TRANSMISSION PROPERTIES OF X-RAY RADIATED FROM CROOKES TUBE USED IN TEACHING OF SCIENCE

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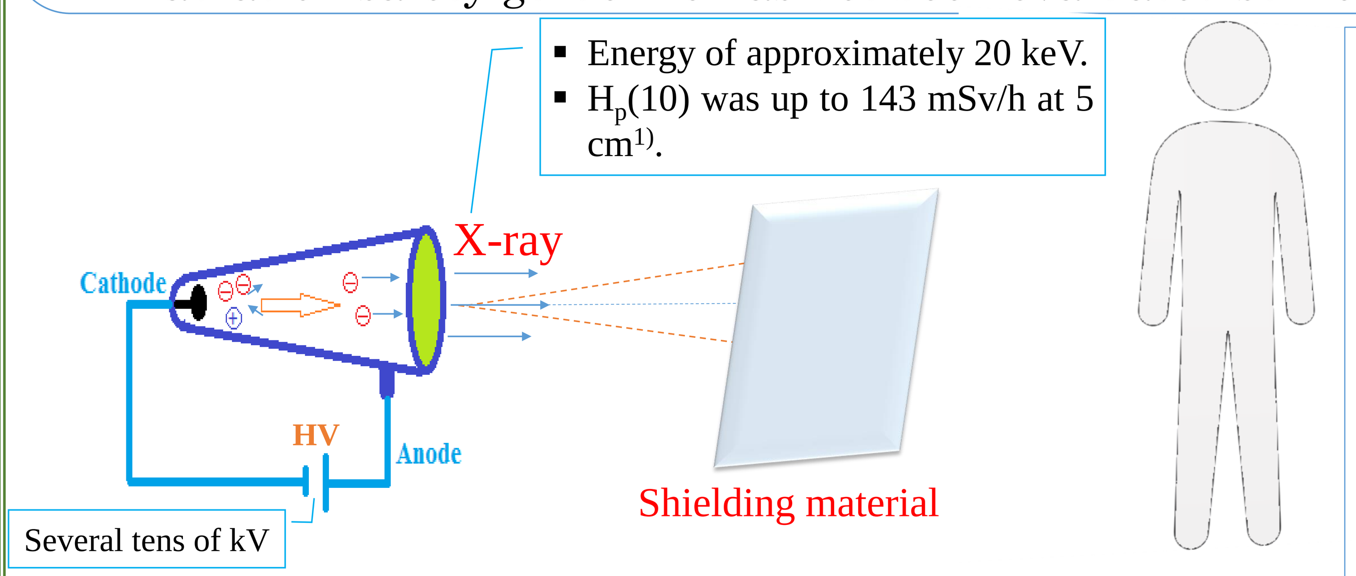
INTRODUCTION

BACKGROUND

- In Japan, a Crookes tube, as a discharge tube, has been used in junior-high science classes, and the primary purpose is to teach the characteristics of electrons and current.
- The X-rays emitted by the Crookes tube may cause exposure to teachers and participating students.
- A radiation safety guideline has not been evaluated sufficiently yet in Japan.



Shielding material:

- To attenuate radiation intensity significantly.
- **Transparent shielding** to observe the behavior of electron beam in a Crookes tube.

SCOPES OF THE RESEARCH

- Investigating the characteristics and properties of X-rays emitted by a Crookes tube used in educational sites.
- Estimating the transmittance of transparent shielding materials to assure radiation safety and demonstration observation.
- Submitting the results as the recommendation and guideline for radiation protection at junior-high school science class.

CORRELATION BETWEEN OUTPUT POWER AND EXPOSURE

Experimental settings:

- The applied voltage was regulated by change of output power, and discharge distance was set at 30 mm.
- The ambient dose equivalent H*(0.07) measured for 3 min at a distance 50 cm from the Crookes tube, and it was converted to a dose rate.

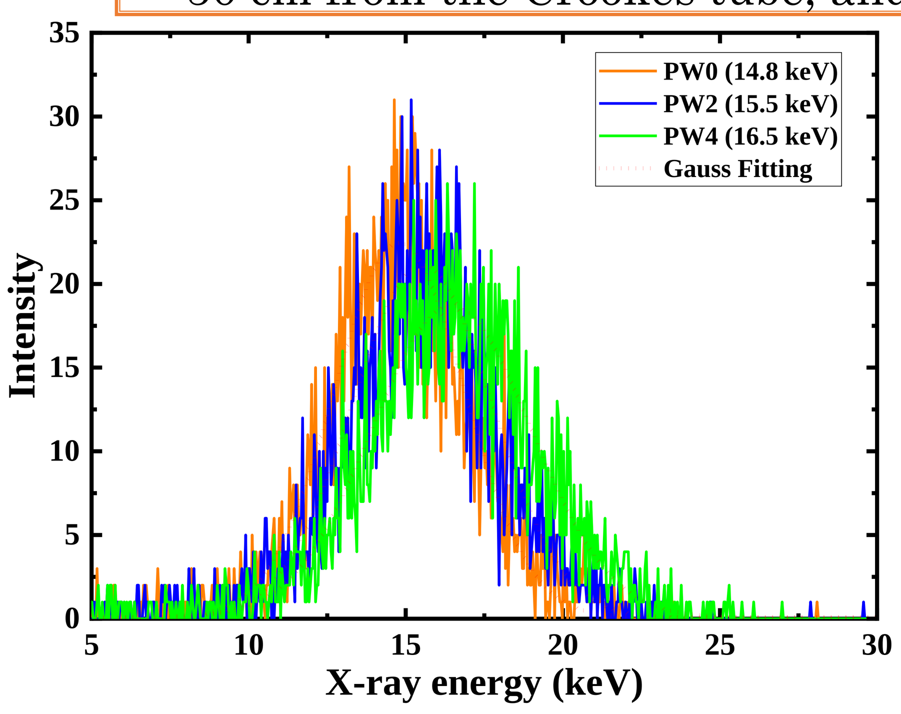


Figure 1. X-ray energy emitted by the Crookes tube acquired by a CZT detector. The energy peak shifted to a higher region of the spectrum as the output power increased.

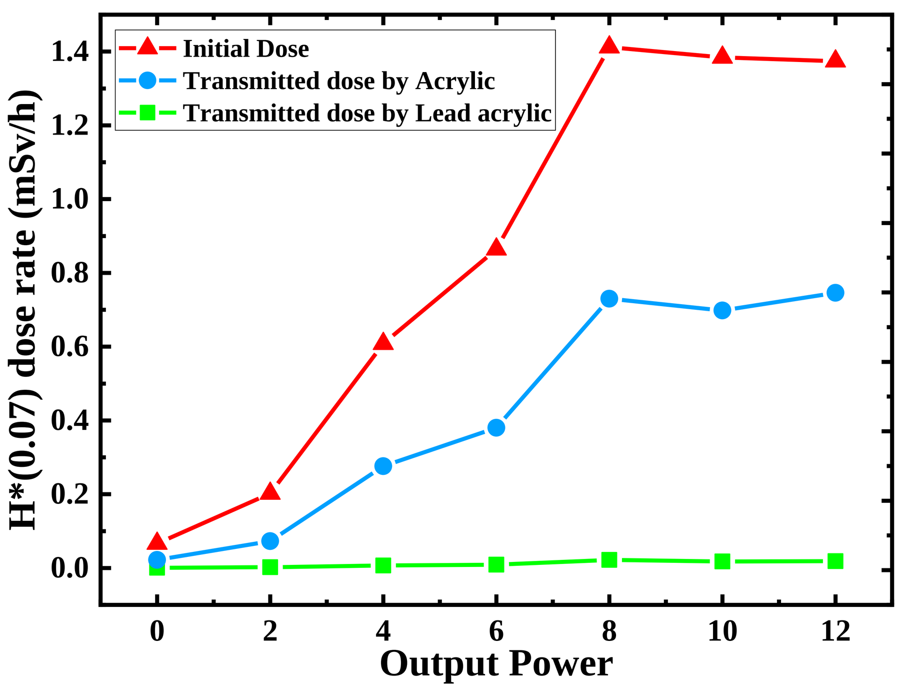


Figure 2. The relevant graphic of the transmitted dose of acrylic and lead acrylic vs. output power.

- ❑ The exposure increased with an increase in the output power, and it is stable from PW8 when a spark occurs. It means that the dose will change if the spark does not occur (Fig. 2.).

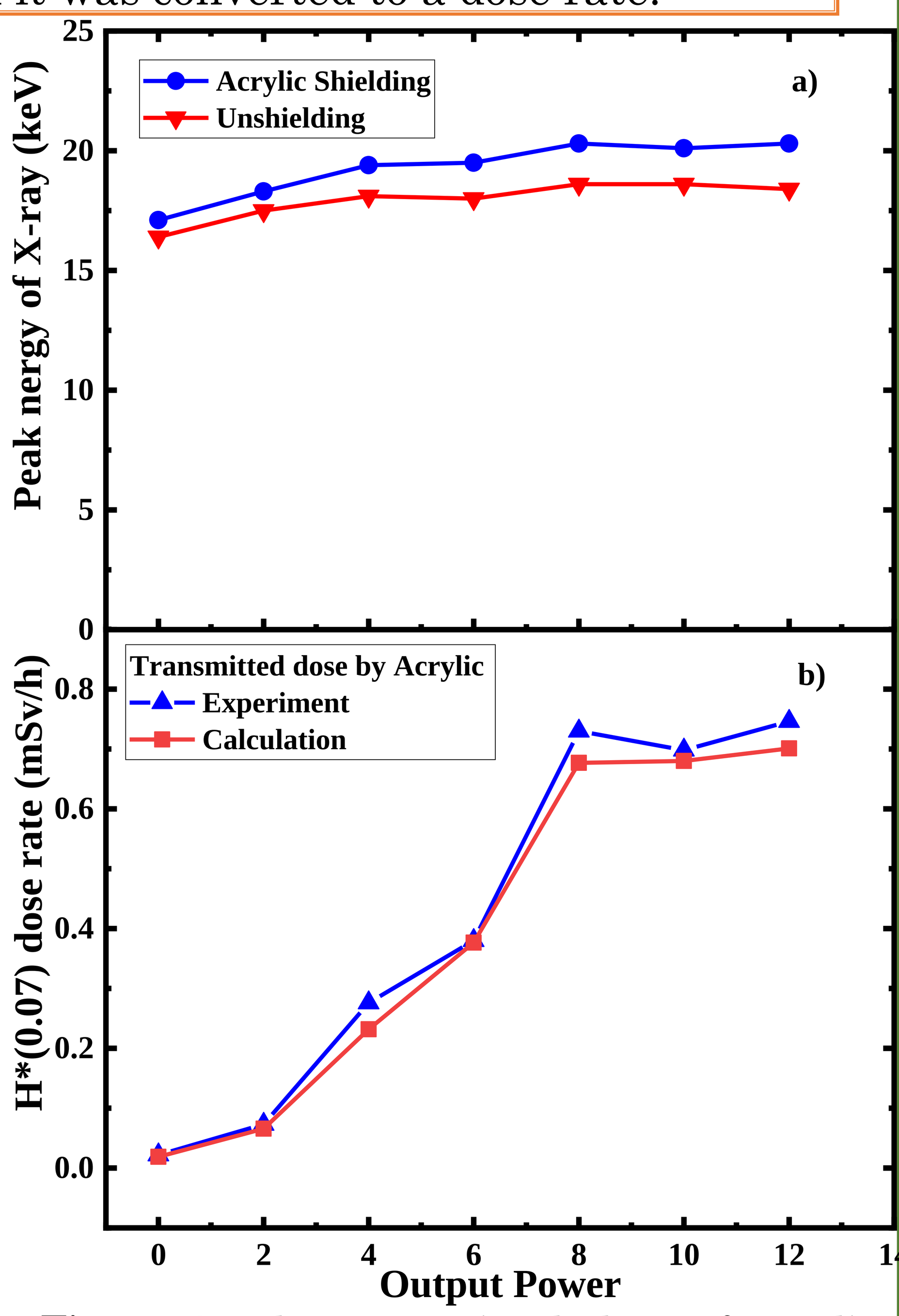


Figure 3. The transmitted dose of acrylic determined by experiment and calculation.

- ❑ The acrylic shielding caused hardening of X-rays owing to absorbing photons with lower energy. As a result, it produced a difference in the energy of X-rays, 7.5% (Fig. 3a).
- ❑ The calculation in Fig. 3b was determined by the equation of $I = I_0 e^{-\mu x}$ where the I_0 was the initial dose in Fig. 2. The linear attenuation coefficient μ of acrylic for each energy was interpolated using data from the National Institute of Standards and Technology (NIST, USA).

- ❑ The energy for the calculation was the peak energy of unshielded X-rays shown in Fig. 3a. The energy of X-rays has a broad distribution shown in Fig. 1, but the calculated results matched to the experiment very well.

Table 1. X-ray energy and its attenuation by materials with the change of the output power.

Output Power	Peak energy of X-ray (keV)	Initial dose* (μSv)	Transmitted dose* (μSv) Lead acrylic	Transmitted dose* (μSv) Acrylic
0	16.4	3.31	0.04	1.10
2	17.5	10.1	0.11	3.65
4	18.1	30.4	0.34	13.8
6	18.0	43.2	0.45	19.0
8	18.6	70.6	1.09	36.5
10	18.6	69.2	0.89	34.9
12	18.4	68.7	0.92	37.3

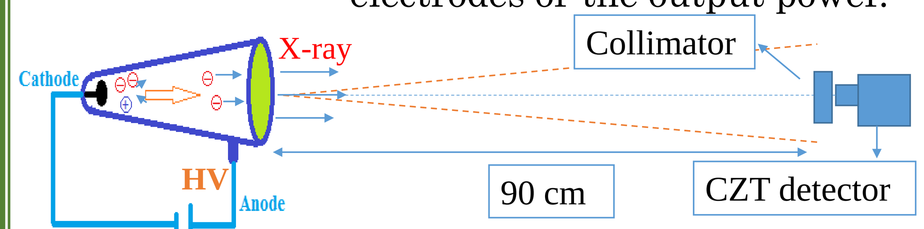
** The dose measured for 3 min at distance 50 cm from the Crookes tube.*

MATERIALS AND METHODS

X-RAY SPECTROMETER

Induction coil:

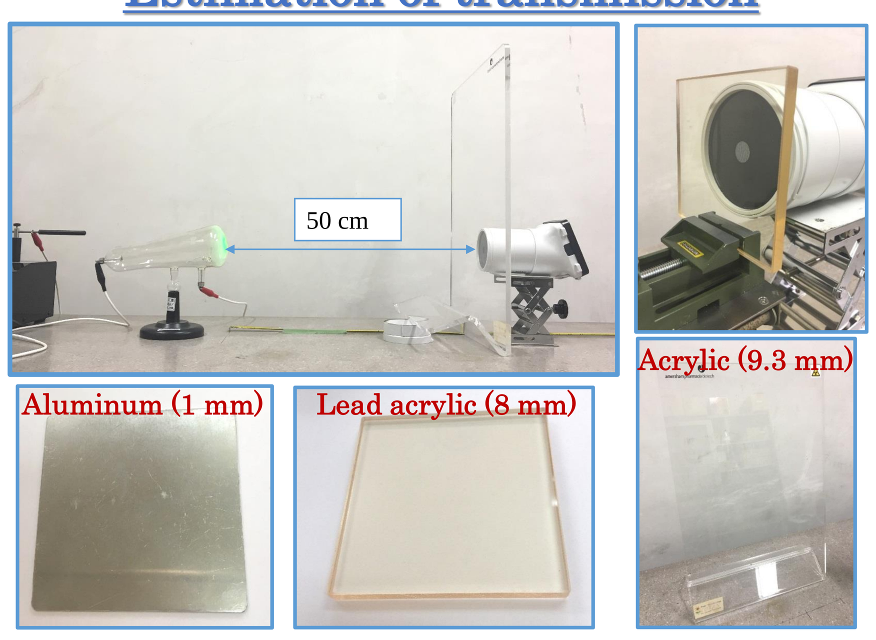
- * High voltage power supply, spark gap of 10 – 100 mm.
- * Nominal dielectric breakdown voltage in the air is approximately 1 kV at 1 mm.
- * The desired output voltage can be obtained by regulating the distance of the discharge electrodes or the output power.



Crookes tube:

- ○ By applying a voltage of several tens of kV between the cathode and the anode, the cations in the evacuated tube are accelerated and impact the cathode, which knock out secondary electrons.
- ○ These electrons emitted by the cold cathode are accelerated to collide with a glass tube to create a bremsstrahlung X-ray.

Estimation of transmission



- Shielding materials:
  - ○ **Aluminum**.
  - ○ **Lead acrylic**: 0.3 mm lead equivalence, Kyowaglas-XA H-8, KURARAY Co., LTD.
  - ○ **Acrylic**: Amersham Pharmicia Biotech LTD.
- The transmission of X-rays was estimated by the ambient dose equivalent H*(0.07) using an ionization chamber (ICS-1323, Hitachi Ltd., Japan).

CORRELATION BETWEEN DISCHARGE DISTANCE AND EXPOSURE

Experimental settings:

- ○ The applied voltage was regulated by change of output power and was limited by the discharge distance.
- ○ For each discharge distance, the output power was set at the position which the spark just occurred.

- ❑ The percentage of transmission was calculated as a ratio of initial dose to transmitted dose (Fig. 4).
- ❑ The transmitted dose of acrylic is higher than aluminum. It caused a higher transmission for acrylic.
- ❑ Lead acrylic exhibits a good attenuation which the percentage of transmission is less than 2%.

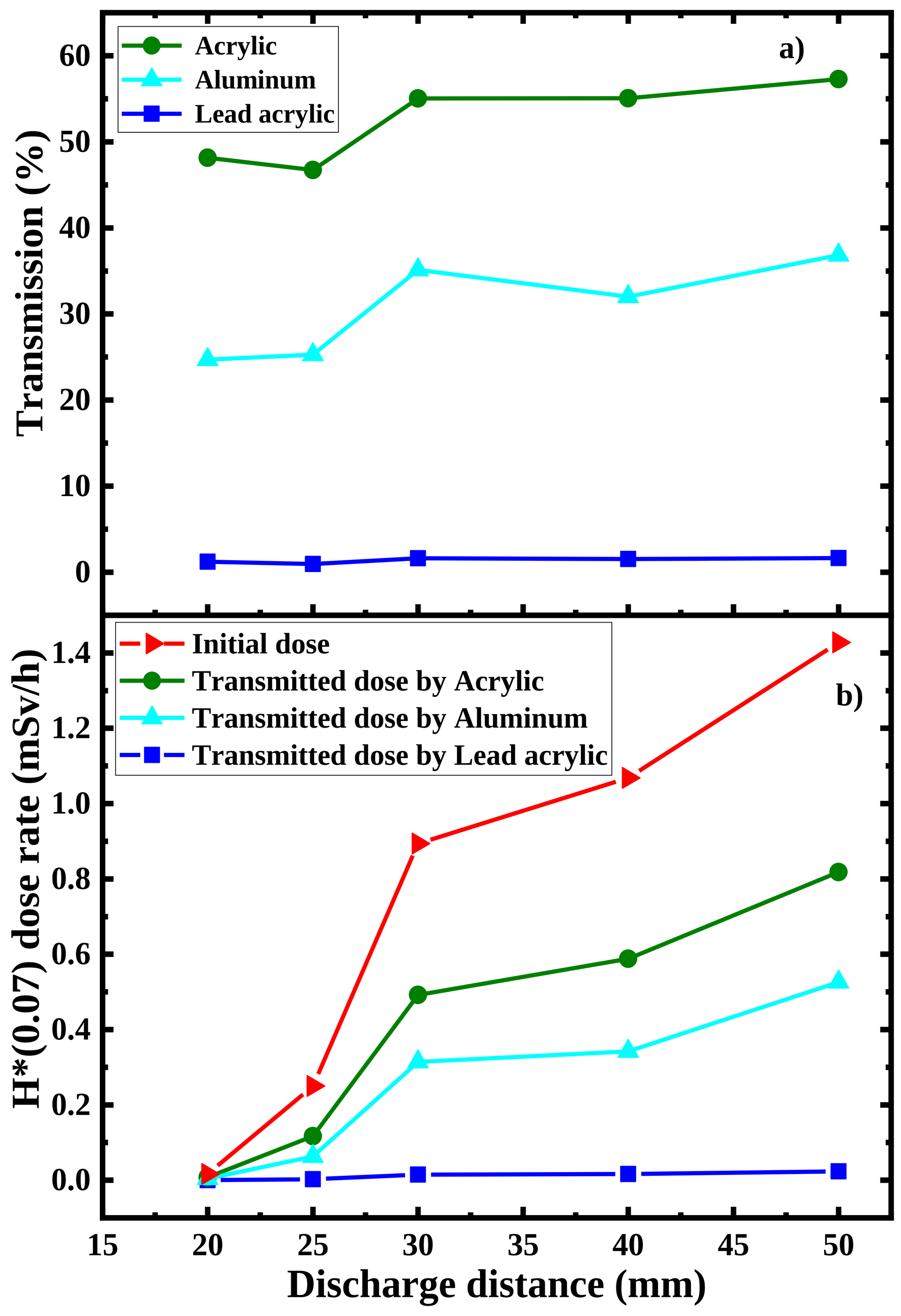


Figure 4. Transmission of X-rays with various discharge distances applied on the Crookes tube attenuated by shielding materials.

Table 2. Transmittance of shielding materials vs. discharge distance.

Discharge distance (mm)	Initial dose* (μSv)	Transmitted dose* (μSv) Lead acrylic	Transmitted dose* (μSv) Acrylic	Transmitted dose* (μSv) Aluminum	Transmission (%) Lead acrylic	Transmission (%) Acrylic	Transmission (%) Aluminum
20	0.81	0.01	0.39	0.20	1.23	48.2	24.7
25	12.5	0.12	5.84	3.16	0.96	46.7	25.3
30	44.7	0.73	24.6	15.7	1.63	55.0	35.1
40	53.4	0.82	29.4	17.1	1.54	55.1	32.0
50	71.4	1.18	40.9	26.3	1.65	57.3	36.8

SUMMARY

- ❑ The Crookes tube emitted X-rays with soft energy of approximately 19 keV.
- ❑ The exposure and X-ray energy changed with electrical settings such as output power, and discharge distance.
- ❑ The lead acrylic attenuated significantly the exposure caused by X-rays radiated from the Crookes tube with the transmission approximately 2%.
- ❑ According to ICRP 36, the dose limit recommended 0.05 mSv per each teaching exercise. The lead acrylic is well-adapted to a radiation shielding for Crookes tube, and its transparence assures to observe the behavior of electron beam during demonstrations.

References:

1) Ohmori Giroh, X-ray exposure in the teaching of science at junior and senior high schools. *NIRS-M—105*, Japan, 107-112 (1995) *(in Japanese)*.
2) M. Akiyoshi, et al., Development of evaluation techniques for low energy X-rays from a Crookes tube, *Radiation chemistry*, 106 (2018) 31-38 *(in Japanese)*.
3) Do Duy KHIEM, et al., Investigation of Characteristics of Low-energy X-ray Radiated from the Crookes Tube Used in Radiological Education, *Radiation Safety Management, submitted*.