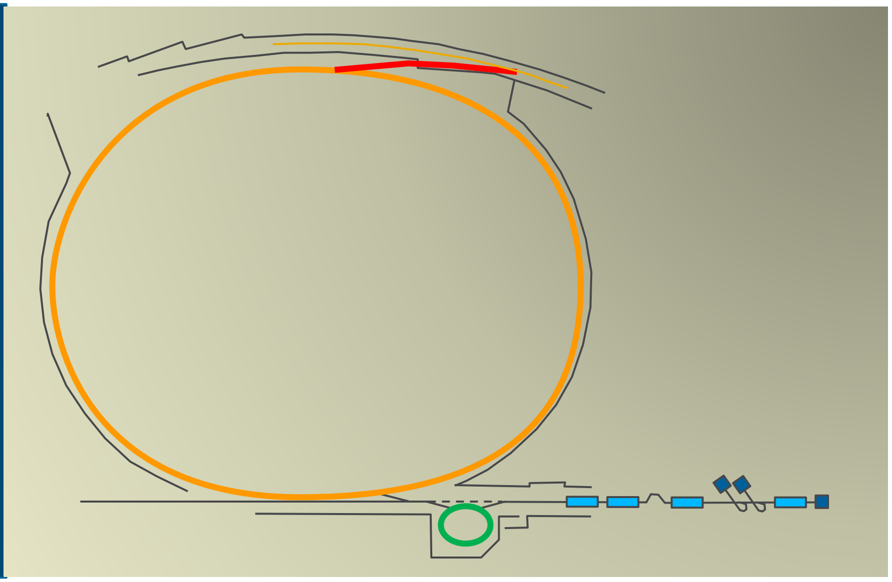
Radiation Safety Considerations for the APS Upgrade Injector

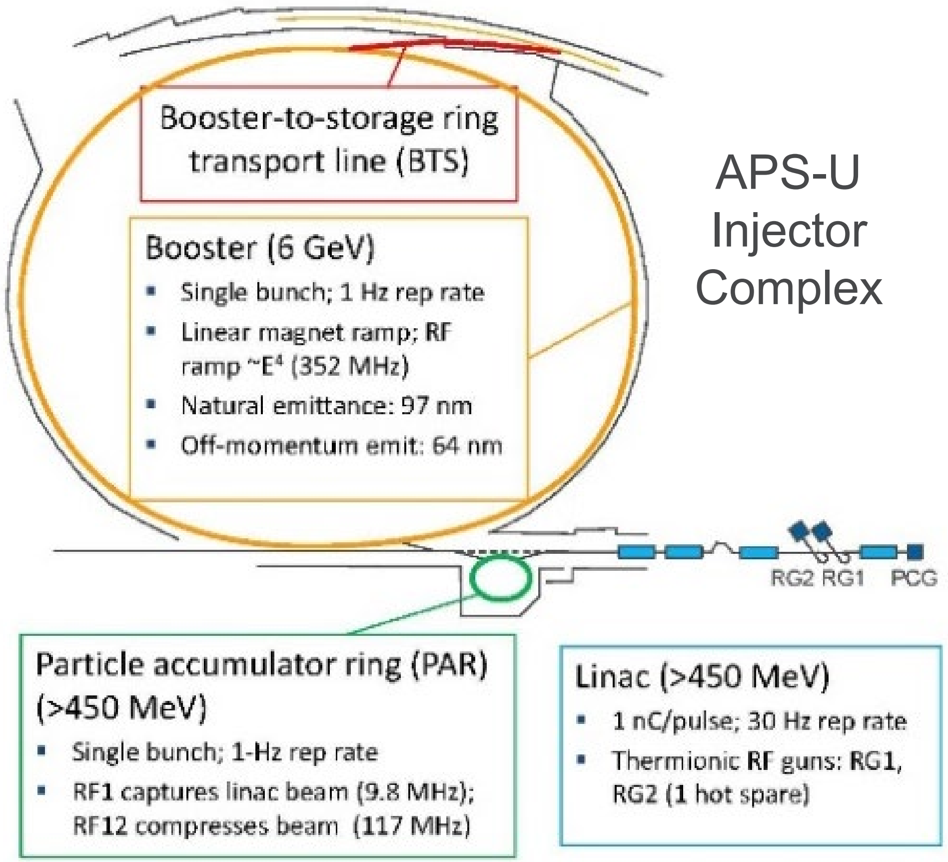


K.C. Harkay, J. Calvey, S. Chitra, G. Fystro, B. Heyeck, M. Henry, B. Micklich, K.P. Wootton
Advanced Photon Source (APS), Argonne National Laboratory, USA

12th International Particle Accelerator Conference
Campinas, Brazil
May 24-28, 2021

Investigated radiation for higher injector charge

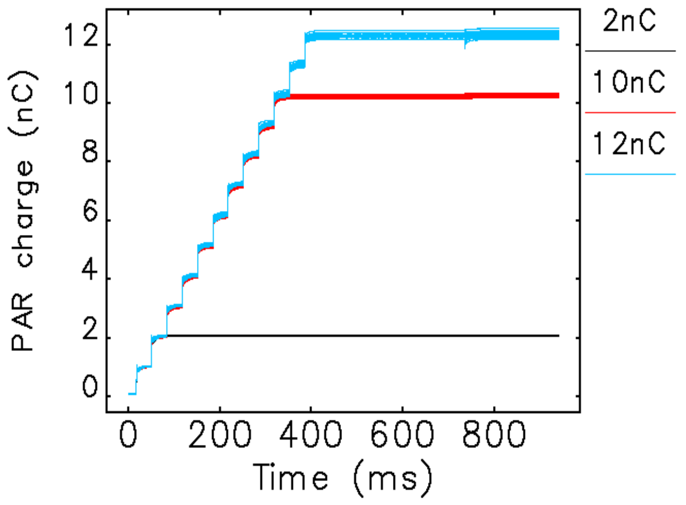
- APS Upgrade (APS-U) needs to consider potential for higher injector beam losses during normal operation as well as possible missteering events. Injector charge is 5x higher than typical for APS.
- Goal is to limit the radiation to < 5 mrem in an hour for missteering events and < 100 mrem in a year under normal operation.

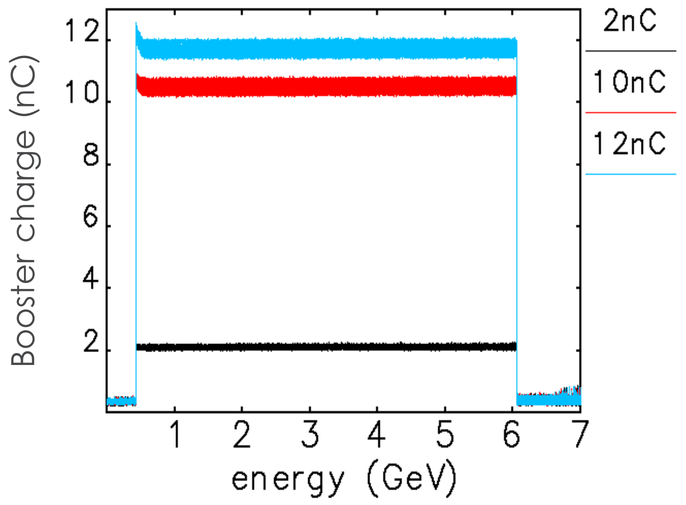


APS-U Injector Complex

Achieved 20 nC accumulated in PAR (>12 nC shown, left).

Achieved 12 nC in booster (right). Further updates to the injectors are expected to enable APS-U goal of 17 nC [1,2].



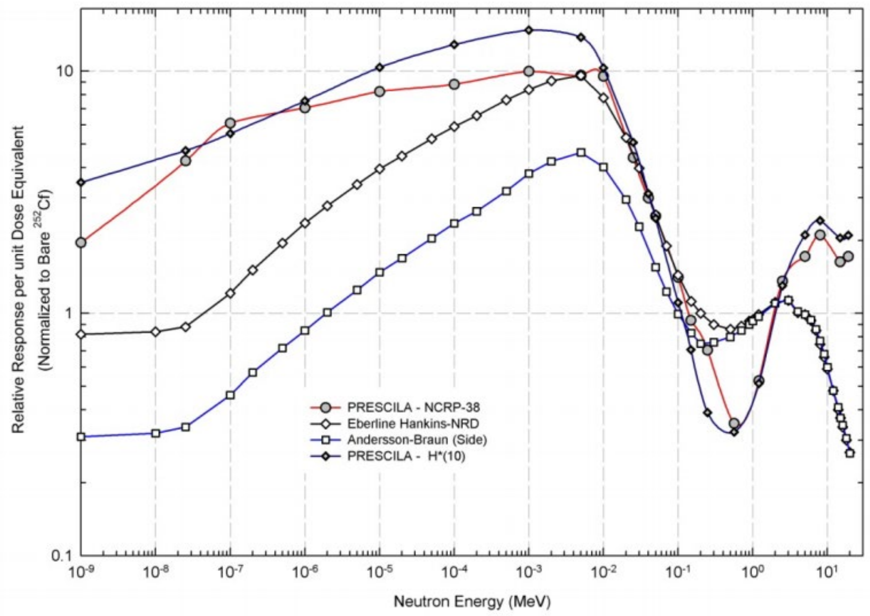


20 traces each

[1] K. C. Harkay et al., Proc IPAC’19, THYYPLM3.
[2] J.R. Calvey et al., Proc IPAC’21, MOPAB045.

Surveys and survey instruments

- Existing shielding in linac and booster injection 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; results are reported elsewhere [4].
- Beam losses at booster extraction are of some concern. Various beam loss scenarios resulted in total radiation dose rates at several locations above BTS that exceed APS-U goals.
- Standard survey meters were used to record the radiation dose: Victoreen 451 for photons and Eberline “remball” for neutrons, which under-responds to neutrons with energies > 10 MeV.
- Dose was also measured with a PRESCILA neutron meter, as a test. The PRESCILA instrument has a better response to neutrons with energies > 10 MeV than the remball [6].

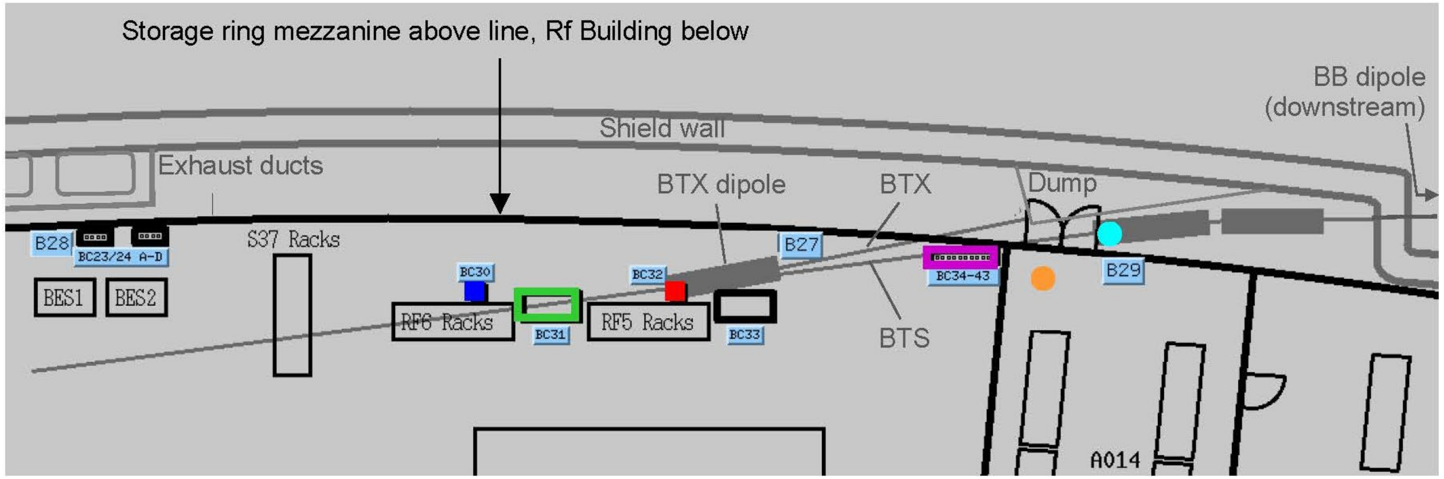


[4] B. J. Micklich et al., Trans. Amer. Nucl. Soc. 123, 1251 (Nov. 2020).

[6] LUDLUM Model 42-41 & 42-41L ‘PRESCILA’ Neutron Probe Product Manual (Jan 2013). https://ludlums.com/images/product_manuals/M42-41_&_M42-41L.pdf

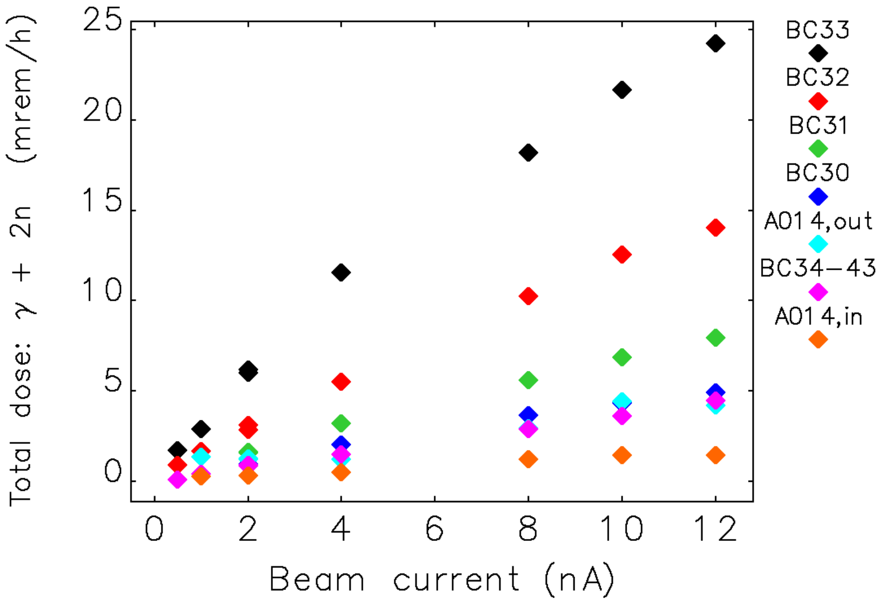
Beam loss surveys in BTS and BTX

- Right: Area above BTS and booster-to-dump (BTX) transport lines; beam travels from left to right.
- Below: Survey summary for 1 nA at the highest-dose locations above BTS outside the shielding, measured at 30 cm: (A) rf waveguide penetration, (B) booster exhaust ducts, or (C) air duct 7 (scenarios described in paper).



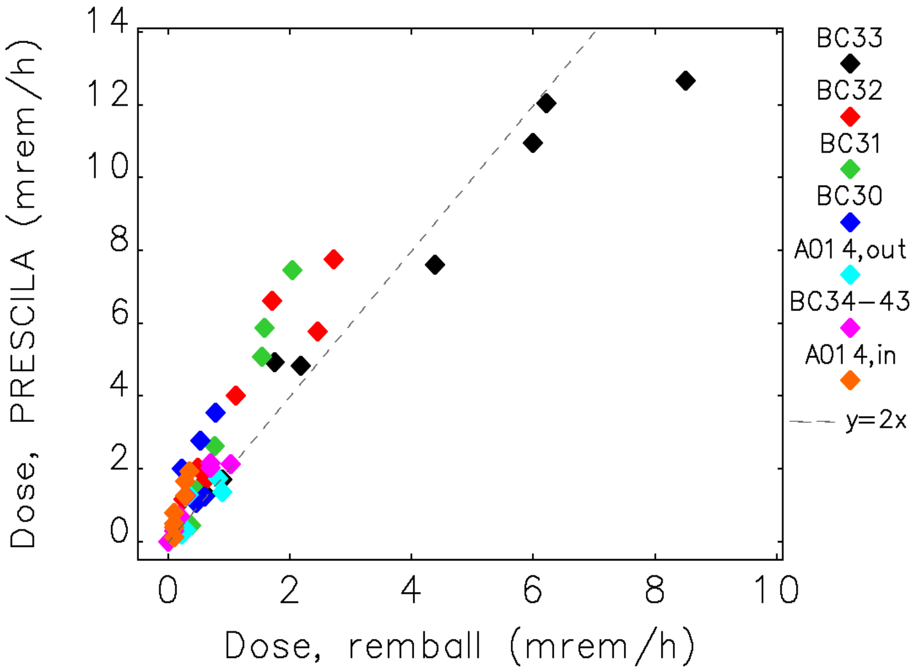
Loca-tion	Scen-ario #	Gamma, mrem/h	Neutron, mrem/h	Total, mrem/h
A	2	0.1	1.5	3.1
A	5	0.2	3.3	6.8
A	6	0.1	2.0	4.1
B	4	1.2	4.7	10.6
C	9	0.8	2.4	5.6
C	10	6.5	3.3	13.1
C	21-24	0.9-5.0	1.1-2.3	4.5-9.6
C	25-28	0.9-2.0	0.9-2.4	3.1-6.8

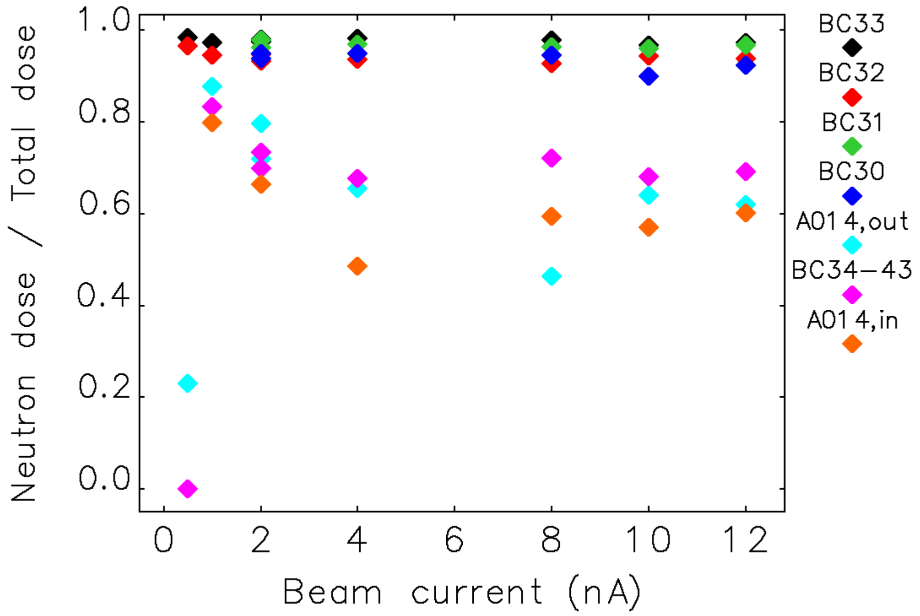
Current-dependent total dose for Scenario 2 (6-GeV beam to dump), at 30-cm.



Total dose accounts for higher-energy neutrons

- The total dose is computed as the gamma (photon) dose plus twice the neutron dose. 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 (left).
- Lead primarily shields photons; polyethylene can be used to shield neutrons.
- Neutrons dominate at large penetrations shielded only by lead (rf waveguide and cable penetrations); about 50% elsewhere (right). Distribution at air ducts is ~50% (not shown).

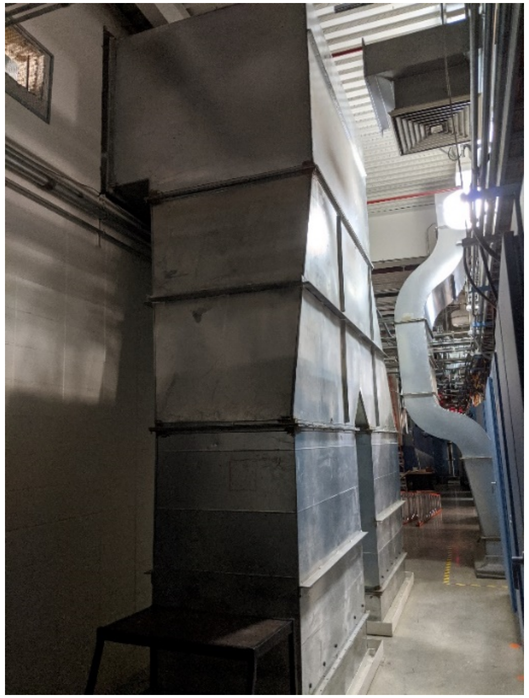




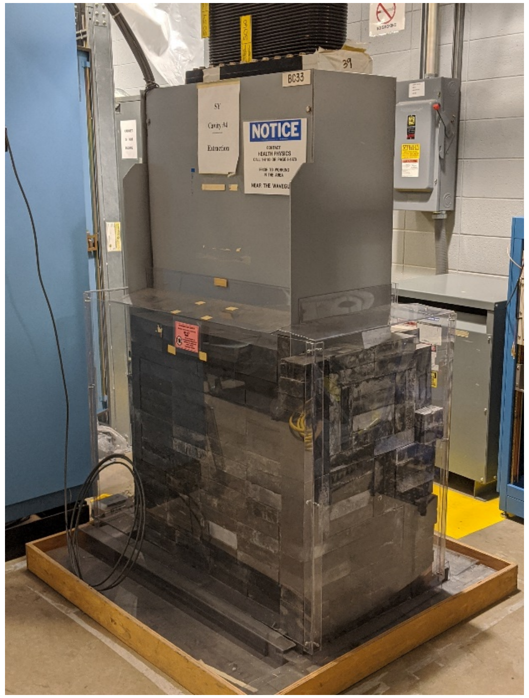
Ideas for mitigation

- Current-limiting interlock for radiation protection against faults at injection in APS-U storage ring also reduces radiation dose caused by beam losses in BTS.
- Maximum BTS charge will be limited to 7200 nC in an hour – equivalent to 2 nA, or 16 nA for 1/8 h.
- Suggested additional shielding at (A) Booster exhaust duct (lead + poly), (B) Rf waveguide (poly), (C) Air duct 7 (lead + poly).

(A)



(B)



(C)

- Radiation physics modeling will be used to determine the particle spectra and relative contributions to dose for neutrons and photons. This will allow effective choices for shielding at the respective locations.

Additional photos

B27 rad monitor (looking North)

B29 rad monitor

BTX dump and flags

Conclusions

- 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. Selected scenarios will be repeated to evaluate the performance of candidate new area radiation monitors.
- 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.
  - BTS current-limiting interlock to limit to equivalent of 2 nA, or 16 nA for 1/8 h.
  - Preliminary ideas were presented for additional supplemental shielding, where the final shielding geometry will be guided by radiation physics simulations.

Acknowledgements

Thanks to discussions with the Injector Working Group and APS-U Radiation Physics Working Group. Thanks also to J. Connolly and P. Rossi for supporting the high-charge surveys for Scenario 2 under special APS Remote Operations in 2020.