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LONG -TERM MONITORING OF THE ONBOARD AIRCRAFT EXPOSURE LEVEL WITH A Si-DIODE BASED SPECTROMETER✧

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ABSTRACT

The radiation fields onboard aircraft are complex (EURADOS, 1996), and several methods are used to characterise them for radiation protection. We have tested a spectrometer based on Si-diode at different sources and accelerator facilities. The energy deposited in the diode is analysed to estimate the contribution of different radiations to dosimetry quantities. The spectrum of energy deposition events onboard aircraft is similar to that registered in the CERN high-energy reference field. We used this similarity to determine the correction factors to appreciate radiation protection quantities from the results of onboard measurements. During 2001-2002, the spectrometer was used to acquire measurements onboard commercial aircraft during five long-term exposures. All necessary flight parameters were acquired; thus permitting calculations of the onboard effective dose and/or ambient dose equivalent by means of both the CARI6 and the EPCARD codes and comparison with the results of the measurements. It was found that the apparent ambient dose equivalent values from measured data are in reasonable agreement with the results of calculations. Quantitative analysis of this agreement as a function of flight parameters (geomagnetic position, solar activity variations, etc.) is presented. During one flight, an important solar event (GLE 60 on 15 April 2001) was recorded by the spectrometer. In some other cases the measurements during a Forbush decreases were acquired. These extremes were well registered by the equipment and the data obtained are analyzed.

MATERIALS AND METHODS

Detector used, Mobil Dosimetry Unit

The Mobile Dosimetry Unit (MDU) monitors simultaneously the dose and number of energy deposition events in a Si-detector. It is designed to be portable and reliable equipment. The amplitude of the pulses is proportional to the energy loss in the detector. Final adjustment of the energy scale is made through the 60 keV photons of ^{241}Am. The amplitudes are digitised and organised in a 256-channel spectrum. The dose D [Gy] is calculated from the spectrum as:

$$D = K*\Sigma(E_i*A_i)/MD, \quad (1)$$

where MD is the mass of the detector in kg; E_i is the energy loss in the channel **i;** A_i is the number of events in it; and K is a coefficient.

The operational time of the instrument depends on the lifetime of the accumulators and on the rate the memory fills up. In the case of continuous operation the lifetime is about 120 hours with the 1.35 Ah accumulators, about 1400 hours with 14 Ah-batteries.

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Calibrations and Onboard Tests

MDU units available were exposed in reference radiation fields. The results obtained at some photon sources are presented in Figure 1. This figure contains both experimental and theoretical spectra for ^{137}Cs and ^{60}Co photons in semiconductors.

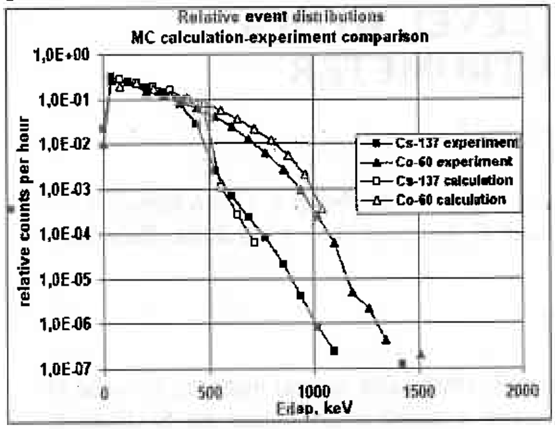

Fig. 1. Event spectra in some photon beams.

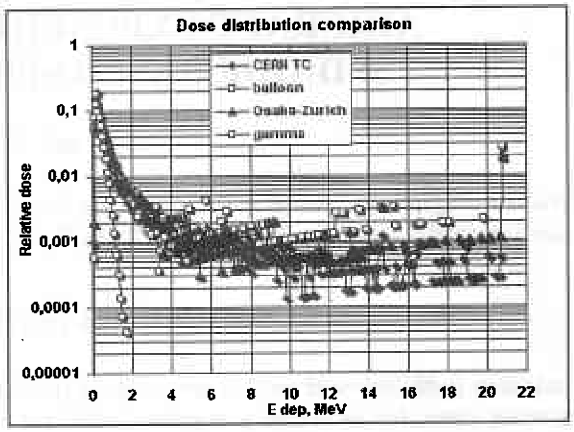

Fig. 2. Comparison of dose spectral distributions.

These spectra were calculated by means of the EGS 4-transport code; the agreement of both spectra is satisfactory. The equipment was also exposed at some neutron sources. Large differences in the event spectra were observed. For photons the maximum impulse height is about 1 MeV; for neutrons it reaches up to 10 MeV (Spurný, and Dachev, 2002). This difference permits identification of photon and neutron induced events in other radiation fields. Tests with MDU units were performed on protons and heavy ions (Dachev, et al., 2000, Uchihori et al., 2002) and good agreement was found between these measurements and the predictions of the GEANT code spectra.

MDU units have been tested since the spring 2000 during three calibration runs in the CERN-EC high-energy reference field behind a concrete shield (Mitaroff and Silari, 2001). In this case the spectrum was still much larger than in the case of neutron sources, reaching the highest values of the energy deposition above 20 MeV. It was found that the signal per monitor unit decreased due to muon background with increasing intensity in low E_{dep} region (Mitaroff and Silari, 2001). For high E_{dep} events, it is independent of the muon background. It is very important for the interpretation of the data measured in reference and similar fields.

As far as the values of dose calculated from the spectra are concerned, they were in very good agreement with the reference values for ^{60}Co photons; the value obtained for ^{137}Cs photons was about 8 % lower than the reference. In the CERN reference field, the doses calculated for low E_{dep} region were about 30 % lower than values measured with other standard low LET measuring instruments (RSS 112 chamber, TLD's, etc.). We have observed the same behaviour also for individual electronic dosimeters based on Si-diode and have accounted for this in the interpretation of detector's readings.

The main effort has been the measurements on board aircraft and their interpretation. First, it was actually observed that the spectra registered in the CERN reference field are similar to the spectra registered on the aircraft and/or on balloons (see Figure 2). To interpret the data measured onboard aircraft (D(Si)), we decided to use the CERN reference field results. The dose in Si measured in the low E_{dep} region was utilized to represent the contribution of low LET radiation; the dose in the high E_{dep} region was utilized for the high LET component (neutrons). Taking into account reference field values for these components (Mitaroff and Silari, 2001), the D(Si) measured on board was recalculated to obtain apparent H*(10) values.

Since April 2000, the spectrometer has been used during more than 50 individual and five long-term exposures, about 1200 hours, with about 400 flights in total. All necessary flight parameters were acquired from colleagues of Czech Airlines in order to calculate the effective dose E on board by means of both the CARI 6 (Friedberg et al., 1992) and the EPCARD codes (Roesler et al., 2002) and compare them with the apparent H*(10) values obtained by our measurements.

As an example of individual flights, the results obtained from the CSA flights from Prague to Athens and return are presented in Figures 3 and 4.

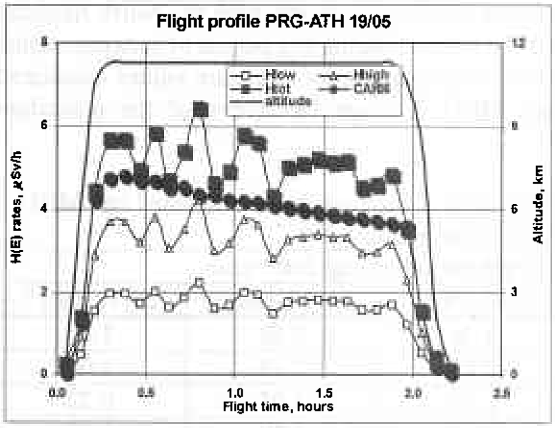

Fig. 3. Flight profiles Prague-Athens

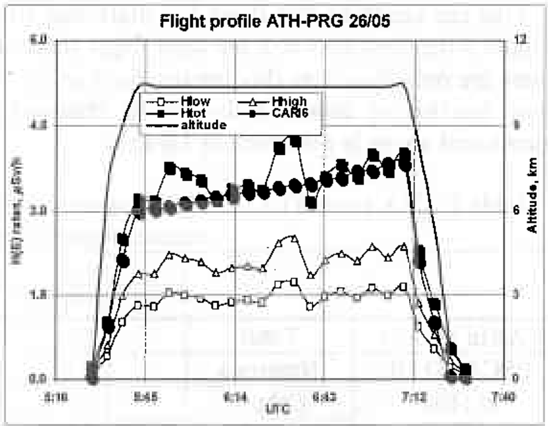

Fig. 4. Flight profiles Athens -Prague

RESULTS AND DISCUSSION

Characteristics of the Quiescent Cosmic Environment

More detailed characteristics of long-term measurements are given in the Table 1. The full record of the detector's data for one set of flights is presented in Figure 5.

Table 1: Characteristics of long-term onboard aircraft monitoring realised in 2001-2002 with the LIULIN semiconductor spectrometer.

Period	Returned flights monitored*)	Total flight numbers
22/03-07/05/01	PRG-NY(25), PRG-TOR(13), PRG-DUB(3)	108
30/05-24/07/01	PRG-NY(41), PRG-TOR(12)	125
29/08-16/10/01	PRG-NY(26), PRG-TOR(13), PRG-DUB(2)	96
25/10-10/12/01	PRG-NY(20), PRG-TOR(7), PRG-AMS(1)	70
06/05-28/06/02	PRG-NY(22), PRG-TOR(13), PRG-DUB(8), PRG-LHR(5), PRG-MAD(5)	124

*) PRG–Prague, NY–New York, TOR–Toronto, DUB–Dubai, AMS–Amsterdam, LHR–London, MAD–Madrid

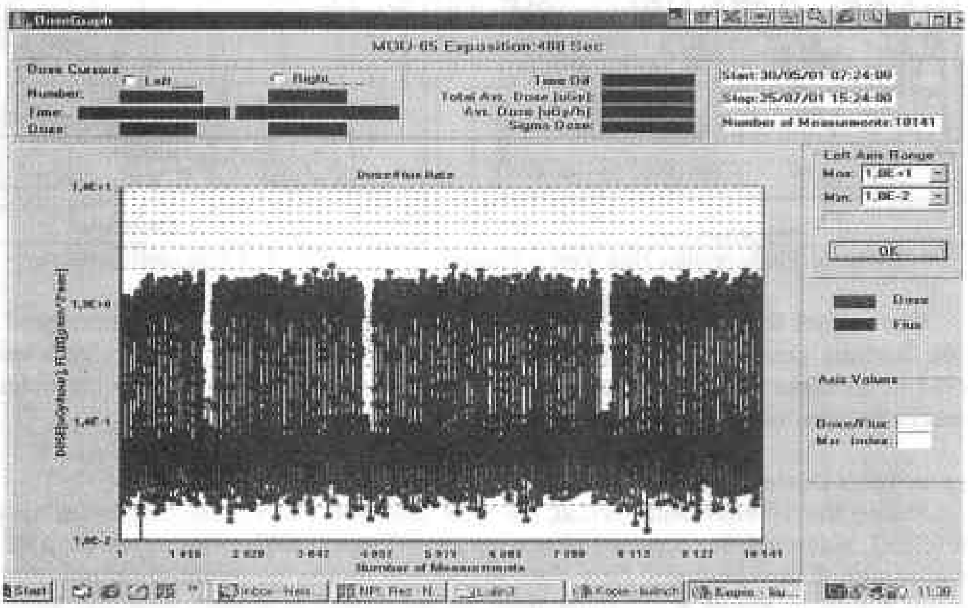

Fig. 5. Full record of measurements for the period 30/05-25/07/01

One can see there that about 400 individual flights were monitored, mostly over the North Atlantic. Figure 5 demonstrates also the tight flight schedule of the aircraft during the period of measurements; there are only three one-day interruptions in the record. A comparison of exposure values calculated from navigation data and the results obtained from MDU readings by means of the procedure mentioned above is presented in Table 2.

Table 2: CSA aircraft (A310-300) long-term exposures 2001 – comparison of calculated and MDU results treated using CERN calibration.

		Flight period during 2001 year			
		22/03-07/05	30/05-24/07	29/08-16/10	25/10-10/12
CARI6 E, mSv	Total	2.68	3.78	2.60	1.88
EPCARD3.0 $H^*(10)$ mSv	Neutrons	1.57	2.12	1.45	1.00
	Others	1.08	1.40	1.05	0.72
	Total	2.68	3.52	2.50	1.72
EPCARD3.0 E-ISO mSv	Neutrons	1.34	1.82	1.24	0.85
	Others	1.77	2.39	1.70	1.17
	total	3.11	4.16	2.94	2.02
Liulin-MDU H_{app} mSv	Neutrons	1.54	2.29	1.55	1.07
	Others	1.14	1.54	1.04	0.72
	Total	2.65	3.83	2.59	1.78

One can see that the data sets agree well. The values of effective dose from the EPCARD code are about an average of ~12 %, higher. Such differences from the point of view of radiation protection are acceptable (EURADOS, 1996). The data from long-term measurements were also treated in the same way as for individual flights. The examples of flight records are presented in Figures 6 and 7.

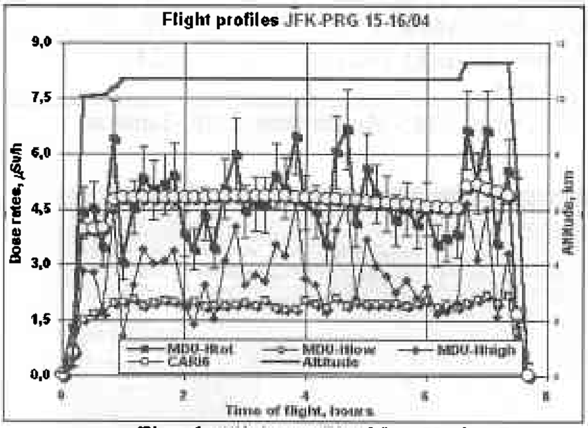

Fig. 6. Flight profiles New York – Prague

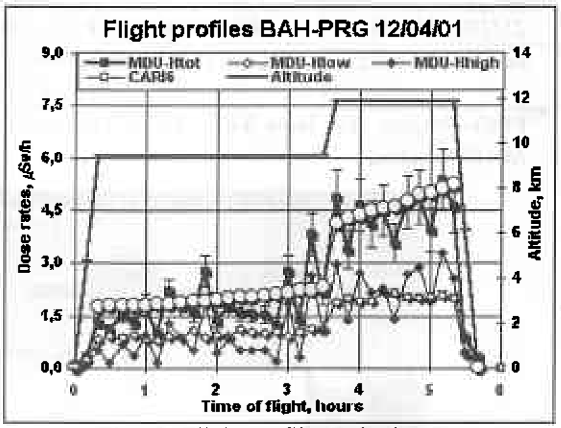

Fig. 7. Flight profiles Bahrajn - Prague

One can see there again that the values of total apparent H*(10) are in rather good agreement with the E-values calculated by means of CARI 6 code (Friedberg et al., 1992). Such tendency was observed in all about 400 flights treated in the same way, the average relative uncertainties of the differences between calculated and treated measured data did not exceed 10 %.

Characteristics During Extremes in the Cosmic Ray Environment

During the 1st monitoring period, we were informed that a solar cosmic ray Ground Level Event (GLE), numbered 60, occurred after noon on 14th April 2002. This event occurred roughly 3 hours after takeoff from Prague to New York as it can be seen in the record of the radiation dose from this event shown in Figure 8; 3rd flight from the left. There is a good time and form-correlation between our measurements and the independent data available from the Oulu (Finland) cosmic ray monitor station and/or from the GOES system satellites as shown in Figure 9.

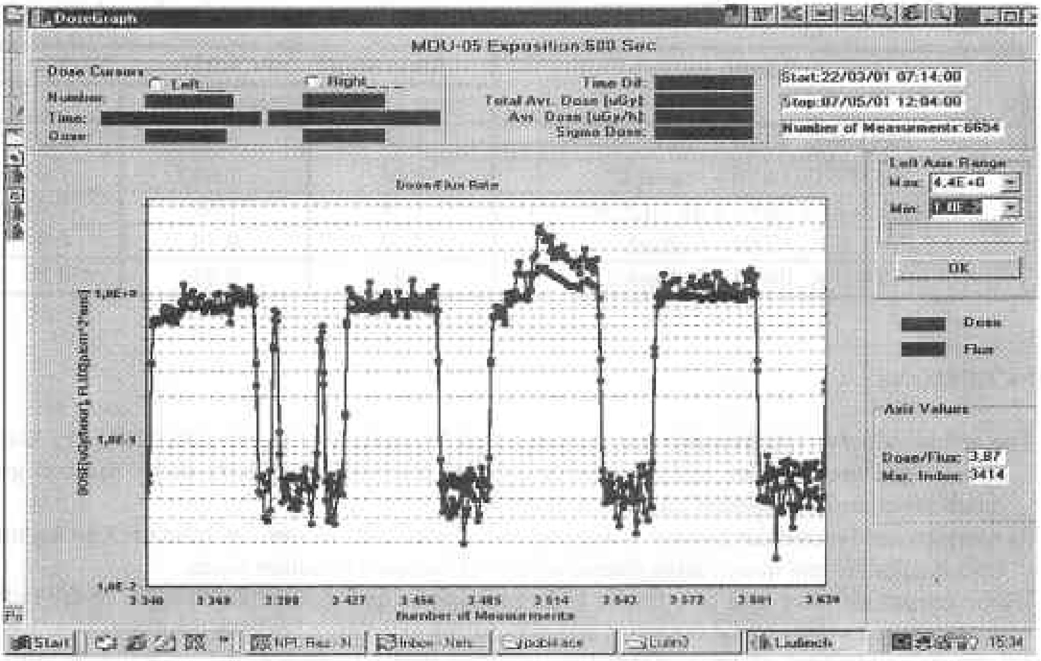

Fig. 8. The radiation dose measurements for period 14/04-16/04/01; the third flight with GLE 60

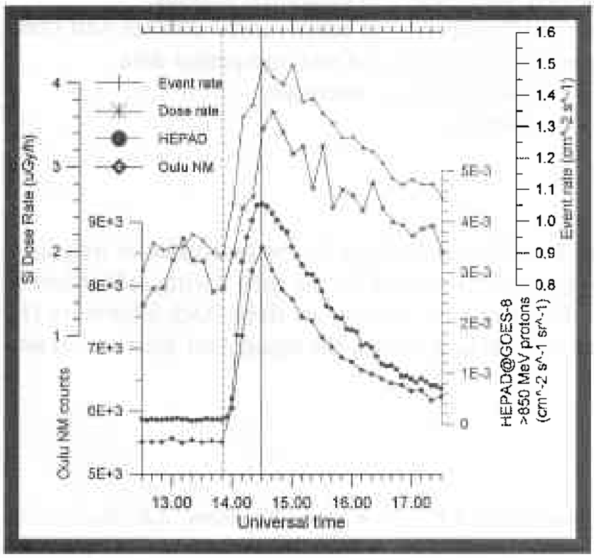

Fig. 9. Correlation of spectrometer and other data

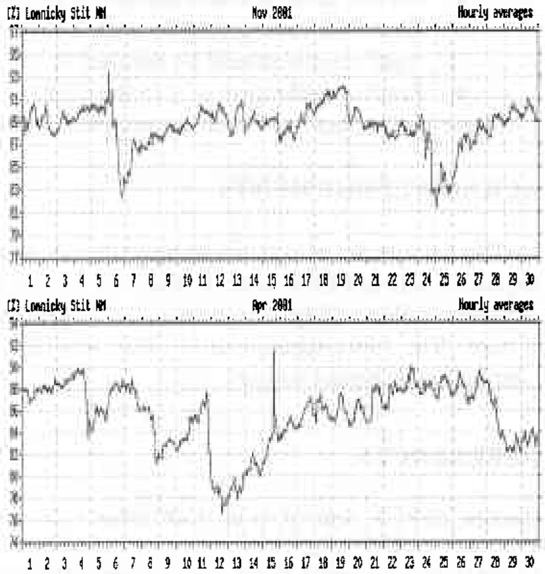

Fig. 10. Lomnicky stit monitor data – 04 and 11/01

The Forbush decreases that occurred on 12 April and 6 November, as recorded by the Lomnický štít cosmic ray monitor are presented in Figure10. During these events the intensity decreased rapidly by more than 10 %. The geomagnetic cutoff rigidity of the Lomnický štít monitor is about 3.9 GV. Also during these extremes our spectrometer was flying onboard the aircraft at both dates, roughly at the same time as for GLE 60 from Prague to New York. We treated data acquired in the same way as for other flights and compared them with the results of calculation by means of EPCARD 3.1 code (Roesler et al., 2002) (see Table 3). One can see that the solar cosmic ray event and Forbush decrease influence the exposure level both quantitatively and qualitatively. The total exposure during the flight that encountered GLE 60 is about 44 % higher than the average; and about 16 % lower on the flight during the Forbush decreases. The influence on the high LET (neutron) radiation component is the most important. The changes observed seem to indicate that the neutron spectrum is softer during a high energy solar proton event, and harder during a Forbush decrease.

Table 3: The influence of extremes on the exposure level measured onboard aircraft

Flight	Ratio MDU /EPCARD, H*(10)		
	"low LET"	"high LET"	total
PRG-JFK, 14/04 - "quiet 1"	1.00	0.96	0.98
JFK-PRG, 16/04 - "quiet 2"	1.01	1.01	1.01
PRG-JFK, 15/04 - with GLE 60	1.24	1.68	1.44
PRG-JFK, 12/04 - forbush 1	0.92	0.78	0.84
PRG-JFK, 06/11 - forbush 2	0.89	0.85	0.87

CONCLUSIONS

1 The semiconductor spectrometer has demonstrated its capability to provide dosimetry data and characterise the complex radiation fields onboard aircraft. Simplicity of its use and general reliability permits long-term onboard monitoring.

2 Its spectrometric properties permits a determination (with well-chosen interpretation procedure), of both qualitative and quantitative characteristics of onboard radiation fields.

3 These properties were able to estimate both quantitative and qualitative changes of the radiation dose during a solar cosmic ray event and also during an intense Forbush decrease.

4 Of course, additional effort is needed to improve its performance and to estimate still more quantitatively the validity of all approaches presented and tested. Among them:
- Further data on board should be accumulated, particularly in equatorial regions;
- Common measurements with a reference tissue-equivalent proportional counter and other instruments should be realized to compare directly measured and interpreted data.
- Further calibration of it in the CERN-EC reference fields is necessary.

All these approaches are in further progress in our laboratories.

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