

# Proton Irradiation Facility and Space Radiation Monitoring at the Paul Scherrer Institute

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## Abstract

The Proton Irradiation Facility (PIF) has been designed and constructed, in cooperation between Paul Scherrer Institute (PSI) and European Space Agency (ESA), for terrestrial proton testing of components and materials for spacecraft. Emphasis has been given to generating realistic proton spectra encountered by space-flights at any potential orbit. The facility, designed in a user-friendly manner, can be readily adapted to the individual requirements of experimenters. It is available for general use serving also in testing of radiation monitors and for proton experiments in different scientific disciplines.

The Radiation Environment Monitor REM has been developed for measurements of the spacecraft radiation conditions. Two instruments were launched into space, one into a Geo-stationary Transfer Orbit on board of the STRV-1b satellite and one into a Low Earth Orbit on the Russian MIR station.

The next generation of monitors (SREMs – Standard REMs) is currently under development in partnership of ESA, PSI and Contraves-Space. They will operate both as minimum intrusive monitors, which provide radiation housekeeping data and alert the spacecraft when the radiation level crosses allowed limits and as small scientific devices measuring particle spectra and fluxes. Future missions as e.g. INTEGRAL, STRV-1c and PROBA will be equipped with new SREMs.

KEYWORDS: Irradiation test facilities, radiation monitors, space radiation environment, low earth orbit.

## 1. Proton Irradiation Facility

Since its commissioning in May 1992, the PIF has been used extensively, not only by the space community but by research teams in other disciplines. Primary, the PIF has been implemented to:

- Investigate radiation hardness, Single Event Effects SEE in electronic components
- Study basic mechanisms of radiation in semiconductors
- Simulate realistic space radiation environment on-earth
- Investigate biological effects for manned space-flights
- Serve as a source of mono-energetic protons for experiments
- Work as a calibration station for dose monitors and radiation detectors

A wide range of applications is feasible due to elementary design aspects assuring:

1. broad range of energies and intensities of the proton beam
2. fast and uncomplicated experimental set-up
3. user friendly operating system
4. flexibility toward users requirements

### 1.1. Test areas

The facility utilizes two irradiation sites for tests in high and low-energy regions [1, 2]. The experimental set-up is in both cases very similar – see Figures 1a and 1b. The beam travels in the air passing through

the dosimetry box – two ionization chambers and one wire chamber, energy degrader, beam collimators and the sample under test. Protons are stopped in the

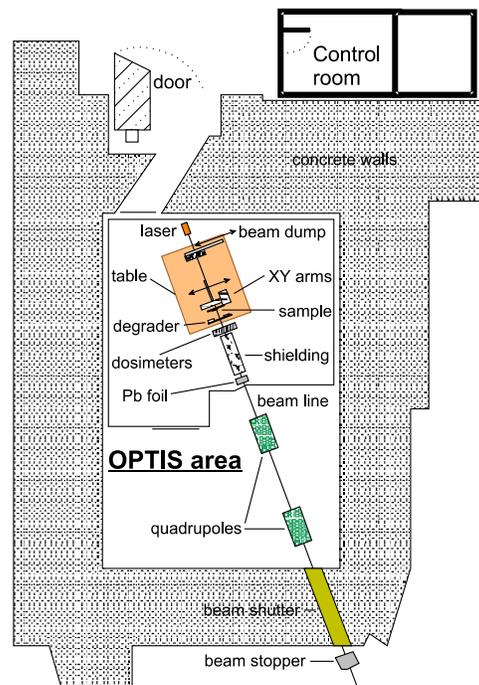


Fig. 1a – PIF layout and typical experimental set-up at the low energy OPTIS area.

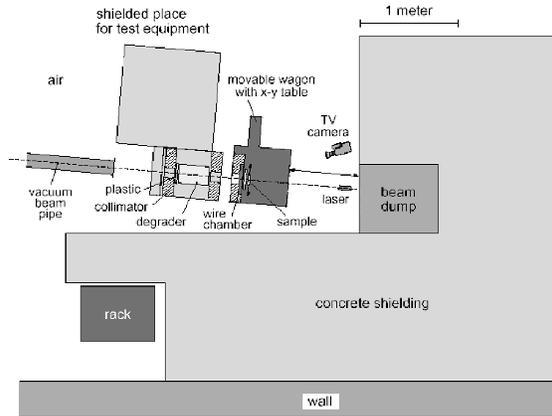


Fig. 1b – PIF layout and typical experimental set-up at the high energy NA area.

Copper beam dump located behind the table with samples. The tested device is mounted on the standard frame that is interchangeable with frames used in facilities in Brookhaven and Louvain-la-Neuve. The frame is fixed to the movable arm of the X-Y table and can be tilted for samples irradiation at different incident angles. A laser and video-camera system located behind the X-Y table allow for accurate arrangement of the device on the proton beam and for its visual checking. The energy degrader and X-Y table are both computer controlled. It makes possible to perform automated irradiation of individual devices on test boards. Change of the energy value with the degrader requires times of the order of 1 sec.

Two test areas are briefly characterized below.

1.1.1. **HIGH ENERGY SITE** - The high energy site is located in the Nucleon Area NA where the proton

therapy area is also located. It is characterized by the following beam parameters:

- Initial Proton Energies: 304, 254, 221, 150, 102, 60 MeV;
- Energy Range: 35 – 304 MeV quasi continuously using Al energy degrader
- Maximum Beam Flux at 304 MeV:  $2.5 \cdot 10^8$  p/cm<sup>2</sup>/sec
- Gaussian-like beam profiles:  $\sigma_x = \sigma_y = 2.5$  cm (can be flattened)
- Maximum Irradiation Area: 10 cm diameter
- Neutron Background:  $< 10^{-4}$  neutron/proton/cm<sup>2</sup>

1.1.2. **LOW ENERGY SITE** - The low energy area utilizes the OPTIS site in the NEA area. It is characterized by the following beam parameters:

- Eight Proton Energies automatically selectable within a range from 9 to 64.5 MeV
- Maximum Beam Flux  $1 \cdot 10^9$  p/cm<sup>2</sup>/sec
- Flat Beam Field
- Maximum Irradiation Area: 3.4 cm diameter

### 1.2. Operation, Users and Experiments

The facility provides 240 beam time hours for the European Space Agency ESA annually. The same amount of the beam time is also available for other users like universities, research institutes and industry. Some tests are performed in a parasitic mode with PIREX (Proton Irradiation Experiment). As the day shifts are reserved for biomedical applications, the irradiation runs are carried out mostly during weekends.

In the 1999 the facility operated from end of January to beginning of December and was used for 35 different experiments by 16 research groups. It resulted with 23 experimental blocks and 51 days with the beam.

The following table provides scope into users and activities at the PIF in 1999.

Research Institution	Experiment
ESA/ESTEC, Nordwijk	RADFET dosimeter radiation response study, Full characterization of PROBA Star-tracker, SRAM/DRAMs proton SEU characterization
PSI/GSFC/Berkeley University	CCD, DSP, ADC total dose and SEE testing, Drop Voltage Regulator testing
LABEN, Alenia Spazio, Milano	Activation measurement of Ta and Mo plates
Bosch-Telecom GmbH, Backnang	Performance studies of BGO veto detectors
Carl Zeiss GmbH, Oberkochen	Proton dose effects in photodiodes
Contraves Space, Zürich	Optical fibers rad-hardness determination
CNES, Toulouse	Damages in encoders and mirror coatings
DIFESA Officine Galileo	ICARE particle monitor calibration
SIRA Electro-Optics, Kent	SRAM/DRAMs proton SEU characterization
ONERA-CERT, Toulouse	Radiation damage of various CCDs
ABB Semiconductors, Lenzburg	Radiation damage of various CCDs
Kopenhagen University	Radiation effects in power MOSFETs
NMRC, Kork	Full characterization of PROBA Star-tracker
SCK/CEN, Mol	RADFET dosimeter radiation response study
SOREQ NRC, Yavne	Proton production of neutrons in PbBi/activation
SODERN, Paris	Proton production of neutrons in PbBi/spectroscopy
	Radiation damage in infrared bolometers

### 1.3. Further development

A dedicated cyclotron and irradiation areas will be constructed in the near future for the biomedical purposes – PSI PROSCAN Project. In addition to the biomedical arrangements, a dedicated site is planned for irradiation experiments. All interesting proton energies from few MeV up to 250 MeV will be covered by the new proton cyclotron. The intensity range and the beam field will be increased resulting in shorter irradiation times and larger areas of exposure. The operation of the new facility will be characterized by very short shutdown periods. Construction works will start in the year 2000.

## 2. Radiation Environment Monitor

### 2.1. Instrument

The REM instrument [3] consists of two independent shielded silicon detectors and measures the energy deposit, DE of charged particles. Energy losses from ca. 100 keV to more than 100 MeV are registered and counted into 16 channels per detector head. Data is accumulated for between 30 and 1000 seconds, depending on mission and orbit position. The aperture of the instrument is defined by an aluminium cone with an opening angle of  $90^\circ$ . Both detectors are covered with a dome of aluminium which defines the lower energy threshold for particles that reach the sensitive detector volume. (It was approximately 0.5 MeV for electrons and 10 MeV for protons in the case of MIR-REM.) One of the detector heads has an additional tantalum shielding, which significantly reduces electrons penetration.

STRV-1b was in a 10.5h Geostationary Transfer

Orbit, GTO with an inclination of  $7^\circ$ , an apogee of 250 km, and a perigee of 36000 km. The space station MIR is in a 90-minute, nearly circular orbit at 420 km altitude and an inclination of  $52^\circ$ . Data from REM aboard STRV-1b is available for August 1994 to September 1998 and from REM aboard MIR, for November 1994 to December 1996.

The design of REM was driven by the goal of a minimum intrusive instrument, with low mass and low power consumption, for the use on potentially any spacecraft. Despite of the simple design, REM has delivered plenty of useful data for the characterization and study of the space radiation environment. As an example, we show the following results from REM aboard MIR at the Low Earth Orbit LEO.

### 2.2. LEO environment

At the LEO, the high energetic particle radiation environment consists of three main components, trapped electrons, trapped protons, and cosmic rays. The electrons are the least penetrative and, up to energy of 1 MeV, they can be efficiently absorbed in a few mm of aluminium. In addition, the energy spectrum is steeply falling with higher energies. The high energy protons and especially the cosmic rays are much more penetrative. Protons of energies above 50 MeV are hardly altered by the additional shielding of the 2<sup>nd</sup> detector.

In order to show the geographic distribution of the different species we plot in Figures 2 to 3 the count rates in two different REM channels projected onto a geographic map. The plots contain data averaged over the year 1995.

Figure 2 shows the count rates in channel 4 of the 1<sup>st</sup> detector (the average energy deposit is

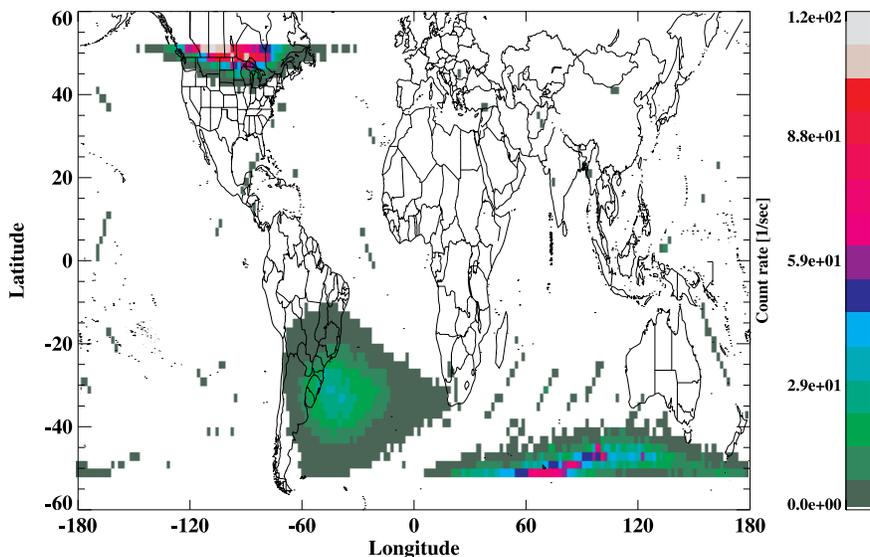


Fig. 2 – Distribution of the low-dE count rates averaged over 1995. High count rates are encountered in the SAA and close to the magnetic polar regions. In the SAA the counts are caused by electrons and high energy protons, whereas at the poles the counts are dominated by electrons.

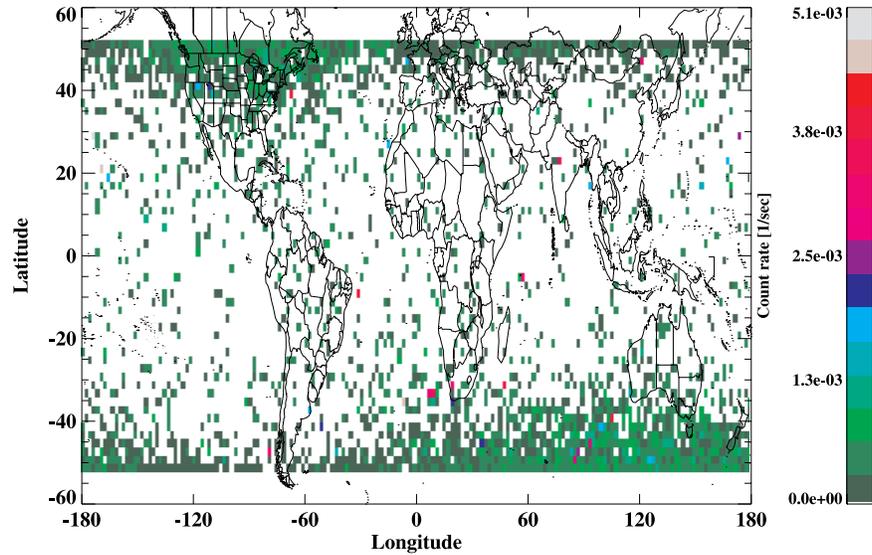


Fig. 3 – Distribution of the high-dE count rates averaged over 1995. The count rates are a function of magnetic latitude, are highest at the poles and diminish towards the equator. This is typical for cosmic rays.

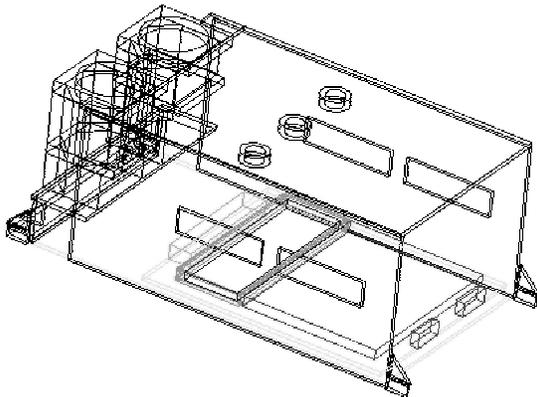


Fig. 4 – SREM mass model assembly – only selected parts are shown.

approximately 200 keV). This channel is sensitive to electrons but also to high energy protons (> 200 MeV). The count rate distribution forms two areas around the magnetic poles and one for the South Atlantic Anomaly. The events at the polar horns represent trapped electrons of the highly dynamic outer radiation belt. They are strongly influenced by the solar wind and interplanetary magnetic field conditions and the fluxes can vary by up to three orders of magnitude within a few days [4]. Figure 3 shows the count rates in channel 16 of the 2<sup>nd</sup> detector (the average energy deposit is approximately 72 MeV). Neither trapped electrons nor protons can deposit this amount of energy in the detector. They are contributed by

cosmic rays. The importance of the different components for the total dose strongly depends on the shielding [5, 6].

### 3. Standard Radiation Environment Monitor

The SREM, manufactured by Contraves Space AG in Zürich in collaboration with PSI and ESA, is a second generation of radiation monitors for space [7,8]. Its basic functions on board of a satellite are: continuous measurements of dose rates deposited by different particles, alerting the spacecraft in case of hazardous radiation environment and providing information on spectra and composition of the space radiation. As a dosimeter instrument with robust research capabilities it can detect protons, electrons and heavy ions in energy ranges relevant for causing malfunctions in electronic devices and damages of astronauts health. The SREM consists of 3 Silicon Surface Barrier Detectors embedded in a bi-metallic shielding/mounting structure of Tantalum (inner) and Aluminum (outer). Two of the detectors are arranged in a telescope set-up to provide better resolutions of type, energy and directionality of the incident radiation. An optional set of external RADFETs enables total dose determination at up to seven distinct locations on the satellite.

#### 3.1. Calibration and Modeling

Successful SREM operation in space requires exact knowledge of its response matrix supported by

precise calibration tests. The calibration was performed in PSI at the PIF using the same particles, energies and fluxes as will be encountered in space. It allowed to determine the response function, verify monitor's parameters and test its computer model.

A detailed mass and geometry computer model of the SREM was constructed at PSI – see Figure 4. Its data-base consists of several hundred of components and is arranged as an input of the GEANT code from CERN. Monte Carlo simulations were used to determine the monitor response matrix for different radiation conditions in space. A comparison with particle calibration data was found imperative for results validation.

### 3.2. Future Missions

The first SREM will fly on board of the STRV-1c satellite to be launched in the year 2000. The next missions are Proba (2001) and Integral (2002).

Several other spacecraft like Rosetta, ISS, Smart, Mars Express and Mercury Orbiter consider having SREM on board for radiation measurements.

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