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RADIATION SAFETY CONSIDERATIONS FOR THE APS UPGRADE INJECTOR*

K. C. Harkay†, J. R. Calvey, S. Chitra, G. I. Fystro,
M. J. Henry, E. Heyeck, B. J. Micklich, K. P. Wootton
Argonne National Laboratory, Argonne, IL, 60439, USA

Abstract

The Advanced Photon Source Upgrade (APS-U) is a high-performance fourth-generation storage ring light source based on multibend achromat (MBA) optics. As such, APS-U will require on-axis injection. The injectors will need to supply full-current bunch replacement in the ring; therefore, the injected bunch charge will be up to five times higher than what is typical for APS. A program was conducted to measure the radiation dose above the injector transport line to the APS storage ring for both normal operation conditions and controlled loss scenarios. Standard survey meters were used to record the dose. A review of the dose data identified opportunities to minimize the potential dose under normal APS-U high charge operation and fault conditions; these include improving the supplemental shielding and adding engineered controls. In addition, the dose data provide a benchmark for evaluating new radiation monitors for APS-U.

INTRODUCTION

APS-U needs to consider the potential for higher injector beam losses during normal operation as well as possible missteering events. Radiation must be controlled to satisfactory levels for personnel protection, following the principle of ALARA (as low as reasonably achievable). The goal is to limit the radiation to < 5 mrem in an hour for missteering events and < 100 mrem in a year under normal operation.

The APS-U injector high-charge upgrade was described previously [1, 2]. The basic structure is as follows: The 450-MeV linac provides 1-nC electron pulses at a 30-Hz rate. Up to 20 pulses are accumulated in a single bunch and damped in the particle accumulator ring (PAR) at the fundamental rf frequency. In the final quarter of the 1-s cycle, the bunch is captured, and the bunch length is further compressed in a 12th harmonic rf system. The bunch is injected into the booster where it is ramped to full 6-GeV energy. Up to 17 nC (17 nA) is extracted into the booster-to-storage ring (BTS) transport line.

Surveys in linac and booster injection showed that the existing shielding is sufficient for electron losses up to 20 nA. Supplemental shielding improvements for PAR were analyzed based on beam loss surveys and radiation modeling with MCNP [3]; results are reported in [4].

Beam losses at booster extraction are of some concern. At several locations near rf waveguide, air duct, and cable penetrations above BTS, various beam loss scenarios resulted in total radiation dose rates that exceed the APS-U goals. Analysis of the survey results and a discussion of mitigations are described in this paper.

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† harkay@anl.gov

SURVEY INSTRUMENTATION

Standard survey meters were used to record the radiation dose: Victoreen 451 for photons (gammas) and Eberline ASP-2E for neutrons. The Eberline meter uses a rem meter ("remball") neutron detector, which under-responds to neutrons with energies > 10 MeV. In addition to standard neutron survey instruments, the dose was also measured with a PRESCILA neutron meter, as a test [5]. The PRESCILA instrument has a better response to neutrons with energies > 10 MeV than the remball [6]. Both the PRESCILA and remball were calibrated using same AmBe neutron source, which has an average energy of 4.4 MeV. The directional sensitivity of the two instruments is comparable: the remball angular response is quoted as ±10%, while the PRESCILA's is ±15%.

BEAM LOSS SURVEYS

Detailed radiation surveys were conducted over the BTS for numerous machine conditions as a function of booster bunch charge. The machine conditions include loss scenarios that could occur during a fault, as well as normal operation such as the beam directed to a dump. Table 1 gives a summary of the survey results for 1 nA at the highest-dose locations above BTS outside the shielding, measured at 30 cm. Scenario 2 is normal operations with 6-GeV beam directed to the dump (1 nC at 1 Hz). The other scenarios are off-normal conditions with 7-GeV beam (2 nC at 2 Hz). The locations A and B are shown schematically in Fig. 1; location C is downstream. To be conservative, the total dose is computed as the photon dose plus twice the neutron dose; this is explained later.

Table 1: Radiation Dose for 1 nA at (A) RF Waveguide Penetration, (B) Booster Exhaust Ducts, or (C) Air Duct 7

Location	Scenario #	Gamma, mrem/h	Neutron, mrem/h	Total, mrem/h
A	2	0.1	1.5	3.1
A	5	0.2	3.3	6.8
A	6	0.1	2.0	4.1
B	4	1.2	4.7	10.6
C	9	0.8	2.4	5.6
C	10	6.5	3.3	13.1
C	21-24	0.9-5.0	1.1-2.3	4.5-9.6
C	25-28	0.9-2.0	0.9-2.4	3.1-6.8

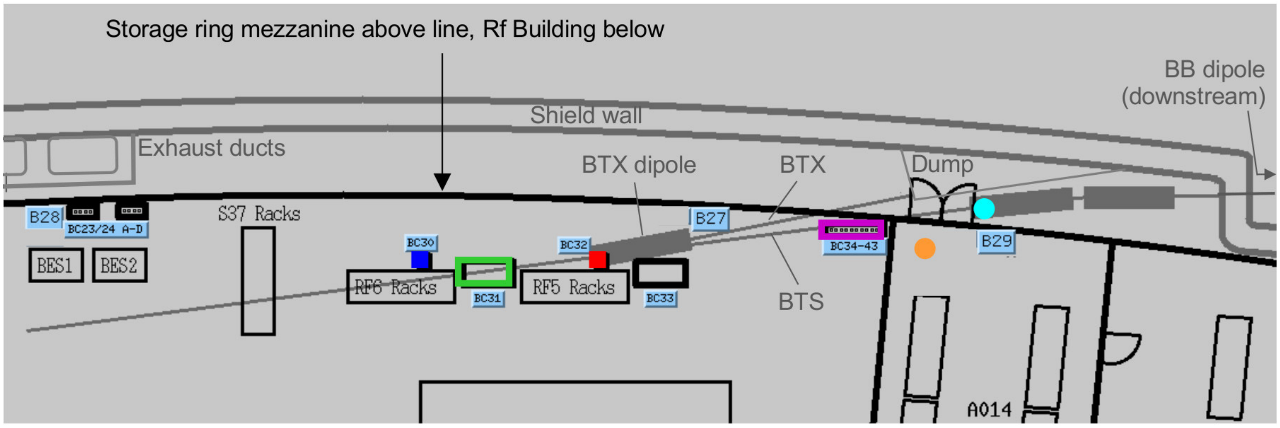

Figure 1: Schematic showing the area above the BTS and booster-to-dump (BTX) transport lines; beam travels from left to right. Upper-level components are black, beamline components are grey. The shield wall separates the storage ring and booster enclosures. Air duct 7 is on the storage ring side, off to the right (not shown). The highest-dose survey locations, all near penetrations, are color-coded and correspond to the symbols in Fig. 2.

Scenario 4 is an energy mismatch at the booster extraction septum. The highest radiation is measured at the large booster exhaust ducts, which penetrate to the upper level. Scenarios 5 and 6 are an energy mismatch at the BTX dipole and missteering to the dump, respectively. The highest radiation is measured at rf waveguide penetration BC33, also for Scenario 2. Scenarios 9-10 are energy mismatches at the BB dipole on the storage ring side. Scenarios 21-28 are for quadrupole scans at the BTS emittance diagnostic flag. For these cases, the highest radiation is measured near Air duct 7, which is above the BB dipole.

During a survey, all locations that have radiation readings above background are identified. In each of these locations, the highest dose is recorded at standard distances from the surface of the shielding (in this case, the floor): 30 cm (this is used for posting requirements) and 1 m (this is relevant to the dose to a human). Figure 2 shows the current-dependent total dose at 30 cm at various locations for Scenario 2 using standard instruments. The data are nearly linear with current, as expected. The 1-m data are lower by a factor of 1.5-2.5, compared to the 30-cm data.

It is readily observed that the highest radiation is measured near various penetrations above the BTS. To meet the dose and dose rate goals for APS-U at 17 nA, the potential radiation dose must be reduced by a factor of 10-40.

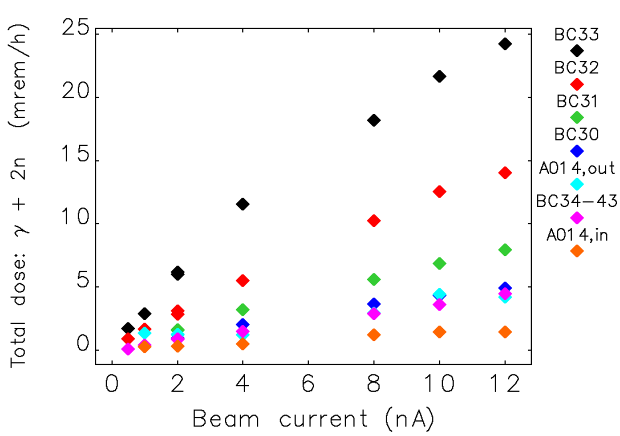

Figure 2: Current-dependent total dose for Scenario 2 (6-GeV beam to dump), at 30-cm. The symbols refer to locations shown in Fig. 1.

Total Radiation Dose

As mentioned above, the total dose in Table 1 is computed as the gamma (photon) dose plus twice the neutron dose. The reason for this is to account for the higher-energy neutrons expected to be produced by 6- or 7-GeV electrons. Measurements show that a factor of two is a reasonable assumption.

Figure 3 shows a comparison of the neutron dose for two instruments for Scenario 2. PRESCILA readings are, on average, about twice as high as the remball. From the dose response [6], the overestimation could be either due to the presence of high-energy neutrons, or due to the over-response of the PRESCILA to energies < 100 keV, where its response is about twice that of the remball. Radiation physics modeling will be used to determine the particle spectra and relative contributions to dose for neutrons and photons at locations of interest. This will allow effective choices for shielding at the respective locations.

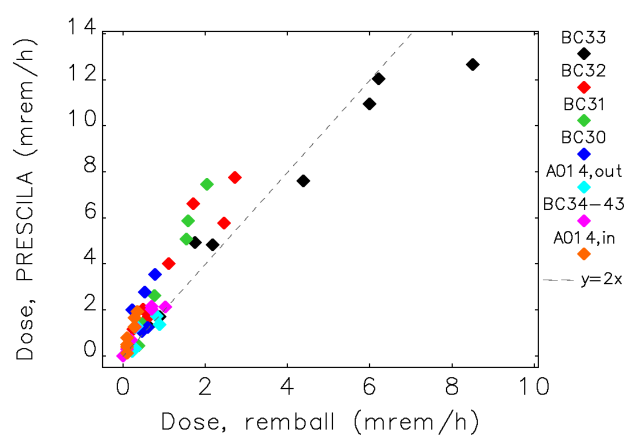

Figure 3: Comparison of neutron dose for two instruments at 1-m, Scenario 2, with varying beam current (6 GeV).

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IDEAS FOR MITIGATON

Air duct 7 was already posted as a controlled area, given its proximity to storage ring injection with higher average losses. Following the BTS surveys, the areas around the rf penetrations in the Rf Building and the booster exhaust ducts were also posted. In addition, there are three area radiation monitors above the BTS, labelled B27, B28, and B29 in Fig. 1, that are interlocked to inhibit the electron gun if neutron dose above 3 mrem/h or photon dose above ~10 mrem/h is detected.

Reducing the dose at rf waveguide, air duct and cable penetrations above the BTS involve a combination of additional supplemental shielding and limiting the beam current in an hour. A current-limiting interlock is planned to be installed in BTS, primarily for radiation protection against faults in the APS-U storage ring. This interlock also reduces any radiation dose caused by beam losses in BTS. The maximum BTS charge will be limited to 7200 nC in an hour. This is equivalent to 2 nA, or 16 nA for 1/8h.

Preliminary ideas for additional supplemental shielding are given below; it is expected that the final geometries will be guided by radiation physics modeling.

Booster Exhaust Ducts

Two large exhaust air ducts are situated on the booster extraction side, with intakes opposite the extraction septum. The exhaust ducts pass through the booster enclosure ceiling and exit on the storage ring mezzanine. Lead could be stacked at the base and around the ducts, similar to what is presently used at all booster and storage ring rf waveguide penetrations. The lead primarily shields photons. Polyethylene stacked on top of the lead could be used to shield neutrons. To mitigate Scenario 4 (energy mismatch at the septum), the supplemental shielding should attenuate the photon dose by a factor of 4 and the neutron dose by a factor of 16. This estimate does not take credit for the current-limit interlock. With the interlock, the required neutron shielding attenuation would be a factor of 2.

Booster Rf Waveguide Penetrations

The booster rf cavity waveguides exit through openings in the ceiling that are about twice the cross-section area of the waveguide. Two extraction-side penetrations are close to the BTX dipole magnet that is used to switch the beam between the storage ring and the dump. The dipole is a potential loss point for an energy mismatch. On the upper level, there is a steel shroud ~71 inches high surrounding the waveguides to both shield and protect the waveguides from damage. The steel shroud is ~1/8-inch thick, and lead is stacked around the shroud to ~39 inches high. Radiation surveys show that the photons are well shielded (Table 1). To improve the neutron shielding, it is suggested to add 10 inches of poly around the base of rf waveguide penetrations.

Air Duct 7

Air duct 7 is near the BB dipole magnet, close to storage ring injection. Air duct 7 was a location of elevated dose when the BB dipole field was mismatched to the beam energy, and also when quadrupole currents were scanned over a range used for standard emittance measurements in the BTS. These quadrupoles are upstream of the BB dipole.

As in the case of the exhaust ducts, it is suggested that lead be stacked around the base of Air duct 7 on the mezzanine, with poly stacked on top of the lead. To protect the duct against damage, a steel shroud could be added, like that used for the rf waveguides. Other air ducts could similarly be shielded in this way (e.g., Air duct 5 near the dump).

It may be beneficial to add a 10-inch thick layer of poly directly above the BB dipole magnet. This could shield neutrons generated by a beam-loss shower upstream of the dipole when the diagnostic flag is inserted and quadrupoles are scanned.

AREA MONITOR EVALUATION

There is a need for additional area radiation monitors around the APS-U storage ring, in the injection area in particular. Longer-term, this is an opportunity to upgrade the existing area monitors as well. The plan is to evaluate candidate area monitors under realistic 6-GeV beam losses. As discussed in this paper, extensive radiation data have been acquired above BTS under numerous conditions. Select scenarios will be repeated and candidate area monitor performance will be studied for down selection.

CONCLUSION

Radiation surveys conducted under numerous scenarios have identified areas with potentially elevated dose above the BTS when scaled to high charge. While most of the loss scenarios are conditions that are not encountered during normal operations, they were used to identify beam loss locations and potential shielding weaknesses. Preliminary ideas were presented for additional supplemental shielding, where the final shielding geometry will be guided by radiation physics simulations. Using a combination of additional shielding and limiting the beam current in an hour, it should be possible to reduce the potential dose by a factor of 10-40 for APS-U operation.

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