Ref. Ares(2020)4094157 - 04/08/2020

BEATS

Workpackage 4

Beamline technical design and instrumentation procurement

Report on the specifications for the radiation protection hutches

D 4.2

July 2020

Funded by the EU's H2020 framework programme under grant agreement n°822535

PROJECT DETAILS

PROJECT ACRONYM
BEATS

PROJECT TITLE
BEAmline for Tomography at SESAME

GRANT AGREEMENT NO:
822535

THEME

START DATE
2019

DELIVERABLE DETAILS

WORK PACKAGE: 04

EXPECTED DATE: 31/07/2020

WORK PACKAGE TITLE: BEAMLINE TECHNICAL DESIGN AND INSTRUMENTATION PROCUREMENT

DELIVERABLE TITLE: REPORT ON THE SPECIFICATIONS FOR THE RADIO PROTECTION HUTCHES

WORK PACKAGE LEADER: ESRF

DELIVERABLE DESCRIPTION: REPORT

DELIVERABLE ID: D4.2

PERSON RESPONSIBLE FOR THE DELIVERABLE: M. J. GARCIA-FUSTÉ

NATURE

☒ R - Report ☐ P - Prototype ☐ D - Demonstrator ☐ O - Other

DISSEMINATION LEVEL

☒ P - Public
☐ PP - Restricted to other programme participants & EC:
☐ RE - Restricted to a group
☐ CO - Confidential, only for members of the consortium

REPORT DETAILS

VERSION: 1

DATE: 31/07/2020

NUMBER OF PAGES: 30

DELIVERABLE REPORT AUTHOR(S): MARIA JOSÉ GARCIA-FUSTÉ

FOR MORE INFO PLEASE CONTACT: MGARCIA@CELLS.ES

STATUS

☐ Template ☐ Draft
☒ Final ☒ Released to the EC

CONTENTS

INTRODUCTION

Objective

The objective of this document is to describe the results of the shielding calculations made for the BEATS Beamline at SESAME to guarantee public zone levels outside its shielding during operation. For the public zone level to be reached at SESAME's experimental hall dose rates must be below 0.5 μSv/h, this limit value is established from the dose limit for non-exposed workers, assuming 2000 working hours per year. Consequently, the dose rates produced by BEATS shall be near the natural background levels during normal operation conditions. BEATS will be installed in the Experimental Hall of SESAME.

Hypothesis for the shielding calculations

The Monte Carlo code used for these calculations is FLUKA code[1],[2]. Following the general methodology in use at other synchrotrons, and in particular at ALBA for this type of shielding calculations [3]-[11], the following parameters are used for the calculations:

- Electron energy: 2.5 GeV
- Current of the stored beam: 400 mA
- Length of the straight section (dipole to dipole): 5.05 m
- Average pressure in the straight section: 5.0×10^{-9} mbar, with the residual gas composition given in Table 1.

Molecule	Relative pressure (%)	Partial pressure (mbar)
H_2	80	1.12×10^{-9}
CO	10	1.4×10^{-10}
CO_2	5	7×10^{-11}
Noble gases	3	4.2×10^{-11}
H_2O	2	2.8×10^{-11}

Table 1 Residual gas composition in the straight sections, used for the bremsstrahlung shielding calculations. The partial pressure in the third column corresponds to a total pressure of 1.4×10^{-9} mbar.

All shielding calculations for the BEATS Beamline are performed with an average pressure in the straight section of 5×10^{-9} mbar, and maximum permitted total dose rates outside the shielding below 0.5 μSv/h. This will guarantee that at the design pressure of 1.4×10^{-9} mbar, the dose rates outside the hutch will be close to natural background, thus allowing the beamline to operate at higher pressure values without surpassing the public access classification.

BEATS operation modes and geometric constraints

The BEATS beamline aims at producing synchrotron beams for tomography techniques in two main operation modes:

1. **White beam or mirrorless mode**: under which the full beam emitted by the ID source can reach the sample in the Experimental Hutch,

2. **Monochromatic beam or mirrored mode**: during which a Double Mirror Monochromator (DMM), placed inside the Optics Hutch, allows filtering the ID source beam so that the sample is analysed under a monochromatic beam of selectable energy in the Experimental Hutch.

In mirrorless mode, there is no optic element inside the Optics hutch where the beam can be scattered significantly under normal conditions. Under the monochromatic mode however one must consider the Double Mirror Monochromator (DMM) as the main scattering element. The characteristics of the DMM are:

- The first mirror (MM1) is placed at 16.155 m from the ID source,
- The second movable mirror (MM2) has a travel range of 320 – 950 mm from MM1 and incidence angle range between 4.99 – 20.82 mrad, allowing selecting monochromatic beams from 8 keV to 50 keV.
- DMM offset range is between 6 – 16 mm.

A schematic layout of BEATS is shown in Figure 1. Figure 2 shows the 3D geometry of BEATS Beamline entered in FLUKA and used for the shielding calculations.

BEATS optical hutch (OH) geometry used for the calculations has one sidewall outward (OH-O) at a distance of 137.7 cm from the beam axis and one sidewall inward (OH-I) at a minimum distance of 78.8 cm.

The outward sidewall (OH-O) and the inward sidewall (OH-I) have a length of 710 cm. The end of the optical hutch is closed by a backwall (OH-B). The roof (OH-R, not shown in Figure 1) is placed at a height of 370 cm.

Between the optical and the experimental hutch, there is a transfer line (TL) with a length of 1050.8 cm, composed of a standard stainless-steel vacuum chamber covered by a lead layer. The tentative thickness of this shielding layer of lead is 50 mm.

The BEATS experimental hutch (EH) geometry used for the calculations features one front wall (EH-F) located 1050.8 cm downstream with respect to the OH-B. In addition, the experimental hutch has one sidewall outward (EH-O) at a distance of 138.5 cm from the beam axis and one sidewall inward (EH-I) at a minimum distance of 138 cm from the beam axis. The outward sidewall wall (EH-O) and the inward sidewall (EH-I) each have a length of 1400 cm. The experimental hutch is closed by a backwall (EH-B). The roof for this hutch is at a height of 290 cm height (EH-R, not shown in Figure 1). The first element of the optics inside the EH is a vessel with the secondary slits followed by a second window through which the beam leaves the vacuum chamber into air. At the end of the hutch there is a beam stop that will absorb the photon beam, placed at 4531.5 cm from the source.

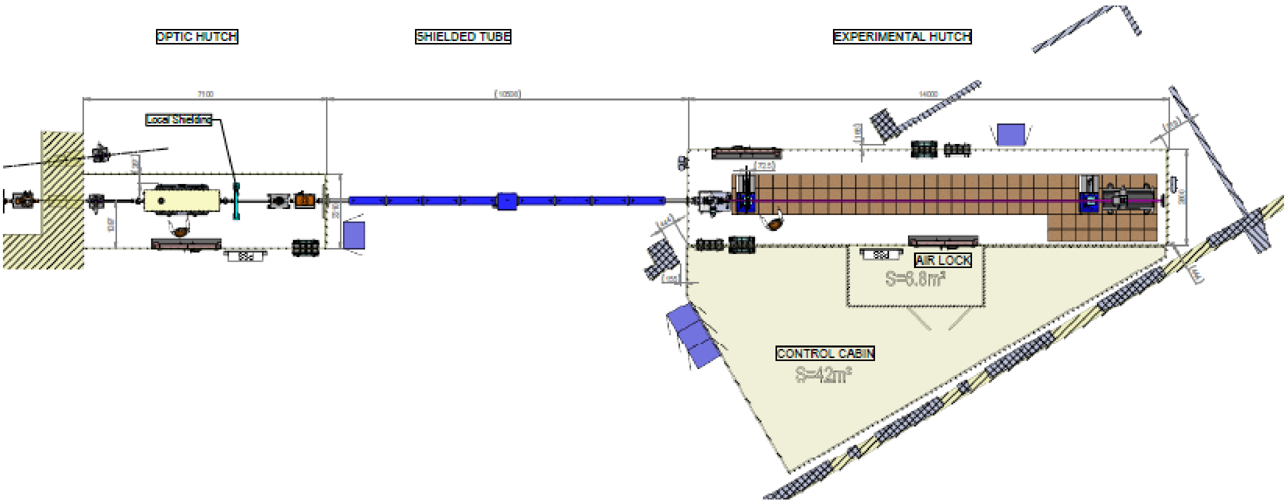

Figure 1 Schematic top view layout of BEATS beamline geometry

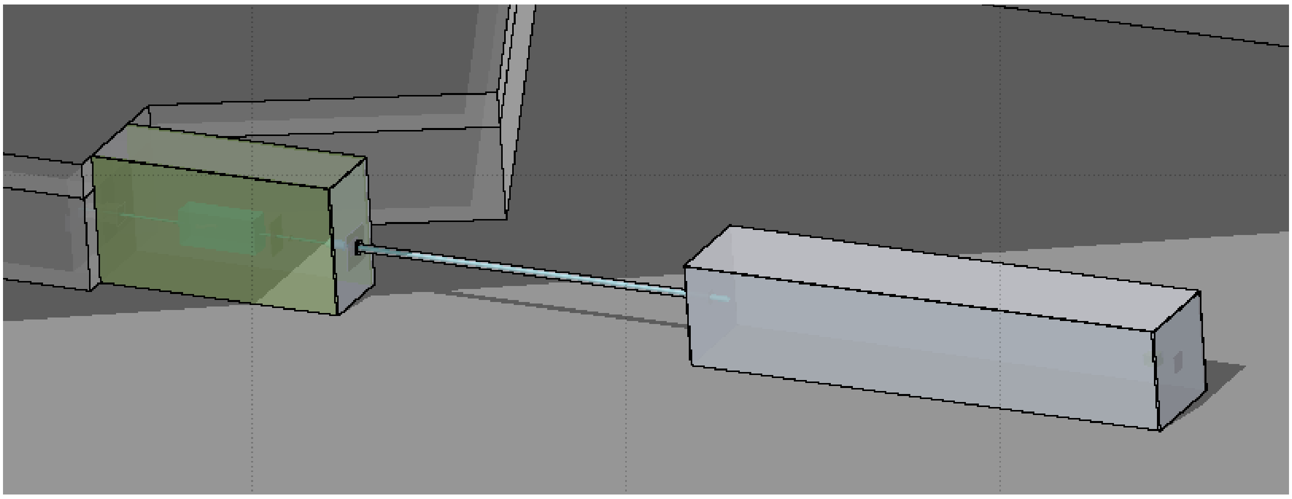

Figure 2 3D geometry entered in FLUKA for BEATS Beamline

Shielding estimations from ALBA hard X-ray Beamlines

The BEATS beamline is a hard X-ray Beamline that will accept white beam in both hutches. From the radiation protection point of view this implies that both enclosures (OH and EH) must be treated as optics hutches. BEATS is similar from a radiological point of view to other hard X-ray Beamlines designed and installed at ALBA, and particularly similar to FaXtor, ALBA's tomography beamline, which is currently under design and construction. In addition, the parameters of ALBA's storage ring and vacuum are basically equivalent to those of SESAME. These facts allow the establishment of shielding requirements estimations making use of ALBA's prior designs and experience. These required shielding constraints (number of elements, material composition and thicknesses) are afterwards tested by simulation with Monte Carlo codes to ensure that the limit dose rate levels outside are kept within the desired levels.

Hutch sidewall estimations

For the sidewall, the results obtained for other hard X-ray ALBA beamlines show that the expected value for sidewalls thickness for an average pressure in the straight section of 5×10^{-9} mbar, and maximum total dose rates below 0.5 μSv/h, are expected to be between 5 mm and 15 mm of lead for OH-O, EH-O and EH-I (approx. 140 cm away from beam axis) and between 20 mm and 30 mm of lead for OH-I (81.3 cm away from the photon beam axis). It may also be necessary to consider the use of polyethylene layers, typically 10 cm thick, to absorb the neutrons produced by the interaction of the white beam photons with the main scattering sources and to increase slightly the lead thickness to cope with secondary photons produced by these neutrons.

Hutch backwall estimations

For the backwalls, the results obtained for other hard X-ray ALBA beamlines show that typically a lead wall of 6 cm thickness is adequate for a medium straight section beamline, which should be reinforced by adding a lead screen of 1 m^2 surface and 5 cm thickness. This reinforcement can be substituted by a proper beam stop, which is the option chosen for the experiments hutch of BEATS. Finally, simple local screens, typically 2 cm thick, placed behind the main scattering sources will provide the necessary extra shielding to cope with eventual degraded vacuum conditions in the storage ring.

Hutch roof estimations

From other hard X-ray ALBA experience, the thickness value for roof shielding is typically 15 mm of lead at 340 cm of height. The same thickness is expected to be adequate for BEATS hutches' roofs at 290 cm and 370 cm height.

BEATS SHIELDING ELEMENTS

Structural shielding

Table 2 summarises the recommendation for the shielding of BEATS hutches: material and thickness for the different walls. Those requirements have been checked by Monte Carlo simulation to ensure that the outside radiation levels are close to the background when considering a vacuum chamber pressure of 5×10^{-9} mbar. As the radiation levels produced are well below the limit and directly proportional to this vacuum pressure, from the results obtained one can escalate and determine the maximum allowed vacuum level that will observe the 0.5 μSv/h limit and compare it to the vacuum operational level for all simulation scenarios.

Finally, it should be pointed out that special attention should be paid to the design of the joints between the panels, the panels and the floor and on the doors or in the tunnel front wall, where the use of lead strips is highly recommended, to avoid photons being scattered outside the shielding enclosure. **The final design of the hutches together with detailed explanations on the solutions proposed to design the joints will therefore have to be sent to SESAME's Radiation Protection Service prior to the call for tender of the radiation protection hutches to be fully verified and approved.**

Table 2 Summary of shielding requirements for BEATS hutches

Element	Material and thickness
Sidewall OH-I	Lead 25 mm
Sidewall OH-0	Lead 20 mm
Backwall OH-B	Lead 60 mm
Roof OH	Lead 15 mm
Frontwall EH Sidewall EH-I Sidewall EH-O	Lead 20 mm
Backwall EH-B	Lead 60 mm
Roof EH	Lead 15 mm

Non-structural shielding

As it has been done with the other beamlines currently in operation at ALBA, non-structural shielding elements are also needed to cope with the scattered radiation produced by the different optic elements. Among them: Lead screens, guillotines, beam stops and chicane entrances to allow feeding the instruments with adequate supplies (power supplies, data acquisition, fluids, etc.).

Local shielding

Taking into account the current optical design some local shielding elements are necessary at the locations shown in Figure 3.

Table 3 provides the characteristics of these BEATS local shielding elements, such as their expected minimum dimensions and construction material. Note that the transverse dimension of the lead screen (element #2 in Table 3) should be such that, depending on its location, it should protect the entire backwall from the scattering source (see Figure 4). The dimensions of the collar around the TL and the front wall guillotine (elements #7 and #8 in Table 3) should be such that they fill the gap between the pipe and the EH-F wall.

Table 3 list of BEATS local shielding elements with expected minimum dimensions

#	Shielding Elements	Height (cm)	Width (cm)	Thickness (cm)	Material
1	Tunnel-to-OH guillotine	30	30	2	Lead
2	Local Pb screen 1 behind DMM	-	-	2	Lead
3	Sidewall OH-I neutron screen	-	-	10	Polyethylene
4	Sidewall OH-O neutron screen	-	-	10	Polyethylene
5	OH-to-EH guillotine	40	40	6.5	Lead
6	OH backwall central reinforcement	100	100	5	Lead
7	Collar around TL	-	-	2.5	Lead
8	Guillotines at both extremes of the TL	-	-	2	Lead
9	ExpHall-to-EH guillotine	30	30	2	Lead

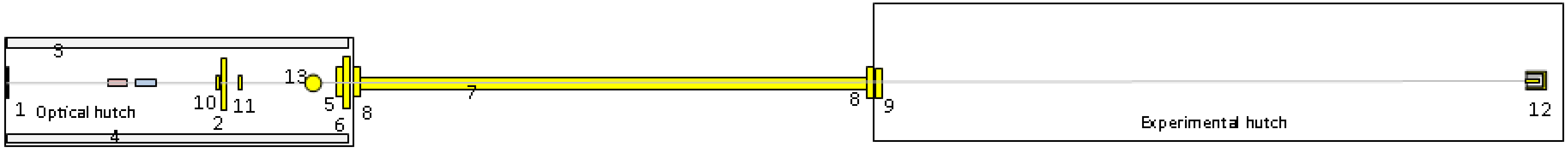

Figure 3 location of BEATS local shielding elements

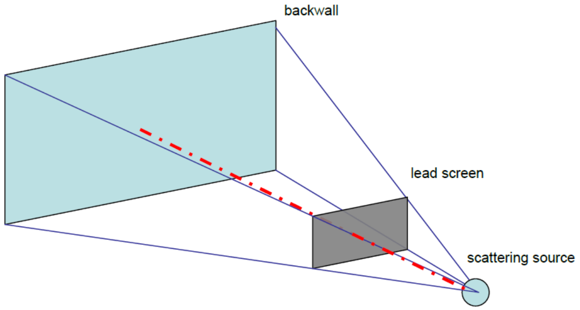

Figure 4 Transverse dimensions of the local Lead screens

Bremsstrahlung collimators and stops

Without any beam stops or collimators, an important amount of scattered gas bremsstrahlung radiation will escape from the OH through the beam hole in the OH backwall. Consequently a double bremsstrahlung collimator system (see Figure 5) is needed.

In addition, a bremsstrahlung stop is needed at the end of the experimental hutch to absorb all the flux coming from the OH through the TL in any beamline configuration. This beam stop must deal with the neutron production induced by the primary photons and needs careful design and optimisation, see Figure 6.

The size and construction material of these collimators and stop are detailed in Table 4.

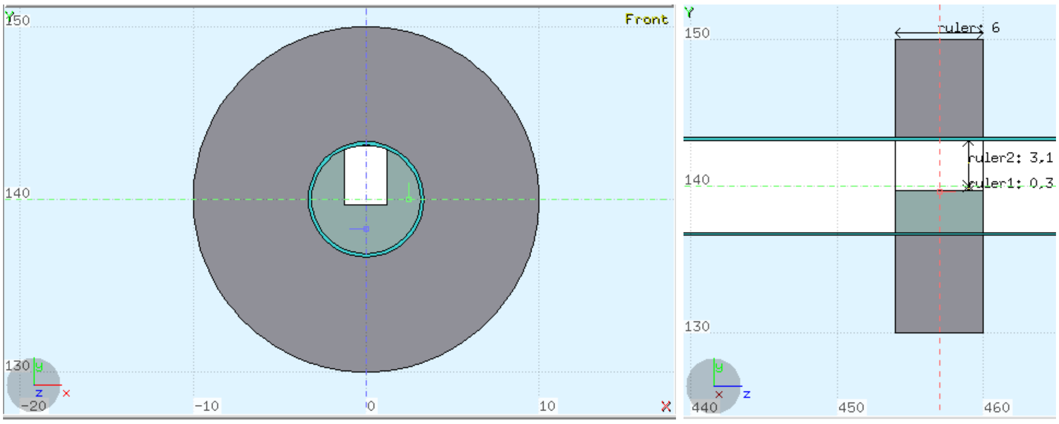

Figure 5 Bremsstrahlung collimators shape (elements #10 and #11) of BEATS Beamline

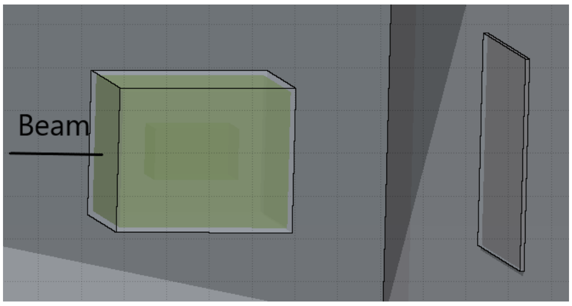

Figure 6 Beam stop for BEATS experimental hutch

Table 4 List of BEATS Bremsstrahlung collimators and stops with dimensions, location and material composition

#	Shielding Element	Height (cm)	Width (cm)	Thickness (cm)	Material
10	1st Bremsstrahlung collimator	Ø 20		6	Tungsten and lead
		Aperture Ver3.4 cm x Hor2.44 cm			
11	2nd Bremsstrahlung collimator	Ø 20		6	Tungsten and lead
		Aperture Ver 3.4 cm x Hor 2.44 cm			
12	EH beam stop				
	- Photon stop	12	12	20	Lead
	- Neutron stop	10 cm in all directions			Polyethylene
	- External layer	1 cm in all directions			Lead

Safety Shutter

Following the standard design of hard X-Ray beamlines, BEATS shall have a safety shutter located at the end of the optical hutch, to allow access to the experimental hutch when there is beam inside the optics hutch. The dimensions of the BEATS safety shutter shall be similar to that placed at the end of the front end because it must absorb the white beam produced by the ID and the possible gas bremsstrahlung field produced inside the ID straight section. The particular dimensions of the BEATS shutter are detailed in Table 5 and its geometry from FLUKA is shown in Figure 7.

Table 5 BEATS Optical Hutch Safety Shutter dimensions and material

#	Shielding Element	Height (cm)	Width (cm)	Thickness (cm)	Material
13	Safety Shutter	12	12	20	Tungsten

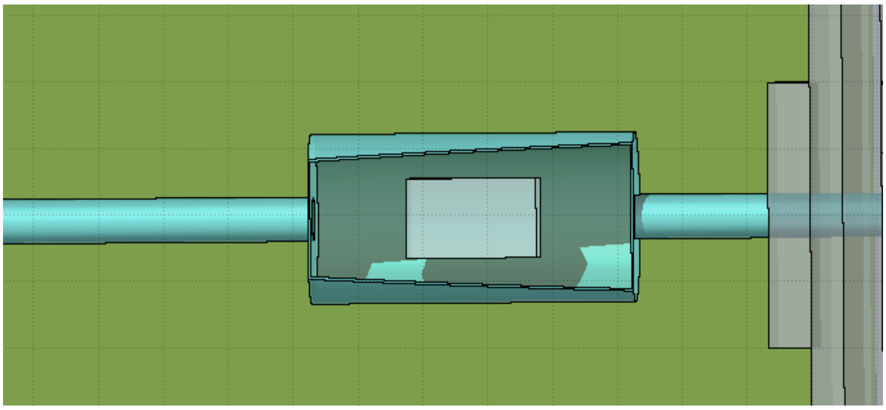

Figure 7 FLUKA geometry of BEATS Safety Shutter (element #13)

Doors, chicanes and construction constraints

Hutch doors for white beam beamlines must be constructed under the following conditions:

- They cannot be placed at backwalls, where they will be exposed directly to the scattered beams,
- Their thicknesses must be the same than those of the sidewalls where they are going to be installed,

A summary of BEATS door locations, material composition and thicknesses are shown in Table 6.

The dimensions of the chicanes are standard and similar to what has been installed for the other SESAME beamlines. The designed chicanes, and any future chicane installed at BEATS beamline, shall have the same lead thickness as the wall in which it is located. A summary of BEATS chicanes and their characteristics is provided in Table 7.

In addition, lead strips (50 cm width x 0.5 cm height) must be foreseen inside both hutches on the floor and Tunnel front wall, to prevent scattered radiation from escaping at hutch walls joints.

Table 6 List of hutch doors, locations, thickness and material

Shielding Element	Location	Thickness (cm)	Material
OH Door	OH-O	2	Lead
Eh door	EH-O	2	Lead

Table 7 List of chicanes, locations, shielding thickness and materials

#	Shielding Element	Location	Thickness (cm)	Material
14	Electrical chicane OH	OH-O	2	Lead
15	Data chicane OH	OH-O	2	Lead
16	Ventilation chicane “in” OH	OH-R	1.5	Lead
17	Electrical chicane OH	EH-I	2	Lead
18	Data chicane OH	EH-O	2	Lead
19	Ventilation chicane “in” EH	EH-I	2	Lead

SHIELDING CALCULATION RESULTS

Radiation levels around synchrotron beamlines are produced by two main processes:

1. The interaction of the photon flux generated by the Insertion Device with the different elements encountered on the beam path,
2. The gas bremsstrahlung radiation field produced by the interaction of primary electrons inside the straight section of the ID with the residual gas inside it.

The shielding requirements in the case of ID beamlines are dominated by the second process, i.e. the gas bremsstrahlung scattered radiation that can send an important flux of high energy photons into the hutches.

The results shown in this section will verify this by FLUKA simulations assuming for the BEATS beamline a maximum current stored the storage ring of 400 mA, an aperture of the front end of 1 mrad, corresponding to the worst case from a radioprotection point of view. The Monte Carlo simulation results allow validating the required lead walls and roof thicknesses for gas bremsstrahlung scattering produced at the optical elements of BEATS. The geometry used for the calculation was the BEATS Beamline geometry as laid out in Figure 1 and Figure 2, together with Table 2, Table 3, Table 4 and Table 5 shielding elements.

Several simulation scenarios have been considered, taking into account the different operation modes and the most probable accidental situations for both processes. In summary:

1. White beam operation mode scenarios – mirrorless configuration
2. Monochromatic beam operation mode scenarios – mirrored configuration with MM1 and MM2 of the DMM inserted at the two extremal positions, representing the minimum and maximum monochromatic selectable energies
3. Bad vacuum conditions inside the transfer line- accidental situation for both processes.

Gas bremsstrahlung source calculations

White beam or mirrorless operation mode

The results found for gas bremsstrahlung source during the mirrorless operation mode are presented in this section. Figure 8 shows the photon, neutron and total equivalent dose rates (µSv/h) at 140 cm height (primary beam level). Figure 9 shows the total dose rate map from scattered gas bremsstrahlung at 375 cm height for the OH and 295 cm height for the EH, just above the roof levels. It can be observed that the maximum total dose rate outside BEATS hutches for this operation mode is 0.025 µSv/h (for 5.0×10^{-9} mbar), allowing a maximum value for the pressure in the straight section of 1×10^{-7} mbar for 0.5 µSv/h.

Without any beam stops or collimators, an important amount of scattered bremsstrahlung radiation will escape from the OH through the beam hole in the OH back wall. Consequently, a bremsstrahlung collimation system is needed in the OH and a beam stop at the EH. The shielding effectiveness of the beam collimators and beam stop can be observed from Figures 8 and 10, comparing the dose rates outside the EH with and without the double bremsstrahlung collimator system under the mirrorless configuration mode. The maximum dose rate values are approximately 5 times lower with the collimation system inserted.

In addition, one can notice that the dose rate levels outside the OH are significantly increased when the collimating system is in place, particularly due to neutron and their secondary lower energy photon dose rate contribution. To cope with this increased neutron level it is advisable to consider the use of materials rich in H content, like polyethylene, that allow the absorption and energy degradation of neutrons through n-p elastic scattering reactions.

A series of simulations have been performed to optimise the position and thickness of the OH polyethylene neutron shields with the gas bremsstrahlung source under the mirrorless configuration. The total dose rate levels produced with no neutron shield, shield only over the whole length of OH-I sidewall, and shield over the whole length of both OH-I and OH-O sidewalls are shown in Figure 11. It is evident that two 10 cm thickness polyethylene screens covering the inner sides of both OH sidewalls are needed to reduce the dose rates below the required levels.

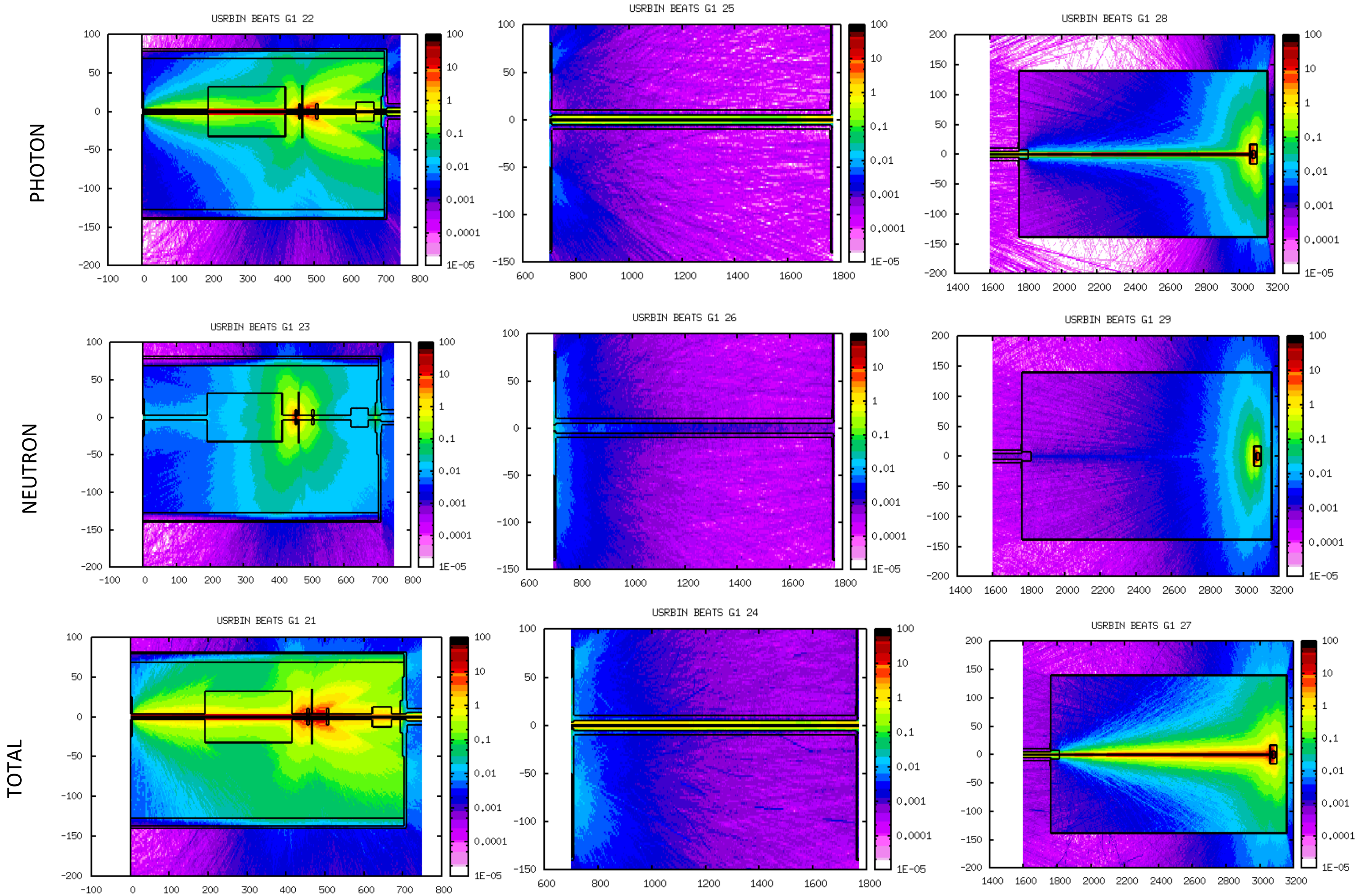

Figure 8 Photon, neutron and total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with the beam collimation system and polyethylene screens at the OH in use for the Gas bremsstrahlung case under the mirrorless operation mode

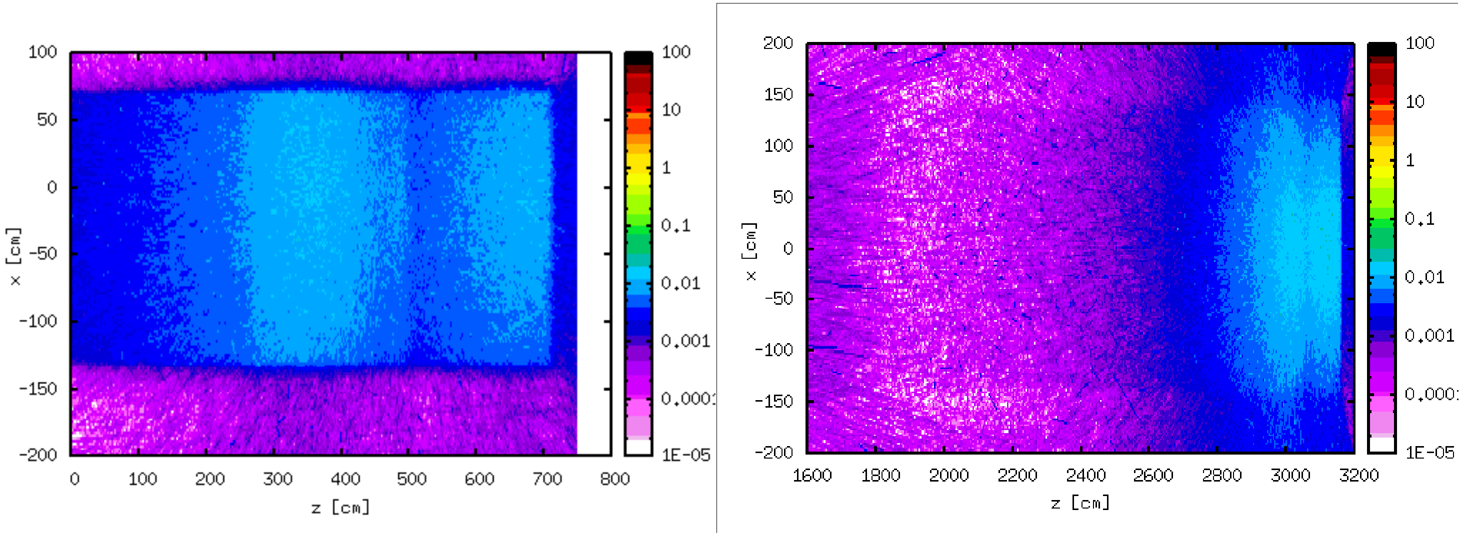

Figure 9 Total dose rates (μSv/h) at roof heights inside and around OH(left) and EH (right) for the Gas bremsstrahlung case under the mirrorless operation mode

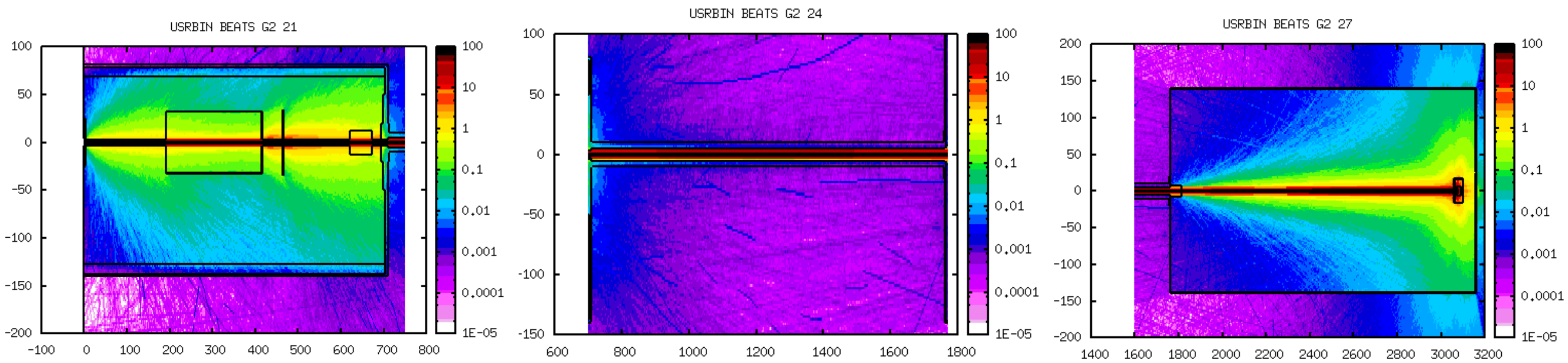

Figure 10 Total dose rates (μSv/h) at 1.40 m height inside and around OH, TL and EH without the beam collimation system and with polyethylene screens at the OH in use for the Gas bremsstrahlung case under the mirrorless operation mode

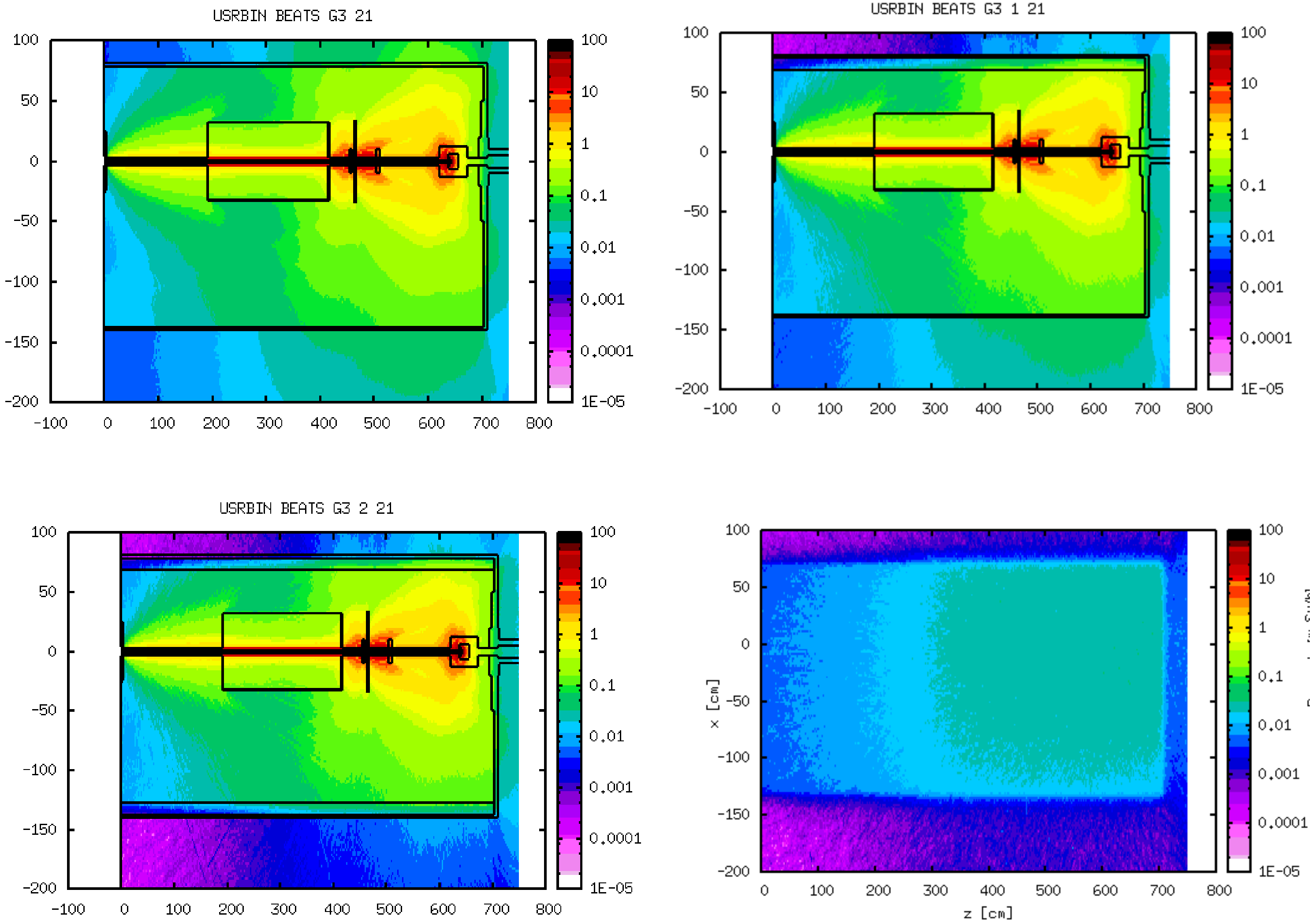

Figure 11 Total dose rates (µSv/h) with Safety Shutter closed for the Gas bremsstrahlung case under the mirrorless configuration and different options as neutron shielding. Top-left corner: doses at 1.40 m height inside and around OH with no polyethylene screen in use. Top-right corner: doses at 1.40 m height inside and around OH with a 10 cm polyethylene screen covering the whole length of the OH-I sidewall. Bottom-left corner: doses at 1.40 m height inside and around OH with two 10 cm polyethylene screens covering the whole length of both OH-I and OH-O sidewalls. Bottom-right corner: doses at the OH roof height with two 10 cm polyethylene screens covering the whole length of both OH-I and OH-O sidewalls

Monochromatic beam operation mode

The results found for the gas bremsstrahlung source under the monochromatic operation mode are analysed in this section for the two extremal positions of MM1 and MM2, corresponding to the minimum and maximum selectable energies. Figure 12 shows the photon, neutron and total equivalent dose rates (in µSv/h) at 140 cm height (primary beam level) for the minimum energy monochromatic operation mode. Figure 13 shows the photon, neutron and total equivalent dose rates (in µSv/h) at 140 cm height (primary beam level) for the maximum energy monochromatic operation mode. The results obtained are, as expected, very similar for both selectable energies and allow to see the effect of having different scattering elements at different positions. The increased total dose rates inside the OH with respect to those produced under the mirrorless mode are also expected and explained due to the production of neutrons and secondary lower energy photons by the mirrors themselves, which cannot traverse the shielding and thus do not contribute to dose rates outside the hutches.

Finally, Figure 14 shows the total dose rate maps (in µSv/h) for the minimum and maximum energy scenarios at 375 cm height for the OH and 295 cm height for the EH.

It can be observed that the maximum total dose rate outside the BEATS hutches for any of these scenarios is 0.25 µSv/h (for 5.0×10^{-9} mbar), comparable to the natural background levels at the SESAME area and allowing a maximum value for the pressure in the straight section for 0.5 µSv/h of 9.6×10^{-9} mbar.

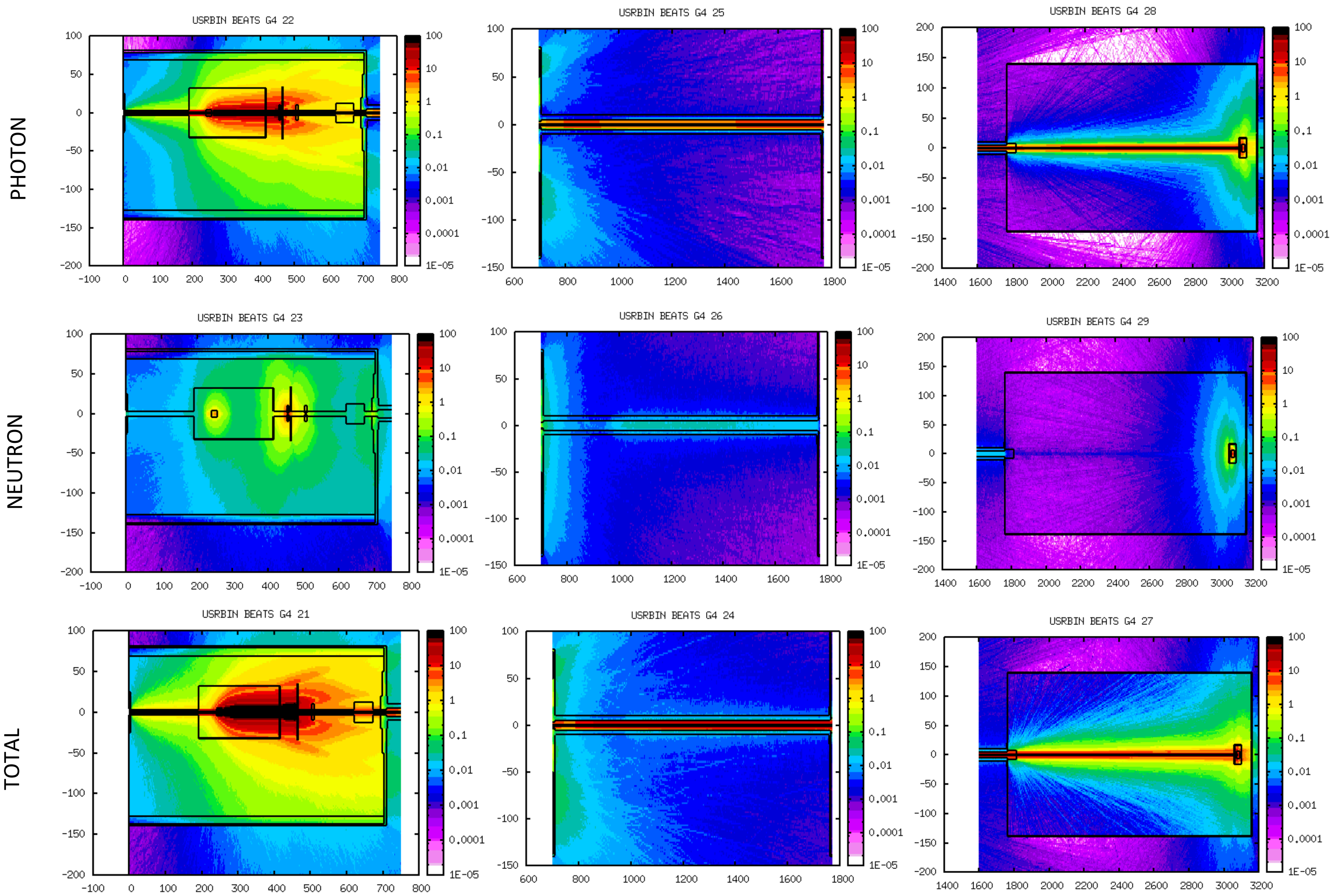

Figure 12 Photon, neutron and total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with for the Gas bremsstrahlung case under the minimum energy monochromatic operation mode

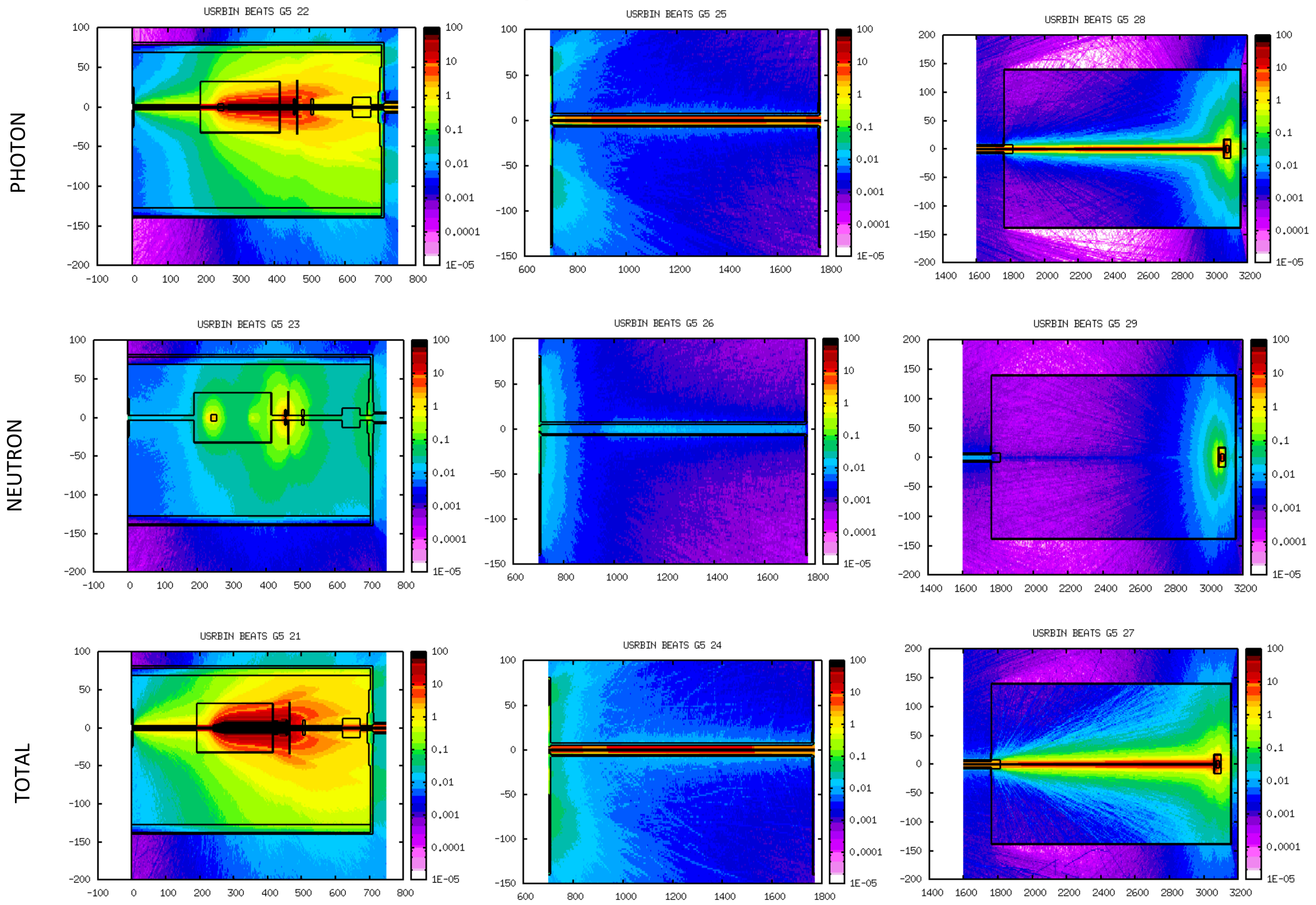

Figure 13 Photon, neutron and total dose rates (μSv/h) at 1.40 m height inside and around OH, TL and EH with for the Gas bremsstrahlung case under the maximum energy monochromatic operation mode

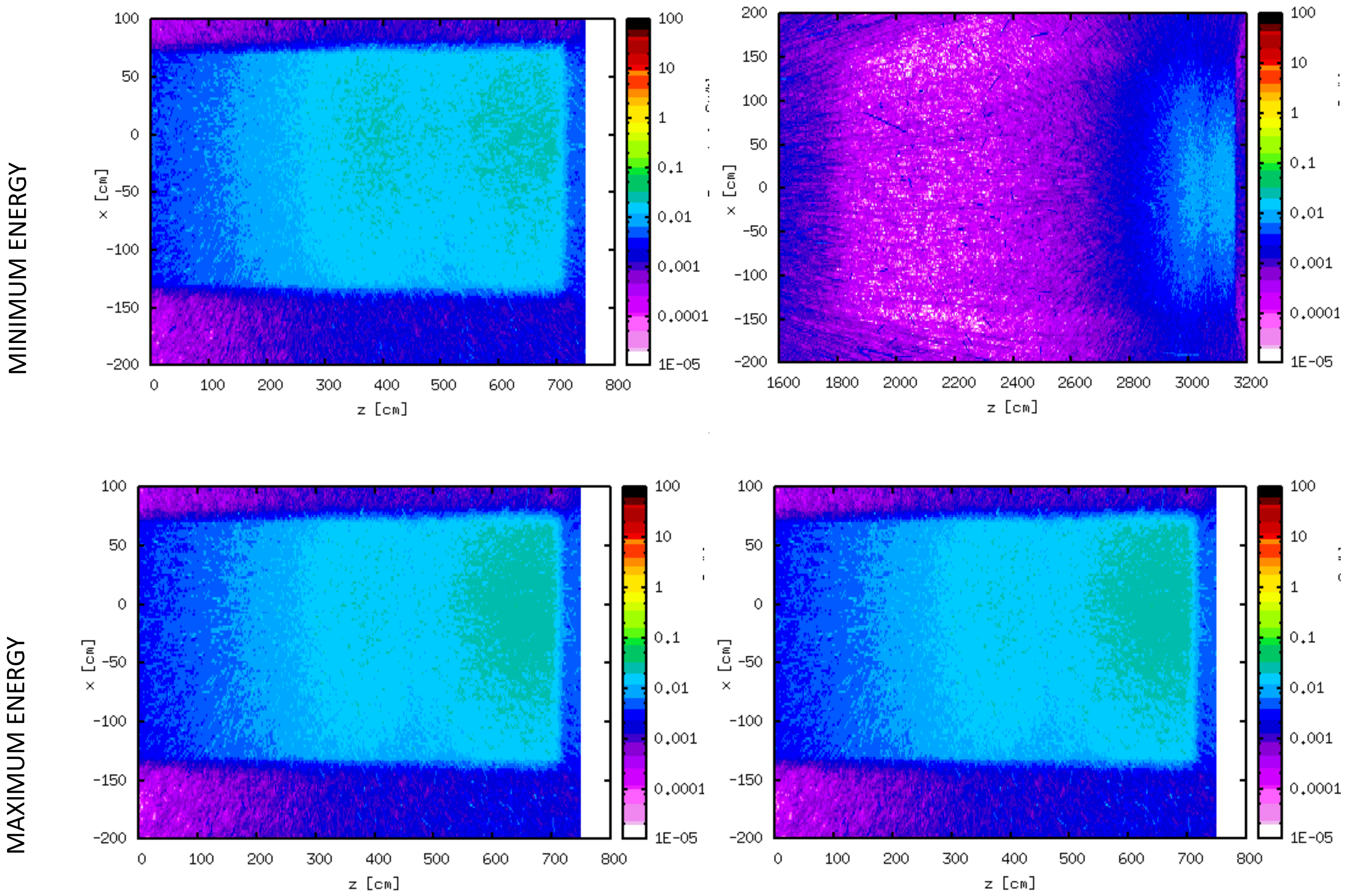

Figure 14 Total dose rates (μSv/h) at roof heights inside and around OH (left) and EH (right) for the Gas bremsstrahlung case under the monochromatic operation mode: minimum selectable energy on top and maximum selectable energy at the bottom

Safety shutter behaviour

The safety shutter should be capable to shield both gas bremsstrahlung and synchrotron radiation from the ID source in the two operation modes (mirrorless and DMM), and should allow free access to the experimental hutch when it is in closed position and there is beam in the optics hutch. The most restrictive scenario for the safety shutter from a radiological point of view is the high energy gas bremsstrahlung source hitting the shutter directly in mirrorless configuration. The results obtained in that case are shown in Figure 15, and confirm that a shutter thickness of 20 cm in tungsten and frontal surface of 12x12 cm^2 is sufficient to shield the scattered gas bremsstrahlung radiation and ensure public levels near the TL in the experimental hall and inside the experimental hutch when the safety shutter is closed and there is beam in the optics hutch.

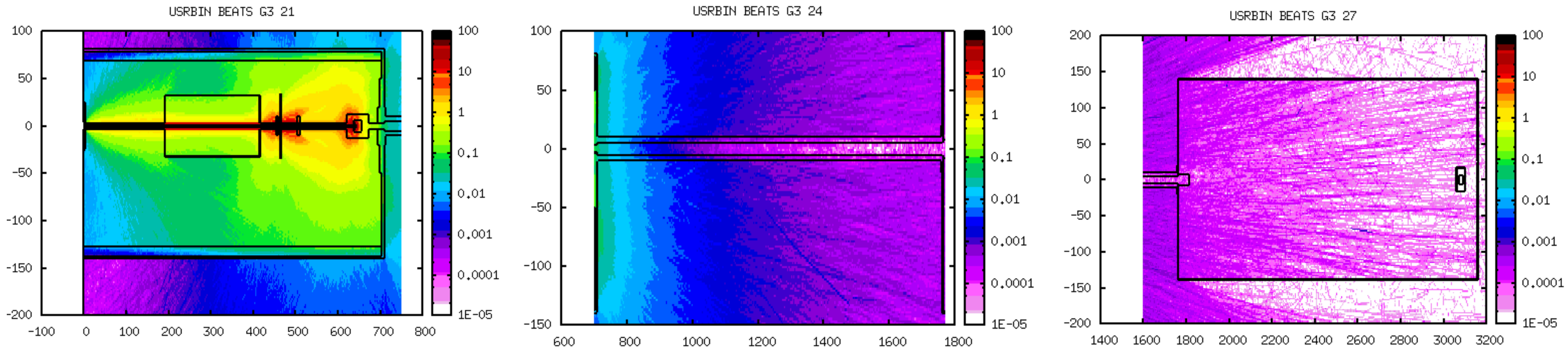

Figure 15 Total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with the OH Safety Shutter closed and for the Gas bremsstrahlung case under the mirrorless configuration

Transfer line behaviour in a vacuum accident situation

Transfer lines at white beam beamlines must always be treated carefully and several constraints must be respected for their construction and shielding:

1. If possible, the whole length of the TL must be free of elements, including vacuum devices such as flanges and pumps.
2. A careful limiting raytracing study must be performed in order to ensure that no scattered rays from the main optic elements at the OH can hit the TL vacuum chamber.
3. Shielding thickness should be enough to cope with accidental situations like vacuum problems where the vacuum levels can be compromised.

Following these principles, an accidental vacuum situation has been considered for the BEATS TL that could lead to the scattering of the gas bremsstrahlung high energy radiation inside the pipe when filled with air at atmospheric pressure (1 atm). From the total dose rate maps obtained, see Figure 16, one concludes that the required lead thickness of 5 cm reduces the radiation levels to values well below background levels. A more detailed analysis is provided at Figure 17, showing the dose rate profile as a function of the TL lead collar thickness at the position where the maximum dose rate is expected. From there, one can see that background levels could already be achieved with only 2.5 cm lead thickness, provided that the 3 conditions established before were completely fulfilled.

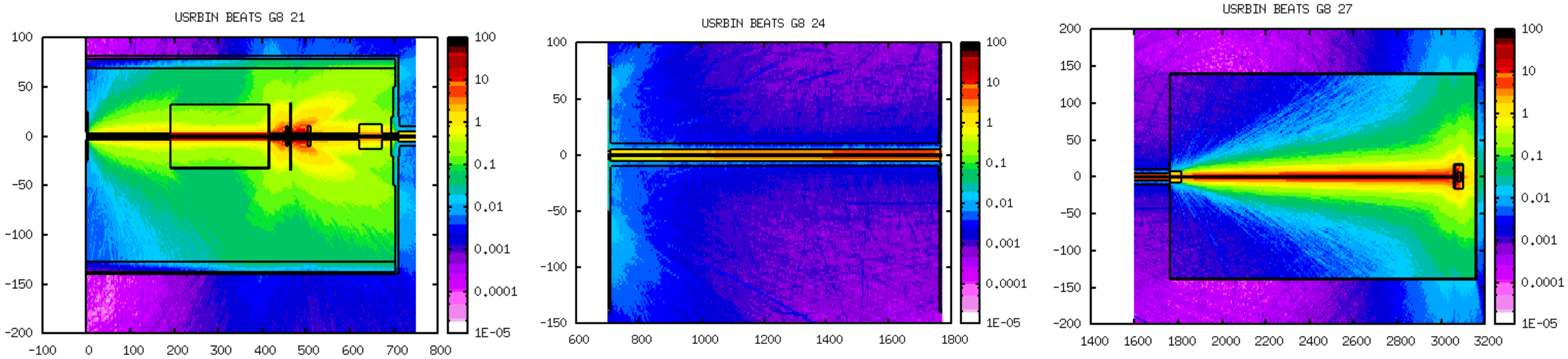

Figure 16 Total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH for the Gas bremsstrahlung case under the mirrorless configuration produced in the accidental scenario where the TL vacuum is compromised and the TL pipe is filled with air at 1 atm.

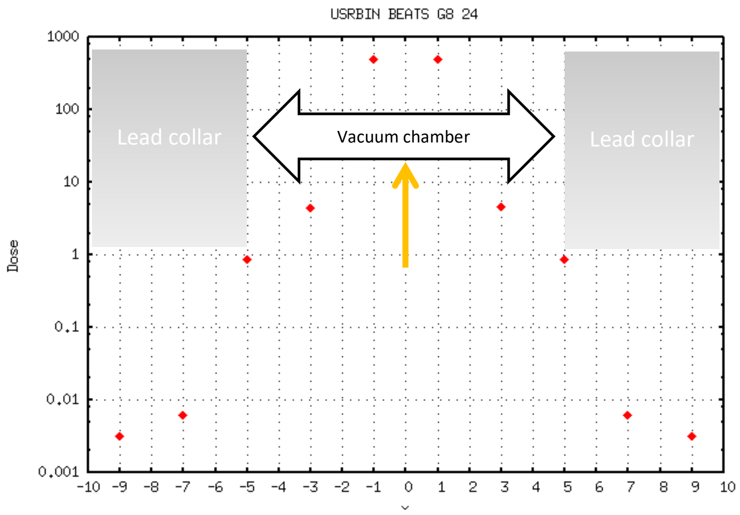

Figure 17 Total dose profile as a function of the TL Lead collar thickness at the position where the maximum dose rate is expected for the Gas bremsstrahlung case under the mirrorless configuration produced in the accidental scenario where the TL vacuum is compromised and the TL pipe is filled with air at 1 atm

ID source calculations

The shielding requirements for scattered synchrotron radiation coming from an ID source like the one of BEATS are largely met by the shielding thicknesses required for scattered gas bremsstrahlung presented previously. This has been verified with FLUKA using as source term the BEATS Insertion Device maximum flux at minimum gap, 1 mrad vertical aperture and for the maximum Storage Ring current (400 mA), see Figure 18. These conditions correspond to the worst situation for the ID source and from a radioprotection point of view.

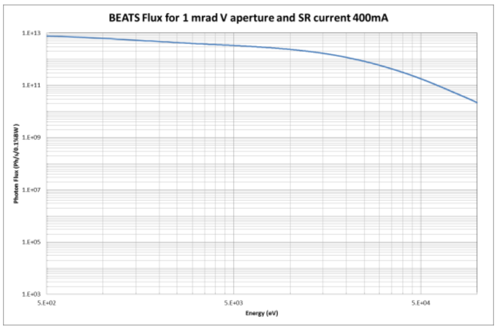

Figure 18 BEATS Insertion Device maximum flux source at minimum gap

White beam or mirrorless operation mode

Figure 19 shows the total equivalent dose rates at 140 cm height (level of the primary beam) for the ID source under the mirrorless operation mode. The results show effective dose rates below background level outside both hutches and TL, confirming that the shielding requirements for scattered synchrotron radiation are largely met by the shielding thicknesses required for scattered bremsstrahlung.

Monochromatic beam operation mode

Figures 20 and 21 show the total equivalent dose rates at 140 cm height (level of the primary beam) for the ID source under the monochromatic operation mode for the two extremal positions of MM1 and MM2, corresponding to the minimum and maximum selectable energies.

The results obtained are, as expected, very similar for both selectable energies and allow seeing the effect of having different scattering elements at different positions. The increased total dose rates inside both OH and EH with respect to those produced under the gas bremsstrahlung source are also expected and explained due to the lower energy of ID photons, which cannot traverse the shielding and thus do not contribute to dose rates outside the hutches.

The results show effective dose rates below background level outside both hutches and TL, confirming that the shielding requirements for scattered synchrotron radiation are largely met by the shielding thicknesses required for scattered bremsstrahlung.

Transfer line behaviour in a vacuum accident situation

Finally, an accidental vacuum situation has been considered that could lead to the scattering of the ID photon flux inside the TL pipe when filled with air at 1 atm. From the total dose rate maps obtained (Figure 23) one concludes that a lead thickness of 5 cm is enough and even reducible to 2.5 cm provided the 3 conditions established before are completely fulfilled.

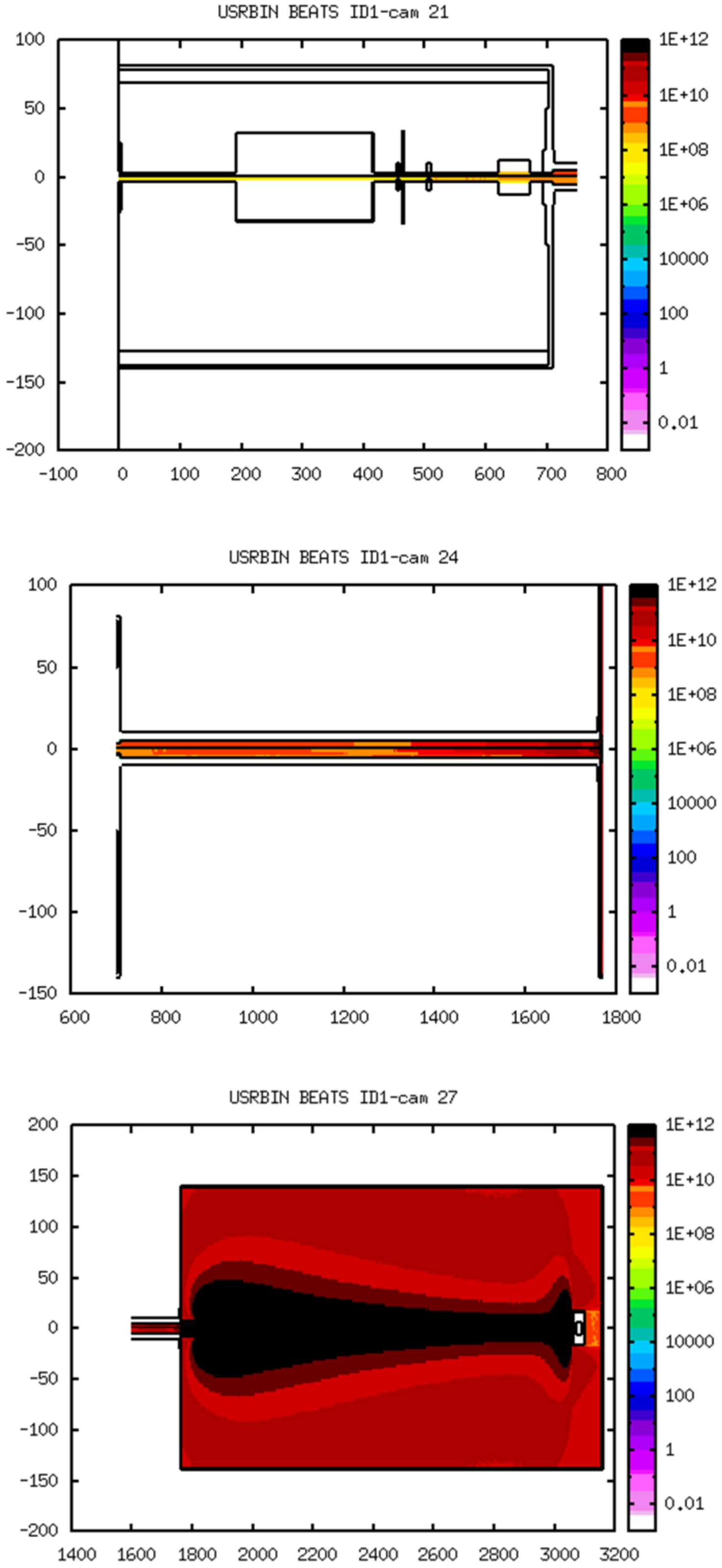

Figure 19 Total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with the beam collimation system and polyethylene screens at the OH in use for the ID source case under the mirrorless configuration

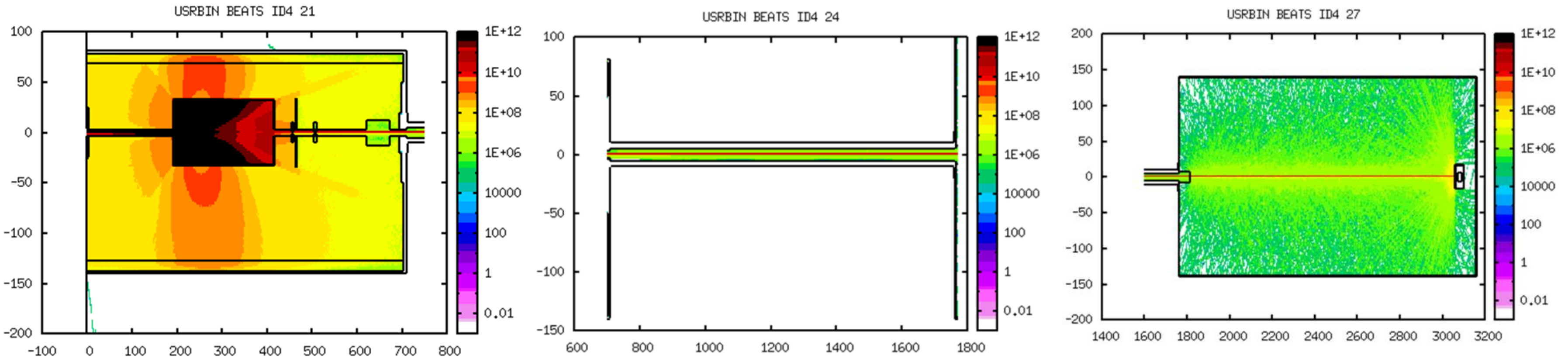

Figure 20 Total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with for the Gas bremsstrahlung case under the minimum energy monochromatic configuration

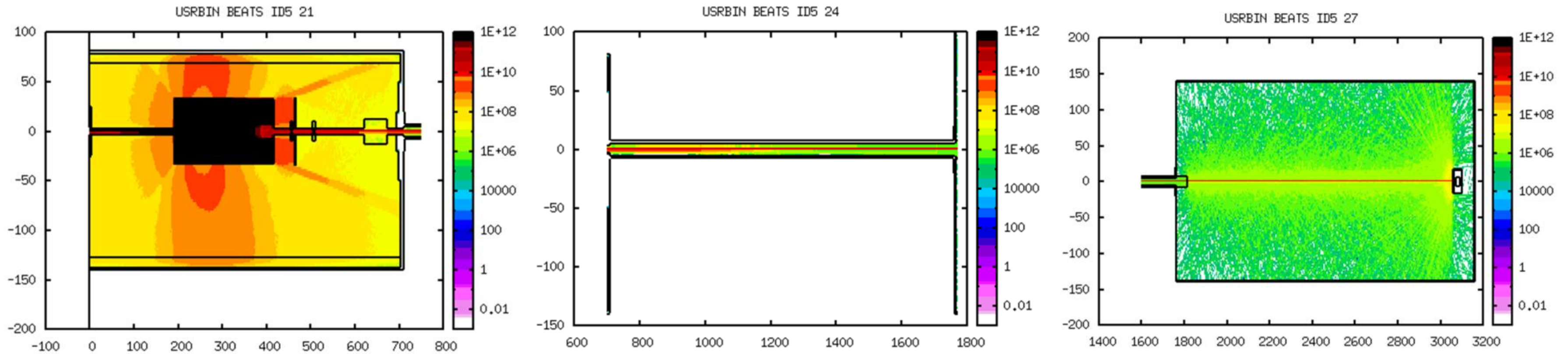

Figure 21 Total dose rates (µSv/h) at 1.40 m height inside and around OH, TL and EH with for the ID case under the maximum energy monochromatic configuration

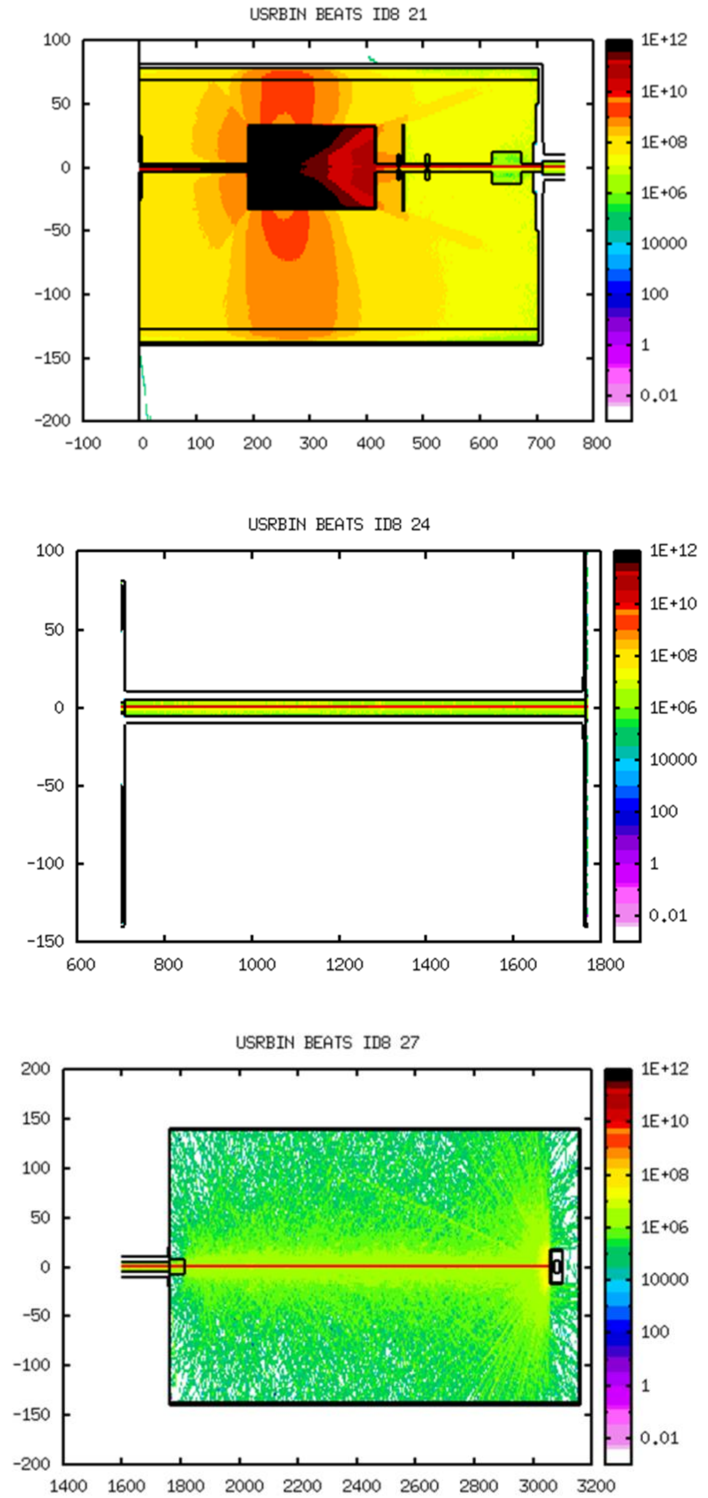

Figure 22 Total dose rates (μSv/h) at 1.40 m height inside and around OH, TL and EH for the ID case under the mirrorless configuration produced in the accidental scenario where the TL vacuum is compromised and the TL pipe is filled with air at 1 atm.

REFERENCES

[1] "The FLUKA code: Description and benchmarking" G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007).

[2] "FLUKA: a multi-particle transport code" A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.

[3] "Shielding of Beamlines at ALBA: Comparison between different types of bremsstrahlung", P. Berkvens. ALBA internal report.

[4] "Shielding calculations for XALOC Beamline at ALBA", P. Berkvens. ALBA internal report.

[5] "Shielding calculations for the design of new beamlines at ALBA synchrotron", A. Devienne, M.J. García-Fusté. Radiation Physics and Chemistry, vol. 171, June 2020, https://doi.org/10.1016/j.radphyschem.2020.108759.

[6] Estudio de Seguridad de la IRA-3075. ALBA internal report.

[7] Guidelines for Beamline Radiation Shielding Design at the National Synchrotron Light Source II, Wah-Keat Lee, Razvan Popescu, Zhenghua Xia, Steve Ehrlich and P. K. Job.

[8] Shielding Calculations for the NSLS-II Beamlines, P.K. Job, W.R. Casey, Proceeding ICRS 11 (2008).

[9] Gas Bremsstrahlung Considerations in the Shielding Design of the Advanced Photon Source Synchrotron Radiation Beam Lines, Nisy E. Ipe, Alberto Fasso , SLAC–PUB–6452.

[10] Impact of gas bremsstrahlung on synchrotron radiation Beamline shielding at the advanced photon source, Nisy E. Ipe, Alberto Fasso SLAC–PUB–6410.

[11] Comparison of Design and Practices for Radiation Safety among Five Synchrotron Radiation Facilities, James C. Liu, Sayed H. Rokni, Yoshihiro Asano, William R. Casey, Richard J. Donahue, P.K. Job, SLAC-PUB-11139.