Journal of Energy

VOLUME 68 Number 2-3 | 2019 | Special Issue

journal homepage: http://journalofenergy.com/

Dose Calculation for Emergency Control Room HVAC Filter

Davor Grgić, Štefica Vlahović, Mario Matijević, Paulina Dučkić
Faculty of Electrical Engineering and Computing, University of Zagreb
Unska 3, Zagreb, Hrvatska
davor.grgic@fer.hr, stefica.vlahovic@fer.hr, mario.matijevic@fer.hr, paulina.duckic@fer.hr

Srđan Špalj
Nuclear Power Plant Krško
Vrbina 12, 8270 Krško, Croatia
srdjan.spalj@nek.si

ABSTRACT

NPP Krsko is introducing Emergency Control Room (ECR) as part of safety upgrades. According to 10CFR50 Appendix A, GDC 19, both main control room and emergency control room should have adequate radiation protection to permit operators to shutdown the plant and keep it in safe shutdown conditions without receiving more than 50 mSv effective whole body dose, within 30 days from accident initiation. One of the important prerequisites to achieve that is proper operation of control room HVAC. In this work we are focused to calculation of gamma doses from radioactive materials accumulated in HEPA and charcoal filters during 30 days of HVAC operation. The dose at selected points around the filter was calculated using Microshield 10.0 point kernel code. The radioactive gamma source is calculated using RADTRAD 3.03 for plant's severe accident SGTR sequence calculated with MAAP 4.0.7 code. Calculated dose rates at peak filter activity are compared against results obtained with SCALE 6.2 MAVRIC shielding sequence (Monaco Monte Carlo functional module and CADIS methodology). The reasonable agreement between point kernel and hybrid Monte Carlo results was obtained.

Keywords: *Emergency Control Room, HVAC filter, gamma dose, point kernel, Monte Carlo*

1 INTRODUCTION

Based on Slovenian nuclear regulation related to Plant Life Extension and consequences after the Fukushima accident, Slovenian Nuclear Safety Administration (SNSA) requested the NEK to reassess the existing Severe Accident Management strategy. Afterwards, the NEK shall implement necessary safety improvements for prevention of severe accidents and mitigation of their consequences. This modernization will extend capability of plant to cope with different internal and external events resulting in so called Design Extension Conditions (DEC). As a part of the NEK Plant Safety Upgrade, the Bunkered Building (BB1) was constructed where the ECR, the Technical Support Center (TSC) and third emergency diesel generator are located, [1], [2].

The ECR is located on the second floor of the BB1 above the new diesel generator. The existing spare room on the second floor was used to construct the ECR and TSC. This project also included the relocation and upgrade of existing Remote Shutdown Panels (SDP) to the new Remote Shutdown Control Board (RSCB) and the construction of a new Design Extension Conditions Control Board (DECCB). The function of DECCB Panels will be to enable the operation of specially provided equipment for preventing and mitigation of Potential Severe Accidents.

The function of the RSCB in the ECR is to provide the necessary resources for the NPP operators to achieve and maintain safe shutdown following the evacuation of the Main Control

Room (MCR). The purpose of the relocated and centralized RSCB is to provide Plant Hot Stand-by and Cold shutdown capabilities in a centralized location.

Taking into account its importance, ECR has to be equipped with the communication, habitability capabilities and other equipment to enable continuous occupation of the operating crew 30 days after the postulated accident. Additionally, it is important that operators do not receive more than 50 mSv effective whole body dose, within 30 days from accident initiation, according to 10CFR50 Appendix A, GDC 19. Therefore, the most important is to achieve the proper operation of room HVAC. In this paper, we will focus to calculate the gamma doses from radioactive materials accumulated in HEPA and charcoal filters during 30 days of HVAC operation.

2 MODELS AND CALCULATION TOOLS

In order to assess maximum possible doses in ECR, the conservative release of radioactive material is assumed. We were more focused on equipment doses, especially related to the influence of radioactive source in HVAC filters.

Selected sequence for radioactivity release is SGTR severe accident as calculated by MAAP code using NEK standard parameter input file (Individual Plan Examination (IPE) release category 8B SGTR).

MAAP is fully integrated code that couples thermal-hydraulics with fission product release and transport [3]. It is developed by EPRI as the fast-running, integral severe accident analysis code, soon after the TMI-2 accident. It simulates the accident progression from a set of initiating events to either safe and stable state or containment failure leading to radioactive releases to the environment. In this paper, the version MAAP 4.0.7 is used.

Core uncover was calculated at 69529 s, HL creep rupture at 77959 s, first core relocation to the lower plenum at 79567 s and vessel failure at 84428 s. First release to the environment was predicted at 72730 s (from first release category different from zero), Figure 1. In Figure 2, release fractions are shown together with liquid and gas flow through SG valve. We can see gas flow rate (steam) relevant for transport of radioactivity. Using upstream gas density, volumetric flow rate is calculated in MAAP and corresponding leakage flow rate (in percent of containment free volume released per day). The volumetric flow rate is required for RADTRAD calculation procedure. It is assumed that release is from the containment volume to simplify calculation (in MAAP calculation it is SGTR containment bypass). The same amount of fluid is released in both cases (MAAP and RADTRAD).

RADTRAD was developed for the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research to estimate transport and removal of radionuclides and dose at selected receptors [4]. The code uses a combination of tables and numerical models of source term to determine the time dependent dose at user-specified locations for a given accident scenario. In this paper, the version RADTRAD 3.03 is used. The program takes output data from MAAP to calculate radioactive gamma source.

Core source term is based on ORIGEN 2.2 plant (102% core power) and cycle specific calculations (NEK cycle 26-29) [5]. It is decayed in ORIGEN till the time of release (72730 s). Alternative Source Term (AST) fuel release fractions are assumed [6]. RADTRAD uses 8 chemical and 4 transport groups. Transport groups are noble gases, elemental iodine, organic iodine and aerosols. The fractions of iodine are according AST specification. Transport groups from the containment atmosphere are calculated using MAAP SG SV/RV volumetric flow after start of radioactivity release. It is assumed that start of calculation and start of the release are at the same time point (0 s).

RADTRAD code uses automatic integration time stepping in order to capture both flow and decay phenomena. First time steps are 2 s, then 10 minutes till 12.6 hours and after that 1 hour. In order to simplify calculation, time dependent flow rate calculated by MAAP was approximated with three release intervals having the same total release as MAAP calculation. Up to 2 hours, the leakage rate is 180% of Vc per day, after that up to 7 days, it is 18% of Vc per day, and then 1% of Vc per day. Environment is approximately treated in RADTRAD and it has not specific volume assigned, but it is included in mass and radioactivity conservation. Any specific point within the environment or the point where any other volume has intake is related to the concentration at the release point using predetermined X/Q values (ARCON96 for building locations close to release point). The activity present in the environment during any time step is determined by release from the containment during the same period and any outflow to other compartments in the model. It is assumed that at the end of time step, due to plume transport, all radioactivity leaves environment volume. Amount of released material, and in the same time amount of radioactivity present in the environment, is product of concentration in the containment, leakage flow rate and time step length. Global reactivity balance is shown in Figure 3. Total activity released is activity measured at release point (after that there is no decay) and activity in the environment is total activity present in the environment at any time (released + decay). The radioactivity present in RADTRAD environment is just part of that activity (close to the release point between two plume transport events).

General layout of RADTRAD model used in calculation of doses in BB1 rooms is shown in Figure 4. Compartment number 1 is containment and that is the only compartment where radioactivity is directly released. In this case, it is used to release radioactivity which is consequence of SGTR accident. Compartment number 2 is environment and compartment number 3 is used to model room where immersion doses are needed (as shown for ECR). There is no deposition assumed in compartments. That is conservative for containment (more material is released). For the environment, it is conservative because all radioactivity is in the air (immersion and intake) and not conservative because all radioactivity is removed by plume transport (no deposits). It is again conservative for immersion dose in rooms (everything is in the air) and not conservative from point of view of surface contamination. Overall effect is that more conservative doses are predicted. There are 4 explicit paths in the model. Path number 1 is used to model release to the environment. It is based on volumetric flow calculated by MAAP code (total release is reproduced). The flow should be in units of percent of upstream compartment volume per day. Path number 2 is for uncontrolled inflow from the environment to the calculated room. It is 6% of room free volume per hour (Campe). Path 4 is used to model HVAC air intake in the room and path number 3 is modeling air exhaust from the model. It is assumed that in all situations exhaust flow is equal to the sum of inflow and intake flows. Activity obtained from paths 2 and 4 is related to release activity rate using X/Q factors calculated by ARCON96 [7]. It is assumed that filter can exist in all of the flow paths 2 to 4. The only filter with non-zero efficiency is on intake flow path (4). It is implicit assumption (no matter what is entered as filter efficiency) of the model that radioactivity is kept in virtual filter F3 (there is no return of radioactivity to the environment). In RADTRAD code recirculation filters are attached to the compartments and there is no explicit flow path for them. In NEK case, recirculation filters F1 and intake filter F4 are the one filter having function of filtration of the intake air or recirculation of ECR/TSC air, depending on HVAC line-up. Radioactivity is removed from the environment compartment at the end of each calculation step to simulate plume transport.

X/Q factors needed for paths 2 and 4 are calculated using ARCON96 code. That is for location called ECR/TSC intake. For shine dose at the BB1 roof (close to the IB building) X/Q factors are calculated for location called ECR/TSC roof. Relative positions of release and receptor points used in ARCON96 code are shown in Figure 5.

RADTRAD 3.03 is used for calculation of immersion doses in BB1 rooms. As already said, the same nodalization is used in all calculations, Figure 4. What is changed from calculation to calculation is volume of compartment 3, Figure 6, inflow rate (6% of free volume per hour), and HVAC operation.

BB1 rooms 011A (ECR), 011B (TSC) and the rooms sharing the same protective pressure barrier (011C, D, E and F, 012 Utility and 013 Toilet, 019 Machine Room MR), Figure 6, have assumed volume of 1665 m^3. The inflow is 99.9 m^3/h. Four different HVAC scenarios are analysed.

The first one (case01) is referent or design scenario. The filtered air intake (600 m^3/h) is present all the time. The HVAC is in recirculation mode (internal recirculation flow rate is 19800 m^3/h) during whole 720 days. The filter (in RADTRAD case filter F1 is recirculation and F4 intake) has efficiency 99.97% for aerosols and 95% for elemental and organic iodine. The outflow is always sum of inflow and HVAC intake flow. The second case (case02) is the same as case01 except for uncontrolled inflow which is assumed to be zero (reasonable due overpressure produced by filtered intake). In case03 HVAC isolation is assumed from 0 till 1.7 hours. The recirculation flow is 20400 m^3/h. From 1.7 till 2.7 hours HVAC is purge mode (filtered intake at 10200 m^3/h) and inflow is present. From 2.7 h till 720 hours filtered intake is 600 m^3/h, recirculation flow is 19800 m^3/h and there is no uncontrolled inflow (established room overpressure). That is called improved scenario and it is optimized to decrease the dose to the ECR operators. Due to different assumptions on radioactivity release and other timing differences, the time to end isolation (intake activity less than room activity) is not the same in this calculation as in operator dose calculation. In case04, isolation time is between 0 and 2.7 h, and purge interval is from 2.7 to 3.7 hours. All other assumptions are the same as for case03. The case04 is called optimized HVAC scenario. The doses calculated in this calculation are beta and gamma air immersion doses to the equipment. The doses to ECR personnel are calculated, but are not shown here. Beta and gamma air immersion doses are shown in Figure 7 for referent case01. Gamma dose suppression is based on whole protected volume and not on separately on ECR, or TSC or any other separate room volume from protected pressure boundary, and that is conservative. The doses calculated for HVAC scenario case01 are highest and the doses calculated for case04 are lowest. Gamma doses depend on number of air exchanges (free volume and HVAC intake flow rate) and volume used in calculation of reduction factor compared to infinite hemisphere immersion. For beta doses most important factor is concentration of radioactive material in air of the room. All rooms are well ventilated and doses are similar. The size of the volume is not important due to limited range of beta rays. For all rooms without filtered HVAC, immersion is dominant source of equipment exposition to radiation. The shine dose from external sources through the building walls is negligible. For rooms within pressure envelope, mainly ECR and TSC, it is required to check for the influence of shine doses from environment, from neighbouring rooms without air filtration, and from concentrated source in HVAC filter.

The dose from the radioactive material kept within HVAC filter is analysed first. As part of already described RADTRAD compartment calculation some radioactive material, depending on selected HVAC scenario, is deposited within HVAC filter. Original RADTRAD code was modified to enable access to deposited activity and to make possible decay calculation of that deposit. The activity of the recirculation filter (F1) and intake filter (F4), for all four cases, is shown in Figure 8. As said earlier, one actual HVAC filter is in RADTRAD treated as two separate filters. That way it is possible to see amount of the material removed from intake flow and during recirculation. Noble gases are not affected by filter operation. As expected, most of the deposit is due to intake flow and recirculation deposit is mainly due to uncontrolled inflow. As can be seen the accumulation of radioactive material depends on HVAC scenario. It is smallest for case02 and largest for case03. The design scenario and final optimized scenario have similar accumulated activities. ECR atmosphere activity, for all four cases, are shown in Figure 9. It is clear that decision to operate HVAC in purge mode should be planned depending on timing of the accident. 30-days immersion air dose is, depending on HVAC case, between 25 and 37 mGy for gamma, and between 1.6 and 2.2 Gy for beta. Calculated immersion beta and gamma doses can be conservatively used for any room within pressure protective envelope, including Machine Room (MR, New HVAC room).

Position of HVAC filter within MR is shown in Figure 10. It is directly above TSC room. Microshield 10 code was used in calculation of gamma shine dose from radioactive material accumulated within filter [8]. The inventory of radioactive material (isotopic activities) is saved from RADTRAD run at selected times. Filter geometry for calculation of shine doses through ECR/TSC ceiling is shown in Figure 11. Green box (assumed dimensions are 3x3x8m) contains radioactive source homogenously distributed within air. Blue box is side shielding (0.5 cm filter wall and 1 m concrete floor/ceiling toward TSC). The dose rates are calculated, for prescribed time points (15), at the middle bottom side of the filter, at the distance 1 cm, 70 cm, 210 cm, and 350 cm from bottom of TSC ceiling. The gamma dose rates are integrated using central integration (dose rate is constant within time interval at the arithmetic average of the dose rates at interval ends) for 720 hours (30 days). Gamma dose from HVAC filter to ECR through ECR/MR ceiling is below 1 mGy, Figure 12. Gamma doses are for referent HVAC scenario (case01) and for optimized scenario (case04). Due to slightly higher radioactive inventory, doses are always higher for improved HVAC scenario.

The filter doses are calculated in the middle of longer side, Figure 13, at the distances 1, 10, 50, 100 and up to 800 cm from filter surface, Figure 14. 30-days filter surface dose is 240 Gy and dose at the distance of 100 cm is around 120 Gy. The integrated dose is below 100 Gy at distance of 500 cm. The doses are given for referent and improved HVAC scenario. The calculated doses can be problem for electronic equipment used for control of HVAC components.

In order to get spatial dependence of dose rates, Figure 15, at peak filter activity (120 h), additional calculation is performed with SCALE 6.2 MAVRIC shielding sequence (Monaco Monte Carlo functional module and CADIS methodology) [9]. The dose rates perpendicular to the longer filter side are shown in Figure 16. The dose rates are similar but higher than corresponding Microshield doses. The improved calculation methodology can be used to determine local dose rates or to calculate local shielding of sensitive parts.

3 CONCLUSION

The methodology starting with reactor core source term calculation and calculation of release of radioactive materials to the environment and ending with calculation of transport of radioactive materials within emergency control room and related HVAC filter was presented. For radioactive materials deposited within HVAC filter shine gamma dose was calculated for period of 30 days after accident using point kernel code Microshield. The shine doses to operators and equipment within ECR is rather small, but the doses to the equipment located within machine room can be limiting for electronic control equipment and some kind of shielding can be needed for absorbed doses above 100 Gy. In that case more detailed Monte Carlo calculation can be used. The reasonable agreement between point kernel and hybrid Monte Carlo results was obtained for simple filter geometry without shielding.

Acknowledgements:

We would like to express our gratitude to the NPP Krško for providing relevant input data used in calculation and for supporting whole activity.

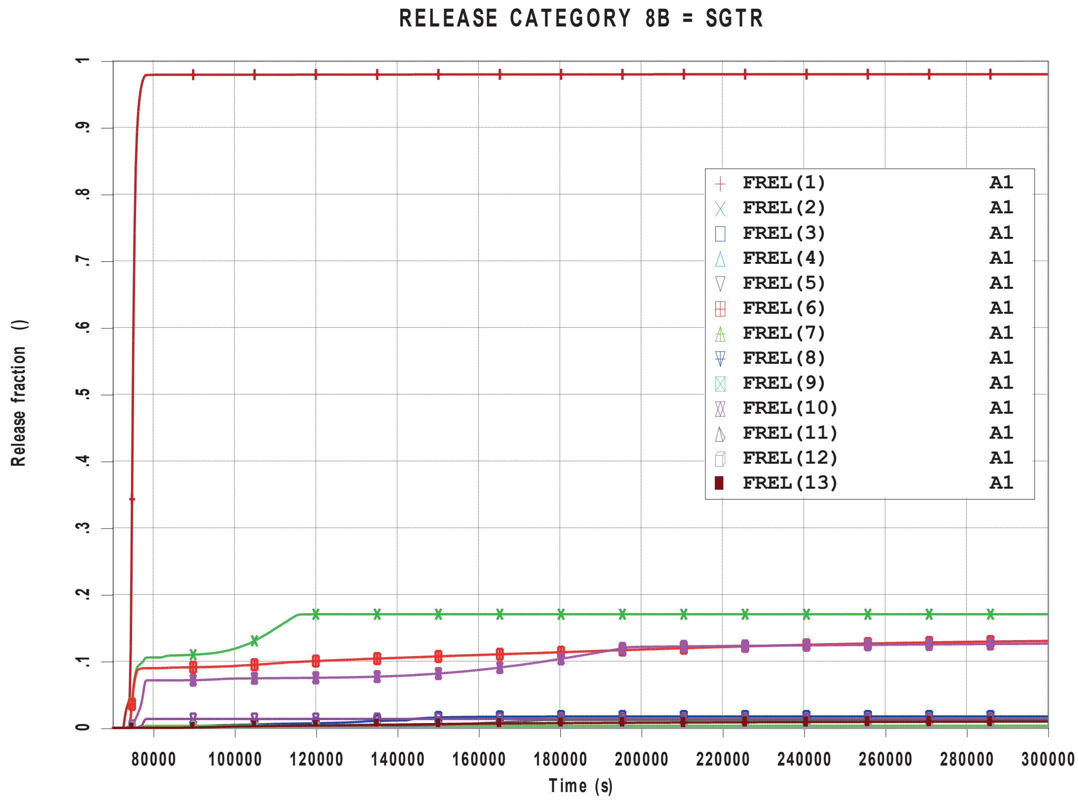

Figure 1: MAAP release categories

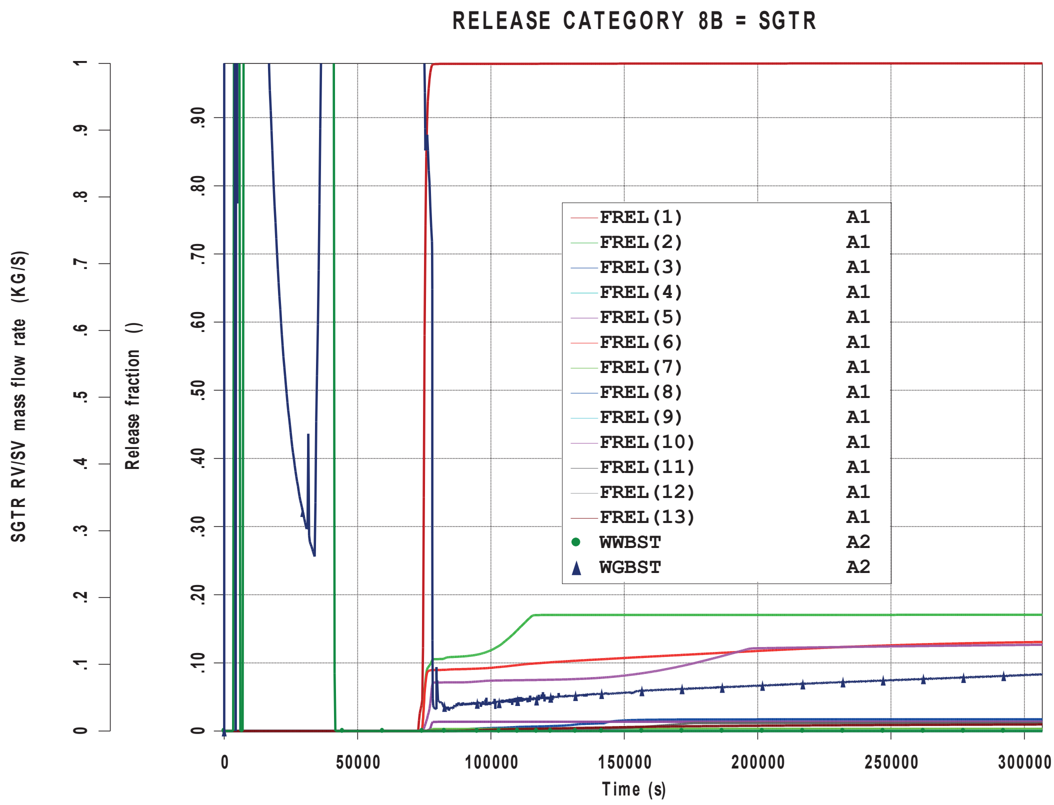

Figure 2: SG SV/RV mass flow rate and release categories

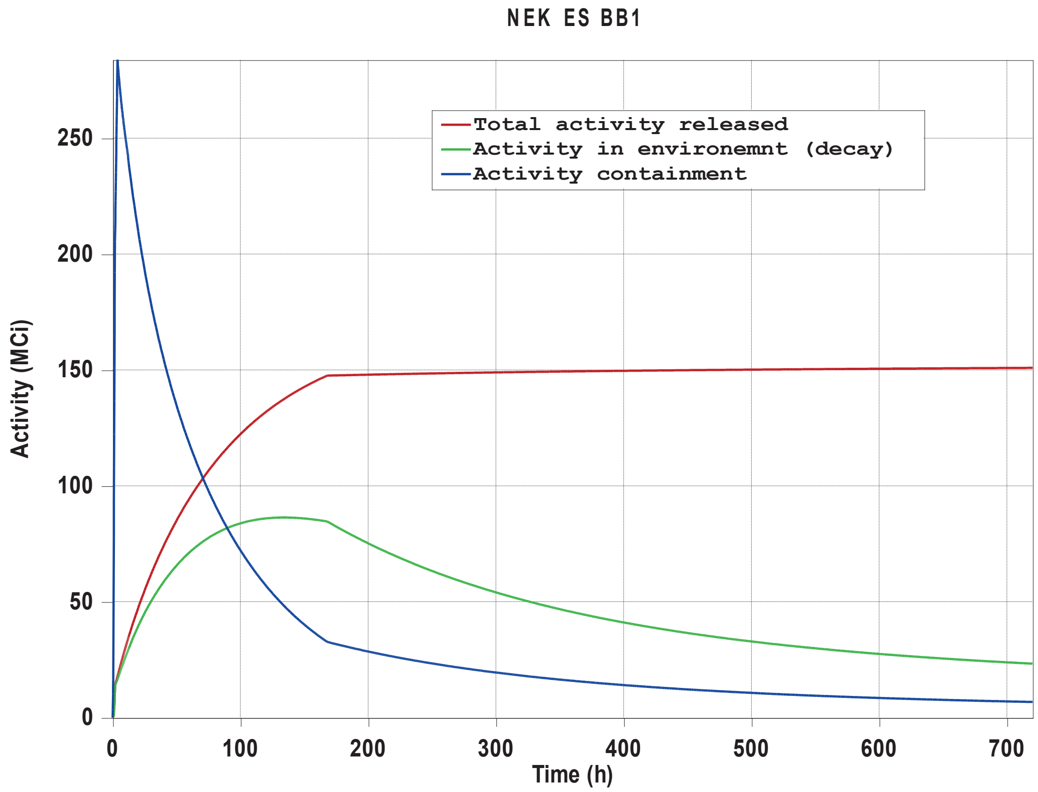

Figure 3: Activity released and activities left in the containment and present in environment

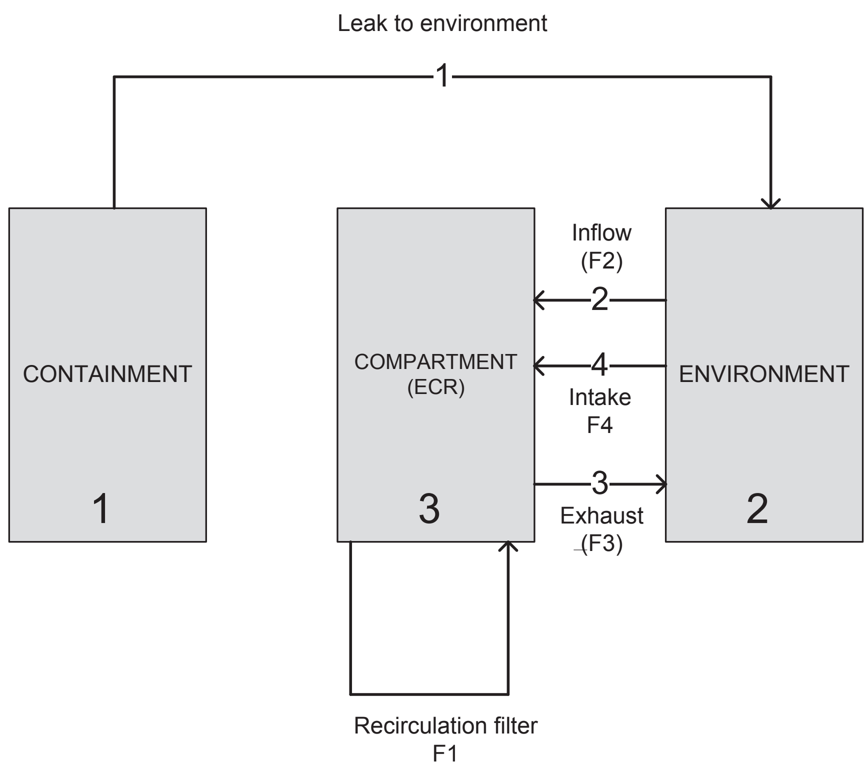

Figure 4: RADTRAD compartment used in calculation of BB1 rooms

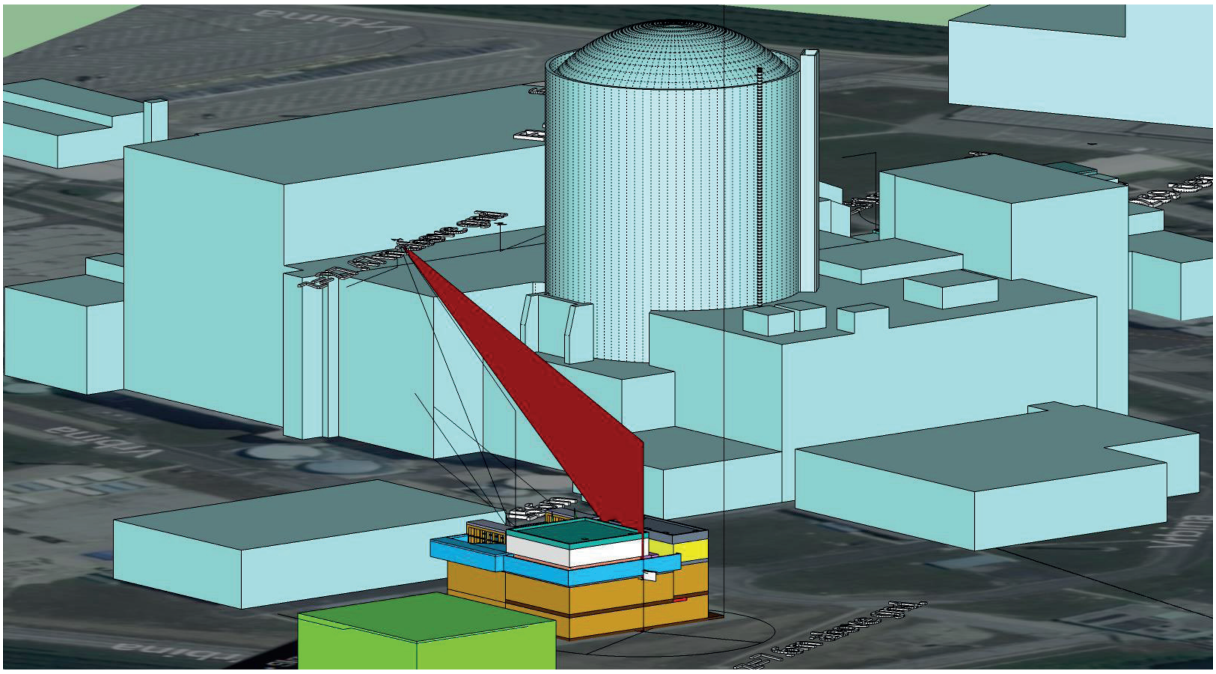

Figure 5: Geometry for ECR/TSC HVAC intake

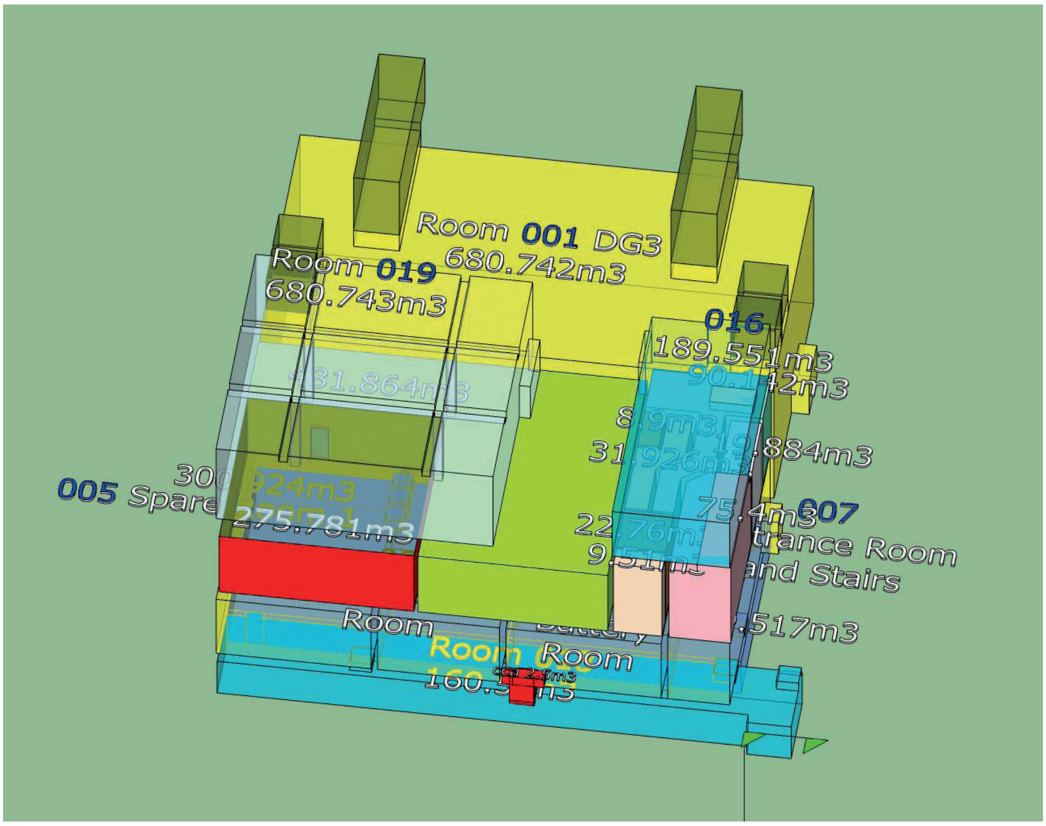

Figure 6: BB1 empty room volumes

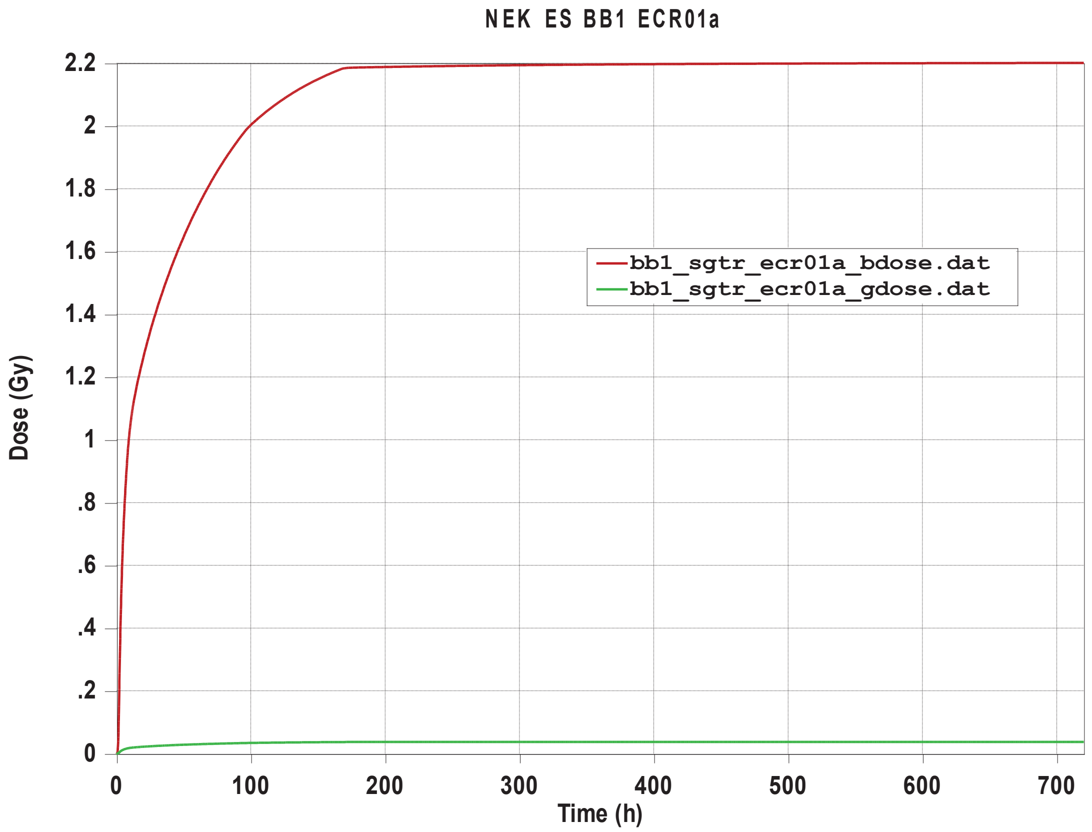

Figure 7: ECR beta and gamma immersion dose

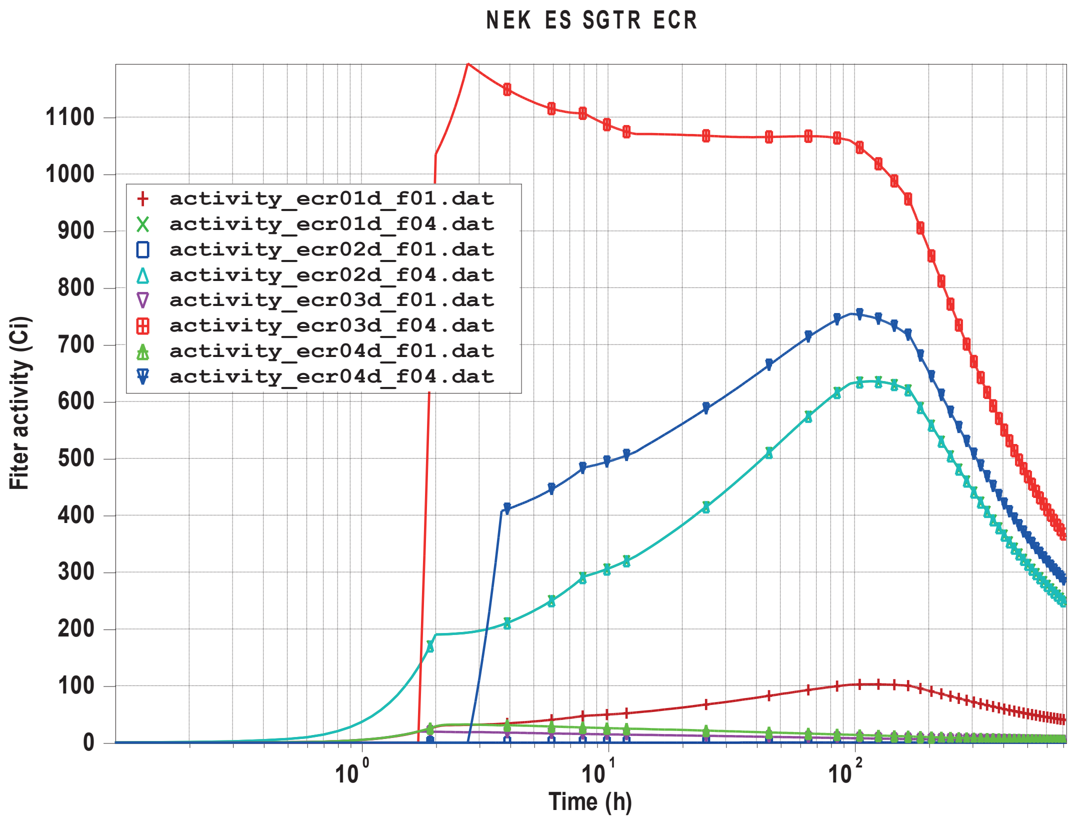

Figure 8: Recirculation and intake filter activity, case01-04

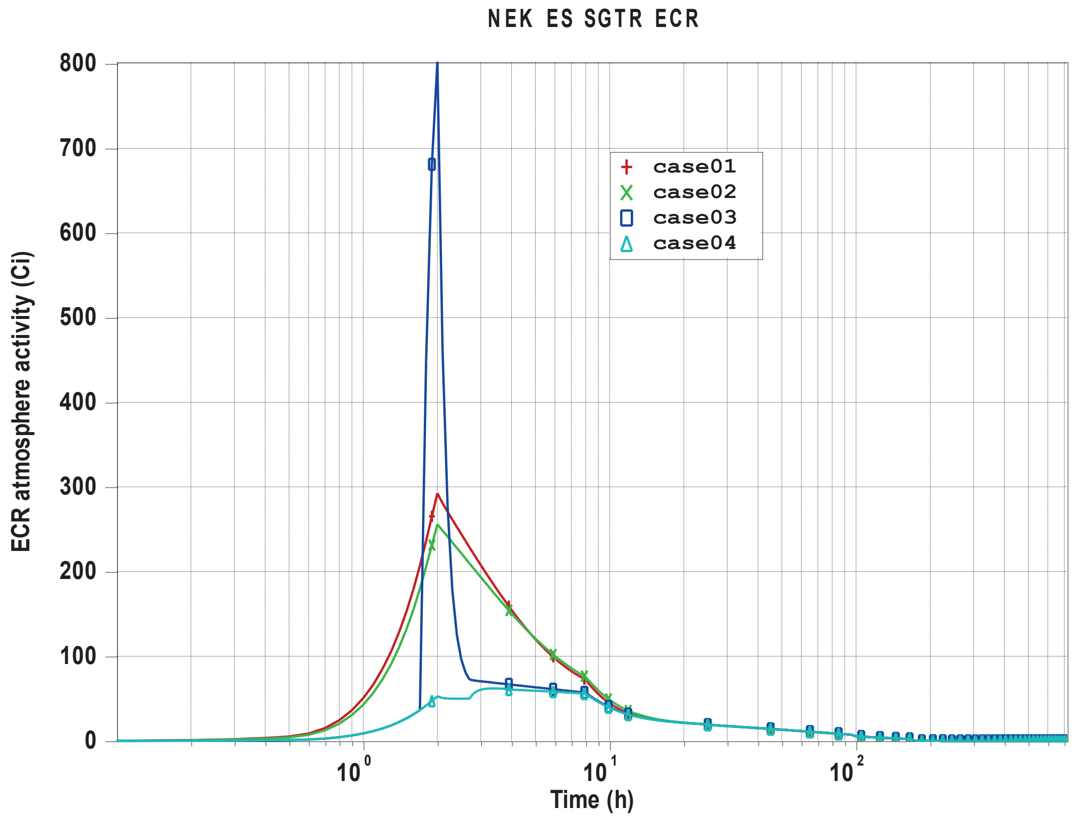

Figure 9: ECR/TSC air activity, case01-04

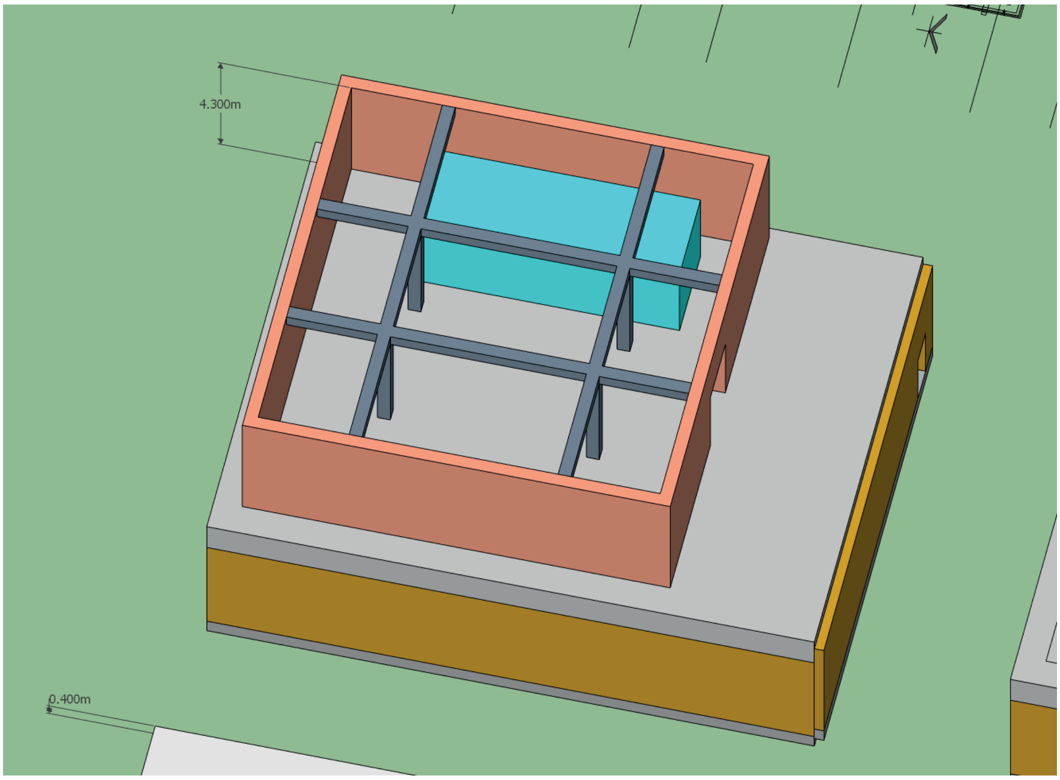

Figure 10: Position of ECR/TSC HVAC filter

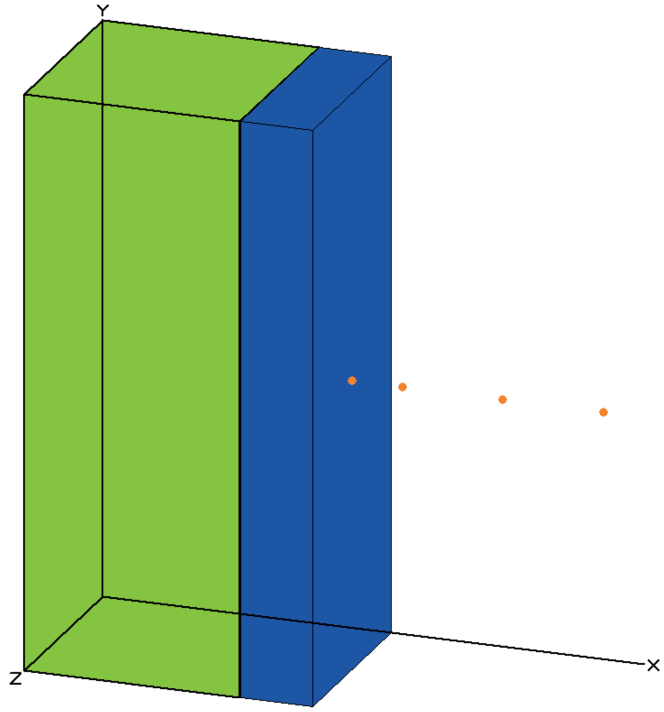

Figure 11: ECR filter geometry layout for dose calculated in upper part of ECR/TSC

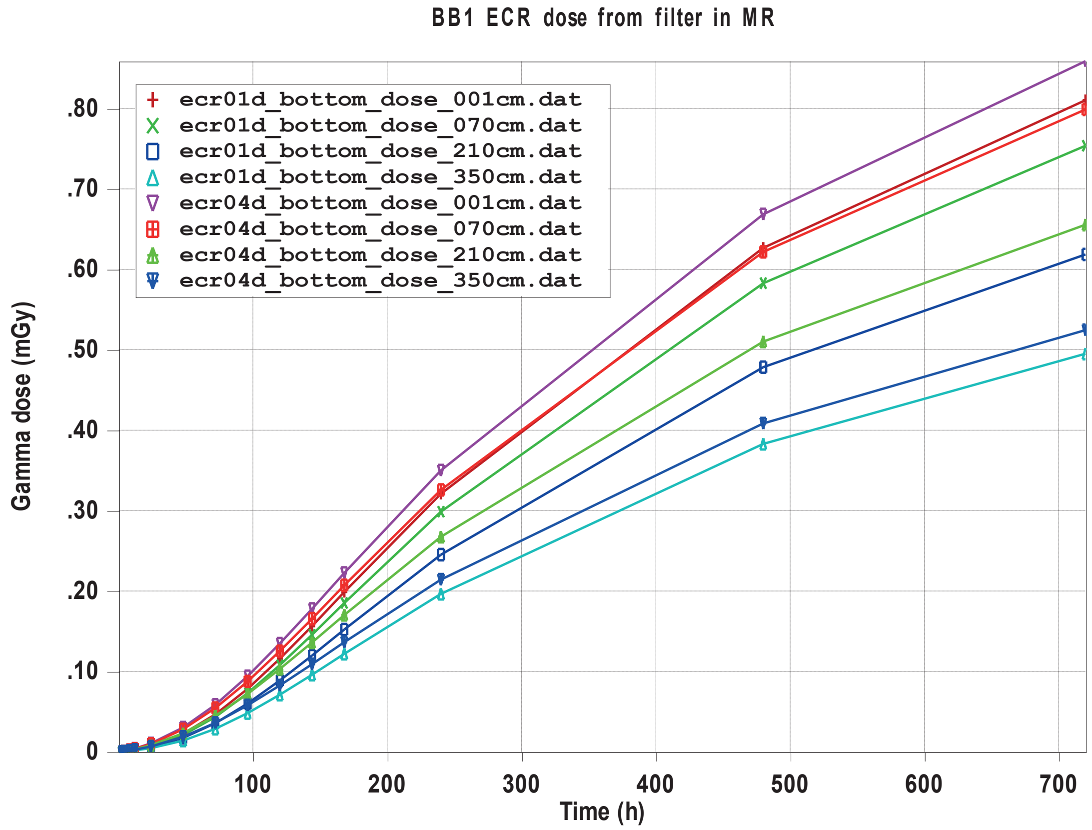

Figure 12: Gamma dose in ECR/TSC upper part from filter in MR

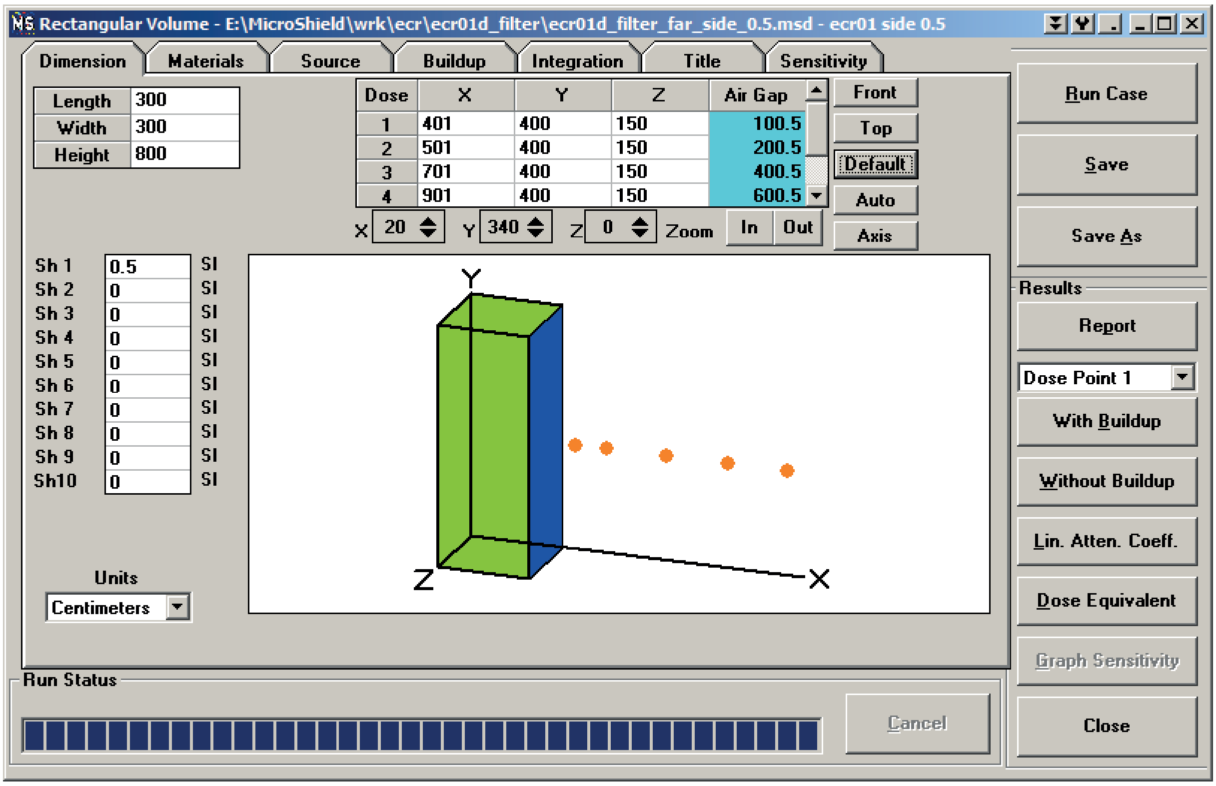

Figure 13: Problem layout for Microshiled dose calculation from filter longer side

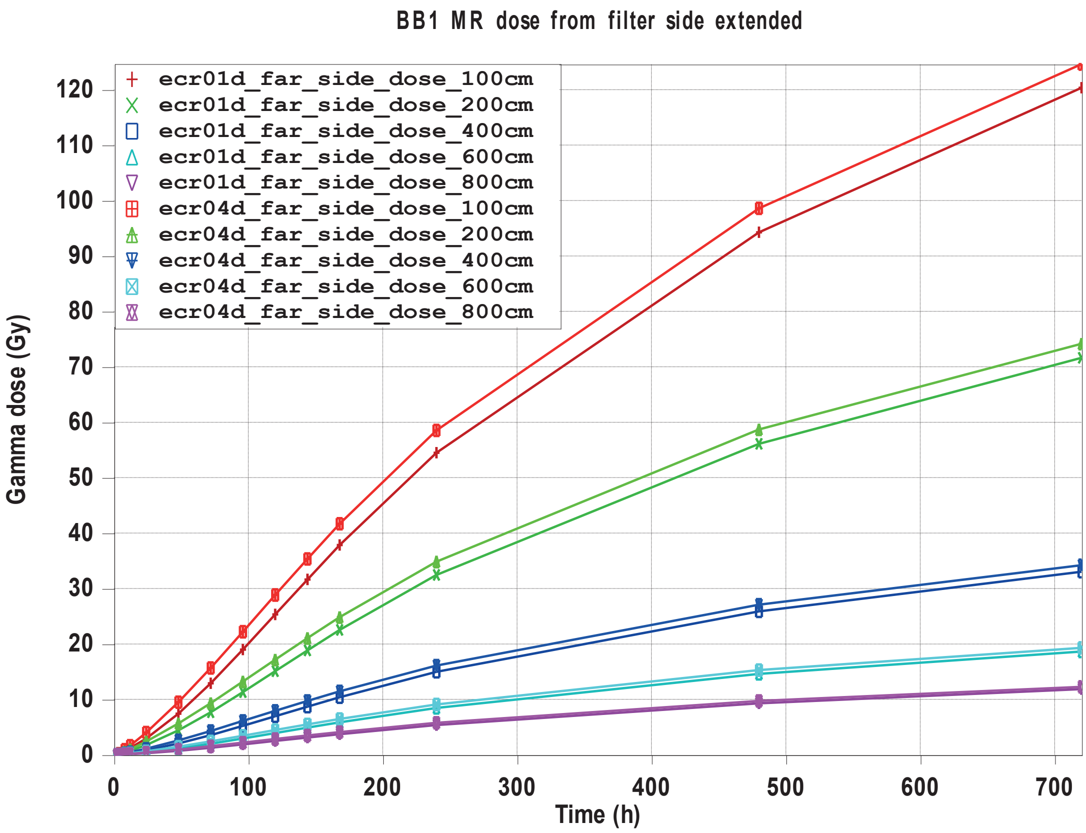

Figure 14: Gamma doses in BB1 MR – filter side

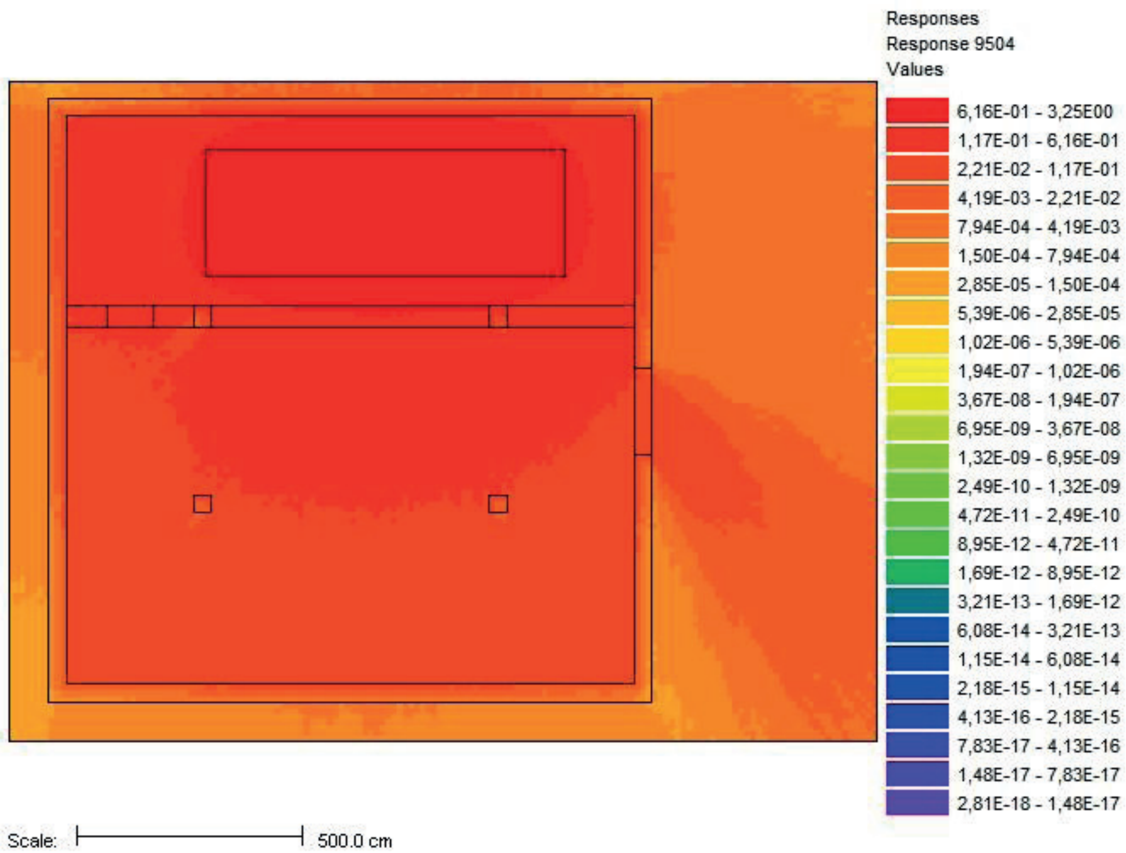

Figure 15: Monte Carlo calculation of dose rate at 120 h

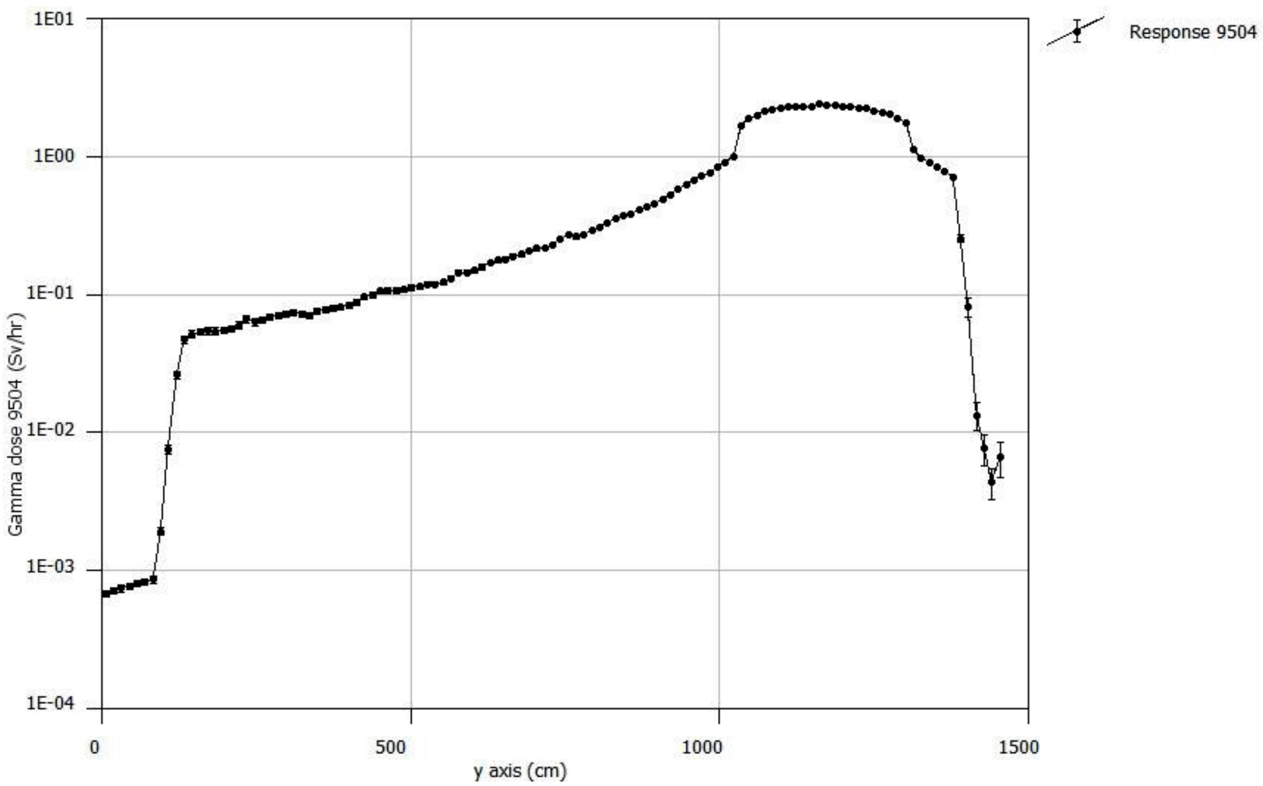

Figure 16: Monte Carlo calculation of dose rate at 120 h – perpendicular to filter side

REFERENCES

[1] NEK Safety Upgrade Project Design Input and Interfaces, Rev.6

[2] STR-NEK-12-04, "NEK SUP equipment under DEC survivability concept", Rev.1 (contains Third Party Proprietary documents)

[3] MAAP4 User Manual, Electric Power Research Institute

[4] NUREG/CR-6604, "RADTRAD: A Simplified Model for RADionuclide Transport and Removal and Dose Estimation," U.S. NRC, December 1997.

[5] ORIGEN 2.1 Isotope Generation and Depletion Code, ORNL, CCC-371

[6] NUREG-1465 "Accident Source Term for Light Water Reactors", 1995

[7] Atmospheric Relative Concentrations in Building Wakes, NUREG/CR-6331, 1997

[8] MicroShield User's Manual, Version 10, Grove Software, 2014.

[9] "SCALE: A comprehensive Modeling and Simulation Suite for Nuclear Safety and Design", ORNL/TM-2005/39, Version 6.1, June 2011. Available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785.