EDMS No.: XXX

European Organisation for Nuclear Research
European Laboratory for Particle Physics

TECHNICAL NOTE
CERN-DGS-XXXX

Radiological assessment of the Tungsten Powder Test (HRM10) at HiRadMat

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Abstract

Granular solid targets made of fluidised tungsten powder have been long proposed and are being studied as an alternative configuration towards high-power (>1MW beam power) target systems, suitable for a future Super Beam facility or Neutrino Factory. A feasibility experiment to evaluate this kind of target is being prepared to be performed at HiRadMat facility of CERN/SPS. Activation studies in order to assess the radiological risk from this experiment have been carried out, in order to estimate the necessary cooling time to access and handle the experimental equipment, and for defining the specialized laboratory class for the post-mortem examination of the sample.

CERN, Geneva, Switzerland
19 MAY 2012

SHORT SUMMARY

Quantities calculated:	- residual dose rate
	- nuclide inventory
Simulation code:	FLUKA version 2011.2
Conversion coefficients:	Fluence-to-dose conversion coefficients by M. Pelliccioni Radiat. Prot. Dosim. 88, pp. 279-297, (2000)
Assumed scenarios:	1 x 10^{13} protons delivered within one extraction of 1 second
Beam momentum:	440 GeV/*c* protons
Transport thresholds:	Neutrons followed down to thermal energies
	100 keV for electrons & positrons, 10 keV for photons
Electromagnetic cascade:	Switched on for residual dose rate calculation

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1.) Introduction

The development of high-power targets is a key element for the next generation of neutrino beams as proposed in future Super-Beams, Neutrino Factory or a future Muon Collider. Targets are used as particle converters, to generate pion or muon beams from high-power primary proton beams. The choice of the target material and the engineering design of the target station as a whole is a challenging issue specific for each application. In the case of a Neutrino Factory (or the future Muon Collider), a high-power proton beam is being intercepted by a target material, usually of high atomic number (Z). The produced pions, are captured using high-field solenoids and let to decay to finally produce a muon beam which after acceleration is fed to a storage ring where muons decay to neutrinos. Liquid mercury targets have been successfully used and operate for high-power spallation neutron sources, however the technical challenges involved, in particular the safety constraints from the use of mercury, make its use less attractive, and therefore an alternative solution has to be found.

The use of granular targets of high-Z materials, have been proposed since long as candidates for high-power targets that offer several advantages and could be considered as valuable alternatives to mercury systems. Recent R&D work at Rutherford Appleton Laboratory in UK demonstrated that fluidized tungsten powder can be circulated in a loop thus possible to create a renewable target combining the advantages of a liquid target without the complexity from the use of mercury. To validate the use of a tungsten powder as high-power target option, a proof-of-principle experiment is proposed in the HiRadMat facility of CERN/SPS [1]. The experiment would allow understanding the impact of an intense proton beam pulse delivering the same energy density as in a future Neutrino Factory application to a static tungsten powder sample.

2. FLUKA studies

2.1) Geometry

In order to study the residual dose rate as a function of the cooling period a model of the experimental sampler holder was prepared (Figure 1).

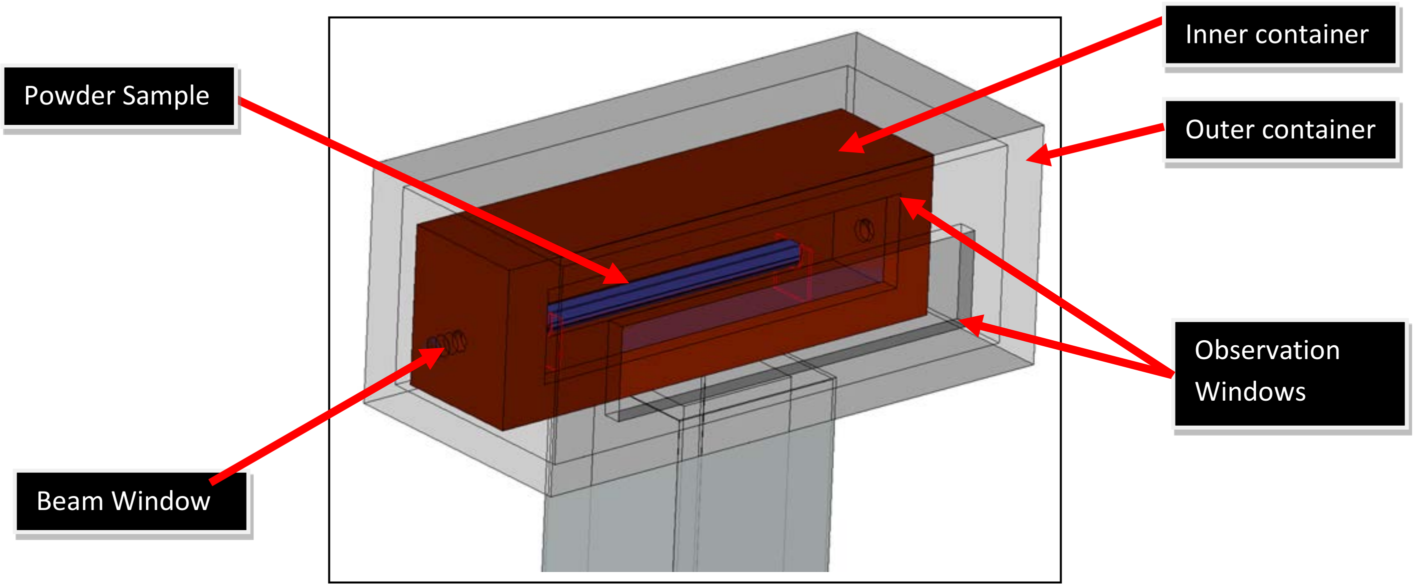

Figure 1: *FLUKA geometry of the sampler holder mode, using SimpleGeo [2].*

The sampler holder is constructed from Aluminum, with a total width of 20mm. The powder support is constructed from Titanium. The observation windows have a thickness of 3mm and they are constructed by Soda-Lima glass. The interior of the sampler holder is surrounded by Helium, in order to avoid possible combustion of the target due to the heating of the beam impact. The target itself it is pure tungsten powder, of diameter about 1.5 cm and length 30cm.

As the accurate number of particles to be shot in the sample is not yet fully confirmed at this time and as the micro-structure of the irradiation pattern will not be noticeable for the studied cooling periods, the irradiation pattern has been simplified to 1 x 10^{13} protons during of 1 second. Although, during the experiment, prior to the actual irradiation, several low intensity pilot beam extractions ("calibration shots") will be used to correctly set up the beam line. These calibration shots only contribute to a percentage of 1% of the total number of protons, so they were neglected in the simulation scenario. Using FLUKA [3,4] Monte – Carlo code, the activation of the sampler holder the TNC tunnel were treated the cooling times of 1 hour, 1 day, 1 week, 2 weeks, 1 month and 2 months. The results can be found in Figures 2-8.

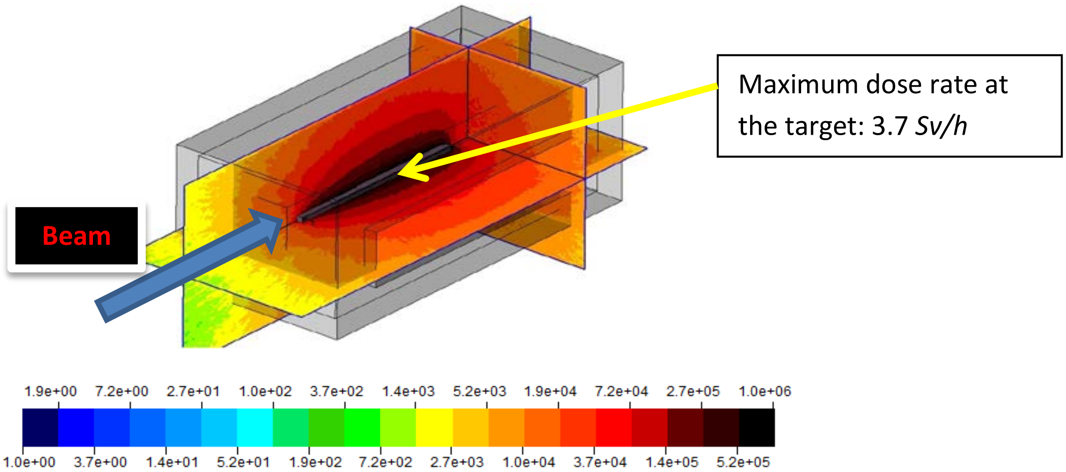

Figure 2: *Residual dose rate of the sampler holder after 1 hour of cool-down. The results are given in terms of [μSv/h].*

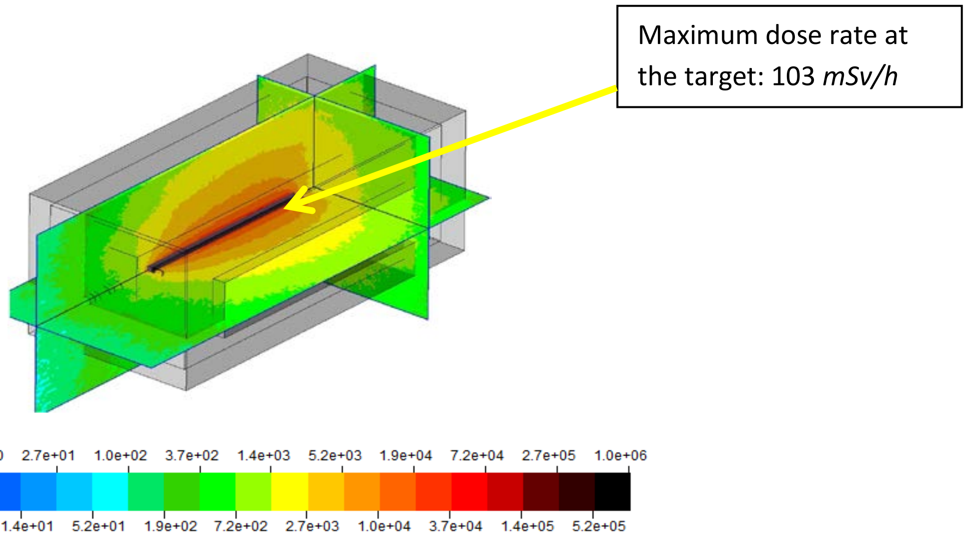

Figure 3: *Residual dose rate of the sampler holder after 1 day of cool-down. The results are given in terms of [μSv/h].*

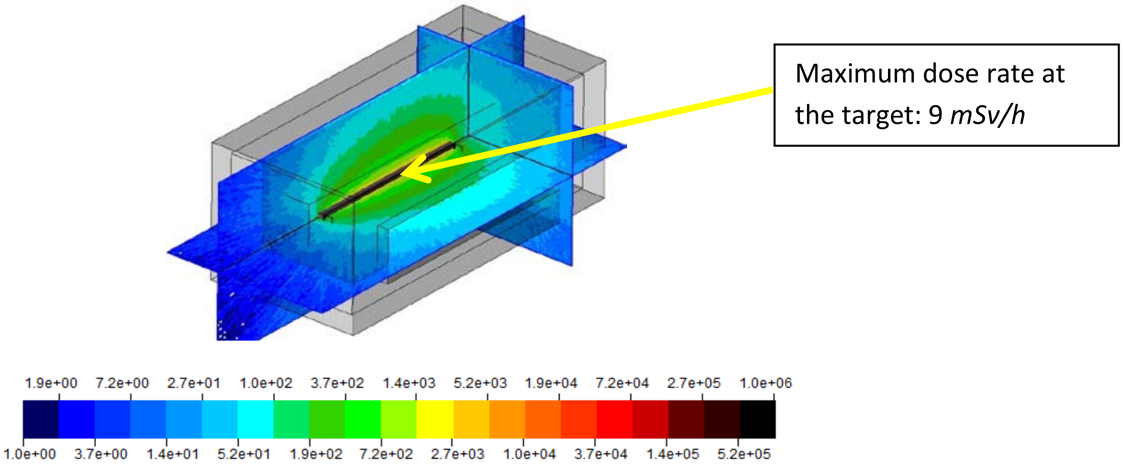

Figure 4: *Residual dose rate of the sampler holder after 1 week of cool-down. The results are given in terms of [µSv/h].*

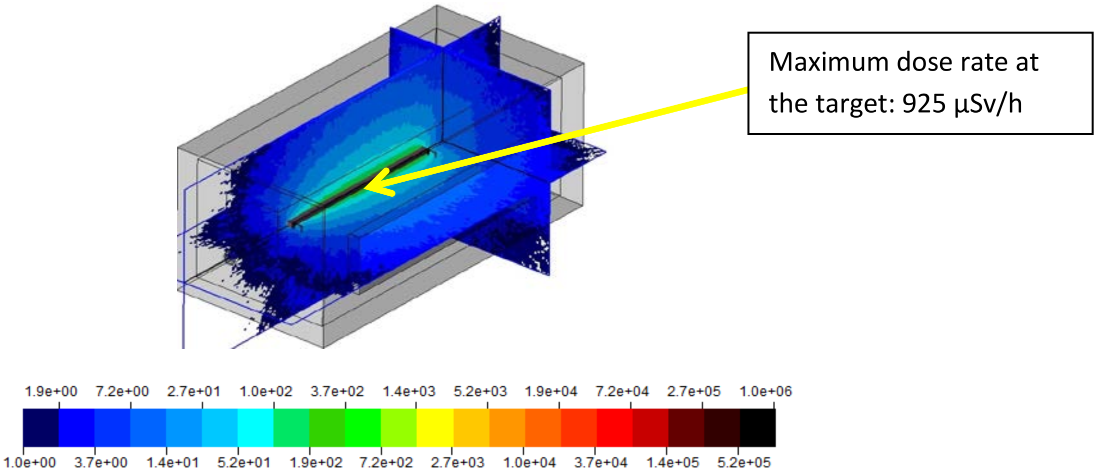

Figure 5: *Residual dose rate of the sampler holder after 1 month of cool-down. The results are given in terms of [µSv/h].*

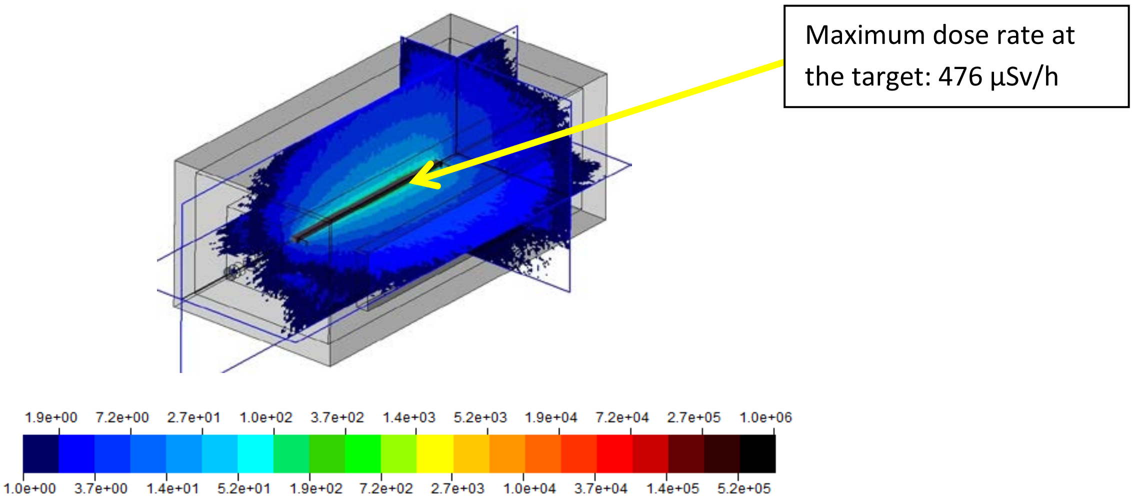

Figure 6: *Residual dose rate of the sampler holder after 2 months of cool-down. The results are given in terms of [µSv/h].*

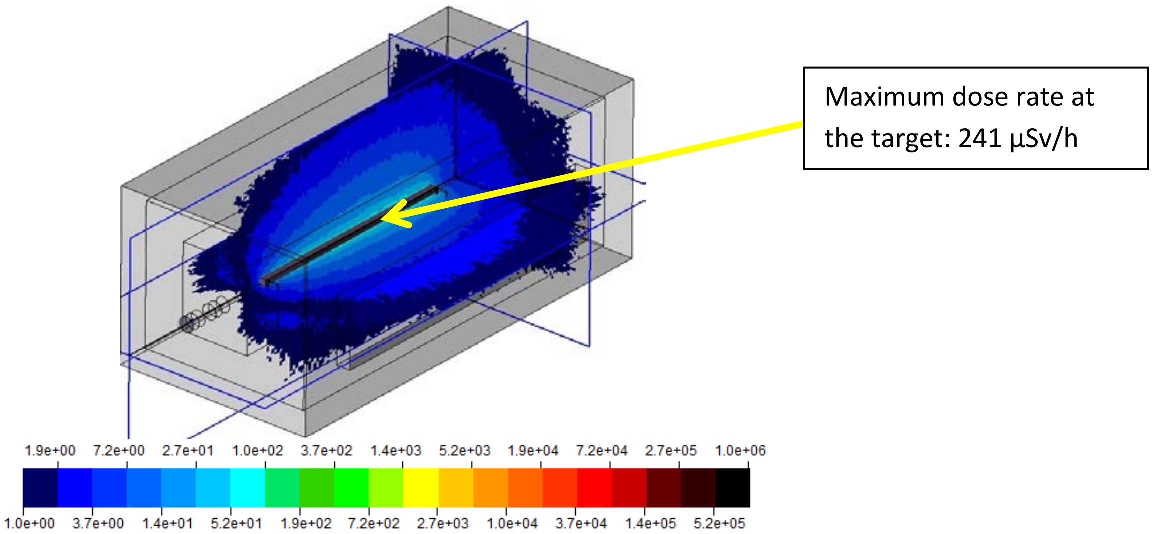

Figure 8: *Residual dose rate of the sampler holder after 4 months of cool-down. The results are given in terms of [µSv/h].*

The maximum dose rates at contact with the sampler holder are listed in Table 1.

Table 1: *Maximum residual dose rates at contact outside of the outer aluminium tank enclosing the sample holder. The statistical fluctuations are generally below 10%.*

Cooling Time	Dose Rate [uSv/h] (appears at the top of the container)
1h	2.74×10^4
12h	3×10^3
1d	1.55×10^3
1w	49
1m	5
2m	3
4m	1.79

The maximum dose rate at contact with the inner container can be found in Table 2.

Table 2: *Maximum residual dose rates at contact outside of the inner aluminium tank enclosing the sample holder. The statistical fluctuations are generally below 10%.*

Cooling Time	Dose Rate [uSv/h] (appears at the top of the container)
1h	5.14×10^4
12h	5.79×10^3
1d	2.90×10^3
1w	113
1m	12
2m	6
4m	3.98

The residual dose on the experimental area (TNC tunnel) and the preparation area (TJ7) tunnel, the cooling times of 1 hour, 1 day, 1 week and 1 month can be found in Figures 9-12. It has to be noted that in these plots, the current background radiation from the activation of the dump is not considered.

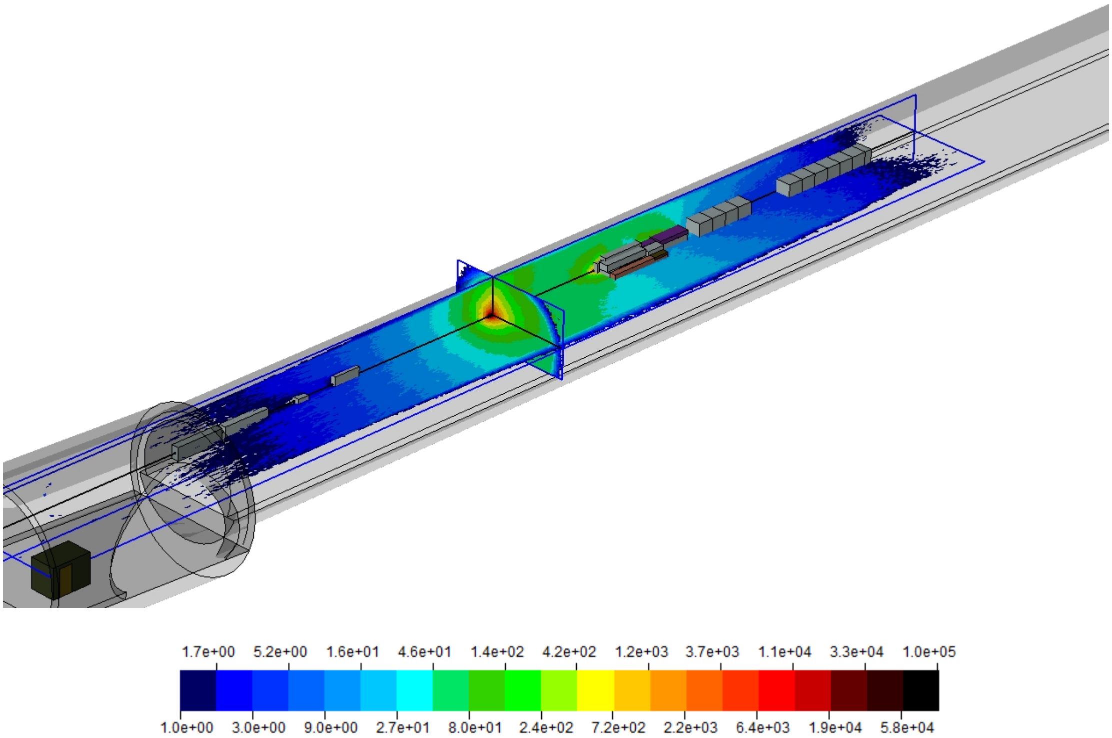

Figure 9: *Residual dose rate of area tunnels after 1 hour of cool-down. The results are given in terms of [µSv/h]. It must be noted that even after 1 hour, the dose rate at TJ7 tunnel is below 1 µSv/h.*

2.2) Nuclide inventory

After the irradiation of the tungsten powder sample, a possible examination of the target may be performed. As a consequence a workshop has to be found which is appropriately classified and equipped for this kind of radioactive materials. In Table # the most contributing radionuclides on the target after several cooling times can be found.

Table 1: The radionuclide inventory of the target after several cooling times.

Cooling Time	Total Activity for powder Volume (90.5 cm^3)	Top contributing isotopes
1h	9.96 GBq ± 0.04	46% Ta-180 13% Tb-149 4% Ta-173 3% Ta-174 3% Ta-176 2% Hf-170

12h	617 MBq ± 0.04	48% Ta-180 6% Ta-176 5% Tb-149 4% Hf-170 3% Yb-166 3% Ta-175 3% Hf-173 2% Lu-169
1d	300 MBq ± 0.04	35% Ta-180 6% Lu-170 5% Yb-166 5% Hf-170 4% Ta-176 4% Lu-169 4% Hf-173 2% Nd-140
1w	31.3 MBq ± 0.05	10% Hf-172 10% Lu-171 8% Lu-170 7% Yb-169 6% Tm-167 6% Ta-183 5% Gd-146 5% Yb-166 4% Nd-140 3% Ce-134 3% Ta-182 2% Eu-145
1m	7 MBq ± 0.06	27% Hf-172 13% Yb-169 9% Gd-146 8% Ta-182 5% Hf-175 5% I-125 4% Lu-171 3% Tm-167 3% Eu-147 3% Eu-146 2% W-185
2m	3 MBq ± 0.05	37% Hf-172 9% Ta-182 9% Yb-169 9% Gd-146 5% Hf-175 5% I-125 2% Eu-146
4m	1 MBq ± 0.05	52% Hf-172 10% Ta-182

		5% Gd-146 4% Hf-175 4% Yb-169 4% I-125 3% Lu-173 2% Lu-172

3.) Summary & conclusions

In order to evaluate the feasibility of a fragmented target under the beam impact, a test is foreseen to be carried out at HiRadMat facility of CERN/SPS. Moreover, a possible “post-mortem” analysis of the irradiated sample may be necessary, therefore an appropriate cool-down period needs to be respected to avoid unjustified exposure of personnel to residual radiation. FLUKA studies have been carried out to evaluate the residual dose rates as well as study the nuclide inventory, which in turn determines the type of workshop required to conduct the post-irradiation analysis.

After 2 months of cooling the maximum residual dose rate at contact outside the outer enclosure is around 3 uSv/h. A period of 4 months after the experiment reduces the maximum dose rate at about 1.79 uSv/h.

References

[1] The HiRadMat facility of CERN/SPS – http://www.cern.ch/hiradmat

[2] Theis C., Buchegger K.H., Brugger M., Forkel-Wirth D., Roesler S., Vincke H., *"Interactive three dimensional visualization and creation of geometries for Monte Carlo calculations"*, Nuclear Instruments and Methods in Physics Research A 562, pp. 827-829 (2006).

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

[4] G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, *The FLUKA code: Description and benchmarking*, 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).

[5] Bundesamt fuer Gesundheit, *Strahlenschutzverordnung (StSV) 814.501 vom 22. Juni 1994 – Stand am 1. Januar 2012,* Appendix 3, Column 10, (2012).