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DOSE RATE AND ACCUMULATED DOSE AROUND THE TAIWAN PHOTON SOURCE IN VARIOUS SCENARIOS

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Abstract

The Taiwan Photon Source (TPS) is equipped with 16 real-time radiation monitoring stations around the accelerator. Each operating scenario entails a different dose rate and accumulated dose. In this study, we assessed the beam current and injection efficiency of the accelerator and the dose rate and accumulated dose at the radiation monitoring stations in five scenarios. The background radiation level of the TPS is approximately 0.1 μSv/h. We observed that when the injection efficiency was over 85%, the accumulated dose was similar to the background level. When the injection efficient was low (~55%), the accumulated dose was high. When the beam trip focused on a hot spot, the accumulated dose was considerably high. The gamma-ray dose rate reached approximately 2,500 μSv/h. These results indicate that the machine should not be continuously operated in injection mode at low efficiency. Furthermore, in beam trip or dump beam mode, operators should pay particularly close attention to radiation safety.

INTRODUCTION

The TPS at the National Synchrotron Radiation Research Center (NSRRC) is a 3-GeV light source with 1-m-thick concrete shielding walls; user experiments are performed in top-up mode at 500 mA. The TPS is equipped with a network of radiation monitoring stations and a safety interlock system to ensure individuals are safe from radiation [1]. These stations contain gamma-ray and neutron detectors. They are also equipped with local computers that display radiation information in real time (Fig. 1). Moreover, radiation data are transferred to remote servers through the network for archive and analysis [2]. The TPS's radiation monitoring system (RMS) with its safety interlock scheme was designed to ensure injection efficiency and thus prevent high radiation dose rates from occurring outside the accelerator enclosure [3]. In the RMS, the trip point is defined as 2 μSv over four consecutive hours. To ensure convenience in the monitoring process, all stations are synchronized, and the accumulated dose is automatically reset every 4 hours beginning at 1:00 a.m. every day. If the interlock is triggered, the injection process stops immediately [4]. This study assessed radiation dose rates and accumulated doses associated with various operating conditions.

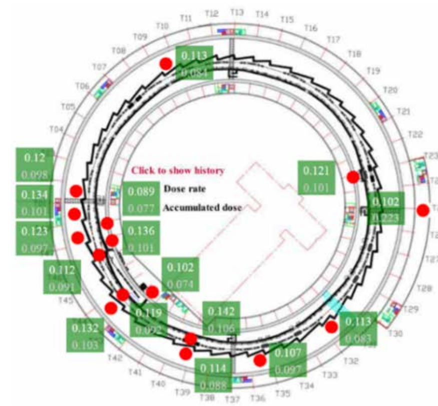

Figure 1: RMS in the TPS.

MACHINE STATUS AND RADIATION SIGNALS

Radiation dose rate and accumulated dose are related to the accelerator's operating conditions, particularly its injection efficiency. In this study, we considered five common operating conditions (Table 1)—namely shutdown, injection mode (efficient), top-up mode (efficient), injection mode (inefficient), and beam trip—and assessed the corresponding radiation dose rates and accumulated doses.

Accelerator Parameters

We focused on three accelerator parameters: booster ring current *BRC*, storage ring current *SRC*, and injection efficiency *InjEff*. During normal TPS operation, the *BRC* is 0.6 mA, *SRC* is 500 mA (max), and *InjEff* is >85%.

Table 1: Assessment Scenarios

Scenarios	Machine Status	Station	RMS Signals
1.	Shutdown	BP47	*d*: 0.1μSv/h, *g*: 0.1μSv/h, *n*: 0.01μSv/h
2.	Injection mode (efficient)	BP01	*d*: 0.1μSv/15min, *g*: 0.8μSv/h (max), *n*: 0.05μSv/h (max)
3.	Top-up mode (efficient)	BP01	*d*: 0.6μSv/4h, *g*: 0.15μSv/h (avg), *n*: 0.02μSv/h (avg)
4.	Injection mode (inefficient)	BP47	*d*: 1.8μSv/2h, *g*: 6μSv/h (max), *n*: 25μSv/h (max)
5.	Beam trip	BP43	*d*: 3.5μSv/1min, *g*: 2500μSv/h (max), *n*: 1.5μSv/h (max)

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Radiation Signals

We considered the gamma-ray dose rate *g*, neutron dose rate *n*, and total accumulated dose *d* as the radiation signals. We assessed these signals at the various radiation monitoring stations. For example, the gamma-ray dose rate, neutron dose rate, and total accumulated dose at the radiation monitoring station located at beam port 01 (BP01) are expressed herein as gBP01, nBP01, and dBP01, respectively. For this study, we assessed these signals at three radiation monitoring stations, namely BP01, BP47, and BP43, which are downstream of the LINAC to Booster (LTB) transfer line, outboard of the LTB, and outboard of the elliptically polarized undulator (EPU), respectively (Fig. 2).

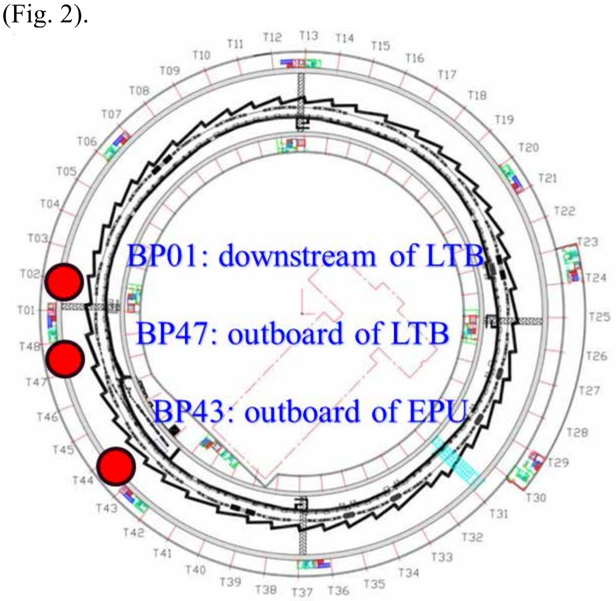

Figure 2: Location of radiation monitoring stations.

RESULTS FOR EACH SCENARIO

The results for each scenario are presented in Figs. 3–7. To help distinguish between the signals associated with the accelerator parameters, these figures indicate *BRC*, *SRC*, and *InjEff* signals in purple, light blue, and orange, respectively. Moreover, to help distinguish between the radiation signals, these figures indicate the *g*, *n*, and *d* signals in blue, green, and red, respectively.

Scenario 1: Shutdown

In this scenario, we assessed radiation signals at BP47 on September 25, 2022. We noted that the *BRC*, *SRC*, and *InjEff* values were all 0 (Fig. 3), indicating that the machine at the facility was not in operation. The *g* and *n* values were approximately 0.1 and 0.01 µSv/h, respectively. Moreover, the *d* value was approximately 0.1 uSv/h averaged over 4 hours. Accordingly, in this scenario, *g*, *n*, and *d* were considered to constitute background radiation signals in the TPS; these are similar to the background radiation levels in most areas in Taiwan.

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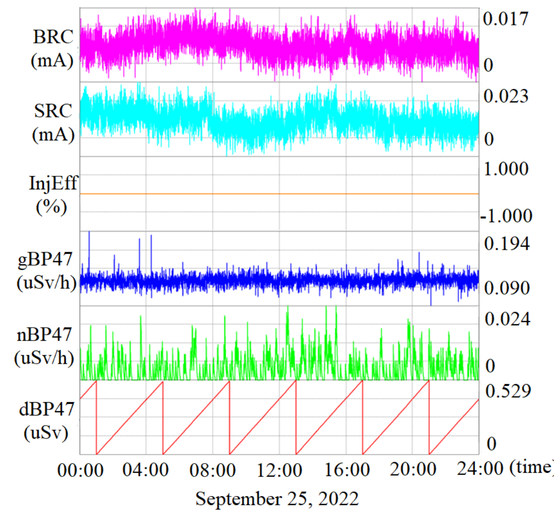

Figure 3: Machine shutdown.

Scenario 2: Injection Mode (Efficient)

In this scenario, we assessed radiation signals at BP01 on October 30, 2022. In Fig. 4, the average *BRC* and *InjEff* values were approximately 0.6 mA and 85%, respectively. The *SRC* value ranged from 0 to 500 mA. Additionally, the *g* and *n* values were approximately 0.8 (maximum) and 0.05 (maximum) µSv/h, respectively. The *d* value was approximately 0.1 µSv/15 min (9:00-9:15). These dose rates and the accumulated dose are low and close to background radiation levels at the TPS.

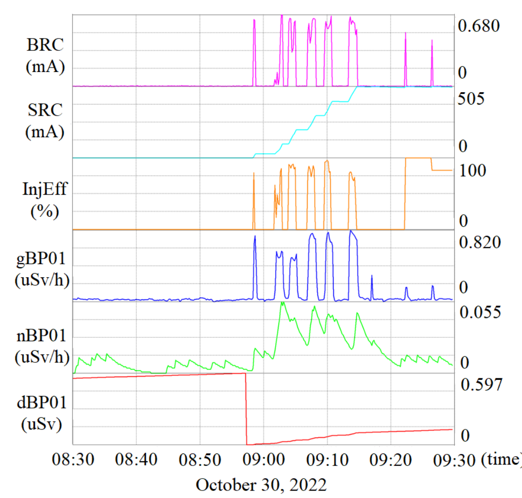

Figure 4: Injection mode (efficient).

Scenario 3: Top-up Mode (Efficient)

In this scenario, we assessed radiation signals at BP01 on November 2, 2022. The average *BRC* and *InjEff* values were approximately 0.6 mA and 90%, respectively. The *SRC* value was approximately 500 mA. Furthermore, the *g* value observed without injection was approximately 0.1 µSv/h, and that observed with injection was nearly 0.2 µSv/h (Fig. 5); the value observed with injection was approximately double that observed without injection. Accordingly, the average *g* value was approximately 0.15 µSv/h. The average *n* value was approximately 0.02 µSv/h.

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The d value was approximately 0.6 µSv/4 h. These dose rates and the accumulated dose are low and close to background levels at the TPS.

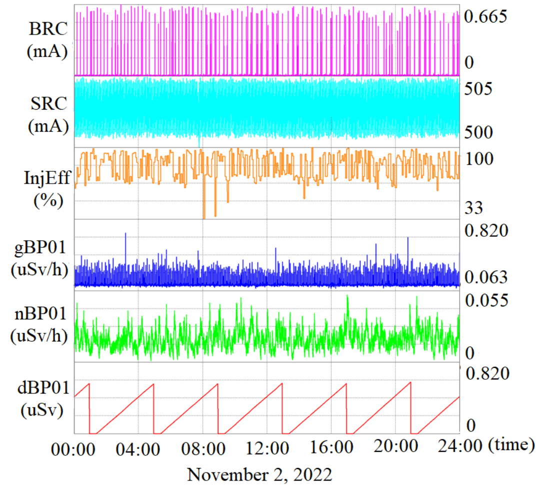

Figure 5: Top-up mode (efficient).

Scenario 4: Injection Mode (Inefficient)

In this scenario, we assessed radiation signals at BP47 on May 14, 2022. The average *BRC* and *InjEff* values were approximately 0.7 mA and 55% (avg), respectively. The *SRC* value ranged from 0 to 250 mA. Additionally, the maximum g and n values were nearly 6 and 25 µSv/h, respectively. The d value was approximately 1.8 µSv/2 h. (18:20-20:20) When *InjEff* was low, the g, n, and d values were high, approximating the limit set for the TPS (2 µSv/4 h; Fig. 6). Notably, we observed that when *InjEff* was low, n was not negligible. Furthermore, the n value was noted to be higher than the g value.

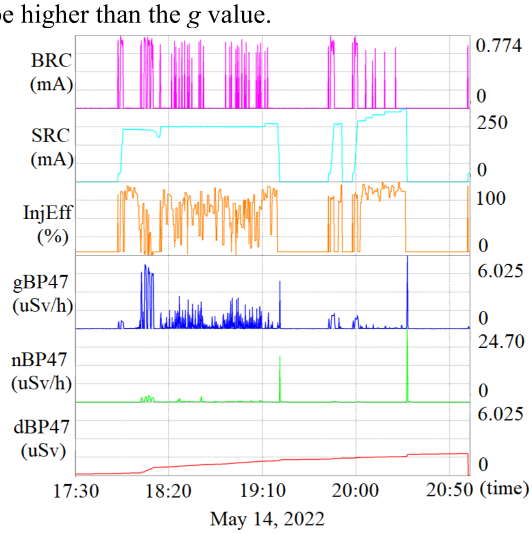

Figure 6: Injection mode (inefficient).

Scenario 5: Beam Trip

In this scenario, we assessed radiation signals at BP43 on April 5, 2022. The average *BRC* and *InjEff* values were both 0 (no injection). The *SRC* value decreased from 150 to 0 mA. In addition, the g and n values were approximately 2,500 (maximum) and 1.5 (maximum) µSv/h. The d value was approximately 3.5 µSv/min (Fig. 7). These results indicate that the dose rate and accumulated dose were considerably high.

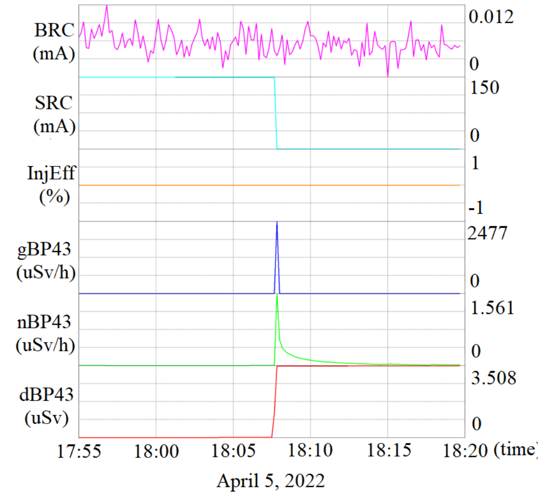

Figure 7: Beam trip.

CONCLUSIONS

We assessed radiation dose rates and accumulated doses in five scenarios. The results reveal that in all scenarios, the background g value was approximately 0.1 µSv/h, n was approximately 0.01 µSv/h, and d was approximately 0.1 µSv/h. When *InjEff* was higher than 85% in both injection mode and top-up mode, radiation levels were low and were noted to be similar to background levels. When *InjEff* was low, radiation levels were high. Accordingly, the accelerator should not be operated with inefficient injection or inefficient top-up mode for long periods without pause, and machine problems should be solved promptly to increase efficiency. Because all of the monitors are in an area that is regularly accessible, a high level of radiation increases—unnecessarily and detrimentally—the radiation dose to user on site. Furthermore, once the accumulated dose exceeds the limit for the NSRRC (2 µSv over 4 consecutive hours), the interlock will be triggered, and the injection process is stopped immediately. The LINAC in unable to perform injection again until the next time shift. In beam trip scenario, hot spots with high radiation levels appeared. Therefore, in beam trip or dump beam mode, operators should pay particular attention to radiation safety. Finally, we observed that in Scenarios 4 and 5, the neutron dose rates were considerable and occasionally higher than the gamma-ray dose rates.

During various scenarios, both on-site user and machine operators require information on the radiation dose levels in the TPS (3 GeV, 500 mA, and 1-m-thick concrete shielding walls). However, no data have been compiled for TPS user reference. Our objective in preparing this article was to provide a source of information for on-site users and machine operators in the TPS and enable them to determine the radiation dose rate and accumulated dose they might receive in five commonly occurring scenarios. We hope our efforts minimize the unnecessary exposure of individuals to radiation.

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