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Memo

Date: *February 12, 2016 (Appended: April 10, 2016)*

To: *RSC, C. Folz, K. Kusche, J. Skaritka, Junjie Li, RSC Memo file (ATFII)*

From: *D. Beavis*

Subject: *Update on UED Shielding Design*

The configuration for the UED experimental shielding was modified to accommodate the potential for future improvements to the UED. This memorandum updates the radiation analysis for the shielding. This report augments the previous analysis[1], which was reviewed by the RSC[2] on July 22, 2016. It will be shown that the design satisfies the dose rate goal of 0.05 mrads/hr. A summary of dose rates by location is given at the end of this report.

X-ray Generation from the UED

The potential rate of x-ray generation from the electron beam used in operations of the UED is discussed in Footnote 1. In this report the dose rate is assumed to be created from a 3 MeV beam of electrons with a total power of $3*10^{-3}$ Watts.

UED Area

The layout of the UED and the associated shielding is shown in Figure 1. The UED experimental area and the laser share an environmentally controlled room (ER) in which the temperature is regulated to 0.1^{o} C. Both the UED and laser require a carefully regulated temperature, which lead to placing them in a common room. The laser is used for the UED and the ATFII facilities. Access to the UED area will be through a gate on the south side of the facility. The Klystron will be required to be off for access through the gate[3]. Maximum radiation levels are expected to be less than a few 100 mrads/hr at a foot and on average much lower[2,1]. Access to the northwest side of the facility that is not shadowed by shielding will be allowed. This area will initially be posted as a Radiation Area. Access to the roof via the roof ladder, which is inside this area, will be allowed. The access will allow trained radiation workers to access equipment and electrical panels.

[1] D. Beavis, July 22, 2015; http://www.c-ad.bnl.gov/esfd/RSC/Memos/7_17_15_UED.pdf
[2] RSC Minutes, July 22, 2016; http://www.c-ad.bnl.gov/esfd/RSC/Minutes/07_22_15Minutes.pdf
[3] Special access may be allowed for qualified personnel conducting special measurements such as radiation field characterization.

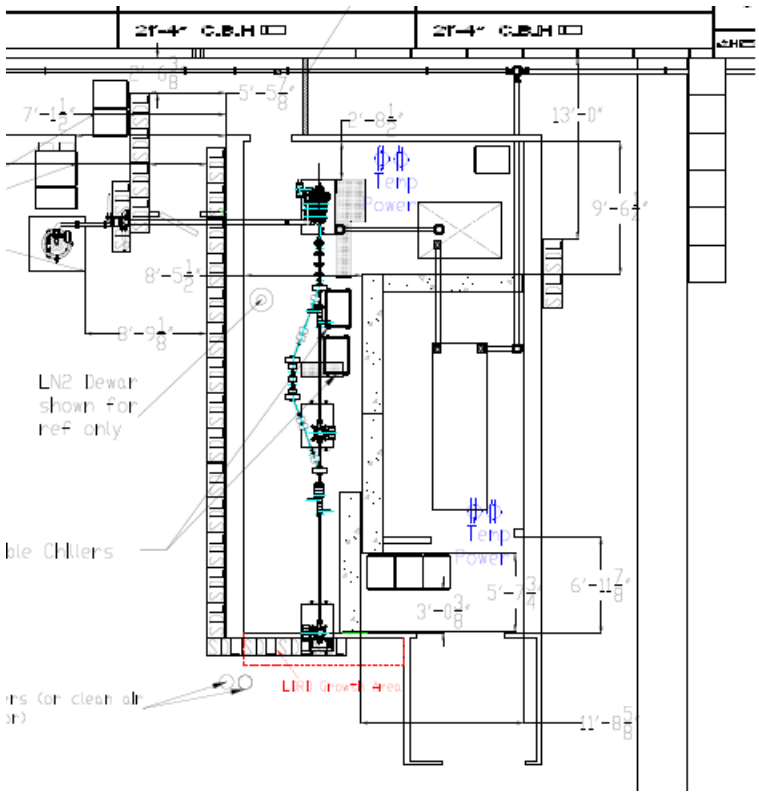

Figure 1: Layout of the UED configuration in the environmentally controlled room (ER). A possible future layout of the UED is also shown. The entrance gate is on the left near the Klystron. A barrier prevents access to the UED except through the gate. The gate key is coupled to the key to operate the Klystron and will prevent access through the gate with the Klystron on. The laser is shown in the north east section of the ER.

Shielding Analysis

The shielding analysis has been conducted using MCNPX with simplified geometry to estimate the dose rate at various locations. The computer model is changed depending on the location being examined. The 3 MeV electron beam is directed at a 1cm thick rod of steel 0.25 cm in radius. The target has sufficient dimensions to simulate the radiation that could be produced from beam striking material in the machine. The equivalent dose from electrons and photons was tallied separately using energy-dependent fluence to dose conversion factors.

The first calculation was the dose rate through the light concrete shielding wall that separates the laser area from the UED area. The 1.5 foot thick concrete was treated[4] as 45 cm of light concrete. This wall is located on the north side of the facility. The beam axis is 85 centimeters from the concrete wall and the target is between z=0 to 1 cm in z. The photon dose as a function of z on the inside surface of the concrete wall and 30 cm from the outside surface are displayed in Figure 3. The dose peaks just downstream of the target with a value of $7.1*10^{-19}$ rad/electron. The 3 milli-Watts of electron beam could create a dose rate of 16 micro-rad/hr.

[4] I often use 30 cm to represent a foot rather than 30.48 cm.

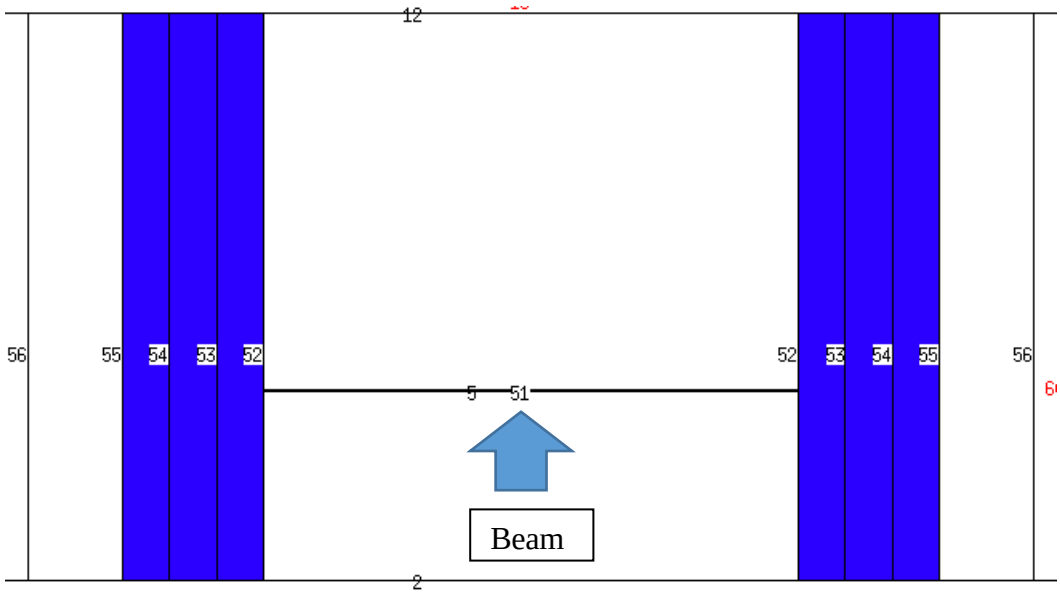

Figure 2: Simple plan view of the shielding. The model has azimuthal symmetry. The 45 cm of light concrete is divided into 15 cm layers to use weighting factors.

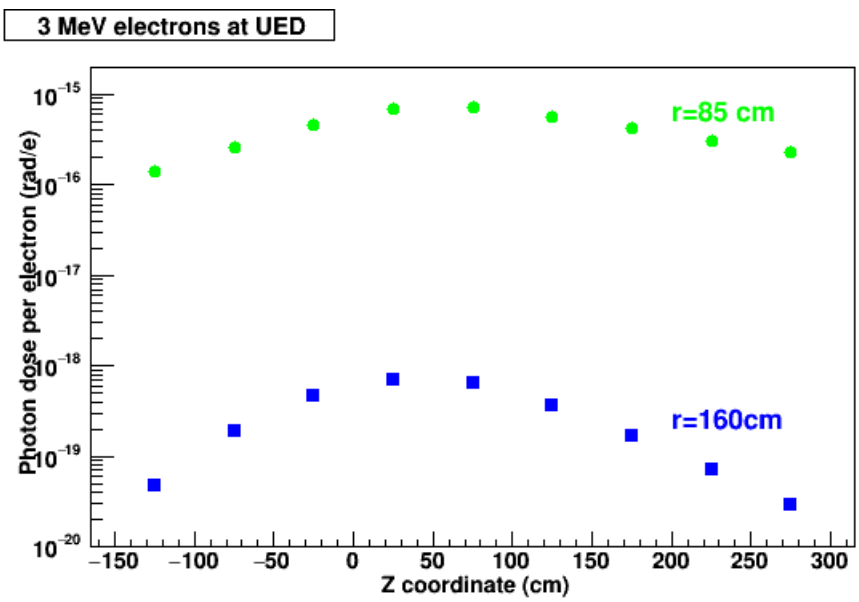

Figure 3: Photon dose per electron as a function of z along the shield wall between the UED and the laser room. The blue squares are the equivalent dose per electron 30 cm from the outside of the shield wall. The green circles are the equivalent dose at the inside surface of the shield wall. The target is located at z=0 to 1cm.

The dose as a function of radius is given in Figure 4 near the peak of the distribution. The simulation is well described by Dose= Norm*$10^{-t/att}$/(r*r) where att is the effective tenth-value layer (TVL) for the light concrete and t is the thickness in cm. The TVL for the transverse

radiation is 19 cm. The results can be compared to thick targets[5] formulas/curves for electrons. The dose rate at a meter is given by thick target curves as 20 mrads/hr without shielding. The MCNPX result scaled to one meter is 11 mrads/hr in reasonable agreement. The TVL for light concrete is given as 27.7 cm. [6]. Using this TVL results in a dose 30 cm 180 micro-rads/hr instead of the 16 micro-rads/hr calculated using MCNPX. The TVL from Footnote 5 is substantially longer than the transverse TVL calculated in this report. Using the thick target numbers and longitudinal TVL leads to overly conservative results in the transverse direction. The results from MCNPX and the approximate formula can be used to calculate the dose rate at other distances and shielding thicknesses.

The south wall shielding can be evaluated using the extracted function from the north wall and other locations. The light concrete wall is constructed from "SDL" blocks[7]. The distance to the inside of the concrete wall is 230 cm and the light concrete wall is 40 cm thick. The peak dose rate one foot from the outside of the shield wall is 10 micro-rads/hr. The peak dose rate two feet above the roof is 1 mrad/hr. Access to the roof will be allowed and it will be initially posted as a Radiation Area. The dose rate at the building wall on the west side has an estimated dose rate of 6 mrads/hr, using the simple formula for the peak dose per electron. A calculation[8] using MCNPX and including electrons gives a dose rate of 9 mrads/hr. The dose rate on the ATFII shielding roof could be approximately 1 mrad/hr. Finally, the dose rate on the north side of the facility transverse to the gun will have a peak dose rate of less than 0.5 mrad/hr. The dose rates 30 cm outside and over the top of the north and south walls are 2.6 and 1.0 mrads/hr, respectively. The dose rate for the north wall where there is no shadowing from the shielding is 10.5 feet above the floor, which is well inside the false ceiling.

[5] The numbers are taken from NCRP Report no. 144, National Council on Radiation Protection and Measurements, 2003.
[6] This is expected as the TVL is calculated in the forward direction with broad beam conditions.
[7] The name is derived from the facility they were used at, the Source Development Lab. The blocks are 16 inches thick, 30 inches long and eight feet high.
[8] The calculation will be discussed later.

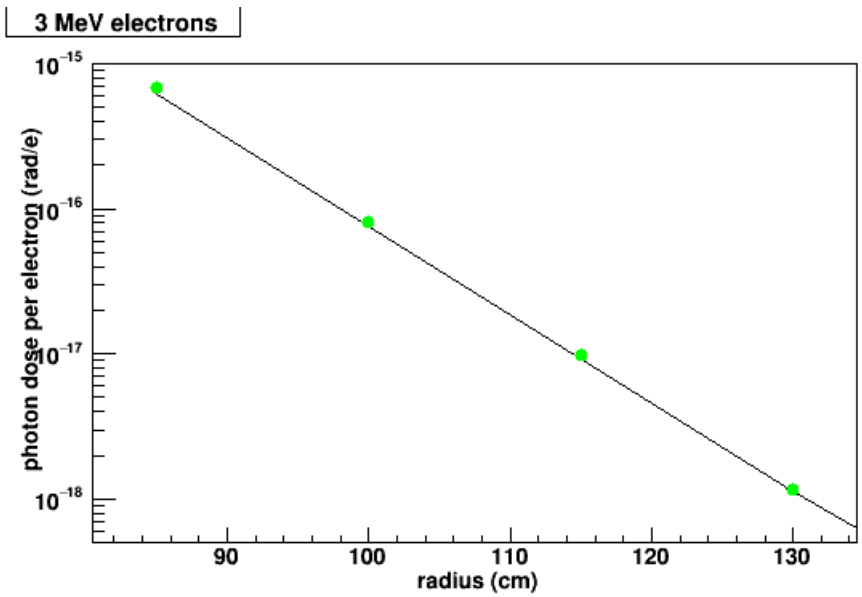

Figure 4: The photon dose as a function of radius. The light concrete starts at 85 cm and ends at 130 cm. The line represents and exponential fit with solid angle. The effective TVL is 19cm.

The dose rate at the downstream shielding wall can be estimated using MCNPX. The wall is 40 cm thick and the top of the wall is about 150 cm above beam height. The target was placed 500 cm in front of the wall[9] and azimuthal symmetry was used. The dose rate 30 cm outside the shield wall with radius less than 50 cm is 33 micro-rad/hr. This can be compared with the values extracted using a thick target source and the TVL for light concrete given in Footnote 5. The result is 36 mirco-rads/hr in good agreement. The dose rate over the top of the wall one foot downstream is 0.8 mrads/hr. This is at an elevation of about 10 feet above the experimental floor.

The dose rate at the entrance gate can be estimated in a simple MCNPX model. The model has azimuthal symmetry with the dimensions appropriate for the south side of the shielding. The volume between the shielding has been filled with air. The air does not substantially impact the dose for photons but does decrease the dose from back-scattered electrons. The dose rate at the gate is estimated to be 29 micro-rads/hr with about a third of the dose rate from electrons[10]. The dose rate at the surface[11] of the ATFII concrete wall was tallied. The average between the labyrinth shield wall (r=360cm) and the inside of the ER shielding (surface 52) is 0.5 mrads/hr with a little more than 50% due to electrons. The dose rate along the ATF shield wall with a radius of less than 100cm has an average of 1 mrad/hr. The opening of the laser port[12] will have an entrance dose of 0.5 mrad. The dose outside will be somewhat smaller. It was not considered necessary to calculate the dose rate external to the laser port, but it will be measured.

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[9] The 5 meteres is approximately the distance from the end of the UED beamline to the concrete wall.
[10] The ER wall material would reduce the electron dose substantially. The material of the ER side walls was ignored in all calculations.
[11] The concrete surface at the bottom of Figure 5 is a portion of the ATFII shield wall.
[12] The laser port is 12 inches high, 15 inches wide and 16 inches long. The labyrinth wall is constructed with SDL blocks. The block adjacent to the ATFII shielding is raise one foot on concrete patio blocks to form the port for the laser tube.

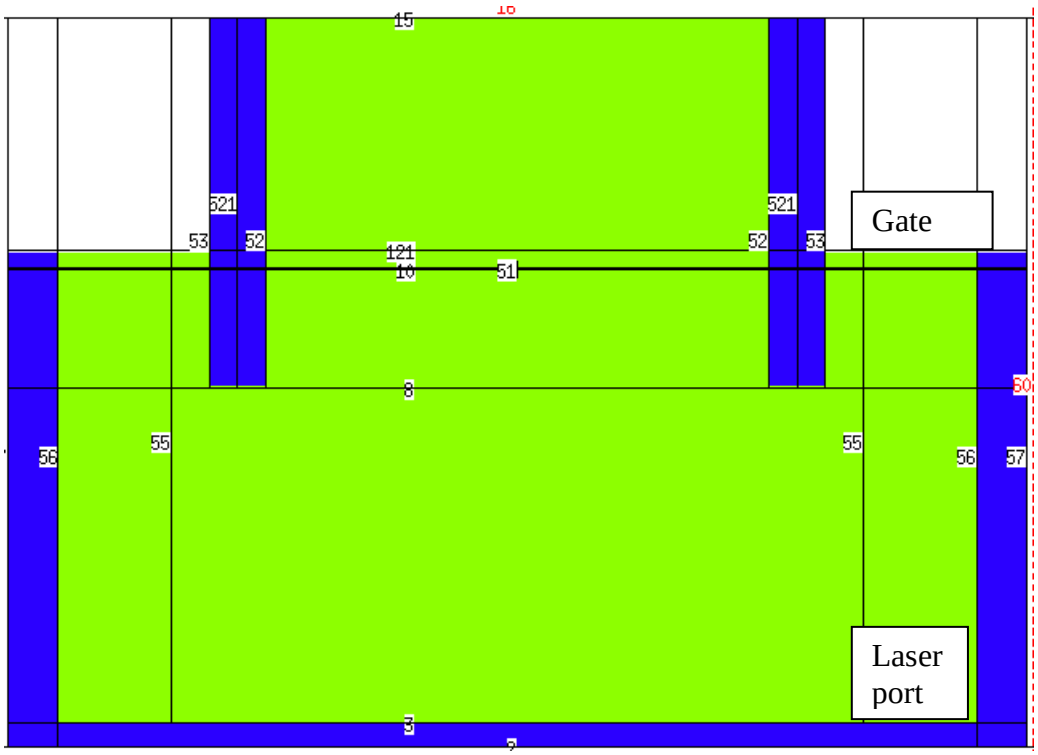

Figure 5: Layout of the shielding to calculate the dose rate at the gate and the laser port in the labyrinth wall. The blue items are the light concrete shielding and the green is the air. The source is the gun at surface 51 and the gate is at surface 121. The laser port is in front of the ATFII shielding at floor level.

The dose rate to the laser area can be calculated using MCNPX. The laser room is located too close to the UED area to use most skyshine formulas. To calculate the dose rate from skyshine the geometry was modeled in a simplified three dimensional geometry. A thin layer of steel is used over the environmental room to account for the scattering off the roof. The volumes are filled with air except for the shielding, which is light concrete. The geometry was extended for 20 meters in each direction from the target. The target is between surfaces 5 and 6 and has a radius of 0.25 cm and a length of 10 cm.

The dose rate was tallied at several locations using point detectors. The dose rates at the three marks on the plan view increase with distance from the source[13]. The dose rates from skyshine[14] are 8, 10, and 13 micro-rads/hr. If the formula extracted from the transverse analysis is used values of 1.4. 1.0, and 0.8 micro-rads/hr are obtained. The skyshine contribution dominates the dose rates away from the shielding. A location 10.4 meters from the target which is not shadowed by shielding was used to compare the skyshine dose rate with the formula dose rate. The skyshine calculation was 170 micro-rads/hr and the formula gave 94 mrads/hr. Since the actual z position was not used for the formula treatment it is expected that there should be some difference. The results are reasonable.

[13] The three locations are at beam height, 400 cm downstream of the target and 400, 500, and 600 cm in the transverse direction.
[14] These numbers also include the direct contribution.

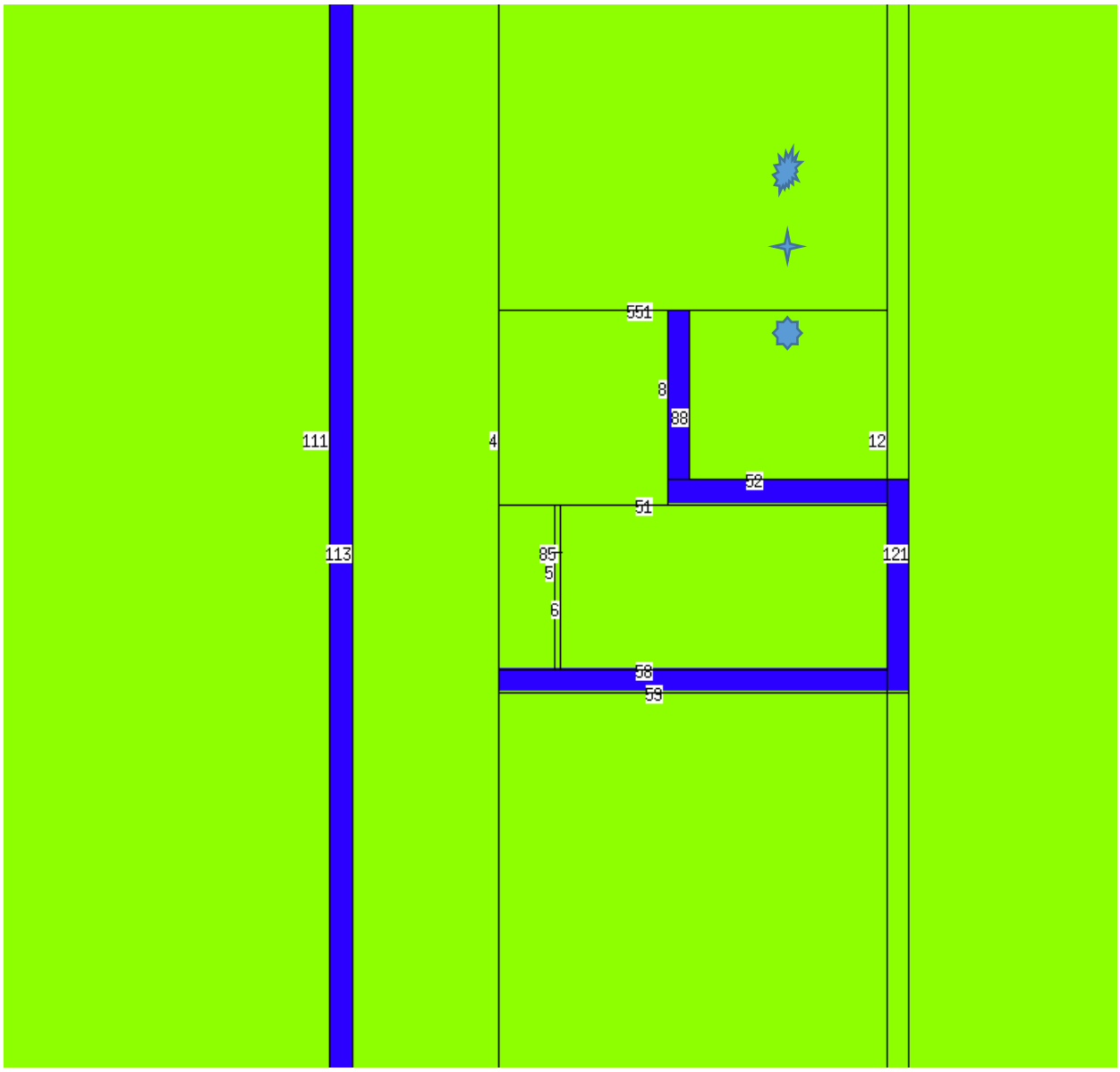

Figure 6: Plan view of the geometry at beam height used for the skyshine analysis. The full ATFII shield thickness was not used and the gate labyrinth shielding was not included. The two shield blocks on the north wall outside the ER were not included. The geometry is displayed for ten meters in each direction at beam elevation.

Summary

The goal of the shielding was to have UED operations create less then 50 micro-rads/hr in areas adjacent to UED where ATF and UED users may work. The shielding layout meets satisfies the design goal of 0.05 mrads/hr. The calculations do not include local shielding near designed beam loss locations such as the aperture and the beam stop, which should reduce routine dose rates substantially. The shielding at these locations will likely be designated as ALARA shielding and experimental shielding to reduce background into the experimental signal. The results presented calculations are summarized in Table 1 below.

Table 1: Summary of UED Dose Rate at Location Near the UED

Location description	Dose rate (mrads/hr)
Entrance gate	0.029
Laser port	Less than 0.500
ATFII shielding roof	0.500
ER roof (two feet above)	1.
Through south wall 30 cm away	0.010
Max. in Radiation Area	6.
Laser room 30 cm from concrete wall	0.016
General area skyshine from UED	0.008-0.015
Over top of side wall (south)	1.0
Through end wall	0.032
Over top of end wall (10 feet above floor)	0.8

E-mail on end wall change copied below to document the calculation as per RSC Minutes, April 6, 2016.

From: Beavis, Dana
Sent: Monday, March 14, 2016 2:59 PM
To: Karol, Raymond C (karol@bnl.gov); Folz, Charles
Subject: dose through wall seam at end of building

I have estimated the dose rate from UED operations out the seam in the shielding caused by the building that creates a gap between the shielding blocks. The gap is 4-5 inches wide and does represent the potential for a full body dose. The area directly outside can be posted and the closest area is the vestibule for the laser section.
The result is 0.02 mrads/hr outside the building and less than 0.005 mrads/hr in the vestibule. This is expected to be conservative and should be easy to make radiation measurements at the location.

Details:

Beam energy	3 MeV
Beam power	.003 Watts
Source distance to shielding	7 meters
Souce term	2*10**4 rad-m**2/(hr-kW)
Wall Area for reflection	0.74 meters used
Albedo coefficient	0.03
Distance Area center to outside	1.07 meters
Distance to vestibule	2.2 meters

Result: Dose(outside seam)= 2*10**4*(.003W*.001kW/W)*(1/7*7)*0.74*(1./1.07**2)*0.03
= 0.02 mrad/hr
In vestibule twice the distance so ¼ the dose rate.

I think we can leave this seam as is. When the beam line is modified we will need to look at where the beam dump is and also beam faults.

dana