Radiation Protection for the Commissioning of Taiwan Photon Source

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Abstract

Taiwan Photon Source (TPS), a 3GeV synchrotron accelerator with circumference of 518m, had completed the installation of accelerator components in August 2014 and the commissioning was commenced. Several phases of commissioning have been planned and radiation control program for each phase has to be implemented to ensure radiation safety. Both hardware radiation safety system and administrative control procedures have to be effectively performed to mitigate the radiological impacts due to dynamic commissioning situations. This paper describes the current status of TPS commissioning and highlights some important radiation protection practices.

1. Introduction

We have two synchrotron accelerators in the campus of National Synchrotron Radiation Research Center (NSRRC) in Taiwan. Taiwan Light Source (TLS) operating at 1.5 GeV, 360 mA top-up mode in an electron orbit of 120meters has been providing high quality synchrotron to more than 20 branch beamlines for two decades. With all the beam ports been occupied and limited space for further upgrade, a new synchrotron accelerator was planned to cope with the increasing demand from our users. TPS has been commissioning since August 2014 and will be operated at 3 GeV, 500 mA top-up mode with circumference of 518 meters [1]. TPS will be able to deliver extremely bright synchrotron light to a maximum of 48 beamlines for various disciplines of scientific research.

It takes more than ten years to make TPS project into reality and the milestone of TPS is shown in Table 1. We started TPS planning in 2004 and went through a lot of preparation work and review process before ground breaking in 2010. Then, we spent 4 years in civil construction and utility installation. At the same time, we have to maintain safe and smooth operation of TLS. Finally, the first phase of TPS commissioning started in August 2014 and concluded in March 2015 with stored current reaching 100 mA. Currently, we are installing 10 insertion devices for 7 beamlines and two super-conducting RF cavities. There are a lot of issues that require the involvement of radiation safety personnel which are marked in Table 1.

2004	TPS plan initiated
2007	TPS proposal approved by government
2008	Accelerator design finalized※
	Environment impact assessment approved by EPA※
2009	Civil construction and utility system contracted out
2010	Radiation safety analysis report approved by AEC※
	Ground breaking
2011	LINAC acceptance test※
2013	SRF acceptance test※
	Beneficial occupancy, phase I accelerator installation started※
2014	Permission of TPS commissioning granted by AEC※
	TPS commissioning started since August※
2015	100mA stored current achieved※
	Phase II accelerator installation: 10 IDs, 2 SRF and 7 BLs

Table 1 - Milestone of TPS project and issues related with safety are marked with.*

2. Radiation Safety Control Plan

The configuration of TPS is a typical donut shape as shown in Fig. 1. But unlike most facilities, we have research staff and users in the Research Building which is contained inside TPS and we also have administrative staff and top executives in the Administrative Building right next to TPS. Machine staff will directly involve in the radiological activities during TPS commissioning, research and administrative staff will also work in the vicinity of TPS. Therefore, radiation safety is a concern to almost everyone in our facility.

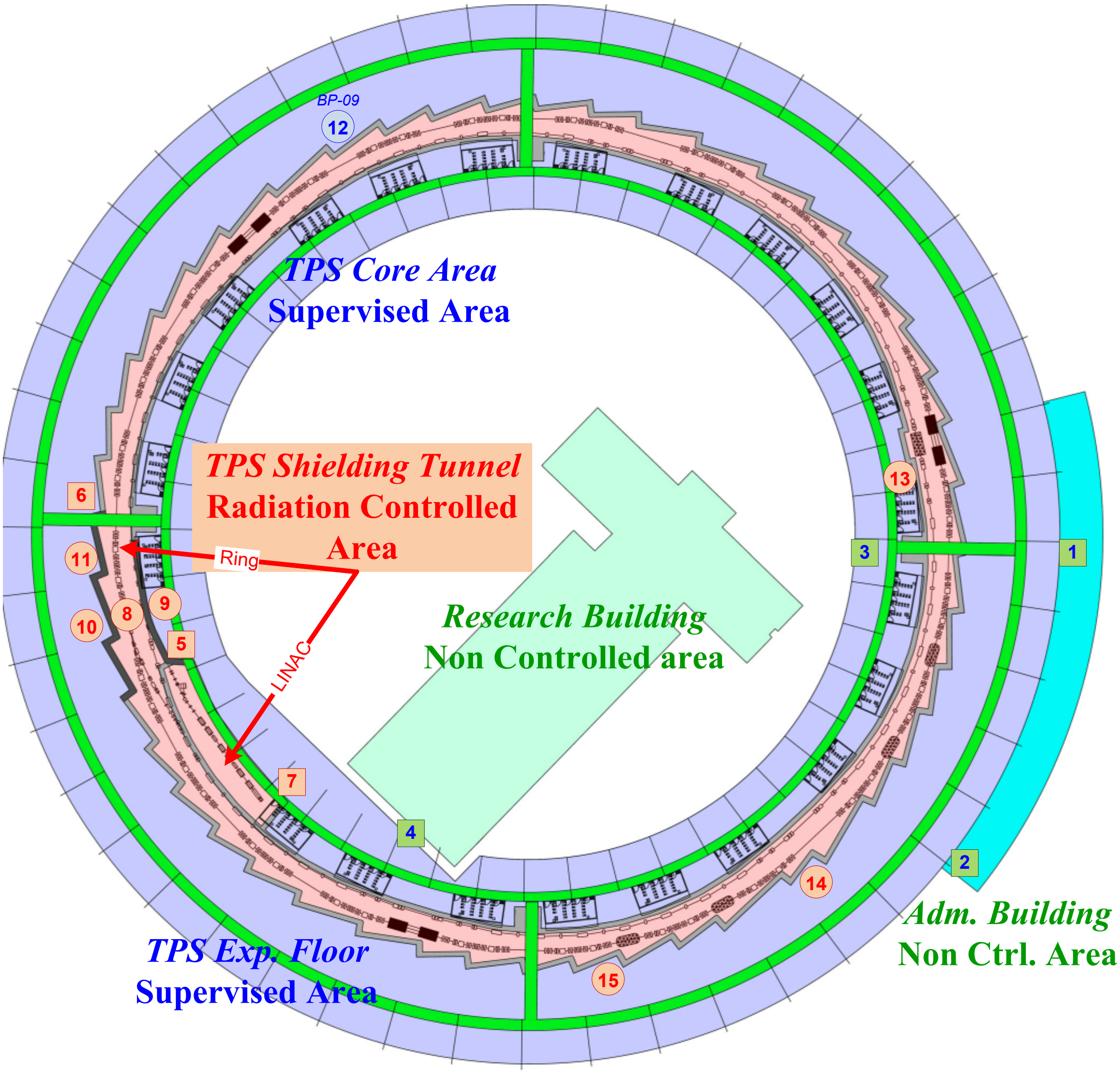

Fig. 1 – The layout of TPS and detector deployment.

2.1. Area Classification

TPS has concentric shielding tunnel to house the storage ring and the booster which is mounting on the inner wall. The stand-alone LINAC area is attached to the ring with same shielding ability. All these areas are classified as Radiation Controlled Area [2] and protected by access control interlock system to make sure no access during operation. The experimental floor and the device area which are painted in purple as shown in Fig. 1 are Supervised Area. We have installed interlocked radiation monitors with both gamma and neutron detectors on the shielding wall and only radiation workers are allowed to work in the Supervised Area. Administrative Building and Research Building, although in the vicinity of TPS, are classified as Non-Controlled Area or Free Access Area that every individual including visitors may access these buildings freely. Several interlock radiation monitors were deployed in Free Access Area to ensure radiation safety during TPS commissioning.

2.2. Dose Limit

It is NSRRC's safety policy that the dose limit for non-radiation worker during TPS commissioning is 1 mSv in a year [3] and this limit will also be applied to the future routine operation. The ALARA dose limit for radiation worker during TPS commissioning is 5 mSv in a year which is a quarter of regulatory limit for radiation worker 20mSv/a. To achieve the goal of radiation protection, we assume each individual will work 2000 hours in a year and we have obtained the dose date limit 0.5 μ Sv/h for Free Access Area and 2.5 μ Sv/h for Supervised Area. Furthermore, to implement these operation quantities into interlock circuit, it is agreed in our Safety Committee to accumulate the dose signal from both gamma and neutron detectors within 4 hours. As soon as the accumulated dose has exceeded 2.0 μ Sv for those monitoring stations in Free Access Area or 10 μ Sv in Supervised Area, the LINAC will be disabled to make sure no electron can be generated and excessive radiation will be terminated. The time duration of 4 hours is a balanced choice between the flexibility of machine operation and the management of radiation protection, which has been widely used in synchrotron facilities and also successfully implemented in TLS for over ten years.

Some high radiation situations may be inevitable due to solution finding, error correction or high power test that the interlock limit may hamper the commissioning progress. For these temporary tests been planned in advance, we may raise the interlock limit to 40 μ Sv per four hours for those detectors on the shielding wall. However, our facility director must approve this application and the supervised area has to be evacuated. Fortunately, we had only two occasions of 8 hours in total requiring the raise of dose limit during the first phase of TPS commissioning from August 2014 to March 2015.

2.3. Interlocked Radiation Monitor

We have deployed 15 interlocked radiation monitors during TPS commissioning featuring FHT191N ion chamber and FHT762 neutron detector at each monitoring station. Due to the unique building arrangement in the TPS complex, four monitoring stations (#1 ~ #4) are located at high occupancy area as shown in Fig.1 and the position remark is illustrated in Table 2. Triggering signal will be activated if the accumulated dose for any of these four monitoring stations exceeds 2 μ Sv within four hours. The other eleven stations are located on the shielding wall at different locations with interlock limit setting at 10 μ Sv for four hours. The locations are selected considering potential high radiation intensities may occur such that radiation safety control can be conservative. We predict high beam loss locations based on our operation experience of TLS to reflect the worst possible radiation distribution.

Detector	Position illustration
1	Entrance to TPS in the lobby of Administrative Building
2	Corridor to parking lot in Administrative Building
3	Gate to the lobby of Research Building in TPS
4	Passage to TPS in the junction of TPS and Research Building
5	Downstream of LINAC beam dump
6	Downstream of LTB and ring injection trajectory at Beam-Port 01
7	Entrance of LINAC maze
8	Roof of BTS
9	LINAC To Booster injection area, at 90 degree with respect to beam direction
10	Outboard of BTS, ~90 degree to the injection trajectory at Beam-Port 47
11	Downstream of BTS, at Beam-Port 48
12	Downstream of 12m long straight at Beam-port 09
13	Booster RF, at core area Pillar 23
14	Downstream of RF#2, at Beam-Port 31
15	Downstream of RF#3, at Beam-Port 35

Table 2 – The deployment of interlocked radiation monitors in TPS. LTB denotes LINAC To Booster transfer line and BTS denotes Booster To Storage ring transfer line.

3. Control Procedures and Measurement Results during TPS Commissioning

Radiation control procedures vary with the progress of the TPS commissioning stages which started with LINAC and followed by booster and finally storage ring. Some important safety control and measurement results are illustrated in this section.

3.1 LINAC

The acceptance test of LINAC has already completed in 2011 in another test site with equal shielding ability as TPS, and a lot of beam tests and radiation measurements have been studied. We have found the radiation intensity from mis-steered beam of 150 MeV, at 5 nC, 3 Hz on the shielding wall is not acceptable whose dose rate may exceeding 7000 μSv/h outside 1 meter of concrete wall where electrons were parked [4]. Therefore, we have installed lead shielding of 20cm in thickness surrounding the dipole, as shown in Fig.2, at three sides, leaving one line of 11 degree to booster and the other line of 31degree into the dump. This will eliminate the possibility of mismatch between dipole strength and electron energy that may cause unexpected high radiation.

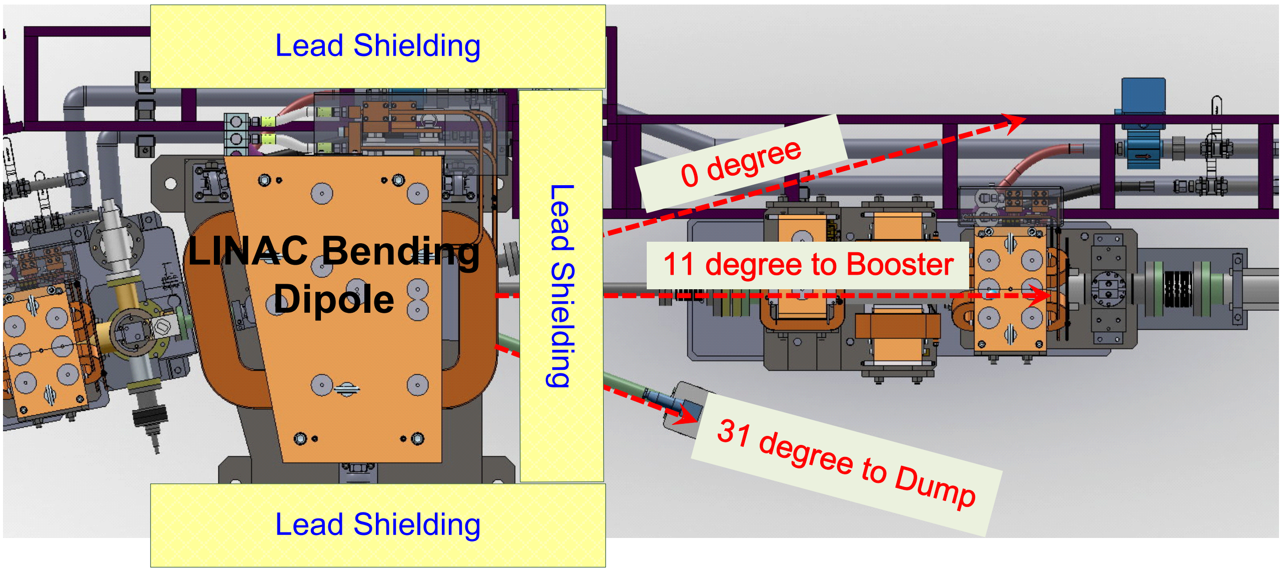

Fig. 2 – Local shielding surround LINAC bending dipole.

The Safety Envelope of LINAC operation requires that the power supply to the bending magnet must be regulated and the position of LINAC To Booster (LTB) safety shutter must be closed in safe position during LINAC commissioning or stand-alone operation. We have implemented interlock protection mechanism for the LINAC dipole and safety shutter as shown in Fig.3. To prevent mis-steered beam, the power supply to bending dipole can be operated at two windows, either at current rating of 80 amp ± 10 amp for 11 degree of bending angle or at 227 amp for 31 degree of bending angle. Safety shutter at the end of LINAC is a critical component to contain electron and has to be controlled by proper interlock mechanism. To enable LINAC safety shutter, the access control system for the booster and storage ring must be secured and ready, also the dipole operation window must be set correctly for electron beam to bend at 11 degree. Otherwise, the shutter is not allowed to open during stand-alone LINAC test into beam pump.

With these precaution measures, the commissioning of LINAC after relocation into TPS took only one night and electron beam was successfully injected into booster.

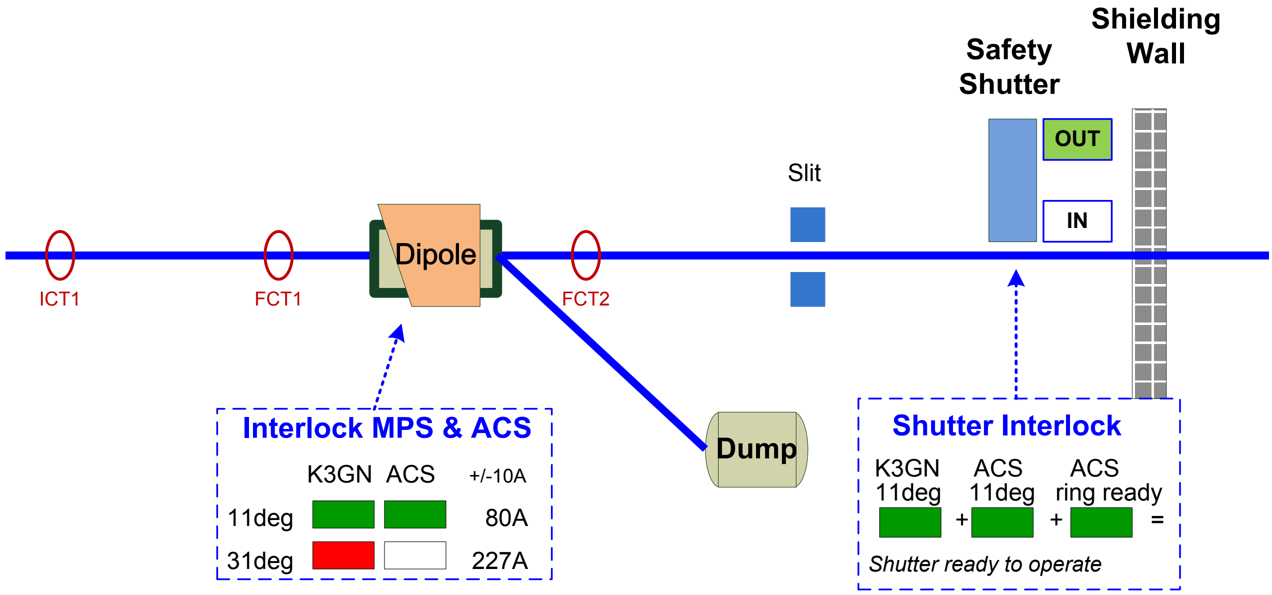

Fig. 3 – Interlock scheme to LINAC bending dipole and safety shutter.

3.2 Booster

The commissioning of booster followed right after LINAC from early August to the end of November 2014 without tangible outcome. Neither beam accumulation nor ramping was achieved during these 4 months of painful struggle. A lot efforts from radiation safety have contributed to the identification of beam loss pattern, such as residual activity measurement and real time radiation monitoring on top of booster orbit. However, no conclusive finding was helpful to the commissioning until the magnetic permeability of the booster chamber made of 304 stainless steel was confirmed out of specification. All the booster chamber, more than 100 pieces, were disassembled and put into thermal treatment up to 1050 degree Celsius to de-magnetize. After reassemble the booster in mid-December 2014, we had stored beam on December 12th and successfully ramp up to 3 GeV on December 16th. From radiation detection point of view, we have detected the first ever record that neutron dose rate is higher than gamma at TPS booster injection septum, as shown in Fig.4, where radiation detector is at 90 degree with respect to the direction of 3 GeV electron hitting the septum [5].

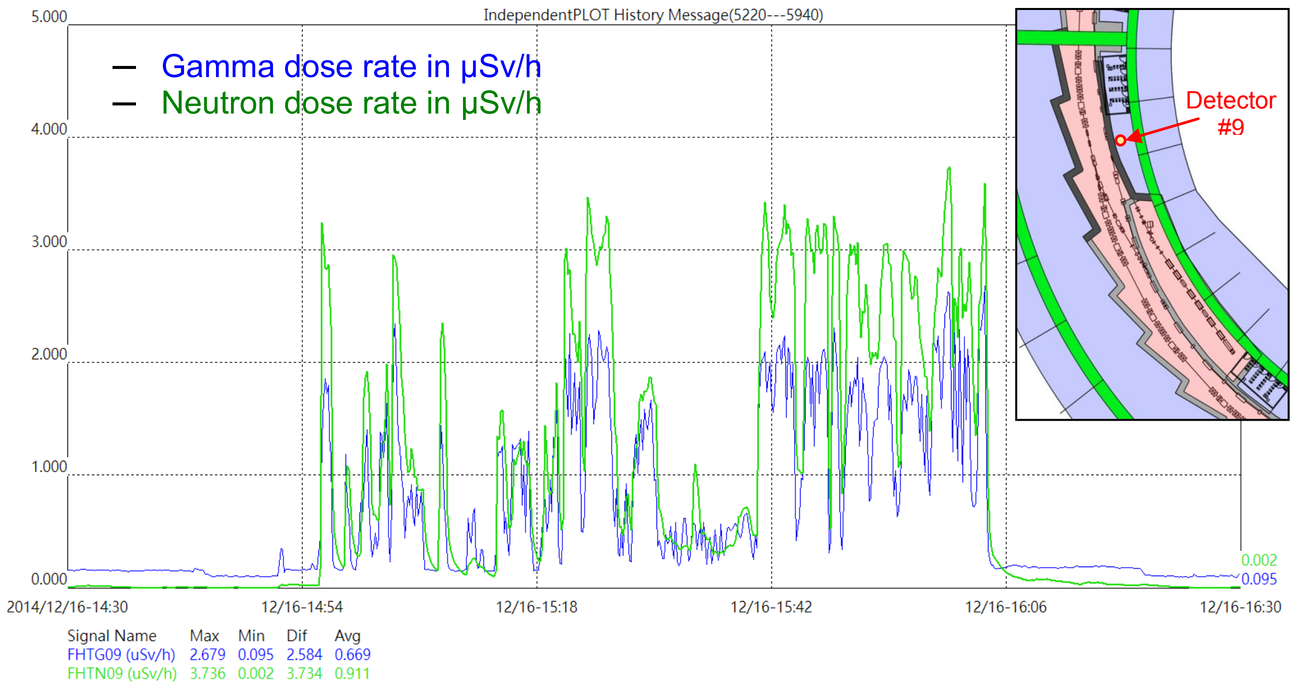

Fig. 4 – Dose rate measured at booster injection septum.

In TPS, no dedicate beam dump nor designate aperture was designed to terminate electron beam during booster operation. Therefore, notable dose can be detected outside the shielding wall where electrons are constantly lost, such as booster injection septum. Although the commissioning of booster does not take long period of time and will not be performed in a regular base, accelerator physicists have worked out a ramp down scheme for booster test that will reduce the electron energy to less than 1.5 GeV before electrons are dumped.

3.3 Storage Ring

The commissioning of TPS storage ring started in the bottom of December 2014 at a steady pace. Just two weeks later, the first synchrotron light had illuminated from TPS at the New Year eve of 2015. To coordinate commissioning coherently and safely, we have enforced a Beam Authorization Process (BAP) to disclose necessary information on the commissioning detail, hazard and safety precaution, comment from supporting group and the review. This BAP significantly avoid possible safety conflict by proper time allocation, area control and personnel notification. All the commissioning schedule together with the work plans performed in TPS are summarized in a web bulletin which can be easily accessed from NSRRC intranet. Not only the pre-work review is vital, checks during the work and after the work also play an important role to minimize possible deviation from normal machine operation envelope.

There are different commissioning steps for TPS storage ring, such as booster extraction, booster to storage ring transfer, ring injection, beam storage etc., that may lead to different beam loss scenarios and resultantly various dose distribution. The highest radiation area during TPS storage ring commissioning is the injection area where beam loss due to injection loss dominates. As shown in Fig. 5 is a typical dose distribution at downstream of injection section (detector #11) during injection to 50 mA where LINAC extraction current was 0.4nC and the overall injection efficiency from booster to storage ring was about 80%. The gamma dose rate reaching 0.4μSv/h during 3 times of injections. The green line shows the neutron dose rate which is lower than that of gamma, except during a short moment at 10:15 that the power supply to the injection dipole failed and caused beam loss locally. The blue line shows the integrated dose every 4 hours, gamma and neutron combined. The integrated dose for March 25th from 8 o'clock to 12 o'clock is less than 1 μSv which includes 3 times of injection to 50 mA and 3 times of beam dump, plus two periods of injection difficulties due to machine malfunctions.

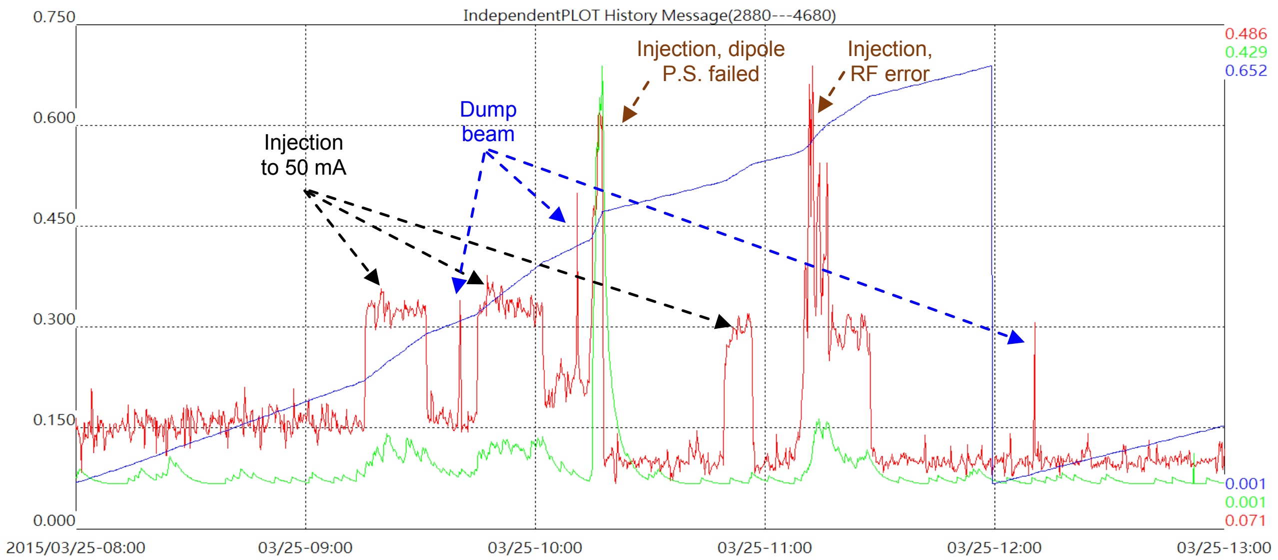

Fig. 5 – Dose distribution at downstream of injection section during injection study, gamma dose rate in red and neutron dose rate in green (unit: μSv/h), accumulated dose every four hours in blue (unit: μSv).

In addition to the monitoring network featuring interlocked radiation monitors and passive thermo-luminescent dosimeters in TPS, radiation survey is an important method to locate high radiation area and to verify radiation distribution. With stored current less than 100mA, we have not found any hot spot or unexpected high dose area on the shielding wall during beam storage period.

4. Conclusions

Although we have been through many obstacles during the first phase of TPS commissioning, but the radiation protection program is satisfactory. The monthly readout of personnel dosimeter shows no tracable exposure due to TPS commissioning. Several importan factors have contributed to this success of radiation control. Firstly, beam power has always been reframed as small as possible, for example 1 Hz injection instead of 3 Hz, before machine performance meets our design specification especially injection efficiency and life time. Secondly, the close cooperation between machine staff and safety officer has made commissioning more efficiently and safely, such as deployment of local shielding effectively, radiation measurement on the spot and clear operation information to all staff.

TPS is a powerful third generation synchrotron accelerator that requires careful radiation control and cautious machine operation. Otherwise, radiological impact due to mis-steered beam with excessive beam power and unaware time duration could be significant. We will continue the second phase commissioning after the installation of ten insertion devices and replacing Petra cavity by two super-conducting RF cavities with the same vigilant steps before TPS is open to users in 2016.

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