X-rays that changes transmittance drastically. Therefore, output power must be kept as small as possible. Furthermore, discharge electrode act as a safety valve to limit the voltage.