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Radiological Environmental Protection for PEP-II Ring High Luminosity Operation

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Abstract

Stanford Linear Accelerator Center (SLAC) is located in northern California, USA. Radiological environmental protection is one of the main elements of the radiation protection program. One of SLAC's accelerator facilities is B-Factory, whose PEP-II accelerator ring has been operating since 1997 and is being upgraded to higher luminosity operation. Four radiological issues associated with high luminosity operation up to CY2008 are re-evaluated: 1) annual doses in IR halls, 2) annual skyshine doses at site boundaries, 3) potential radioactive air releases, and 4) potential groundwater activation. This paper presents the skyshine doses and air emission doses to the Maximally Exposed Individual (MEI) at SLAC site boundaries.

The normal beam loss scenarios around PEP-II ring are presented first. In CY2008, the luminosity is $2x10^{34}$ $cm^{-2}s^{-1}$, and the stored current is 4.0-A for low-energy ring (LER) and 2.2-A for high-energy ring (HER). The beam losses around PEP-II ring include those near injection region in IR10 and IR8 and those at collimators (e.g., HER collimators in IR12, LER collimators in IR4 and IR6). The beam losses in IR8 and IR10 (where injection into ring occurs) are further divided into septum, BAD (beam abort dump) and TD (tune-up dump), as well as apertures.

The skyshine prompt dose rate distributions as a function of distance from an IR hall at four directions were calculated using the MARS15 Monte Carlo code. For skyshine dose to the MEI, the annual dose (7200 h/y occupancy) is calculated to be 2.9 mrem/y at Sand Hill Road (from e^- losses in IR12 HER collimators) and 1.2 mrem/y at Horse Track Offices near IR6 (from e^+ losses in IR8, IR6 and IR4). These are lower than the SLAC skyshine limit of 5 mrem/y for any single facility within SLAC.

Radionuclide productions in the air at the PEP-II IR10 were calculated using MARS15. Beam losses of 9-GeV electrons were assumed in three target cases: the copper TD, septum and BAD. Energy spectra of secondary particles of photons, neutrons, protons and pions in the IR10 air region were calculated. Radionuclide yields of ^{11}C, ^{13}N, ^{15}O, ^{3}H, ^{7}Be and ^{41}Ar were estimated using the obtained particle energy spectra, folded with the reaction cross sections. With certain operation and ventilation conditions, the annual air emission dose to the MEI at Sand Hill Road from e^- losses in IR10 is calculated to be 0.004 mrem/y (7200 h/y occupancy). The annual dose to the MEI at Horse Track Offices is 0.002 mrem/y from e^+ losses in IR8, 0.003 mrem/y from IR6, and 0.025 mrem/y from IR4. The doses are dominated by ^{13}N. Therefore, the EPA annual dose limit of 10 mrem/y for SLAC and the continuous ventilation monitoring limit of 0.1 mrem/y for each release point are not exceeded.

Keywords: Accelerator, environmental, beam losses, skyshine, Monte Carlo, air

1. Introduction

The SLAC accelerator facility PEP-II has a low-energy ring (LER) and a high-energy ring (HER). PEP-II is being upgraded to high luminosity operation in 2006 and a new beam loss scenario was estimated (1). Four radiological issues associated with high luminosity operation were addressed and documented (2-6): 1) annual doses in the IR halls, 2) annual skyshine doses at the SLAC site boundaries, 3) radioactive air production and emission into environment, and 4) groundwater activation. The results have been summarized (7) and this report presents the main results for the skyshine and radioactive air doses to the Maximally Exposed Individual (MEI) of the public off-site.

2. Sources of Radiation

Figure 1 layouts PEP-II ring with its IRs and beam loss points, which include those near injection region in IR10 and IR8 and those at collimators (e.g., HER collimators in IR12, LER collimators in IR4 and IR6). The beam loss values (inside parenthesis) are average power in W in CY2008, with a luminosity of $2x10^{34}$ $cm^{-2}s^{-1}$ (4.0-A for LER and 2.2-A for HER). The beam losses in IR8 and IR10 (where injection into ring occurs) are divided into septum, BAD (beam abort dump) and TD (tune-up dump), as well as apertures. In IR8, the main sources of radiation are the 3.1-GeV e^+ injection beam losses in the LER injection septum, e^+ stored beam abort in the LER BAD, and TD. TD is located ~20-m upstream of IR8 center while other losses are in the 20-m-long IR straight. Therefore, TD dose not give much doses outside IR8 wall or skyshine dose to site boundary. However, TD is one of the main sources of potential air activation for e^+ beam. In IR4 and IR6, the main sources are the LER collimators.

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IR12 has a similar concrete hall shielding geometry as IR8, but the main sources of radiation are the 4 HER collimators in the 20-m-long IR straight. In IR10 (an underground cave and no IR hall), the main radiation sources are the 9-GeV e^- injection beam losses in the HER injection septum, the e^- stored beam abort in BAD, and TD. TD is located ~20-m upstream of IR10 center and is the main source of the potential air and groundwater activation for e beam. In IR2, the main sources of radiation are the e^+ beam losses in the LER collimators upstream of BaBar detector and the leakage photons from the HER wiggler.

3. Annual Skyshine Doses at SLAC Site Boundary

The DOE-5400.5 dose limit for general public from all exposure pathways is 100 mrem/y to the MEI. The corresponding SLAC administrative limit for skyshine radiation to site boundary is 10 mrem/y (7200 h/y occupancy assumed) from all SLAC facilities and the limit for each single facility is 5 mrem/y. The concerns here are the skyshine dose to Sand Hill Road from the e^- stored beam losses in IR12 and the skyshine dose to the Horse Track Offices near IR6 from the e^+ beam losses in IR8, IR6 and IR4.

MARS15 was used to calculate the effective dose in an IR hall and the skyshine doses to the site boundary as a function of distance from an IR. Detailed results are documented [(4)] and the main results are summarized below. The calculations were divided into 3 steps: 1) beam interaction and secondary particle productions from the beam line, 2) transmission through concrete wall or roof, and 3) skyshine neutrons and photons scattered off from the air molecules. Figure 2 shows the two-dimensional distribution of total dose rate scored (a vertical cut at the first Q-magnet location). The beam loss is 9-GeV, 1-W electron beam hits the 1st Cu collimator in IR12. The 40″ concrete wall, 1′ concrete curtain wall, 4′ concrete roof, and two 2’ concrete blocks on the bridge in IR hall are shown. The secondary particles of neutron and photon crossing over the 4’ concrete roof and steel hall roof beyond the thin curtain wall are scored and used as the source particles in the 2nd step of calculations.

Figure 3 shows the total, neutron, and photon skyshine dose rate distributions (at two different heights) along the direction perpendicular to the electron beam direction. At 200-m North (the distance and direction from IR12 to Sand Hill Road where the MEI for this source resides), the skyshine total dose is 10^{-4} mrem/h/W, which corresponds to an annual dose of 0.7 mrem/y/W. The Horse Track Offices is the MEI at the south site boundary, and it has annual doses of 0.02 mrem/y/W from IR8, 1.0 mrem/y/W from IR6, and 0.1 mrem/y/W from IR4.

The skyshine neutron/photon dose ratio is more than 20, as expected. The neutron dose equivalent ratio between high (> 14.5 MeV) and low (< 14.5 MeV) energy skyshine neutrons is 0.2. As a comparison, the SKYSHINE analytic code will give a dose rate of 0.72 mrem/y/W at 100 m and 0.05 mrem/h/W at 300 m at all directions, which are comparable with the MARS results.

From the MARS15 skyshine results and the beam losses, the CY2008 annual MEI dose is 2.9 mrem/y at Sand Hill Road (from electron beam losses in IR12) and 1.2 mrem/y at Horse Track Offices (from positron beam losses in IR8, IR6 and IR4). Both are lower than the SLAC skyshine shielding design limit of 5 mrem/y for a single facility. Skyshine dose measurements have been made and are in general agreement with calculations.

4. Potential Radioactive Air Emission into Environment

The 40CFR61.H (NESHAPS) regulatory limit for public doses due to emission of airborne radioactivity is 10 mrem/y. In addition, the facility must monitor continuously each air release point which can cause doses > 0.1 mrem/y. According to SLAC’s annual NESHPAS report [(8)], the electron beam losses in IR10, as well as the positron beam losses in IR8, IR6 and IR4, are the main contributors to the potential air activation and the subsequent release to the environment for PEP-II operation. Detailed results of air dose evaluation are documented [(5)] and the main results are summarized below.

Radionuclide productions in the IR10 tunnel air environment were calculated using MARS15 for 9-GeV, 1-W electron beam loss at three targets: TD, injection septum, and BAD, with detailed modeling of IR10 geometry. The resulting energy fluence distributions of secondary particles (photons, neutrons, protons and pions) in the IR10 region are shown in Figure 4. Radionuclide yields of ^{11}C, ^{13}N, ^{15}O, and ^{41}Ar were then calculated by folding the particle energy spectra with the reaction cross sections, e.g., photo-nuclear, photo-spallation, and hadron-spallation. The latter two can create isotopes of ^{11}C, ^{3}H, ^{7}Be, etc. Reaction of $^{40}Ar(n,\gamma)^{41}Ar$ is dominated by thermal neutrons. Table 1 summarizes the calculated results for radionuclide air release into environment from beam losses in IR10 and the MEI dose at Sand Hill Road for PEP-II CY2008 operation. The calculations assumed:

1) Because IR10 is not sealed and has no forced ventilation, a full air exchange in 2 hours was assumed.

2) In IR10, average electron beam power losses at TD (167 W), septum (8.7 W), and BAD (14 W) in CY2008 are used to estimate the MASR15 activity yields (Ci) at the end of 2-h.
3) The operational time in CY2008 is 6480 h and there are 3240 air releases in CY2008.
4) The dose factor (mrem per 1-Ci release) for each isotope from IR10 release to the MEI at Sand Hill Road was calculated using the CAP88 code with the Bay Area meteorological data and CY2000 population data [(8)]. The dose factor is dependent on distance and direction between the source point and dose point.

The majority of annual release is ^{13}N (2.51 Ci/y out of 3.55 Ci/y for all 4 isotopes). The annual dose to the MEI at Sand Hill Road from IR10 radioactive air release is 0.004 mrem/y, dominated by ^{13}N (63%) and ^{41}Ar (28%). Similar calculations were performed for radionuclide air release from positron beam losses in IR8, IR6 and IR4, as well as the MEI dose at Horse Track Offices. The majority of annual release for the three IRs is ^{13}N (7.3 Ci/y out of 9.3 Ci/y for all 4 isotopes). The annual dose to the MEI at Horse Track Offices is 0.03 mrem/y, dominated by ^{13}N (~80%) and ^{15}O (12%). The MEI annual doses from PEP-II radioactive air releases is much less than the EPA's air dose limit of 10 mrem/y and the ventilation monitoring limit of 0.1 mrem/y.

Table 1. Calculated results for radionuclide air release into environment from electron beam losses at 3 targets in IR10, and the MEI dose at Sand Hill Road for PEP-II CY2008 operation.

Target	**TD**	**Septum**	**BAD**				
	MARS Yield at 2-h (Ci/W)						
C-11	4.7E-08	5.1E-06	1.3E-06				
N-13	2.4E-07	5.4E-05	1.9E-05				
O-15	6.3E-08	7.8E-06	2.6E-06				
Ar-41	7.1E-07	5.2E-07	1.0E-06				
Power (W)	**167**	**8.7**	**14**	**Yield Sum at 2-h (Ci)**	**Annual Yield (Ci/y)**	**Dose Factor (mrem/Ci)**	**Annual Dose (mrem/y)**
	MARS Yield at 2-h (Ci)						
C-11	7.8E-6	4.4E-5	1.8E-5	7.0E-5	0.23	0.0013	0.0003
N-13	4.0E-5	4.7E-4	2.7E-4	7.8E-4	2.51	0.0010	0.0025
O-15	1.1E-5	6.8E-5	3.6E-5	1.1E-4	0.37	0.0003	0.0001
Ar-41	1.2E-4	4.5E-6	1.4E-5	1.4E-4	0.44	0.0024	0.0011
			Total	1.1E-3	3.55	NA	**0.004**

5. Conclusions

The radiological issues for PEP-II ring operation with upgraded luminosity have been evaluated. For the planned PEP-II ring operation up to CY2008, the impacts of skyshine doses and radioactive air doses to the MEI at SLAC site boundary are lower than the relevant regulatory limits and SLAC administrative limits.

6. References

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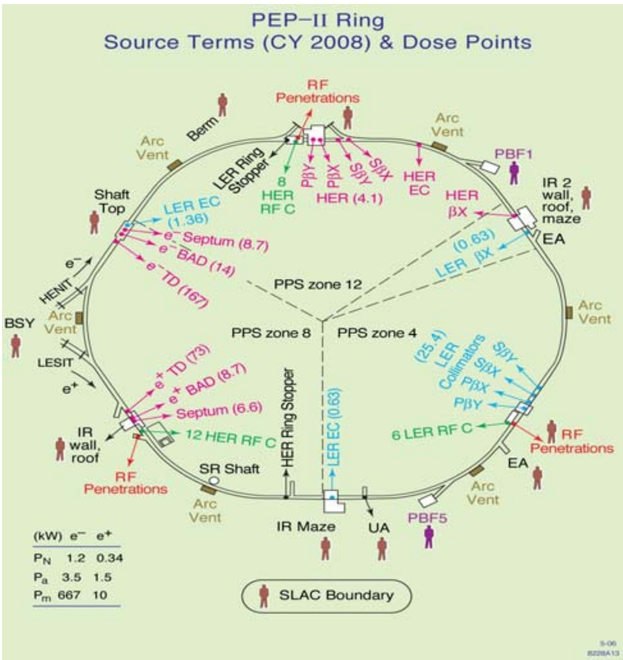

Figure 1. PEP-II ring with its five IR halls and the underground IR10, as well as beam losses in CY2008.

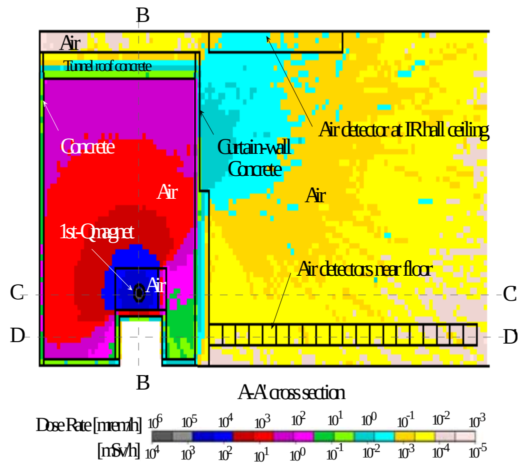

Figure 2. Three-dimensional HER ring tunnel and IR12 hall modeling geometry in MARS15 calculations.

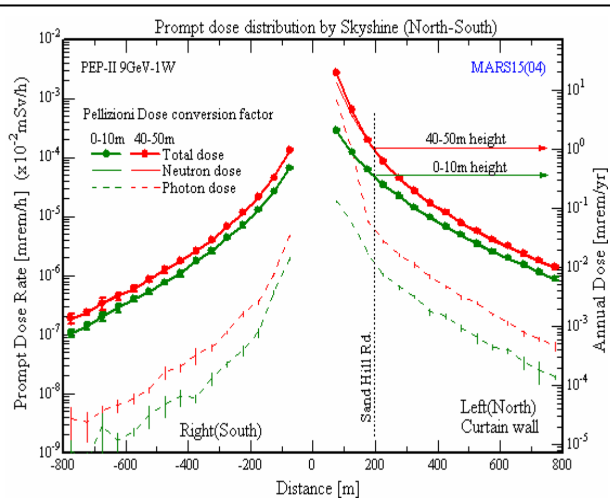

Figure 3. Total, neutron and photon skyshine dose rate (1 W loss) distributions along the direction perpendicular to the beam line (for estimation of skyshine dose to Sand Hill Road at 200-m north from IR12).

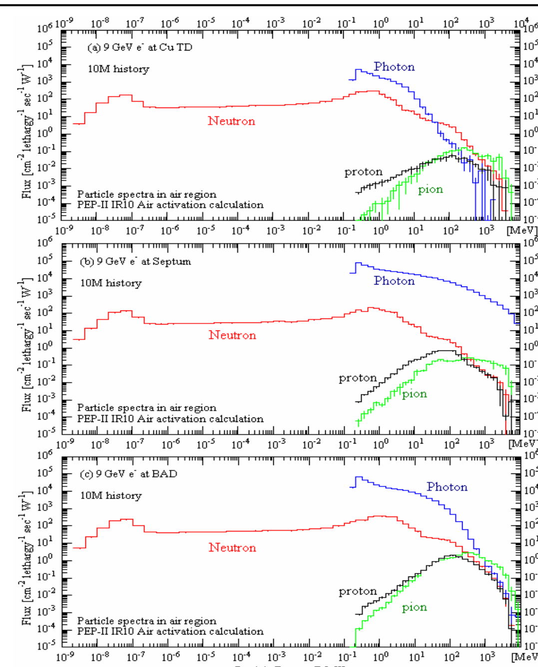

Figure 4. Energy spectra of secondary particles (photons, neutrons, protons and pions) in IR10 air region from 1-W beam loss at three different targets.