Beam accounting in Hall-C

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1 Introduction

Radiation budget needs to be evaluated with every experiment. In this study it is shown the result for run groups E12-09-011,E12-09-017,E12-09-002 that will run in Hall-C during the Fall of 2018. In order to evaluate this, I have developed different tools that will permit to speed up similar analysis for Hall-C and other Halls. The scope of this technical note is to show the status of this tools and the results obtained analyzing the results from simulations for these experiments.
During an experiment in Hall-C, in order to account for beam exposure and activation in the Hall, with normal configuration, one will need to take into account the radiation in the enclosure of the beam-line. Multiple targets will run multiple times with different intensities. Radiation budget for this experiment will be a cumulative answer from all these configurations. Fluka has the key feature to easily obtain statistics for these low process without too high computing power and can calculate activation dose at different times from beam exposure.

2 Getting info from the CAD design

Different experiments will have a different beam-line setup. Since too much detail will be difficult to debug and will also consistently slow-down the simulation, it is important to transfer just the key part of the setup for radiation simulation in FLUKA. In order to achieve this, simplified information regarding the beam enclosure were filtered from the design and transformed in information useful for the FLUKA model. Different materials for the flange in the beam-line (bolts, nuts, washers) had their weight determined and a local material was created for each flange in order to address local activation without adding too much detail in the design. The other relevant information was then transferred to a text file with:

- Start Z (cm)
- Stop Z (cm)
- Outer Radius (cm)
- Thickness (cm)
- Inner Radius (cm)
- Weight (lbs)
- Length (cm)
- Material

See table 1 for the info used in this example.

Start Z(cm)	Stop Z(cm)	Outer R(cm)	Thickness(cm)	Inner R(cm)	Weight(lbs)	Length(cm)	Material
69.85	71.12	3.50012	1.651	1.84912	0.48768	1.27	6061-T6Alum
71.12	78.8924	2.14884	0.29972	1.84912	0.4953	7.7724	6061-T6Alum
78.8924	258.5212	2.54	0.47752	2.06248	9.53008	179.6288	6061-T6Alum
258.5212	260.096	3.65252	1.5875	2.06502	0.65278	1.5748	6061-T6Alum
260.096	417.449	3.65252	0.51816	3.13436	25.146	157.353	6061-T6Alum
417.449	419.1762	7.06628	3.92938	3.1369	3.11404	1.7272	6061-T6Alum
419.1762	422.6687	6.35	1.5875	4.7625	4.01066	3.4925	6061-T6Alum
422.6687	804.6212	6.35	0.635	5.715	139.573	381.9525	6061-T6Alum
804.6212	806.8437	9.017	2.54	6.477	4.064	2.2225	6061-T6Alum
806.8437	868.68	8.89	0.635	8.255	32.8422	61.8363	6061-T6Alum
868.68	870.966	13.6525	5.3975	8.255	11.3284	2.286	6061-T6Alum
870.9787	873.5187	13.6525	3.7084	9.9441	29.1338	2.54	347SS
873.5187	886.4219	10.16	0.2159	9.9441	7.747	12.9032	347SS
886.4219	888.9619	13.6525	3.7084	9.9441	29.1338	2.54	347SS
888.9619	891.8194	13.6525	2.8575	10.795	8.88238	2.8575	6061-T6Alum
891.8194	1087.3994	13.6525	0.9525	12.7	229.7811	195.58	6061-T6Alum
1087.3994	1090.2569	22.86	10.16	12.7	43.59656	2.8575	6061-T6Alum
1090.2569	1094.0669	29.845	14.605	15.24	112.93348	3.81	6061-T6Alum
1110.5261	1114.3361	29.845	14.68374	15.16126	114.3	3.81	6061-T6Alum
1114.3361	1265.4915	16.1925	1.03124	15.16126	232.16108	151.1554	6061-T6Alum
1265.4915	1268.349	22.86	7.69874	15.16126	38.49878	2.8575	6061-T6Alum
1268.349	1273.175	22.86	6.985	15.875	59.90844	4.826	6061-T6Alum
1273.175	1648.46	22.86	0.9525	21.9075	756.6279	375.285	6061-T6Alum
1648.46	1653.2225	30.48	8.5725	21.9075	97.58934	4.7625	6061-T6Alum
1653.2225	1657.985	30.48	7.62	22.86	89.78138	4.7625	6061-T6Alum
1657.985	1896.7958	30.48	0.9525	29.5275	646.03376	238.8108	6061-T6Alum
1896.7958	1901.5583	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
1901.5583	1906.3208	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
1906.3208	2145.3983	30.48	0.9525	29.5275	646.75512	239.0775	6061-T6Alum
2145.3983	2150.1608	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
2150.1608	2156.2441	40.64	11.1125	29.5275	207.49006	6.0833	6061-T6Alum
2156.2441	2534.2977	30.48	0.9525	29.5275	1026.45718	378.0536	6061-T6Alum
2534.2977	2539.0602	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
2539.0602	2543.8227	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
2543.8227	2608.4911	30.48	0.9525	29.5275	175.58258	64.6684	6061-T6Alum
2608.4911	2613.2536	40.64	11.1125	29.5275	162.39744	4.7625	6061-T6Alum
2613.2536	2619.95158	40.64	11.1125	29.5275	474.4466	6.69798	304SS
2619.95158	2667.12192	29.845	0.3175	29.5275	493.8268	47.17034	304SS
2667.12192	2671.88442	40.64	11.1125	29.5275	474.4466	4.7625	304SS

Table 1: Beam-line properties to be transferred in Fluka

A bash script [Code] will help create the full geometry of the beam-line, with each region divided by different materials. This will help to speed up the implementation of a new beam pipe design into the Hall.

3 Running the simulation in the farm system at Jlab

The different target cells where created in different input files: These will be used for creating the multiple different outputs. All the infos for the run period were screened and put in an input file containing:

- Target

- hours
- current(μA)
- Energy(GeV)

See Table 2 for the beam time for this experiment.

n	Target	hours	current(μA)	Energy(GeV)
1	H_2	108.0	70	9.4
2	Al	12.0	40	9.4
3	H_2	31.2	70	6.4
4	Al	4.8	40	6.4
5	H_2	74.4	35	4.9
6	Al	9.6	40	4.9
7	H_2	108.0	35	3.8
8	Al	12.0	40	3.8
9	H_2	240.0	70	10.6
10	Al	26.4	40	10.6
11	H_2	240.0	70	8.5
12	Al	26.4	40	8.5
13	H_2	57.6	50	10.6
14	H_2	45.6	10	10.6
15	D_2	134.4	50	10.6
16	D_2	91.2	25	10.6
17	D_2	45.6	10	10.6
18	Al	36.0	40	10.6
19	H_2	12.0	50	8.5
20	D_2	12.0	50	8.5
21	Al	2.4	40	8.5

Table 2: Prospected beam time for the full experiment

These info will be convoluted in the different input files in order to create the different configurations needed. In order to obtain the desired statistic and well use the structure of the Jlab farm computing system, each configuration will run multiple times. In order to speed up this procedure of creating multiple inputs, each configuration file will have similar structure, with the info that need to be modified at the same line. What the submission script [Code] does is:

- The current is given in μA and will need to be transferred in number of particle per seconds for the activation with this configuration

- The energy will be switched for each configuration
- The hours of running with each configuration will be transformed in seconds and divided in 5 parts. In order to assume a more accurate accelerator efficiency during run time, each of the 5 time ranges of beam exposure will be followed by the same time range of no beam. This will give roughly a 55% efficiency.
- The integrated beam exposure will be recorded for each time in order to have a final number to be used in the normalization later (Fluka calculates some of their obervable in (quantity measured)/(incident beam particle)).
- The full activation of the experiment is a convolution of the different configurations recorded at the sane time after all the different targets were exposed. The time of activation from beam exposure at the end of the experiment will depend of the time that is left in the experiment: For this reason, in order to get the correct time at each configuration, one start the time accounting from the last target exposed, and build the correct time delay for each configuration adding each contribution to the time for the full exposure.
- The activation was then calculated at different time from beam exposure (1 hour, 12 hours, 1 day, 1 week, 1 month) for each target exposure and for the full experiment exposure, using different times for each targets, decided from the algorithm explained in the previous point
- For each configuration multiple simulation were created. The random seed was created and modified for each simulation in order to assure that each simulation was statistically independent and that the statistical result could be added.
- A unique submission file was created for each simulation in order to be used in the farm and automatically submitted.
- Since Fluka needs to run in batch mode a script was created in order to run single and multiple simulations and handle the results.

4 Analyzing the results

In order to analyze the results, we will need to take into account how these results are recorded in Fluka. The activation is recorded in pSv/second, rather than the dose and the 1 MeV neutron equivalent flux on Silicon where it is recorded per incident beam particle.

4.1 Activation studies

For activation studies the results are recorded for each target in dose equivalent pSv/second. In order to get the activation for all the targets at the times of observation after the end of the all experiment, One will need to add all the different contribution from the the different running times with the different targets, where the observation time window has been shifted correctly in order to point to the correct moment in time. While averaging the different activation from different targets, it is important to keep the same number of simulations with each target configuration, in order to give the same weight to each esposure. Scaling the results with the total number of configuration run will then give the final result. The final result will then be scaled to mrem/hour.

4.2 Accumulated dose and 1 MeV neutron equivalent flux

For these observable the recorded data for each target is done for single incident particle. In order to get the right sample of simulations for the experiment one will need to scale each configuration with the number of incident particle that was run for each configuration. Since the data is cumulative, a full average over this weighted sample will give the dose per electron for the full experiment.

5 Results

Results were calculated after each target and after the full experiment. Activation was calculated in the volume surrounding the beam line with a granularity of a cube of 10cm size:

- Z: from -2m from the target to the beam dump at the end of the wall
- X: from -2m from the target to 2m
- Y from the floor($- \sim 4m$) to 1m over the target.

The accumulated radiation level is projected on a plane at 1.5m from the ground (and observed in planes perpendicular to the beam-line at different distance from the target: 1.1m, 3.0m, 5.0m, 10.0m, 15.0m, 20.0m. Radiation levels are also projected on the beam-pipe and the walls. The radiation is averaged over a cube of 10cm in size. In Figure 1 it is shown the expected accumulated dose after the full experiment. In order to address electronics radiation damage, one can consider also the 1 MeV equivalent neutron flux on Silicon per cm^2: This is shown in Figure 2. From Figure 3 to Figure 7 it is shown the expected activation in the Hall after the experiment is finished. The activation is estimated after 1 hour, 12 hours, 1 day, 1 week, 1 month from beam exposure and is expressed in mrem/hour.

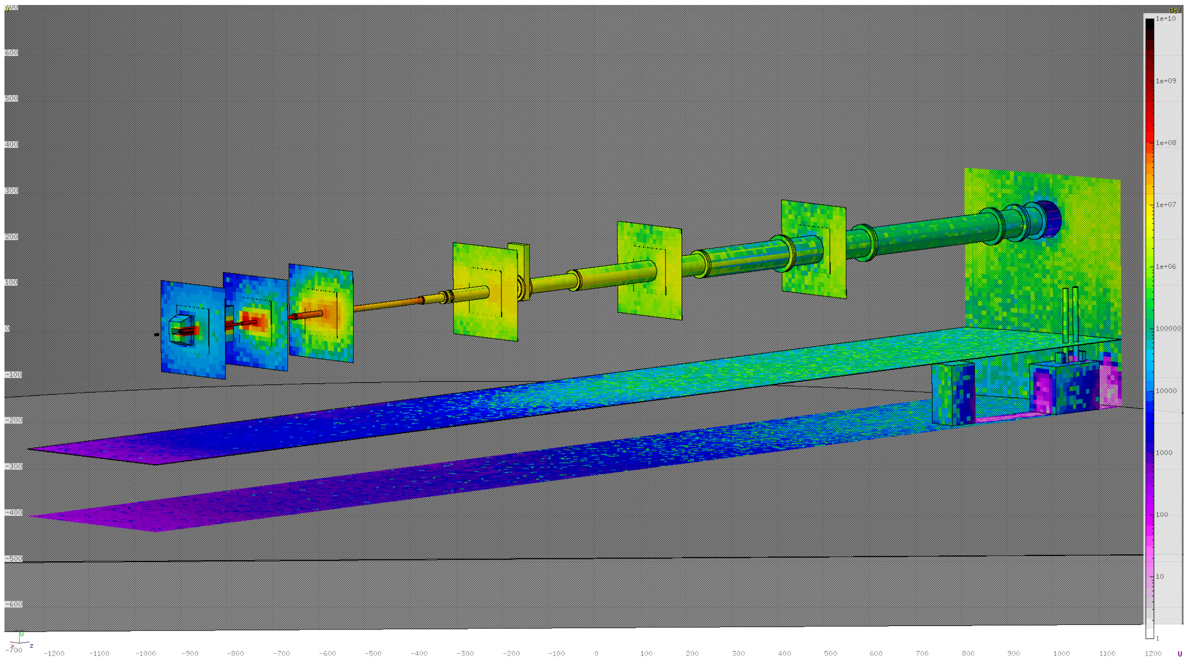

Figure 1: Accumulated Dose (rad) cumulative for the full exposure as shown in Table2.

References

[Code] *Fluka Hall-C Beam Accounting code:* https://github.com/lorenzozana/Fluka-Hall-C-Beamline, Lorenzo Zana

[Fluka1] *The FLUKA Code: Developments and Challenges for High Energy and Medical Applications:* T.T. Bhlen, F. Cerutti, M.P.W. Chin, A. Fass, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov and V. Vlachoudis, **Nuclear Data Sheets 120, 211-214 (2014)**

[Fluka2] *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**

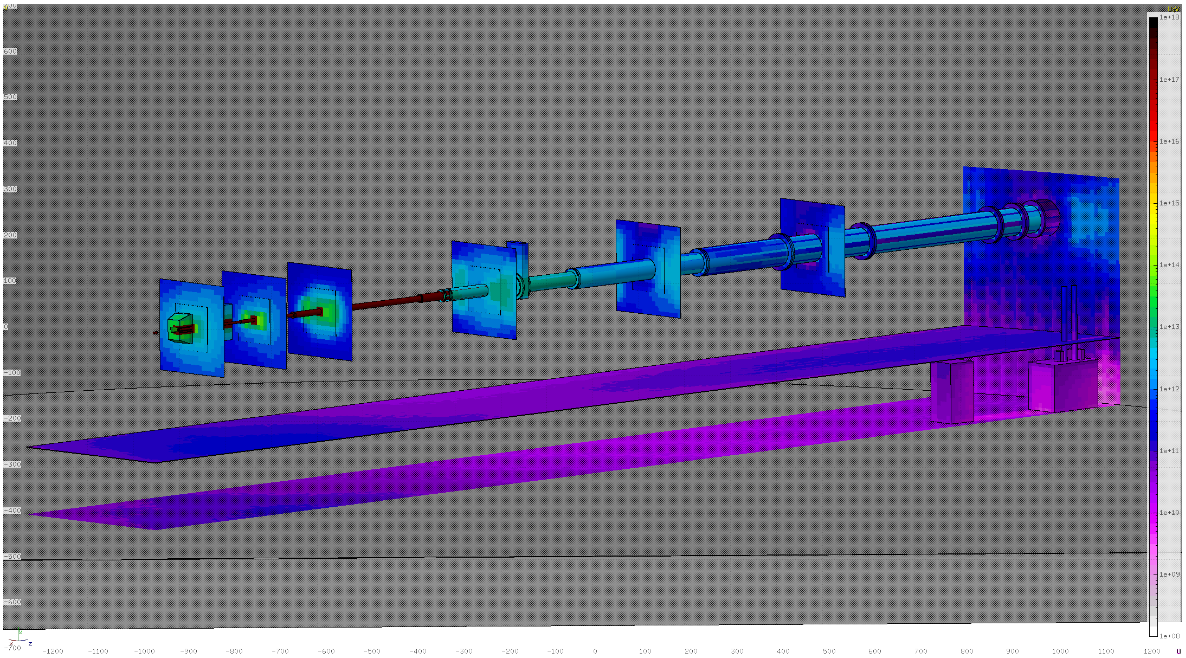

Figure 2: Accumulated 1 MeV equivalent neutron fluence on Silicon cumulative for the full exposure as shown in Table2.

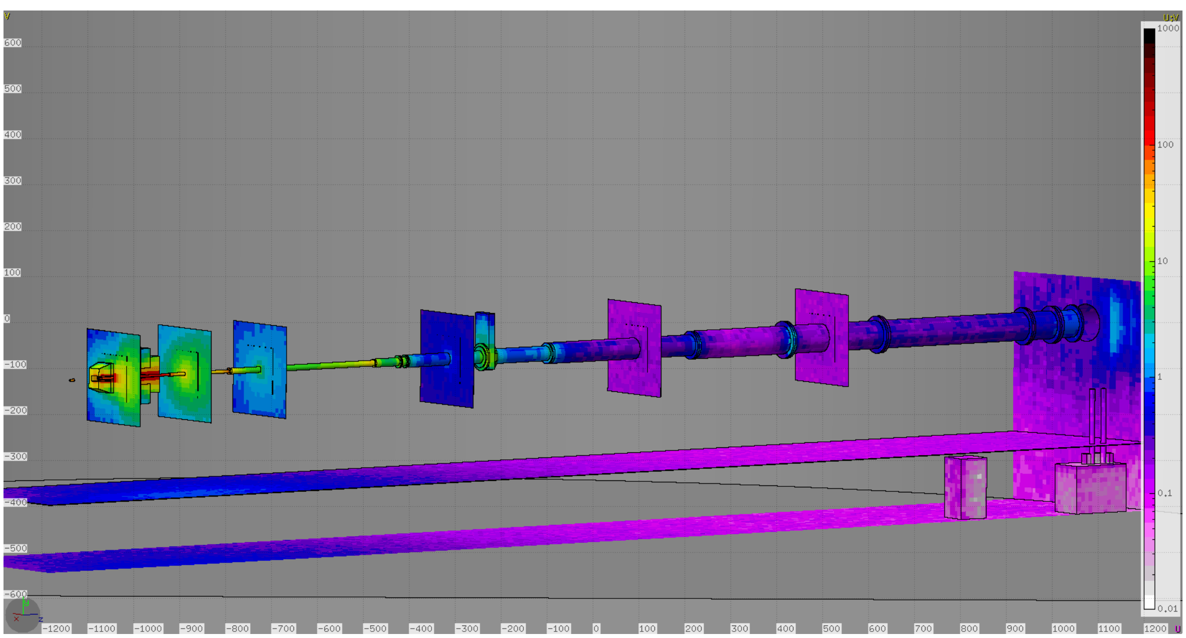

Figure 3: Activation after 1 hour from full exposure as shown in Table2. Radiation level is expressed in mrem/hour.

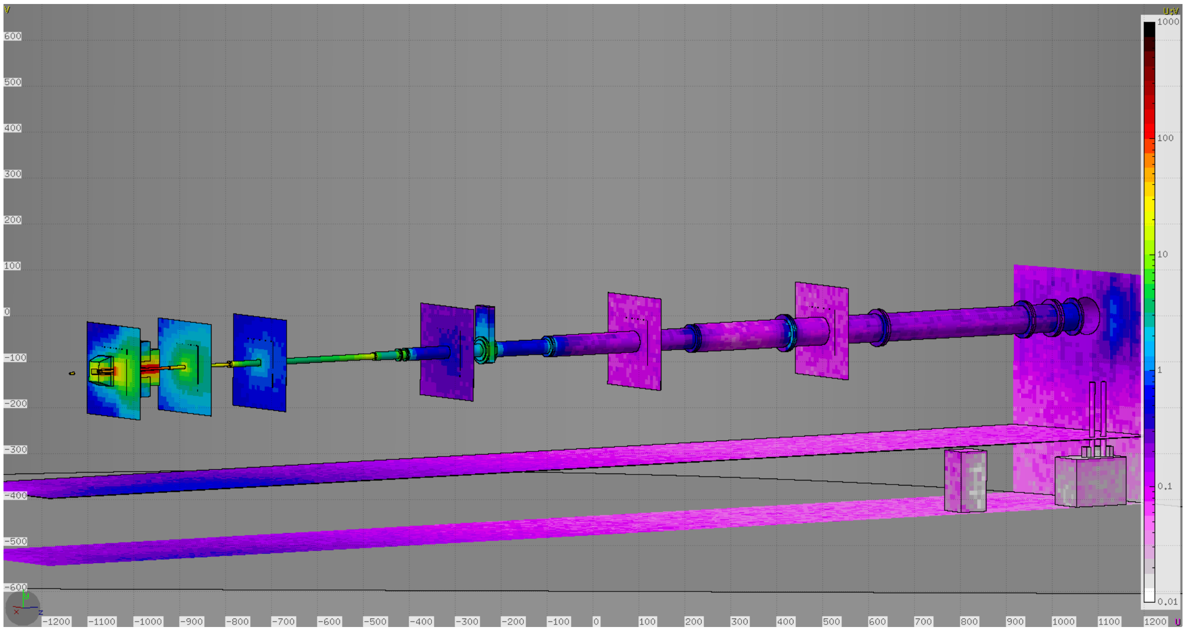

Figure 4: Activation after 12 hours from the full exposure as shown in Table2. Radiation level is expressed in mrem/hour.

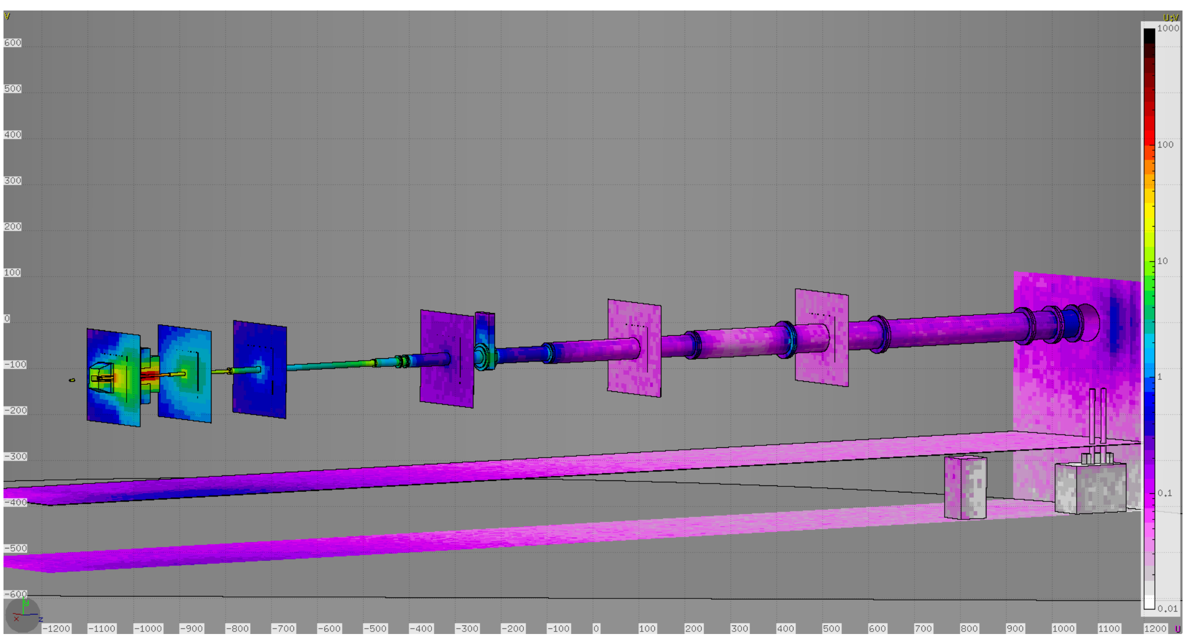

Figure 5: Activation after 1 day from the full exposure as shown in Table2. Radiation level is expressed in mrem/hour.

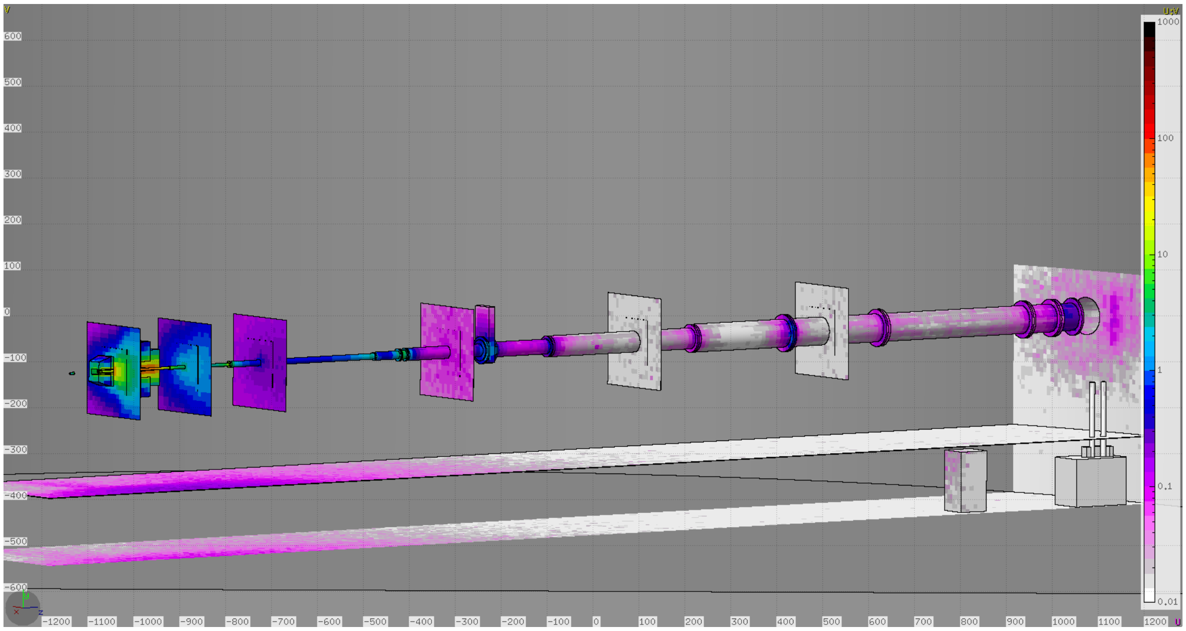

Figure 6: Activation after 1 week from the full exposure as shown in Table2. Radiation level is expressed in mrem/hour.

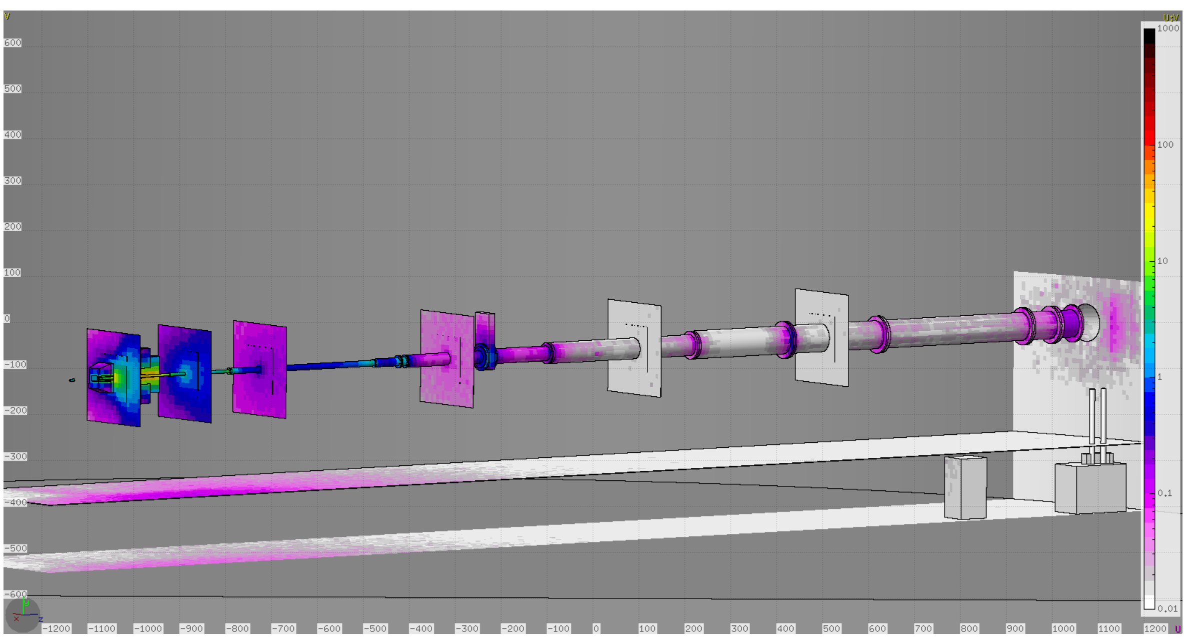

Figure 7: Activation after 1 month from the full exposure as shown in Table2. Radiation level is expressed in mrem/hour.