RESPONSE AND SPACECRAFT CORRELATED MODIFICATIONS IN SENSITIVITY OF ESA STANDARD RADATION MONITORS

Wojtek Hajdas[1], Christina Eggel[1], Paul Bühler[1], Eammon Daly[2], Ali Mohammadzadeh[2], Alex Zehnder[1], Pierrik Vuilleumier[2], Hans-Jacob Schneider[3]

PSI Paul Scherrer Institut, CH-5232 Villigen PSI, Switzerland
ESA-ESTEC, Keplerlaan 1, 2200 AG Nordwijk, The Netherlands
Contraves Space AG, Schaffhauserstr. 58, CH-8052, Zürich, Switzerland

Response calculations were performed for the ESA Standard Radiation Environment Monitor (SREM). Devices were characterized for protons and electrons using Monte Carlo simulations with energies typical to space environment Sensitivity corrections due to spacecraft mass and monitor location were computed for SREMs installed on orbiting and future satellites (STRV, PROBA, INTEGRAL)

INTRODUCTION

SREM – Standard Radiation Environment Monitor was developed in partnership between ESA, PSI and Contraves Space AG (Zürich) [1]. The full set of 10 identical instruments was manufactured and calibrated. Two monitors are already in space (STRV, PROBA), the third one (IREM) will be launched onboard of the INTEGRAL mission in October 2002 and the rest is already assigned to other future satellites. The SREM is a space dedicated detector system for dosimetry and onboard proton and electron spectroscopy. In more and more cases the mission autonomous radiation monitoring is crucial for the satellite operation, its lifetime and health conditions of electronic components. In order to assure monitor ability of performing accurate space radiation measurements the extensive qualification test have been performed. SREM calibrations were done using the Proton Irradiation Facility (PIF) [2] as well as its gamma and electron radioactive sources in PSI. An important requirement was to use the same particles and spectra as anticipated in space. Results from the full set of particle energies and incoming angles provided a reference data for the instrument sensitivity matrix. In the next step, a series of calculations of the response function was carried out using a precise computer model of the monitor With the help of the GEANT code from CERN, the SREM responses were obtained for protons and electrons for the whole energy range encountered in space.

MAIN FEATURES

The SREM consists of three Silicon Surface Barrier Detectors embedded in a bi-metallic shielding of Tantalum (inner) and Aluminium (outer) Two of the detectors are arranged in a telescope to provide better resolution and directionality of the incident radiation. All pre-amplified detector pulses are scrutinised by a set of fifteen fast comparators – ten for single events, four for coincidences and one heavy ion channel Comparator levels are optimised to get the most accurate information on the spectrum shape of the detected particles. The low energy detection thresholds for protons and electrons are defined by thickness of the Aluminium entrance windows. The particles come through the conical collimators with ±20° opening. High energy particles however, can enter the detector from any direction. Some of them may be stopped in the satellite mass bulk before they hit the monitor. Therefore, large mass of the satellite reshapes SREM response and influences spectra de-convolution procedures. The level of such alteration depends on the satellite mass, mass distribution and location of the monitor.

CALIBRATIONS

During the PIF calibration runs [2] the following measurements were performed:

- Low energy response at 0°
- Thresholds determination
- Detector area, dead-time and pile-op measurement
- Response determination for set of energies and angles
- Electron spectra from radioactive sources
- Spectra of ^{60}Co gamma and cosmic rays

The energy of incoming protons was varied in the range from 8 to 300 MeV while angular positions covered the full scale of particle incidence angles from 0° to 180°.

Basing on the calibration data, the computer model for each SREM unit was individually adjusted with values obtained from the proton characterization. energy threshold, active detector area and absorber thickness. This modification was found to be on the level of about ten percent as all monitor units were very similar.

Experimental results were compared with fine-tuned computer calculations performed with the help of the GEANT code from CERN. To obtain better accuracy of the calculations, the SREM model was merged with a computer model of the proton irradiation facility. This way, all changes in the beam parameters, such as energy and angular straggling due to a usage of the aluminum energy degrader or wire chambers, were automatically taken into account. Comparison between measured data and simulation results is shown in Fig. 1 for three selected energy/angle configurations.

The agreement between experimental data and simulation results is in general very good. In few cases the deviation, however, was found to be of about 20 % or more. It was due to some inaccuracies of the SREM discriminators settings and monitor internal materials distribution. Additional reasons were test related: non-uniformity and divergence of the beam and detector pile-ups/dead time.

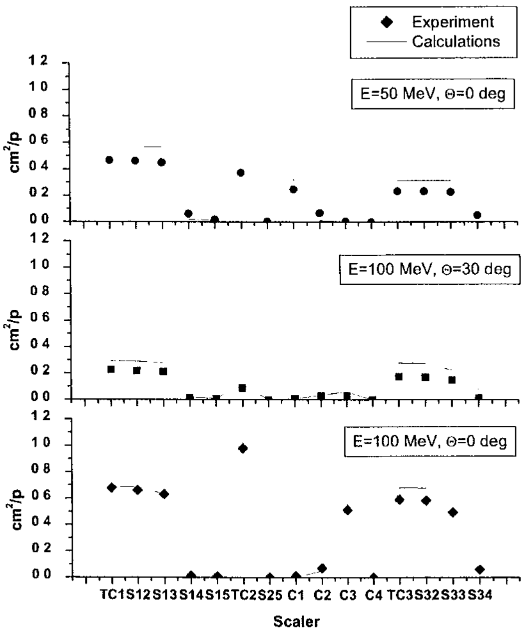

Fig. 1 Count rate per proton/cm^2 as a function of energy and incoming angle for all SREM INTEGRAL scalers.

MODELLING

Monte Carlo simulations of the SREM proton response were performed with the GEANT particle transportation code. An accurate modelling required constructing of the data bank with all the structures inside the SREM box. The monitor was separated into functional blocks and all parts and materials in them were decomposed into simple geometrical shapes of know physical properties. The whole model consists of few hundred of such shapes properly positioned and oriented in space.

The proton response was calculated for twenty three energy bins equally spanned on the logarithmic scale between 8 and 420 MeV The response presented for selected scalers in Fig. 2 shows results integrated over the full 4π angle of incoming particles As one can see, each scaler has its maximum sensitivity in a different energy region allowing for proper extraction of the energy spectrum. The second maximum at high energies is also there and is related to protons coming from rear sides of the detector. This part of the sensitivity curve strongly depends on the extra shielding provided from the SREM lateral and bottom sides by the satellite.

For electrons, the number of bins was only equal to nine and covered the energy range from 0.36 to 7 MeV. The bins had equal widths on the logarithmic scale as well.

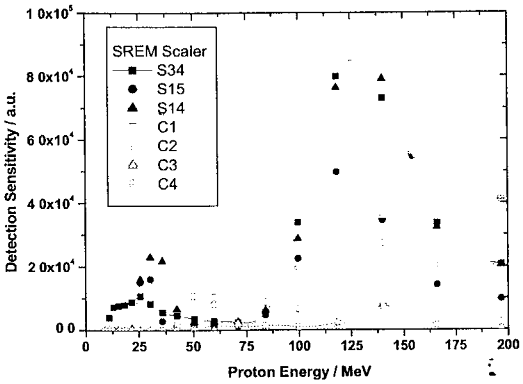

Fig. 2 Proton response for selected scalers as a function of particle energy.

The response calculations are presented for selected scalers in Fig. 3. Results are integrated over the full 4π angle of incident particles. As one can see, each scaler has its well-defined energy threshold and it enables reconstruction of the initial spectrum of electrons. The shielding of the monitor fully stops not only the bremsstrahlung but also all electrons coming from outside of the entrance collimators. It implies that in most cases the electron response function is not affected by the satellite.

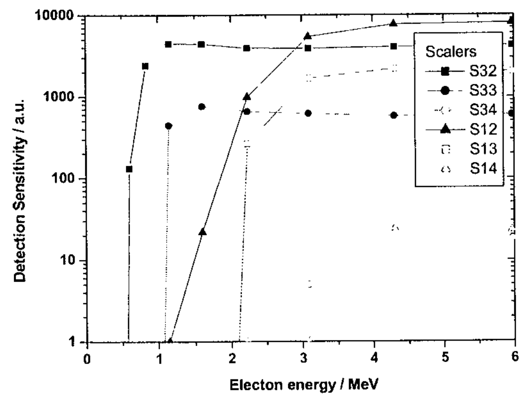

Fig. 3 Electron response for selected scalers as a function of particle energy

MODELLING WITH SPACECRAFT

Adding of the spacecraft mass model to the SREM extended Monte Carlo simulations of the monitor proton and electron responses. The calculations were performed for three satellites. STRV-1c, PROBA and INTEGRAL. The STRV-1c was a 70 kg big micro-satellite launched on November 15th, 2000 by DERA. Unfortunately, it was lost after several weeks of successful operation The PROBA is a small autonomous satellite (100 kg) developed for ESA by Verhaert and launched on October 22nd, 2001. It is still in the commissioning phase and the first data from SREM are now being evaluated. The International Gamma-Ray Astrophysics Laboratory (INTEGRAL) is the next ESA medium-size science mission with the spacecraft mass of more than 4 tons. Its launch is foreseen on October 17th, 2002 aboard a PROTON rocket. IREM (adopted SREM) is the main instrument for radiation environment monitoring of INTEGRAL. Mass models of above spacecrafts were constructed in an uncomplicated manner. Simple shapes were used to describe most of the parts. The material bulk was approximated by Aluminium with adapted density. An example of the satellite mass model is shown in Fig. 4.

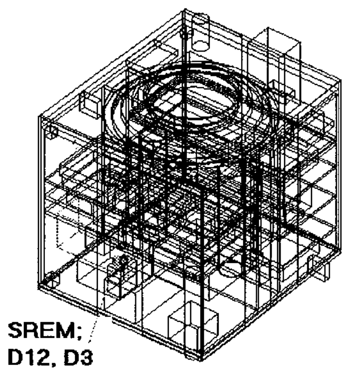

Fig. 4. Simple model of the STRV satellite with SREM. The monitor with two detector heads is also seen.

Monte Carlo calculations were carried out using exactly the same settings for all four cases – SREM alone and with satellites. The results are compared in the Figures below.

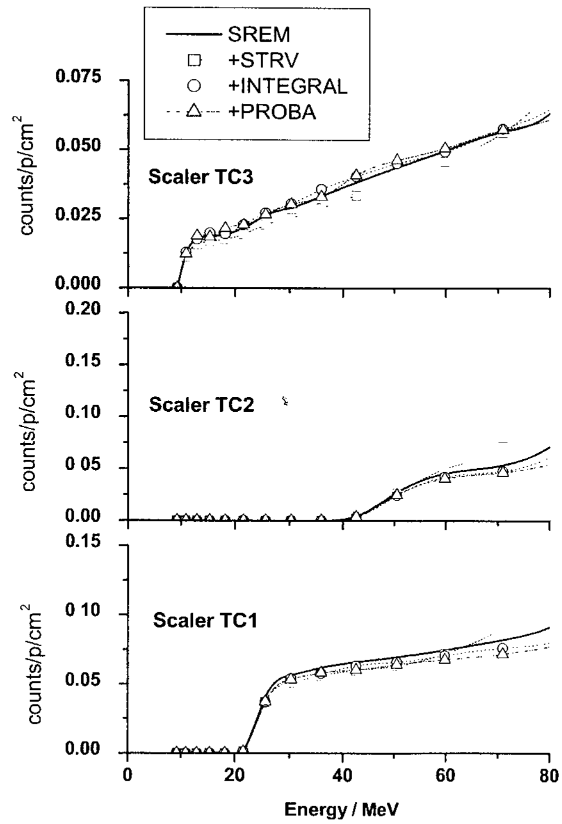

Fig. 5. Response function comparison at low energies for three detectors total counts scalers (TC1-3)

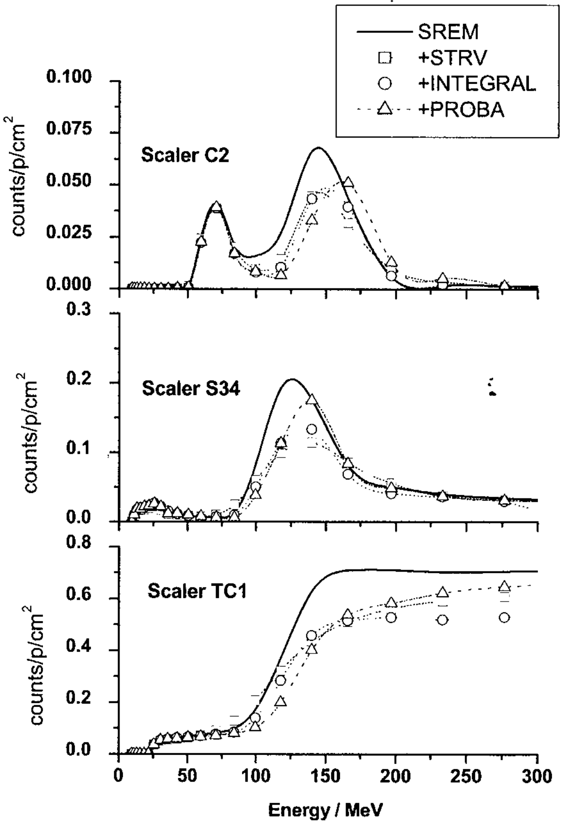

Fig. 6. Response function comparison over the whole energy range for three selected scalers.

As one can see in Fig. 5 the sensitivity differences at energies up to about 70 MeV are rather small. It is in agreement with expectations, as the Al-Ta shielding of the monitor should stop all protons with energies below 80 MeV that come outside of the entrance collimator. At higher energies the response discrepancies are much bigger. As it is shown in Fig. 6, the count rate in TC1 scaler of the standalone monitor reaches a plateau at the value proportional to its area (about 70 mm^2) for energies of protons that can penetrate the monitor. Other curves are up to 30% apart In addition, they have different shapes and show shifts in positions and intensity of their maximum for both S34 single and C2 coincidence scaler.

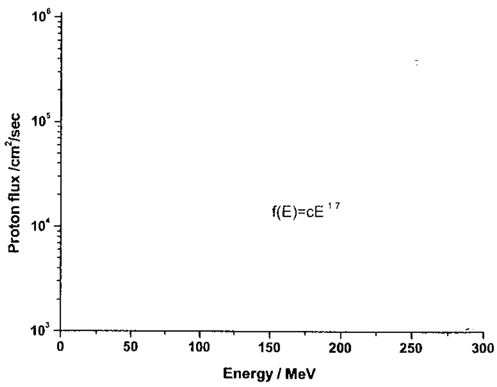

Fig. 7. Proton spectrum used to study response changes.

Modified response functions were used to investigate differences in detector scaler count rates for typical proton radiation environment in space. For this purpose the calculations were performed using a power law proton spectrum with the index of $\gamma=1.7$. Similar spectra can be encountered e.g. by the IREM during solar mass ejections events. The integral spectrum intensity was artificially set to be equal to $4\bullet10^6$ p/cm^2/s at 9 MeV. Calculation results are presented in Fig. 8-10.

Figures 8-10 show that SREM-alone spectral sensitivity to the power law spectra is for all scalers about 10-20% higher than for the monitors onboard. In addition, all responses for SREM with the spacecraft are quite similar.

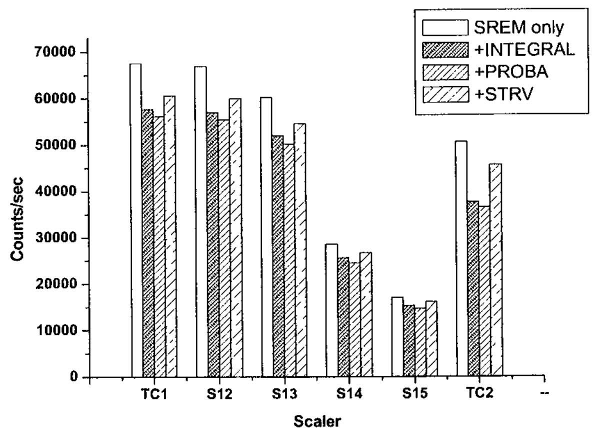

Fig 8. Detector 1 (scalers TC1, S12-S15) and 2 (TC2) response to the proton spectrum from Fig. 7.

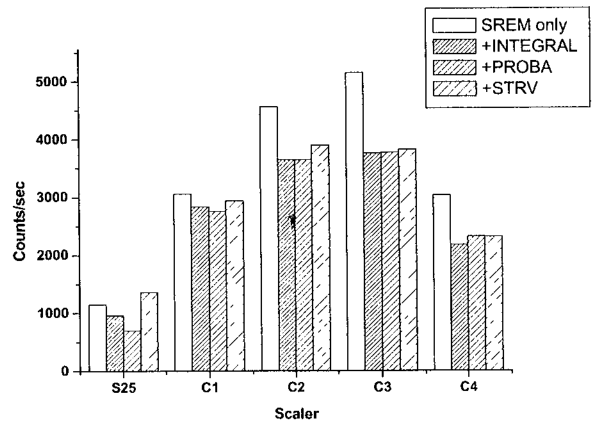

Fig 9. Coincidence channels (C1-4) and heavy ion scaler (S25) response to the proton spectrum from Fig. 7.

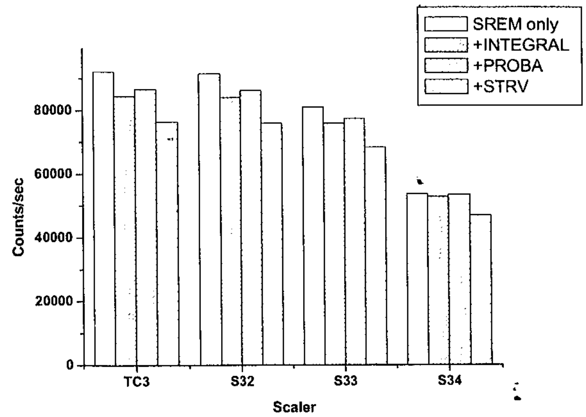

Fig 10. Response of the detector 3 scalers to the proton spectrum from Fig. 7.

It indicates that even a small satellite with the mass of about 100 kg provides similar shielding effectiveness as a large spacecraft of INTEGRAL type.

SUMMARY

ESA Standard Radiation Environment Monitor was calibrated and characterized. Proton exposure data were compared with fine-tuned calculations. For this purpose an accurate mass model of the monitor was constructed. The agreement between experiment and computations is very good. The certified computer model was used to determine monitor sensitivity for protons and electrons in the energy ranges as anticipated in space. Further calculations were performed for present and future missions with SREM onboard with simplified mass models of the satellites. The response function for electrons were almost unchanged but the proton sensitivity alterations at energies above 80 MeV were rather large. New space characteristics for monitors onboard were obtained by folding response matrixes with typical space spectra. Generally, changes in SREM scalers counting rates were on the level of only 10-15%. The biggest differences were found in coincidence channels that are most sensitive to high energy protons. Response variations between satellites were very small demonstrating that even a low mass spacecraft may provide and adequate lateral and rear shielding for SREM.

REFERENCES

[1] SREM Technical Prospect, Oerlicon Contraves Space 1996, e-mail: czmbg@lx_hea.ocag.ch

[2] W Hajdas et al., Nucl. Instr And Meth B113, 54 (1996)