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The photoneutron yield predictions by PICA and comparison with the measurements

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Introduction

The photoneutron yields at higher photon energies have become very important since the advent of high energy electron accelerators [1,2]. Bremsstrahlung is produced when the particle beam interacts with the storage-ring components or residual-gas molecules in the storage-ring vacuum. Bremsstrahlung thus produced interacts with the high-Z materials in the beamline like the beam dumps and collimators to produce photoneutrons. There are three modes of neutron production by bremsstrahlung. At low energies (≤25MeV), photons are absorbed by the dipole interaction and the compound nucleus thus formed decays emitting protons and neutrons and other heavier particles. At higher energies (≥25MeV), photon interacts with the nucleus through absorption on a quasi-deuteron, which subsequently decays producing a neutron and proton pair which can interact with the rest of the nucleus. At still higher energies the photopion production becomes possible and competes with the quasi-deuteron process. In this paper we have calculated the photoneutron yield from a thick copper target using the photonuclear interaction code PICA[3]. Using this as the neutron source, we have calculated the dose rates through heavy concrete and compared it with the measurements[4] made at the Advanced Photon Source at Argonne National Lab.

PICA Photonuclear Interaction Code

PICA calculates the results of nuclear reaction caused by the collision of the photons with the nuclei[5]. PICA can do these calculations for incident mono-energetic photons as well as for bremsstrahlung spectra. For the dipole interaction the available cross sections are used [6]. The higher energy interaction cross sections are derived from the quasi-deuteron model of Levinger[7]. This is the photoabsorption by a neutron- proton pair. For photons above the pion threshold photon -pion production on nucleons is allowed to compete with the quasi-deuteron absorption process. The effect of the secondary nucleon- nucleus and pion-nucleus interactions following the photon absorption is calculated by the intranuclear cascade concept[8]. Each particle involved in the collision is traced through the nucleus using the appropriate particle-particle cross sections until the particle escapes or is captured by the nucleus. In all parts of the calculation, the fermi momentum of the struck particle, the exclusion principle and the nonuniform density distribution of the nucleus are taken into account. After the cascade process is complete, the nucleus is in an excited state and the excitation energy is

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dissipated through particle emission. The de-excitation of the nucleus is handled by the evaporation model[8].

Geometry used for the simulation

Figures 1 and 2 give the schematic and the simulated geometry for the PICA calculations. The particle beam during injection at the Advanced Photon Source can be partially or fully lost in one of the transition regions between the storage ring vacuum chamber and the insertion device straight section. The transition piece is a copper interface between the two vacuum chambers. The 56 cm thick high density concrete ratchet wall is located 164 cm from the transition piece. The photon track lengths from the electromagnetic shower, when the injected particle beam is fully lost on the transition piece, were calculated by EGS4[9]. The neutron yield from these photon track lengths was then calculated by PICA. These neutrons were transported by the one dimensional ANISN code using the 400 MeV HILO86 cross section library to estimate the photon and neutron dose rates outside the ratchet wall. The results are given in Table I.

Measurements

Radiation survey measurements were conducted outside the ratchet wall, while injected beam was being lost at one of the transition pieces. The primary objective of this was to study two potential beam loss scenarios, although some other measurements were also accomplished. First of all one of the corrector magnets adjacent to the transition piece was used at full strength to deflect the particle beam into the transition piece. Secondly, the beam was directed onto the closed gate valve which is just upstream of the transition piece. In both cases data was collected for 10 minutes while the charge entering the storage ring through the beamline transfer section was integrated. Prior to taking the data, the injection was tuned by the operating personnel to insure minimum loss between the booster transport system current monitor and the intended loss point.

The radiation survey instruments used for these measurements were a Victoreen 450P ionization chamber for gamma radiation and an Eberline ASP-1 electronics package with a HP 2080 (Albatross) in the integral mode for neutrons. Prior to the commencement of the data taking, a survey determined the location of the maximum dose point along the length of the ratchet wall. Neutron monitors were placed at that location and at three other locations along the ratchet wall and a 5 minute count was taken in the integral mode. The gamma dose rate at the maximum dose location and the neutron dose rate at 90^0 from the transition piece are given in Table I, along with the PICA predictions.

Table 1. Dose rates due to beam loss at the insertion device transition region during injection into the storage ring.

	Charge[a] /pulse	No. of e^- / sec	Dose Rates (mrem/h)	
			Neutron	Gamma
Expt. 1	1.1 nC	6.87×10^9	26.4	1.5
Expt. 2	1.1 nC	6.87×10^9	39.6	1.1
PICA/ANISN	1.1 nC	6.87×10^9	55.0	1.0

a Injection rate is 1 Hz

Results and Discussion

The PICA simulation shows reasonable agreement with the measurements. The possible errors in this study are the beam loss scenario and the response of the neutron detectors to the high energy neutron radiation. The photoneutron yield from the transition piece depends on the shower development in the transition piece. Depending on the shower containment, this quantity and the resultant dose may vary at the most by a factor of three. For the present calculations we have assumed that only one-third of the electromagnetic shower is contained in the transition piece. The gamma dose rates outside the ratchet wall are negligible. This is attributed to the incomplete development of the electromagnetic shower in the copper transition piece (which is a maximum of 4 cm thick) so that much of the radiation is forward peaked and contributes to a resultant shower downstream. This also explains slightly elevated readings of the gamma dose rates at approximately 450 cm downstream of the transition piece on the ratchet wall. When incident on the ratchet wall, the shower encounters a much larger effective concrete thickness because of the shallow incidence angle. It can be seen from figure 1 that the slant thickness of concrete, downstream of the transition piece, is much large compared to the real thickness of 56 cm. The increased gamma attenuation through the slant thickness of concrete accounts for low gamma radiation levels outside the ratchet wall.

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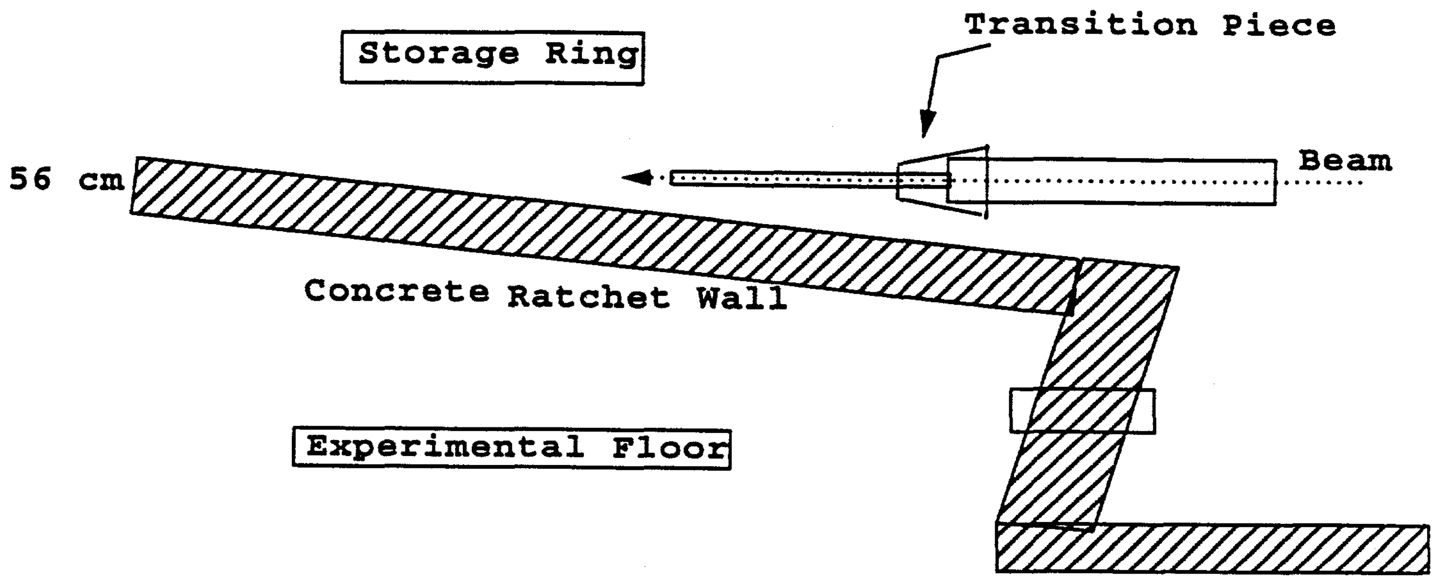

Figure 1 Beam Loss Cofiguration

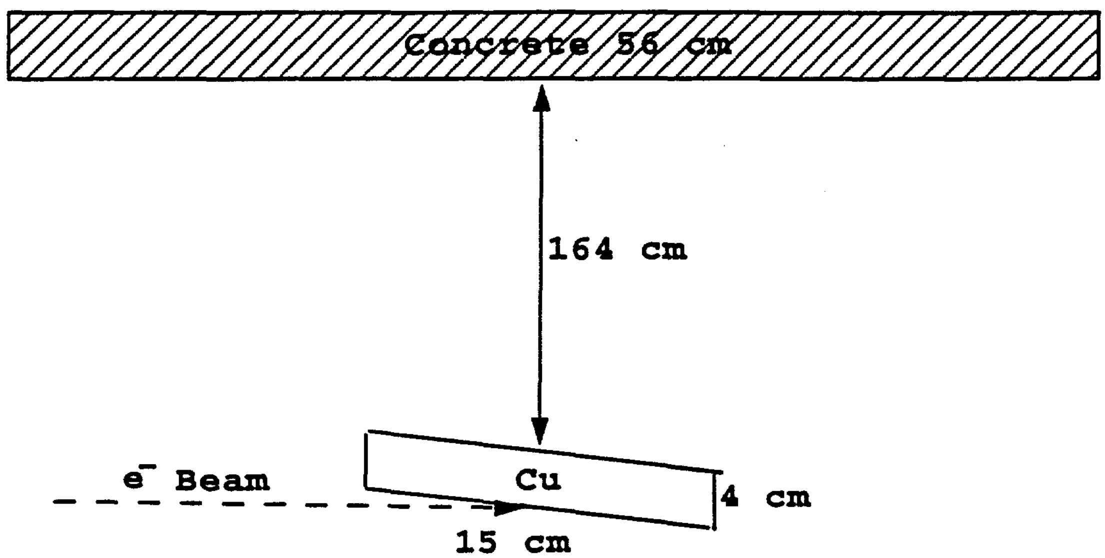

Figure 2. Geometry Used for PICA Simulation