4. BACKGROUNDs

4.1 Synchrotron Radiation

There are two potential background sources of photons. Synchrotron radiation is present in any storage-ring facility. The critical energy of X rays produced by synchrotron radiation from bending magnets is ~ 1 keV (at 1 GeV). The X rays propagating toward the γ-ray vault are generated in the edge field of the bending magnet and have energies below 100 eV. These X rays are totally absorbed by the down-stream mirror of the OK-4 optical cavity and the flux of X rays with higher energy decreases exponentially and does not represent any background problem.

The other sources of soft-X-ray spontaneous radiation are the OK-4 wigglers, which generate high harmonics with energies up to 300 eV. These photons propagate in the same direction as the γ rays. Nevertheless, they are reduced by the downstream mirror of the OK-4 FEL by 5 to 7 orders of magnitude. Therefore, they also do not represent any background problems.

In addition, the energies for these photons are all less than a few keV and they can be easily filtered from the γ-ray beam.

4.2 Bremsstrahlung

The second source of background radiation originates from high-energy electrons interacting with residual atoms in the evacuated beam line. As the electrons pass the atoms, the positive nuclei accelerate and decelerate the electrons, causing them to radiate. Like synchrotron radiation, the bremsstrahlung intensity decreases exponentially with γQ. However, unlike synchrotron radiation, it is directed down the γ-ray beam axis and has energies comparable to the electron beam. A calculation (conservatively using Zvac =10) of the bremsstrahlung energy spectrum is shown in Figure 4.1 [RIN82]. The bremsstrahlung photon-production rate is linearly proportional to the beam current. The γ-ray beam flux is approximately proportional to the beam current to the 2.5 power.

Measurements of the bremsstrahlung flux in the DFELL storage ring were taken using a NaI detector positioned along the beam axis [LAY]. The experimental arrangement for the measurement is shown in Figure 4.2. Photon fluxes were measured for electron beam energies from 280-800 MeV. The resulting spectra were compared with a simulated model to verify that the observed photons were bremsstrahlung and not produced through some other mechanism. The simulated spectra were created by assuming an ideal bremsstrahlung spectrum and convoluting it with a simulated NaI response function. The simulated and measured spectra for Ee=400 MeV, as well as the measured spectra for Ee=600 and 800 MeV, are shown in Figure 4.3. The results of these tests totally confirm our expectations. The bremsstrahlung flux which will be present in the γ-ray beam on target will be of the order of 400 γ/sec, most of which is below 50 MeV. At an
electron scattering current of 10 mA, this background will contribute an intensity which will be about 0.1% of the total flux in the peak energy region. If more current becomes available, the relative background will be even less.

Table 4.1: Loss rates in percent for various material thicknesses for 20 MeV γ-rays.

<table>
<thead>
<tr>
<th>n</th>
<th>0.1</th>
<th>1.0</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.17 mm</td>
<td>1.7 mm</td>
<td>18 mm</td>
</tr>
<tr>
<td>SiO₂</td>
<td>0.20 mm</td>
<td>2.0 mm</td>
<td>21 mm</td>
</tr>
</tbody>
</table>

Figure 4.1. Bremsstrahlung background for a 10 mA electron beam current as a function of γ-ray energy.

Figure 4.2. Setup used for bremsstrahlung measurement using a 10"x10" NaI detector.

Figure 4.3. Simulated and measured bremsstrahlung flux for E_e=400, 600, and 800 MeV.
4.3 Other Sources of Background

The geometry of the DFELL-TUNL system requires the γ rays to penetrate several media between the interaction point and the target, all of which are potential sources of background. The γ rays must penetrate an aluminum or silicon dioxide mirror that forms part of the optical cavity for the FEL. The high vacuum of the storage ring will be separated from the lower vacuum of the target area by a beryllium window. Finally, the γ rays will interact with the lead collimator. In principle, scattering can occur in any of these media, reducing beam resolution and flux at the target.

To limit the fractional loss of the γ rays, the thickness of the mirror (t) must satisfy

\[ t \leq -\frac{\lambda}{\rho} \ln(1-n/100) \]

where \( \lambda \) is the attenuation length in g/cm², \( \rho \) is the density of the material in g/cm³, and \( n \) is the percentage loss. Since the attenuation length is longest for 20 MeV γ rays, we consider that case first. The thickness needed for various loss rates at 20 MeV are shown in Table 4.1.

To limit the fraction (T) of the γ rays passing through a lead collimator, it must have a thickness given by

\[ t \geq \frac{\lambda}{\rho} \ln\left(\frac{1}{T}\right) \]

The thicknesses required for ~20 MeV γ rays are shown in Table 4.2.

<table>
<thead>
<tr>
<th>T</th>
<th>0.1</th>
<th>0.01</th>
<th>0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>4 cm</td>
<td>8 cm</td>
<td>16 cm</td>
</tr>
</tbody>
</table>

A more detailed study of these results was performed for \( E_\gamma \) ranging from 20-224 MeV using the EGS4 code. The simulation conservatively assumed a 4 mm aluminum mirror, a 5 mm beryllium window, and a 45.7 cm lead collimator. As expected, the lead collimator was successful in preventing unwanted photons and charged particles from reaching the target to better than \( 10^{-4} \) background events per incident photon. The mirror and window did not have any significant effects on the flux which reached the target.

A small percentage of the γ-ray photons will strike the inner wall of the 1 mm collimator. The scattering of these photons, which account for \( 10^{-4} \) or fewer of the total incident photon flux, was simulated using the EGS4 code. Gamma-ray beams below about 50 MeV do not produce significant backgrounds at the target region. Incident γ rays of higher energy generate higher levels of background. Figure 4.4 shows the distribution of photons and e± at the target region for \( E_{\text{max}}=224 \) MeV γ rays. The overwhelming majority of scattered photons have energies well below
Approximately one fourth of the electrons and positrons generated have energies of 10 MeV or less, but the remainder are distributed fairly evenly between 10 MeV and $E_{\text{max}}$.

The $e^\pm$ background can be eliminated by employing a sweep field. The EGS4 simulation was modified to include a 20 kilo-gauss magnetic field 20 cm long located immediately downstream of the 1 mm collimator, followed by a 30 cm gap and an additional 10 cm thick, 1 cm radius collimator. Figure 4.5 shows the energy distribution of photons and $e^\pm$ that pass through the sweep field and the 1 cm radius hole in the second collimator for the case of 224 MeV $\gamma$ rays. The electron flux on target is reduced by two orders of magnitude from the background experienced without the field and collimator. Increasing the strength of the sweep field does not reduce this flux. This indicates that the few remaining electrons that do hit the target region, all of which have energies less than 2 MeV, result from photons scattered by the first collimator interacting with the second.

Although a negligible number of photons successfully penetrated the lead collimator, there was significant backscattering which, while not directly affecting the target region, would produce a significant background of photons and $e^\pm$ in the laboratory. The majority of these photons and $e^\pm$ have energies less than 4 MeV, as shown in Figure 4.6.

![Figure 4.4](image)

**Figure 4.4.** Photons and electrons reaching the target area as a result of scattering of 224 MeV photons from the inside wall of the collimator. The fluxes are presented as fractions of the total flux ($2 \times 10^8 \, \gamma/\text{sec}$) for this configuration. The histogram is divided into 25 MeV bins.
Photons and e\(^\pm\) reaching the target area as a result of scattering of 224 MeV photons from the inside wall of the collimator after passing through the sweep field and second collimator. The fluxes are presented as fractions of the total flux (2x10\(^8\) γ/sec) for this configuration. The histogram is divided into 25 MeV bins.

Figure 4.5.

Energy histogram for photons and e\(^\pm\) backscattered from the lead collimator. The histogram is divided into 1 MeV bins.

Figure 4.6.

4.4 Shielding Requirements

The present radiation shielding in the ring room and in the existing experimental area are adequate for the initial low-energy γ-ray experiments described in this proposal. Shielding considerations for the full-scale operation have been carefully considered in the design of the new HIGS target room (see Section 7.3). These studies indicate that, due to radiation generated during
the injection process, and as a result of electrons lost from the ring during \( \gamma \)-ray production, the present ring shielding wall will need to be raised by approximately 5 feet. Furthermore, local shielding at the site where the electrons leave the ring, in the area of the booster-injector, the injection channel, and in the areas where the \( \gamma \)-ray beam collimators are located, will be required.

The permanent solution for the shielding of the entire HIGS facility will include a concrete roof over the Duke storage ring.