Irradiation Plan for PbF_2 Blocks

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1 Introduction

We plan to irradiate PbF_2 blocks in the 100 MeV dump region of the JLab FEL, in order to test the proceedure for radiation damage curing by blue light illumination. JLab RadCon has given us a maximum radiation budget of 1 μA at 100 MeV in the dump area. This is a total beam power of 100 Watt. Radiation damage to PbF$_2$ is lilely a function of both total dose and dose rate. The criterion for the FEL tests is not necessarily to achieve the exact same does as for E07-007, but rather to achieve multiple cycles of 20% attenuation in light transmission (transverse through the block) followed by $\geq$ 95% recovery by blue light illumination.

1.1 Radiation Dose Estimates for E07-007 and E12-06-114.

In our proposal Pr07-007, we estimated the (peak) dose rate during E00-110 at 0.7 kRad/hr and the projected dose rate for E07-007 and E12-06-114 at approximately 5kRad/hr. A one week run will therefore acquire a cumulative dose of 840kRad, or 8.4 kGy. To test the radiation damage, we would like to accumulate this 7 day operational dose in 2 hours of FEL irradiation. Hence we require a maximum FEL irradiation rate of 420 kRad/hr = 4.2 kGy/hr = 1.2 Gy/sec = 1.2 Watt/kg.

1.2 Lead Fluoride

The physical properties of Lead Fluoride, PbF_2, are:

- Density: 7.77 g/cm^3;
- Refractive Index at 400 nm: 1.82;
- Radiation Length: 0.93 cm;
- Moli\‘ere Radius: 2.22 cm.

Our SICCAS blocks are $3 \times 3 \times 19.6$ cm^3, for a total mass of 1.37 kg/block. If the blocks are irradiated from their front face, the dose profile is not uniform. However, we assume that the energy spectrum of the degraded FEL beam will approximate that background flux from M\o oller electrons and inclusive π^0 decays *in situ* in Hall A. Therefore, for both the E07-007 configuration, and the FEL tests, we calculate effective dose rates as if the blocks were uniformly irradiated (longitudinally). Therefore, a 1.37 Joule radiation of one block is dose of 1.0 Gy.

The original Mainz radiation studies were performed with a Co-60 source intensity of $\leq$ 0.3 Gy/sec and a maximum dose of 7 kGy[1]. The heat capacity of lead is 100 J/(K·kg); those of NaF_2, SiO_2, and UO_2 are 1000, 796, and 240 J/(K·kg), respectively. In the range $T \in [360, 560]$ K, the α- and β-phases of lead fluoride have the following heat capacities [3]:

$$\alpha - PbF_2 : \; C_p = \left[70 + (12 \cdot 10^{-3} K^{-1})T \pm 1\right] \frac{J}{\mathrm{mol} \cdot K}$$

$$\beta - PbF_2 : \; C_p = \left[65 + (31 \cdot 10^{-3} K^{-1})T \pm 2\right] \frac{J}{\mathrm{mol} \cdot K}.$$

I believe we have the β-phase. Extrapolating to $T = 300K$, we have a heat capacity

$$C(300K) = [74 \pm 2]\,\frac{J}{\mathrm{mol}\cdot K} = 300\frac{J}{\mathrm{kg}\cdot K}$$

I assume a maximum safe heating rate of a block at $10^\circ K/\mathrm{hr}$ [2]. Then the maximum irradiation rate is 1.1 Watt/block, or 0.8 Gy/sec. Hence the dose rate of 1.2 Gy/sec to achieve 8.4kGy in 2 hours is probably close to the maximum safe exposure rate (or may even damage the blocks from thermal stress)

1.3 FEL Requirements

At this time, it is not clear how low in intensity the FEL can deliver stable beam. However, based on a conversation with G. Krafft, as long as we are not concerned with peak current, the FEL can probably deliver as low an average current as we ask for.

We require a dose in each block of 1.2 Gy/sec (or lower). This implies a beam power incident on each block of 1.6 Watt. The quoted "standard FEL" conditions (K. Jordan and G. Williams) are

- Beam Energy 115 MeV
- Beam macro pulse of 250μs at 2 Hz.
- 4 MHz micropulse rep rate at 135 pC per micro pulse.
- Peak current averaged over 250 μs is 500 μA.
- Average (DC) current is 250 nA.
- Total Beam Power is 29 Watt.
- The beam can be rastered to up to 1 cm total dimension.

2 Irradiation Plan

A Cu radiator (X_0 =12.86 g/cm^2, density = 8.96 g/cm^3, minimum ionizing = 1.4 MeV·cm^2/g) can diffuse the beam. For a thin radiator, we can use a gaussian multiple scattering approximation to estimate the doses in each block. For a thick radiator, we should use a GEANT simulation. Since the blocks will not all respond identically to the irradiation, and we do not know the exact dose to achieve a 20% transmission attenuation, it is useful to simultaneously expose several blocks to varying doses. At the same time, it is useful if the variation in dose across the face of each block is not too large (although the shower formation in the block will tend to equalize the dose internally to the block). The blocks themselves act as secondary diffusers. A 10% Cu radiator, at the exit to the beam line, will diffuse the 100 MeV primary electron beam with a (plane projected) rms angle of

$$\theta_0 = \frac{13.6\,\mathrm{MeV/c}}{p\beta}\sqrt{\frac{X}{X_0}} = 0.04\,\mathrm{rad}.$$

If the blocks are at 40 cm from the radiator, the one-σ cone has a radius of 1.6 cm. From the total incident beam power of 29 Watt, a block centered at 0° will receive a dose rate of 10 Gy/sec and a block immediately to the side will receive a dose of 2 Gy/sec. If the radiator thickness is increased to 20%, then the dose rates change to 7 and 2.3 Gy/sec, respectively. The exact configuration of blocks and radiator can be optimized in the next few weeks. It should be possible to optain a configuration in which 3 or 4 set of blocks are irradiated at once, with typical dose ratios of a factor of 3, and with a maximum dose rate in the range 2 – 10 Gy/hr.

References

[1] P. Achenbach *et al., Nucl Inst Meth A* **416**, 357 (1998).

[2] S. Nanda, private communication, estimate of heating rate during attachment of brass brackets

[3] L.M. Volodkovich, *et al.*, *Thermochimica Acta* **88**, 497–500 (1985).