RADIATION MEASUREMENTS AT THE ADVANCED PHOTON SOURCE (APS) LINEAR ACCELERATOR*

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Abstract

The injector and source of particles for the Advanced Photon Source is a 2856-MHz, S-band, electron-positron linear accelerator (linac) [1]. It produces electrons with energies up to 650 MeV or positrons with energies up to 450 MeV. Radiation measurements were made during normal electron and positron operation, as well as during several beam loss scenarios. Neutron and gamma measurements made outside the shielding walls during normal operation are within DOE guidelines. Measured radiation fields are compared to predicted levels for different conditions.

I. INTRODUCTION

The design goal of the APS electron linac is to accelerate 1.7 A of electrons in 30-nsec-long pulses to an energy of at least 200 MeV at a rate of 48 pps. The electrons are then focused to a 3-mm-diameter spot on the tungsten target that serves as a positron converter. To date, 1.4 A of electrons have been accelerated to 225 MeV at a 30-Hz rate, and focused to a ≈ 5-mm-diameter spot on the target.

The linac is housed inside a concrete-shielded enclosure that protects personnel in nearby areas, including the adjacent klystron gallery, from radiation during linac operation. The linac shielded enclosure is constructed of concrete that is 2 m thick along the entire length between the linac and the klystron gallery. The shield is modified in the vicinity of the positron target, where 0.4-m-thick steel plates are embedded within 1.6-m-thick concrete to further reduce photon radiation levels in the klystron gallery. Calculated unshielded x-ray dose rates inside the linac tunnel 1 m downstream of the positron target are as high as 7 x 10^9 mrem/hr [2,3]. Unshielded neutron dose rates are on the order of 10^6 mrem/hr.

Measurements of radiation from the target were made in normally occupied areas of the klystron gallery using gamma and neutron instruments. The measured data are compared to computations of the estimated radiation leakage at the nominal and the maximum (safety envelope) operating power. The rationale for defining the safety envelope in terms of beam power is that within the APS linac's energy range, production yields of secondary radiation including positrons, neutrons, and gamma rays are proportional to the beam power. Measurements during some types of beam missteering incidents were performed at low power. In addition, the radiation leakage fields at shield-wall penetrations for waveguide, cable tray, and pipe passages were measured. Additional shielding was added where necessary.

II. MEASUREMENTS

A Victoreen 450P ion chamber survey meter [4] was used for the gamma measurements. The pulse response of this meter was checked by measurements made at the Argonne National Laboratory (ANL) 21-MeV electron linac. Neutron measurements were made with an Andersson-Braun type moderator and a BF_3 tube, supplied by Nuclear Research Corporation [5]. The response of this instrument to pulsed fields was also checked at the ANL linac. Although this device begins to show saturation at 1 μrem/pulse, it is adequate for these 30-Hz measurements.

Measurements were made every 1 m along the entire length of the klystron gallery, along a line offset 6 m from the beamline, as shown in Figure 1. This line represents the closest distance to the beamline in normally occupied regions of the gallery. In order to separate radiation caused by the target from possible contributions from the klystron waveguides and optical arc- detector ports, the measurements were made in two steps. First, radiation fields were measured with both the beam and the rf on, under conditions that resulted in 225 W of beam power on the target. The beam was then stopped by turning off the electron gun, but the rf power was left on. The radiation measurements were then repeated. The difference between the two sets of measurements represents the contribution from the target, and is shown in Figure 2.

Because of the low levels of leakage radiation from the target, the data are somewhat sensitive to x-ray interference from the klystron waveguides. The small negative values in the difference plot in Figure 2 are the result of such interference. The dose rates shown in Figure 2 are photon radiation dose rates, since neutron levels are still below the 10 μrem/hr detection limit of the instrument. Additional lead shielding is being installed to mitigate localized x-ray radiation from the klystron waveguides.

Measurements of radiation fields during missteerings to simulate accident conditions have not yet produced any readings that can becompared with predicted values for the postulated maximum credible incident (MCI).

Measurements inside the penetrations have shown photon levels in the few mrem/hr range and neutron levels in the tenths of mrem/hr range, except for the penetration nearest the target. The higher radiation levels measured at that penetration have been mitigated by the addition of lead and polyethylene shielding.

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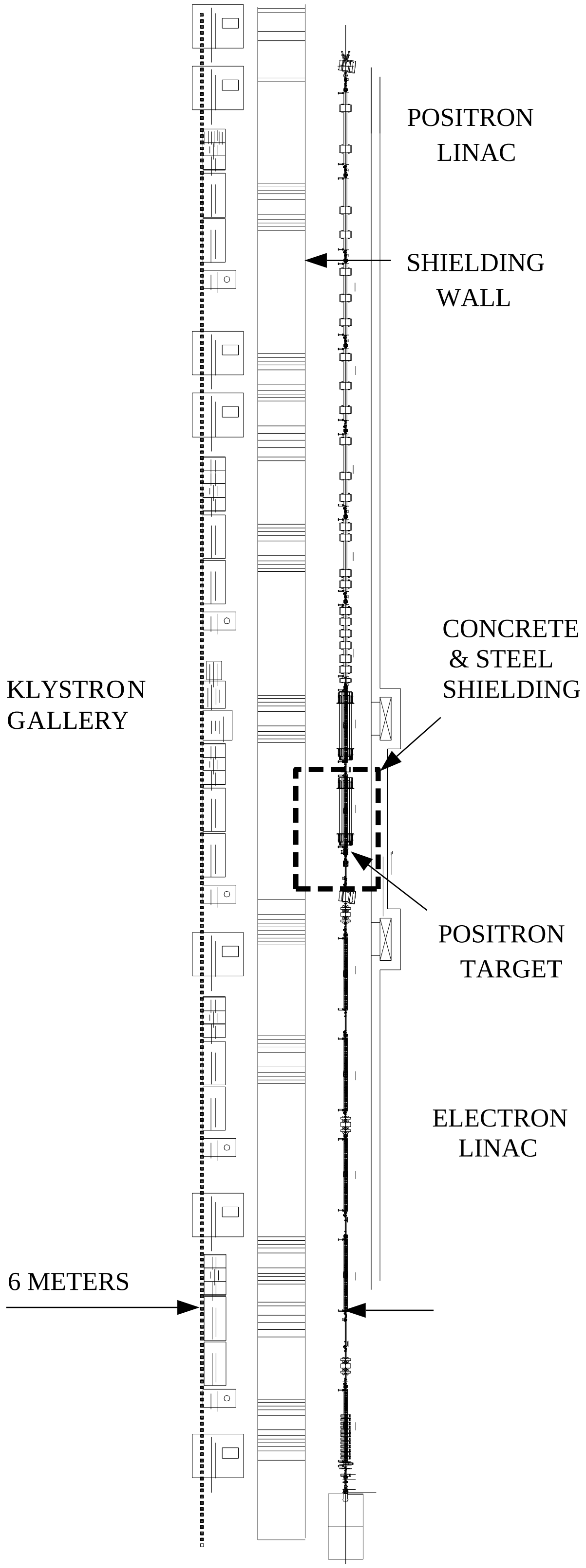

Figure 1: Radiation measurements were made in the klystron gallery along a line offset 6 m from the beamline.

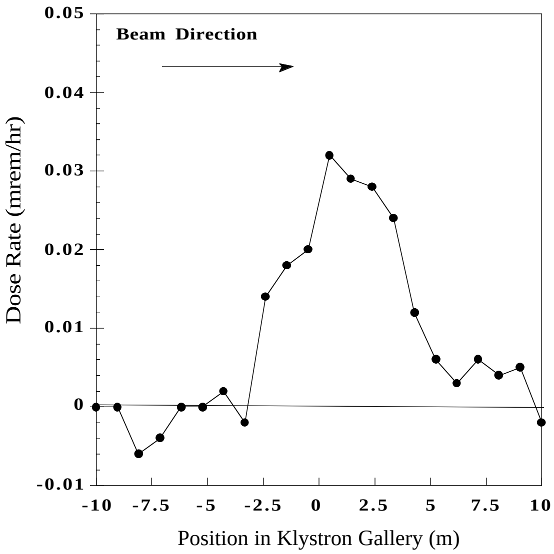

Figure 2: Measured radiation field in the klystron gallery as a result of 225 W of beam power on the target. The difference between the "Beam On" field and the "Beam Off" field is plotted.

III. CALCULATION

The predicted total leakage radiation levels from the target [6] for nominal 480-W operation and operation at the safety envelope (1000 W) are shown in Figure 3.

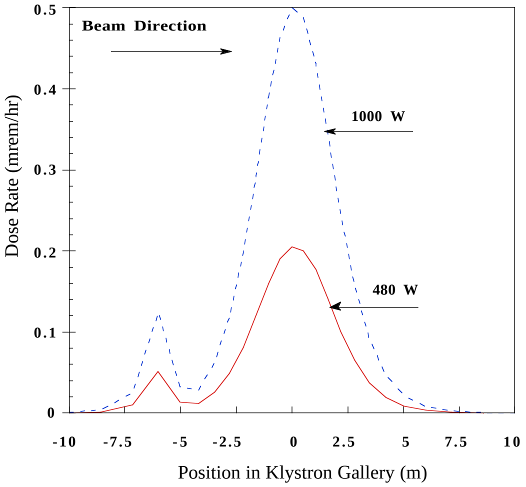

Figure 3: Predicted radiation fields in the klystron gallery at locations comparable to those in Figure 2. The lower curve is at the nominal operating power of 480 W, and the upper curve is at the safety envelope power level of 1 kW.

The maximum predicted dose rate values are 0.21 mrem/hr and 0.5 mrem/hr, respectively. Calculations for the bremsstrahlung dose distribution with angle are based upon the semi-empirical formula of Swanson [7]. The neutron yield and neutron angular distributions are based on the calculations of Gabriel and Alsmiller [8]. Neutron fluence-to-dose conversion constants were obtained from ICRP Publication 51 [9]. Self-shielding provided by the accelerating structures and magnets was not taken into account in these calculations. The peak dose rate occurs at a point adjacent to the target. The small structure in the calculated curve reflects the change in total shielding ability between that portion of the linac shield wall that is constructed only of concrete and the portion with additional steel embedded in the concrete.

IV. RESULTS

Comparing the predicted peak total dose rate of 0.21 mrem/hr for 480-W operation from Figure 3 to the measured peak total dose rate of 0.033 mrem/hr from Figure 2 and normalizing to the same operating power as in Figure 3, indicates a ratio of $\frac{0.21}{0.033 \times 480/225}$ ~ 3. Using the peak value at the safety envelope, the ratio would become $\frac{0.5}{0.033 \times 1000/225} = 3.4$. This result indicates that the DOE design criterion for new facilities that requires dose rates outside of shielded areas to be less than 0.25 mrem/hr would be met, even at the safety envelope, with no additional mitigation. That the detailed structure predicted by the calculation was not measured can be attributed to masking effects by interference from the x-ray radiation from the klystron waveguides.

V. CONCLUSION

The results obtained in this study indicate that the linac shielding is adequate for operation up to the safety envelope and is in compliance with DOE guidelines. Beam power has been limited thus far by equipment conditioning, and measurements will be made at higher power levels as soon as possible. At the higher levels, the neutron radiation may make a contribution. Beam missteering tests at higher power might possibly also give dose rate data that can be extrapolated to the MCI conditions. At the low dose rates seen in these measurements, great care must be taken to exclude extraneous radiation fields in order to obtain representative results.

VI. REFERENCES

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