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Prompt and Residual Radiation Fields due to Beam Termination in the Beam Collectors for DTL Tank 2-6 Commissioning

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Introduction

For the commissioning phase, the doses in the vicinity of the DTL were investigated for the scenarios of running a 160 W proton beam into the beam collectors located at the downstream end of the DTL tanks. For calculating the residual dose, activation scenarios of 10 days of continuous operation at 160W power, and a decay time of 1 hour after terminating the beam were considered for each step of commissioning.

Methodology

Monte Carlo transport calculations were performed using the MCNPX[1] code, simulating the generation of secondary radiation fields due to the impact of proton beams on beam collectors.

The isotope production rates resulting from the MCNPX calculations were fed into the Activation Analysis System[2] (AAS) to obtain the time dependence of the isotope buildup and decay for the given commissioning scenarios, and to extract gamma decay spectra for all material cells in the problem.

These gamma decay spectra were used as sources for subsequent MCNPX transport analyses for calculating the residual gamma flux distributions and residual dose equivalent rates in the vicinity of the beam collectors.

Model

For the analysis, a DTL model composed of the six DTL tanks located in the accelerator tunnel was built that included the drift spaces and beam collectors located between the DTL tanks (see Fig. 1). The drift spaces between the tanks increase in length with increasing tank number. The beam collectors were modeled as 8 cm diameter sandwich of discs with an energy-adjusted absorber layer thickness of graphite or copper as listed in Table 1, followed by a collector layer of 6-mm-thick copper layer in a water-cooled copper housing. The beam collector sandwiches were designed to completely range out the incident protons.

The DTL tanks were modeled as vessels with 28 cm outer radius SS316 vessel with 7.5-cm-thick side walls and 1-cm-thick end walls, and with a length of 6.3 meters except for tank #1 which was 4.3 meters long. The lined up drift tubes in the tanks were homogenized to 8 zones extending throughout the length of the tank.

Table 1: Absorber thickness and materials of the DTL beam collectors.

Collector No.	Proton energy (MeV)	Absorber thickness	Absorber material
1	7.5	0.409 mm	graphite
2	22.3	3.036 mm	graphite
3	39.8	8.299 mm	graphite
4	56.6	4.197 mm	copper
5	72.5	6.546 mm	copper
6	86.8	9.139 mm	copper

Sources

The source were input as pencil proton beams incident to the beam collectors with proton energies and currents as listed in Table 2 for each of the commissioning steps. Beam losses were not considered, as they were believed to be negligible compared to the 160 W beam power deposited into the beam collectors.

Table 2: Proton pencil beam parameters for the commissioning steps.

Commissioning step	Proton energy (MeV)	Proton current (p/s)	Beam power (W)
2	22.3	4.48e13	160
3	39.8	2.51e13	160
4	56.6	1.77e13	160
5	72.5	1.38e13	160
6	86.8	1.15e13	160

For the activation calculations it was conservatively assumed that the DTL structure and the beam collectors were continuously exposed to a 160 W beam power for 10 days.

Radiation sources due to the RF system, namely x-ray generation from electron dark currents, were not included in this study.

Calculations and Results

The prompt and residual doses profiles along the accelerator tunnel were calculated at 60 cm radius from the beam axis (corresponding to 30-cm distance from the DTL tanks) averaged over 1-meter-long segments. The dose equivalent values were obtained by folding the energy dependent flux-to-dose conversion coefficients taken from the

HILO2k library with the neutron and gamma flux spectra. The results are presented in Figs. 3 and 4. The prompt dose levels consist of both neutron and gamma contributions (the neutron contributions are generally dominating) whereas for the residual doses only the decay gamma contribution is present.

The dose profiles peak near the positions of the beam collectors, starting out with prompt peak dose levels of about 20 rem/hr for commissioning DTL tank2, ramping up to 200 rem/hr and 2000 rem/hr for tanks #3 and #4, respectively. The reason for this sharp increase is seen in the increase of the neutron production rates for the increased final energies of the different commissioning steps (see Table 2). For tanks #5 and #6 the dose levels increase only slightly to 3000 rem/hr indicating that the increase of the neutron production rates due to the increased final beam energies is more or less compensated by the reduction of the beam current by having the beam power fixed to 160 W.

The residual dose profiles (10 days of operation at 160W and 1 hour after beam termination) are reduced by a factor of 10,000 for the tanks #4-6 resulting in peak doses of 200-300 mrem/hr near the beam collimators. The residual dose levels at tanks #3 and #2 are suppressed to peak at levels of 5 and 0.2 mrem/hr, respectively, indicating reduction factors even higher than 10,000 compared to the prompt dose levels.

The time behavior of the gamma power of the beam collimators including the nearby DTL tank walls is presented in Figs. 5 and 6 for the commissioning steps of DTL tank #3 and #5, respectively. The dose levels around the beam collimator following DTL tank #3 will not fall significantly within weeks. The dominating radioactive nuclide is Be-7 in the graphite absorber layer that has a half-life of 53 days. With a drop of the gamma activity of a factor of 50 within a day, the time characteristic of the gamma activity and hence of the residual dose is completely different for the beam collimator following DTL tank #5, as the absorber layer of the beam collimator is fabricated of copper. Thus this decay characteristic, which will result in acceptable dose levels after one day of decay time, is also representative for commissioning of DTL tanks #4 and #6.

Mesh tally dose evaluations were done simultaneously with the regular tallies for the vicinity of the beam collectors to get dose contours with finer spatial (5 cm radial and 5 cm axial) resolution and more accurate peak dose values, for all commissioning steps. Both for the prompt and the residual radiation fields show very distinct dose distributions that peak radially extending from the beam collimators. Dose equivalent contour maps are provided for DTL tank #3 commissioning in Figs. 7 and 8, and for DTL tank #5 in Figs. 9 and 10. The contour maps confirm the dose levels obtained by the regular tallies and show that the DTL tank structures act very well as radiation shields.

References

1. H. G. Hughes et. al., “MCNPX for Neutron-Proton Transport,” International Conference on Mathematics & Computation, Reactor Physics & Environmental Analysis in Nuclear Applications, American Nuclear Society, Madrid, Spain, September 27-30, 1999.

2. N. Odano et al., “Development of the Activation Analysis Calculational Methodology for the Spallation Neutron Source (SNS),” 1998 ANS radiation Protection and Shielding Division Topical Conference, American Nuclear Society, Nashville, Tennessee, April 19-23, 1998; and Greg McNeilly, “AAS-Activation Analysis System”, SNS-101040200-TR0003R00, UT-Battelle (1999).

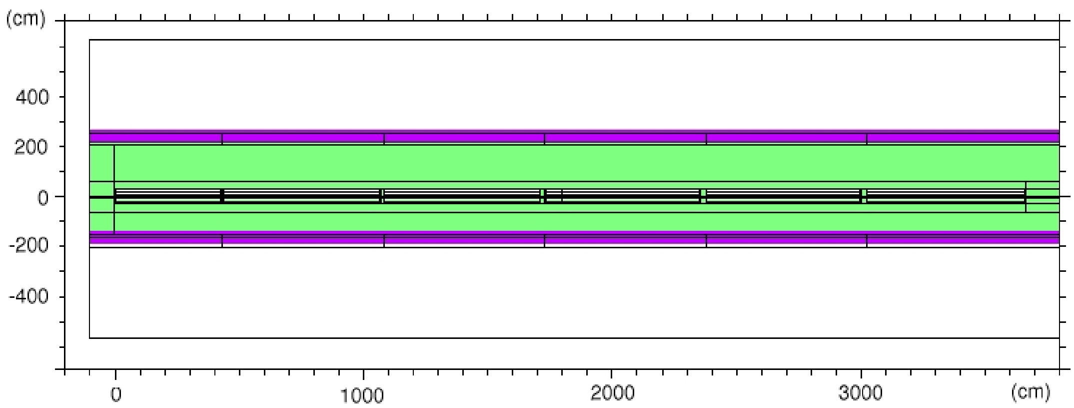

Fig. 1: Horizontal cut through the DTL and the accelerator tunnel at the nominal beam axis.

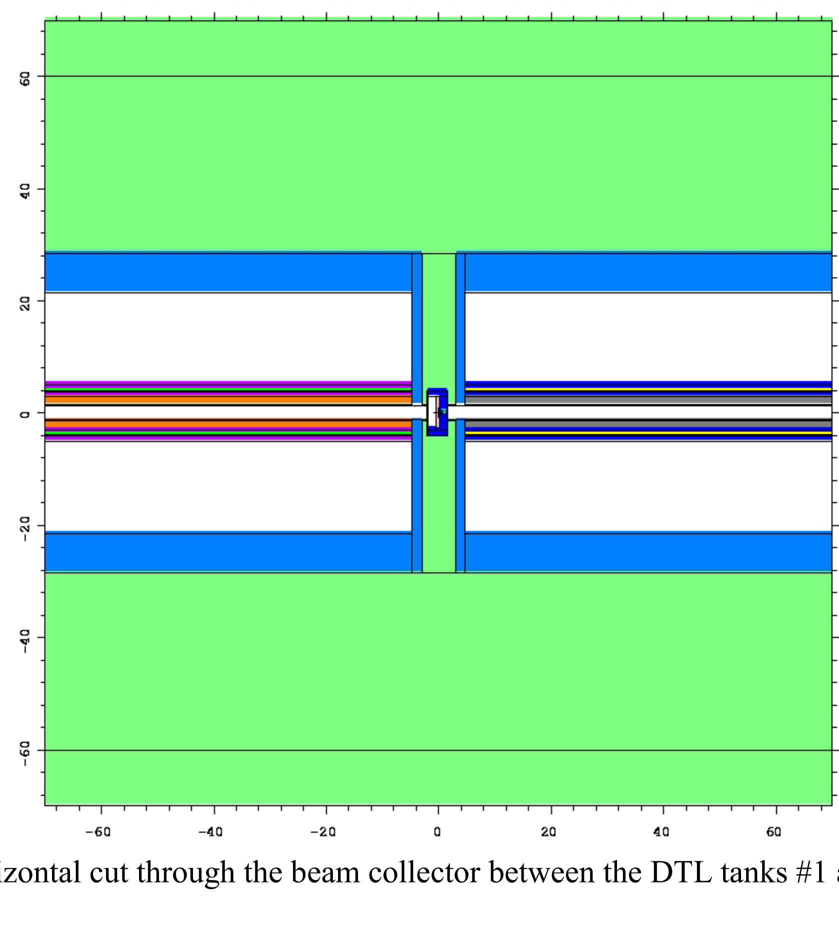

Fig. 2: Horizontal cut through the beam collector between the DTL tanks #1 and #2.

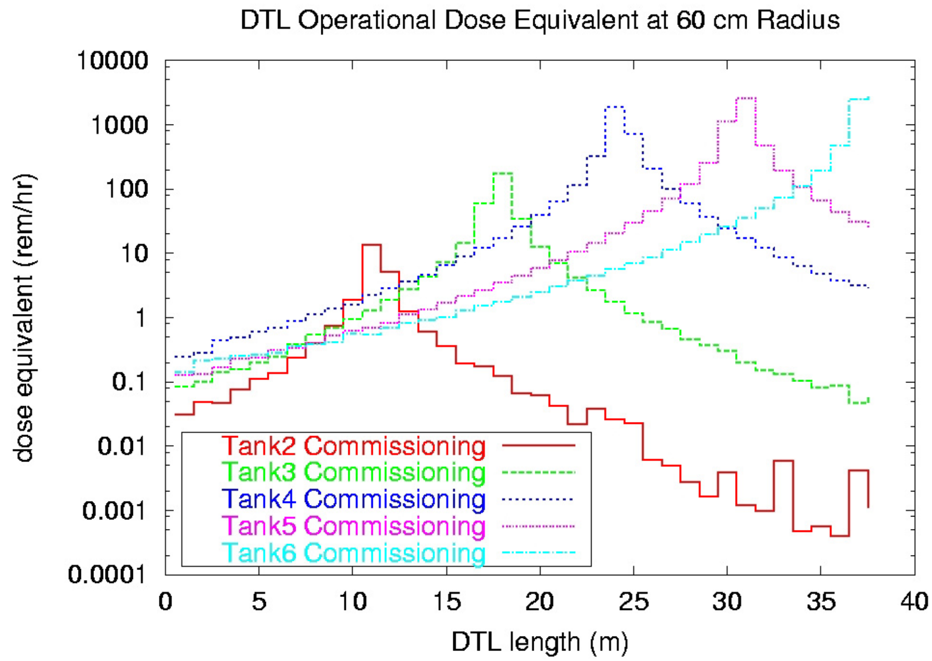

Fig. 3: Prompt dose equivalent profiles (neutrons+gammas) in the accelerator tunnel at 30 cm distance from the DTL structure assuming 160 W beam power impinging on the beam collimators at the exit of the DTL tank to be commissioned.

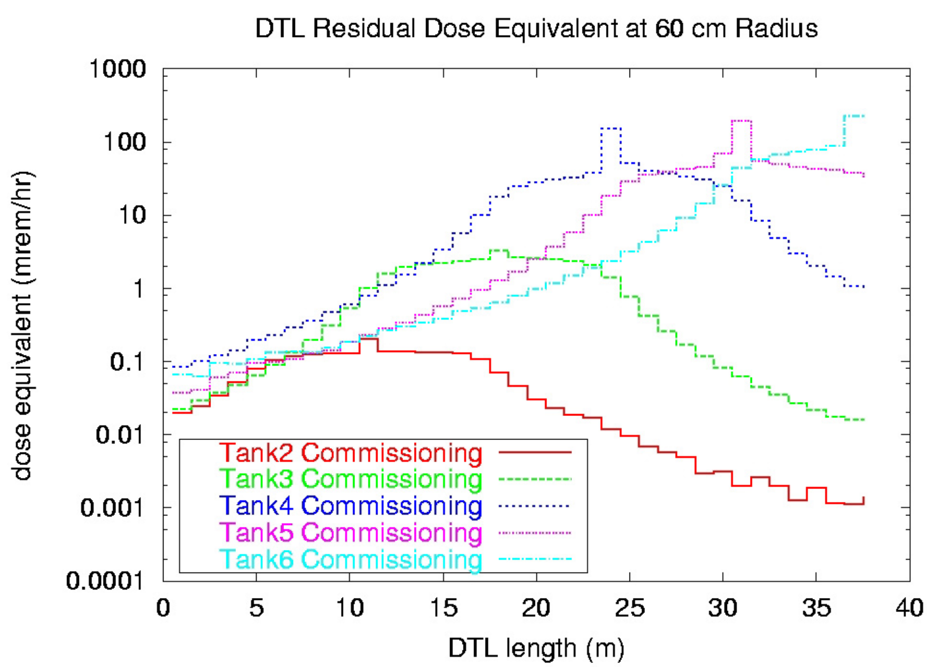

Fig. 4: Residual dose profiles in the accelerator tunnel at 30 cm distance from the DTL structure assuming 160 W beam power impinging on the beam collector at the exit of the DTL tank to be commissioned for 10 days, and a 1 hour decay period after beam termination.

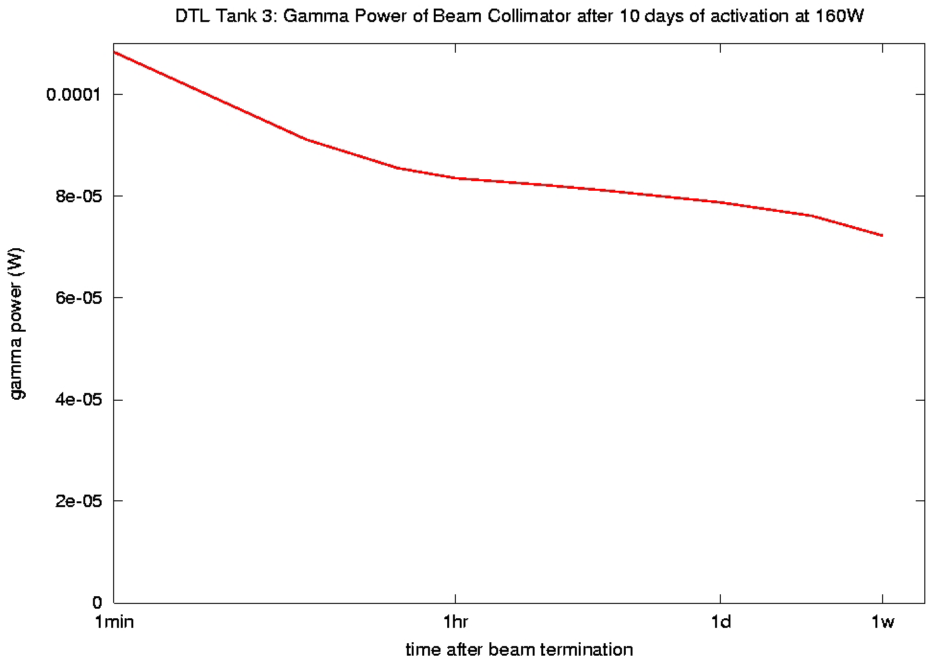

Fig. 5: Gamma decay power of the beam collector between DTL tanks #3 and #4 for 10 hour irradiation at 160 W beam power at a beam energy of 39.8 MeV.

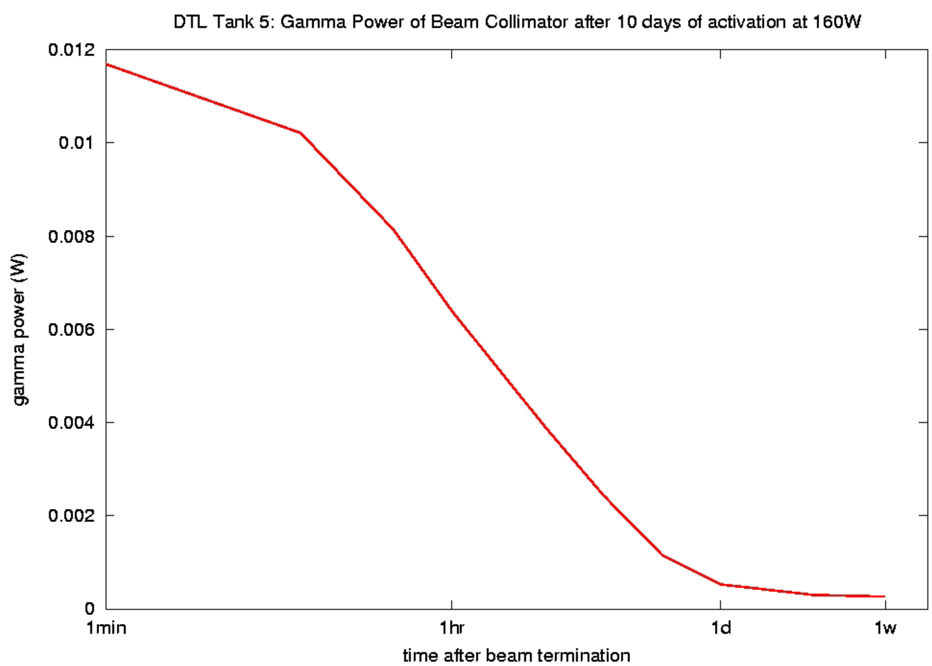

Fig. 6: Gamma decay power of the beam collector between DTL tanks #5 and #6 for 10 hour irradiation at 160 W beam power at a beam energy of 72.5 MeV.

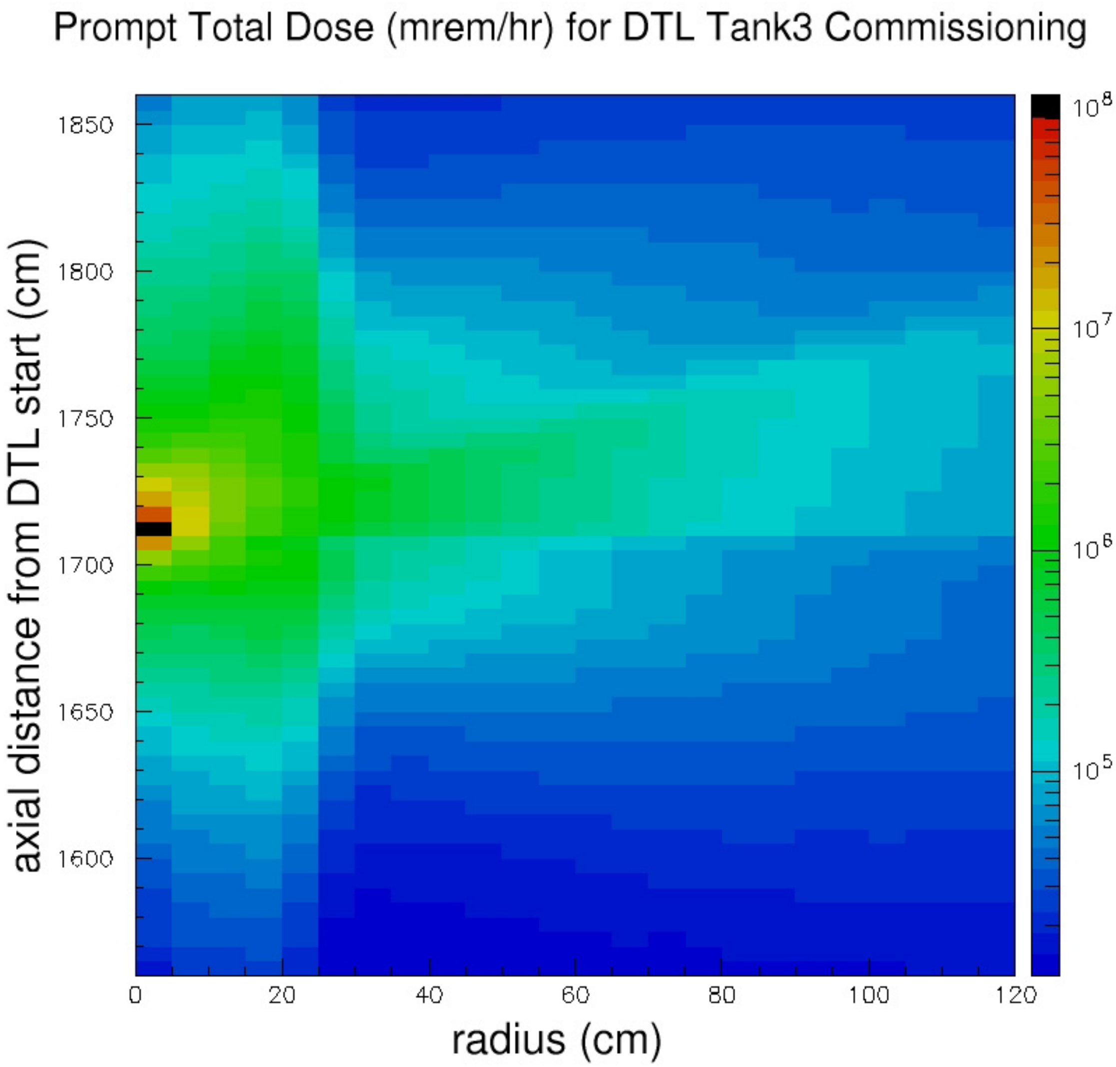

Fig. 7: Dose contours (neutron+gamma dose) in the vicinity of the beam collector for DTL tank #3 commissioning having 160 W beam power impinging the collector.

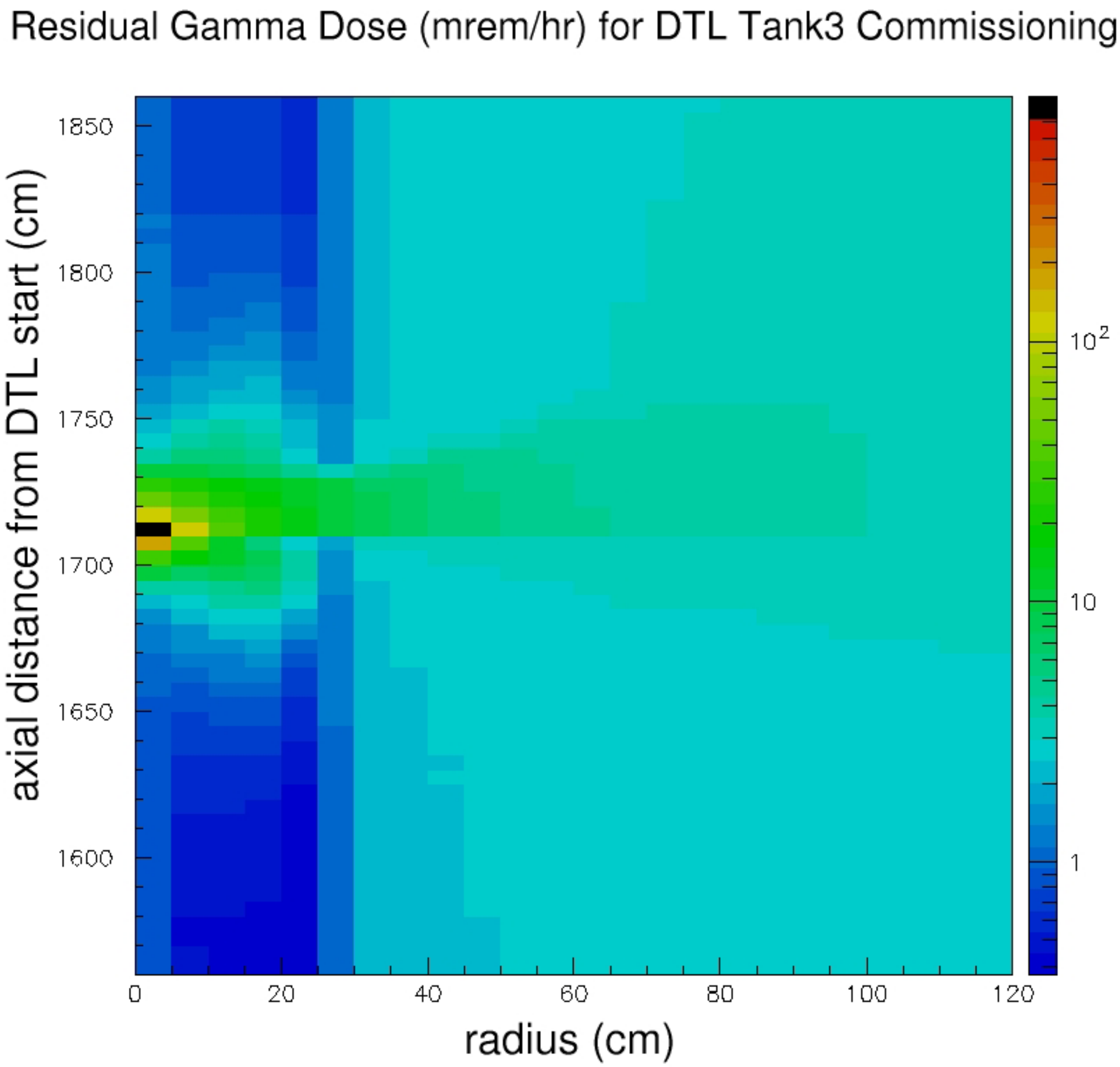

Fig. 8: Contours of residual doses in the vicinity of the beam collector for commissioning the DTL tank #3 one hour after beam termination after irradiation of the collimator at 160 W beam power for 10 days.

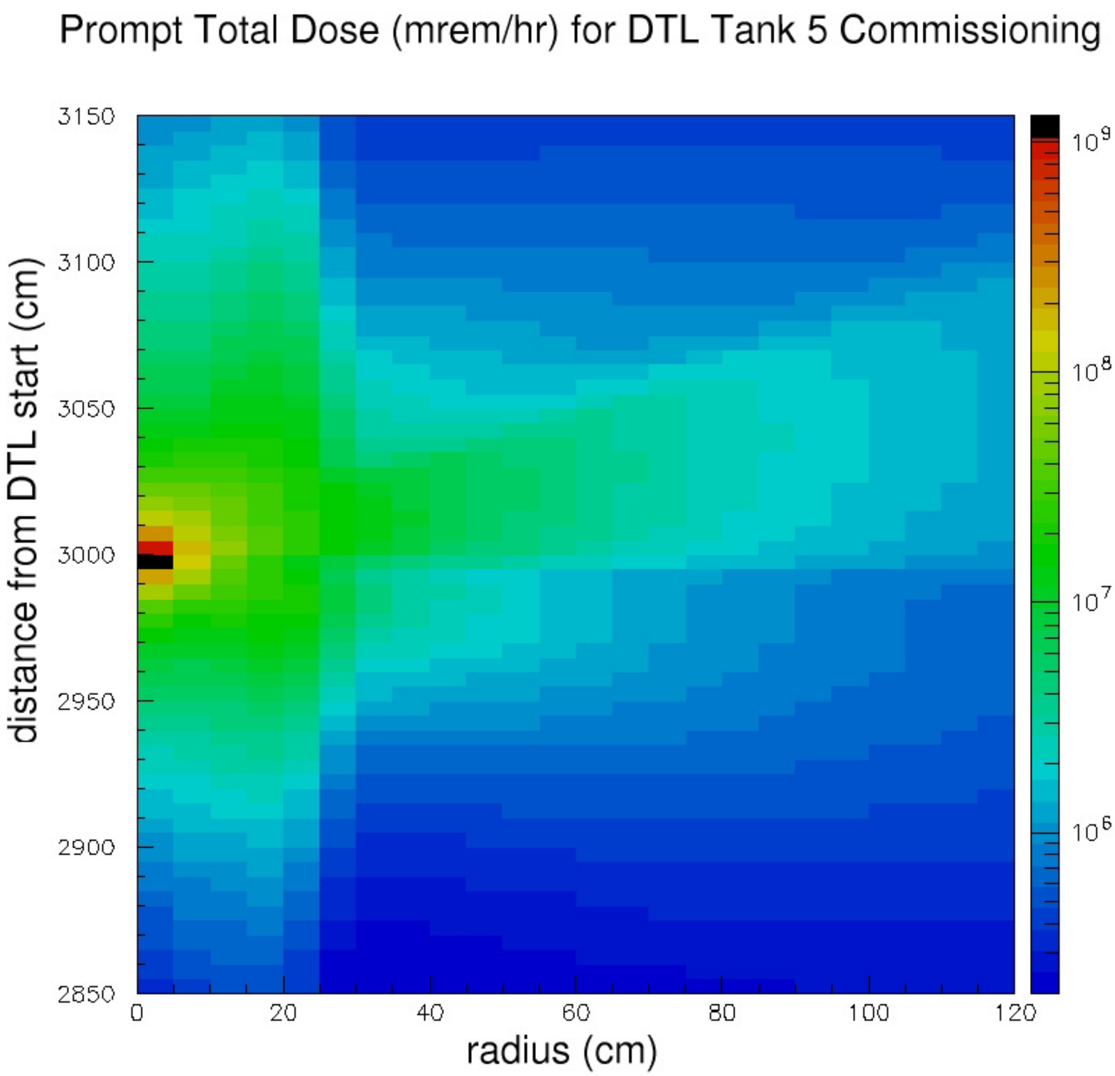

Fig. 9: Dose contours (neutron+gamma dose) in the vicinity of the beam collector for DTL tank #5 commissioning having 160 W beam power impinging the collector.

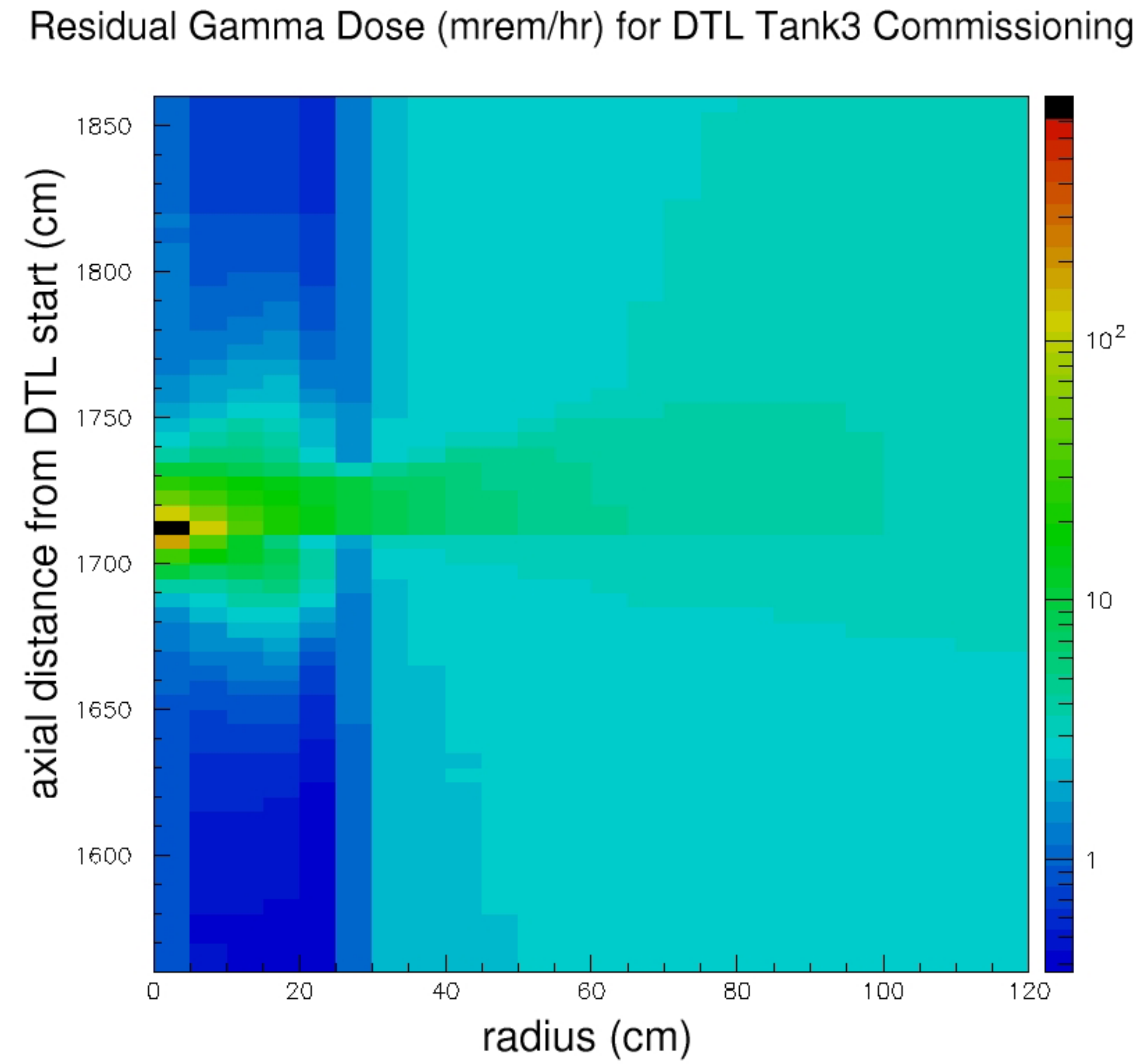

Fig. 10: Contours of residual doses in the vicinity of the beam collector for commissioning the DTL tank #5 one hour after beam termination after irradiation of the collimator at 160 W beam power for 10 days.