Radiation measurements during commissioning of SESAME 800MeV Booster Synchrotron

A. Hamad

Synchrotron-light for Experimental Science and Application in the Middle East (SESAME), ALLAN, Jordan
Adli.hamad@sesame.org.jo

Abstract

SESAME, Synchrotron-light for Experimental Science and Applications in the Middle East, is a 2.5 GeV synchrotron light source under construction in Allan- Jordan. Commissioning is foreseen by the end of 2016. At SESAME the ALARA principle is applied by guaranteeing the radiation limits for non-exposed workers of 1mSv/y which corresponds to 0.5µSv/h, for 2000 working hours per year. The Booster synchrotron (former BESY I) is operated at 1 Hz; full electron energy (800MeV, 4mA) has been achieved successfully in 2014. Radiation measurements are performed by using five combined radiation monitors stations (Gamma and Neutron) around and inside booster tunnel in addition to passive monitoring by area and personnel TLD's. Total Photons and Neutrons dose rates and accumulated doses have been carried out during commissioning for different injection schemes.

1- Introduction

This document describes the radiation measurements around the booster tunnel during the commissioning of SESAME's injector (Microtron at 20MeV and the Booster 20-800MeV electron energy), during 2014.

As well known the SESAME accelerator facility comprises:

1- A 22.5MeV circular microtron.
2- The transport line from microtron to booster (TL1)
3- A 800MeV booster synchrotron.
4- The transport line from booster to storage ring (TL2).
5- A 2.5GeV storage ring.

2- Operational permit

SESAME was aware about the commitment toward Jordanian radiation authority to not start commissioning unless we have their approval to start and throughout the head of safety group SESAME has contacted Energy and Mineral Regulatory Commission (EMRC) for this purpose and they send us the operational permit and after submitting this file to them we expect to get operational Microtron and booster license.

3- Shielding objectives

The basic principle of radiation protection is the ALARA (As Low As Reasonably Achievable) principle, which states that exposure to any person should be kept as low as reasonably achievable. At SESAME the ALARA principle is applied by guaranteeing the radiation limits for non-exposed workers (1mSv/y, corresponding to 0.5µSv/h, for 2000 working hours per year or 2µSv during 4 hours shift periods), except in controlled areas where access will not be possible during operation.

The standard analytical shield models [1, 2, 3] have been used for the SESAME shielding calculations. These standard models give an expression for the effective dose rate in a point behind a shield wall due to a local beam loss of a given power or number of electrons losses per unit of time:

Keeping in mind both the Microtron and the booster had been operated over many hours on daily basis, however, in the normal operation we are going to operate both accelerators for not more than one hour daily and hence all measured values in this document are belong to commissioning phase only. All staff member especially those which were involved in the commissioning period (directly or no) are enforced to wear three kinds of passive personnel dosimeters: see fig.1 below

1- JAEC/ whole body/ photon.
2- SESAME/ DIS-1 from RADOS/ Hp (10) and Hp (0.07)/ photon and electrons.
3- LANDAUER/ INLIGHT+NEUT-T 3M /photon and neutrons.

Fig.1: different types of personal dosimeters used at SESAME

All recorded values which concern personnel and area monitoring were being archived.

4- Personal Safety System (PSS)

PSS restrict and control the access to forbidden areas while accelerators (Microtron and Booster) in operation.
It also surveys any anomaly and trips accelerators and / or beam lines if any safety conditions is not fulfill or goes to an unauthorized state.
PSS is consisting of:

1- Radiation Monitoring System.
2- An Access Control System.
3- An Interlock System.

The PSS is an independent from any other system in the facility.
The personal safety system is based on PLC technology fail safe configuration, redundant and diversity to increase the reliability and safety of the system.
Each identified hazard will be controlled by two independent methods, either of which will make the hazard safe. Each method will function by inhibiting the operation of two of the fundamental of the associated equipment. For example, to prevent stored beam we may inhibit the RF and the dipole magnets. The RF is inhibited by removing the drive signal and by inhibiting the high voltage, while the dipole power is also inhibited by two techniques. In this way each hazard is made safe by four independent actions.
The system has been officially engaged in the commissioning from first of JUNE-2014.

Before PSS implementation administrative procedures were taken deeply and carefully in consideration to make sure that nobody is inside the booster tunnel before turn on the Microtron.

Each one in the commissioning shift team has been trained and asked to comply totally with the procedures under supervision of the shift leader.

5- Live Radiation Monitoring System (LRMS)

Five combined (Thermo-Scientific) photons and neutrons trolleys monitors (in an open zones) and mobile gamma radiation monitors from the same company (in some crowded zones) have been used to supervise and measure the radiation levels around the booster tunnel during all shifts, the information (Total Gamma and Neutron Dose rate and Total Accumulated Dose / 4 hours shift) are directly transmitted to the control room only by using the combined monitors and noticed using specific screen by the shift leader during the shift periods and by the radiation safety officer in details in coming morning (RSO is on call during the shift periods and the leader shift is well trained for the dealing with radiation monitors).

The most in advance critical losses points were taken in to account are: see figs.2a, b, c, d, and e.

1- On the booster roof above the Microtron, (temporary).
2- On the roof above the injection septum (permanent).
3- Inside the booster service area (Pool), (permanent).
4- Inside the storage ring next to the combined shielding wall (four main positions)
5- In the main service area (two main positions)

6- Passive Radiation Monitoring System (PRMS)

A 23 LANDAUER/ INLIGHT+NEUT-T 3M AMP/ passive combined photons and neutrons dosimeters have been distributed in the critical points inside, outside the tunnel, across main building and outside the building in order to have an idea about the radiation level during long periods of time of operation and all these date will be archived and kept at SESAME as well as for personal dosimeters.

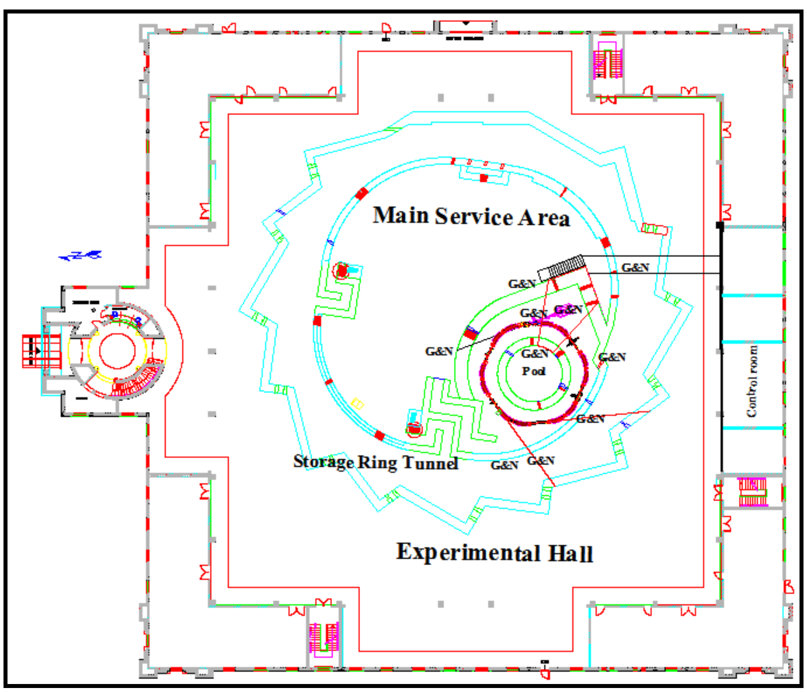

Fig: 2a. Locations of radiation monitors around the booster tunnel, five positions at the same time.

Fig: 2b. Next to booster door

Fig: 2c. On both bridge and Microtron roof.

Fig: 2d. In the main service area.

Fig: 2e. In the storage ring, different places.

7- Commissioning safety strategy

The operations in the beginning were carried out during night shifts, so, no one is allowed to enter the whole area unless we make sure about the radiation levels around the whole booster tunnel, and we scanned first the bridge, Microtron roof, and main service area, pool and booster roof then storage ring finally.
After the main service area, roof, Storage ring tunnel were scanned at many times and different injection schemes we permitted for the shift worker to have an access only to the main service area and we prevented any body from entering the roof and hence the pool and Storage ring when the booster is in operation and a steel door has been installed on the bridge to prevent workers from entering the booster roof at all.

8- Sources of radiation inside the tunnel

8-1 Injection septum:

Because the Microtron is usually operated at 10 Hz as a repetition rate and the Booster is running at 1Hz, we speculate to have high electron losses throughout the injection septum which permit only for one shot of an electron beam entering the booster ring and kicks 9 shots outside and hence high radiation levels are foreseen outside the booster tunnel particularly along TL1, zero angle in the direction of service area and at 90 degrees in the direction of main service area, the Booster service area (pool) and the roof above the injection septum, and because both the shielding walls thicknesses along zero angle of TL1 and in the direction of main service area at 90 degrees are 1.5 m of ordinary concrete no radiation levels have been noticed above 0.5μSv/h and because the shielding walls in the other two direction are 1 m of ordinary concrete the radiation measurements showed high radiation levels.

In order to minimize the radiation level outside the tunnel (roof and pool) as much as possible the microtron has been operated at 5 Hz, the measurements showed decreasing in values, nevertheless, the radiation level still above the predefined values which is 0.5μS/h, taken in to account many injection schemes have been used along weeks of working to have a stable electron beam rotating along the vacuum chamber only for one turn.

Finally we managed to operate the microtron at 1 Hz to minimize the losses in the injection septum part as much as possible; fortunately, the readings showed decreasing to safe level, unless total electron beam losses were taken place at any place especially when one of the diagnostic metal plates inserted in the path of electron beam.

8-2 Diagnostic screens for electron beam measurements:

In order to have an idea about the electron beam shape and position at any part in the booster vacuumed chamber tube, we inserted a suitable fluorescent screens (each straight section has one screen) to be in the direction of electron beam directly and hence all the electron beam will be lost at this locations and then high radiation is foreseen outside the tunnel along the beam trajectory (mainly at 0 degree and less up to 90 degrees angle), the most critical screen is the one in the transfer line number one (TL1), since the amount of electrons hitting this screen are five or ten times higher than other screens (fig.3a and b) in the other parts of the booster tunnel because of the injection septum role (this kind of losses were minimized later at 1Hz).

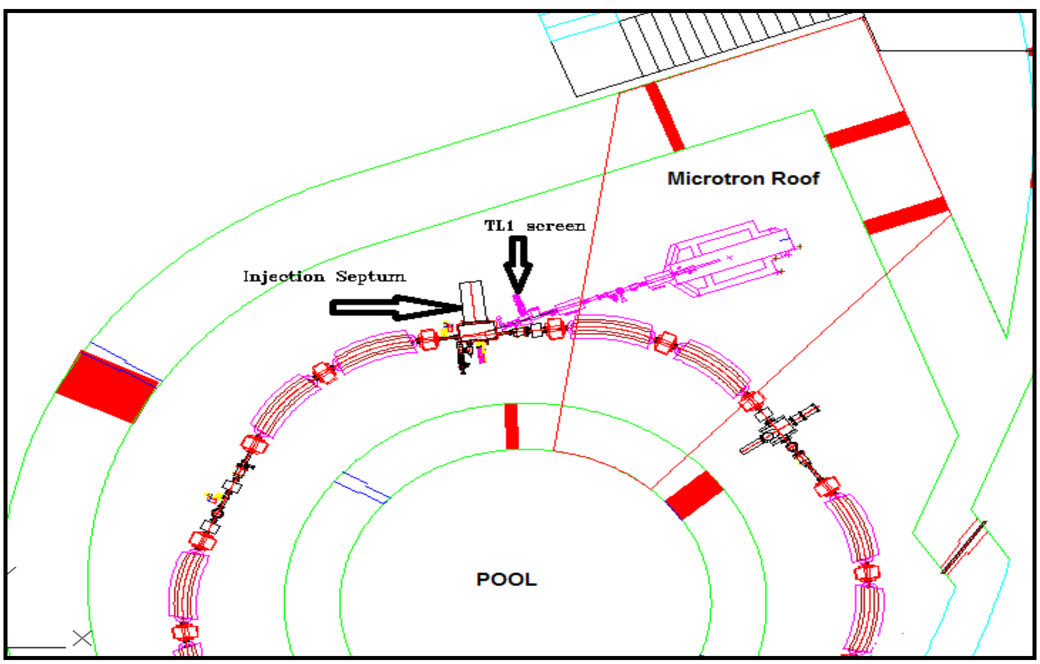

Fig: 3a. Injection septum and TL1 fluorescence screen close to each others.

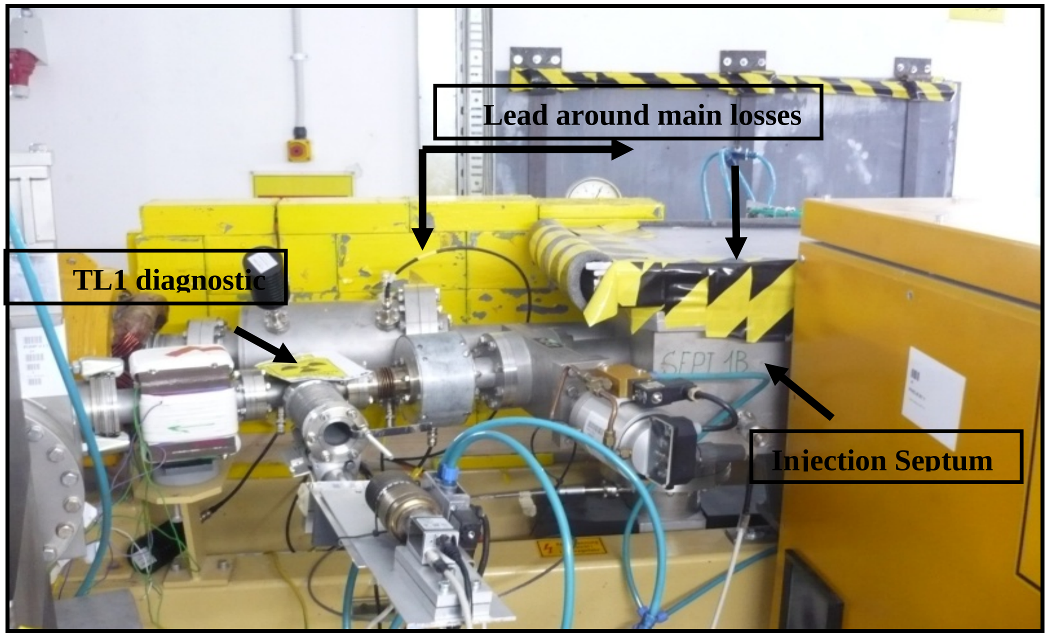

Fig: 3b. Lead plates and bricks around both TL1 diagnostic screen and the injection septum.

9- Radiation levels around the Booster tunnel:

The radiation measurements have been registered and archived during all commissioning shifts, real measurements using 5 combined (photons & neutrons) radiations monitor, two kinds of data have been watched (live values, fig.3.1) easily at any time, acquisition time equal to 2 seconds for each reading:

1- Total dose rates and
2- Total accumulated dose (Gamma + Neutrons)

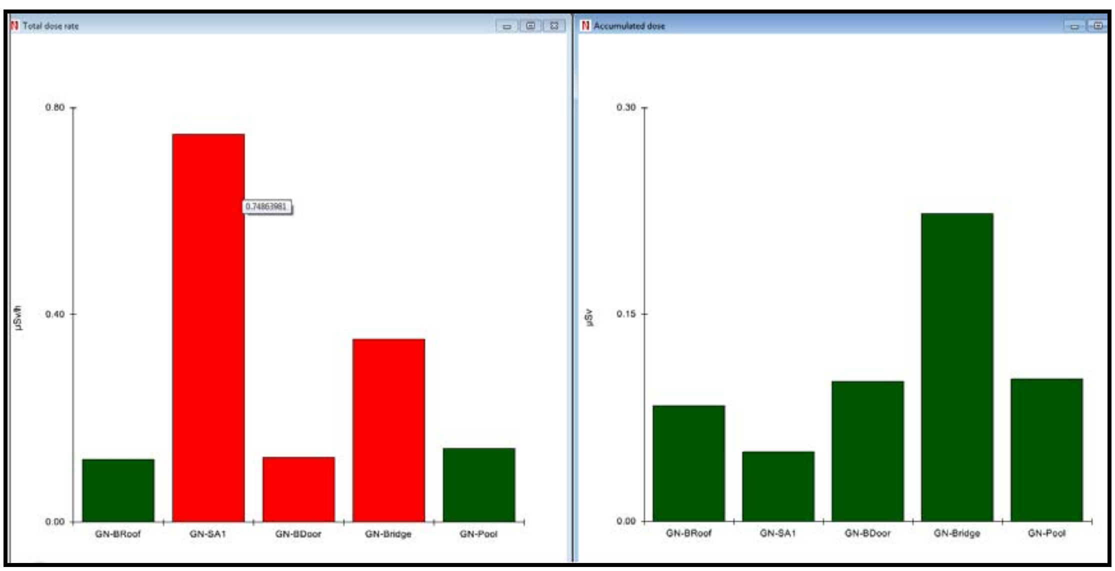

Fig: 3.1. Live values for both total dose rates and accumulated doses.

At any time we can have an idea about:

1- Accumulated total doses over any period of time especially 4 hours shift periods, fig3.2.

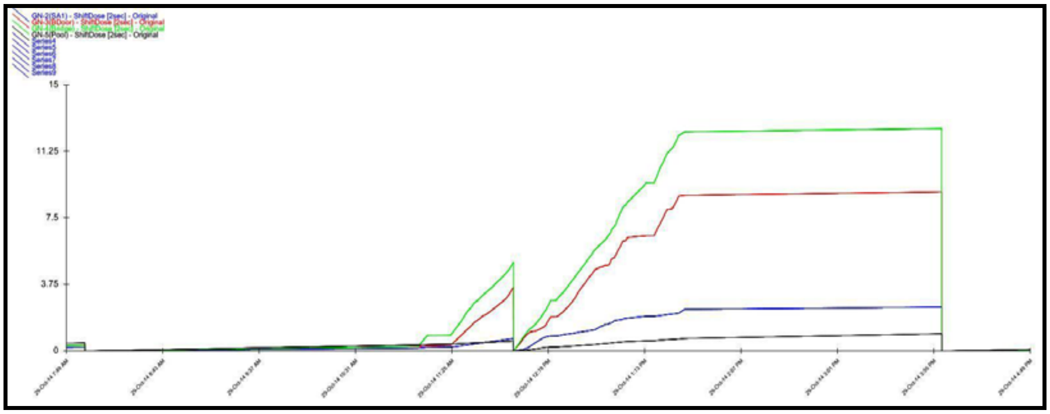

Fig: 3.2. Total accumulated doses during two shift dose periods, 4 hours each.

2- Total dose rates (graphical view) over any time period for both photons and neutrons, fig3.3.

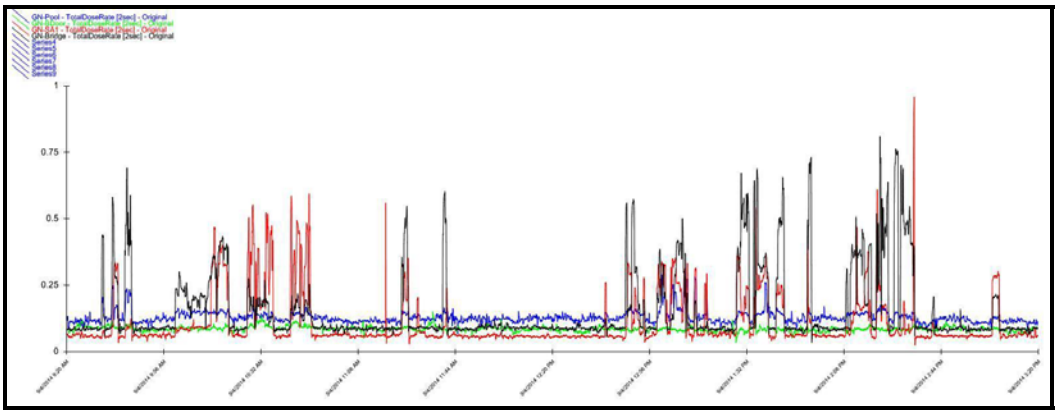

Fig: 3.3. Graphical values for total dose rates over any period of time .

In addition to the most important locations as mentioned before (See Fig.2a), many other locations have been investigated and watched during months of booster operations by using either portable monitors or TLD's.

10- Results and Analysis

-The operations were taken place in three major steps in order:

First: Operating the microtron only at 20MeV at different frequencies (10 and 5Hz).
Second: Injecting electron beam at different frequencies (10 and 5Hz).
Third: Injecting electrons at 1Hz and circulating in the booster ring at 20MeV and ramping electron energy in the booster ring up to 800MeV.
NOTE: all mentioned graphs were included the highest measured values during operations which reflect the worst scenarios of injections, operations and continuous losses over months of commissioning.

First: Operating the microtron only at 20MeV and at different frequencies:

All measured values for the dose rates around the booster tunnel showed safe readings and below predefined value (0.5µSv/h) as a result of single losses inside the Microtron at 10, 5 and 1Hz, Fig 4 shows that the total dose rate on the roof above the Microtron is less than 0.1µSv at 10 Hz and consequently would be at least the same or less for 5and 1 Hz which means that the roof is safe only during Microtron operation, other locations outside the booster tunnel showed safe values.

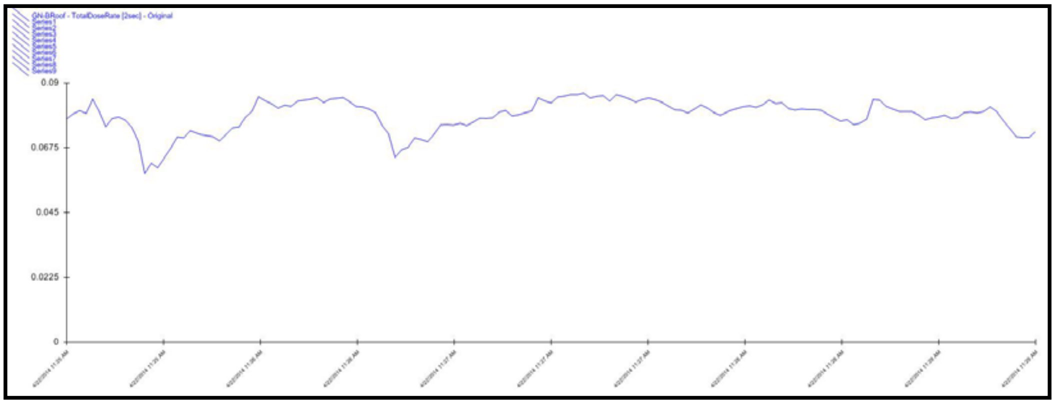

Fig.4: Total dose rate on the roof above the Microtron at10 Hz.

Second: Injecting electron beam into booster ring at different frequencies (10 and 5Hz).

a- Injecting @ 10Hz.

All measured values outside the tunnel and around the injection septum showed high dose rates and less than 15µSv/h, 20µSv/h on the roof and in the pool respectively.

Fig.5 shows that the total dose rate is less than 15µSv/h as a result of TL1 screen losses, this value is much higher than SESAME limit which means during operation of the booster the roof is very critical area otherwise we need to add some shielding to minimize the dose rate below SESAME predefined value.

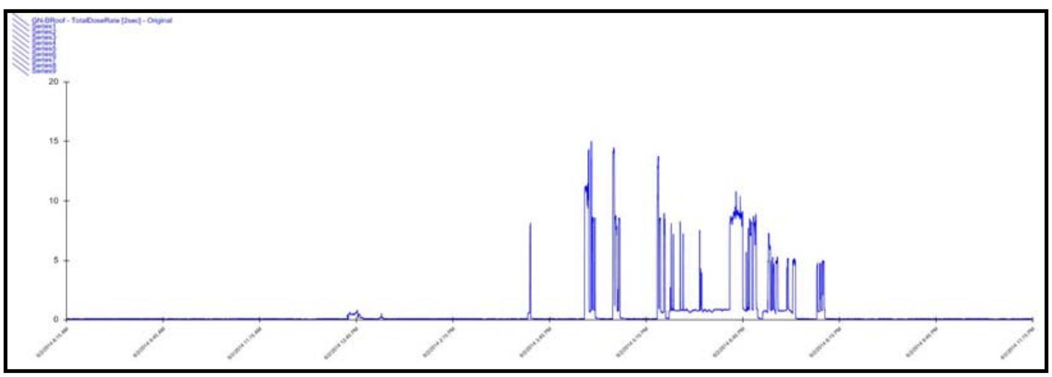

Fig.5: Total dose rate above the roof as a result of TL1 screen losses.

5 cm of lead has been added on the top surface of the injection septum directly, fig.6 shows that the total dose rate on the roof is less than 0.7µSv/h.

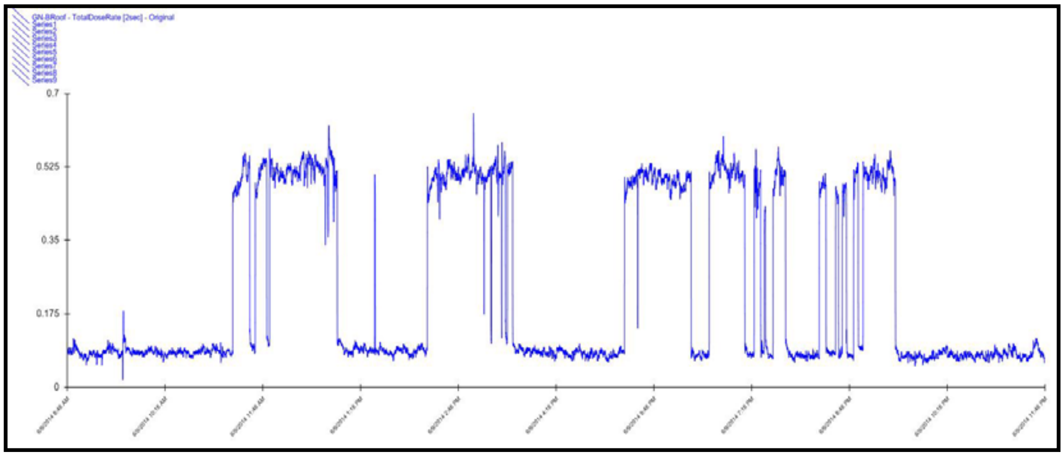

Fig.6: Total dose rate on the roof as result of injection septum losses only.

Fig.7 shows that the total dose rates inside the pool are less than 20µSv/h which is higher than our critical value; this area must be treated as a controlled area during booster operation.

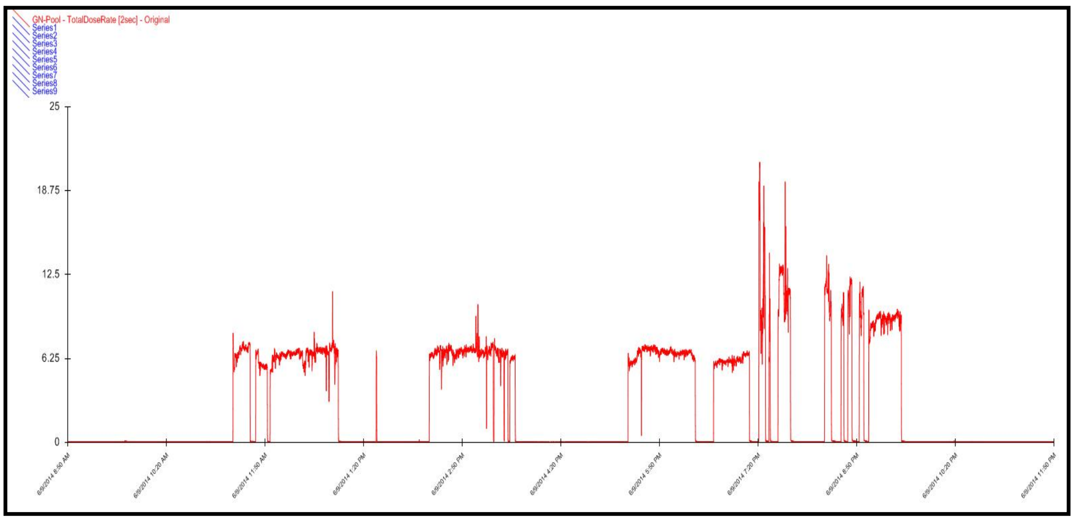

Fig.7: Total dose rate in the pool as result of IS and TL1 screen losses.

Many critical locations inside the storage ring next to combined shielding wall have been chosen to have an idea about the radiation levels inside the storage ring, the most worst two positions have been demonstrated in fig.8a and fig.8 b. which are less than 14µSv/h and less than 6µsv/h respectively, this high dose because the shielding wall has 0.8 m ordinary concrete thickness.

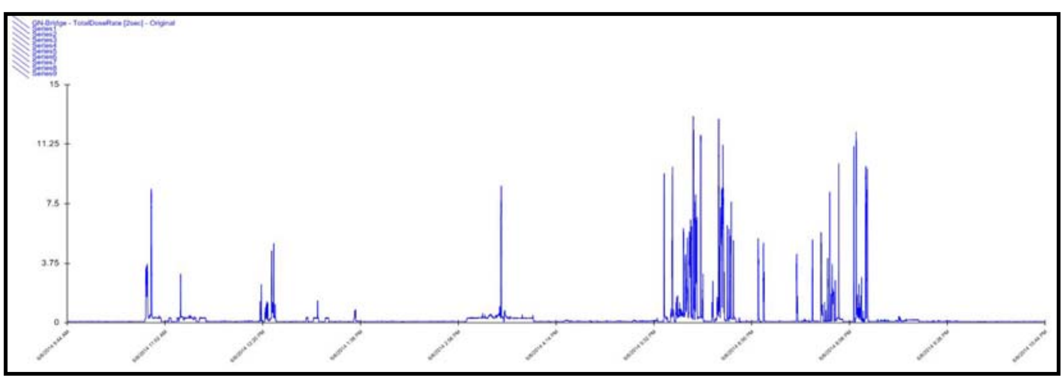

Fig.8a: Total dose rates inside the storage ring during one day shift.

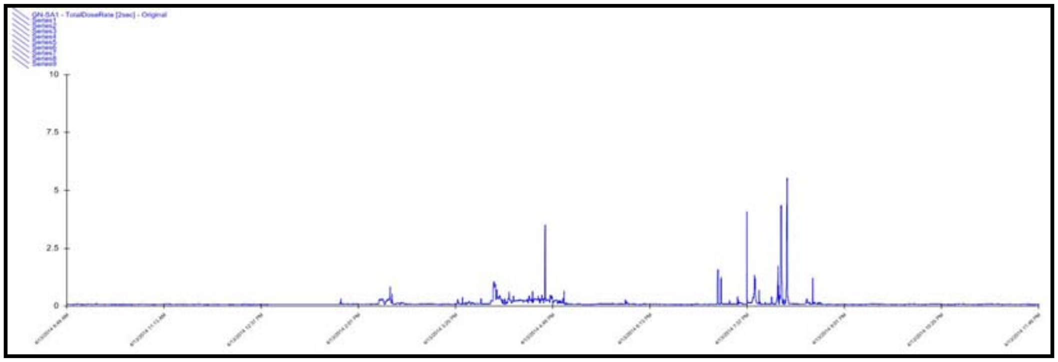

Fig.8b: Total dose rates inside the storage ring during one day shift.

Fig.9 shows that the dose rates just next to the shielding wall (main service area) is below 0.5µSv/h which means that the curved 1.5 m thickness ordinary concrete is enough.

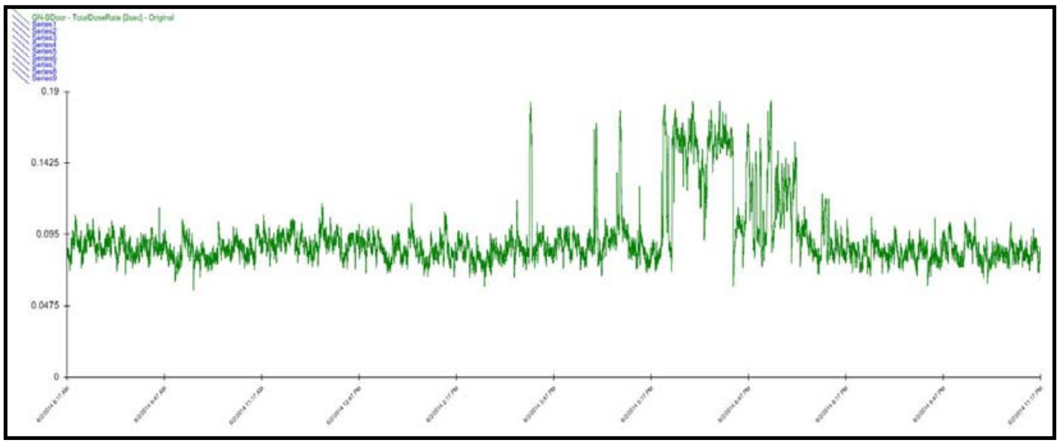

Fig.9: Total dose rates next to the curved 1.5 m ordinary concrete.

To have an idea about the radiation levels around the booster tunnel, fig.10 illustrates the maximum dose rates which have been measured during months of commissioning (different single losses schemes at different locations along the booster ring), Fig.10 shows that main service area, experimental hall and on the microtron roof are totally safe.

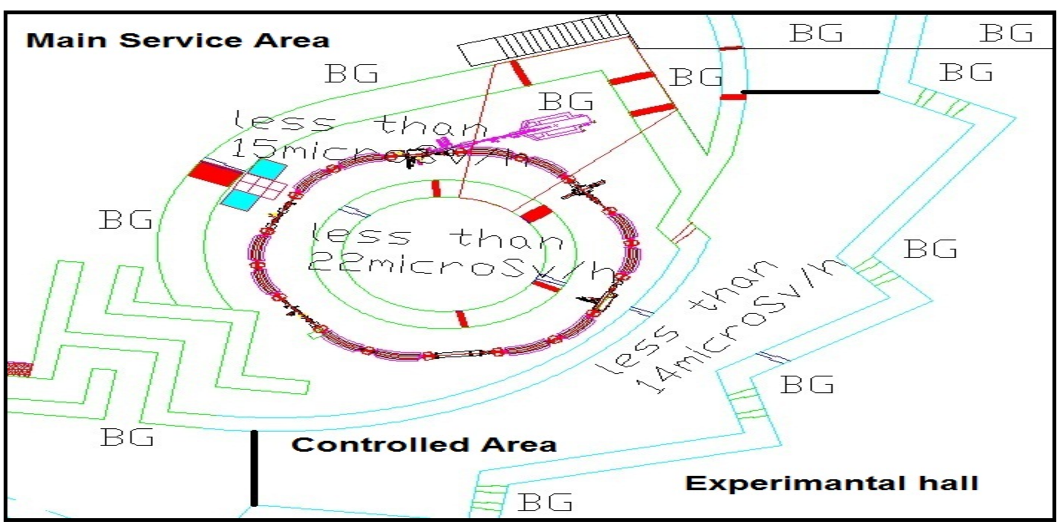

Fig.10: Radiation map during months of working including Storage ring controlled area, BG stands for back ground

Fig. 11 shows the shift dose/ 4 hours of working and over worst scenarios of commissioning, 27μSv, 4μSv and 0.5μSv for pool, roof and next to the booster tunnel door were measured respectively.

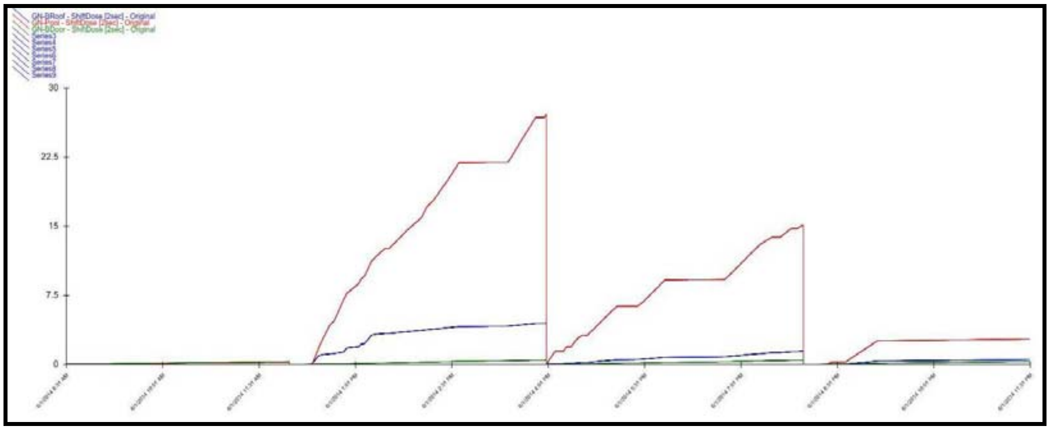

Fig.11: Accumulated doses during 4 hours shift periods.

b- Injecting @ 5Hz.

Since we have high dose rates around the injection septum outside the tunnel we decreased the microtron operating frequency to be 5Hz to see the consequences on the dose rates outside the booster tunnel in all directions except the main service area as shown before.

From fig.12 and 13, it is clear to notify that still we have high dose rates in the direction of the pool, less than 19μSv/h and less than 14μSv/h on booster roof above injection septum respectively.

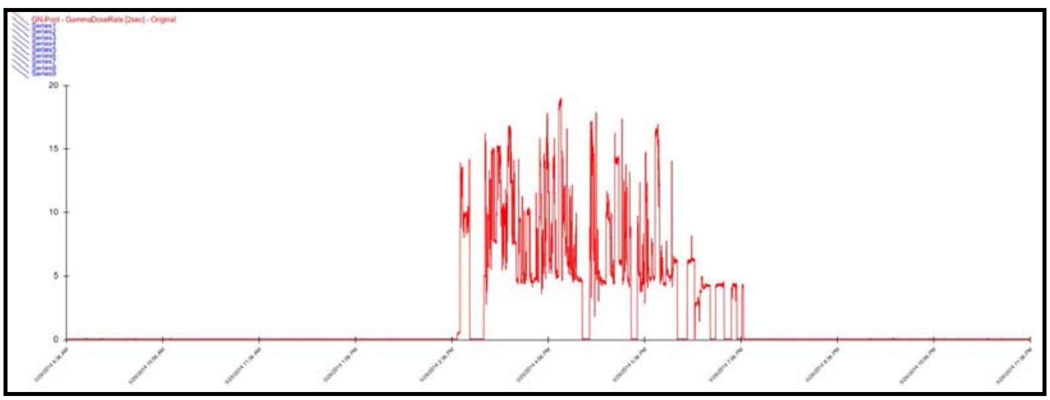

Fig: 12. Dose rates in the pool opposite to the lost point in the injection septum.

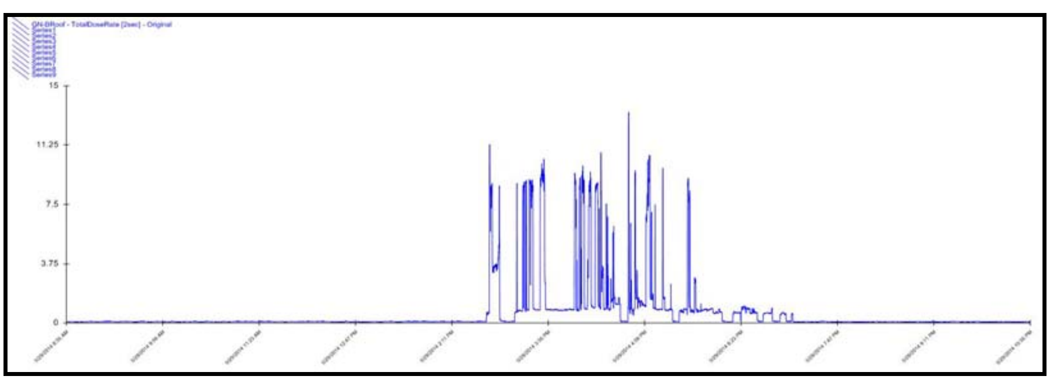

Fig: 13. Dose rates on the roof directly above the lost point in the injection septum.

At that time still we could not have the possibility to decrease microtron frequency down to 1Hz, so, we enforced to add lead shielding around both TL1 diagnostic screen and injection septum positions in the direction of the pool and the roof (see fig.3).
Fig 14 shows the effect of having such lead shielding to minimize the dose rates in the pool less than 1.3μSv/h which is more than 0.5μSv/h, nevertheless, still the shift dose over 4 hours equal to our second condition of having safe operation which is 2μSv, see fig.15.

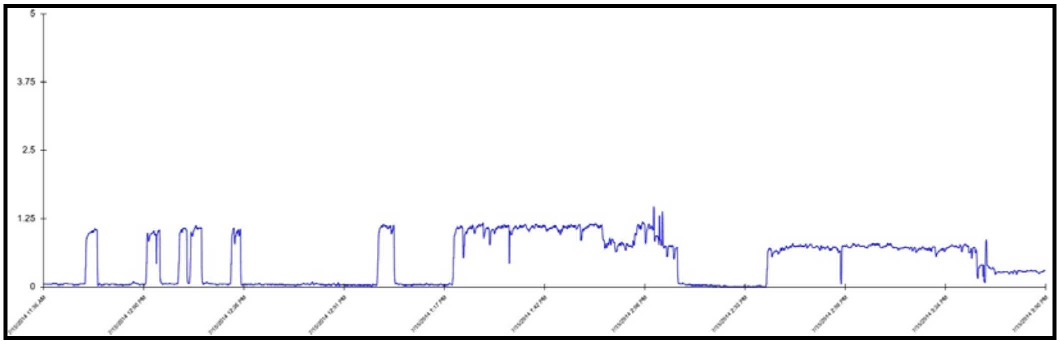

Fig.14.Dose rates in the pool after adding lead lateral to TL1 screen and Injection septum in the direction of the pool.

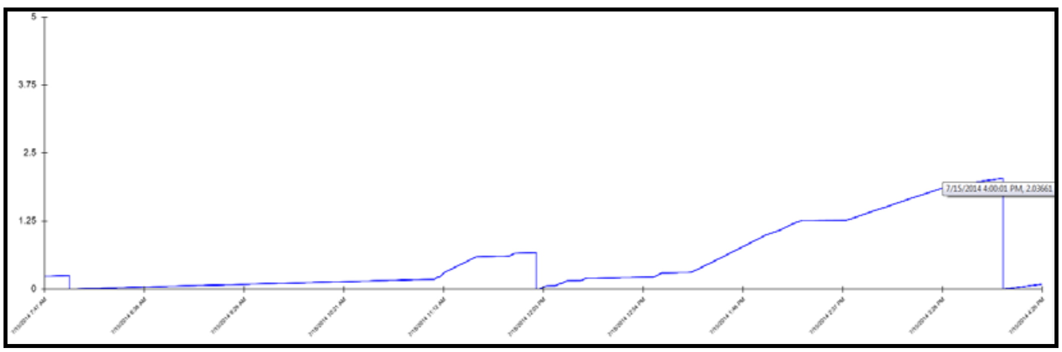

Fig.15. shift dose in the pool over 8 hours of operation of microtron at 5Hz.

For the roof, both the dose rates and shift dose were less than 3μSv/h and below 1.2μSv respectively after lead introduced above the injection septum, which means we are in safe side according to our other safe criteria (Note: both fig.16 and fig.17 were taken in different date and times).

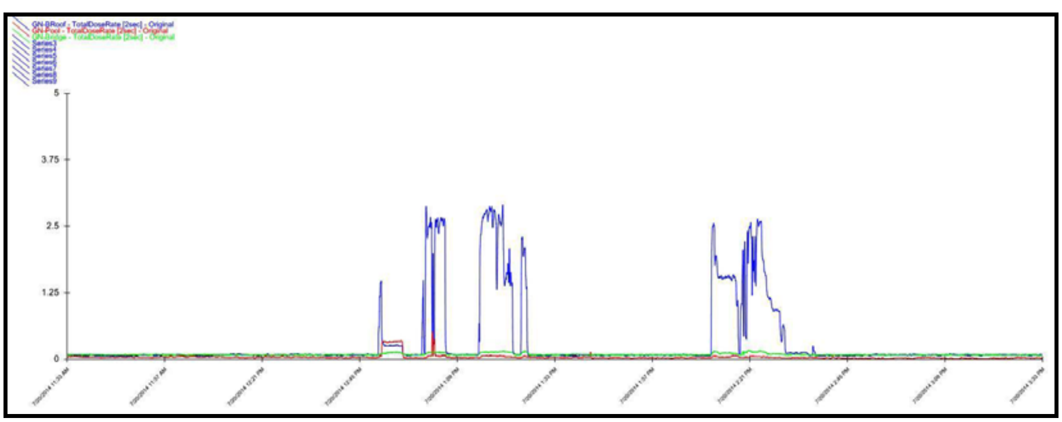

Fig: 16. Total dose rates on the roof (blue graph) opposite to the lost point in the injection septum at 5Hz

Note: Since the storage ring was totally closed, till now we did not pay an attention and it was delayed after made a good study for accessible zones around the booster tunnel.

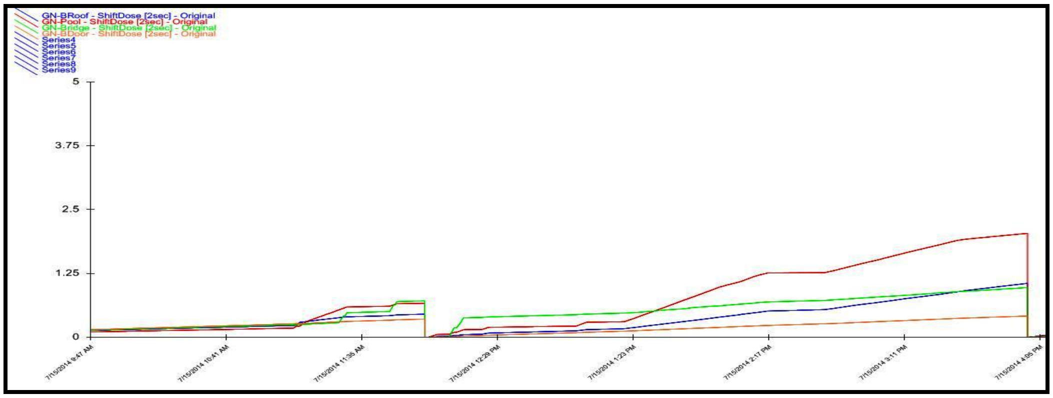

Fig.17. Shift dose on the booster roof (blue graph) over 8 hours of operation of microtron at 5Hz.

THIRD: Injecting electrons at 1Hz and circulating in the booster ring at 20MeV and ramping electron energy in the booster ring up to 800MeV.

Finally we manage to operate the microtron at 1 Hz and successful injected to the booster ring throughout TL1 and fully circulating electron beam in the booster ring and ramping up the electron energy to 800MeV. A huge measurements at different injection schemes were taken places in different places, all values showed values less than 1.5µSv/h inside the pool and above the roof (at that time all the lead around both TL1 diagnostic screen and injection septum were removed and the only lead plates kept was attached to the inner booster shielding wall in the direction of the pool).

For the storage ring, Fig.18 and fig.19 show the total dose rates and shift dose next to the common wall maximum 20.5µSv/h and 9µSv respectively which means that the storage ring part is not allowed to be entered during booster operation at all and for that the whole tunnel was close all the time.

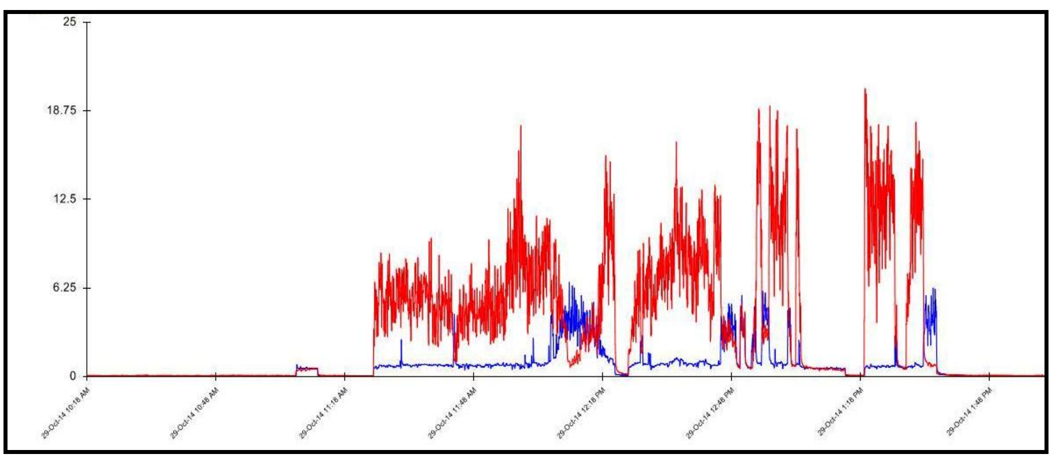

Fig.18, total dose rates in the storage ring part

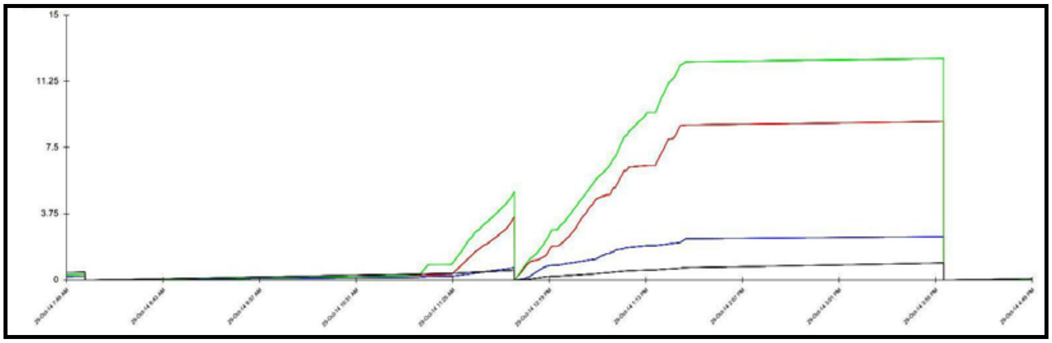

Fig.19, total shift dose in the storage ring (red line and blue lines)

For the pool, we can notice from fig.20 that the total dose rates maximum was 1.25µSv/h and shift dose was 1µSv (see fig. 18, black curve).

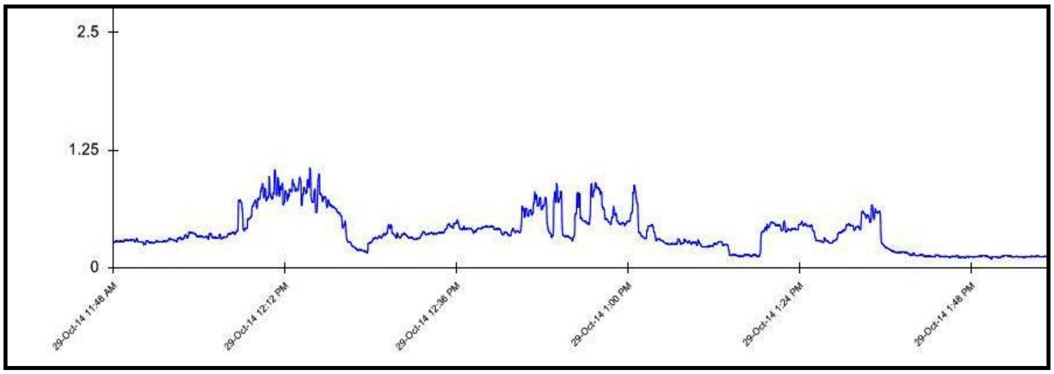

Fig.20. Total dose rates in the pool.

11- **Steel activation**

Each morning the radiation safety officer doing a full activation survey for all ring components and marking all components by radiation hazard precaution sign which showing contact dose rate more than 0.5µSv/h and inform all participant in the commissioning and all maintenance workers to taking care, these measurements were updated every around 6 hours, the most suspected components as mentioned before are the injection septum and all fluorescence screens.

12- Conclusions during injector operation (table 1):

1- Bridge and Main service area are totally safe.
2- The area which is next to the common shielding wall in the storage ring tunnel is mandatory to be controlled area during booster operation, see fig.10. (Between two bold lines).
3- The booster tunnel roof and the pool will be accessible with wearing TLD's for authorized personnel; bearing in mind the roof will be basically closed during commissioning by steel door.
4- Since the injector will be operated only for around one hour a day and based on previous measurement we expect to have low shift dose during normal operation.
5- During microtron operation, all areas around the booster tunnel are safe including storage ring.

Booster operation / Area	Normal	Continuous losses	Notes
Bridge	**Safe**	**Safe**	
Main SA	**Safe**	**Safe**	
Experimental Hall	**Safe**	**Safe**	
Pool	**Safe**	**Safe**	With Personal dosimeters and Safe pathway
Booster roof	**Safe**	**Safe**	With Personal dosimeters
Storage Ring Tunnel	**NOT**	**NOT**	Can be accessible under certain conditions
Storage Ring Roof	**Safe**	**Safe**	
Microtron operation at 1, 5and 10 Hz	**Safe**	**Safe**	For all areas around booster tunnel

Table: 1. Area can or cannot be accessible during injector (microtron and booster) operation.

13- Future soon work

a- To make sure that the storage ring is safe during booster operation we should do the following:

1- Calculating the thickness of lead safety shutter which will be a part of TL2 which allowing the electron beam to be injected in to storage, this will take place soon.

2- Safety shutter testing during TL2 commissioning.

3- Possibility of adding lead belt layer attached to the common shielding wall between booster and storage ring at beam height.

b- Doing more operation of the booster accelerator in order to get much more information related to the level of radiation around the booster tunnel.

c- This report will be sent after being modified to EMRC as a main part to get SESAME’s injector (microtron and booster) operational permanent license.

References:

1- Berkvens P., 14/02/2000, Shielding requirements for the Singapore Synchrotron Light Source, internal report.

2- Swanson W.P., Radiological Safety Aspects of the operation of Electron Linear accelerators. IAEA, Technical report Series No. 188, 1979.

3- Jenkins T.M., Neutron &photon measurements through concrete from a 15GeV electron beam on target; Comparison with models and calculations, Nucle. Instr. &Methods 159(265) 1979.