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Radiation Levels Experienced by the Insertion Devices of the Third-Generation Synchrotron Radiation Sources

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Abstract

Third-generation synchrotron radiation sources like the Advanced Photon Source (APS) use insertion devices made of Nd-Fe-B permanent magnets to produce x-rays for scientific research. The concern of radiation-induced demagnetization of these insertion devices spurred a project aimed to measure and analyze the radiation levels experienced by these insertion devices during the operation of synchrotron radiation sources. The project required a reliable photon high-dose dosimetry technique capable of measuring high integrated dose levels during one operational cycle. Radiachromic dosimeters were considered for this purpose. In collaboration with the National Institute of Standards and Technology (NIST) these dosimeters were tested, calibrated, and used at the Advanced Photon Source. Prior to each run radiachromic dosimeters are placed on the upstream and downstream edges of the 2.5-m-long insertion devices. Following each operational cycle these dosimeters are retrieved from the storage ring and optical density changes are analyzed. The measurements are compared with previous estimates. The results show that the previous predictions grossly underestimate the radiation levels received by the insertion devices.

Introduction

The Advanced Photon Source (APS) uses Nd-Fe-B permanent magnets in the insertion devices to produce x-rays [1,2]. Earlier investigations have exhibited varying degrees of demagnetization of these magnets [3] due to irradiation from electron beams [4,5,6], ^{60}Co γ-rays [5], and neutrons [7,8]. A growing concern for the APS insertion devices, as well as the permanent magnets that will be used in next-generation high-power light sources, resulted from the radiachromic dosimeter measurements and also from the partial demagnetization observed in some of the devices at the European Synchrotron Radiation Facility [4,6]. This concern in relation to radiation-induced demagnetization spurred a long-term project aimed to measure and analyze the total absorbed doses received by the APS insertion devices. The project required a reliable photon high-dose dosimetry technique capable of measuring absorbed doses greater than 10^6 rad, which was not readily available at the APS. In collaboration with the National Institute of Standards and Technology (NIST), one such technique using radiachromic dosimeters was considered, tested, and calibrated at the APS. This consequently led to the implementation of radiachromic dosimeters as the technique of choice for measuring the total absorbed doses received by the insertion devices for each of the APS runs.

Dose Measurements with Radiachromic Dosimeters

Radiachromic dosimeters are nylon-based aminotriphenyl methane dye derivatives [9,10]. Upon exposure to ultraviolet light or ionizing radiation, these films undergo radiation-induced coloration by photoionization [9,11]. The change from a clear or colorless state to a deep-blue-colored state occurs gradually as a direct function of the radiation exposure received [9,12]. The change in color intensity, or optical density, is measured using an optical reader, or a spectrophotometer. The radiachromic dosimeters used at the APS have a linear response to ionizing radiation over a dose range of approximately 0.1 Mrad to 10 Mrad [9,12,13]. They have an equivalent response to x-rays, γ-rays, and electrons from ultraviolet energies up to approximately 1 MeV [14,15,16].

Results and Discussion

Figure 1 gives the absorbed dose received by the APS insertion devices for a particular run, as registered by the radiachromic dosimeters placed on the upstream and the downstream ends of the devices. The results show that, on an average, each insertion device receives approximately 1 Mrad of absorbed dose during a typical run period of 6-8 weeks. It is evident that doses on the downstream end of the insertion devices are typically higher than doses on the upstream end of the devices. This may be explained by the greater amount of synchrotron radiation present, and consequently the higher absolute number of scattered photons at the downstream end of an insertion device. It may also be explained by the greater possibility of a bremsstrahlung shower, produced just in front of the insertion device, to strike the downstream end rather than the upstream end due to the larger dimensions of the shower at the downstream end.

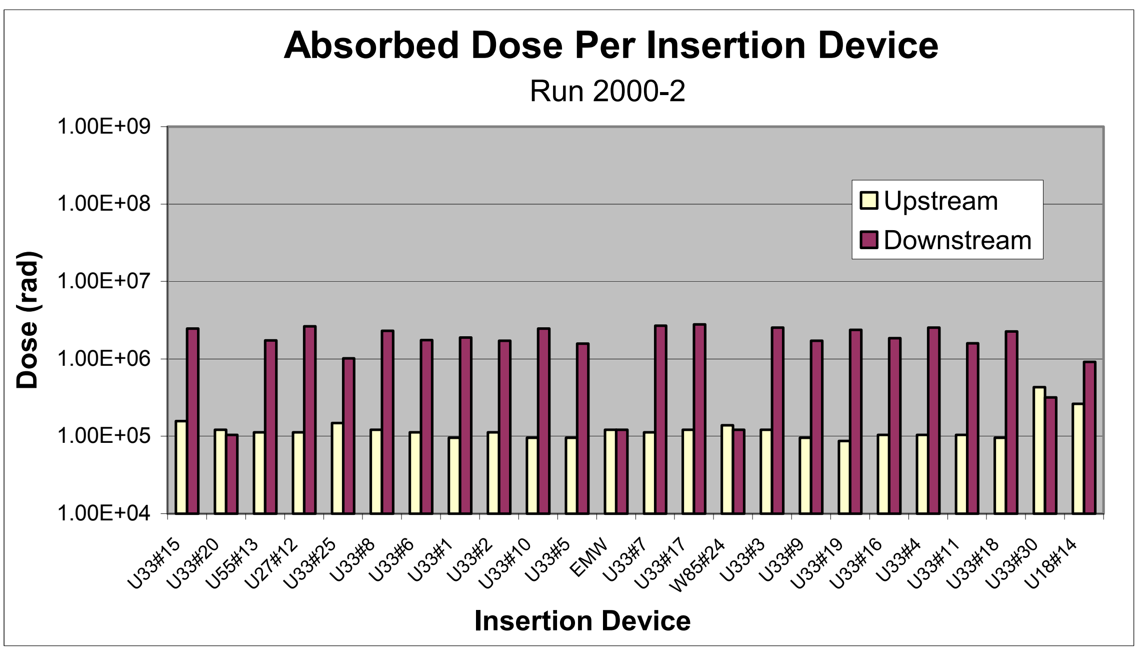

Figure 1. Absorbed dose per insertion device during a typical run of eight weeks.

The results shown in Figure 2 provide the measured absorbed dose results as shown in Figure 1, normalized to the total beam current for a particular run period of eight weeks at the Advanced Photon Source. These results can be compared with earlier estimates [17] of unshielded radiation levels outside the vacuum chamber, at the center of a long straight section at the APS. These estimates project the total dose as 2.6×10^7 rad for 20 years of APS operation. Present results from radiachromic dosimeters project an average absorbed dose of greater than 10^8 rad for 500 Amp-h operation per year during a 20-year operation period. The EGS4 estimates of the photon radiation levels at the ALS insertion devices [18] provide 3×10^6 rad for 20-year operation at a beam current of 400 mA. This number scales to approximately 10^5 rad for 20 years of APS operation at 100 mA. The comparisons show that the estimates are nonconservative and the measured photon dose rates are even higher than the conservative estimates.

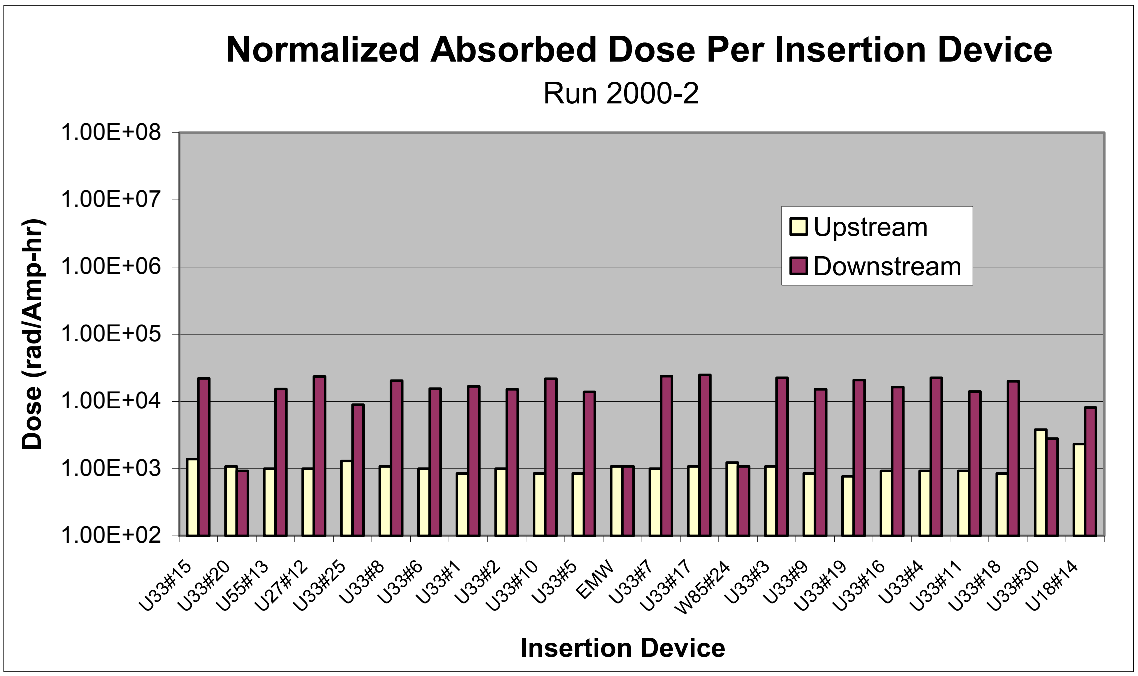

Figure 2. Normalized absorbed dose per insertion device during a typical run.

Absorbed dose measurements at the PETRA (17-23 GeV) storage ring [19,20] showed considerably higher radiation levels, typically 10^4 to 10^5 rad/Amp-h in the PETRA tunnel with a 3-mm lead-shielded vacuum chamber and 4.8×10^8 rad/Amp-h with unshielded vacuum chambers, which is at least four orders of magnitude larger than the measured doses in the APS storage ring. This discrepancy cannot be explained by only the higher particle energy in the PETRA ring. This may be explained by the fact that in the modern machines like the APS, the beam losses are better controlled by active feedback mechanisms during injection and operation.

Over the three-year period beginning with Run 1996-6 and ending with Run 1999-5, the highest dose received by an APS insertion device was approximately 2.0×10^7 rad. This worst-case scenario is important because we are ultimately interested in the total doses received by each insertion device in relation to the radiation-induced demagnetization of the insertion devices over time. A dose rate of 2.0×10^7 rad every three years could be projected to a dose of 1.4×10^8 rad after twenty years, which is the desired lifespan of the insertion devices.

Conclusions

The results of this series of measurements show that the earlier estimates of the radiation doses received by the insertion devices of the third-generation light sources were not conservative. Better control of beam loss mechanisms, due to an active feedback system, have helped to reduce the dose received by the insertion devices to a considerable extent. As the insertion devices become more sophisticated (like in-vacuum insertion devices) better understanding of dose levels at the vicinity of the beam is essential. It is also important to know the threshold radiation levels that cause the deterioration of the magnetic materials, to develop better radiation-resistant magnets.

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