Radiation Safety Analysis for the TPS Accelerators

Prompt radiation fields and induced radioactivity due to the operations of TPS accelerators have been investigated using the FLUKA Monte Carlo simulations. Based on conservative and representative beam loss scenarios, radiation levels outside the bulk shielding and radiation streaming through penetrations on shielding walls were evaluated. The results demonstrate that the basic shielding design of the TPS is highly feasible and the 1 mSv/y design dose limit for staff and users should be practicably achievable. Meanwhile, the environmental dose at the nearest site boundary is also far below the regulatory requirement with comfortable margin. In addition to prompt radiation hazards, the design and operation of the TPS accelerators also requires a careful assessment and planning for the radioactivity induced around the facility. Our calculated results lead to the conclusion that the TPS is a fairly low electron consumption synchrotron light source; therefore radioactivities induced in accelerator components and surrounding concrete walls are rather moderate and manageable; and possible activation of air and cooling water and their environmental releases should be negligible.

Author

R. J. Sheu

National Synchrotron Radiation Research Center, Hsinchu, Taiwan

Taiwan Photon Source (TPS) will be a 3 GeV light source with a circumference of 518.4 m and operating fully at 400 mA in top-up mode, aiming to provide synchrotron light with extremely high brilliance and low emittance. Significant amount of radiation will be produced due to the loss of such high-energy electrons and result in radiation safety concerns. The design objective of radiation safety system is to minimize the possible radiation hazards due to the TPS operation.[1] Figure 1 is a portion of the TPS layout showing the main accelerator components and its bulk shielding configuration. Its basic structure consists of a ratchet style shielding for the outer wall of the storage ring and shielded labyrinths in the inner shielding wall for mainly personnel access. The 150-MeV LINAC will be housed in an independent room with 1 m thick concrete shielding. Both the storage ring and concentric booster will be installed in a shared tunnel made of 1 m thick concrete walls and removable roof. The shielding in the injection area and ratchet end walls will be at least 1.2 m thick concrete. The regulatory dose limits in Taiwan are 20 mSv/y for radiation workers and 1 mSv/y for both non-radiation workers and the general public off site. To comply with ALARA principle and recommendations from similar facilities, NSRRC has decided to accept a more challenging dose limits for the TPS of 1 mSv/y for all staff and users who are working 2000 hours a year and an environmental dose of 0.5 mSv/y at site boundaries for operating 6000 hours a year. These design limits guide shielding requirements and the design of radiation safety systems and program.

Beam loss analysis is crucial for the shielding design of an accelerator facility. All electrons generated from the gun filament, accelerated by the LINAC and booster, transferred by transport lines, and finally injected into the storage ring are eventually lost somewhere along the orbit. Based on a reference beam loss scenario under normal operating conditions, we have defined a more conservative operation envelope to ensure the safety envelope, i.e. the design limits, will not be exceeded. Two extreme beam loss cases are assumed to bound the possible beam loss scenarios occurring in the shared tunnel, i.e. all elec-

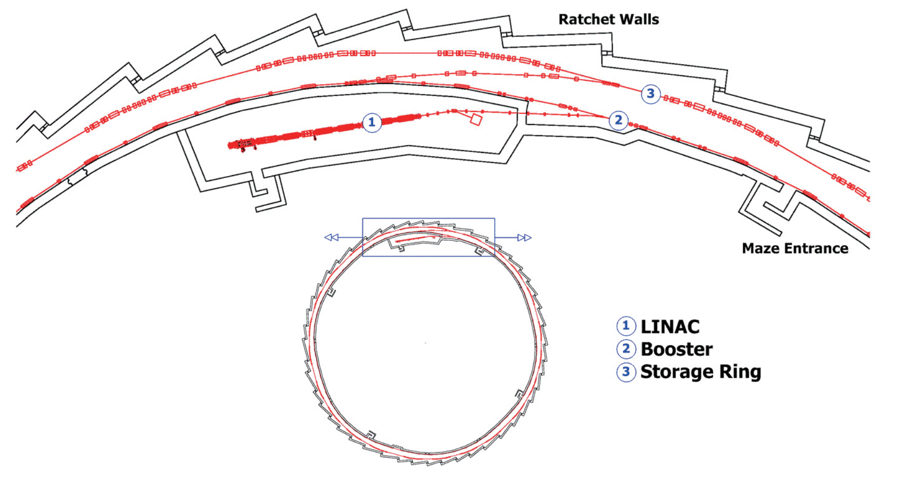

Fig. 1: A schematic layout of the main accelerator components and shielding design of the TPS.

trons are lost at one point or they are lost uniformly along the electron orbit. The point loss model is the worst case of beam loss for radiation protection in accelerators. Comparing with the worst case of point beam loss, we consider uniform beam loss around the booster or storage ring should be more realistic for long-term dose evaluation since most of the hot spots could be easily compensated by local shielding arrangement. We have used the FLUKA Monte Carlo code[2] to simulate the high-energy electron induced electromagnetic cascade and the subsequent photonuclear reactions to calculate the energy spectra and dose distributions of those secondary particles, including gamma rays, neutrons and muons. FLUKA is not only a particle transport and interaction Monte Carlo code but also an integrated code for the buildup and decay of produced radioisotopes. Calculations of induced radioactivities and their time evolution as well as tracking of emitted radiation from unstable residual nuclei can be performed together with radiation transport.

Energy spectra and dose distributions of the prompt radiation field outside the bulk shielding of the TPS have been thoroughly evaluated.[3] Under normal operation conditions, the maximal annual dose in the experimental hall of TPS is estimated to be 0.44 mSv/y and the total dose at the nearest site boundary is only about 14 μSv/y. For the worst operation case before interlock system to intervene, i.e. our operation envelope, the maximal annual dose in the experimental hall may increase to 2.2 mSv/y and the total dose at the nearest site boundary will then be roughly 70 μSv/y. The possible doses at the nearest site boundary due to the TPS operation are apparently far below the environmental dose limit of 0.5 mSv/y, i.e. 500 μSv/y. On the other hand, the maximal dose of 2.2 mSv/y in the experimental hall is obtained based on the condition of 6000-h operation; therefore the expected personnel dose for 2000-h working time should be less than 0.73 mSv/y and that is also within our design limit of 1 mSv/y. The results indicate that the proposed bulk shielding arrangement for the TPS accelerators should be highly practicable to achieve its annual dose limit. However, in reality, no practical accelerator shielding can be constructed perfectly intact without penetrations for the access of personnel and supporting utilities. Compared to the relatively thick shielding walls, radiation streaming through those penetrations should be more carefully evaluated because they undermine the integrity of bulk shielding. According to the layout of the TPS shielding as shown in Fig. 1, a total of five maze entrances have been allocated along the inner shielding walls of the TPS mainly for personnel access. There are also 24 ducts on the upper part of inner shielding walls for air-conditioning piping and 96 underground trenches for the connection between accelerators and supporting utilities. They are all typical multi-legged labyrinth design to minimize the radiation streaming.[4] Figure 2 shows two examples of the FLUKA-predicted radiation environment around those penetrations. All the calculated results lead to the same conclusion that the design dose limit can be met even with all those penetrations on the TPS bulk shielding.

Radioactivity may be induced in various accelerator components and its surroundings when irradiated by a high-energy electron beam directly or exposed to the secondary radiation fields. They present an additional hazard that needs to be carefully analyzed and managed. Similar to beam loss analysis, two extreme irradiation conditions for the TPS operation are assumed to investigate the possible impact. One case (case 1) is a long-term continuous irradiation by an average low-power electron beam derived from annual beam loss estimation, and the other case (case 2) is a short irradiation period by an intense full injection power. The first condition corresponds to the irradia-

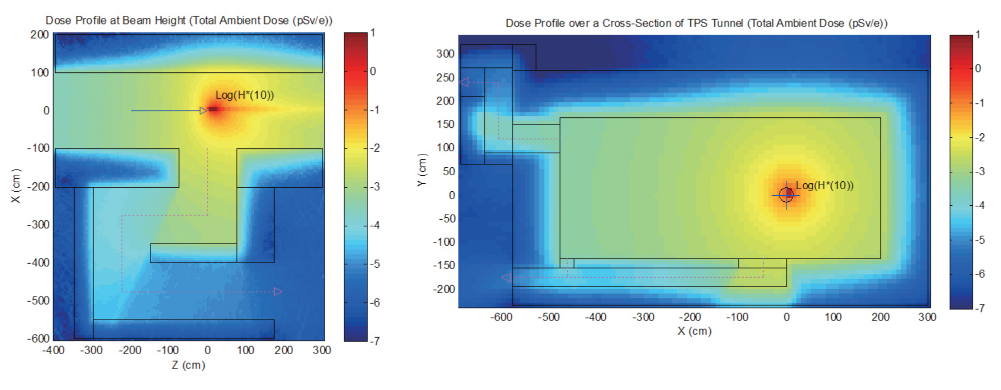

Fig. 2: Dose distributions around TPS penetrations including personnel maze, air-conditioning ducts and underground trenches for a storage ring beam loss.

tion situation of a 20-year operation during TPS lifetime and the second condition intends to simulate a possible irradiation event of a 1-hour beam loss during injection difficulty. Figure 3 shows an example of the decay of residual activities in various targets after the case (1) irradiation. For 20-year operation, some long-lived radionuclides have the opportunity to build up and play an important role after the shutdown of machine. For a short high-power irradiation, the initial residual activities in targets should be much higher, but they decay quickly after shutdown since only short-lived radionuclides are dominantly produced and accumulated. It is evident in Fig. 3 that, among these materials, aluminum is the most preferred and tungsten is more susceptible to activation. In addition to an inventory

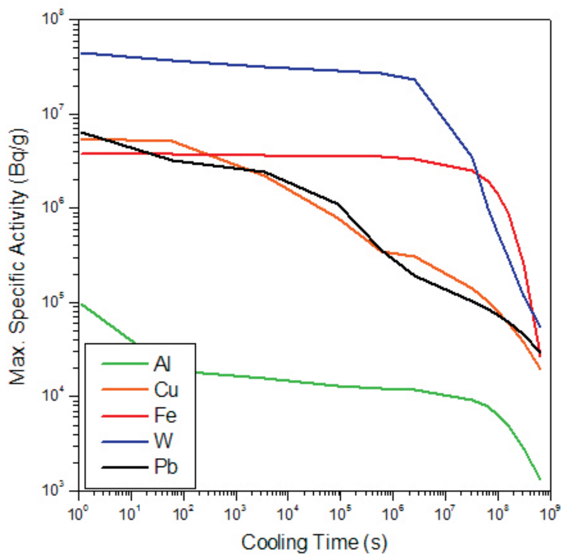

Fig. 3: Time evolution of the maximal specific activities inside various targets after the case (1) irradiation.

management, electrons, positrons, X-rays or gamma rays emitted from the decay of radionuclides result in remnant dose around an activated component. They may pose a possible radiation hazard to the workers nearby during a maintenance period after machine shutdown. Fortunately since most radionuclides found in high-energy electron accelerators are produced in a certain depth below the surface of the target. Due to the self-shielding effect of target material, the remnant dose rates in either case is not very high and should only have moderate impact on the staff working nearby during a maintenance period. Furthermore, considering the impact of possible environmental release, the activation of air and cooling water in the accelerator tunnel as well as the concrete activation itself should be evaluated cautiously. Based on the current estimates,[1] even considering the maximal injection power loss in the tunnel, the possible concentrations of radionuclides in the air and cooling water inside the tunnel are well below the exemption limits; also the massive concrete block used in bulk shielding can be treated as a general waste after decommissioning without further storage for cooling.

This article briefly highlights some results of the radiation safety evaluation for the TPS accelerators. A final design of radiation safety system and program managing the issues of prompt radiation and residual activity in the TPS will be prepared accordingly.

References

1. R. J. Sheu, J. Liu, C. R. Chen, F. D. Chang, K. S. Kao, M. S. Chang, J. P. Wang, NSRRC-TR00073 (2009).
2. A. Ferrari, P. R. Sala, A. Fassò, J. Ranft, CERN 2005-10, INFN/TC_05/11, SLAC-R-773 (2005).
3. R. J. Sheu, J. Liu, J. P. Wang, K. K. Lin, G. H. Luo, Nuclear Technology **68**, 417 (2009).
4. R. J. Sheu, J. Liu, Health Physics **98**, 565 (2010).

Contacted E-mail

srj@nsrrc.org.tw