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Memo

date: *March 28, 2008*

to: *RSC*

from: *D. Beavis*

subject: *Dose Rate Estimates for ERL Penetrations*

Introduction

Dose estimates for the penetrations in the ERL facility are provided. The estimates use a combination of simple source terms and estimates of the attenuation of the radiation as it propagates through the opening. The estimates provided in this document are intended to be crude order of magnitude estimates. Conservative assumptions are usually used so that the estimates represent upper limits for the potential dose rates. The low-intensity commissioning process of the RF-gun, five-cell cavity, and transport of the low energy and high energy electron beams will be used to verify the source terms and radiation transport through the shielding and penetrations.

Figure I is a plan view of the shielded area of the facility. There are approximately 20 penetrations through the external shielding. Two of these penetrations are used for personnel and equipment access. Several of the penetrations are buss blocks containing several dozen small penetrations for access of utilities. Other penetrations are intended for electrical cables, cryogens, gas exhaust, laser beam, etc. The overall features are a superconducting RF gun, a five-cell superconducting energy recovery linac (ERL), low energy beam transport to the beam dump, and the 25 MeV electron ring. The side walls are composed of between four and eight feet of light concrete. The thin sections of wall are shadowed from the potential sources with inner shield walls located appropriately. The entire facility has a single layer of light concrete roof beams four feet thick, except for a transition region where the roof is two layers of roof beams. This transition region is where the 13 foot ceiling height in the center is reduced to 9 feet at both ends.

There are restrictions on access for the facility areas. Access into the machine area is prevented by dual interlocks when the machine is operational. This includes the operation of the electron beams, the RF-Gun and five-cell cavity. Personnel will not be allowed on the roof during operations. Personnel will not be allowed in the 1 megawatt power supply room during operations. A substantial area the between adjacent experimental building and the ERL shielding

on the west side will be fenced and locked with personnel excluded during operations or with limited access.

The radiation sources are predominately x-rays and gamma rays. The 25 MeV electron beam is capable of generating neutrons. Only in conditions where substantial high-Z shielding materials have been used or where it takes many bounces for radiation to get through a penetration is it possible for the neutron dose rates to dominate the x-ray dose rates.

The shielding is evaluated for two types of exposures, chronic and fault conditions. As will be discussed below the dose rates during fault conditions are typically many orders of magnitude larger than that of the chronic (routine) conditions. The penetrations will not be considered for the chronic dose to personnel since the areas around the penetrations are typically not occupied and they can be posted for localized elevated dose rates. The penetrations are considered as an issue for dose to personnel during a fault condition.

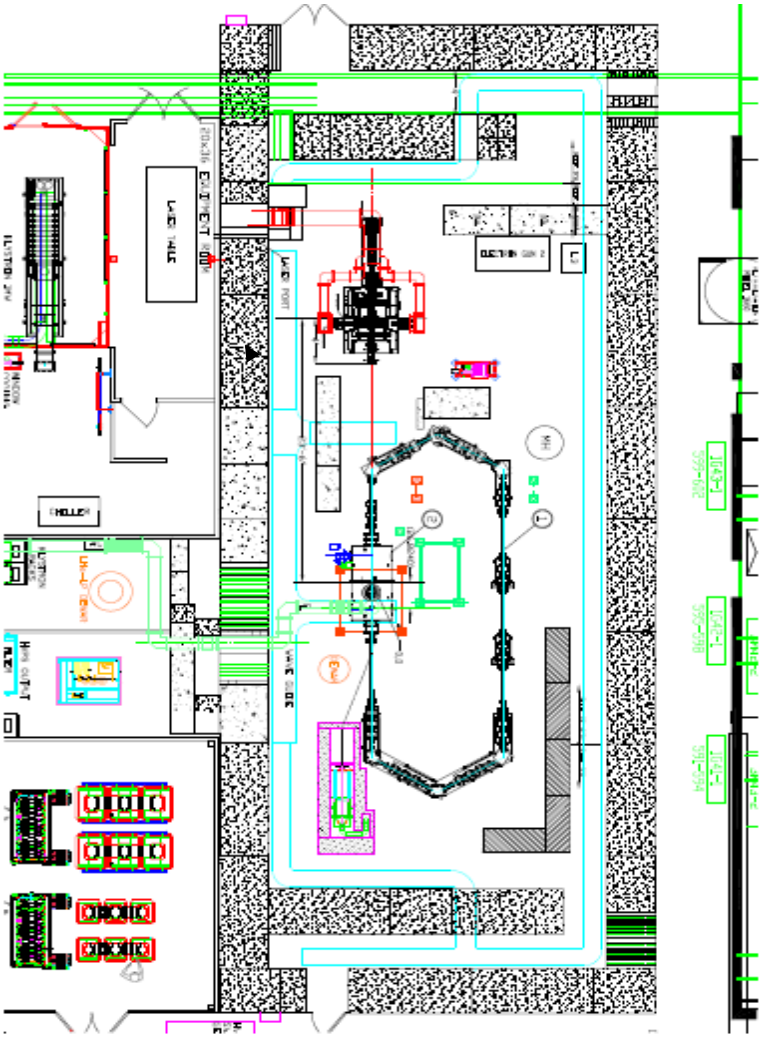

Figure I. Shielded ERL Area

All areas near the ERL shielding should be posted at least as a Radiation Area, TLD Required. Any unplanned exposure exceeding 100 mrem is a DOE reportable occurrence. This establishes an upper limit of exposure to personnel during an unexpected fault condition. Large dose rates caused by unusual operating conditions will be detected by radiation monitors (chipmunks) distributed around the area. These devices are coupled with the interlock system and will terminate the radiation in 1 to 9 seconds depending on the level of radiation at the detector. **This establishes an upper dose rate of between 40 and 360 rem/hr depending on the duration of the fault for areas that can be occupied by personnel.**

Radiation Source Terms

The four sources of radiation in the area are the RF-Gun, beam losses of the low-energy (E_k<3.5 MeV) electron beam, the five-cell cavity, and beam losses of the high-energy electron beam (E_k<25 MeV). Most of the calculations used in this note will use the source terms discussed in reference 1, which were based formulas and figures from references sited in that note. In some cases more detailed calculations are used. The source terms used are conservative. The commissioning process will provide a check on the source terms and the effectiveness of the shielding.

The RF gun and the five-cell cavity can generate copious x-rays. No modeling has been conducted for the RF gun and the five-cell cavity in terms of the x-ray generation, but experience from other systems can be used for guidance. When these devices are commissioned, careful attention will be given to the measurement of their potential to create x-rays. The conditioning of the cavities will cause the largest x-ray generation from the cavities. The five cell cavity is expected to be able to absorb 100 to 1000 watts from electron emission before boiling too much helium and becoming normal. The voltage difference that the electrons cross will typically be less than the gradient of a single cavity, 5 MV. Only a few electrons would be accelerated across several cavities. It is assumed that **all the electrons are at 3.5 MeV with a maximum conditioning loss of 250 W**. It is expected that the **routine loss is less than 10 W** for the five cell cavities. **We will assume that the RF gun has the same limits**. The methods discussed in reference 1 can be used to estimate the 90-degree radiation, using thick target formulas. The expected dose rates for commissioning and routine operations are:

Cavity X-rays assuming 3.5 MeV

cavity	**Conditioning (250W) rem/hr at 1m**	**Routine (10W) rem/hr at 1 m**
Five-cell	2000	80
RF-gun	2000	80

The maximum kinetic energy of the x-ray gun is 3.5 MeV. It is expected that it will typically operate at a lower kinetic energy. The rule of thumb[2] for 0 degree radiation in this energy region is that it grows as the energy squared at fixed power. Therefore using 3.5 MeV represents a conservative figure.

3.5 MeV e- losses rads/(hr-kW)at 1 m

0 degrees	$4*10^4$
90 degrees	$8*10^3$

The source terms for electron losses at one meter for 25 MeV electrons are (an approximate value for 30 degrees has been added):

25 MeV e- losses rem/(hr-kW) at 1 m

angle	gamma	neutron
0 degrees	$8*10^5$	430
30	$8*10^4$	430
90 degrees	$8*10^3$	430

The dose rates for beam losses at 3.5 MeV and 25 MeV given above are based on high-Z thick target formulas or curves and are a conservative estimate. The radiation from actually losses can be up to a factor of 10 lower than the above estimates.

Reference 3 estimated the dose from a 25 MeV electron beam loss in the near zero degree direction to be 9000 rad/hr at 3 meters with 2 feet of heavy concrete between the source and the point of interest with a 50 kW loss. This will be used for locations where an inner shield wall (see Figure I) acts as a shadow for the 25 MeV beam losses.

The routine beam losses and maximum credible beam losses are needed to estimate the potential dose from chronic sources and for unusual conditions. The **maximum sustainable beam loss that the 5 cell cavity can support is 50 kW**, which is limited by the power supply. Many people believe that the **maximum local loss that can occur is between 10-100 W before the machine is damaged and shuts down**. The ERL will have machine protection devices to limit the losses to avoid equipment damage. However, no demonstrated mechanism to limit the beam loss has been demonstrated so a **50 kW limit is used for the 25 MeV electron beam**. The facility will have several chipmunks distributed at key locations to limit the duration of the beam faults. A 50 kW loss is probably appropriate to apply for short durations appropriate to the time required for the interlocks to stop the beam, which is typically 1-10 seconds depending on the dose rate at the chipmunk sensing the radiation. The 50 kW is considered conservative.
Routine losses are expected to be less than 10 W.

The **3.5 MeV beam has a power limit of 1 MW**. This power can be placed in the water cooled beam dump, which has local shielding. Again it is not expected that the machine can survive a large beam loss at any location, except the beam dump. The beam dump has a shielding criteria that it will represent less than a routine loss and is not considered for the penetration in this note. An **arbitrary maximum limit of 1 kW (10^{-3}) is assumed** without justification in this analysis. **A routine loss of 10 W (10^{-5}) or less is expected.** Any routine loss higher than this will be reviewed for the possible addition of local shielding.

Table I provides a summary of the source intensities used for fault conditions and routine operations. These are expected to be conservative and checked during the commissioning process.

Table I. Dose Rates for Routine and Maximum Losses

Condition	**Dose rate (rem/hr) at 1 meter for Max. sustainable loss**		**Dose rate (rem/hr) at 1 meter for Routine loss**	
	Gamma	Neutron	Gamma	Neutron
RF GUN	2000		80	
5-cell Cavity	2000		80	
3.5 MeV-0 deg.	$4*10^4$		$4*10^2$	
3.5 MeV-90 deg.	$8*10^3$		$8*10^1$	
25 MeV-0 deg.	$4*10^7$ $2.15*10^4$		$8*10^3$	4.3
25 MeV-30 deg.	$4*10^6$ $2.15*10^4$		$8*10^2$	4.3
25 MeV- 90 deg.	$4*10^5$ $2.15*10^4$		$8*10^1$	4.3
25 MeV-0 deg. 2ft HC at 3 meters from source	$9*10^3$		1.8	

The dose rate through a penetration is estimated by scaling the dose rate of Table I with 1/(r*r) to the entrance of the penetration and then applying an attenuation factor for the penetration. The attenuation for neutrons can be estimated using empirical formulas such as those presented in references 4 and 5. Typically the attenuation for gammas in multi-legged labyrinths is lower than neutrons, but the neutron formulas do not typically apply to gammas. For gammas, reflection coefficients are used for the surfaces of the labyrinths. This technique can also be applied for neutrons but is limited in applicability. Curves in Sullivan[4] are used for straight penetrations unless otherwise stated.

Some penetrations are shadowed by shielding. The entrance dose for the penetration has a component of radiation that arrived at the penetration by reflecting off surfaces to avoid the shadow shield. Another component of the entrance dose penetrates through the shadow shielding and then travels to the penetration. The TVLs from reference 1 and reference 8 are used[9] to calculate the attenuation of the radiation by the shield.

Laser penetration

The laser penetration is a straight hole through the shielding to allow for the transport of the laser beam to the RF gun. The penetration is 3 inches by 4 inches and is about one foot above the floor. It is located underneath the 1 MW wave guide shown in Figure 1. An enlargement of Fig I for this area is provided in Figure II. The arrows in Fig. II show potentials sources for several penetrations. The 5-cell cavity is shadowed by the inner-shield wall and will not be considered as a source. Locations that represent the largest possible dose rates have been used for the analysis. The equivalent of two feet of heavy concrete will shadow the laser penetration from any radiation that could arrive directly from the potential sources. The two feet of heavy concrete provides attenuations from $1.5*10^{-2}$ to $3.2*10^{-4}$. Dose rates at the entrance to the laser port are given in the Table II below.

Table II: Laser port entrance Dose rates

Condition	**Distance (m)**	**Max. dose rate (rem/hr)**		**Routine Dose rate (rem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	0.06		0.002	
3.5 MeV e	4.3	1.4		0.014	
25 MeV e-90 degree	7.3	25.5	3.9	0.005	0.0008
25 MeV e-30 degree	12	420	1.4	0.08	0.0003

The radiation can also enter the laser penetration from the side wall after one or more reflections. The details of the area are not sufficiently complete to evaluate the attenuation at this time. The design of the shielding will ensure that the exit dose rate for radiation that circumvents the shielding will be less than the dose rate for the punch through contribution.

The approximate the attenuation of this penetration is $5*10^{-3}$ based on figures 2.25, 2.26, and 2.27 of Sullivan. The exit dose rates are given in the table below.

Table III: Laser port exit Dose rates

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (mrem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	0.3		0.01	
3.5 MeV e	4.3	1.2		0.01	
25 MeV e-90 degree	7.3	128	20	0.03	0.004
25 MeV e-30 degree	12	2100	1.4	0.4	0.001

There are several comments that are worth noting. The highest gamma dose rate does not come from the same location as the highest neutron dose. These cannot be added since this would

represent to beam losses at twice the maximum. Since one is looking for order of magnitude estimates it is not important to add these for a fault condition and the error will be smaller than the accuracy of the calculation. The routine dose rates are small and will not be presented throughout this note. The maximum dose rates can be scaled using Table I to obtain the routine/chronic dose rates. The chronic rates assume that the entire routine beam loss occurs at the worst possible location for the penetration being considered, which is an over estimate.

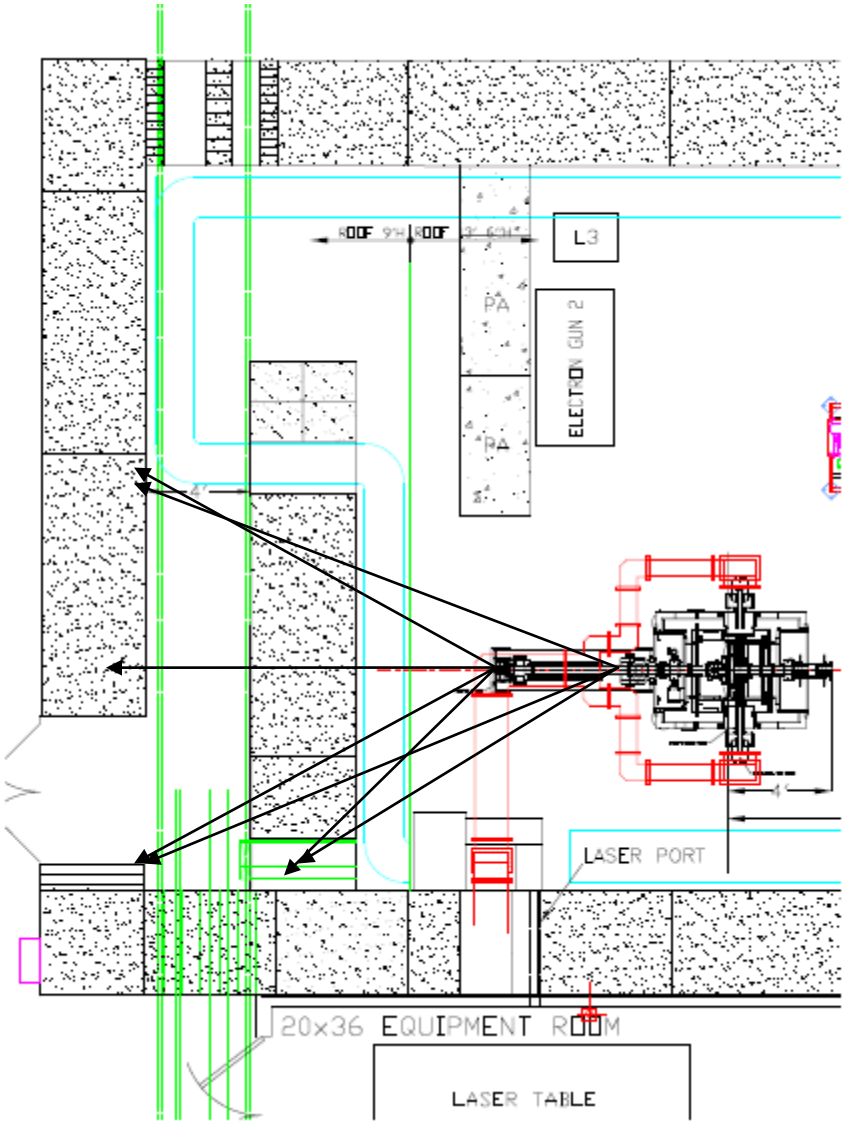

Figure II. Plan view of South section of ERL Area

I MW Waveguide Penetration

The penetration for the 1 MW waveguide is a two legged labyrinth. An elevation view is shown in Figure III. The cross sectional area of the first (second) leg is 2ftx2ft (1ftx2ft). The length of the first (second) leg is 2.9 ft (4 ft). The radiation has two pathways to get to the exit of the port. Two-foot thick heavy concrete shadows the opening in the main concrete shield wall from the x-ray and neutron sources. The gamma radiation can penetrate the heavy concrete and shine into the second leg. The attenuation factors are the same as those used for the laser penetration. The distance to the source will be assumed to be the same as the laser port at lower elevation, which means the entrance dose rates for radiation "punching-through" the heavy concrete is the same as the laser port. An attenuation factor of 0.1 for the hole in the shielding is used from reference 4. The exit dose rates for radiation punching through the heavy concrete are given in the Table IV below:

Table IV: 1 MW Waveguide Exit Dose Rates for punch-through

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (rem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	6		0.2	
3.5 MeV e	4.3	140		1.4	
25 MeV e-90 degree	7.3	2550	390	0.5	0.08
25 MeV e-30 degree	12	42,000	140	8	0.03

The contribution for the dose for neutrons propagating through the two-legged labyrinth can be estimated using the attenuation formulation of Goebel[5]. An approximate attenuation of $1.0*10^{-3}$ is obtained for the neutrons. The gamma attenuation is estimated using the reflection coefficients. An area for the first scatter of 20 ft^2 is used with a reflection coefficient of $3*10^{-3}$ and a distance of 5 feet. An area of $4ft^2$ is used for the second scatter along with a distance of 5 feet and a reflection coefficient of $3*10^{-2}$. A net attenuation of $1.2*10^{-5}$ is obtained for the gammas.

Table V: 1 MW Waveguide Exit Dose Rates –as Labyrinth

Condition	**Distance (m)**	**Max. dose rate (mrem/hr)**		**Routine Dose rate (mrem/hr)**	
		Gamma	Neutron	gamma	Neutron
RF Gun	3.3	2			
3.5 MeV e	4.3	5		0.05	
25 MeV e-90 degree	7.3	90	400	0.02	0.08
25 MeV e-30 degree	12	330	149	0.07	0.03

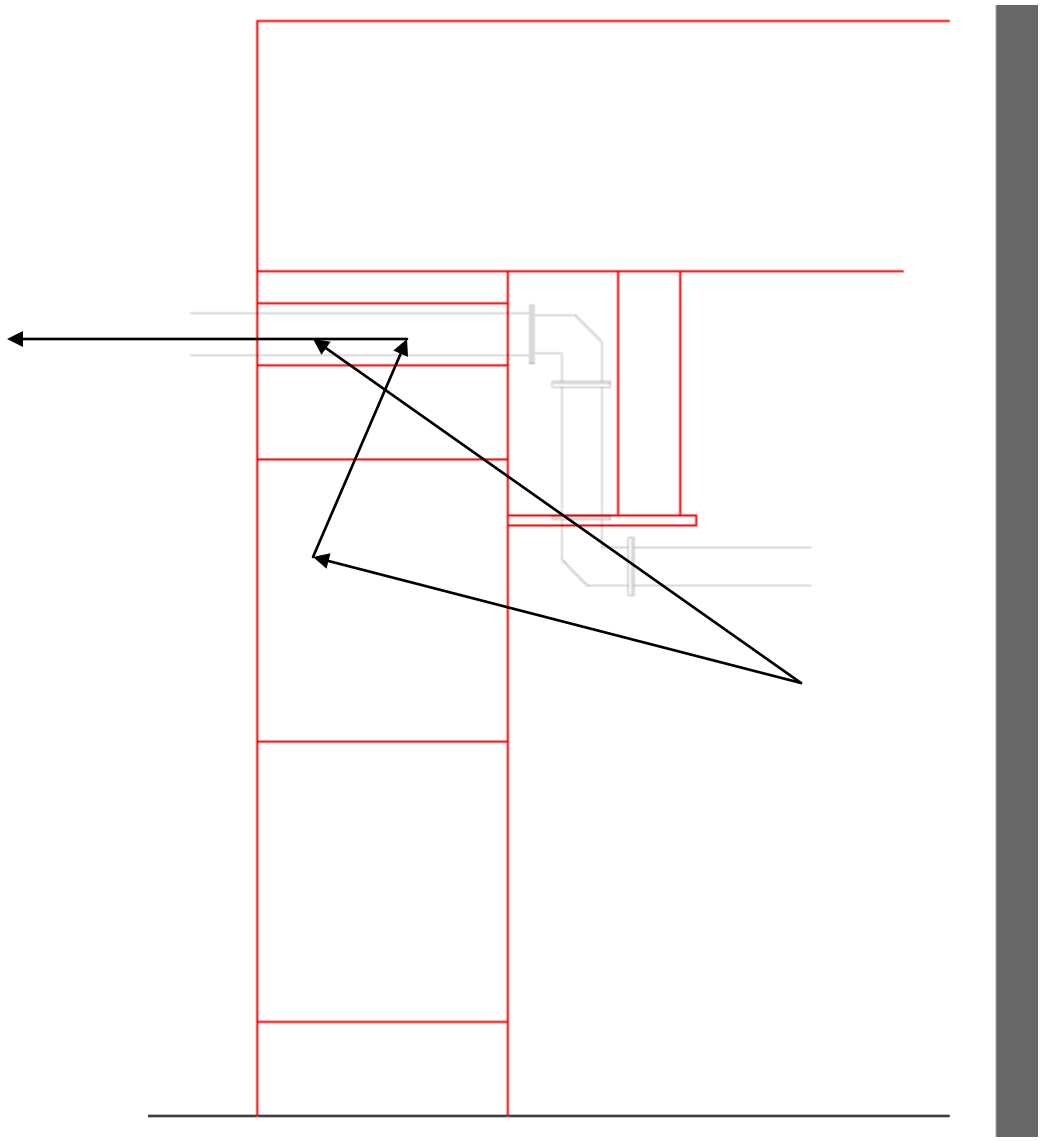

Figure III. 1 Megawatt Waveguide Penetration

Cryo Ports

Five 1ft by 1 ft penetrations exist at the top of the back wall for cryogenics. These ports are straight penetrations. The present plan is to close several of the port with packing block. They will be available in the future for use as utility ports if necessary. One port already has vacuum jacketed cryogenics piping in it. This pipe extends nearly to the adjacent building. Another port will be used for a vent, which will have an elbow immediately outside the shield wall. One port may be used for a few utility pipes and will be packed with shielding. Table VI shows the dose rates at exit of the ports assuming no packing, no shadow shields, and no credit for the shielding provided by the pipes:

Table VI: Cryo Ports Exit Dose Rates

Condition	Distance (m)	Max. dose rate (mrem/hr)		Routine Dose rate (mrem/hr)	
		Gamma	Neutron	gamma	Neutron
RF Gun	6.2	21,000 (470)		840 (19)	
5-cell cavity	6.2	21,000 (470)		840 (19)	
3.5 MeV e	6.2	84,000 (1900)		840 (19)	
25 MeV e-90 degree	3.2	3,800,000 (84,000)	200,000 (4400)	760 (17)	40 (0.9)
25 MeV e-30 degree	5.3	2,800,000 (63,000)	73,000 (160)	560 (12)	15 (0.3)

The worst cases were used for the estimates. The area between the shield wall and the EEBA building is intended to be a fenced area to keep personnel away from these ports. The edge of the building is seven feet away. If we assume the radiation exiting the hole is uniformly diffused over a cone of half-angle of 45 degrees then the radiation levels in the adjacent building will be a factor of 45 lower. **The numbers in parenthesis are the dose rates in the adjacent building** directly across from the port at a height of 12.5 feet.

The ports shall be modified to reduce the fault dose rates by a factor of at least 10. For a port using a steel shielding plate this requires 4 inches (10cm) of steel. For ports that are made smaller the area should be at least a factor of 9 smaller to reduce the radiation more than a factor of 10.

North Personnel Labyrinth

There are several aspects of this area that need to be considered. Figure IV shows a detail of the north labyrinth area. The north-west corner of the labyrinth has a buss block with penetrations to the outside. There is a cable port that acts as a short cut to the labyrinth about 10 feet from the gate. In addition the radiation that penetrates through the inner concrete wall then can enter the labyrinth close to the gate. In the final design the dump shielding shadows the gate entrance from the ring losses. Presently there is a two-foot thick iron shield in that location. Finally, the labyrinth can be treated as a four-legged labyrinth.

Direct radiation is shadowed from striking the buss block area. The near zero degree gamma radiation can arrive at the buss block area with two reflections. Using reflection coefficients the gamma dose would be expected to be reduced about $3*10^{-5}$ from that of the source at a meter. Using the penetration curves from Sullivan one would expect a reduction of another $3*10^{-3}$ for the radiation exiting the port. This gives a net reduction of 10^{-7}. **A beam loss of 50 kW at 25 MeV produces a gamma dose rate of 4 rem/hr**. The routine dose rate is expected to be less than 1 mrem/hr. This is not expected to be an issue. A chipmunk should limit the losses well below 50 kW anywhere in the 25 MeV ring and if desired the area outside the buss block can be

part of the exclusion area needed for the cryogenics penetrations that have been discussed earlier. **The neutron dose rate exiting the buss blocks is estimated to be 100 mrem/hr for a 50 kW beam loss close to the labyrinth opening**.

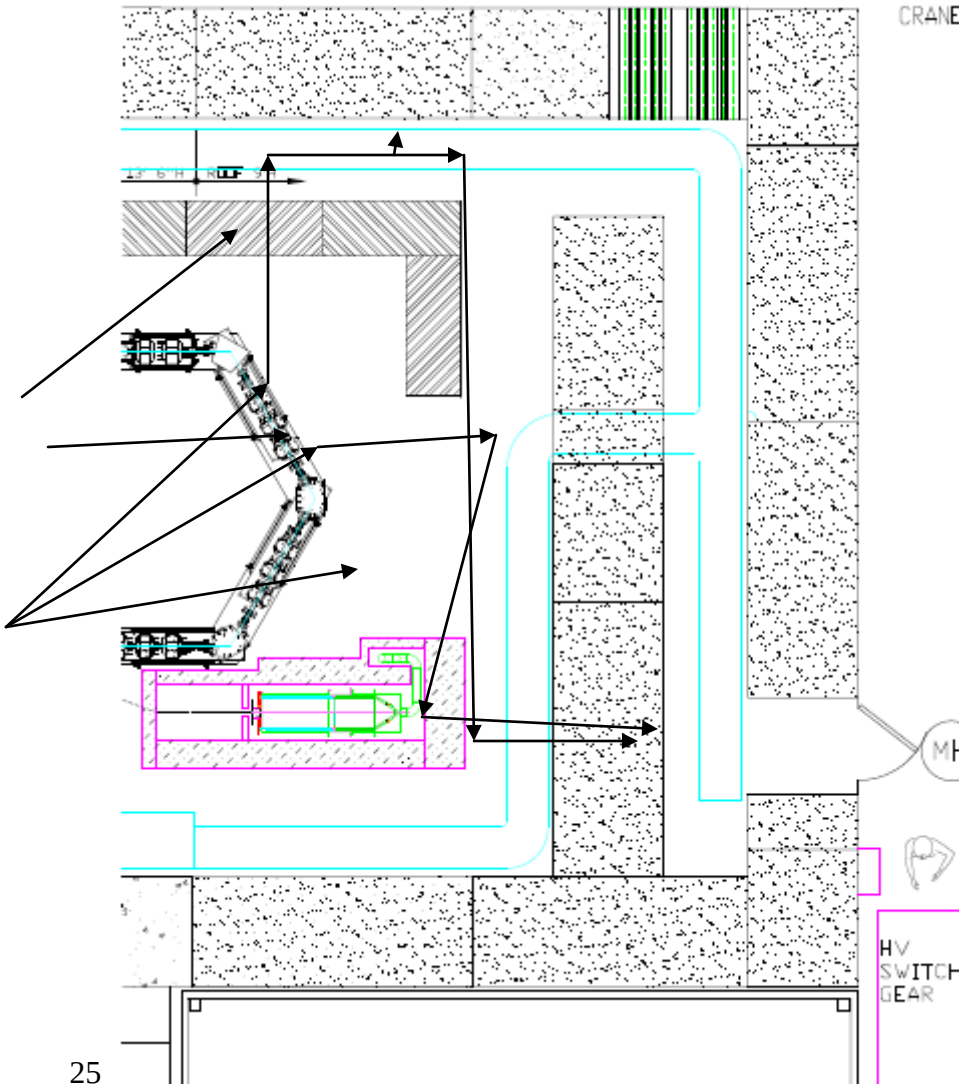

Figure IV. The Area of the North Personnel labyrinth

The radiation can also get to the ports in the buss block by penetrating the inner two-foot thick iron shield wall. The shield wall will provide an attenuation of $3*10^{-6}$ for forward gammas, ignoring the additional reduction due to the angle through the shield. The gamma dose is negligible when the port attenuation is taken into account. The reduction for neutrons, ignoring the angle through the steel, is $9.3*10^{-3}$. **The neutron-dose rate exiting the port would be 25 mrem/hr from this contribution**. In reality, the additional distance through the steel would reduce the neutrons another factor of ten.

The north labyrinth can be treated as a four-legged labyrinth using the formulation of reference 5 to obtain the dose rate for neutrons at the gate. The attenuation for neutrons is 10^{-5}. The neutron

entrance dose rate into the labyrinth is 75 rem/hr when a 50 kW beam loss occurs near the entrance. The **exit neutron dose rate at the gate is less than 1 mrem/hr for the 50 kW loss**. The routine loss is negligible.

The gamma and x-rays traveling through the labyrinth require at least 5 bounces to get to the exit gate. The maximum reflection coefficient[6] for 0.2 to 10 MeV gammas is .04. Using this fixed value for 5 bounces an attenuation of 10^{-7} is obtained without taking credit for the reduction due to distance. The zero degree gamma dose is very peaked in the forward direction. A crude estimate of $8.2*10^{5}$ rads/hr is used for the entrance dose averaged over the opening of the labyrinth. **The 50 kW beam loss produces an exit gamma dose of 80 mrem/hr at the gate.**

The zero-degree radiation can penetrate the shield wall to the west of the gate. The radiation would require two bounces to get to the gate. The peak dose rate penetrating the 4 feet of light concrete has about 1350 rads/hour for gammas 50 cm off axis of the zero beam[7]. Using an effective area of 28 ft^2 and the reflection coefficients a **gamma dose rate at the gate of 28 mrem/hr is obtained for a 25 MeV beam loss of 50kW.**

The neutrons penetrating the inner shield wall can be calculated using TVLs. A neutron dose rate of 2.7 rem/hr would exist at the light concrete wall. The transport to the gate can be estimated as a two legged labyrinth with an attenuation of $2*10^{-2}$. An additional factor for the source size to the width of the isle, about a factor of four, should be incorporated. This results in a **potential neutron dose rate at the gate of 250 mrem/hr neutrons for a 50 kW beam loss.**

Cable tray that penetrates the wall about 8 feet from the gate will allow neutrons and gammas to get to the gate without going through or around the inner shield. The dose is calculated at the exit the cable port and then transported using the two-legged labyrinth formula for neutrons and 2 bounces for gammas. **The dose rates at the gate are 1.8 rem/hr neutrons and 260 mrem/hr gamma for a 50 kW beam loss.**

The various paths of radiation for the same loss location to the gate are additive. The contribution of the cable tray penetration through the inner shield wall contributes the largest portion of the dose.

South Personnel Labyrinth

The south personnel and equipment labyrinth has pathways for radiation to reach the gate as well as penetrations from locations in the labyrinth to the outside. These will be examined similar to the north personnel labyrinth.

The labyrinth can be viewed as a four legged labyrinth. For neutrons the attenuation of the labyrinth is $3*10^{-5}$. The closest neutron source from a scraping loss produces a neutron-entrance dose of 342 rem. **The expected neutron-exit dose is 10 mrem/hr for a 50 kW beam loss.**

Photons can strike the shielding wall and then be reflected into the labyrinth. It takes a minimum or four bounces for the photons to reach the gates. The photon reduction is of the order of 10^{-8}

and even for a 50 kW beam loss the dose rates at the gate are well less than 1 mrem/hr. The maximum loss of the 3.5 MeV beam would create a few micro-rem/hr at the gate.

Photons and neutrons can punch through the wall behind L3 and reduce the effectiveness of the labyrinth. Using the results of reference 2 the photon dose at the light concrete is 336 rem/hr for a 50 kW beam loss. Two bounces are required to get the photons to the gate. The **photon dose rate at the gate is estimated to be 200 mrem/hr for a 50 kW beam loss.**

For neutrons the shield wall behind L3 was treated as heavy concrete with an attenuation factor of 45gm/cm^2. The neutron dose rate at the light concrete wall is 6 rem/hr. Using a labyrinth formula this will produce a few mrem/hr of neutrons at the gate for a 50kW beam loss.

Photons can travel over the shield wall near L3 and strike the roof transition. With two reflections the photons can be at the light concrete wall. The estimated dose rate via this path is **235 rem/hr at the light concrete wall**. This is similar to the number reached above and is additive. The cable tray can allow some neutrons to get to the light concrete with only one bounce. The estimated dose rate is 70 rem/hr at the light concrete wall. These contribute to the **photon-dose rate at the gate for a total of 400 mrem/hr.**

Neutrons can take a similar path and are expected to produce a few tens of mrem/hr at the gate.

Both neutrons and gammas rays can penetrate the concrete wall opposite the gate and then shine on the gate. The Table VII below lists the results of the dose rate estimates:

Table VII: Radiation Penetrating the Shield Wall opposite the Gate

source	**Dose rate mrem/hr Fault (routine)**
RF-gun	1.8
Gamma-3.5 MeV e	4.5 (0.5)
Gamma-25 MeV e; 90 degree	1,900 (0.4)
Gamma-25 MeV e; 30 degree	49,000 (10)
Neutron-25 MeV e	160 (0.03)

A shield block could be placed in the center of the e-ring to shadow this wall from the forward angle radiation and substantially reduce the potential dose. Since the results are conservative, it might be desired to wait for commissions and see if this area is an issue for operations.

The cable port opposite the gate is approximately 7 inches by 24 inches. It is shadowed with 24 inches of heavy concrete used to form the labyrinth for the 1 MW waveguide. The TVLs for the various particles and energies were used to reduce the radiation at the port entrance. An attenuation factor of 0.1 was used for the penetration. The dose rates at the gate are substantially smaller than the dose rate at the exit of the penetration. A factor of 0.1 was used and expected to be conservative. The ratio of the gate area to the cable port area is more than a factor of 50. The estimated dose rates at the gate are given in Table VIII below:

Table VIII: Radiation at the Gate from Nearby Cable Port

source	**Dose rate mrem/hr**

	Fault (routine)
RF-gun	0.4
Gamma-3.5 MeV e	0.9 (0.01)
Gamma-25 MeV e; 90 degree	960 (0.2)
Gamma-25 MeV e; 30 degree	2400 (0.5)
Neutron-25 MeV e	33 (0.007)

The cable port 10 feet from the gate is shadowed from all sources except the RF-gun and perhaps the 3.5 MeV electron losses near the RF-gun. X-rays of the level 34 rem/hr and 135 rem/hr can exit the cable port for the RF-gun and electron beam losses respectively. After two reflections these can contribute 1.6 mrem/hr (RF-gun) and 2.3 mrem/hr (3.5 MeV beam loss).

The south labyrinth has several penetrations that allow radiation to escape the shielding. There are two cable way penetrations on the west end of the labyrinth (see Fig. II). The larger hole is 11 inches by 17 inches and the smaller is 6 inches by 12 inches. Dose rate estimates for photons near the adjacent light concrete wall was previously estimated to total 600 rem/hr for a 50 kW beam loss at 25 MeV. An area of the wall (approx. 1ft by 8 ft) can shine out the hole with one bounce off the concrete wall. This would give an estimated 5 rem/hr at the exit of the hole. The 600 rem/hr also shines on the opening of the hole and will produce approximately 60 rem/hr at the exit. The numbers will be smaller for the other port. **A combination of access controls and shadow shielding are required to reduce the levels to acceptable levels**.

The photons can bounce into the trench and exit the shield wall on the west side. The 600 rem/hr would produce 6 rem/hr outside the shielding wall. **It is recommend that the trench be blocked as much as possible to reduce this dose.**

The photons can also bounce off the light concrete wall and exit the trench on the east side or through the buss block on the east side. The trench is estimated to have a phonon dose of rate of 2 rem/hr. The buss block holes would have a lower dose rate. **Again it is recommended that the trench be blocked as much as possible.**

ODH Port on the Roof

The roof over the beam dump and ring has a ventilation port. This port represents a large opening with dimensions of 2 feet by 4 feet. The port is constructed as a 3-legged labyrinth with a block shadowing the initial opening. The ODH port labyrinth is shown in Figure V.

The dose rate exiting the penetration should be compared to what is expected to penetrate directly through the four feet thick light concrete roof. Using the TVLs for light concrete we expect:

Table IX: Radiation Through 4 foot light concrete Roof

source	Dose rate through roof at max. fault

	condition (mrem/hr)
3.5 MeV RF Gun or Five-cell cavity	5
3.5 MeV e beam-photons	22
25 MeV e beam-photons	18,000
25 MeV e beam-neutrons	1,000

The neutron and gamma radiation can penetrate the 4 foot light concrete and then shine to the end of the labyrinth. These dose rates are lower than the adjacent roof since the shielding is the same thickness but the distance is greater and therefore is less than the adjacent roof given in Table IX.

The area under the air handling unit has a shielding path that is about 80 gm/cm^2 thinner. This would make the radiation levels 10 times higher than the adjacent roof if the extra distance is ignored. The dose rates would be of the order of 10 **rem/hr neutron and 180 rem/hr gamma**. This area is blocked by the air handling unit.

For neutrons the port can be treated as a three-legged labyrinth. The attenuation is approximately 10^{-3}. The **neutron dose rate for a 50 kW beam loss is 4 rem/hr**.

It requires a minimum of three bounces for gamma rays to exit the ODH port. Similar to above a fixed reflection coefficient of 0.04 for each bounce will be used. Ignoring distances and areas a **gamma dose rate of 10 rem/hr** is estimated.

Holes on Roof Created by Lifting Fixtures

There are four holes on the roof formed by the roof elevation transition and the lifting fixture for the roof beams. These holes are 4 feet long and are approximately 0.4 ft^2 in area. Personnel are excluded from the roof when the sources or machine operating.

Using the figures in Sullivan (figures 2.24-2.27) an attenuation of $5*10^{-2}$ will be used for both neutrons and photons. The exit will be blocked with the equivalent of 1 foot of light concrete.

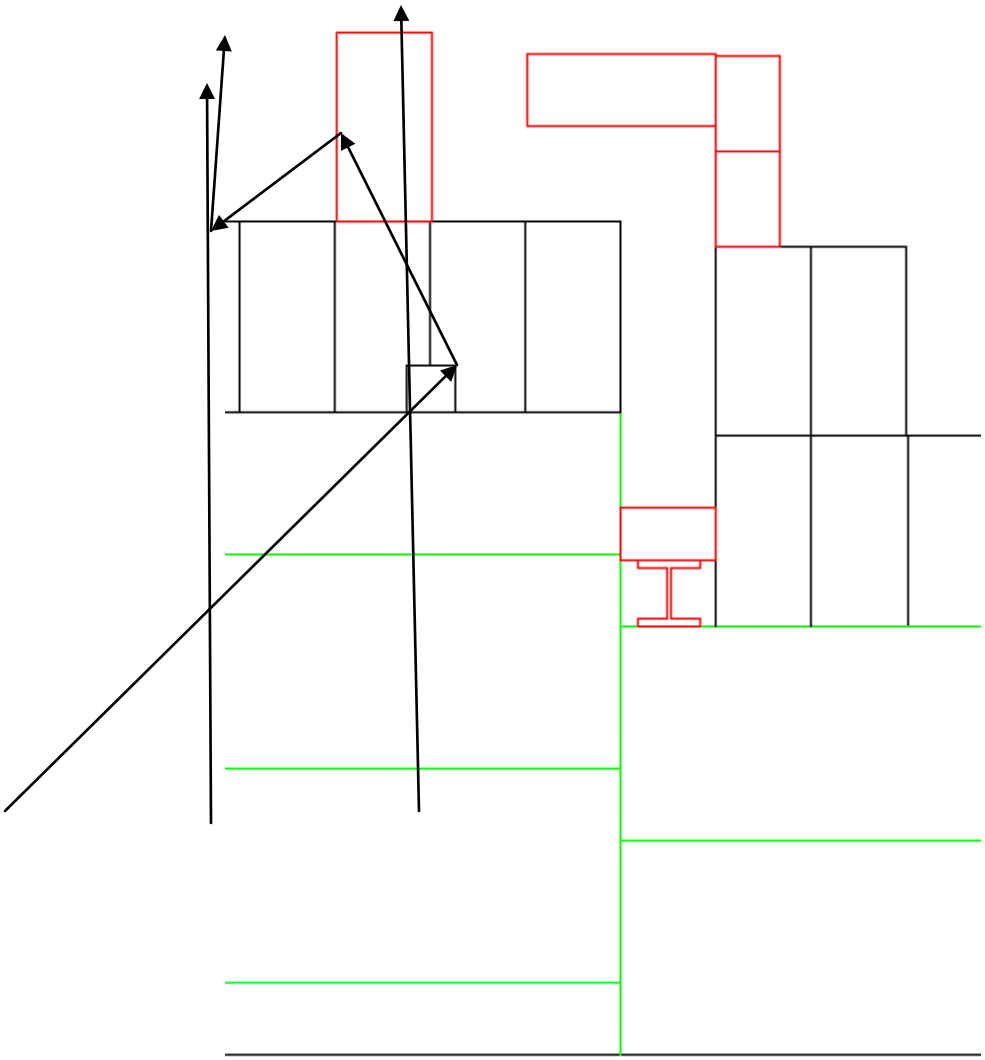

Figure V. Elevation View of ODH Port

This provides a reduction of 0.068 for low energy gammas and a reduction of 0.13 for high energy gammas and neutrons. The following results were obtained for worst case examples for the various sources and the holes:

Table X: Dose Rates at lifting Fixture Holes

Source	***Dose rate mrem/hr***	***Loss***
RF gun	520 (1)	2000 rads/hr at 1 m
3.5 MeV e	1,100 (2)	1 kW
25 MeV e; neutrons	3,800 (8)	50 kW
25 MeV e; gammas at 30 deg.	700,000 (1,400)	50 kW

The edge of the shield wall is at least eight feet away. The number in parenthesis is the expected dose rate at the shielding edge assuming that the radiation is uniformly distributed in a cone with a 45 degree opening half-angle.

Summary

Table XI provides a summary of the worst dose rates at each area for the gamma rays and neutrons. The maximum neutrons can come from a different source location than the gamma rays. If all cases the maximum gamma dose rates are from the 25 MeV electron beam losses.

XI: Maximum Penetration Dose Rates

penetration	**Max. Gamma Dose rate (mrem/hr)**	**Max. neutron Dose Rate (mrem/hr)**
Laser port	2,100	20
1 MW Waveguide	42,000	400
Cryo Ports (5)	8,400 [1]	2000 [1]
North Gate	260	1800
North Labyrinth Buss Block	4,000 [2]	100
South Gate	49,000 [3]	160
Port in South Labyrinth (2)	60,000 [4]	600 [5]
West Trench	6,000	100 [5]
East Trench	2,000	1,600 [5]
South labyrinth buss block	100	300 [5]
ODH Vent	10,000 [6]	4,000 [6]
Lifting Fixture holes (4)	1,400 [7]	8 [7]
50 kW waveguide	28,000 [8]	1,000 [8]

Comments:
[1] Assumes that steel has been used to reduce the gamma rays by a factor of 10.
[2] This is directly outside the buss block. This may be in a fenced area.
[3] A shield block in the ring center would substantially reduce this number, if desired.
[4] At port exit which may be in a fenced area. Port may be packed in the future. This value is for the port with the highest dose rate of the two ports.
[5] Not presented in text.
[6] This is on the roof and is not allowed to have personnel.
[7] Evaluated at the edge of the shielding and not on the roof.
[8] The penetrations for the cables ports, water pipes and the 50 kW waveguide are presented in another note (see reference 10). The dose rates presented here are at a height of 12 feet above the floor.

All the dose rates in Table XI are sufficiently low that with appropriately placed radiation monitors to terminate the beam on large beam losses the exposure to personnel will be less than 100 mrem in a fault. Several of the larger dose rates can be reduced and some suggestions have been made in the text. Many of the large dose rate estimates are most likely very conservative

and not expected to occur. The initial commissioning process at low currents will provide a check of the estimates.

The initial commissioning of the RF gun and five-cell cavity will provide an opportunity to examine the penetrations for x-rays at a much reduced level. One or two chipmunks are planned to be placed inside the shielded area to verify the source terms for the RF gun and five-cell cavity. The proposed test to run low intensity 25 MeV electrons into a flange at the north side before the ring is operational will also provide an early check on the shielding and penetrations.

There have been several suggested or assumptions to the shielding in this note. Table XII lists some of them for consideration:

XII: Suggestions for Penetrations

Area	**suggestion**
I MW Penetration	Check shielding meets assumptions
Laser penetration	Check shield meets assumptions
Cryo ports	Check shielding is added
Outside adjacent area to shielding	Define as radiation area
West side of shielding	Fence and lock when machine operational
South labyrinth penetrations on west side	Consider enclosing in locked area and adding shielding
Roof	Examine Roof access is properly prevented
Trench under shielding	Add some shielding to reduce dose rate and prevent access
South Gate	Consider block in center of ring to block forward radiation
Chipmunks-radiation monitors	Consider chipmunk locations to terminate large losses

References

1) D. Beavis," Simple Estimates of ERL radiation", August 9, 2008.
2) W.P. Swanson, Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Technical Report Series No. 188, IAEA, Vienna, 1979.
3) D. Beavis, "The effectiveness of a two-foot Thick Inner Concrete Wall", Dec. 11, 2006. See figure 1 of the note.
4) A.H. Sullivan, A guide to radiation Protection and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear technology Publishing, 1992. See figures 2.25, 2.26, and 2.27.
5) K. Goebel et. al., "Evaluating Dose Rates Due to neutron leakage Through the Access Tunnels of the SPS", CERN LABII-RA Note/75-10(1975).
6) NCRP Report No. 144, Radiation protection for Particle Accelerator Facilities, NCRP 2003. See figure 4.12
7) See reference 3 and the figure for the MCNPX calculation.

8) P.K. Job and W.R. Casey,“ Preliminary Radiological Considerations for the Design and Operation of NSLS II Storage Ring and Booster Synchrotron”, NSLS II Technical Note No. 13, July 25, 06.
9) The attenuation lengths for ion and heavy concrete given in reference 8 have been converted to TVLs.
10) D. Beavis, “Estimate of the Radiation Exiting Penetrations for the ERL 50 kW Waveguide, Cable Buss Block, and Water Pipes”, Dec. 6, 2006.