Analysis and Improvement of Cyclotron Thallium Target Room Shield

N. Hajiloo, G. Raisali, G. Aslani

Nuclear Science and Technology Research Institute (NSTRI),
Agriculture, Medicine and Industry Research School of Iran.

INTRODUCTION

- **One of the most important radio-nuclides produced by cyclone30 cyclotron, at Agriculture, Medicine and Industry Research School (AMIRS) of Iran is Tl-201.**

- **This radioisotope is generated by bombarding the thick copper substrate electroplated with enriched ^{203}Tl, with 28.5MeV protons, at ~145µA beam current via ^{203}Tl (p, 3n) ^{201}Pb $\longrightarrow$ ^{201}Tl reaction.**

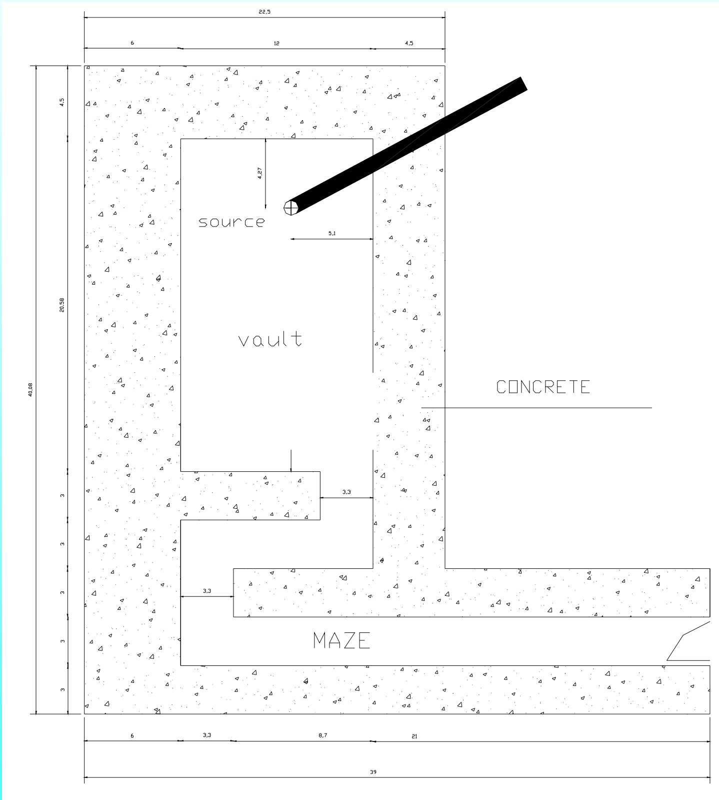
- **The target bombardment results in the production of intense fields of high-energy neutrons and gamma rays.**

- **In order to avoid radiation exposure to cyclotron workers and members of the public, the efficient shielding of the target vault plays an important role in the radiological safety of the cyclotron facility.**

Thallium target vault

- Thallium target vault is a room with ordinary concrete walls and multi-leg maze.
- The thickness of walls changes from 1 to 2m according to their position in the shield. The width of the labyrinth is one meter.
- The maze is the main passage for personnel and equipments towards the target and cyclotron vault.
- In a well-designed maze and shield, the total neutron/gamma dose equivalent, ultimately decreases below the stated dose rate limit value at the maze entrance door and behind the shield.

Geometry setup of thallium target room and its maze



Previous works

- We determined the intensity and energy spectra of neutrons and gamma rays produced during bombardment of a thallium target with 28.5 MeV protons, using SRIM2003 and ALICE codes.
- Neutron and gamma ray source strengths were 1.22E13 n/s and 1.96E13 gammas/s.
- Also we have analyzed the neutron and gamma rays streaming along the maze of thallium production target room. It has been shown that using 28.5 MeV protons, at ~ 145 µA beam current, total neutron and gamma dose equivalent rate at the entrance door is 156µSv/h.

In this work

- **Because of high neutron and gamma ray intensities during thallium target bombardment, thallium target room shield and its improvement have been investigated.**
- **Neutron and gamma-ray leakage dose rates at various points behind the shield have been calculated by simulating the transport of neutrons and photons using Monte Carlo MCNP4C computer code.**

Three designs for enhancing shield performance have been analyzed

- **A shielding door at the maze entrance, covering maze walls with layers of some effective materials and adding a shadow shield in target room in front of the radiation source, have been considered and analyzed.**
- **Dose calculations were carried out for all the considered shielding scenarios separately for different materials and dimensions, then the most suitable shield was selected and built.**

MATERIALS AND METHODS

Monte Carlo transport simulation

- The simulations were performed using Monte Carlo N Particle transport code (MCNP4C), in its coupled neutron-photon transport mode.
- According to previous works, the dose equivalent rate of primary gamma rays falls off very rapidly as we go farther from the target along the maze, therefore in the present work, contribution of the primary gamma rays have been disregarded.
- Two different calculations were performed, one for leakage from shield. And the other was carried out for streamed neutron and gamma ray dose equivalent rates along the maze.

Leakage dose calculation from the shield

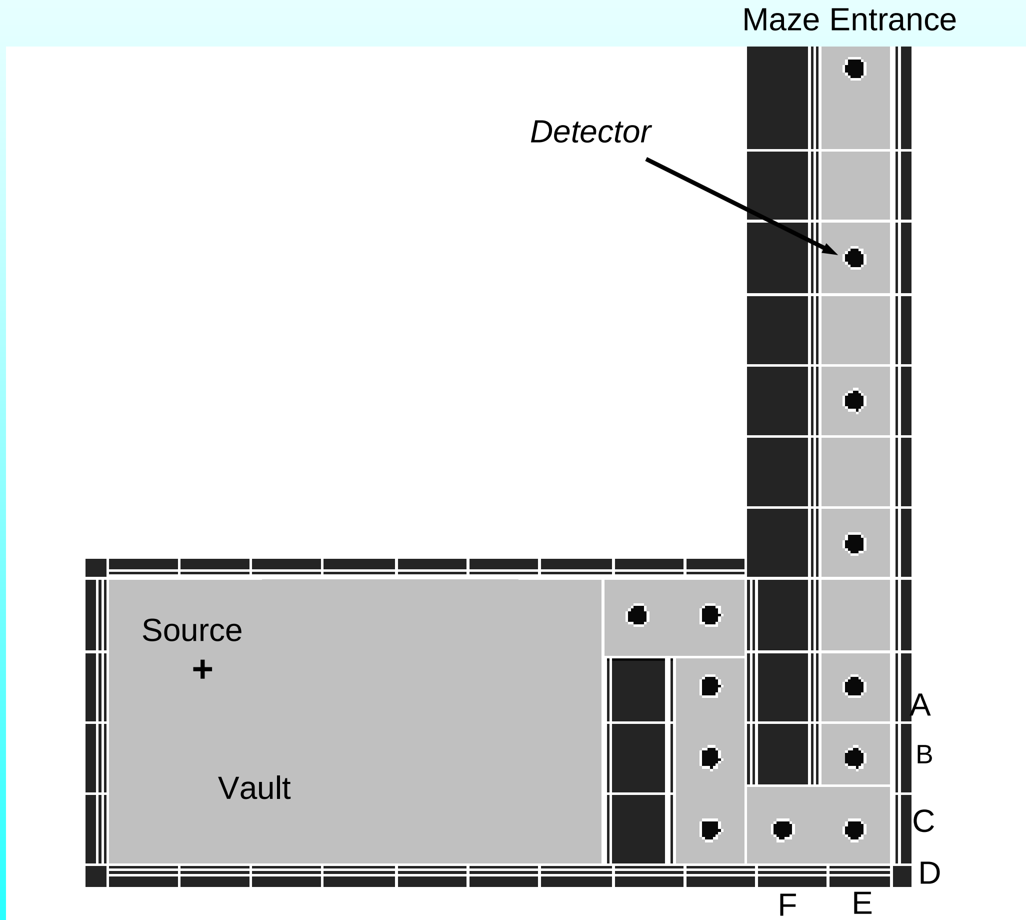
The room and maze walls were first simulated with their initial shape and ordinary concrete. The concrete has been assumed to have a density of 2.35 g cm^{-3}.

- We applied the MCNP code for the neutron source in (n p) mode which gives the dose distribution and energy spectrum of neutrons and secondary gamma rays.
- The results of previous calculations for neutron and gamma ray intensities and spectra in Tl target bombarding with 28.5 MeV protons at 145 µA, have been considered.
- To calculate the leakage neutron and gamma dose equivalents, we have considered several air-filled spheres of radius 15cm, at different positions behind the shield and used the F4 tally and flux-to- dose rate conversion coefficients.

Streamed neutron and gamma ray dose

- **Detectors were located at different points along the maze.**
- **The thickness of walls, floor and ceiling was simulated to be a few tenth of centimeters, instead of real values. This is due to the negligible contribution of neutrons covering forward and backward distances larger than 30cm. This way, the computation time was conveniently reduced. This causes just about %1 deviation from reality.**
- **To better define the radiation field, importance sampling was also applied in the simulations. For this purpose, the room and maze were subdivided into cells of different importances.**

Geometry setup of thallium target room with the position of the employed detectors and splitting surfaces for variance reduction.



Enhancing shield

By considering target room geometry, its associated shield, neutron and gamma ray source strengths and spectra, three designs for enhancing shield performance have been analyzed.

- A shielding door at the maze entrance,
- Covering maze walls with layers of some effective materials
- Adding a shadow shield in the target room in front of the radiation source

Dose calculations were carried out for all the considered shielding scenarios separately for different materials and dimensions

A shielding door at the maze entrance

By assuming a door made from different materials such as:

- Polyethylene,
- Borated polyethylene
- Two-ply iron- polyethylene
- Iron-borated polyethylene,

in different thicknesses, as a shield at maze entrance, the neutron and gamma dose equivalent rates have been calculated at the maze entrance and outside the door.

Covering maze walls with layers of some effective materials

In the other case, we covered the maze walls, with layers of different thicknesses of some effective materials such as

- polyethylene,
- borated polyethylene
- two-ply iron-polyethylene and
- iron-borated polyethylene

and the total neutron and gamma dose equivalent rates have been calculated.

Adding a shadow shield in target room in front of the radiation source

- It was also assessed that by increasing the number of maze bends, the dose equivalent rate of neutron and gamma rays could be decreased. Therefore by assuming a concrete wall in the target room, both in front of the source and parallel to the maze wall, the dose equivalent rates have been calculated for several points along the maze. These calculations were performed for 1, 1.5, 2 and 2.5m of the added wall lengths.
- The calculations for the optimum wall length have been performed for several wall materials, such as paraffin, polyethylene, borated polyethylene and tow-ply wall of iron-polyethylene and iron- borated polyethylene.
- Among the above mentioned materials, the material with maximum reduction of total neutron and gamma dose equivalent rates has been selected as the shadow shield material.
- Dose equivalent rate calculations have been performed for 7.5, 15, 20, 25 and 30cm thicknesses of the selected material.

Measurement of neutron and gamma dose rate distributions

- As reference data, the neutron and gamma ray dose equivalent rates at various positions along the maze and behind the shield walls have been measured using Berthold LB6411neutron dosemeter and Rados RDS-110 gamma dosemeter.
- Duration of measurements was chosen such that the counting statistical errors were lower than 10% for each measuring position.
- All the measurements and calculations have been performed at the center of the maze, 100 cm above the floor.
- The neutron dosemeter was calibrated for Cf-252 neutron source spectrum; therefore the readings at each position have been corrected according to the energy spectrum of neutrons.

- **The correction factor for each position has been calculated using the energy spectrum calculated by MCNP according to equation (2):**

$$F(a) = \frac{\sum_g F_g \varphi_g(a)}{\sum_g \varphi_g(a)} \qquad (2)$$

where F(a) is the overall correction factor at point "a" , F_g is the calibration factor at energy group "g" and φ_g(a) is the neutron flux at the energy group g and position a.

- **The corrected dose equivalent rates are then calculated using equation (3):**

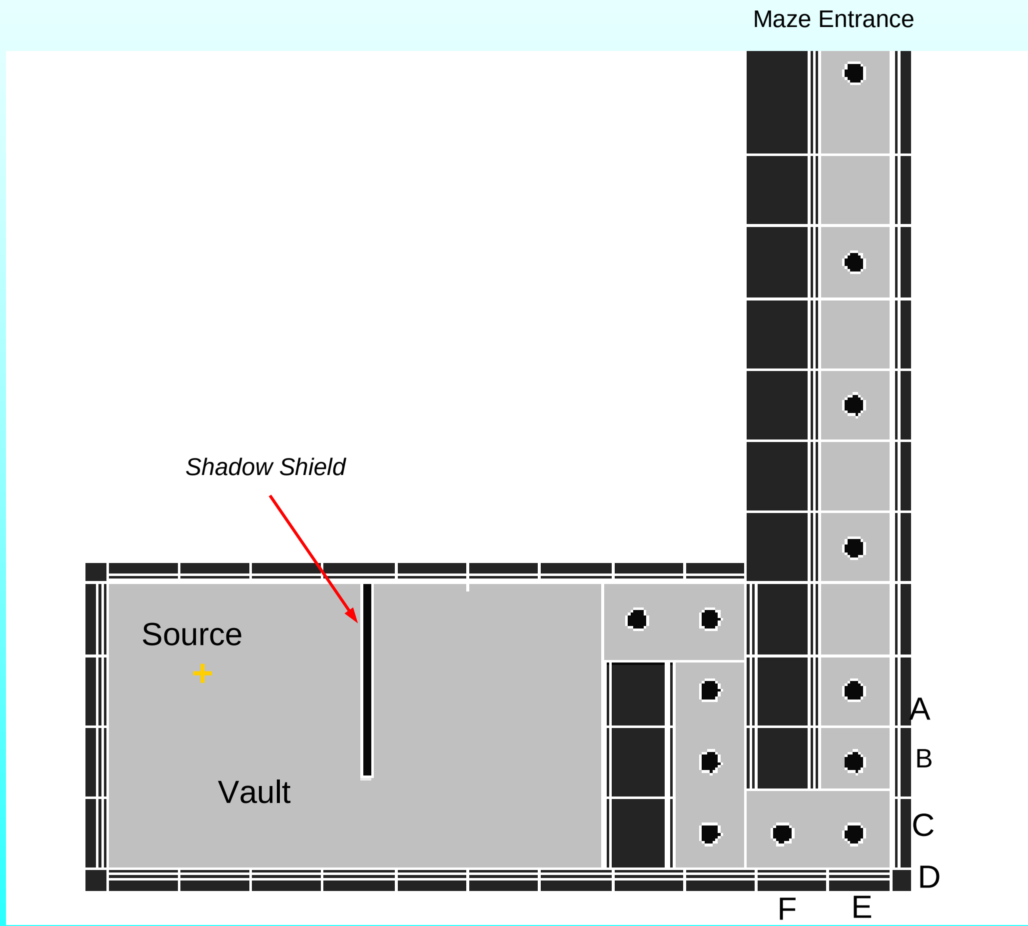
D (a) corrected= F (a) D (a) non-corrected. (3)

- **The gamma dose equivalent rate measurement does not suffer a strong energy dependence as the neutron measurement.**

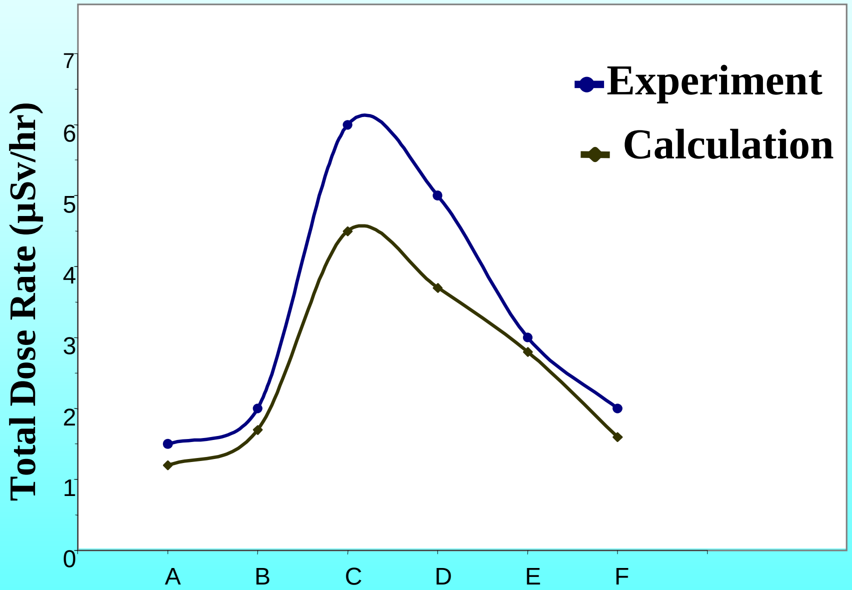
RESULTS AND DISCUSSION

By analyzing the thallium target room and its maze, it was found that:

- **Except for the maze, maximum leakage occurs from the zone shown in figure 1 as “c” (approximately 100cm above the floor, the same height as the source).**
- **Calculations and measurements confirm that the zone “c” has more leakage than other points behind the walls.**


Maze Entrance
Shadow Shield
Source
Vault
A
B
C
D
F
E

Total neutron and gamma leakage dose rates at different positions, during 145μA of 28.5 MeV proton beam bombardment

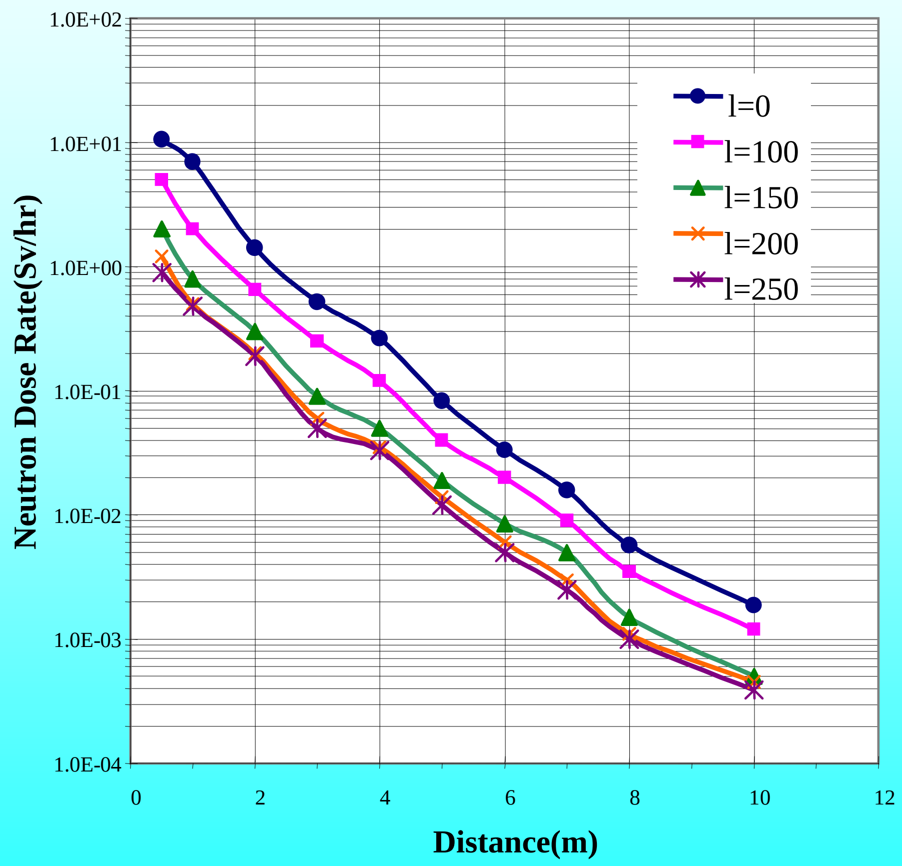


- **Calculations performed with MCNP code showed that by covering the maze walls with polyethylene and borated polyethylene, the reduction of exposure due to neutrons and capture gamma rays is negligible for all the chosen materials.**
- **For further reduction of neutron dose equivalent at the maze entrance, the effect of few centimeters of borated polyethylene liner on the maze door has been investigated.**
- **By considering a shadow-shield in the target room, calculations performed using MCNP code showed that a shadow-shield length of about 2m can reduce dose equivalent rates effectively along the maze.**

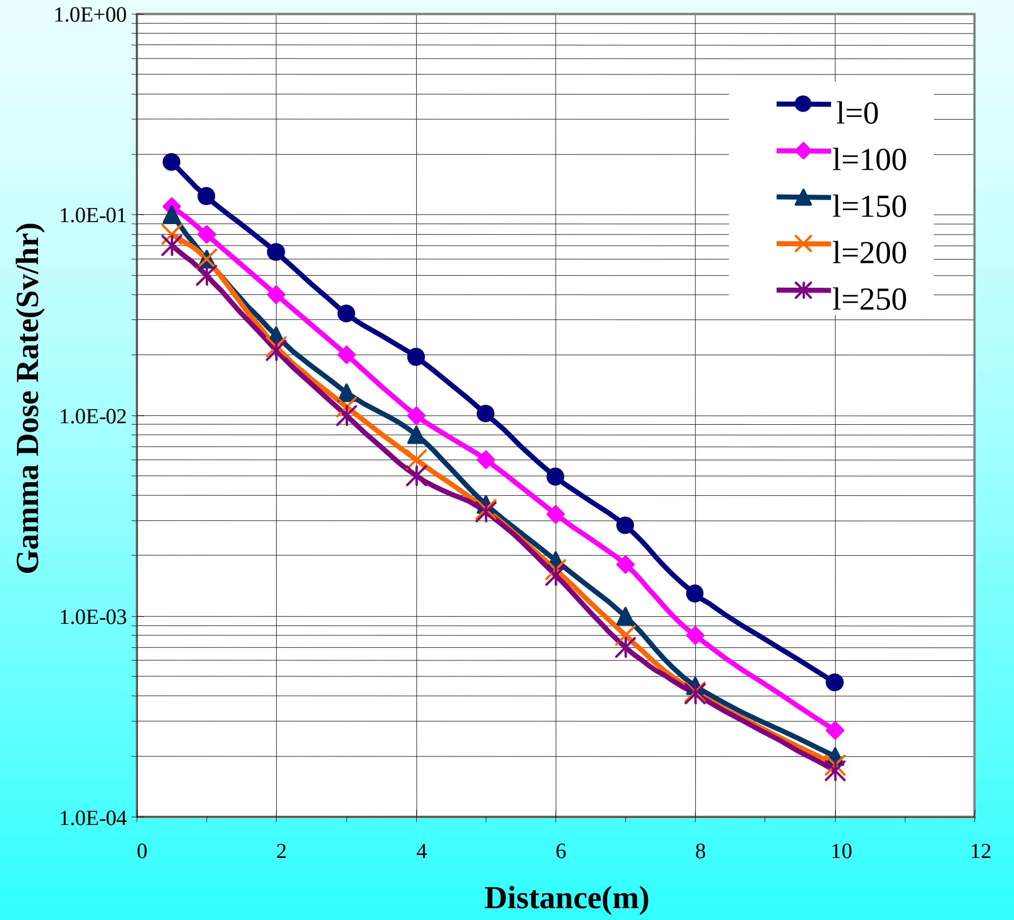
MCNP results for neutron, gamma and total dose equivalent rate at the entrance door for two different thicknesses of shadow shield (3.5 m fixed length) during 145µA 28.5 MeV proton beam bombardment

	Thickness (cm)	Neutron Dose Rate (µSv/hr)	Gamma Dose Rate (µSv/hr)	Total Dose Rate (µSv/hr)	Dose Attenuation Factor
Door	0	109	47	156	1
	2 cm Polyethylene	10	42	52	0.33
	5 cm Polyethylene	6	35	41	0.26
	10 cm Polyethylene	0.3	28	28.3	0.18
	5 (3cm Polyethylene + 2cm Iron)	6.16	16.7	22.86	0.15
	7.5 (5cm Polyethylene + 2.5cm Iron)	5.5	15	20.5	0.13
	10 (5cm Polyethylene + 5cm Iron)	5.5	12	17.5	0.11
	12.5 (5cm Polyethylene + 7.5cm Iron)	5	9	14	0.08
Shadow Shield	7.5 cm Polyethylene Shadow Shield	25	24	49	0.31
	15 cm Polyethylene Shadow Shield	14	10	24	0.15

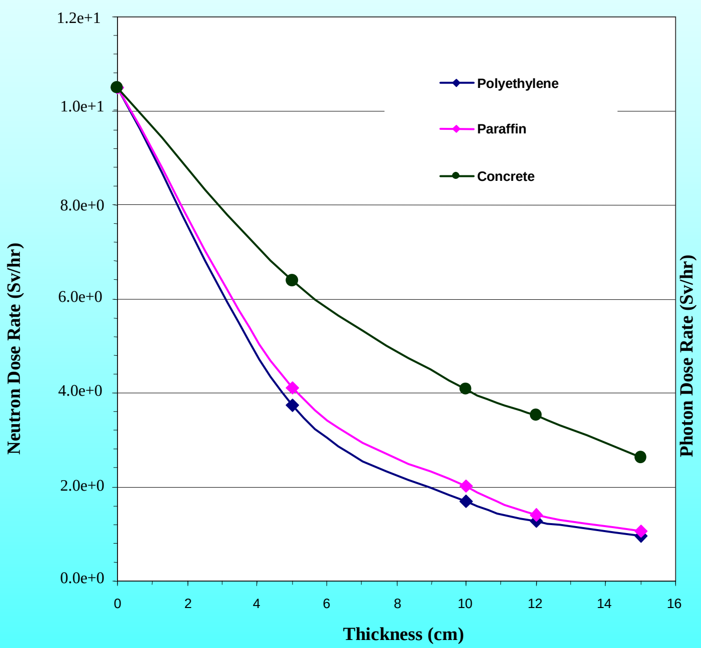
Neutron dose equivalent rate at various points along the maze for a polyethylene 30 cm thick shadow shield with four different lengths (MCNP results)

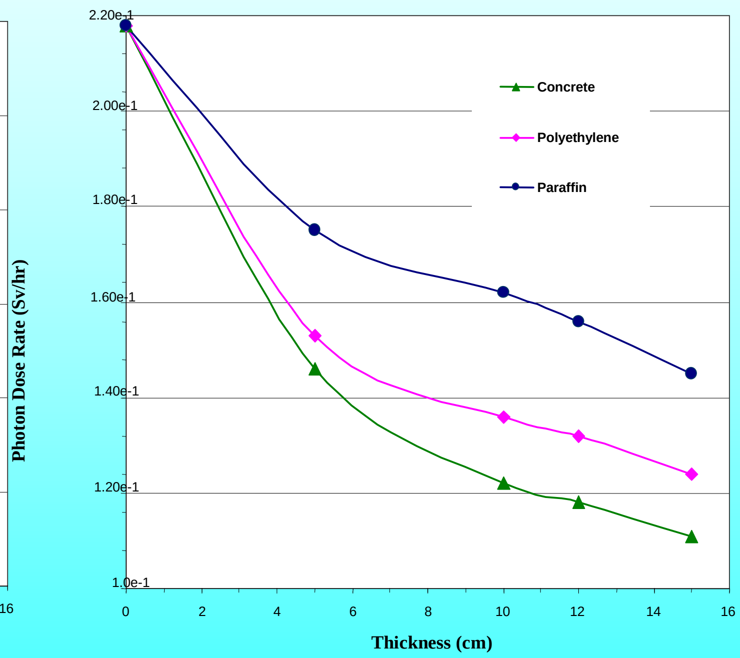


Gamma dose equivalent rate at various points along the maze for a polyethylene 30 cm thick shadow shield for four different lengths (MCNP results)

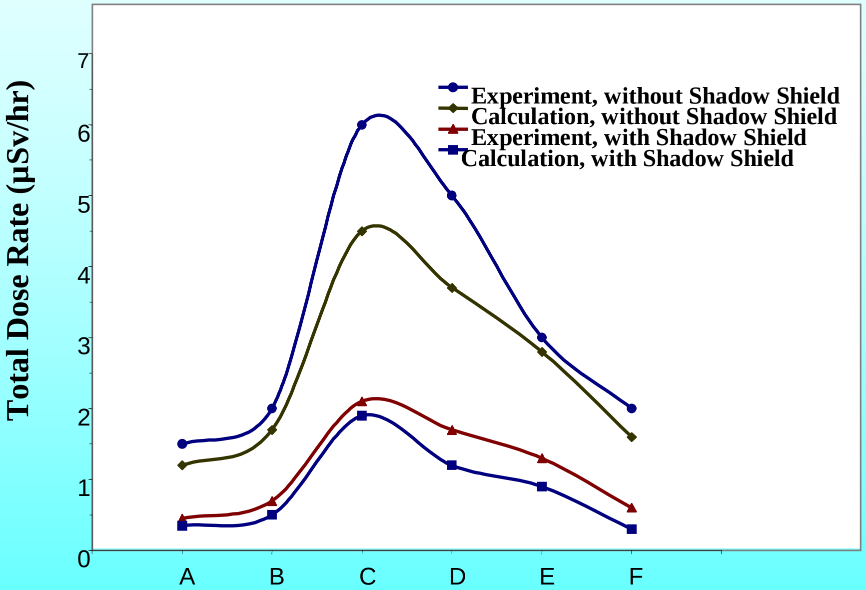


Comparison of neutron and photon dose equivalent rates behind the shadow shields of different materials: concrete, paraffin and polyethylene for the same shield length and various thicknesses (MCNP results)





Total leakage neutron and gamma dose rates at different positions, during 145μA 28.5 MeV proton beam bombardment



CONCLUSIONS

- The shielding analysis of the thallium target room and its maze, showed that the maximum neutron and gamma leakage is due to streaming through the maze.
- Except for a small region behind the shield where the total neutron and gamma dose equivalent rate is 6μSv/h, the dose rates at any point behind the shield are negligible.
- To evaluate the radiation leakage as a function of position, we investigated three kinds of shields to reduce leakage values:

1- Sheets of borated polyethylene or iron- borated polyethylene on the maze entrance door,

2- A shadow shield of polyethylene in the target room and addition of one more bend in the maze,

3- Overlaying the maze walls with a neutron absorbing material.

Shadow shield was preferred to the two others:

- **Because of its ability to reduce both neutron and gamma dose equivalent rates at maze entrance position and position “c”.**
- **Its application significantly reduces the leakage dose rate behind the shield.**
- **By setting up a polyethylene shadow shield (7.5cm thickness and 3.5m length) the total dose equivalent rate at the maze entrance and behind the shield (position “c”) is reduced by a factor of 3.**
- **Calculations and measurements are in satisfactory agreement.**


Thanks for your attention