RADIATION SAFETY CONSIDEREATIONS OF THE OPERATION OF INDUS-1 SYNCHROTRON RADIATION SOURCE

G. Haridas, M.K. Nayak, Vipin Dev, Dimple Verma, K.K. Thakkar,
Health Physics Unit, Raja Ramanna Centre for Advanced Technology, Indore, India 452 013
P.K. Sarkar, D.N. Sharma
Radiation Safety Systems Division, Bhabha Atomic Research Centre, Mumbai 400085

Abstract

Radiological safety aspects of the operation of the electron storage ring, Indus-1 (450 MeV, 100 mA) is described in the paper. The ring is provided with a modular hybrid shielding comprising of mild steel and lead through which synchrotron radiation (SR) beam lines pass out. During the commissioning phase several radiation protection problems like streaming of high-energy bremsstrahlung x-rays through front ends of SR beam lines, shield joints, its detection and containment were encountered. Experimental measurements on the response of conventional radiation monitors with respect to water phantom were carried out to evaluate the dose build up factors in the streaming high-energy radiation field. The studies lead to the deduction of correction factors for the monitors for use in Indus-1. Improvement in monitor response on account of spectral degradation through shield and radiation levels during accidental beam loss are other problems, which are evaluated. Details of the radiation protection programme, radiation physics studies, the current status of radiation levels and access control are presented.

INTRODUCTION

Indus-1 is a 450 MeV electron storage ring [1] operated at Centre For Advanced Technology, India, giving rise to synchrotron radiation with a critical wavelength of 61A^0 (202 eV). It has a circumference of 18.96 m with four bending dipole magnets from which synchrotron radiation is tapped through front ends and has five beam lines for different types of experiments like reflectivity, photoelectron spectroscopy etc. [2]. Bremsstrahlung x-ray photons form the major radiation hazard at intermediate energy electron storage rings like Indus-1. These photons have a continuous energy spectrum, whose maximum energy extends up to the energy of electrons in the ring. During commissioning of the storage ring, several radiation safety problems in regard to high-energy photons were encountered. For installation and commissioning of synchrotron radiation beam lines, modular hybrid shielding [3], comprising of lead and iron was installed, with a total thickness of 160 mm (80 mm lead + 80 mm iron). This modification has left shield joints and penetrations at some locations through which bremsstrahlung x-rays, produced as a result of interaction of electrons, with accelerator structures, mainly vacuum envelopes and residual gas molecules [4], streamed out to accessible areas. For proper monitoring of these high-energy photons no radiation monitors are commercially available. However, Victoreen survey meter, model 450 P (which is a pressurized ion chamber based survey meter) was used with water phantom to study its adequacy for radiation monitoring in such high-energy photon fields, experimentally. It was found that the dose rate builds up to certain thickness of water and reduces. From the measurements dose equivalent build up factor was found out. Build up factors were also calculated from Monte-Carlo calculations carried out using the code EGSnrc [5] and was found to be in good agreement with measurements. To see the spectral degradation of bremsstrahlung photons on account of radiation shield and adequacy of radiation monitors behind thick shields, photon spectrum measurements were carried out with a 50.8 mm X 50.8 mm BGO detector in the direct and transmitted photon field (through shield) from the storage ring. The transmitted spectrum showed spectral degradation and indicated good response by radiation monitors. Radiation levels around the storage ring during accidental beam loss due to different reasons like tripping of dipole, RF etc also were evaluated.

RADIATION MEASUREMENTS

Measurements of radiation dose with conventional instruments gave underestimation in streaming high energy photon field as dose was found to build up when measured with respect to different thickness of water phantom. The depth dose measured at two different locations (one at a front end in the accessible area and another near a bending magnet within the shielded enclosure) around Indus-1 is reproduced [6] in Fig 1. Monte Carlo calculations on the dose build up factors in water due to different incident bremsstrahlung photon spectra (obtained from semi-infinite copper slabs of different thickness on 450 MeV electron bombardment using EGS-4) gave comparable results with experimental values.

Fig 2 shows the average energy of the incident spectra and the respective the build up factors obtained in water when plotted as a function of the thickness of water where the maximum dose occurred (designated as shower maximum, X_{max}).

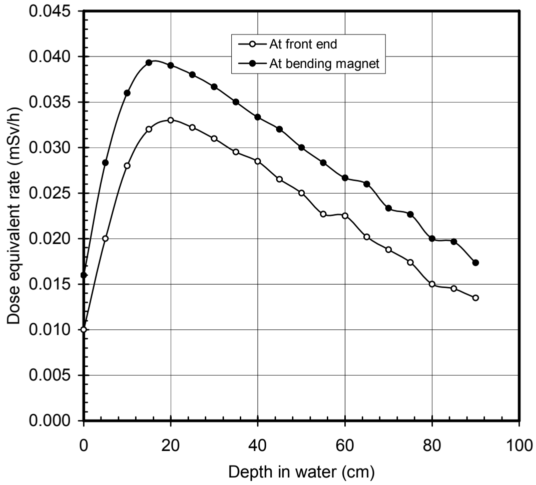

Figure 1: Depth dose measured at front end and near bending magnet around Indus-1

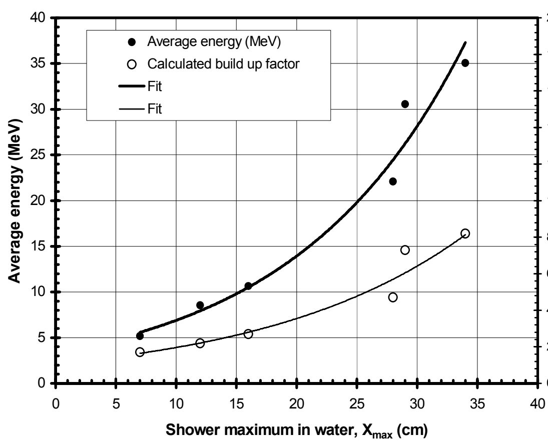

Figure 2: Average energy of the incident photon spectrum and the corresponding build up factors calculated for water phantom

From the studies a fit for the dose build up factor obtained is given below.

$$BF = 1.08\exp\left(\frac{X_{\max}}{16.9}\right)$$

Using the fit dose build up factor at a depth of 30 cm (size of a human body) is found out to be 6.4, which is used as a conservative correction factor for radiation monitors for use in Indus-1.

Also the depth at which the maximum dose occurs, X_{max} as a function of the average energy assumes the form

$$X_{\max} = 14.29\ln\left(\frac{E_{avg}}{3.41}\right)$$

which says that for an average energy ≤ 3.41 MeV, no build up takes place.

SPECTRUM MEASUREMENTS

In order to see the effect of spectral degradation on account of shield, and the subsequent response of the survey meter, spectrum measurement was done using a 50.8 mm x 50.8 mm BGO (Bismuth Germanate) detector and an 8KMCA in the direct and transmitted radiation field from the storage ring. It was possible to get an energy range from 300 keV to 12 MeV with the set up. As high-energy calibration was not possible beyond 2.7 MeV (^{24}Na) it was assumed to be linear up to 12 MeV.
For the measurement in the direct photon field, a through hole on the hybrid shielding wall, at the median plane of the storage ring, was used and for the transmitted field, 80 mm of lead was inserted in the hole. The spectra obtained in both the cases during the storage mode of operation of the ring are presented in Fig 3.

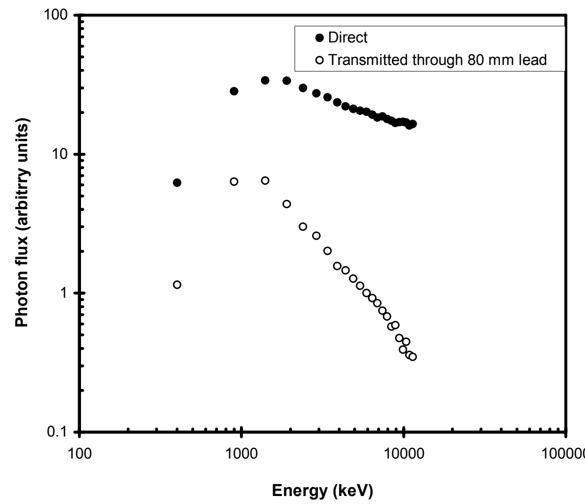

Figure 3: Direct and transmitted photon spectra measured around Indus-1

The spectral degradation was clearly evident from the transmitted spectra. The average energy of the transmitted spectrum worked out to be 3.3 MeV, and hence no dose build up is expected to take place, which is verified experimentally. Therefore the response of radiation monitors need not be corrected outside the hybrid radiation shielding of Indus-1 storage ring.

RADIATION LEVEL DURING NORMAL OPERATION

Radiation level during the normal operation of injection as well as storage at the design current of 100 mA at 450 MeV was found to be well within permissible dose limits recommended by International Commission on Radiological Protection (ICRP). Radiation level measured outside the shielding, in accessible areas is about 0.5 μSv/h. Victoreen survey meter 450P was used for photon radiation survey and pressurized ion chamber based pulsed x-ray monitor developed in house is used for area radiation monitoring. Photo- neutron dose rate is found to be negligible. Neutron monitoring is done with Rem-meter. No sky shine problem was observed. Maximum induced activity found at Indus-1 accelerator complex was 2 μSv/h, at injection septum of booster synchrotron. No measurable activity in cooling water or in air was observed.

RADIATION LEVEL DURING ACCIDENTAL BEAM LOSS

During the condition of beam storage in the ring, there are chances of beam getting killed due to several reasons, due to which occupational workers out side the shielding may receive some dose. The possible reasons of beam killing identified are tripping of a) Bending dipole magnet b) Quadrupole Magnet and c) Radio Frequency to accelerating cavity. An experiment was carried out to evaluate the radiation level around the ring during the accidental beam loss.

For the present experiment, electron beam at 450 MeV was accumulated up to 100 mA and the dosimeters (Direct Reading Pocket Dosimeters) were placed within and outside the radiation shielding covering the $3/4^{th}$ circumference of the ring excluding the injection section. Then the beam was suddenly killed either by dipole tripping, quadrupole tripping or by RF tripping. Each type of accidental loss mentioned was experimentally simulated four times and the dose per event (maximum dose per killing) is found out. It was observed that in case of dipole trip and RF trip the radiation level around the ring is almost uniformly distributed (maximum up to 0.4 mSv/event) whereas in the case of quadrupole trip high radiation level was recorded at a location near bending magnet –3 (maximum up to 7.5 mSv/event), indicating a localized beam loss. However, dose recorded outside the hybrid shielding, in accessible areas was negligible in all the three cases.

RADIATION SAFETY SYSTEMS

Various radiation safety systems like search & scram, door interlocks, area radiation monitoring, shielding, audio-visual warning systems and public address systems are provided within the accelerator complex. The radiation safety systems have undergone modifications based on operational experiences from time to time and now optimised. Details of the radiation safety systems can be found in literature [7]

CONCLUSION

Commissioning and operation of the synchrotron radiation source Indus-1 has indicated several radiation protection problems, mainly streaming of high-energy photons through shield joints front ends. The streaming locations were identified and shielded subsequently. Conventional radiation monitors which have an energy response up to few MeV was found to be inadequate for correct measurement of radiation dose in high energy streaming photon fields. Studies indicated that radiation dose builds up within a water phantom up to few tens of centimeters. Systematic studies on the dose build up at two locations together with Monte Carlo calculations suggest a high-energy response correction factor of 6.4 for radiation monitors within the shielded enclosures and in streaming high-energy photon fields from Indus-1. Radiation levels in accessible areas during normal operating condition were found to be within permissible limits. Radiation level outside the shielding due to accidental beam loss of 100 mA stored beam current was found to be negligible. The radiation safety systems provided was found to be adequate with the result that no unusual occurrences have occurred till date.

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