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Calculation of the Dose Equivalent Rate from Induced Radioactivity Around the CNGS Target and Magnetic Horn

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Abstract

Radiation levels from induced radioactivity have been calculated in the common region that extends 15 meters from the target till the collimator beyond the magnetic horn. To estimate the radiation levels from induced radioactivity in this region the 2004 Monte-Carlo simulation program FLUKA and some Fortran subroutines have been used. The results obtained are presented in this report.

Outline

1. Introduction

In this report results are shown of the dose equivalent rate in the region that contains the horn, the target and the passageway. The contributions of the horn and target on their own are also shown. The radiation levels around the "Fast Coupling System" area were documented in a separate report [1]. The results of the present report include also the contribution of the elements located in the target area.

A schematic view of the horn, target and passageway region is shown in Figure 1. A layout of the CNGS installation can be seen in [2].

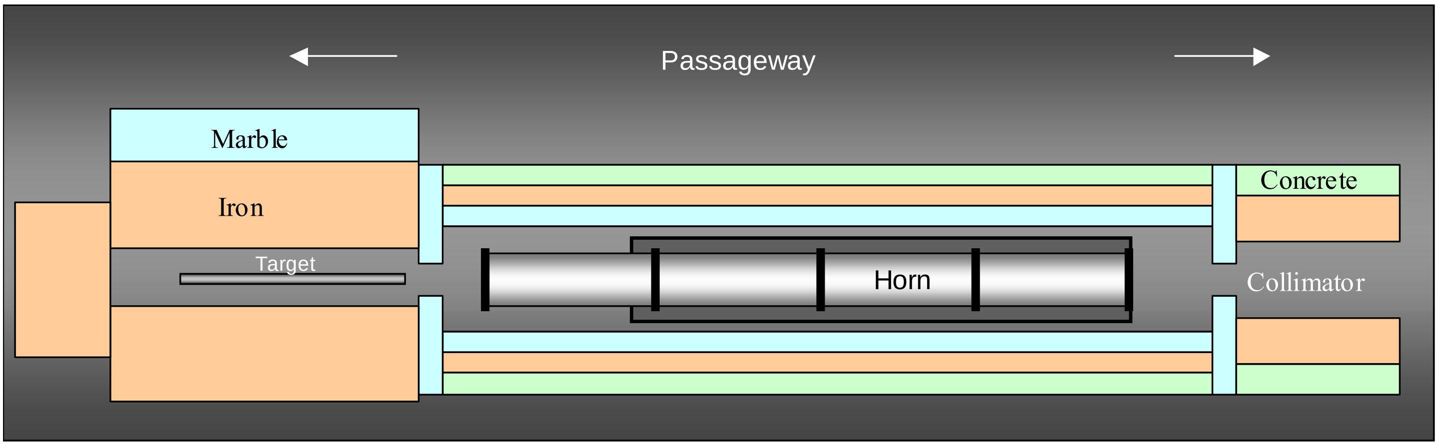


Figure 1 Schematic view of the target and horn area

1.1 Status of the FLUKA Geometry

The geometry of these calculations is the same like the one in the report of reference [1].
The coordinate frame used for the FLUKA geometry input has its origin in the center of the target, which is located 50 cm downstream of the focal point in the present layout [2], the x axis points towards the aisle, the y axis upwards and z the axis coincides with the beam axis.

The thicknesses of the different layers of the target shielding are given in Table 1. For the thickness and for the material compositions of the horn shielding please refer to [1]. Figure 2 and Figure 3 show sections of the geometry where the results of dose equivalent rate have been calculated.

	Thickness (cm)
Iron roof shielding of the target	80
Lateral iron shielding of the target	80
Bottom iron shielding of the target	40
Lateral marble shielding of the target	40
Marble downstream of the target	30
Concrete of the wall/floor tunnel	40

Table 1 Thicknesses of the different shielding materials in the target area and of the concrete in the wall/floor of the tunnel

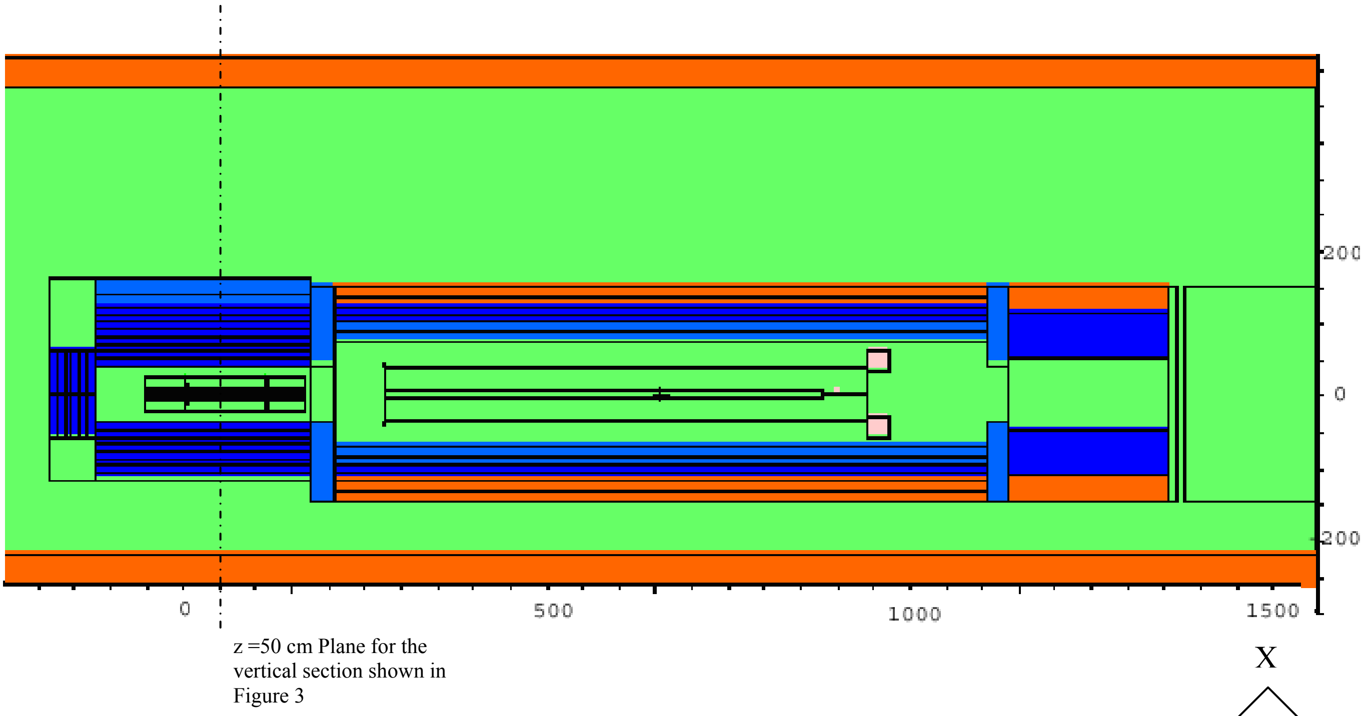
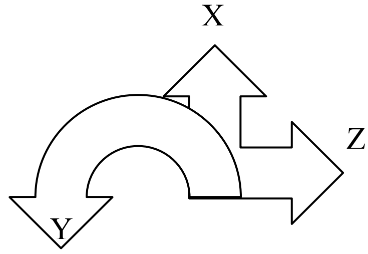


Figure 2 Horizontal longitudinal section at y=0cm



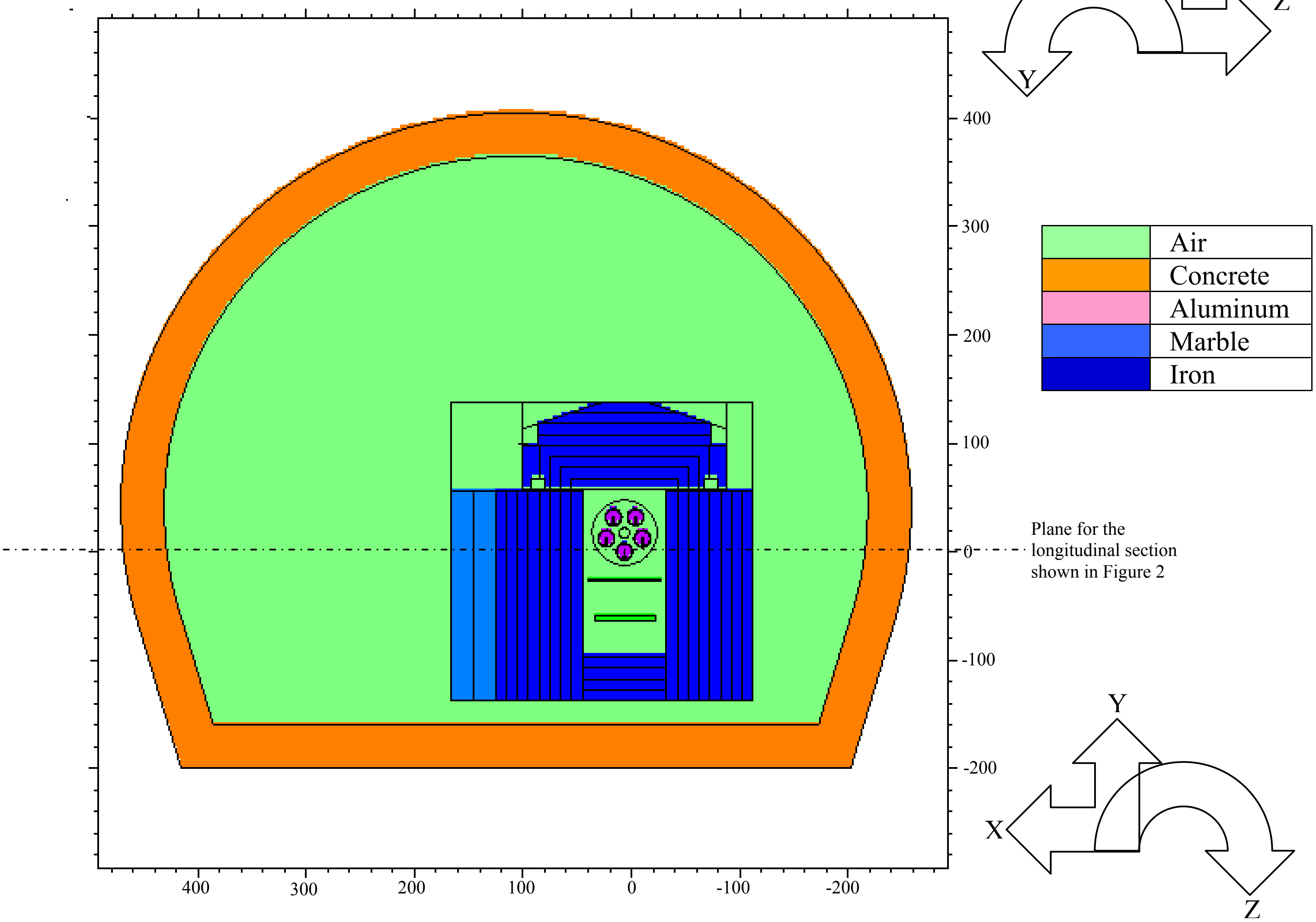


Figure 3 Vertical transverse section at z=50cm (center of the target unit)

2. Simulations

For the calculations the version 2004 of the FLUKA Monte-Carlo computer code (see [3] and [4]) has been used. In parallel some subroutines have been used to dump the isotope production, for the isotope decay and to fold fluence with fluence-to-dose equivalent conversion factors. For a benchmark of these tools refer to [5] - [7].

The simulations are based on the following beam parameters:

- Proton intensity: 8.0×10^{12} per second
- Proton beam energy: 400 GeV
- Gaussian profile of the beam ($\sigma_x=\sigma_y$ = 530 μm)
- Irradiation time: 200 days
- Cooling times: 1 day, 1 week, 1 month, 2 months, 4 months, 6 months

The simulations were performed in two steps:

2.1 Calculation of Isotope Production

The primary and the secondary particles generated in the nuclear cascade activate the materials around generating radioactive isotopes. Figure 4 illustrates the trajectories of the positive and negative particles in the cascade. In this figure the focusing effect of the horn and reflector with respect to the positive particles can be seen.
In the first step of the calculation full information on the produced isotopes in seven different parts of the geometry has been written into an external file. The different parts were chosen according to their location and size.

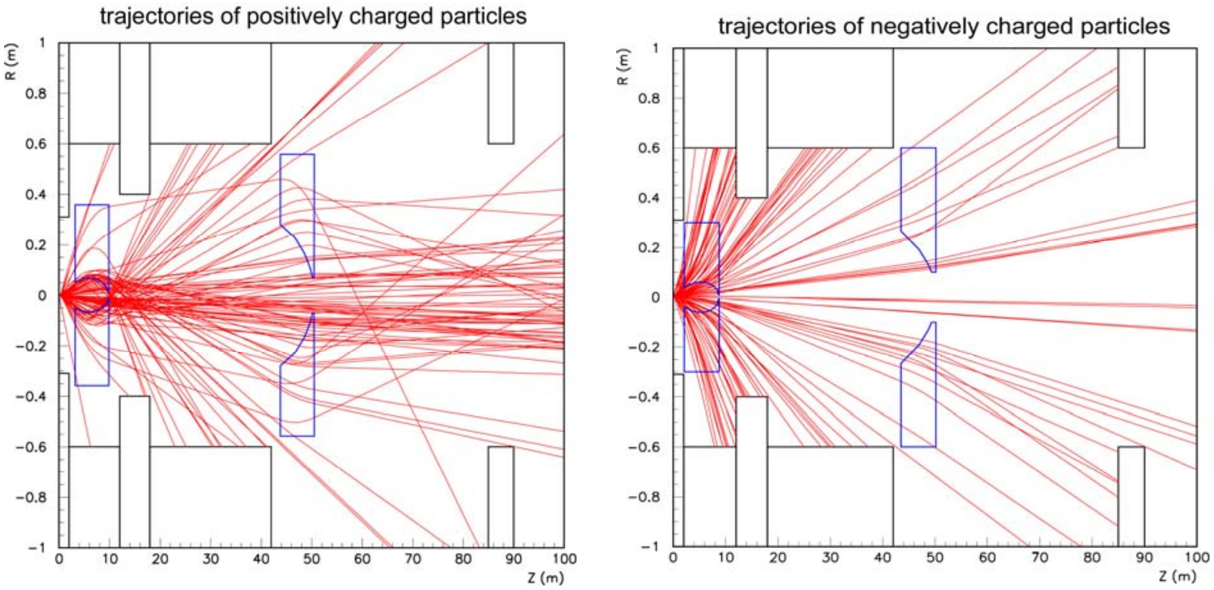


Figure 4 Trajectories of primary and secondary particles generated in the nuclear cascade

The parts of the geometry considered for the isotope production are:

1. Concrete of the cavern walls/floor
2. Shielding in the horn area
3. Horn and adjacent structures
4. Materials near or inside the opening of the horn shielding
5. Collimator downstream the horn
6. Shielding in the target area
7. Target and adjacent structures

The first five contributions are explained in [2]. In this report the results of the contributions 2, 3, 4 and 5 will be combined and referred to as the contribution of the elements in the horn area.

The contribution 6 of the shielding in the target station includes the lateral iron shielding, the iron of the roof and also the iron at the bottom; the lateral left shielding of marble and the marble downstream of the target station.
The contribution 7 of the target and adjacent structures includes the revolver structure of the target, the tube and windows of the target unit, the target support, target rods, supports of the bars, beryllium windows as well as support structures.

2.2 Calculation of Remanent Dose Rates

In a second step, with this file used as input, the photons and positrons from the radioactive decay at a certain cooling time were sampled. This is used for the simulation of the electromagnetic cascade induced by these particles and finally the dose equivalent rate at any point of interest and for each cooling time was obtained.

In the next paragraphs results are shown for the total remanent dose rate in the target and horn areas and for the total remanent dose rate in the target region.

3. Results for the Target and Horn Areas

3.1 Total Dose Equivalent Rate in the Target and Horn Areas

In Figure 5-8 the results for the total equivalent dose rate for different cooling times are presented.
In the passageway the dose rate decreases rapidly (namely it decreases almost two orders of magnitude from 1 day until 1 week) until about one week and beyond rather slowly (namely it decreases approximately two orders of magnitude from 1 week until 6 months). However, inside the target-shielding box the dose rate hardly decreases (less than one order of magnitude). Inside the horn-shielding box the dose rate varies faster but not as fast as in the passageway (it decreases one order of magnitude from 1 day until 6 months).

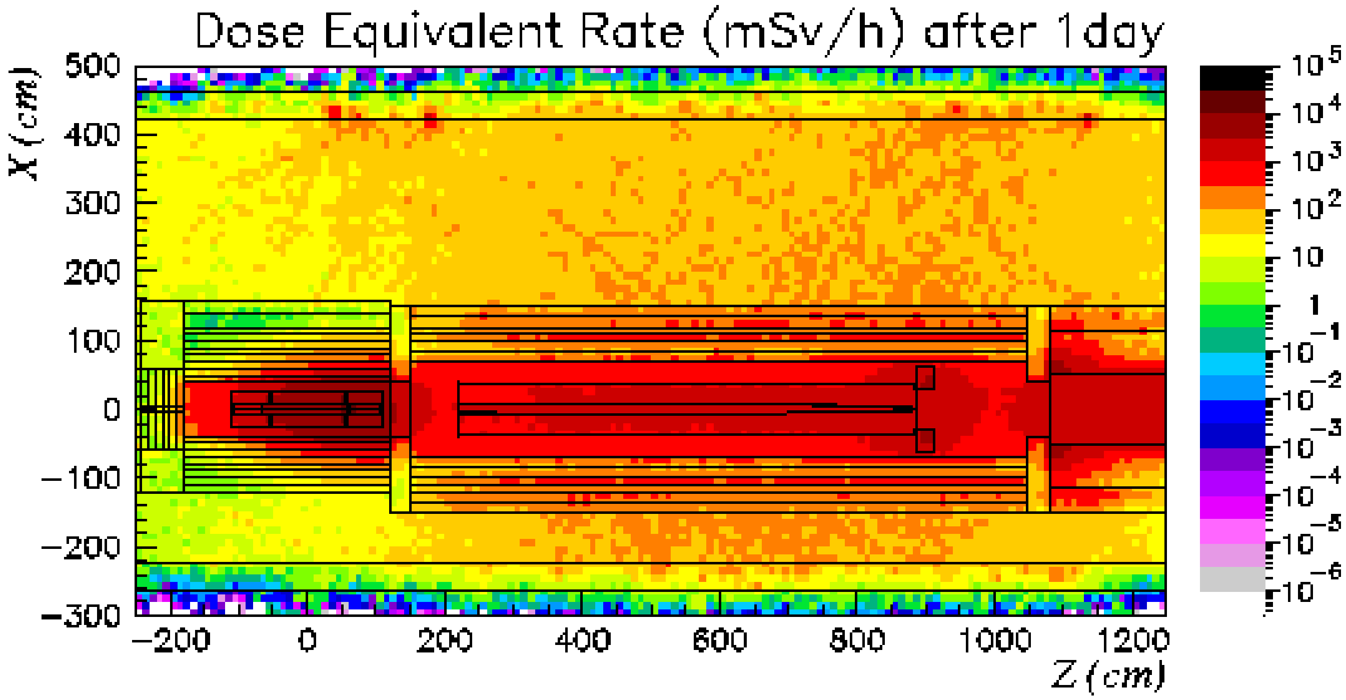


Figure 5 Total dose equivalent rate for a cooling time of 1 day for a longitudinal horizontal section at the level of the beam axis

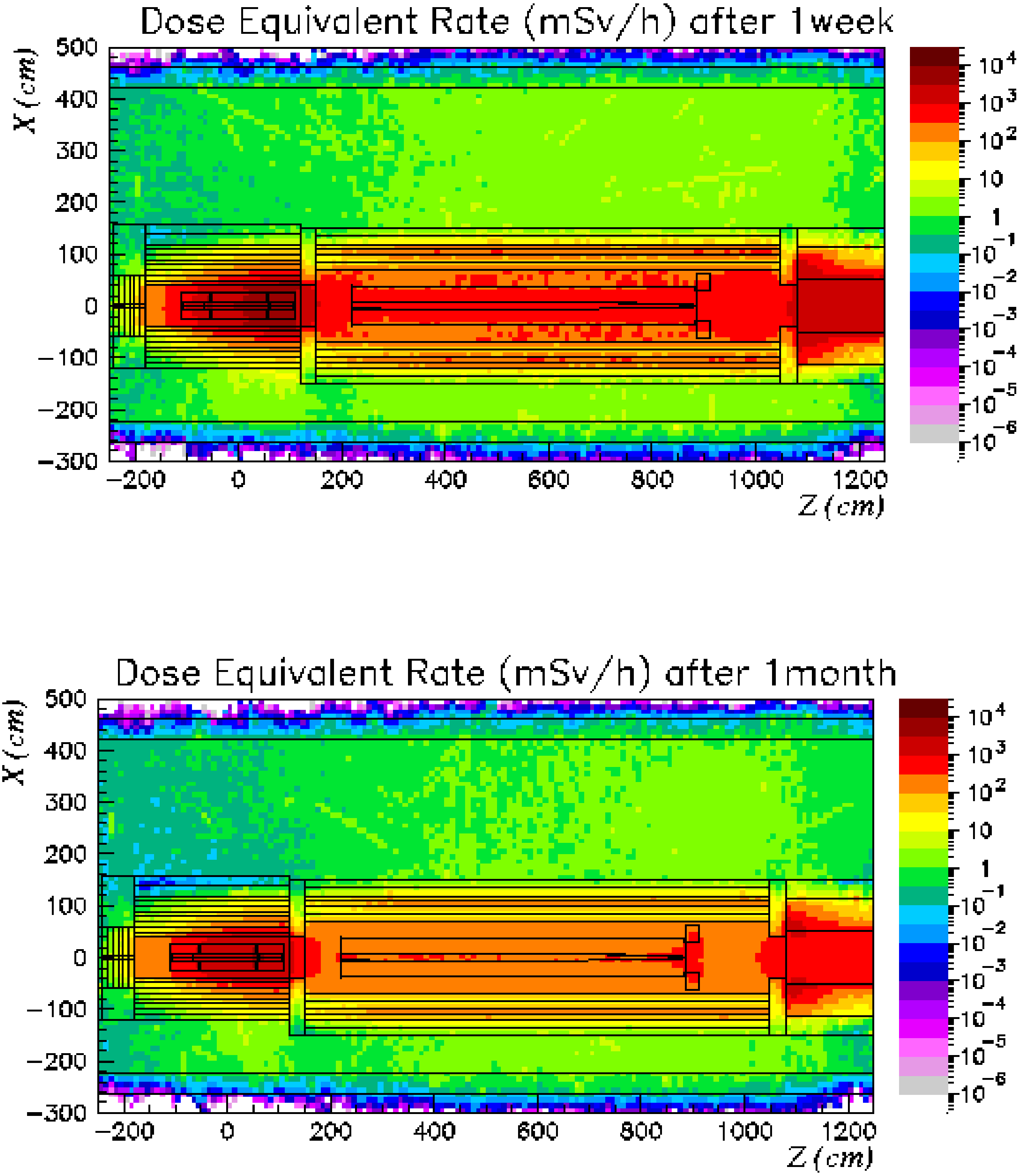


Figure 6 Total dose equivalent rate for cooling times of 1 week and 1 month for a longitudinal horizontal section at the level of the beam axis

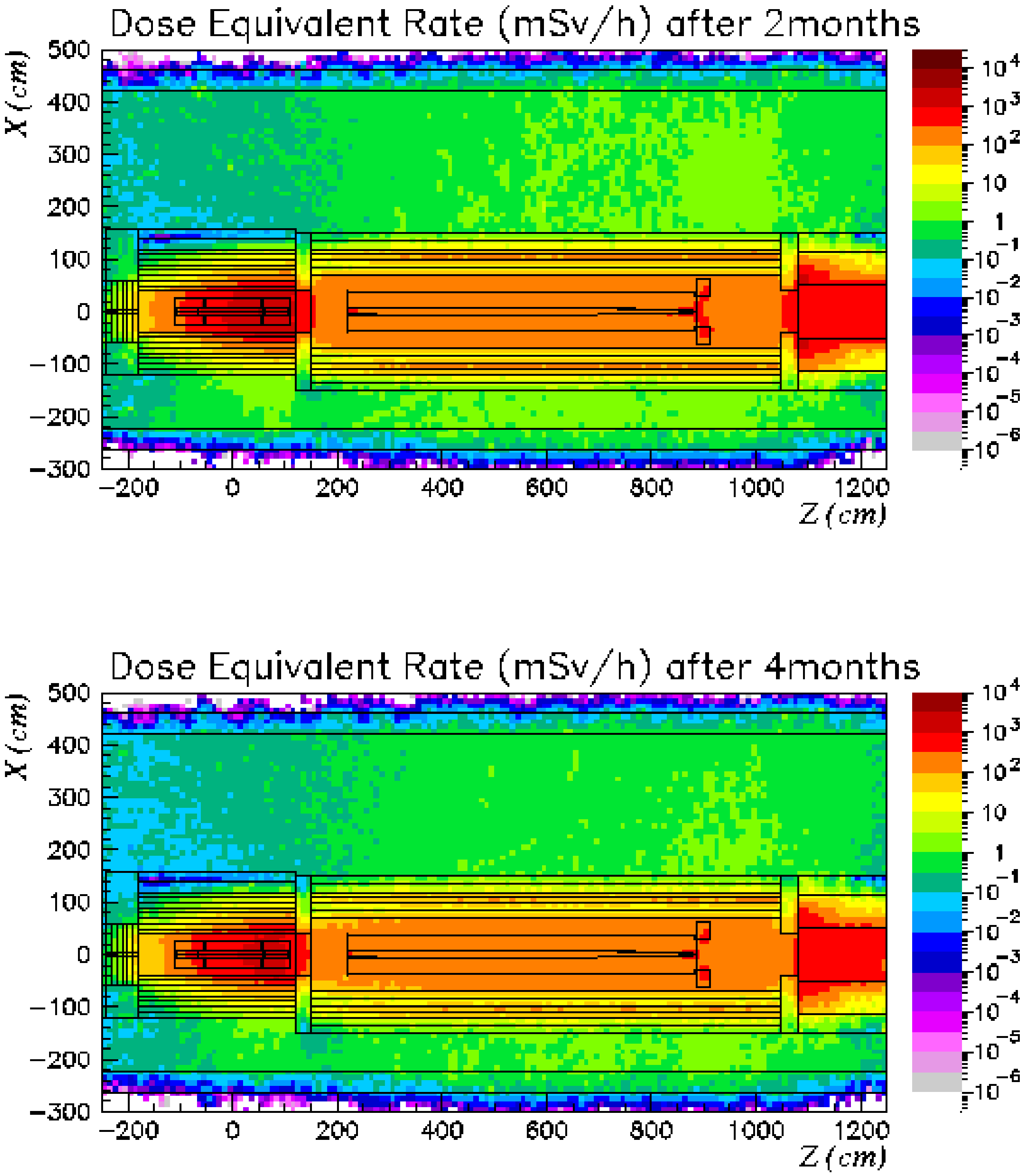


Figure 7 Total dose equivalent rate for cooling times of 2 months and 4 months for a longitudinal horizontal section at the level of the beam axis

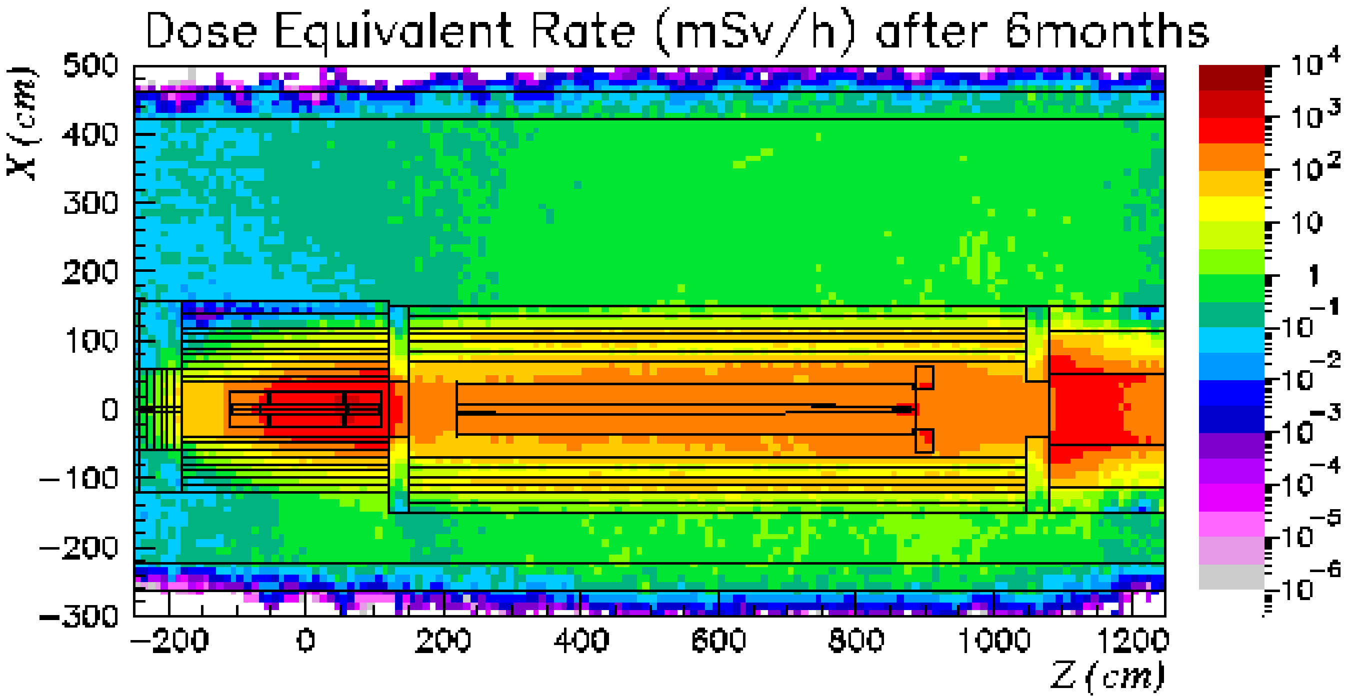


Figure 8 Total dose equivalent rate for a cooling time of 6 months for a longitudinal horizontal section at the level of the beam axis

3.2 Total Dose Equivalent Rate for selected locations in the Passageway

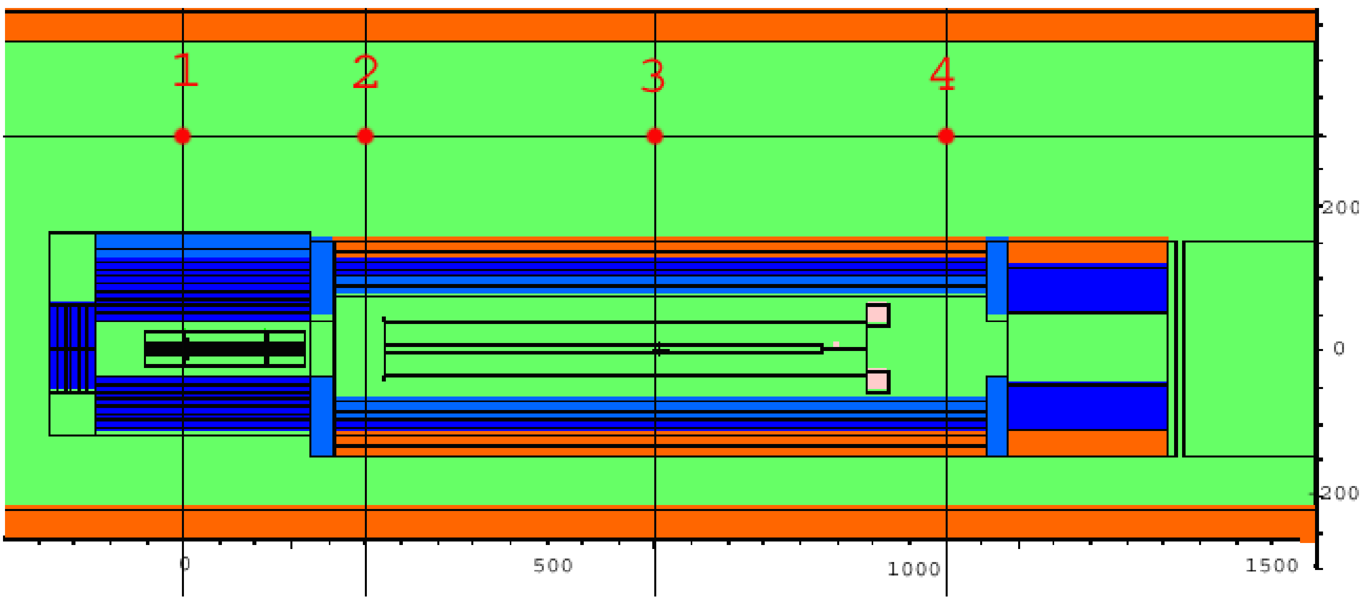


Figure 9 Horizontal longitudinal section at y=0 cm showing the locations for which dose equivalent rates are given in table 2

Cooling time / Position	1 day	1 week	1 month	2 months	4 months	6 months
1 at z=0cm	21.4	0.7	0.25	0.17	0.09	0.08
2 at z=250cm	37.7	1.5	0.36	0.33	0.28	0.26
3 at z=650cm	71.3	1.9	0.95	0.93	0.69	0.53
4 at z=1050cm	79.9	2.4	1.13	1.11	0.99	0.91

Table 2 Values in mSv/h of dose equivalent rate for different locations in the passageway as shown in Figure 9

In Table 2 dose equivalent rate values in the passageway are shown for four different locations at the level of the beam axis and for different cooling times. Each of the values shown in Table 2 is an averaged value over a cubic volume of 20x20x20 cm^3 centered in the positions shown in Figure 9.

The values increase with the distance from the target for the same cooling time and decrease with the cooling time for the same position. In the target area the dose equivalent rate is different on the left and on the right of the target due to the fact that on the left side of the target there is a 40 cm thick marble shielding. Downstream of the target the radiation level map is more symmetric. The presence of the opening in the horn shielding makes the variation of the dose equivalent rate non-uniform in the passageway.
The maintenance operations will be carried out on the aisle side of the target chamber. The access to the wall side will be prohibited with a fence.

3.3 Analysis of the Different Contributions in the Target and Horn Area

In the following figures the results of the different contributions in the target and horn area are represented. In Figure 6 the total contribution after one-week cooling time was shown; it is interesting to compare it with the partial contributions shown in Figure 10, 11, 12 and 13. The most important contribution to the dose equivalent rate in the passageway is the one of the horn elements; this contribution is the sum of several contributions downstream the target and includes the contribution of the horn itself, the contribution of the horn shielding, the contribution of the opening of the horn shielding and the contribution of the collimator. This contribution results in more than 60% of the total value in the passageway. The next contribution in importance is the one of the concrete tunnel and floor. This contribution is rather uniform and varies quickly up to a cooling time of about 1 week but for longer cooling times the variation is much lower. After this contribution the next in importance is the one of the target shielding. This contribution has to be considered only near the target. The contribution of the elements inside the target shielding to the total dose equivalent rate in the passageway is negligible. In Table 3 some values of equivalent dose rate are shown for some locations of interest.

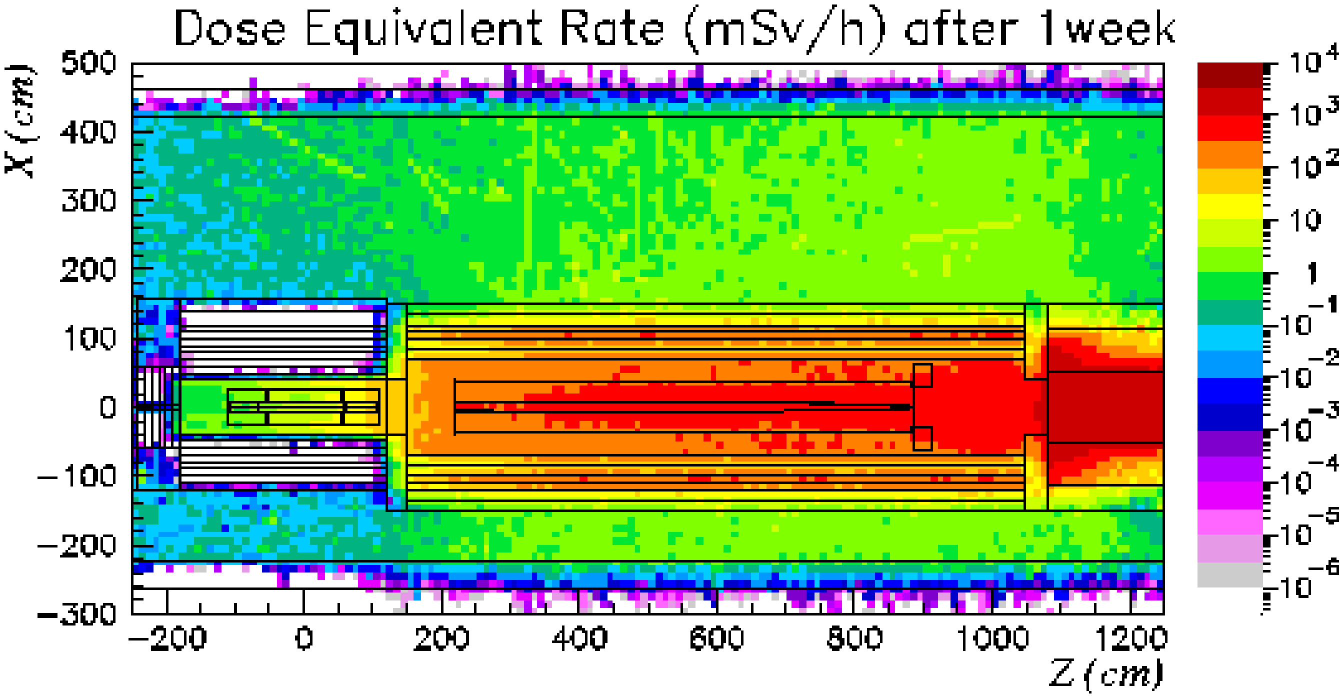


Figure 10 Contribution of the horn elements, horn shielding, electrical connections and collimator

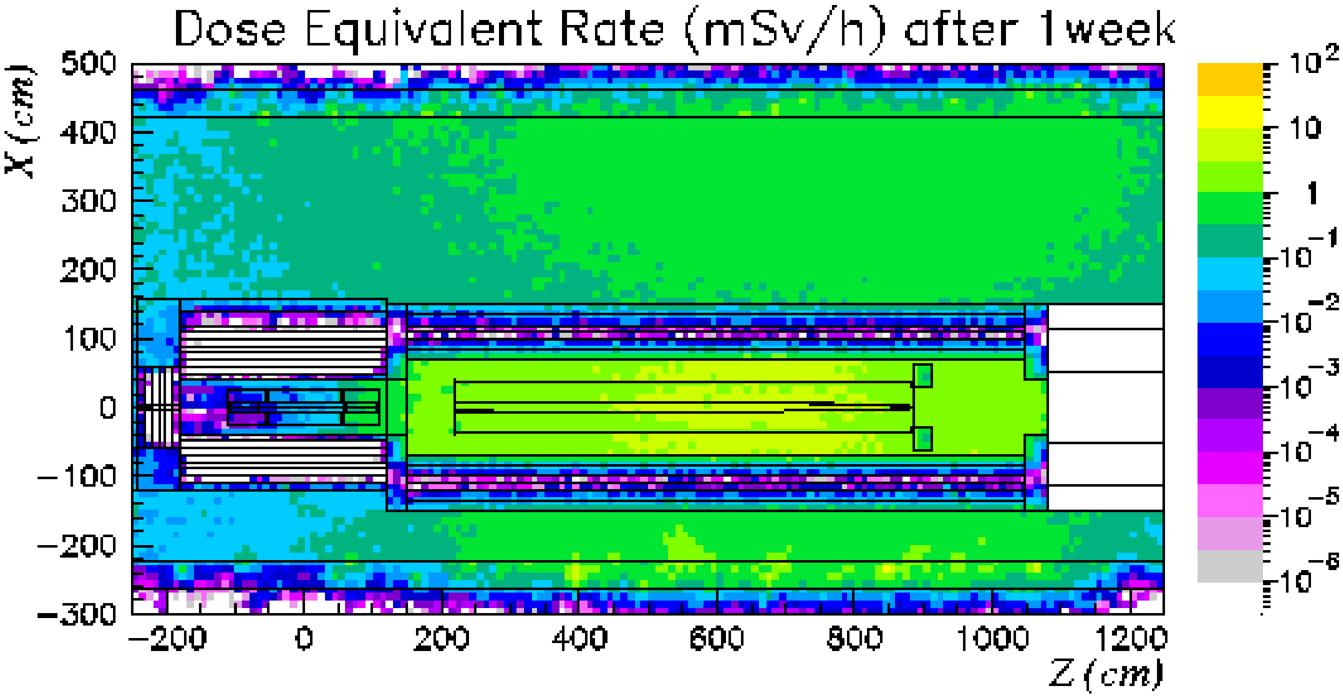


Figure 11 Contribution of the walls/floor of the cavern

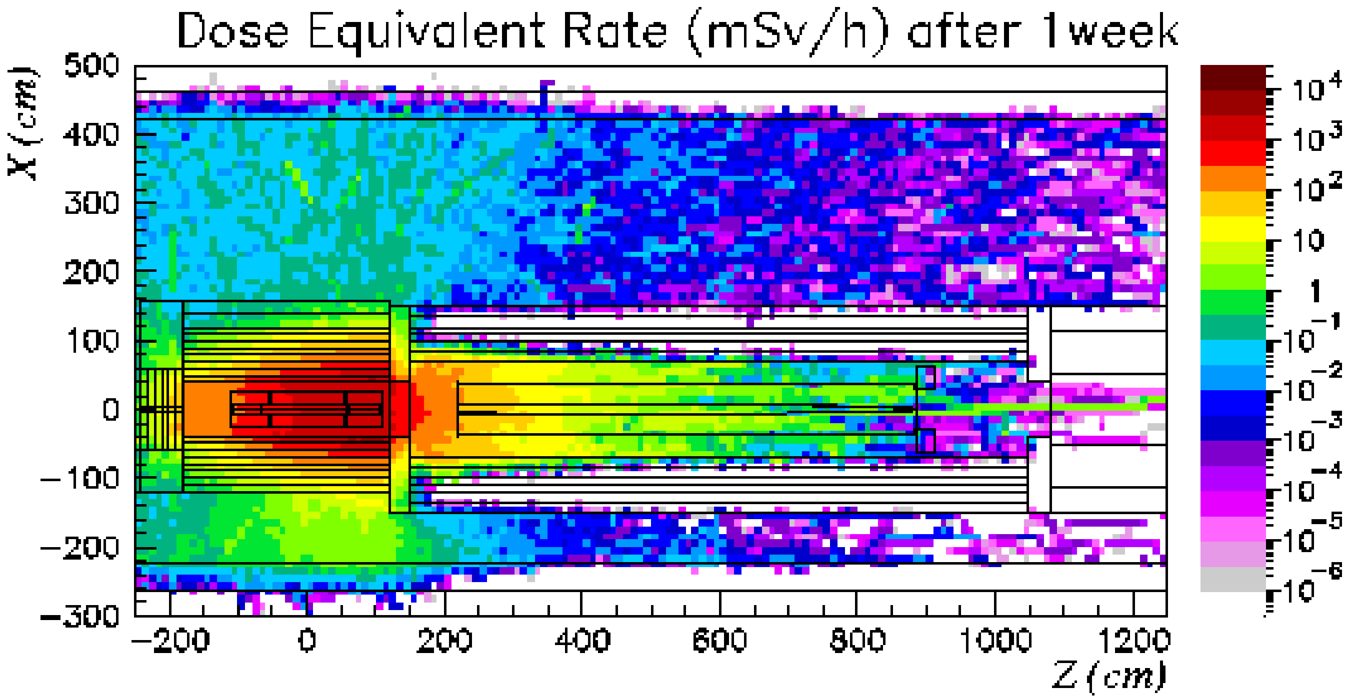


Figure 12 Contribution of the target shielding

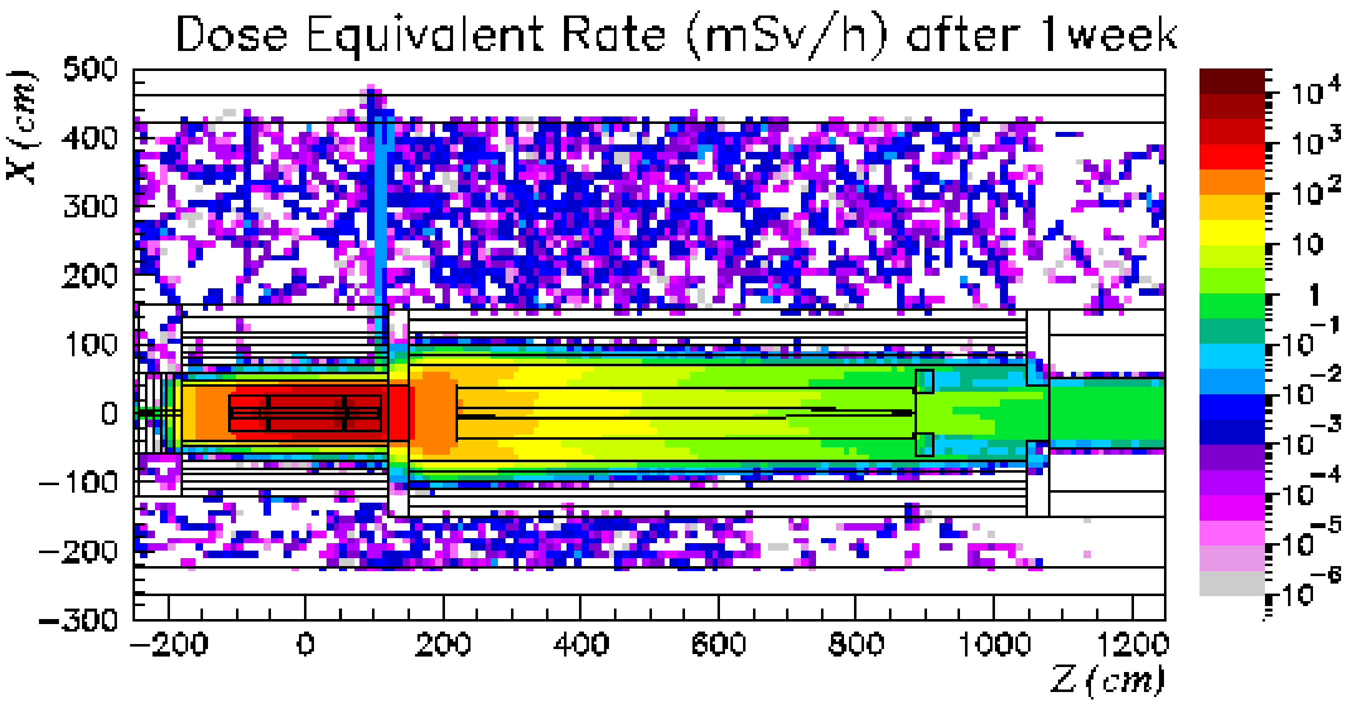


Figure 13 Contribution of the elements inside the target shielding

3.4 Contributions to the Total Dose Equivalent Rate for selected locations in the Passageway

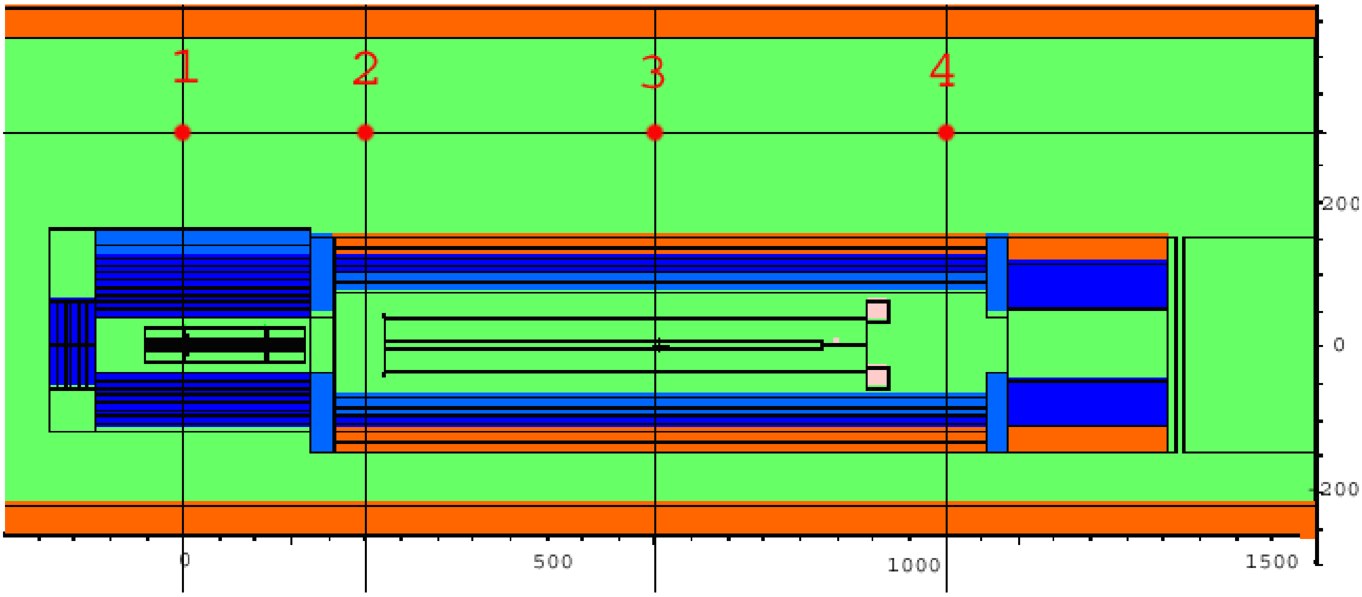


Figure 14 Horizontal longitudinal section at y=0 cm showing the locations for which dose equivalent rates are given in table 3

Contribution / Position	Total	Horn Elements	Cavern	Target shielding
1 at z=0cm	0.7	0.4	0.2	0.08
2 at z=250cm	1.5	1.2	0.2	0.01
3 at z=650cm	1.9	1.4	0.5	0.003
4 at z=1050cm	2.4	1.7	0.7	10^{-5}

Table 3 Values in mSv/h of dose equivalent rate for the different contributions, for different locations in the passageway as shown in Figure 14 and for a cooling time of one week

In Table 3 dose equivalent rate values in the passageway are shown for four different locations at the level of the beam axis and for a cooling time of one week. The contribution of the elements inside the target-shielding box to the total dose rate is not included because it is negligible. Each of the values shown in Table 3 is an averaged value over a cubic volume of 20x20x20 cm^3 centered in the positions shown in Figure 14.
The individual contributions of the horn elements, that is to say the horn shielding, the horn tube and adjacent materials, the materials of the opening of the shielding and the collimator are represented in Figure 15, 16, 17 and 18. It can be clearly seen in these figures that the contribution of the horn shielding is dominating the dose rate in the passageway as well as inside the horn shielding.

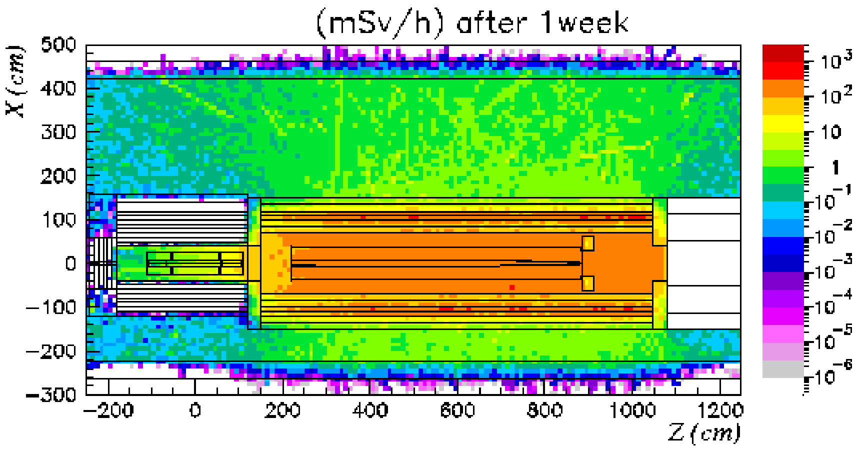


Figure 15 Dose equivalent rate from the horn shielding contribution

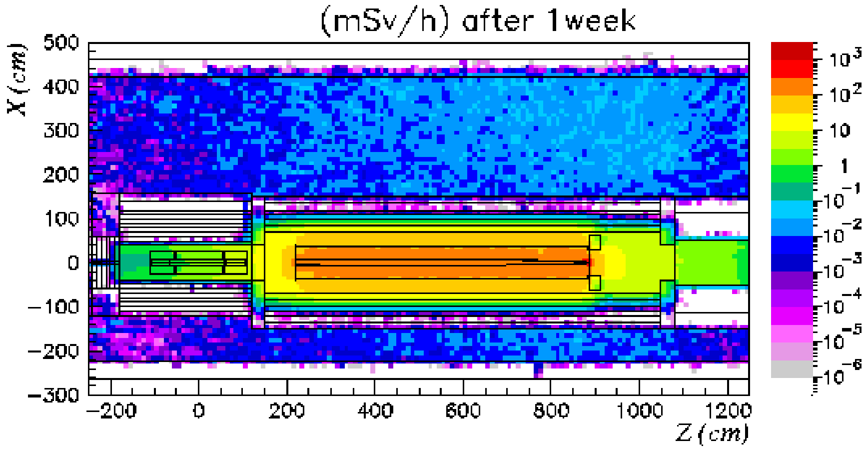


Figure 16 Dose equivalent rate from the horn tube material contribution

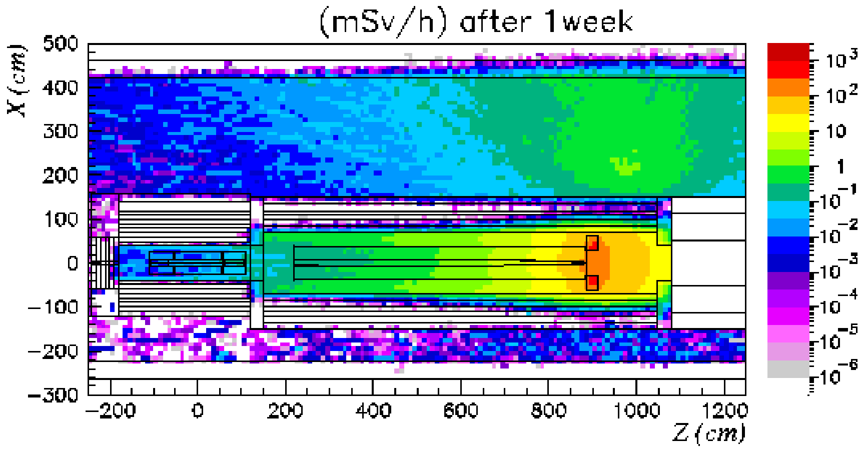


Figure 17 Dose equivalent rate from the stripline and elements of the shielding opening contribution

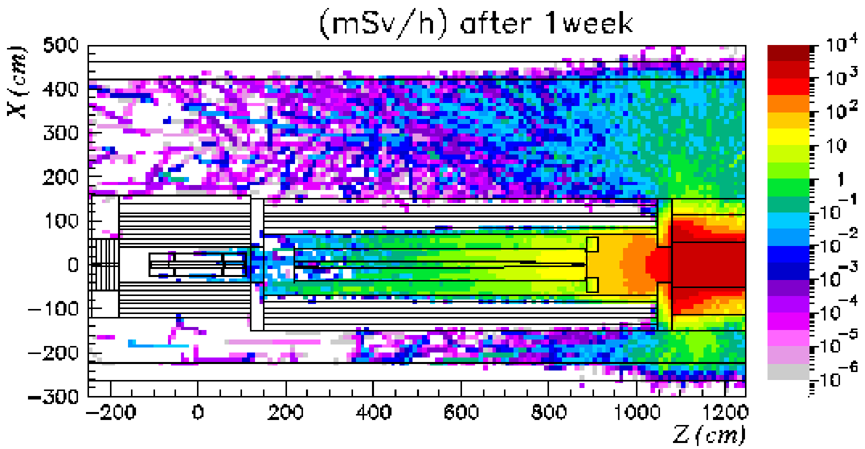


Figure 18 Dose equivalent rate of the collimator contribution

4. Dose Equivalent Rate around the Target Station

4.1 Total Contribution in the Target Area

In this paragraph the dose equivalent rates are shown in Figure 19-23 for a transverse vertical section located in the center of the target. In the passageway a rapid decrease of the dose rate is observed for cooling times up to one week. Beyond one week the dose rate varies gradually. A slower decrease is observed inside the target-shielding box. This fact is explained due to the different exponential decay of the isotopes created in the iron shield and in the concrete wall. In the passageway the concrete contribution to the dose rate dominates and therefore the exponential decrease is relatively fast. Inside the target shielding the iron contribution dominates and therefore the slower exponential decay.

These results are an update of the results obtained in [8] which included only the target station and the concrete tunnel between -250cm and 250cm. In this report in addition, also the horn shielding, the elements inside the horn shielding, the whole concrete tunnel, the elements of the opening of the shielding and the collimator are considered. The inclusion of the horn shielding and a much bigger tunnel in the new geometry explains the difference of results with respect to the results obtained in [8]. For example the concrete tunnel/floor contribution increases one order of magnitude with respect to the results in [8]. The importance of the horn elements contribution is clearly seen in Figure 26.

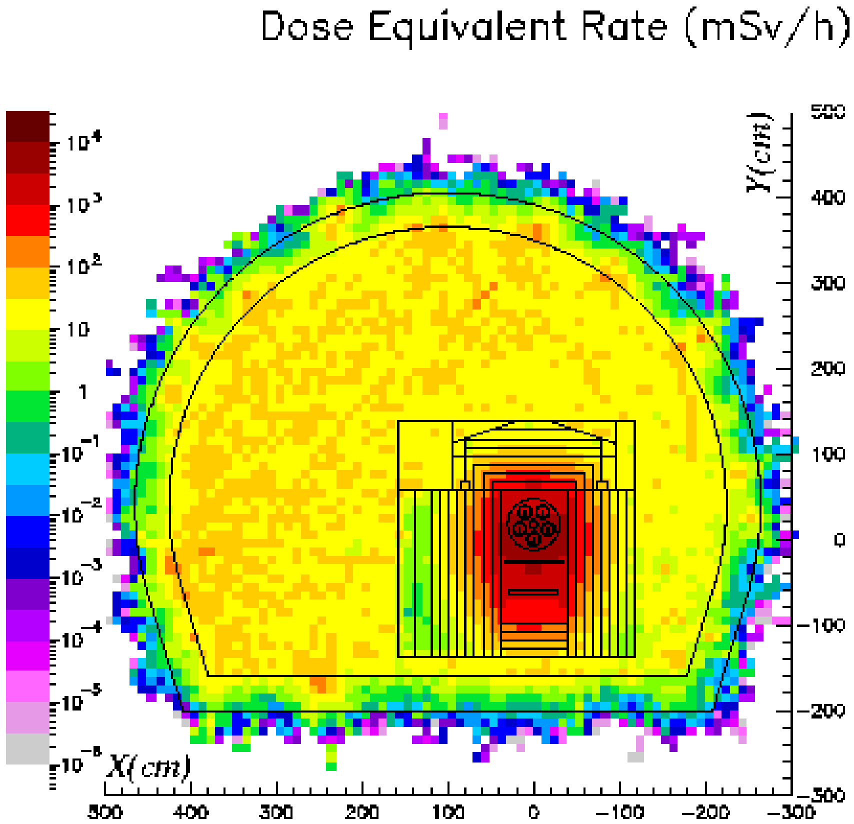


Figure 19 Total dose equivalent rate (mSv/h) after a cooling time of one day

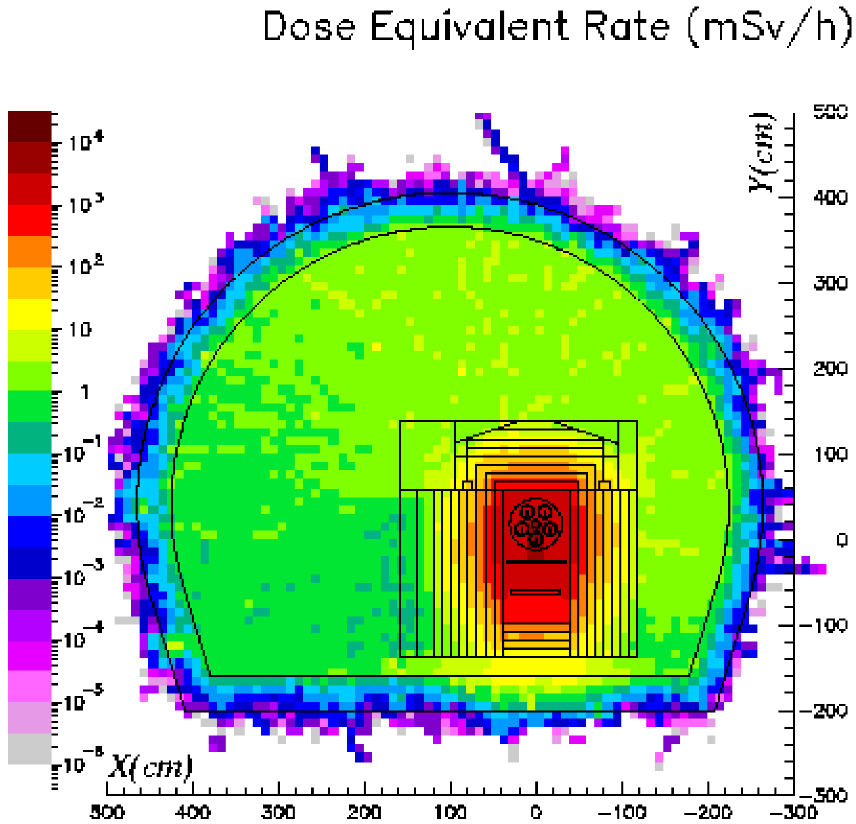


Figure 20 Total dose equivalent rate (mSv/h) after a cooling time of one week

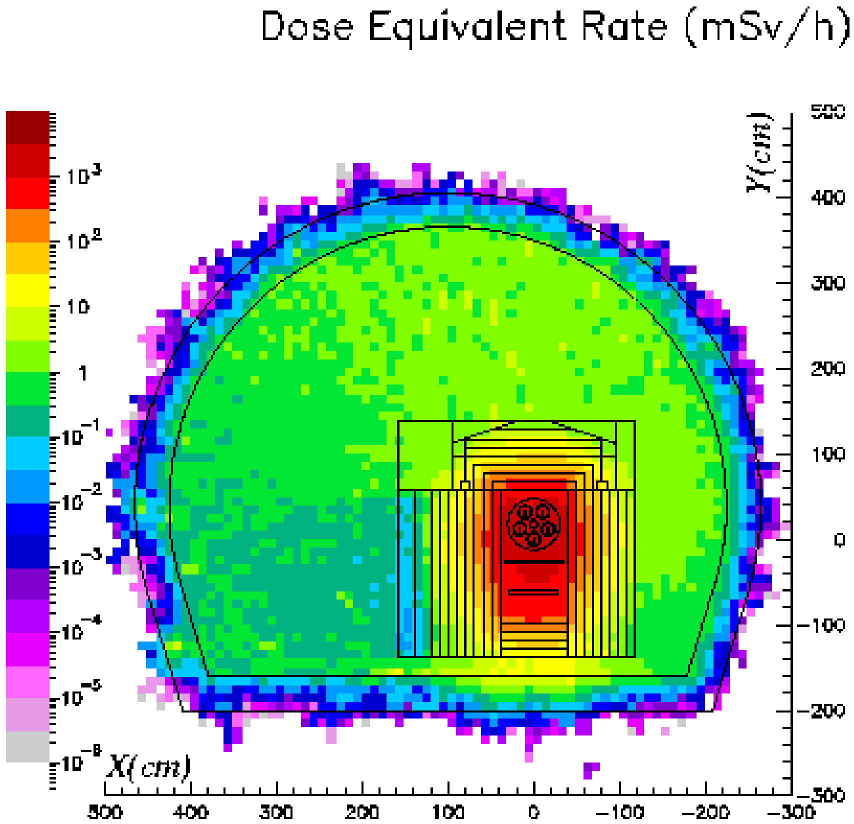


Figure 21 Total dose equivalent rate (mSv/h) after a cooling time of one month

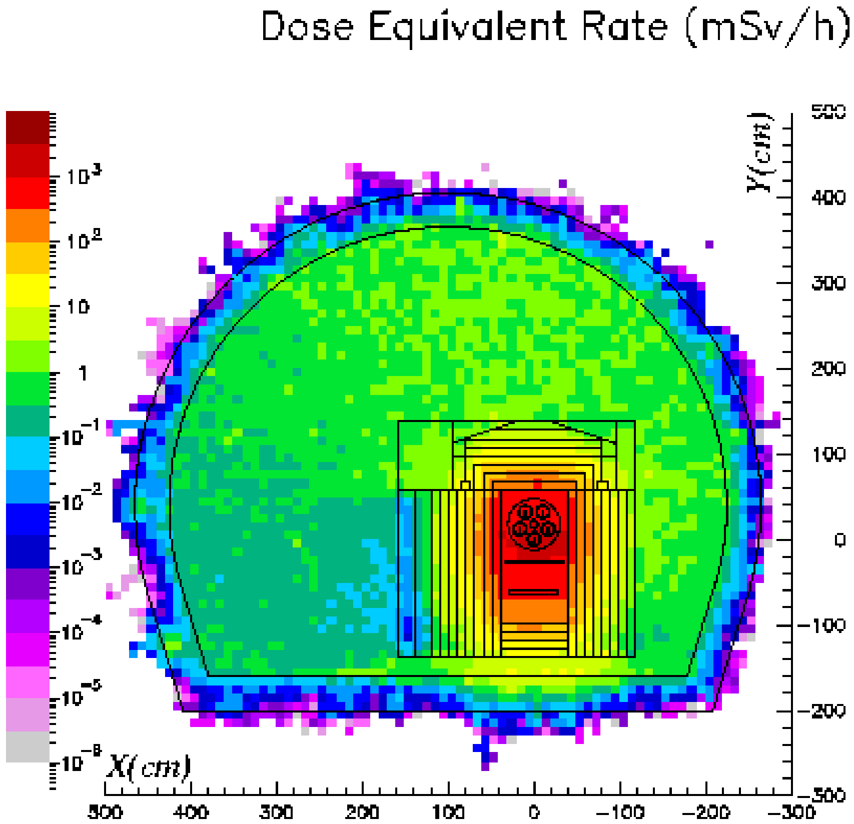


Figure 22 Total dose equivalent rate (mSv/h) after a cooling time of two months

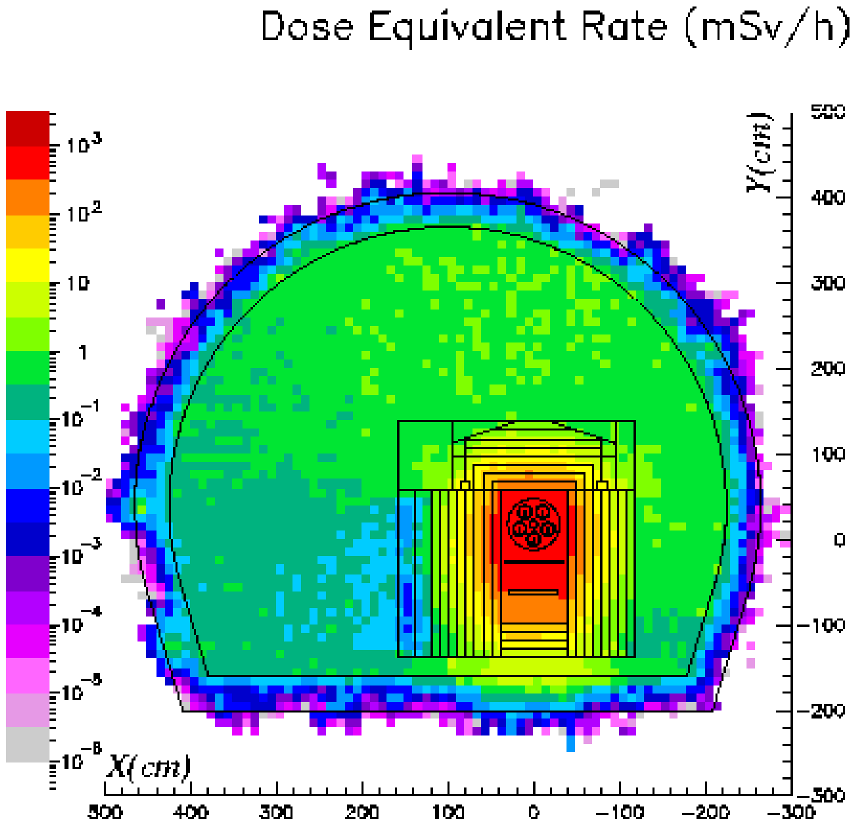


Figure 23 Total dose equivalent rate (mSv/h) after a cooling time of four months

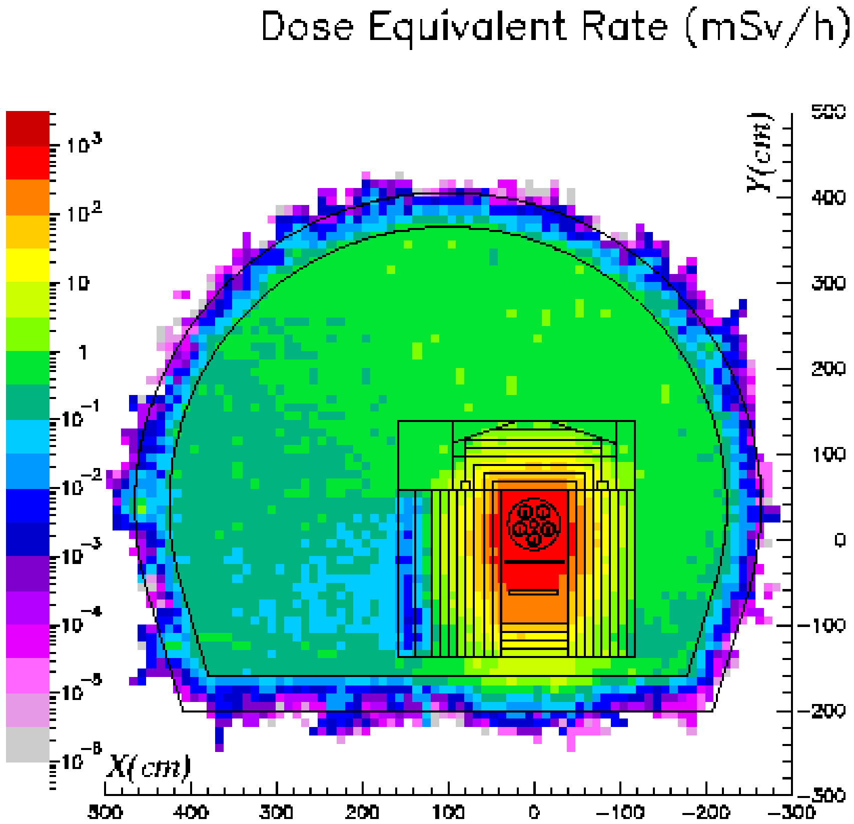


Figure 24 Total dose equivalent rate (mSv/h) after a cooling time of six months

4.2 Analysis of the Different Contributions in the Target Area

In order to show the importance of the different contributions to the total value of dose equivalent rate in the passageway near the target area, the example of a cooling time of one week has been chosen. The results of the different contributions are shown at z=50cm in Figures 25, 26, 27, 28 and 29. The values shown in Table 4 is an averaged values over a cubic volume of 20x20x20 cm^3 centered at x=300cm, y=0cm and z=50cm. In the passageway, the main contributions to the total dose rate come from the following parts:

- The contribution of the horn shielding and the elements inside the shielding (see Figure 25) is the main contribution; in the passageway it reaches a value of 0.42 mSv/h.
- The contribution of the concrete of the wall/floor of the cavern (see Figure 25) tend to be uniform outside the target-shielding box for vertical transversal sections in the target chamber, in the passageway the dose equivalent rate is 0.21 mSv/h.
- The contribution of the target shielding (see Figure 27) is small; in the passageway an average value of 0.05 mSv/h has been calculated. The presence of the marble block on the left side of the target shielding prevents that the dose equivalent rate in the passageway near the target reaches higher values.
- The contribution of the target elements situated inside the target-shielding box (see Figure 27) is negligible outside the shielding box but not inside it.

The total dose rate after a cooling time of one week at x=300cm, y=0cm and z=50cm is therefore about 0.7 mSv/h. These results are summarized in Table 4.

Cooling Time 1 week	Total	Horn area elements	Concrete of Walls/Floor	Target Shielding
Dose equivalent Rate (mSv/h)	0.7	0.42	0.21	0.05

Table 4 Contributions to the dose equivalent rate at x=300cm y=0 z=50cm after a cooling time of one month

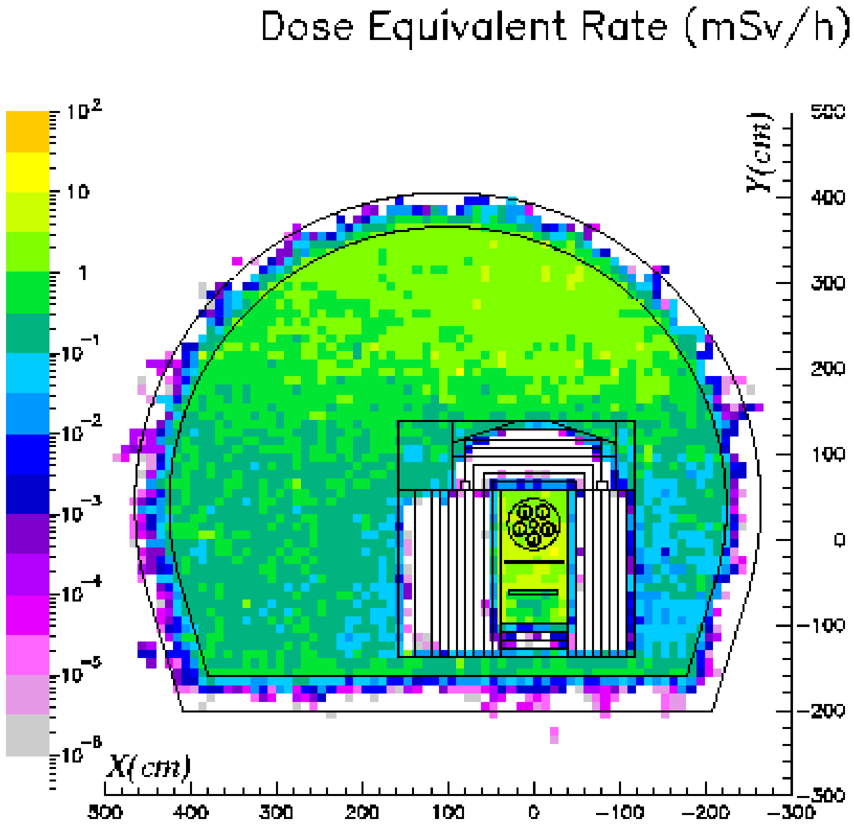


Figure 25 Horn area materials contribution after a cooling time of one week

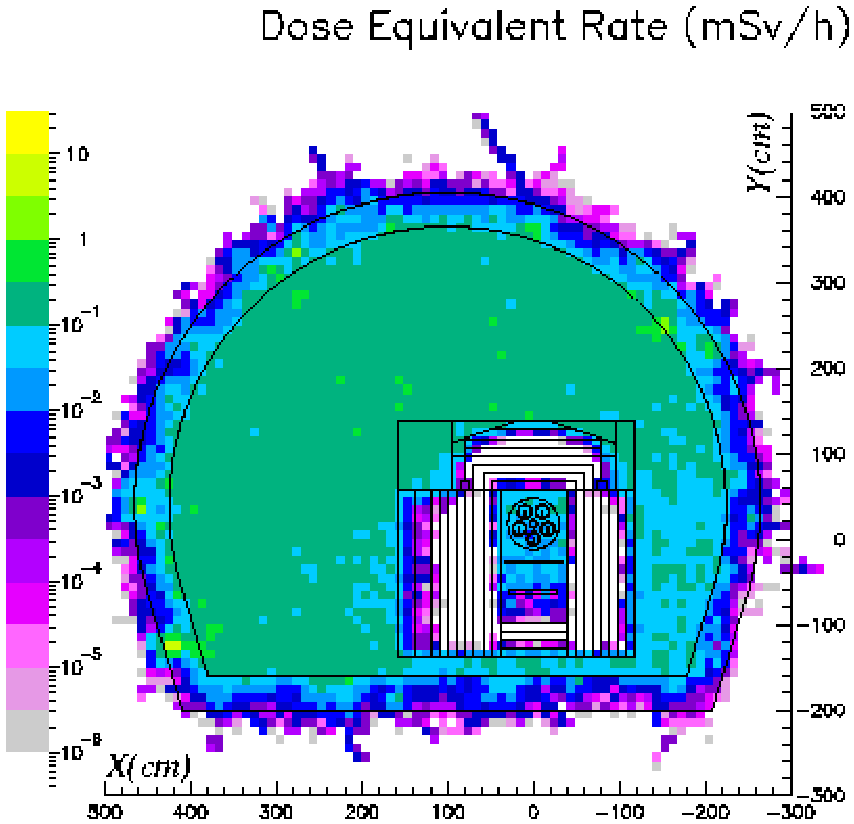


Figure 26 Wall/Floor contribution (mSv/h) after a cooling time of one week

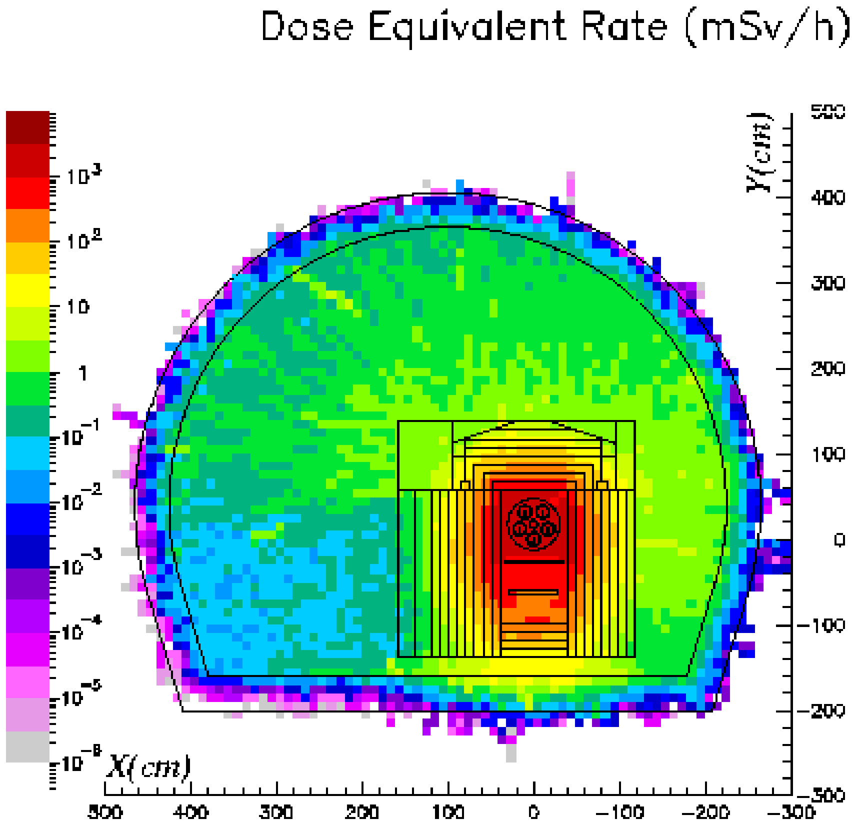


Figure 27 Target shielding contribution after a cooling time of one week

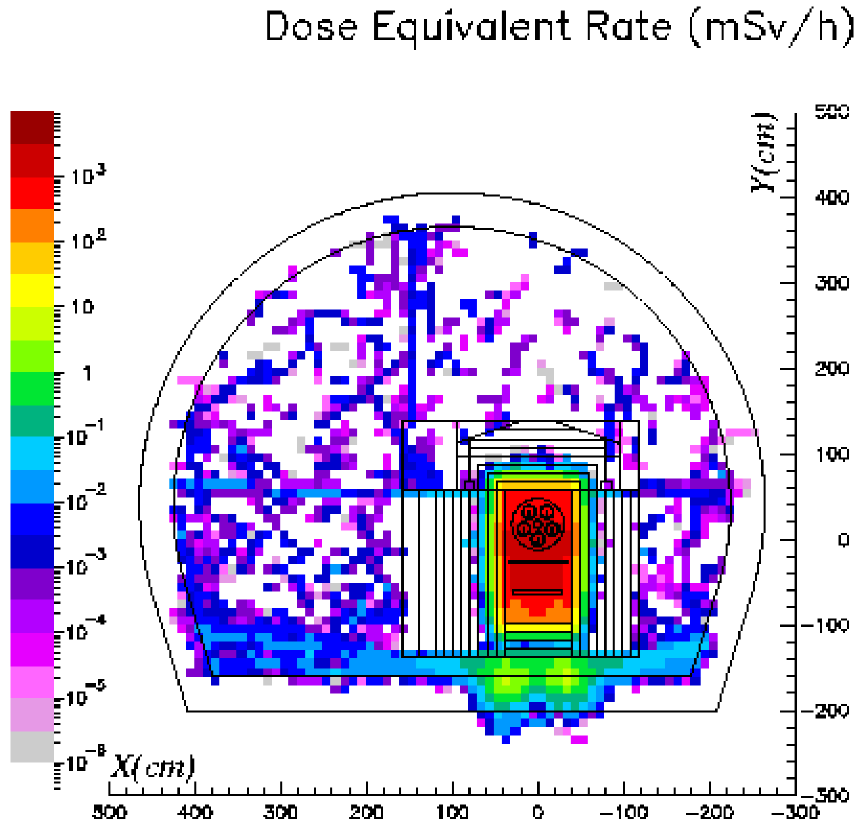


Figure 28 Target tube and adjacent materials contribution (mSv/h) after a cooling time of one week

5. Conclusions

- Large variations of the dose equivalent rates in the passageway around the target and horn region are observed for cooling times up to one week but for longer cooling times the variations are small.
- The most important contribution to the dose equivalent rate in the passageway along the target and horn is the one of the horn shielding. Even in the target area the contribution of the horn shielding makes more than 60% of the total value.
- The presence of the marble block on the left side of the target shielding prevents that the dose equivalent rate in the passageway near the target reaches higher values.

Acknowledgments

I would like to thank Konrad Elsener and Stephane Rangod for their support regarding the questions related to the CNGS project.

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