RSC Meeting on 5-23-18

Date: May 31, 2018

To: RSC, M. Palmer, M. Babzien, K. Kusche, C. Cullen, I. Pogorelsky

From: E. Lessard

Subject: ATF Laser Penetration


Summary of New ATF Laser Penetration

The ATF are proposing a penetration in the 18-inch concrete ceiling to the experimental Hall. The penetration is planned as a 10-inch by 10-inch square. It was discussed that this should be reduced to 9-inch by 9-inch if practicable. The upgraded 2 TW CO2 laser beam will be transported through this penetration from the adjacent laser room into a beam line in the Experimental Hall. See Figure 1. Also see Attachment 1 for more details on physical changes to the Experimental hall due to the new laser piping system. See Attachment 2 for correction to ceiling thickness.

Figure 1 Laser Penetration and Transport Line into Experimental Hall

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managed by Brookhaven Science Associates
Summary of Dose Rate Estimates at Laser Penetration

Relevant accelerator parameters from the Accelerator Safety Envelope upon which dose and dose rate estimates are based:

- 5 W and 85 MeV electron beam
- 5 W and 250 MeV electron beam

Details of 250 MeV beam and dose rate estimates are in Attachment 1. A result of the RSC discussion was to set a future RSC review for 250 MeV beam operations as this is not planned soon.

The 85 MeV electron beam will be directed into a lead beam stop by a bending magnet connected to a unipolar power supply. See Figure 2.

Figure 2 Electron Beam Side View

Equation 3.2 and Table 3.3 from Radiation and Radioactivity Levels near High Energy Particle Accelerators, A.H. Sullivan, Nuclear Technology Publishing, 1992 were the source for unshielded dose estimates. The results at the opening in the ceiling for 85 MeV electron beam hitting a thick target (beam stop) are:

- Neutrons – 0.56 rem/h at opening to penetration at 5 W normal operations
- Bremsstrahlung – 0.57 rem/h at opening to penetration at 5 W normal operations
To reduce the neutron fluence rate by about a factor 100, which reduces neutron dose at the ceiling penetration, as much as 15 inches of borated polyethylene shielding will be added to the top side and downstream side of the beam stop. Because of the re-entrant cavity in the lead stack and the downstream location of the ceiling penetration, the existing lead-brick shield is sufficient to attenuate Bremsstrahlung photons at the ceiling penetration by a factor of 10,000.

Unshielded Bremsstrahlung fault dose rate at the penetration opening due to electron beam going straight into the downstream wall rather than the beam stop, after failure of the bending magnet power supply, is about 5 times greater than the routine operating level, and neutron dose rate about 3 times greater. It was discussed that an ATF Control Room operator would quickly become aware of the bending-magnet power-supply failure from signals in the control room.

Access to Attic and Roof of Experimental Hall

Key access to the attic is through an attic hatch inside the ATF enclosure, which prevents access during beam operations due to gate interlocks. An inspection of the attic showed there is an awkward but possible access to the attic through the false ceiling in the adjacent laser room. It was discussed that a posting should be installed near the ceiling panels along the laser room wall adjacent to the Experimental Hall wall. They should indicate that one must contact the control room before going above the ceiling panels.

Access to ATF building 820 lower west roof, which is above the control room, is by vertical fixed ladder. Access to the Experimental Hall roof via the ladder, which is north of the lower west roof ladder, is posted and barricaded by RCD. Access to the Experimental Hall roof from the west, north and east walls is posted by RCD.

Possible Fault X-Rays Near Plasma Shutter

Relevant laser parameters for dose rate estimate:

- Laser pulse length: 2 ps
- Laser pulse energy: 4 J
- Laser pulse rep rate: 0.03 Hz
- X-ray energy / laser energy: 0.001
- Laser pulse power after upgrade: 2 TW

There are potential x-rays from the CO2 laser beam when focused above 3E14 W cm^-2. Studies show 70 to 400 keV x-rays can be produced if hitting a solid.\textsuperscript{1,2} An auxiliary YAG laser focused on the edge of a pin-hole induces a plasma that blocks CO2 laser beam and this plasma is used as a “shutter.” The CO2 laser beam is focused to 1E15 W cm^-2 at the pinhole between the 6-inch and 4 inch-mirrors. The CO2 laser beam could be misaligned and hit the pinhole edges; although diagnostics make missteering visible to the laser operator. See Figure 3.

\textsuperscript{1} Physical Review A Volume 32, Number 6 December 1985, Superhot-X-Ray and -Electron Transport in High-Intensity CO2-Laser-Plasma Interactions, G. D. Enright and N. H. Burnett

The plasma shutter is in a 6-mm steel-walled chamber. Steel has 2-mm and 9-mm dose-half-value layers for 70 keV and 400 keV x-rays, respectively. Based on References 1 and 2, it is estimated 0.13 R/h at 1 foot from high-energy x-rays (250 keV to 400 keV) can be created at the pinhole in a missteering event. Many assumptions go into this estimate and there is uncertainty in the estimate due to variations in laser-pulse shape and other factors such as the assumed shape of the temperature distribution. For example, the factor used to convert laser-pulse-energy to the energy of high-energy x-rays is variable due to the temperature distribution in the solid struck by the beam, and is assumed to be 0.001 in this calculation. However, best-fit data show 0.001 +50% and –30% for this factor. Thus,

- 4 J laser pulse x 0.001 x 0.03 Hz = 0.00012 J s\(^{-1}\)
- 0.00012 J s\(^{-1}\) = 7.5E11 keV s\(^{-1}\)
- Assuming all x-rays are 400 keV yields 1.9E9 photons s\(^{-1}\)
- Micro Shield yields 0.13 R/h at 1 foot assuming an unshielded 400 keV point source

Summary of RSC Action Items to be placed in C-AD Family ATS (Responsible Person)

1. Post signs to indicate workers “Contact ATF Control Room Before Going Above Ceiling Panels.” Suggest posting signs near ceiling panels along laser room wall adjacent to Experimental Hall. (K. Kusche)
2. Reduce laser penetration in ceiling from 10” square to 9” square if practicable (C. Cullen)
3. Add borated polyethylene blocks to floor-stop shield (K. Kusche)
4. Investigate x-rays at plasma shutter (K. Kusche, P. Bergh)
5. Require review by RSC prior to a 250 MeV experiment (M. Palmer)

Copy to:

T. Roser
D. Passarello
C. Hoffman
RSC Meeting

New ATF Penetration

E. Lessard, C. Cullen
5-23-18
ATF Penetration - Outline

- Layout of Penetration Relative to Dump
- ASE Parameters
- Unshielded Dose Rates
- Dose Rates at 5 W at Experimental Hall Opening to New Penetration
- Shielding and Access Issues
- Summary
5 Views - Electron Beam Stop, Laser Piping and Ceiling Penetration
Accelerator Safety Envelope

- Relevant ATF Credited Controls in ATF ASE
  - 2.1. For the Linac: the maximum electron beam power shall be limited to 5 Watts averaged over one hour. The maximum beam energy shall be 85 MeV.
  - 2.2. For the Experimental Hall: The maximum electron energy that the electron beam may be accelerated to is 250 MeV. The maximum electron beam power in the Experimental Hall shall be 5 Watts averaged over one hour.
Bremsstrahlung Absorbed Dose Rate From Electron Beam on Thick Target

<table>
<thead>
<tr>
<th>Angle</th>
<th>$\text{rad h}^{-1}/\text{kW at 1 m from source, 85 MeV beam}$</th>
<th>$\text{rad h}^{-1}/\text{kW at 1 m from source, 250 MeV beam}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^\circ$</td>
<td>2.5E6</td>
<td>4.3E6</td>
</tr>
<tr>
<td>$90^\circ$</td>
<td>2.9E3</td>
<td>5.0E3</td>
</tr>
<tr>
<td>$135^\circ$</td>
<td>1.6E3</td>
<td>2.7E3</td>
</tr>
<tr>
<td>$180^\circ$</td>
<td>1.0E3</td>
<td>1.8E3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Angle</th>
<th>For $5 \text{ Watts}, \text{rad h}^{-1} \text{ at 1 m}$</th>
<th>For $5 \text{ Watts}, \text{rad h}^{-1} \text{ at 1 m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1^\circ$</td>
<td>1.2E4</td>
<td>2.1E4</td>
</tr>
<tr>
<td>$90^\circ$</td>
<td>1.5E1</td>
<td>2.5E1</td>
</tr>
<tr>
<td>$135^\circ$</td>
<td>7.9E0</td>
<td>1.4E1</td>
</tr>
<tr>
<td>$180^\circ$</td>
<td>5.2E0</td>
<td>8.8E0</td>
</tr>
</tbody>
</table>

Shielding Modification

Attic

Existing block shielding, ~18” thick

New 10” square penetration

BL1 in EH

BL1 beam stop

No line of sight path from BL1 through penetration
Distance to Hole Opening – Routine Operations

Beam dump to start of shielding penetration

Beam dump to top of shielding penetration
Distance to Hole Opening – Fault

Shielding wall at BL height to ceiling penetration
# Photon Dose Equivalent, Routine Operations and Fault at 5 W

<table>
<thead>
<tr>
<th>rad/h at Mouth of Ceiling Penetration</th>
<th>Location</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.57 (routine)</td>
<td>180° at 3 m, 85 MeV</td>
<td>- Electron beam into floor routinely</td>
</tr>
<tr>
<td>0.98 (routine)</td>
<td>180° at 3 m, 250 MeV</td>
<td>- No attenuation assumed between floor and entrance to hole</td>
</tr>
<tr>
<td>2.7 (fault)</td>
<td>135° at 1.7 m, 85 MeV</td>
<td>- Electron fault is beam into wall or upstream floor for 250 MeV beam</td>
</tr>
<tr>
<td>4.7 (fault)</td>
<td>135° at 1.7 m, 250 MeV</td>
<td></td>
</tr>
</tbody>
</table>
Neutron Dose Equivalent at Mouth of New Penetration, Routine Operations and Fault

<table>
<thead>
<tr>
<th>rem/h at 1 m from Source at 5 W</th>
<th>Neutron Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&lt;25 MeV</td>
</tr>
<tr>
<td>&lt;0.08 (85 MeV beam)</td>
<td>&gt;25 MeV</td>
</tr>
<tr>
<td>&lt;0.4 (250 MeV beam)</td>
<td>&gt;25 MeV</td>
</tr>
<tr>
<td>negligible</td>
<td>Albedo from floor into penetration</td>
</tr>
</tbody>
</table>

- Neutrons < 25 MeV
  - 1000 rem h⁻¹ kW⁻¹ at 1 m (Sullivan, pages 78-81)
  - Isotropic
  - Dose rate is independent of electron energy
- Neutrons >25 MeV contribute little to dose rate at mouth of penetration
- Albedo is from <25 MeV neutrons hitting floor and bouncing 180° into penetration

<table>
<thead>
<tr>
<th>rem/h at 5 W, Routine Dose at Penetration</th>
<th>rem/h at 5 W, Fault Dose at Penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.56</td>
<td>1.7</td>
</tr>
</tbody>
</table>
## Shielding TLVs

<table>
<thead>
<tr>
<th>Shielding Material</th>
<th>Density, g cm$^{-3}$</th>
<th>TVL for Dose Equivalent, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete (SiO2)</td>
<td>2.35</td>
<td>19 (photons)</td>
</tr>
<tr>
<td>Concrete (SiO2)</td>
<td>2.35</td>
<td>16 (neutrons)</td>
</tr>
<tr>
<td>Lead</td>
<td>11.35</td>
<td>1.7 (photons)</td>
</tr>
<tr>
<td>Iron</td>
<td>7.86</td>
<td>4.3 (photons)</td>
</tr>
<tr>
<td>Borated polyethylene</td>
<td>1</td>
<td>7.6 (neutrons)</td>
</tr>
</tbody>
</table>
Summary of Issues

Unshielded Floor Dump

- Routine level of 1.1 rem/h (neutron plus photon) through penetration
- Attic level (~250 mrem/h)
- Roof level (~50 mrem/h)
- Skyshine level (~1E-3 to 1E-4 x roof level or 5 to 50 μrem/h)

Solution:

- Add neutron shielding to floor beam dump (15 inches borated poly = 1E-2 neutron dose attenuation)
- Ensure existing floor shield is sufficient for photons (existing 12 inches Pb = 1E-4 photon dose attenuation)
- Post signs to indicate Potential Radiation Area Above Ceiling – Contact ATF Control Room Before Entry. Suggest posting near ceiling tiles in room adjacent to Experimental Hall.
Summary of Issues Continued

- 250 MeV beam not sent to floor dump by dipole

- Add action item in ATS to remind ATF Director that increase from 85 MeV to 250 MeV for a specific experiment must be reviewed by RSC prior to experiment
Access Issues

- Key access through attic hatch inside Experimental Hall interlocked door - OK
- Awkward but possible access to attic through false ceiling in laser room – posting should fix this
- Access to B820 lower west roof (above control room) is by vertical fixed ladder. Access to the Experimental Hall roof via the ladder (to the north of the ladder) is posted/barricaded by RCD. Access to the EH roof from the west, north and east walls is posted by RCD.
Fault X-Rays Near Plasma Shutter

- Possible X-rays for CO2 beam focused > 3E14 W cm² (70 to 400 keV x-rays produced) if missteered
- Auxiliary YAG laser focused on edge of pin-hole induces a plasma that blocks CO2 laser; a “shutter”
- CO2 is focused to 1E15 W cm² at the pinhole between the 6 inch and 4 inch mirrors
- CO2 laser beam could be misaligned and hit pinhole edges; diagnostics make missteering visible
- Shutter is in 6 mm steel-walled chamber; 2 mm and 9 mm are HVLs for 70 and 400 keV X-rays
- Estimated 0.13 R/h at 1 foot if 0.001 laser pulse energy converted to high-energy x-ray energy at pinhole
Fault X-Rays Near Plasma Shutter

- Fault mode can be spotted in the 1\textsuperscript{st} shot, maximum 2\textsuperscript{nd} as CO\textsubscript{2} beam profile is observed with pyro-camera; accumulation over an hour unlikely
- 400 keV x-rays require similar electron temperature; Igor Pogorelsky thinks electron temperature in the laser focus is below 1 keV; there are special methods to accelerate electrons to MeV energies, but not under conditions of routine beam hitting of a solid material
- Efficiency of producing high-energy accelerated electrons by specially optimized methods is about 0.1\%
- Multiplying all these factors leads to estimates that may be $10^{-4}$ to $10^{-5}$ times less than 0.13 R/h
Summary

• RSC Recommendations
  • Reduce penetration from 10” square to 9” square
  • Add borated polyethylene blocks to floor dump shield
  • Add signage to laser room ceiling near penetration
  • Investigate X-rays at plasma shutter
  • Add ATS action item to remind ATF Director that review is required by RSC prior to 250 MeV experiment
ATF EH Shielding Update

Chris Cullen
May 31, 2018
One Shielding Modification is Required

Attic

New 10” square penetration

Existing block shielding, 11” thick

BL1 in EH

3D geometry submitted to the RSC for evaluation

BL1 90° dipole & beam stop

No line of sight path from BL1 through penetration