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

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ABSTRACT

The radiation fields on aircraft board are complex, they contain the particles with energies up to few hundreds MeV [1]. There are different methods used to characterise this field for radiation protection purposes. We tried to test for such purposes a spectrometer based on Si-diode, largely tested at different sources and accelerator facilities. The energy deposited in the diode by a particle is analysed and permits to distinguish the contribution of different types of radiation to integral dosimetry quantities. During 2001-2002 years, the spectrometer was used to measure on board of commercial aircraft during five long-term exposures. It was found that the spectrum of energy deposition events onboard of aircraft is similar to that registered in CERN high-energy reference fields behind the concrete shield. We used this similarity to determine the correction factors to estimate radiation protection quantities from the results of onboard measurements. All necessary flight parameters were acquired, it permitted to calculate the effective dose and/or ambient dose equivalent on board by means of CARI-6 and EPCARD codes and compared them with the results of measurements treated as mentioned above. It was found that the apparent ambient dose equivalent values from measured data are in reasonable agreement with the results of calculation. Quantitative analysis of this agreement as a function of flight parameters (geomagnetic position, solar activity variations, etc.) is presented. During one of flights, an important solar event (GLE 60 at the 15th April 2001) was registered by means of the spectrometer. In some other cases the measurements during forbush decreases were also realized. These extremes were well registered by the equipment and the data obtained are also analyzed. The contribution of events with high E_{dep} is relatively more important during GLE60, less important during forbush decreases. The semiconductor spectrometer proved we believe its possibility to characterise dosimetric characteristics of complex radiation fields on aircraft board. Further effort would improve its performance.

MATERIALS AND METHODS

Detector used, mobil dosimetry unit

The Mobile Dosimetry Unit (MDU) can monitor simultaneously the doses and numbers of energy deposition events in a semiconductor Si-detector. It is designed as handy 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:

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

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 of 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, onboard tests

MDU units available were exposed in reference radiation fields. The results obtained at some photon sources are presented in Fig.1. Not only experimental but also theoretical event spectra in the semiconductor are presented there for ^{137}Cs and ^{60}Co photons.
They were calculated by means of EGS 4-transport code and one can see that the agreement of both spectra is rather satisfactory. The equipment was also exposed at some neutron sources. Rather large difference in the event spectra were observed. While for photons the maximum impulsion's height is about 1 MeV, for neutrons it reaches up to 10 MeV [3]. It could permit to distinguish photon and neutron induced events in other radiation fields. Tests with MDU units were performed on protons and heavy ions [2,4] and good agreement was found between the measured and predicted by the GEANT code simulations spectra.

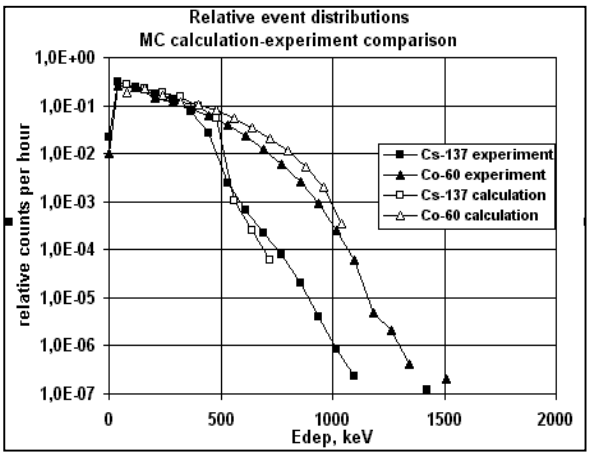

Fig. 1: Event spectra in some photon beams

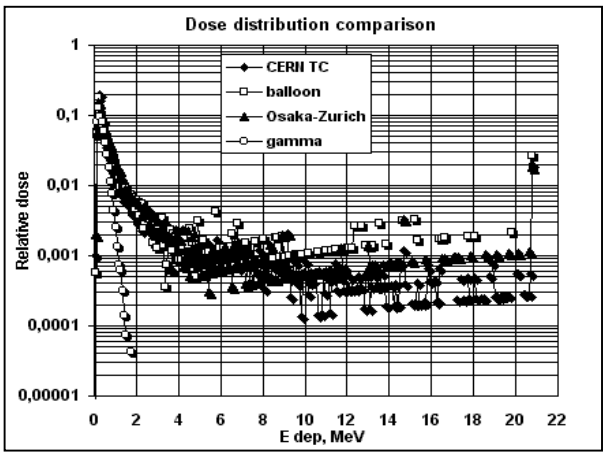

Fig. 4: Comparison of dose spectral distributions

MDU units have been tested since the spring 2000 during three calibrations runs in the CERN-EC high-energy reference field behind the concrete shield [5]. It should be stressed that 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 decreases in low E_{dep} region with increasing intensity, due to muon background [5]. For high E_{dep} events, it is independent of the intensity given by monitor units. 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 one. In CERN reference field, the dose 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 dosemeters based on Si-diode and taken it into account for the interpretation of these detector's readings.

Main effort was given to the measurements on aircraft board and their interpretation. First, it was actually observed that the spectra registered at CERN reference field are very similar to the spectra registered on the aircraft and/or balloon (see Fig.2). To interpret the data measured on aircraft board (D(Si)), we decided to use CERN reference field results. The dose in Si measured in low E_{dep} region was supposed to represent the contribution of low LET radiation, the dose in high E_{dep} region that of high LET component (neutrons). Taking into account reference fields values for these components [5], D(Si) measured on board was recalculated to obtain apparent H*(10) values.

Since the April 2000, the spectrometer has been used during more than 50 individual and five long-term exposures, about 1200 hours each, with about 400 flights in total. All necessary flight parameters were acquired from colleagues of Czech Airlines, that permitted to calculate the effective dose E on board by means of CARI 6 and EPCARD codes and compare them with the apparent H*(10) values obtained as mentioned above.

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

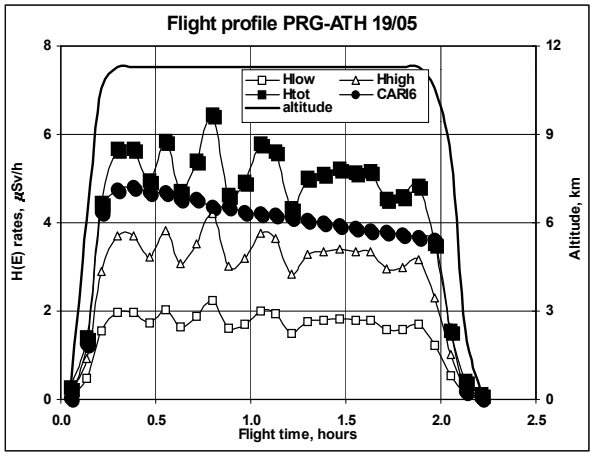

Fig. 3: Flight profiles Prague-Athens

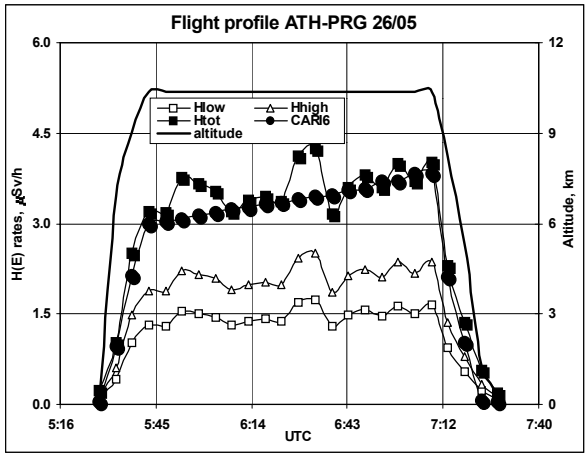

Fig. 4: Flight profiles Athens -Prague

RESULTS AND DISCUSSION

Characteristics at quiet cosmic environment

More detailed characteristics of long-term measurements are given in the Table 1, the record of detectors data for one of them is presented in the Figure 5.

Table 1: Characteristics of long-term onboard aircraft monitoring realised in 2001-2002 with 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

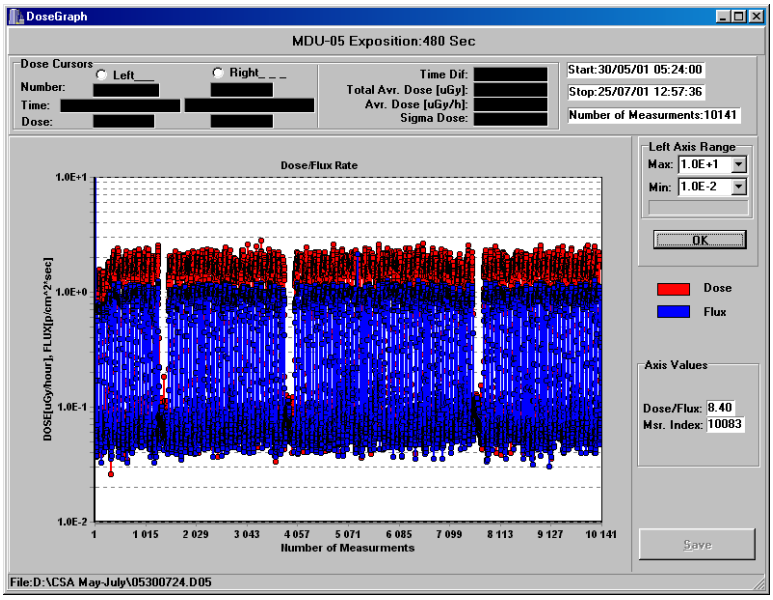

Figure 5: Record of measurements for the period 30/05-25/07/01

One can see there that about 500 individual flights were monitored, mostly over the North Atlantic. Figure 5 demonstrates also, how tight was flight schedule of the aircraft during the period of measurements, only three one-day interruptions can be registered in the record. Similar was the schedule also for other long-term runs, with the exception of periods during and after 11th September event.

CSA colleagues submitted us navigation data on all flights. It permitted to calculate the total exposures during them and compare calculated data with results obtained by means of procedure mentioned above. The results obtained up to now for integral values of dosimetric quantities are presented in the 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 very well, only the values of effective dose are, when EPCARD code is used, a little, in average by 12 %, higher. Such difference is from the point of view of radiation protection largely acceptable [5].

The data from log-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.

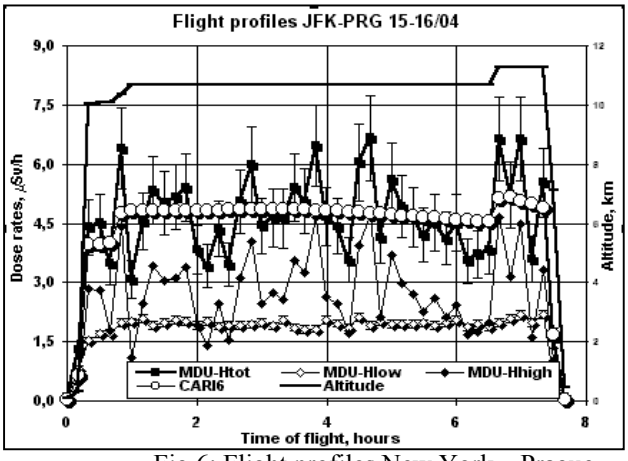

Fig.6: Flight profiles New York – Prague

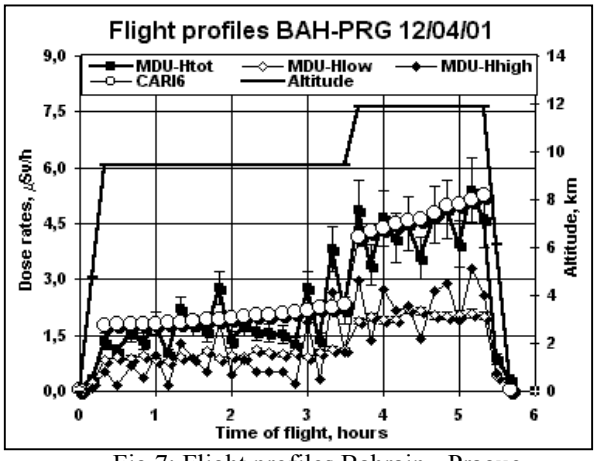

Fig.7: Flight profiles Bahrajn - Prague

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. 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 exceeded 10 %.

Characteristics during extremes in the cosmic environment

During the 1st monitoring period, several colleagues informed us that an intense solar flare, Ground Level Event (GLE), numbered 60, occurred after the noon of 14th April. The Si-spectrometer was taken away only the 7th May to assure sufficiently high exposure of passive detectors irradiated with it. We have really observed a maximum in full record (Fig.8) situated at the 15th April, its zoom (Fig.9) demonstrate that solar flare took place roughly 3 hours after the taking off from Prague to New York. A good time and form-correlation's of our measurements with independent data available from Oulu (Finland) cosmic ray monitor station and/or from the GOESS system satellites was also confirmed as shown in the Figure 10.

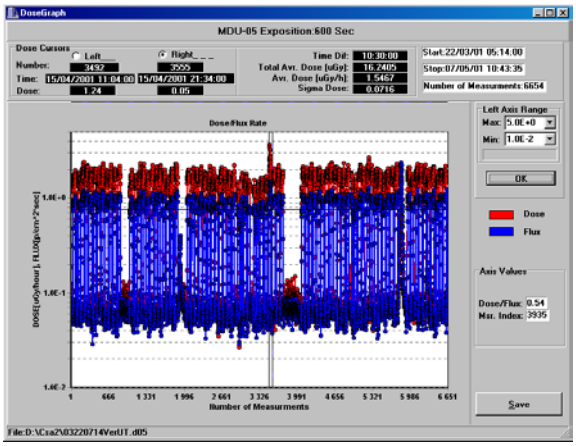

Fig.8: Record of measurements, period 22/03-07/05/01

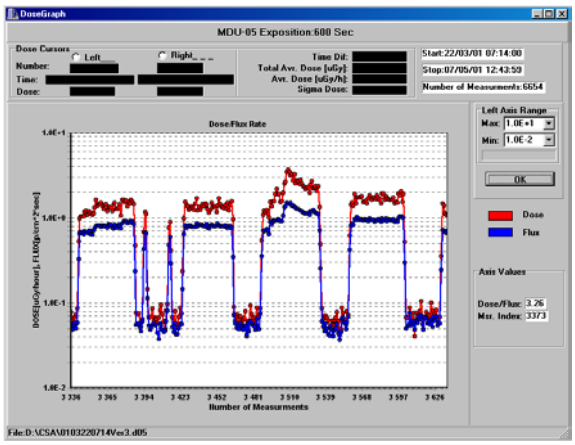

Fig.9: Zoom of the record, 14-16/04/01

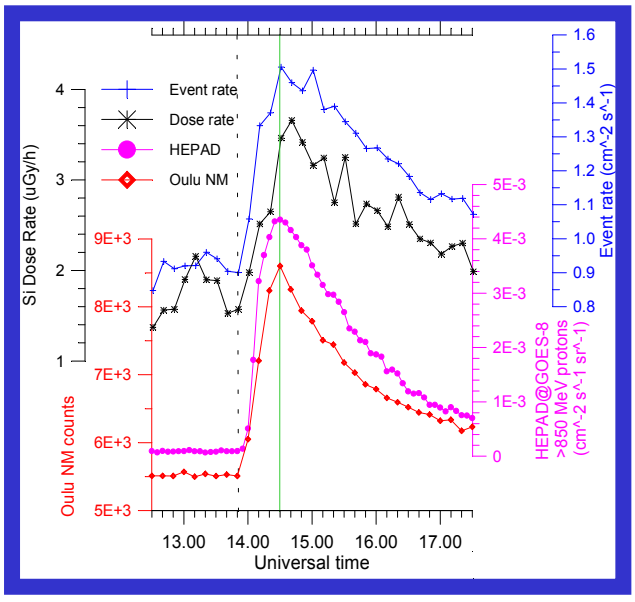

Fig. 10: Correlation of spectrometer and other data

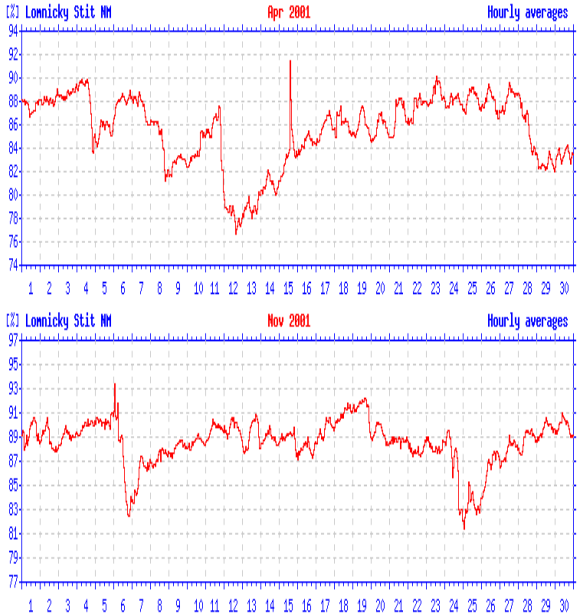

Fig.11: Lomnicky stit monitor data – 04 and 11/01

Another extremes occurred also during 2001 year, so called forbush decreases. Particularly important there were at 12th April and 6th November, as can be seen in records of Lomnický štít cosmic ray monitor data presented in the Fig.11. During them the intensity decreased rapidly by more than 10 %, it would be reminded that the geomagnetic rigidity of Lomnický štít monitor is about 3.9 GV.

Fortunately, also during these extremes our spectrometer was flying on the board of aircraft. The aircraft with the Si-spectrometer was at the both dates mentioned flying roughly at the same time as for GLE 60 also from Prague to New York. We treated directly measured data in the same way as for other flights and compared them with the results of calculation by means of EPCARD3.1 code [7]. The results of such comparison are presented in the Table 3. One can see there that solar flare and forbush decrease influence the exposure level both quantitatively and qualitatively. Total exposure is

for GLE 60 about 44 % higher, for forbush decrease about 16 % lower. Besides, the influence is more important for high LET (neutron) radiation component. The changes observed seem to indicate that the neutron spectrum is softer during a solar flare, harder during the forbush decrease. It would correspond to the expectation.

Table 2: The influence of extremes on the exposure level measured on aircraft board

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 proved according our opinion its capability to characterise dosimetric characteristics of complex radiation fields on aircraft board. Simplicity of its use and general reliability permits to perform also long-term onboard monitoring.
2. Its spectrometric properties seem to allow, together with well-chosen interpretation procedure, to obtain both qualitative and quantitative characteristics of onboard radiation fields.
3. These properties were able to estimate both quantitative and qualitative changes also during a solar flare and sufficiently intense forbush decreases.
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 realised to compare directly masured 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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