OPTIMUM SHIELDING DESIGN FOR ELECTRON LINAC ONCOLOGY FACILITIES INCORPORATING SEISMIC BASE-ISOLATION STRUCTURE

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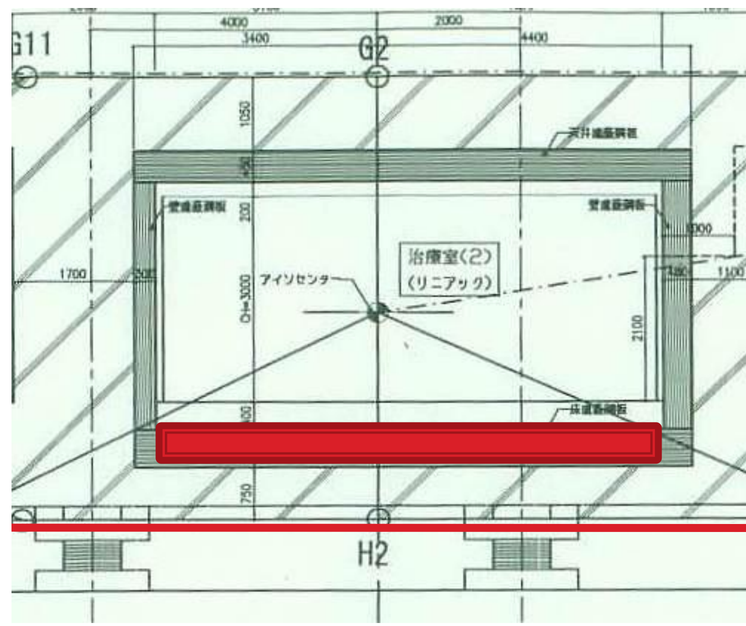
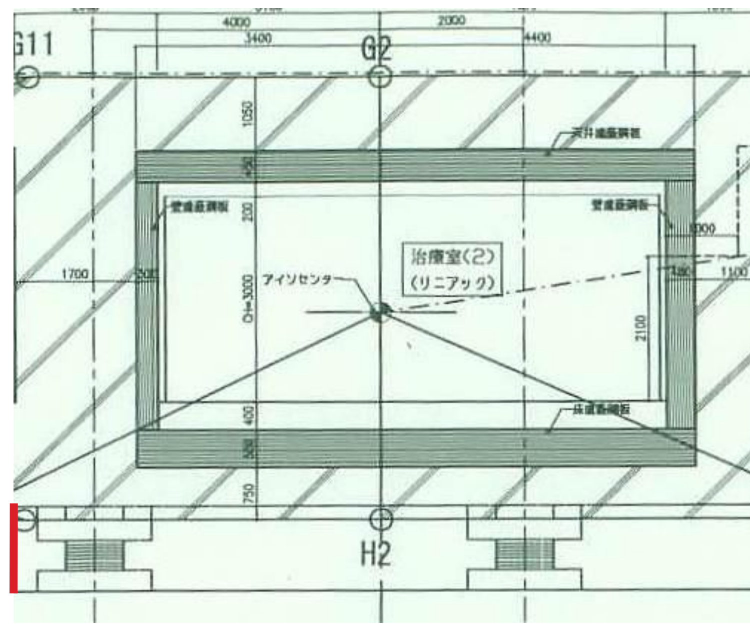
1. Background

- Recently electric linac oncology facilities incorporating seismic base-isolation structure have become very popular in Japan to prevent strong impact to the equipments by the earthquakes.

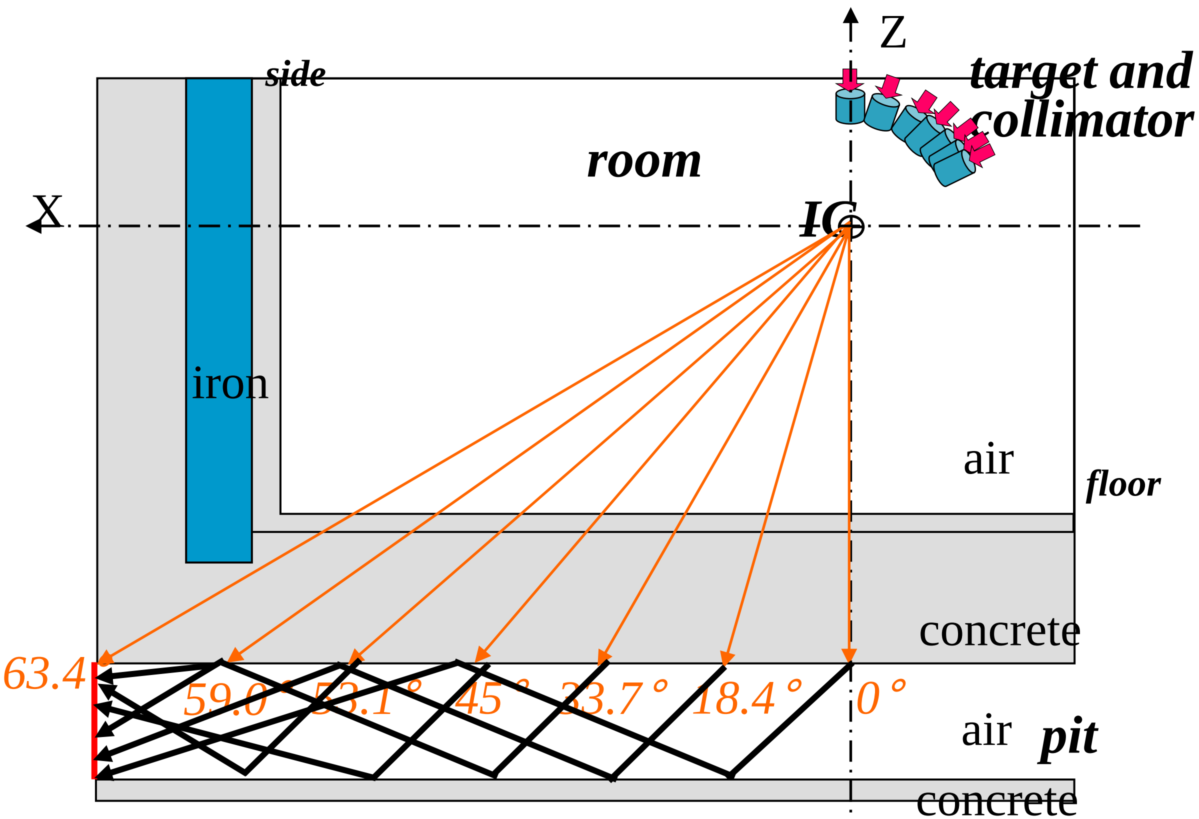
- When the boundary of the controlled area is set below the base-isolated foundations, additional shielding of iron plate is needed and the cost for shielding increases <u>up to $100M</u>.



- Since no one usually accesses underneath the base-isolated foundation, except short maintenance period for base-isolation structure, it is reasonable to set the boundary around the downstairs room by fence.



- However, it is very difficult to estimate the dose rate of new boundary by using the simple shielding calculation method, because of rotating gantry head and effect of scattering radiation in the base–isolation floor.



2. Objectives

1. To investigate the complicated behavior of photons in the "pit" by the analysis,

   (1) Which angle of the gantry will influence the most to the dose rate at the new boundary ?

   (2) How much can we reduce the thickness of additional iron plate ?

   (3) Which component of the radiation is dominant at the new boundary ?

2. To verify the calculated results by the measurement.

3. Assess the feasibility of simple calculation method from this study.

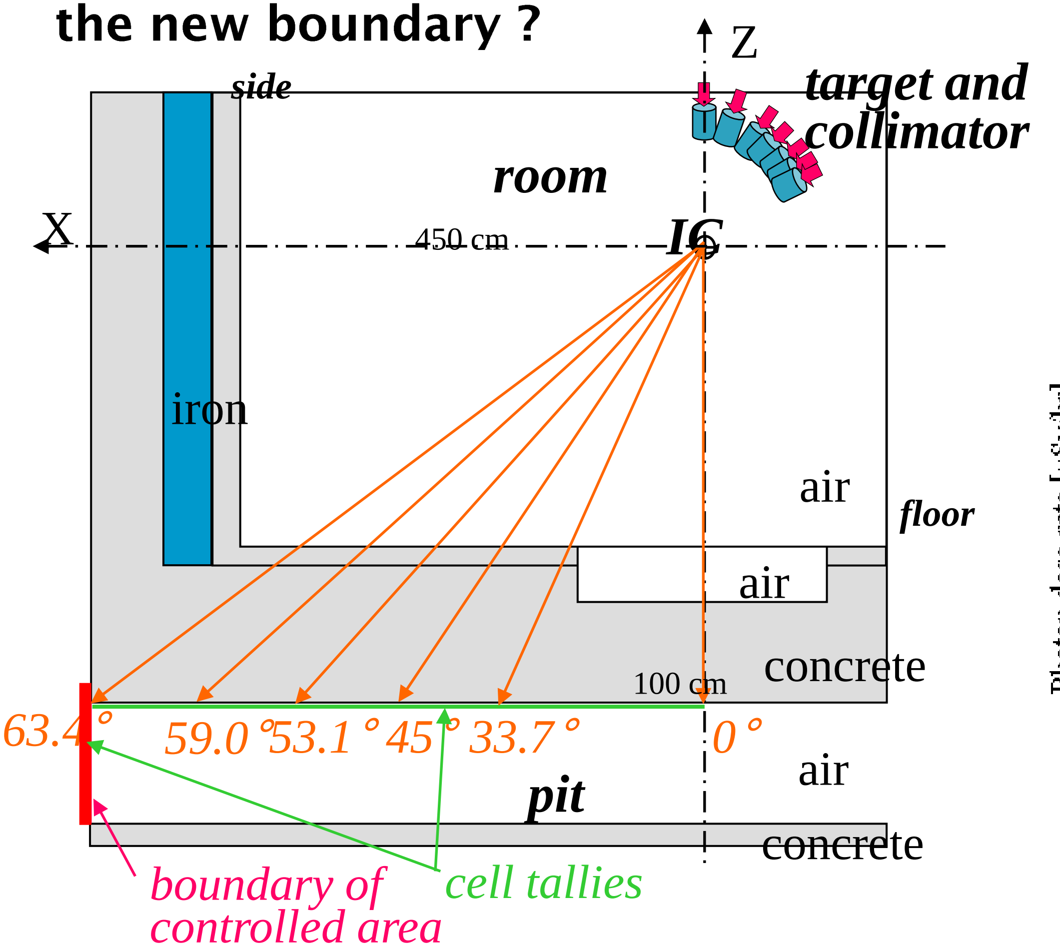
3. Calculation conditions

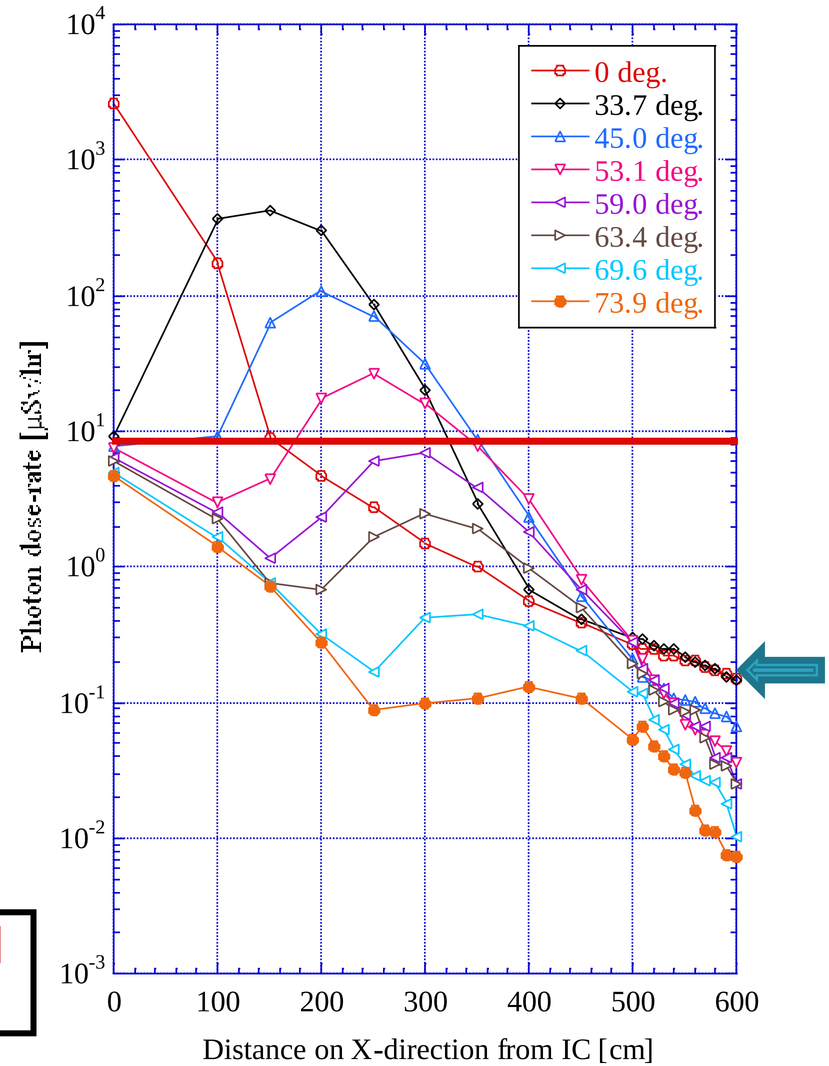
- Code: MCNP5
- Library: EL3 for electron, MCPLIB04 for photon
- Source: 10 MeV electrons (pencil beam)
- Target: Cu (2 cm-thick)
- Tally: # cell tallies for photon and electron flux
  : lower layers in pit (1 cm-thick, $10x20cm^2$)
  # point detectors for photon at positions estimated.

- The criteria of the boundary dose rate is <u>8.3 micro Sv/h</u>.
  (1,300 micro Sv/h) /156 h = 8.3 micro Sv/h)

4. Calculations

(1) Which angle of the gantry will influence the most to the dose rate at the new boundary ?

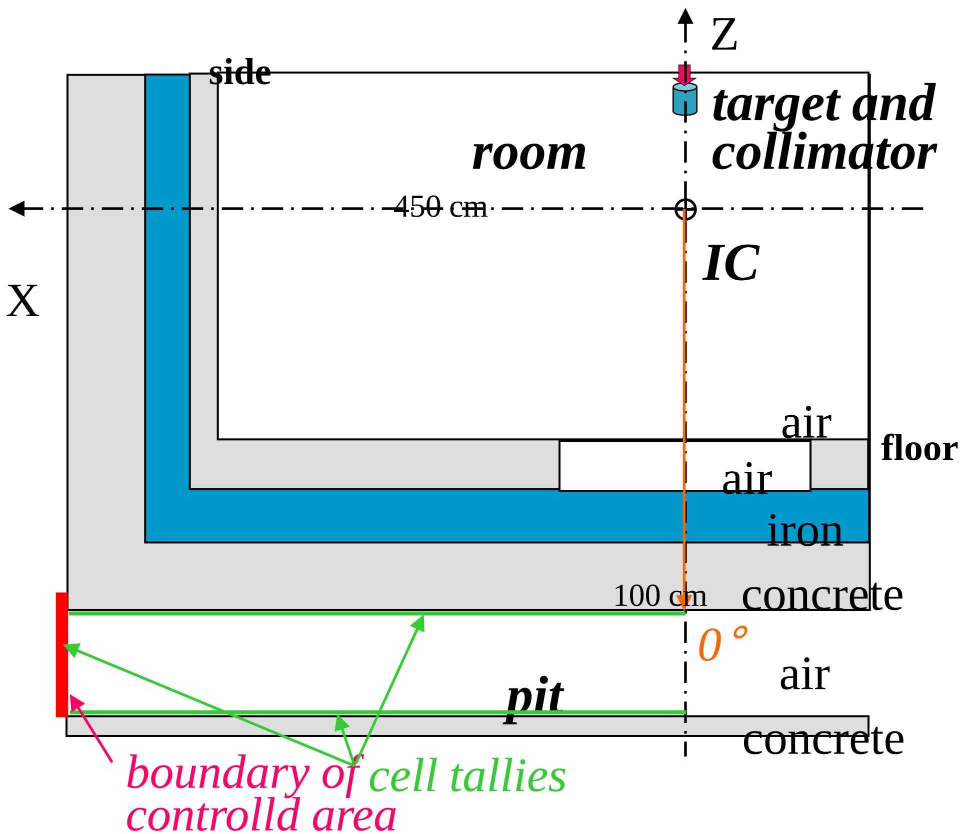


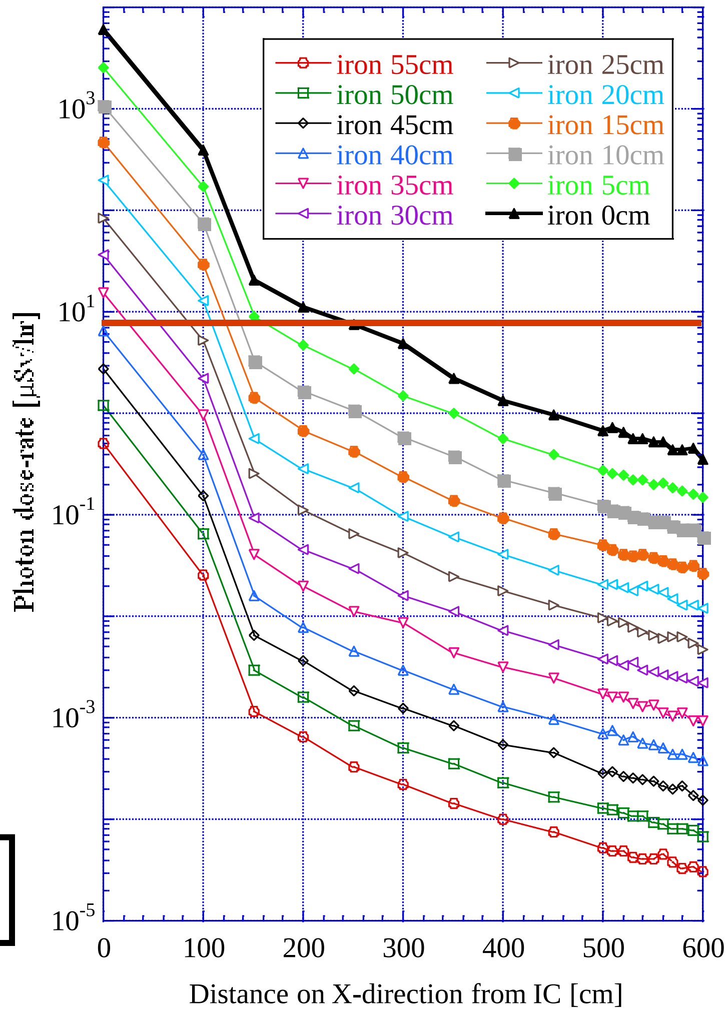


Photon Dose-rate distribution at upper position in pit space for floor direction shielding (beam angle = 0 to 73.9 deg., current = 64.8 μA).

The highest dose rate was obtained at the direction 0 degree.

(2) How much can we reduce the thickness of additional iron plate ?





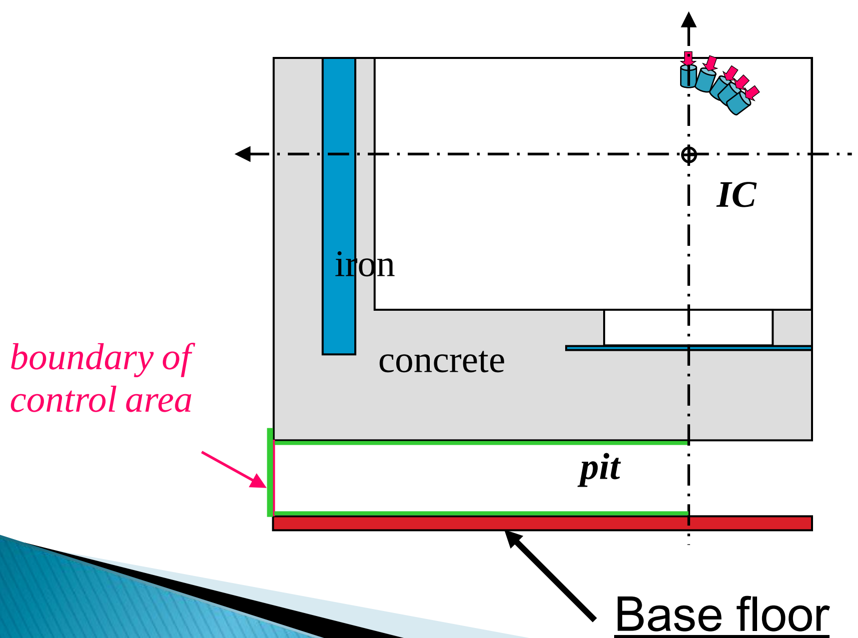
Photon Dose-rate distribution at upper position in pit space for floor direction shielding (beam angle = 0 deg., current = 64.8 µA).

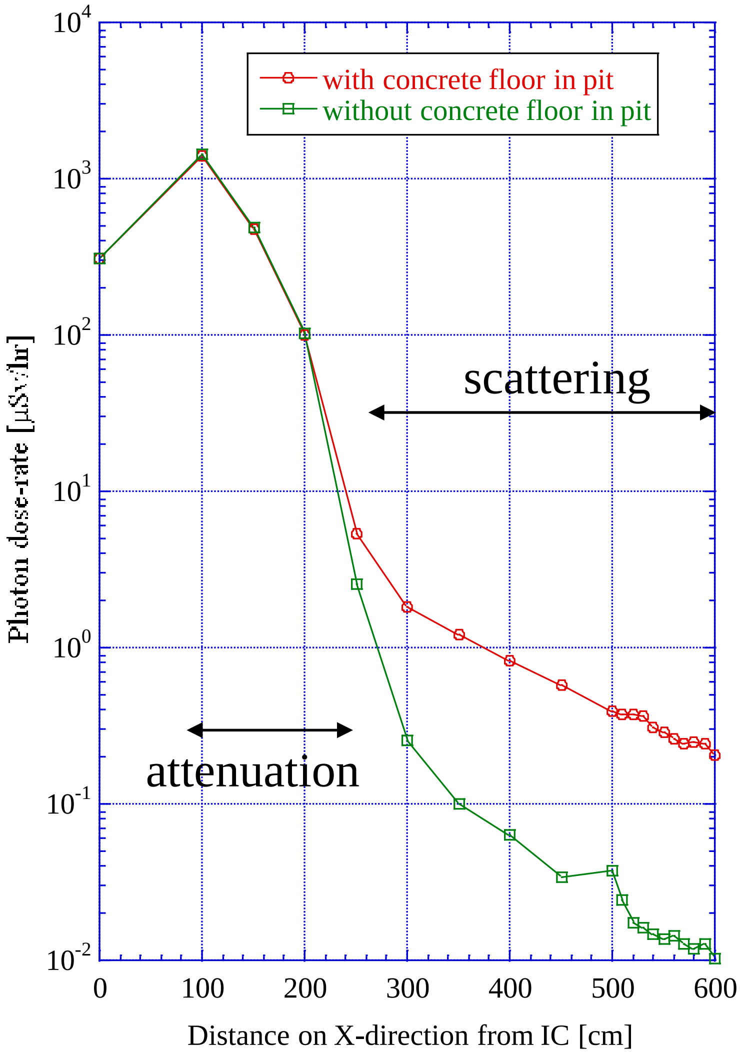
No additional iron shield is necessary.

(3) Which component of the radiation is dominant at the new boundary ?

To estimate the component of dominant radiation to the new boundary, we have performed calculation with and without base floor.

The influence of scattered radiation from the floor became dominant to the new boundary at the position greater than 3m.
It decreased constant inclination.

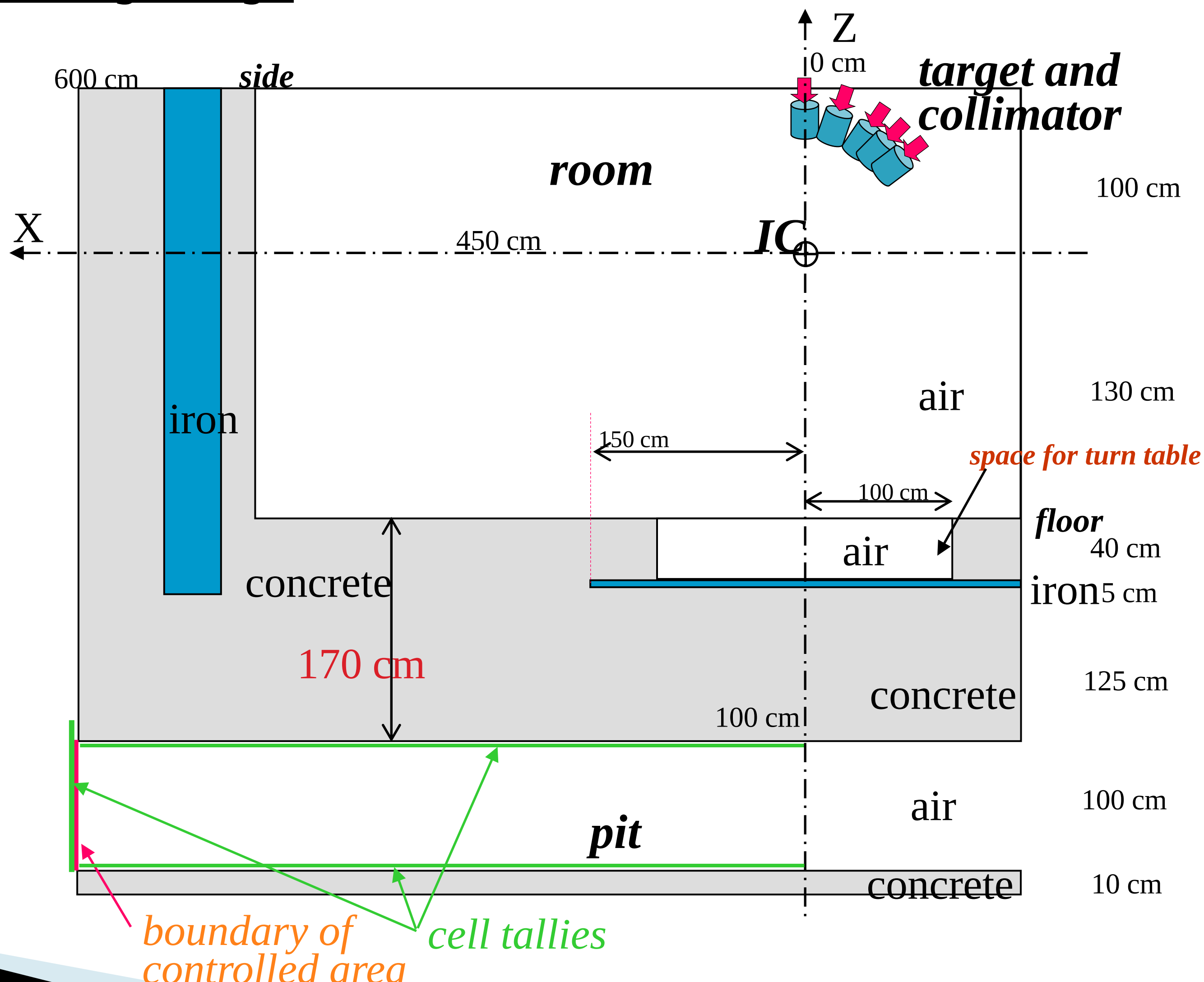




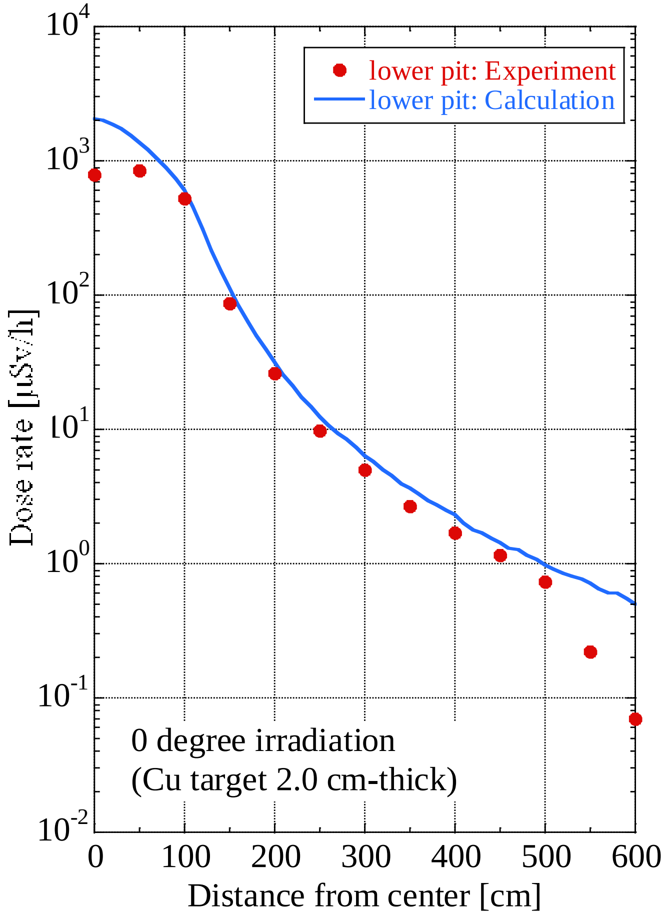
Photon Dose-rate distribution at upper position in pit space for floor direction shielding by with or without pit floor (beam angle = 18.4 deg., current = 64.8 μA, iron thickness = 5 cm).

5. Comparison between calculated and measured results

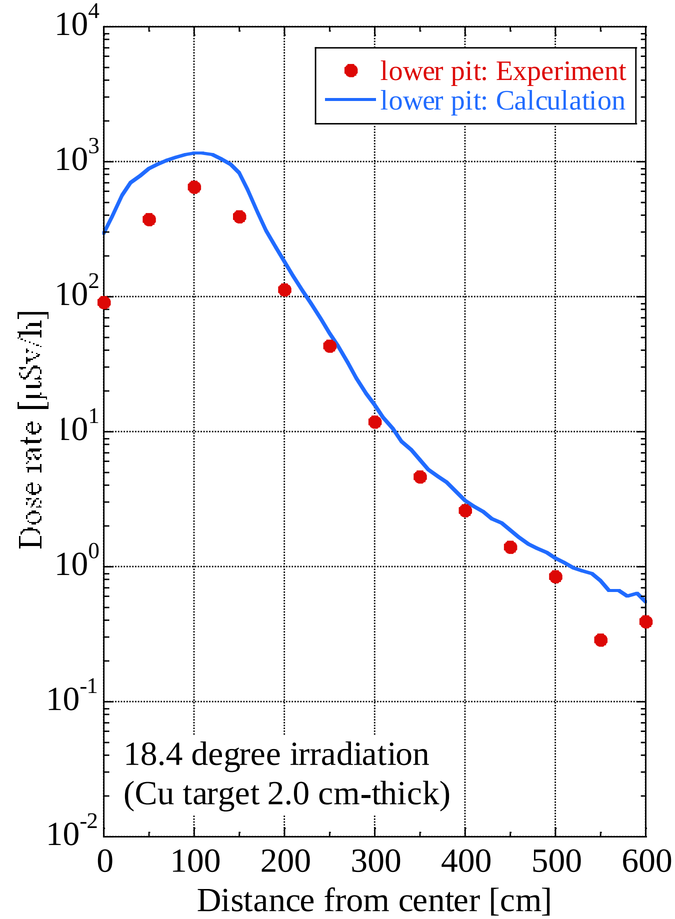
Final shielding design



We have measured dose rate along the pit floor by ionization chamber.



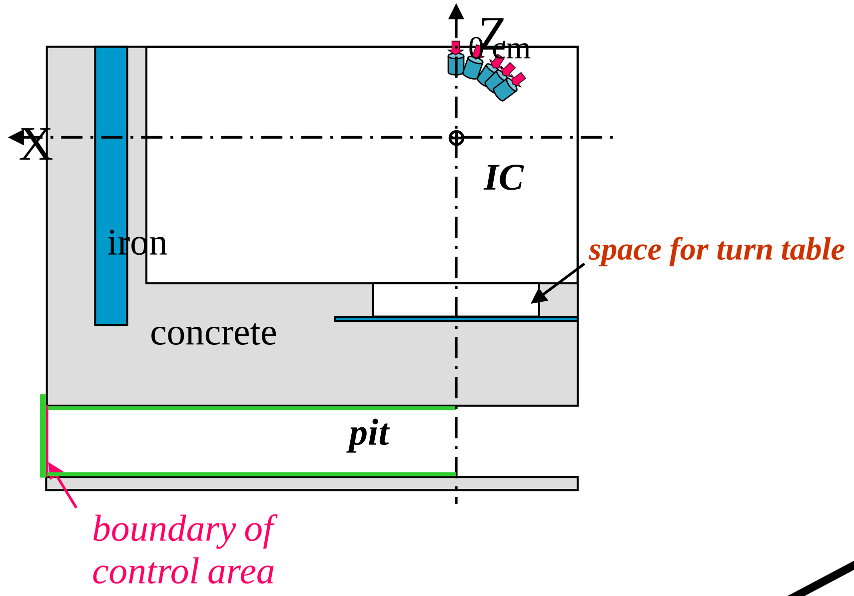
Gamma-ray dose rate distributions in the underground pit for
0 degree irradiation by 10 MV linac at the Tama-PFI hospital.



Gamma-ray dose rate distributions in the underground pit for
18.4 degree irradiation by 10 MV linac at the Tama-PFI hospital.

Very good agreement was obtained within 20%, except beneath iso-center and boundary.

Reasons of disagreement between calculated and measured results



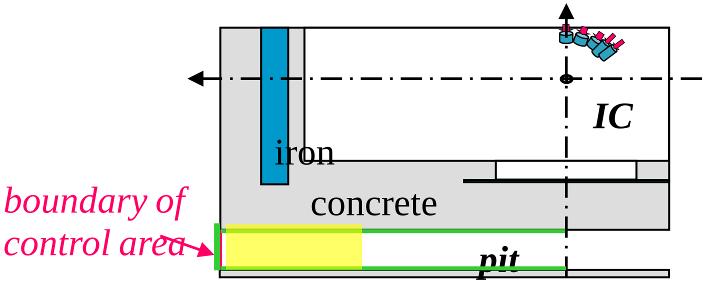
The structure of turn table in the treatment room

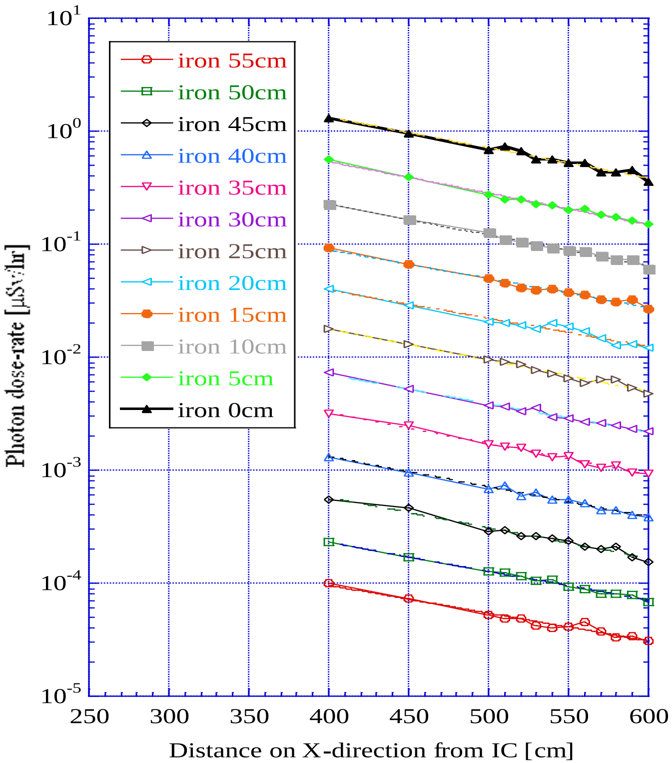
Pipes near the boundary

Anisotropy of turn table base was not considered in the calculation model.

Pipes and some equipments near the boundary were not considered in the calculation model.

6. Possibility of simple calculation method





Photon Dose-rate distribution at upper position in pit space for floor direction shielding (beam angle = 0 deg., current = 64.8 μA).

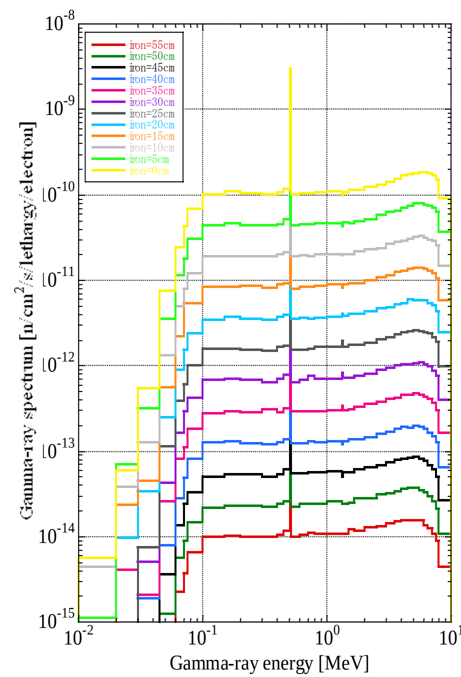
Although the structure of the shielding wall is different, the <u>slope of attenuation coefficient is almost the same</u>.

The energy spectra of attenuated photons are also very similar.

We may define <u>Tenth Value Layer (TVL)</u> in the pit for simple calculation method.

Thickness of iron (cm)	TVL (cm)
55	406.64
50	391.06
45	370.32
40	376.01
35	363.22
30	389.46
25	362.37
20	400.99
15	390.24
10	366.88
5	358.98
0	372.41

TVL in the pit varied from 360 to 400 cm



Gamma-ray energy spectra at upper position in pit space for floor direction shielding (beam angle = 0 deg.) of Tama-PFI Hospital.

Conventional calculation method for primary shield for linacs

$$ {}_U E_{(X)} = \frac{\dfrac{I_0 \times 60 \times 10^6}{L^2} \times Dt_{iron} \times Dt_{con} \times T \times U \times 1.0}{} \times \underline{\underline{Dt_{pit}}} \times \underline{\underline{f}} $$

$$ Dt = 10^{-t_i / x_i} $$

Dose rate outside of the primary barrier

$_U E_{(X)}$: effective dose [μSv/(3 month)] at an evaluation position

I_0 : X-ray dose rate [Gy/min] at 1 [m] of distance from target

60 : conversion coefficient from minute to hour unit

10^6 : conversion coefficient from Gy to μGy unit

L : distance [m] from target to an evaluation position

Dt : transmittance of shielding material with thickness t [cm]

where *ti*: effective thickness [cm] of shielding material

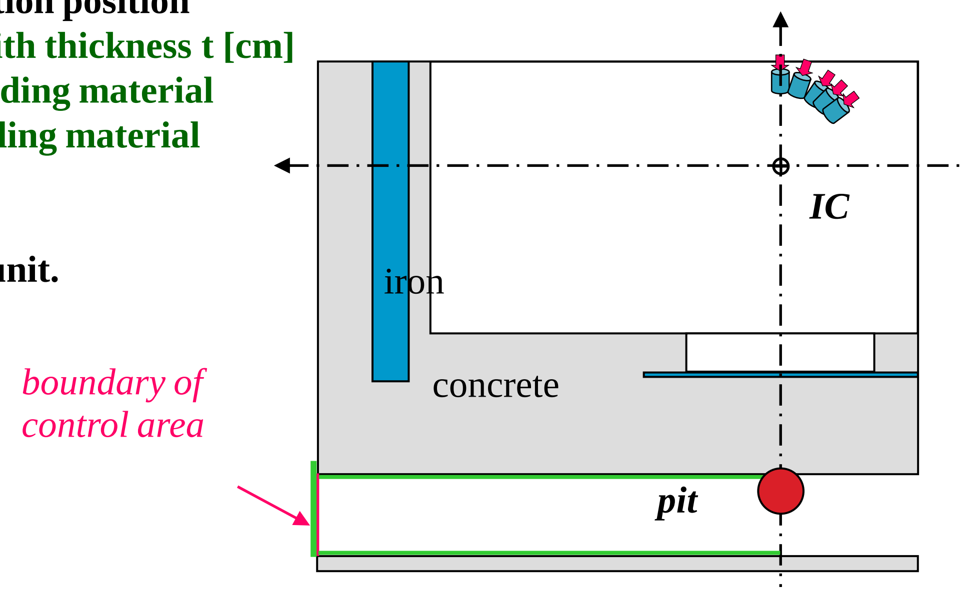
xi: Tenth value layer [cm] of shielding material

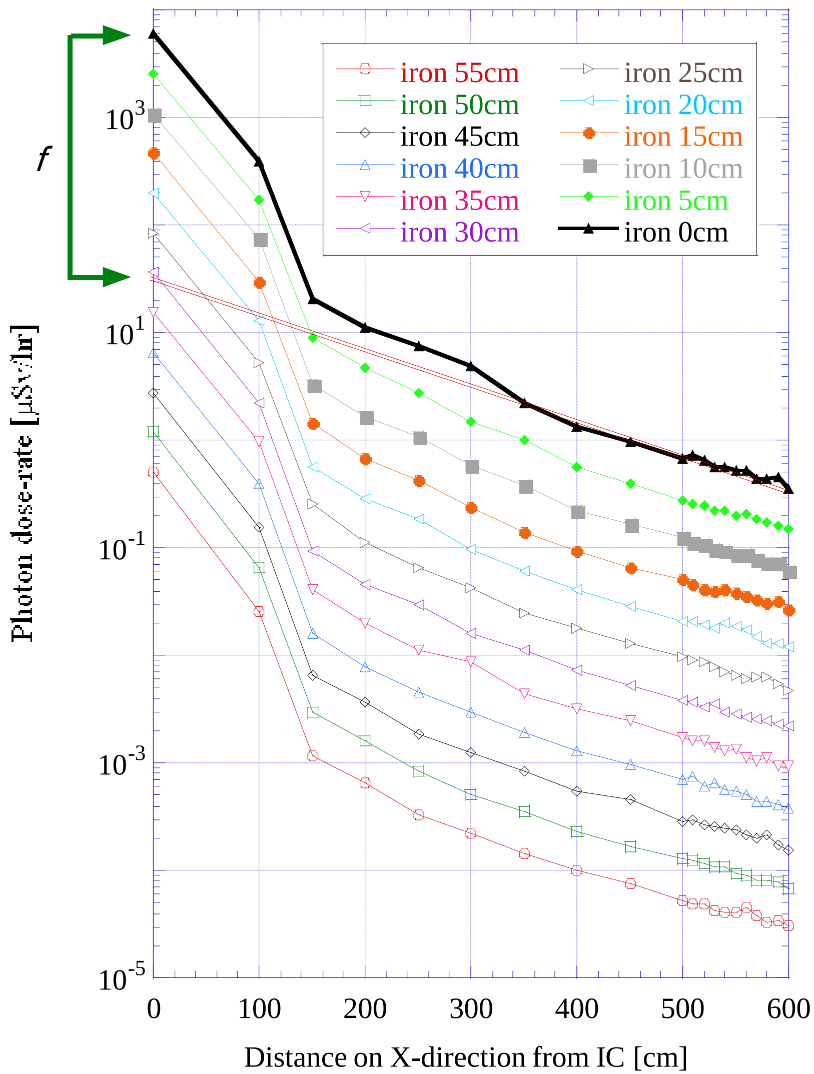
T : operated time [hours/(3 month)]

U : directional useful rate

1.0 : conversion coefficient from Gy to Sv unit.

f : correction factor





Photon Dose-rate distribution at upper position in pit space for floor direction shielding (beam angle = 0 deg., current = 64.8 μA).

$$_U E_{(X)} = \frac{I_0 \times 60 \times 10^6}{L^2} \times Dt_{iron} \times Dt_{con} \times T \times U \times 1.0 \times \underline{\underline{Dt_{pit}}} \times \underline{\underline{f}}$$

$$Dt = 10^{-ti/xi}$$

Thickness of iron (cm)	*f*
55	393.80
50	362.31
45	320.51
40	334.47
35	273.15
30	340.50
25	294.91
20	326.02
15	303.71
10	243.04
5	204.05
0	169.83

Result of simple calculation method = 0.57 micro Sv/h

Result of MCNP5 calculation method = 0.36 micro Sv/h

7. Conclusion

1. We have performed the analysis of the behavior of photons in the pit and found out no additional iron shielding was necessary, which carried out an extreme reduction of costs.

2. Good agreement between calculated and measured results were obtained, and passed the examination by the authority.

3. It has been suggested there is a possibility of simple calculation method for the estimation of dose rate at the new boundary.

End