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# RADIATION STUDIES IN THE COLLIMATOR REGIONS OF THE ATLAS EXPERIMENTAL AREA

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**Abstract**

In order to shield the superconducting inner-triplet quadrupoles from particles originating from the p-p collisions, copper collimators will be inserted 19 metres from the LHC high luminosity interaction points. Consequently, the collimators and surrounding material will become radioactive. This note reports on results obtained in evaluating the dose rates due to the induced activities, an important parameter in defining handling, maintenance and storage procedures. Monte-Carlo simulations have been made using DTUJET93 to generate $7 \times 7$ TeV p-p events, FLUKA97 to follow the hadronic cascades induced in the collimator regions and FIASCO to calculate the dose due to induced activity.

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## 1. Introduction

According to the event generator DTUJET93 [1] over 95% of the energy originating from p-p events is carried by particles having an absolute pseudorapidity* $|\eta| > 5.0$ ($\theta < 0.77$ degrees). To protect the superconducting inner-triplet quadrupoles from quenching, copper collimators/absorbers will be inserted 19.0 m on both sides of the LHC high luminosity interaction points (ATLAS and CMS). The collimators cover a pseudorapidity range $5.0 < |\eta| < 7.8$ and will intercept a significant fraction of the p-p event energy. The front-faces of the first inner-triplet quadrupoles are positioned 23.0 metres from the interaction point (version 5.0 optics). The hadronic cascades generated in the collimators and surrounding shielding will produce gamma-emitting radionuclides; a determination of the resulting dose rates will be required for defining handling and maintenance procedures employed in these regions. A knowledge of the dose rates will also be necessary for determining the short and long-term storage requirements of materials removed during shutdowns or decommissioning.

This note reports on results obtained in evaluating the dose rates from induced activities in the collimator, the surrounding shielding and the adjacent vacuum equipment. Results are given for the following cases:

- Calculation of contact dose rates in the collimator; obtained directly by using empirical factors ($\omega$-factors) to relate star-densities, scored by FLUKA97 [2], to contact dose rates.
- Determination of dose rates, using FIASCO † [3], in the vacuum equipment regions adjacent to the collimator with the shielding and collimator in place.
- Determination of dose rates, using FIASCO, in the vacuum equipment regions adjacent to the collimator with the collimator in place but with some of the shielding removed (as will be required for detector maintenance or removal).

Although it is envisaged to use the same types of collimator and inner-triplet for both the ATLAS and CMS experiments, the scenarios for removing the collimator and shielding are likely to be different. This means that the results obtained in the first two cases above are applicable to both ATLAS and CMS, but those obtained with some of the shielding removed are specific to ATLAS.

## 2. The Simulations

### The DTUJET and FLUKA Codes

The DTUJET93 code has been used to generate the $7 \times 7$ TeV p-p events, predicting an inelastic cross-section of 80 mb (including diffractive events). This gives a p-p collision rate of $\sim 10^9$ s$^{-1}$ for the LHC design luminosity of $\sim 10^{34}$ cm$^{-2}$ s$^{-1}$, and an average total multiplicity of 123 particles per p-p collision. The FLUKA code transports the particles generated by DTUJET93 through the material regions of interest, simulating particle cascades from TeV energies down to keV energies (except neutrons which can be transported down to thermal energies). The FLUKA code has been benchmarked against experimental data over a wide energy range for both hadronic and electromagnetic showers [4, 5, 6, 7, 8, 9]. For the present study the latest version of FLUKA has been

*Pseudorapidity is defined by $\eta = -\ln(\tan\theta/2)$, where $\theta$ is the angle with respect to the beam axis.
†**F**luka **I**nduced **A**ctivity **S**hielding in **CO**mbinatorial geometry.

used to estimate the number and distribution of the inelastic hadronic interactions (stars) having energies greater than 50 MeV. A total of 25000 DTUJET93 secondaries with $|\eta| > 3.5$ have been transported.

### Induced Activities and the FIASCO Code

$\omega$-factors are commonly used to relate star-densities, calculated by hadron cascade codes, to contact dose rates. They are usually defined for 30 days of irradiation and 1 day of cooling ($\omega$(30,1)); a value of $1 \times 10^{-8}\,\mathrm{Sv\,h^{-1}/(cm^{-3}s^{-1})}$ is typically used, as suggested in [10]. The basic idea behind the $\omega$-factor is that radionuclide production depends on the number of inelastic hadronic interactions at high energies. Some experimental observations [11] indicate a lower $\omega$ value (by a factor of $\sim 2$) so that the above value can be considered conservative.

In complicated multi-shield problems it is necessary to take into account dose build-up and photon attenuation; otherwise there can be significant differences in the true dose rates when compared to contact dose rates. The FIASCO code was written to address this problem and, for each point where dose is to be scored, computes an integral over the volume of the geometry taking into account photon attenuation. It is interfaced to FLUKA so that that path-lengths needed for the integral can be taken, as well as the required material and compound properties (photon attenuation data etc.). The FIASCO input requires a star density map from a full FLUKA simulation.

## 3. Description of the geometry.

For these studies, of interest are the forward regions of the ATLAS experimental cavern. Figure 1 shows the geometry constructed in FLUKA and includes (from left to right):

- the ATLAS beampipe. The design has not yet been finalised so details have been taken from the latest working plan [12] dated 15/07/97; materials used are beryllium, aluminium and steel.
- the ATLAS forward calorimeters (FCAL). These are the only parts of the ATLAS detector contained inside the $|\eta| > 3.5$ cones. Each one comprises three calorimeter modules (one made of copper and two of tungsten) and a copper plug. Details have been taken from the technical design report [13].
- copper shielding inside the magnet toroid and iron shielding around the collimator. The purpose of this shielding is to keep the radiation levels in the cavern down to reasonable levels. Details have been taken from the latest design proposal [14]. The outer part of these shields will probably be replaced with materials to further reduce the neutron and gamma fluxes; however this is not relevant for the current radiation studies close to the collimator region.
- the collimator and adjacent vacuum equipment (valves and pumps). The copper collimator is positioned 1900 cm from the interaction point. Current design parameters [15] are: length = 180 cm; external diameter = 50 cm; aperture = 3.4 cm. On either side of the collimator is the vacuum equipment, comprising sector valves, pumps and flanges. It is in this region where maintenance operations will be required.

- the inner-triplet cryostat with the first quadrupole and beam position monitor. Both remote and manual handling of the vacuum equipment and monitors positioned between the collimator and quadrupoles may be difficult due to the limited working space available. A correct assessment of the hazards requires an accurate determination of the radiation levels in this area.

## 4. Results

All the dose rates are given for 30 days of irradiation and 1 day of cooling. A p-p interaction rate of $10^9$ $s^{-1}$ is assumed and a track selection cut of $|\eta|$ >3.5 is applied for the particles transported in FLUKA97. Dose rates corresponding to alternative irradiation and cooling times, $t_i$ and $t_c$ respectively, can be obtained using the time dependence part of the Sullivan-Overton formula [16]:

$$D(t_i, t_c) \propto \ln\left(\frac{t_i + t_c}{t_c}\right)$$

The Sullivan-Overton formula gives reasonably correct answers for materials with medium atomic masses and for cooling times greater than $\sim$ 30 minutes.

Shown in Figure 2 are the contact dose rates as a function of collimator length for different radii. Of particular importance for radiation protection are the dose rates on the outer surface of the collimator. A maximum contact dose rate of $\sim$ 0.3 Sv/h is predicted close to the centre of the front-face and $\sim$ 0.02 Sv/h at the outer layer at a depth of $\sim$ 40 cm. The star densities used to obtain the contact dose rates can be compared to those obtained in a previous study [17] in 1992 in which the LHC experimental areas were approximately modelled. The position and dimensions of the collimator were similar to those used in the present study; however, the bin-volumes used for star-scoring were much larger. This means that a comparison requires an averaging over the smaller volumes used in the present study to obtain similar bin-sizes. When this done, a value of 2.12 $\times$ $10^{-3}$ stars $cm^{-3}$ is obtained for the present study, compared to the estimated value of $\sim$ 2.0 $\times$ $10^{-3}$ in [17]. Considering older versions of DTUJET and FLUKA were used to score stars in collimators and low-$\beta$ quadrupoles, this agreement is remarkable, indicating the consistency of such calculations.

Figure 3 shows the residual dose rates in and around the collimator region. The colour data represent contact dose rates, so the values obtained for the collimator correspond to those obtained in Figure 2. Dose rates have also been calculated at various points around the gate-valves, pumps and flanges using FIASCO. In front of the collimator the dose rates range from 4.9 mSv/h to 45.6 mSv/h; behind the collimator the rates are typically less than 10 mSv/h. The small flanges closest to the collimator are no longer foreseen; however, the value of 71.5 mSv/h on one of them is indicative of the dose rates close to the beampipe at that point. The dose rates close to the front-face can be compared to those previously estimated, using FLUKA95 and FIASCO, for the CMS experimental area [18]. Values are found to agree to within $\sim$ 25%.

Shown in Figure 4 are results corresponding to removing the ATLAS shielding up to 18.6 m; a possible opening scenario to allow access to the detectors. Dose rates have once again been calculated using FIASCO. The three values obtained directly in front the collimator, in the proximity of the vacuum equipment, are significantly lower. This is due to fewer contributing active volume elements because part of the shielding was removed. Also given are eight values in front of the remaining iron shielding to give an idea of the dose rates to be expected in this area. Values are typically less than 1 mSv/h. The values obtained behind the collimator have not changed (to be expected as all the geometry changes are in front of the collimator).

## 5. Conclusions

The levels of induced activity in the collimator region are significant and will require well defined handling and storage procedures. Certainly the dose rates very close to the collimators are too high for manual operations to be carried out so that remote-handling will be obligatory. In regions near the collimator where radiation levels are in the tens of mSv/h (such as around the vacuum-equipment and the adjacent shielding) manual operations may be possible with strict radiation monitoring. Current CERN radiation safety regulations restrict the maximum annual effective dose for persons exposed in the exercise of their profession to 15 mSv. To ensure that this limit is respected, it is normal policy to insist on remote-handling for radiation levels in excess of 20 mSv/h.

## 6. Acknowledgments

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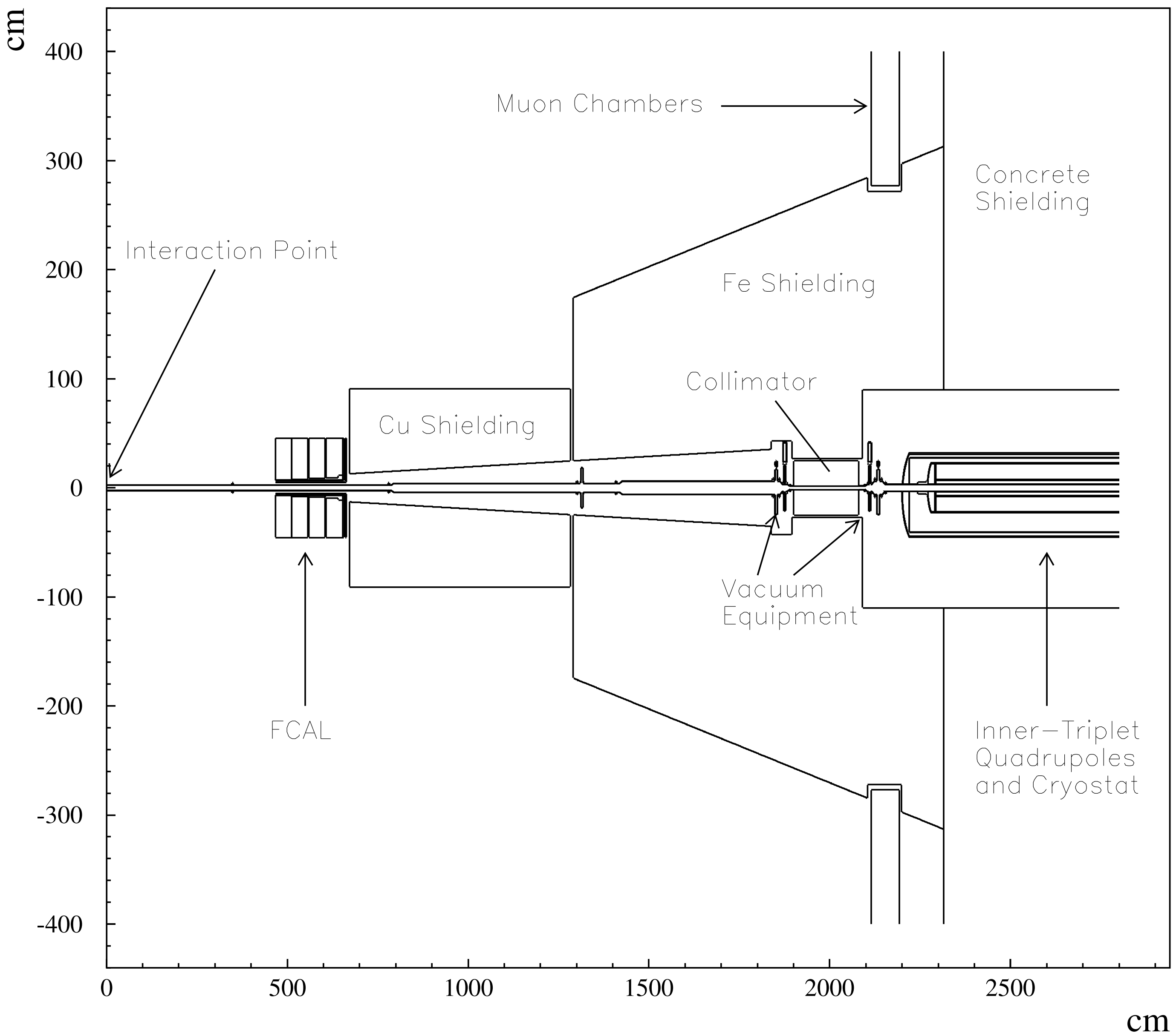


Figure 1: Vertical slice through the forward shielding region in the ATLAS experimental hall. Apart from the vacuum equipment the geometry is symmetrical around the beam axis.

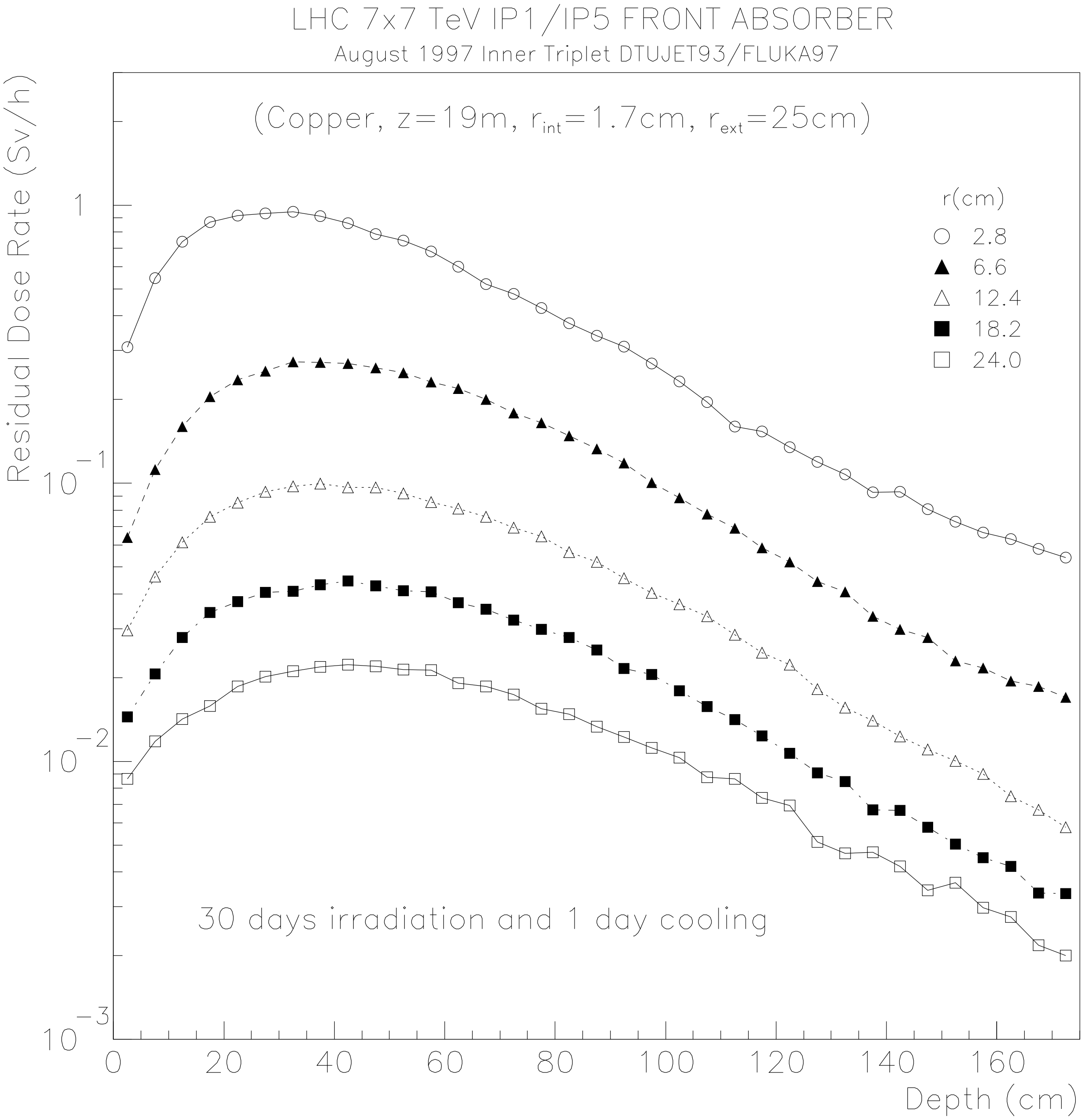


Figure 2: Contact dose rates in Sv/h as a function of collimator length for different radii. A p-p interaction rate of $10^9$ s$^{-1}$ is assumed and an $\omega$-factor of $1 \times 10^{-8}$ Sv h$^{-1}$/(cm$^{-3}$s$^{-1}$).

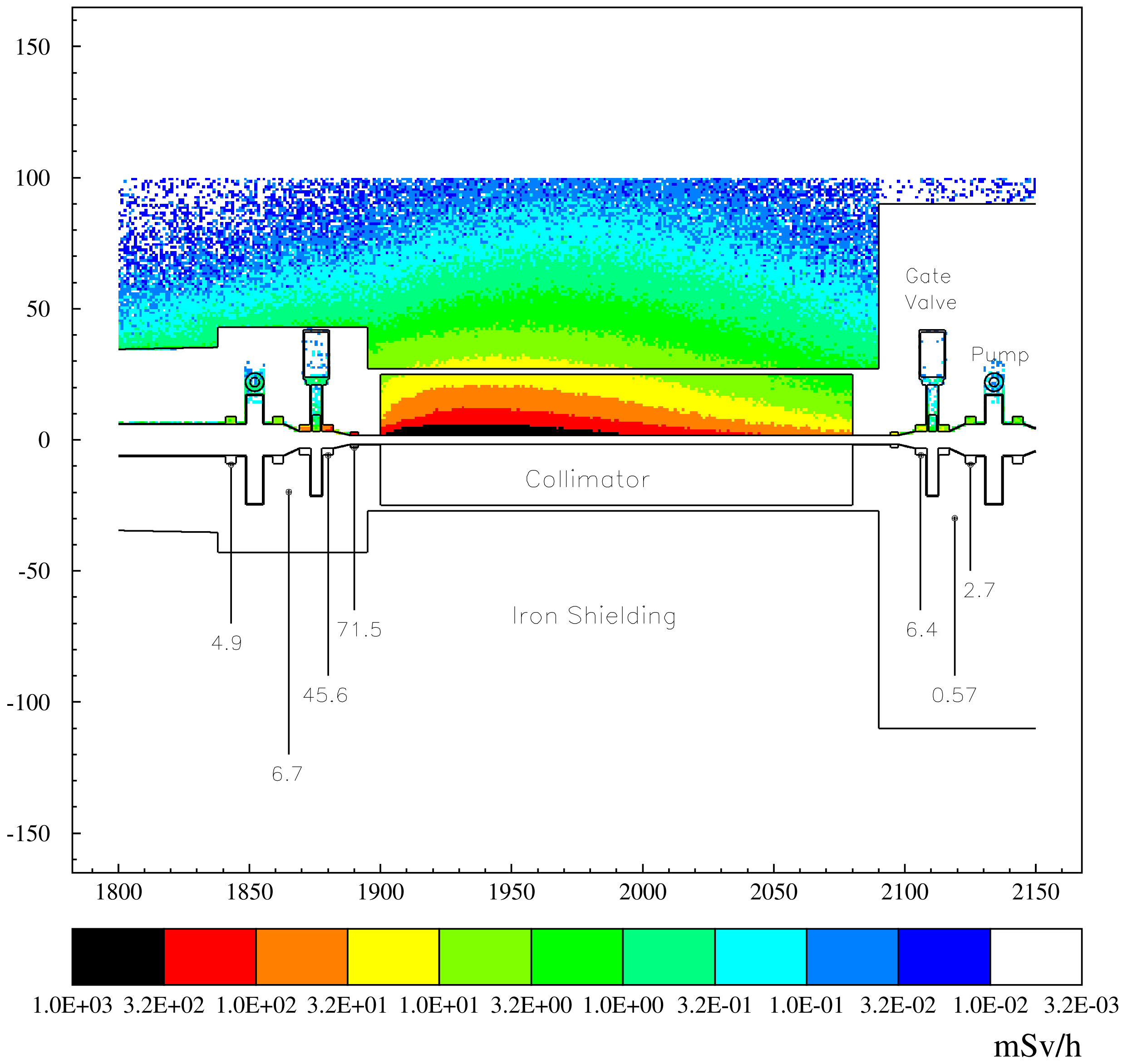


Figure 3: Calculated residual dose rates in the collimator region (in mSv/h). The coloured data represent contact dose rates; the point data around the valves, pumps and flanges have been calculated using FIASCO. In both cases a p-p interaction rate of $10^9$ $s^{-1}$ is assumed. The geometry is symmetrical around the beam axis except for the gate-valves and pumps.

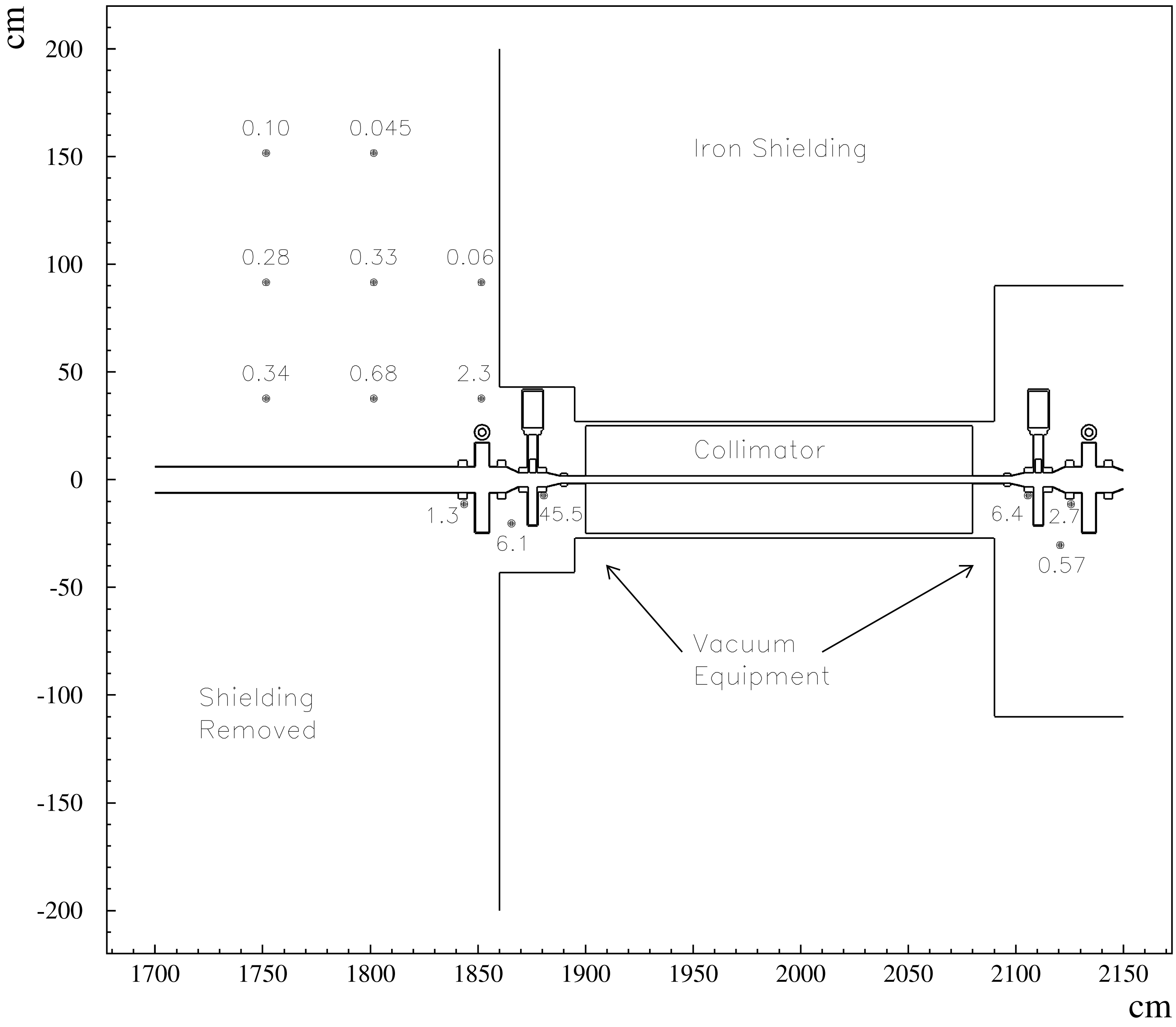


Figure 4: Calculated residual dose rates in the collimator region (in mSv/h) with part of the shielding removed (up to 18.6 m). A p-p interaction rate of $10^9$ $s^{-1}$ is assumed. The point data around the valves, pumps and flanges and in front of the iron shielding have been calculated using FIASCO. The geometry is symmetrical around the beam axis except for the gate-valves and pumps.