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A new method to verify MCNP-calculated thermal neutron fluence using TLDs and a cadmium sheet

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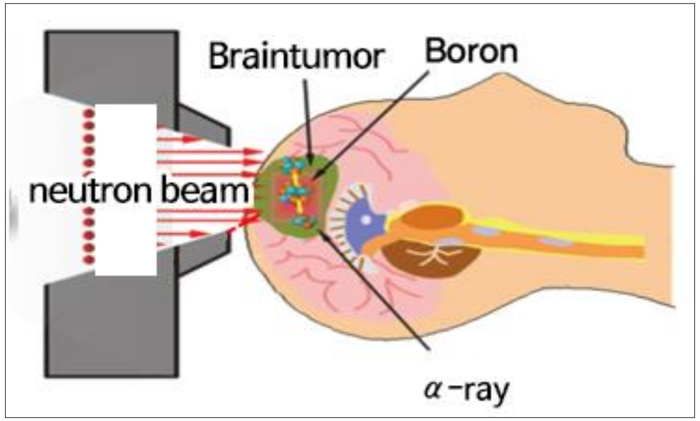
Contents

Introduction

- Thermoluminescence dosimeters are versatile, compact and widely used for mixed field neutron and photon dosimetry.
- Activation foils are normally used to evaluate thermal neutron fluence
- In BNCT, the neutron beam should ideally be mostly epithermal neutrons where the ratio of thermal to epithermal neutrons should be less than 0.05[1]



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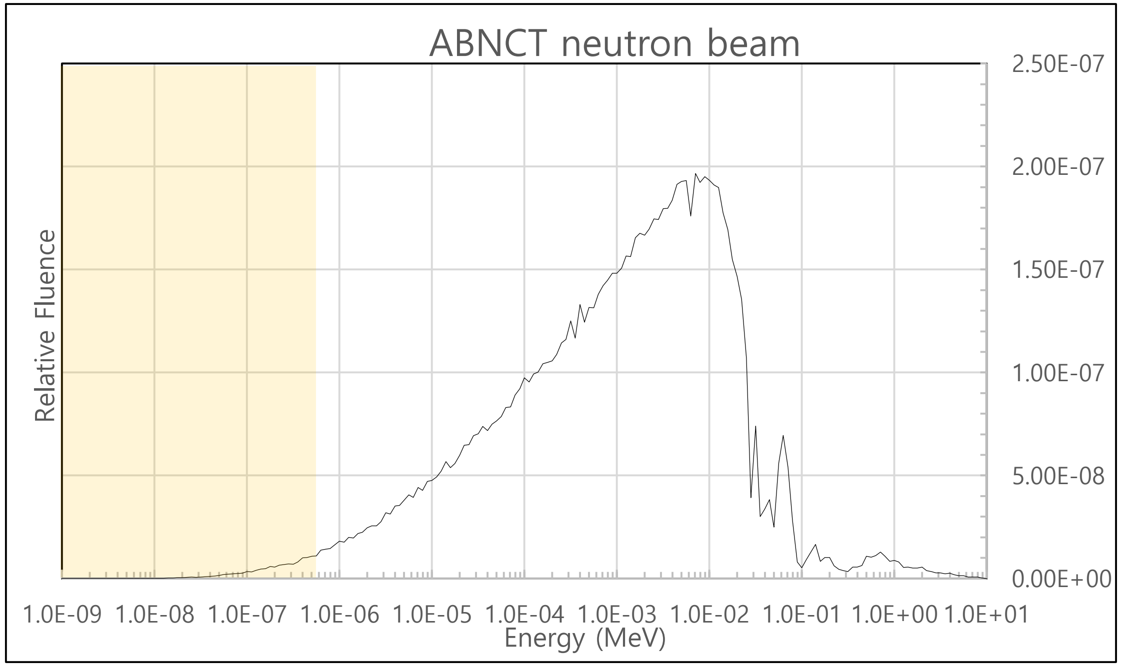


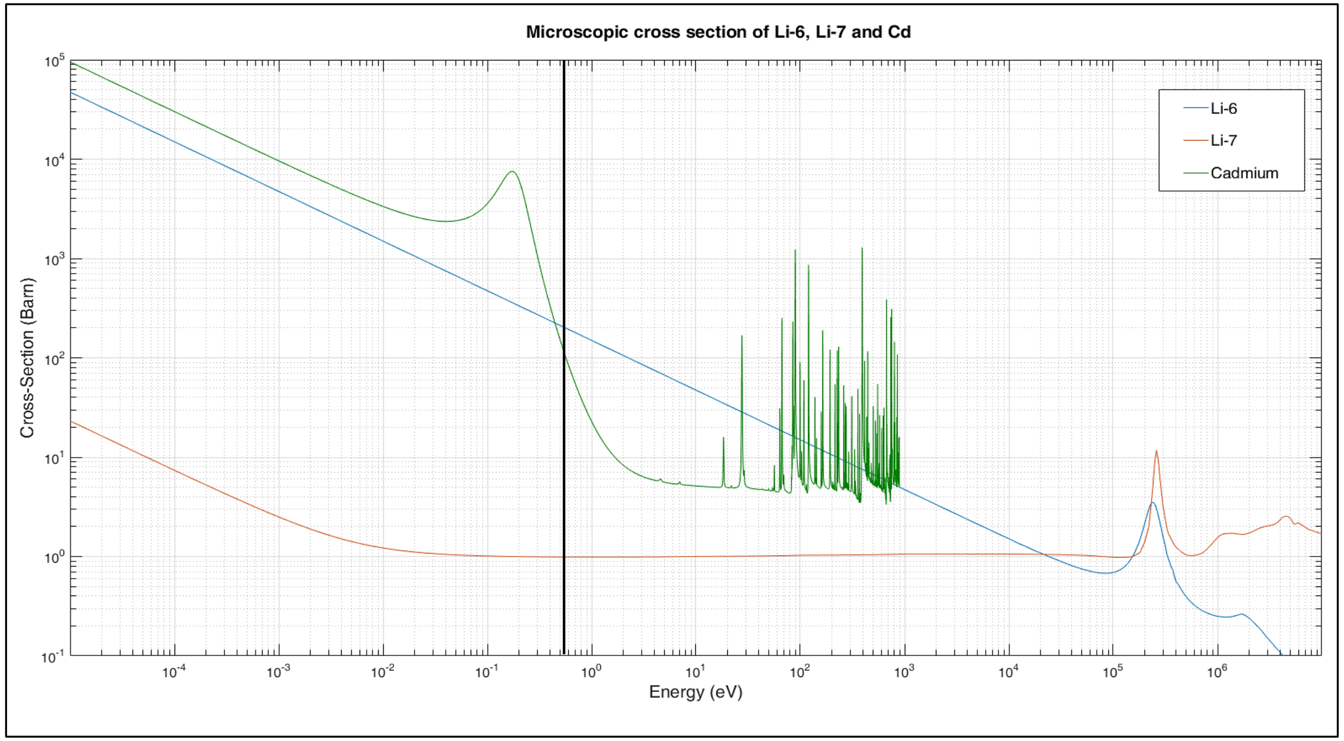
Simulation of beam from ABNCT

[1]. JRC Europe (2008). *A review of the recommendations for the Physical Dosimetry of Boron Neutron Capture Therapy (BNCT)* (EUR23632 EN-2008).

Introduction

In this study, LiF based TLDs are used with a cadmium sheet to evaluate thermal neutron fluence

- TLD-600 = $^{6}LiF:Mg,Ti$ (Neutron + Photon) sensitive
- TLD-700 = $^{7}LiF:Mg,Ti$ Photon sensitive



Cross section of Li-6, Li-7, and cadmium.

Objective: To obtain thermal neutron fluence contribution in mixed photon and neutron fields

Materials and methods

Experiment:

- Neutron irradiation
- Calibrated dose rate measurement

Flux to dose conversion factors

MCNP Simulation:

- POSTECH neutron irradiation room
- Neutron fluence (TLD)
- Neutron energy deposit (TLD)

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Result:

- Thermal neutron dose contribution
- Thermal neutron fluence

Materials and methods

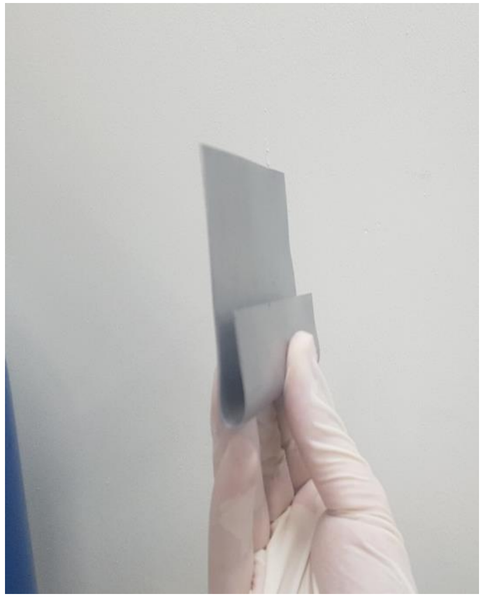
- **Prior to irradiation, new batches of TLD-600 and TLD-700 were prepared**
  - 80 TLD-600 and 80 TLD-700 were annealed:
    - At 400°C for 1 hour, then
    - At 100°C for 2 hours

Annealing → Irradiation → Reading out

Electric oven used to anneal TLDs

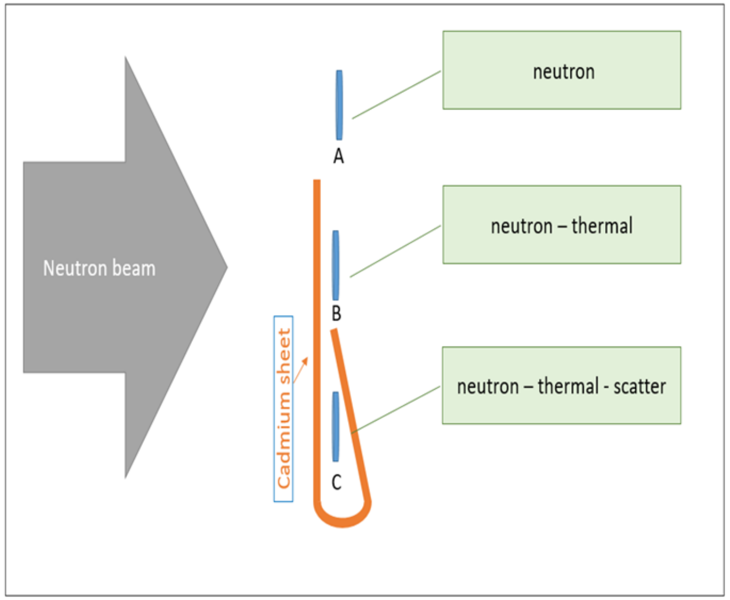
Materials and methods

- Sets of TLD-600 chips and TLD-700 chips were grouped to be
  - A – Directly exposed to the neutron beam
  - B – Shielded in the front by a cadmium sheet
  - C – Placed inside a folded cadmium pocket



Side view of the cadmium sheet

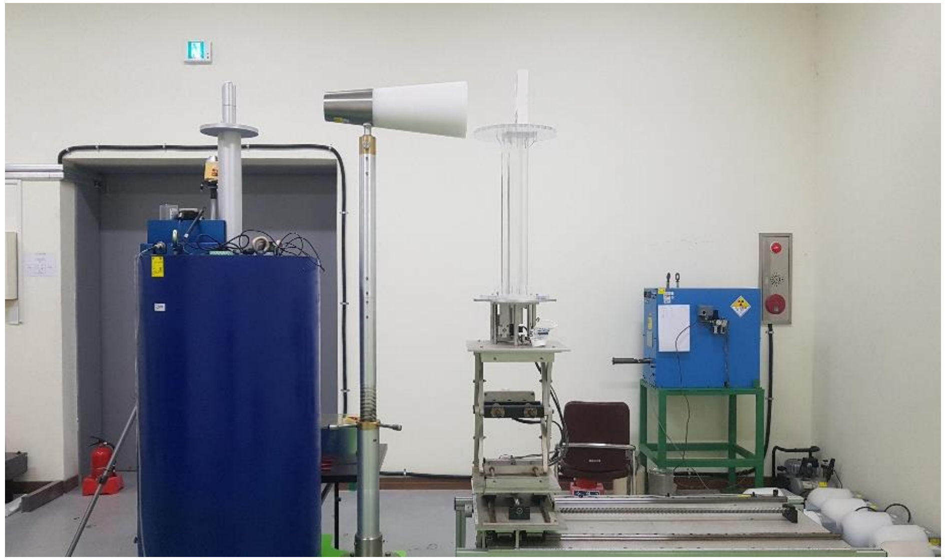
Backward view of the TLD setup with cadmium sheet in place



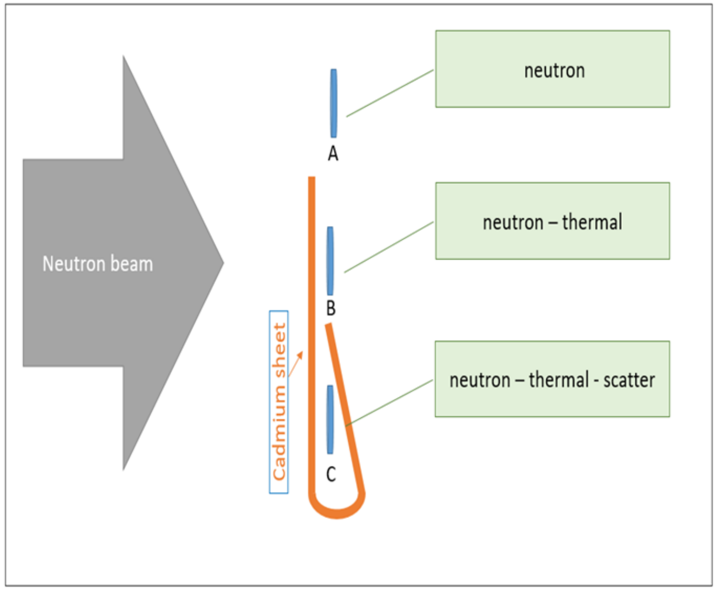
Side view schematic demonstrating the TLD positioning.

Neutron irradiation

- POSTECH neutron irradiation room using Cf-252 neutron source:
  - 830 × 640 × 410 cm
  - 50 cm thick concrete walls
  - TLDs at 1m from source
  - 50 cm shadow cone moderator
  - TLDs were at 1m from the source
  - Irradiation was continued for 48 hours



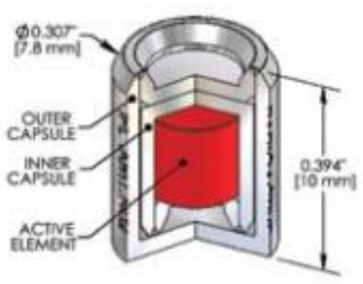
Side view photograph of irradiation setup at POSTECH irradiation room



Side view schematic demonstrating the TLD positioning.

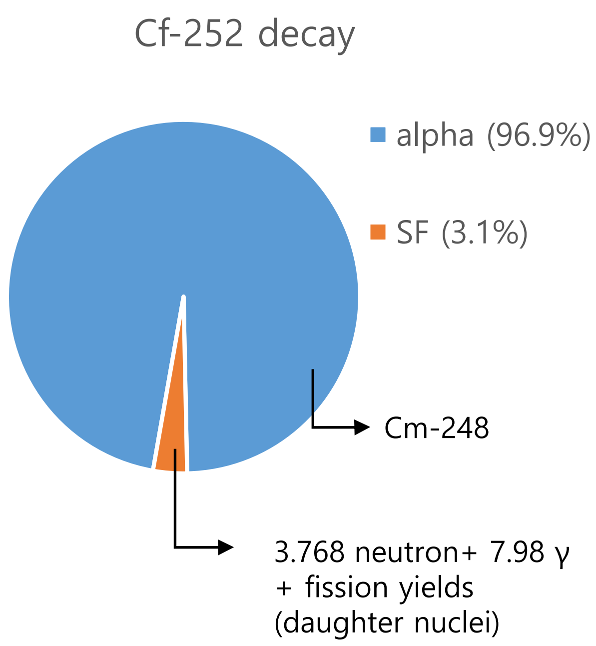
Neutron irradiation – Californium source

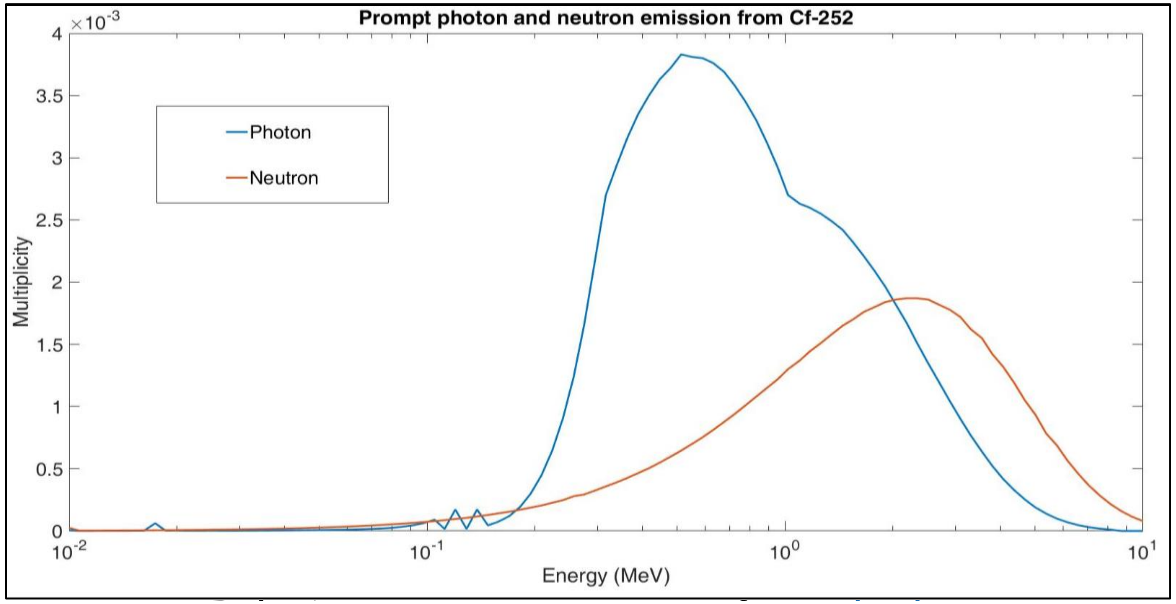
- Californium-252 neutron source:
  - Eckert & Ziegler 3036 cylindrical source
  - 480 µCi on 1.7.2018 (calibration date) (2.073E6 n/s)
  - 414 µCi on 23.1.2019 (irradiation date) (1.789E6 n/s)



Eckert & Ziegler 3036 cylindrical source

- The gamma emission of daughter nuclides accumulated from fission are non-negligible.





prompt photon and neutron emission multiplicity from bare Cf-252 source

TLD READING

- All TLDs were readout after irradiation using Harshaw 3500 TLD reader to obtain TLD glow curve

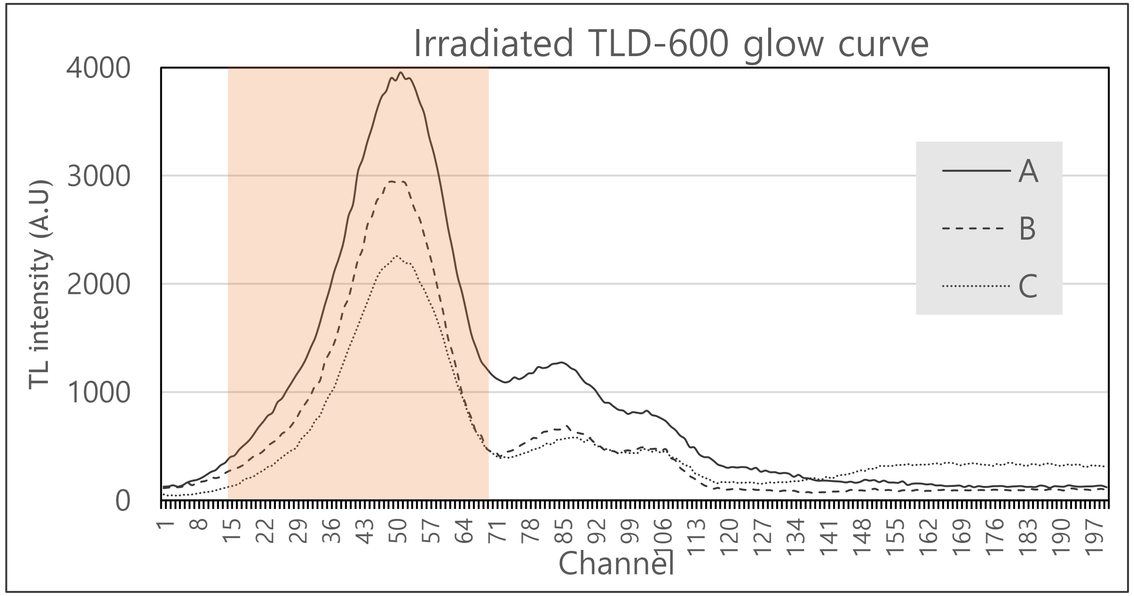
- The TLDs were labelled after irradiation.

- TLD glow curve for each group of TLDs was averaged,
    - A Region of interest was selected between channels 16 - 66
    - Five TLD readings that showed high deviation from the averaged reading were omitted.

Harshaw 3500 TLD reader

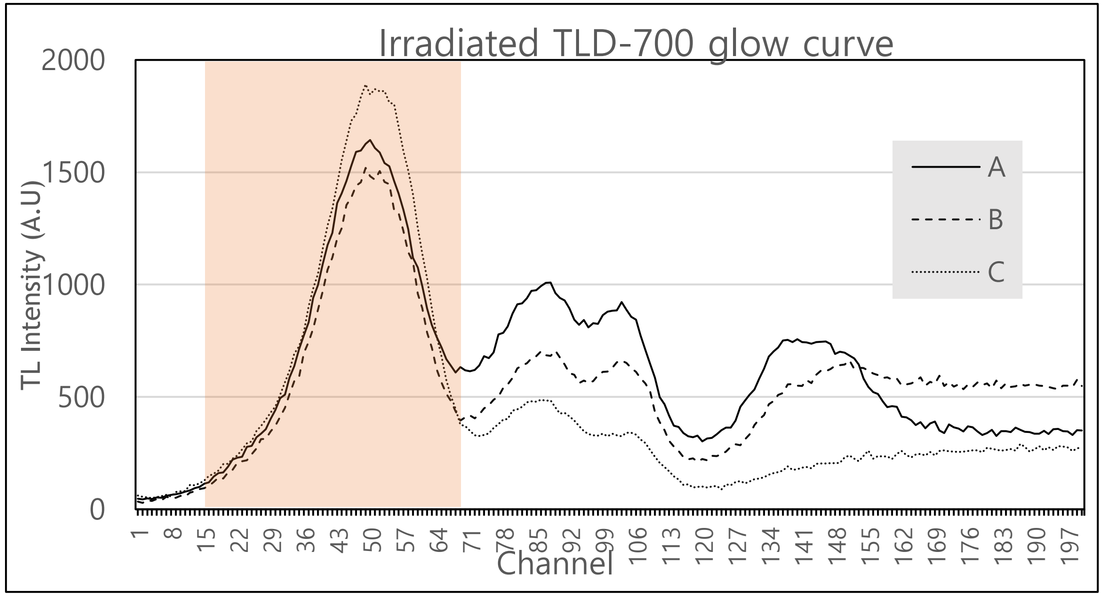
Resulting glow curve from reading TLD-600

- Heating TLDs in the Harshaw™ 3500 TLD reader yields glow curves corresponding to the amount of dose response the TLD has received.
- The TLD glow curve shows different peaks at different temperatures, the main peak between channels 16 to 66 was chosen as region of interest ROI
- The integrated area under the curve of the ROI is selected and analyzed



Averaged glow curve from TLD-600 disks in positions A, B, and C

TLD-600 : Neutron + Photon

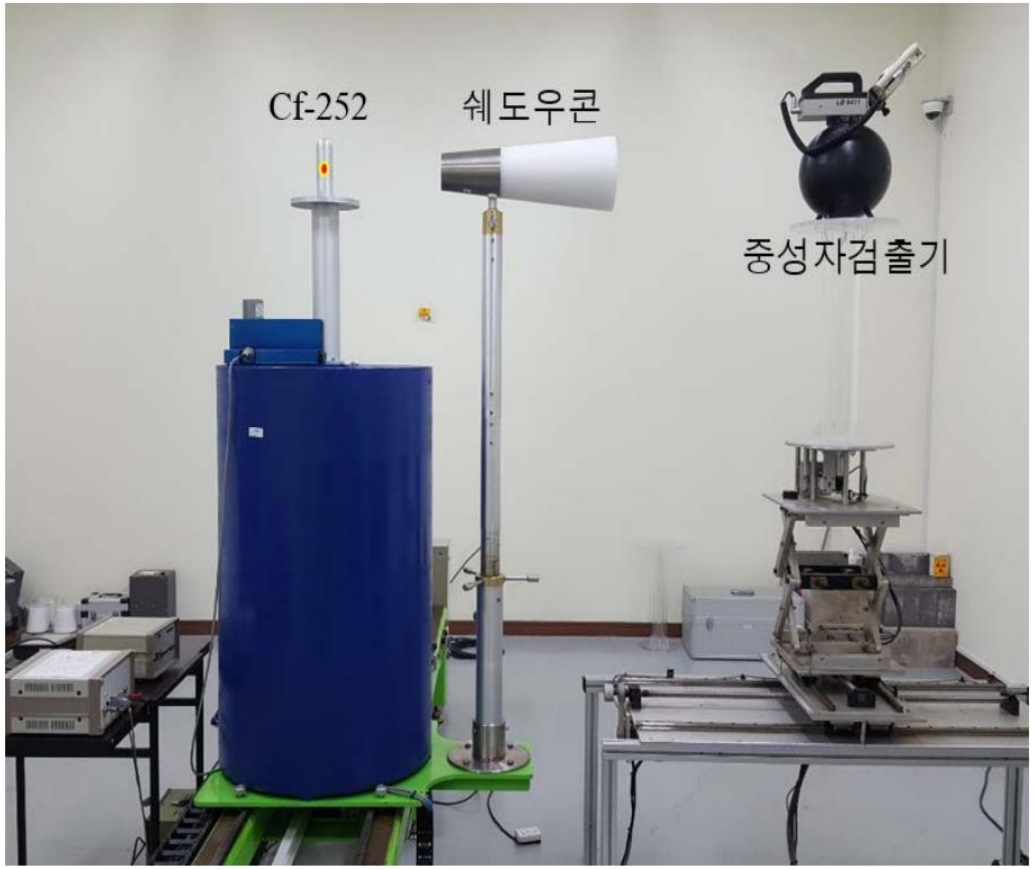


Averaged glow curve from TLD-700 disks in positions A,B, and C

TLD-700 : Photon

Post irradiation measurement

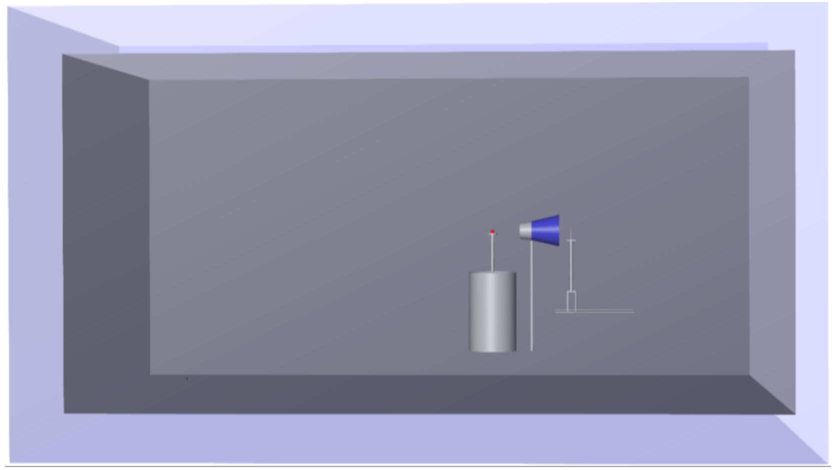
- Neutron dose rate was measured after Irradiating TLDs using a calibrated neutron dose rate meter.
- Ludlum Measurements® LB-6411 calibrated neutron dose rate meter
- Ambient dose rate equivalent H*(10) calibrated according to ICRP-60
- Dose rate readings averaged over several hours was 3.46 μSv/h



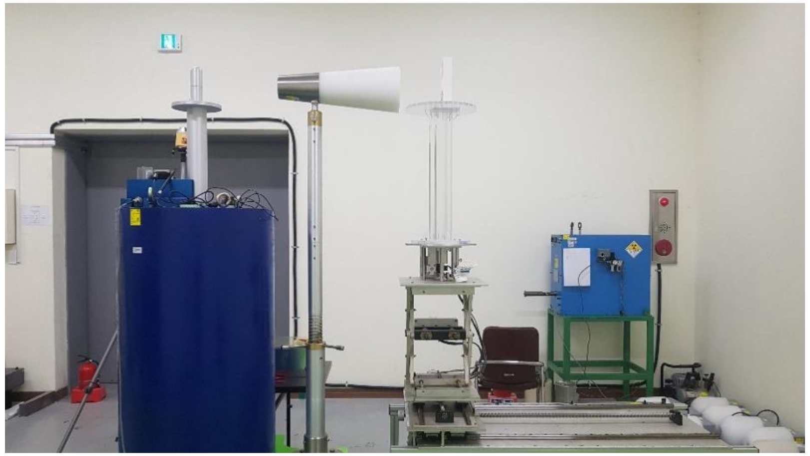
Photograph of Neutron dose rate measurement device, *courtesy of POSTECH*

MCNP SIMULATION

- Irradiation room geometry was replicated using SimpleGeo
- Cf-252 source shield, holder, shadow cone, TLD holders were all included in the simulation
- Special cross section data treatment was used for hydrogen molecules bound in polyethylene
- A Cf-252 point source was simulated at the real coordinates of the source using Watt fission spectrum *a*=*1.025*, *b*=*2.926*
- F4 tally was used to obtain neutron flux and later ambient dose equivalent H*(10)
- F6 tally was used to obtain energy deposition in TLDs in MeV/gram
- Simulation continued until tally error < 0.05

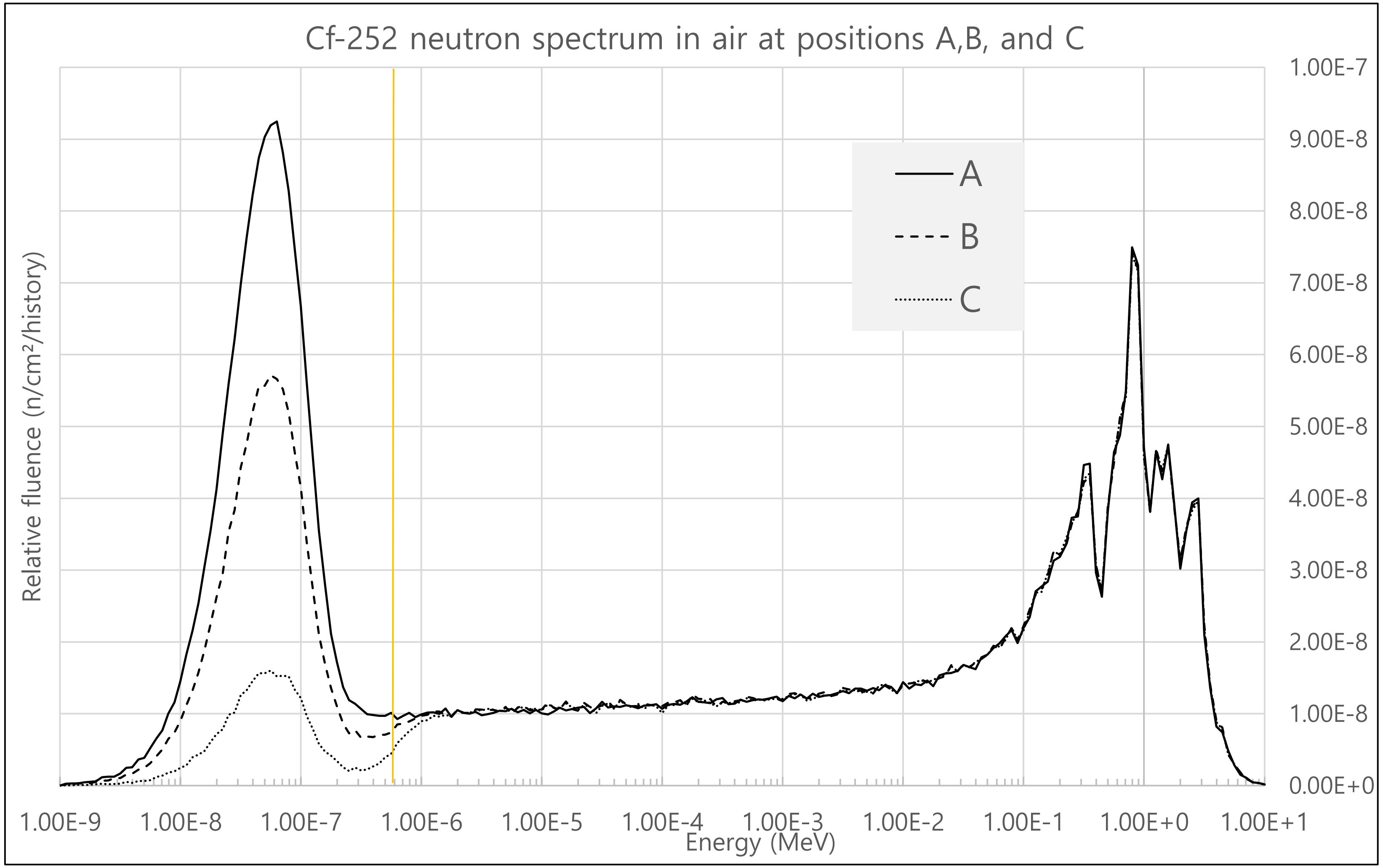


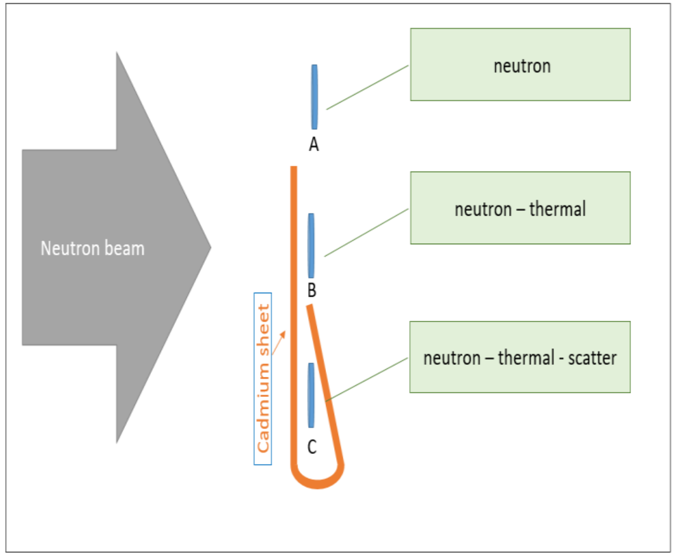
Neutron irradiation room as visualized using SimpleGeo



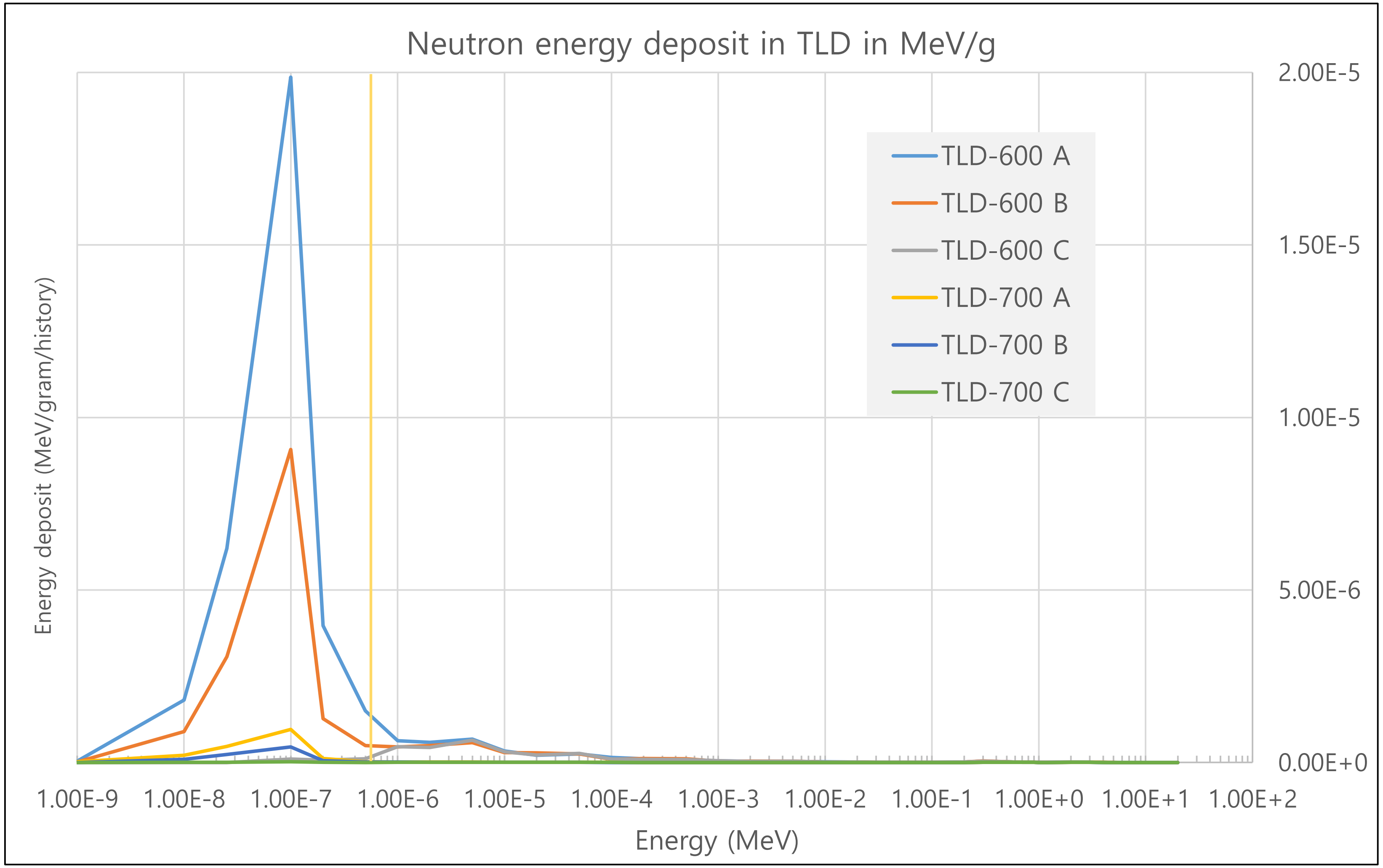
Actual Photograph of the neutron irradiation room

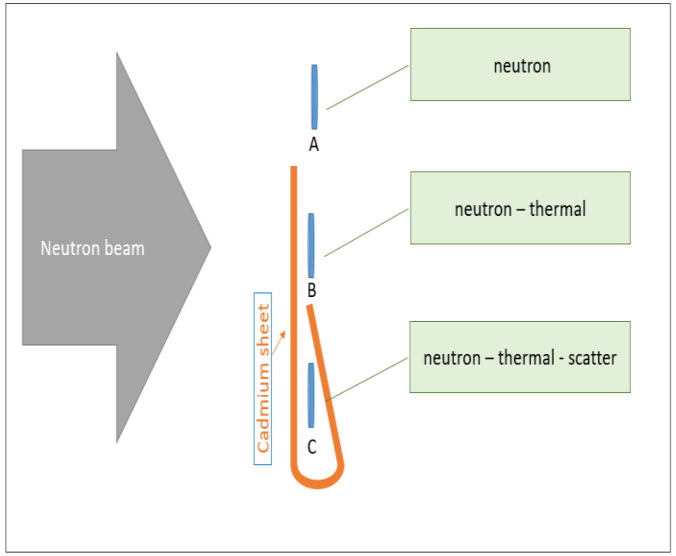
Neutron fluence spectrum resulting from F4 tally





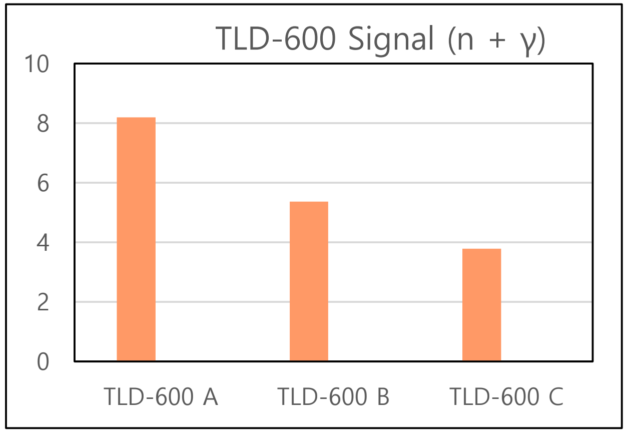
Neutron energy deposit per TLD in MeV/g from F6 tally

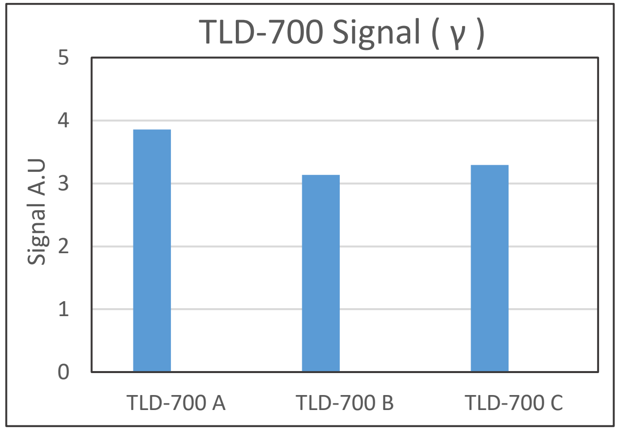


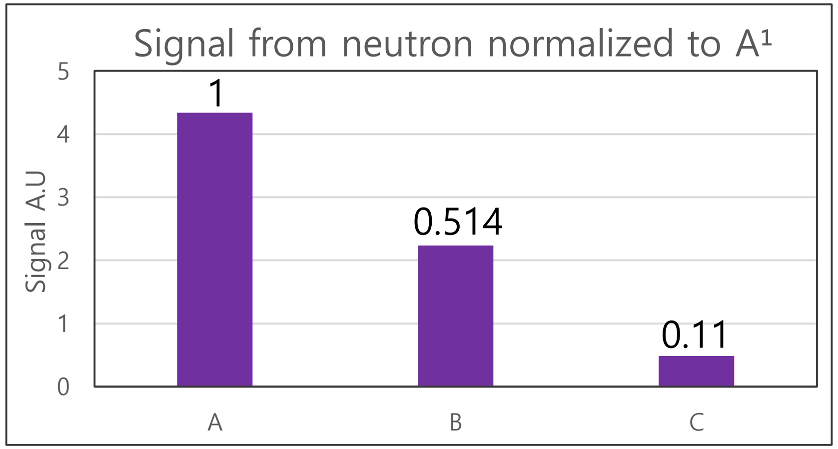


Results and discussion - Experimental

- Neutron dose was obtained by subtracting TLD-700 from TLD-600 reading

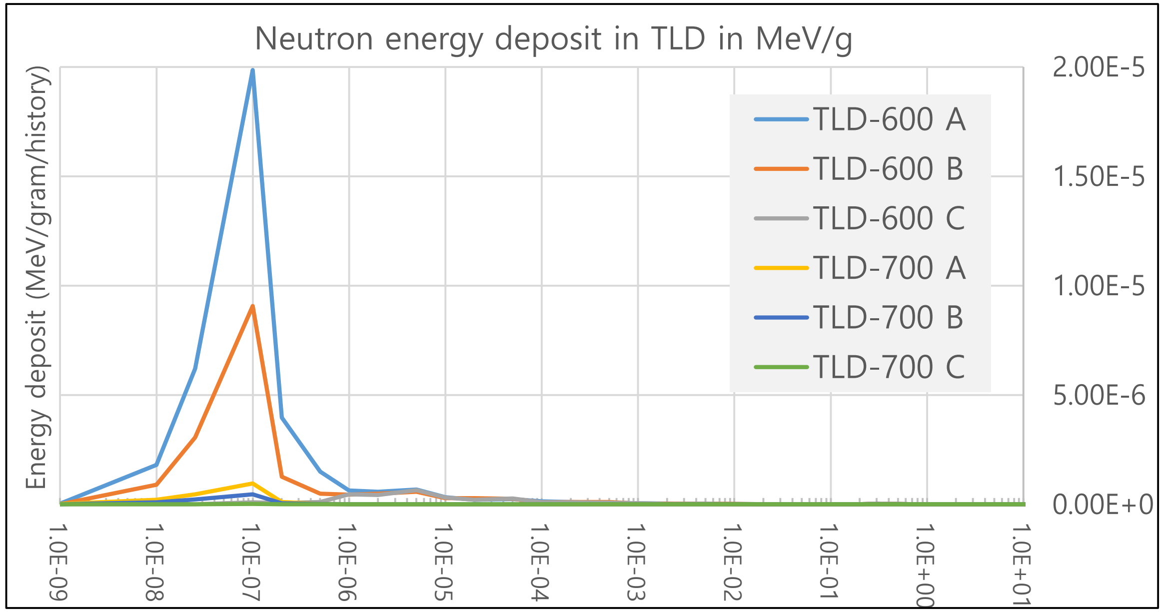


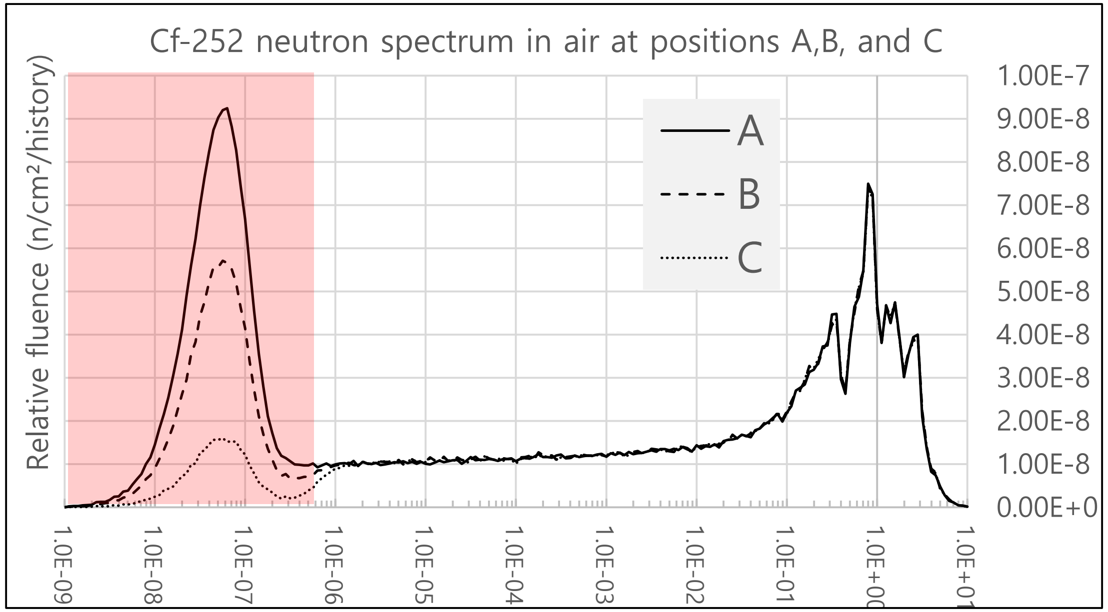




-	Experimental			
Position	TLD-600 signal A.U.	TLD-700 signal A.U.	Neutron signal A.U.	Normalized[1]
A	8.19	3.85	4.34	1
B	5.36	3.13	2.23	0.514
C	3.78	3.29	0.49	0.11
Signal A.U.	Air – Cd (scatter)	2.11	Air - Folded Cd	3.85

Results and discussion – Simulation





-	Simulation			
position	MeV/g/n/history	Normalized[1]	Thermal n/cm²/history	Normalized[1]
A	3.56E-05	1	4.31E-07	1
B	1.83E-05	0.514	2.01E-07	0.466
C	3.19E-06	0.0896	2.32E-08	0.0538
Thermal neutron fluence n/cm²/history	Air – Cd (scatter)	2.30E-7	Air - Folded Cd	4.08E-7

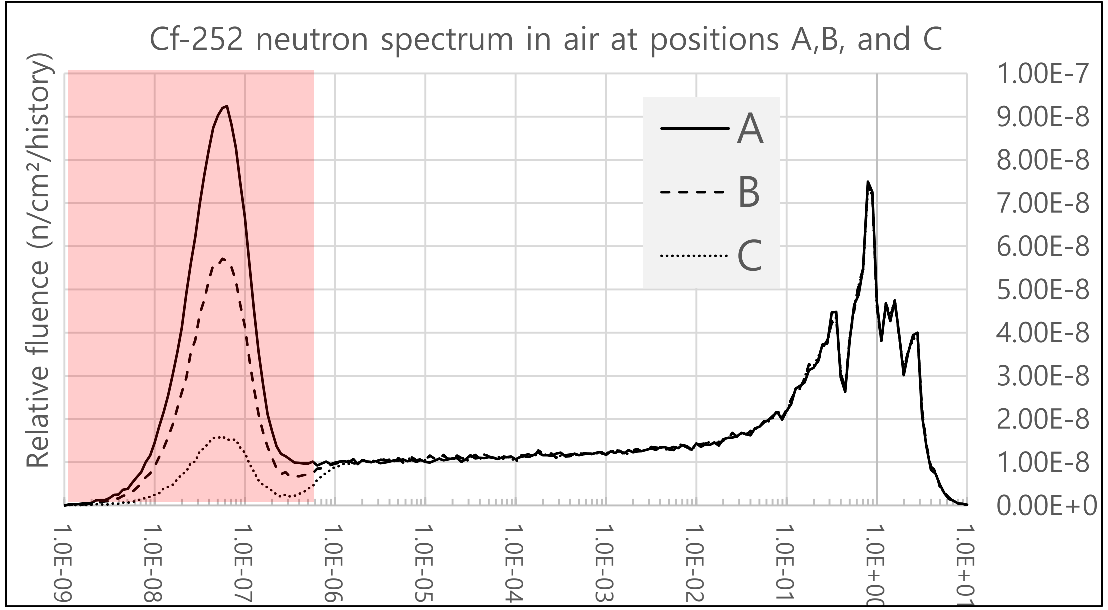
Results and discussion – Neutron fluence

Neutron dose was obtained by using :

DF4 dose modifier card in MCNP to convert neutron flux to ambient dose rate H*(10) in μSv/h according to ICRP-60 recommendations.

$$D_{H*(10)} = \int_{emin}^{emax} h_{*10} \times \mathbf{\Phi}_{*10} \cdot dE$$

The resulting neutron dose rate was 3.585 μSv/h which is with close agreement with the experimental value.



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Thermal neutron fluence n/cm²/history	Air – Cd (scatter)	2.30E-7	Air - Folded Cd	4.08E-7

Conclusion

- The ratios of TLD response in positions A,B,C in experimental vs. simulated energy deposit matched to within < 3%.
- H*(10) was experimentally measured using calibrated LB 6411 neutron probe (3.46 μSv/h).
- Converting simulated neutron flux to neutron dose rate using flux-to-dose conversion coefficient (ICRP-60) yields a dose rate of (3.585 μSv/h). This is in close agreement with experimentally calibrated neutron measurement (3.46 μSv/h).
- We can conclude that this method is sufficient to evaluate thermal neutron fluence as alternative to the complicated activation foil method

Q & A

Thank you for your attention.