Contribution of the Nuclear Physics Institute of the AS CR to the BEOBAL Project 2004 - 2006

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Activities NPI 2004-2006 related to BEOBAL - overview

1. **Scientific and technical (S&T) cooperation:**
- Environmental external radiation studies
- TLD studies
- Environmental radioactivity measurements
2. **Technical assistance, upgrading, consultations**
- ^{14}C and Rn – technology transfer
- Common methods development
3. **Improvement of Human Resources**
- Stays for PhD students in NPI
- Seminars to advanced topics
- Special visits and consultations

S&T cooperation NPI 2004-2006 related to BEOBAL - overview

1. **Environmental external radiation studies:**
- **High mountains measurements**
- **Cosmic neutron component studies**

2. **TLD studies:**
- **LET dependence of the relative response**
- **Response to high-energy protons, linearity**
- **Onboard aircraft and spacecraft studies**

3. **Environmental radioactivity measurements**
- **Rn and its daughter products – method's upgrading**
- **Environmental radionuclide's activity measurements**

Environmental external radiation studies

- **Results of studies on the territory of the INRNE and at BEO Moussala with different instruments**
- **Acquisition of MDU by INRNE – comparison with MDU of NPI; common studies at some radiation sources, and at BEO Moussala**
- **Results of common studies on the high-mountain station at Moussala with MDU equipments, comparison with Lomnický Štít (High Tatras)**

Methods used

1. Active instruments:

- ***Environmental radiation dose rate meter NB 3201*** **with a plastic scintillator as sensitive element; able to measure the environmental radiation background with low linear energy transfer (LET) (10 nSv to few mSv/h)**
- ***MDU-Liulin semiconductor spectrometer*** **with Si-diode as the sensitive element; able to estimate both low LET and neutron component of the natural background (10 nSv to few mSv/h)**

2. Passive detectors:

- ***Thermoluminescent detectors (TLD) $CaSO_4$:Dy***
- ***Moderator sphere (12 inches)with TED in contact with B-radiators***

Measuring localities

1. *Territory of the INRNE BAS at Sofia:*

- Outside of the building of the Division of Cosmic Ray Physics (DCRP) and on its terrace on which a radiation monitor is permanently measuring;
- Around the reactor IRT 2000 building

2. *Basic Ecological Observatory (BEO) Moussala;* altitude 2925 m, geographic coordinates 25°35’ E and 42°11’ N
3. *Lomnický Štít Observatory of the Institute of Experimental Physics SAV, High Tatras;* altitude 2634 m, geographic coordinates 20°22’ E and 49°20’ N

Results - INRNE

Measuring point	H*(10), nSv/h, as measured by		
	NB 3201	MDU-Liulin*	TLD
DCRP – in front of	106	-	-
DCRP – terrace	102	103	78-141
Reactor – 1	110	134	130-154
Reactor - 2	100	104	124

* Mean value for two MDU units

Results – BEO Moussala

Measuring point	H*(10), nSv/h, as measured by		
	NB 3201	MDU	TLD
Ground level of building	240	-	-
First floor of building	138	130*)	-
Outside of building	176	-	165-183
Terrace of building	138	140*)	-

***) Corresponding only to low LET radiation**

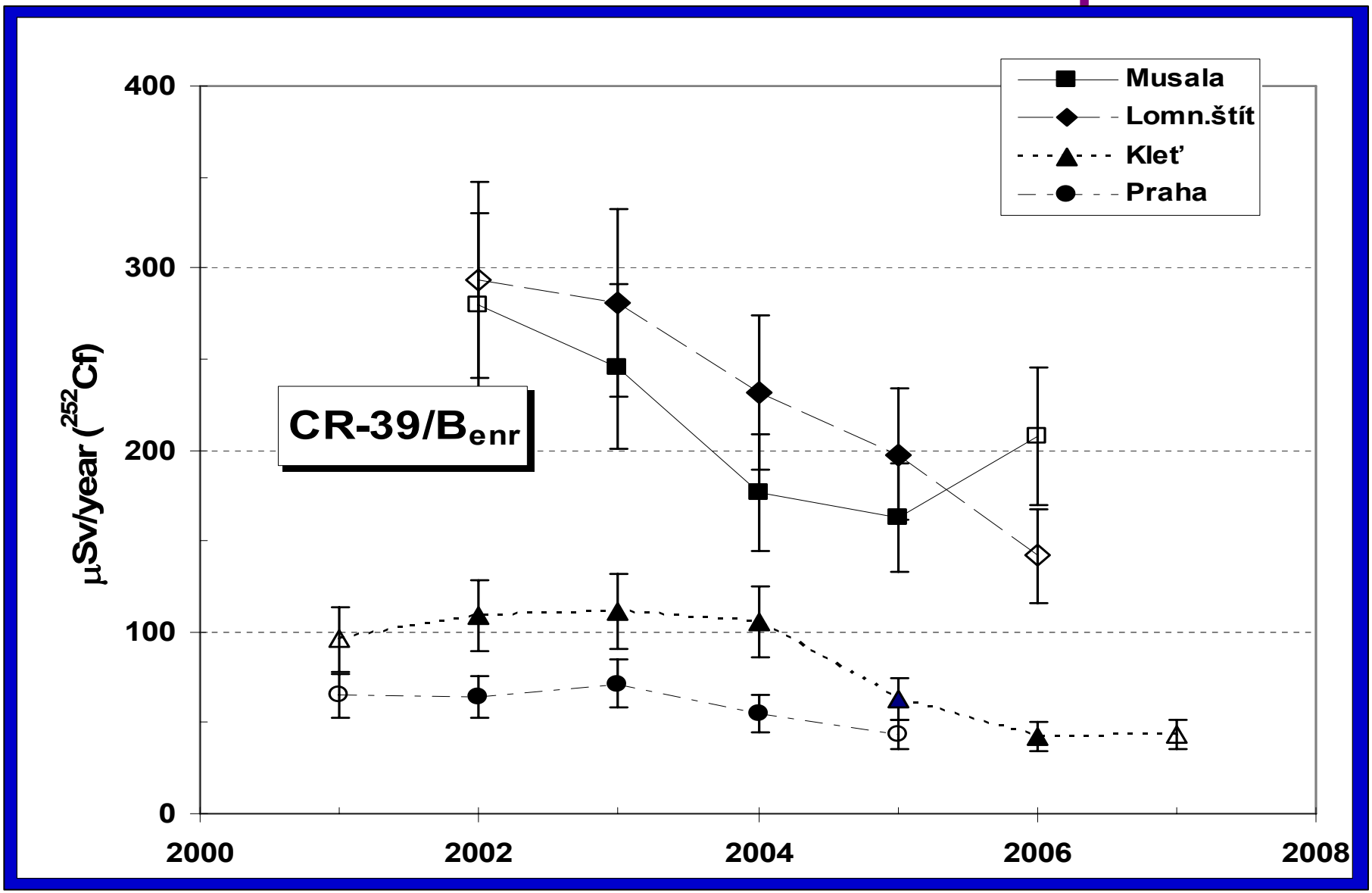
The average value of monitors of INRNE BAS110 nSv/h; minimum and maximum values 87.5 and 128.1 nSv/h

Results - neutron component of cosmic radiation at BEO Moussala – Comparison of different instruments and methods

Method (Quantity measured)	Annual value measured	Annual value corrected
Harwell 3208-1	(190 - 390) μSv[1)]	(380 – 780) μSv
Sphere with ^{10}B	(216 ± 26) μSv[2)]	(450 ± 52) μSv
MDU-Liulin (NPI)	(98 ± 15) nGy[3)]	(630 ± 90) μSv
UNSCEAR 2000	-	~ 680 μSv

[1)] Period 09/02 ÷ 05/03; [2)] Period 01/02 ÷ 12/06; [3)] October 2006

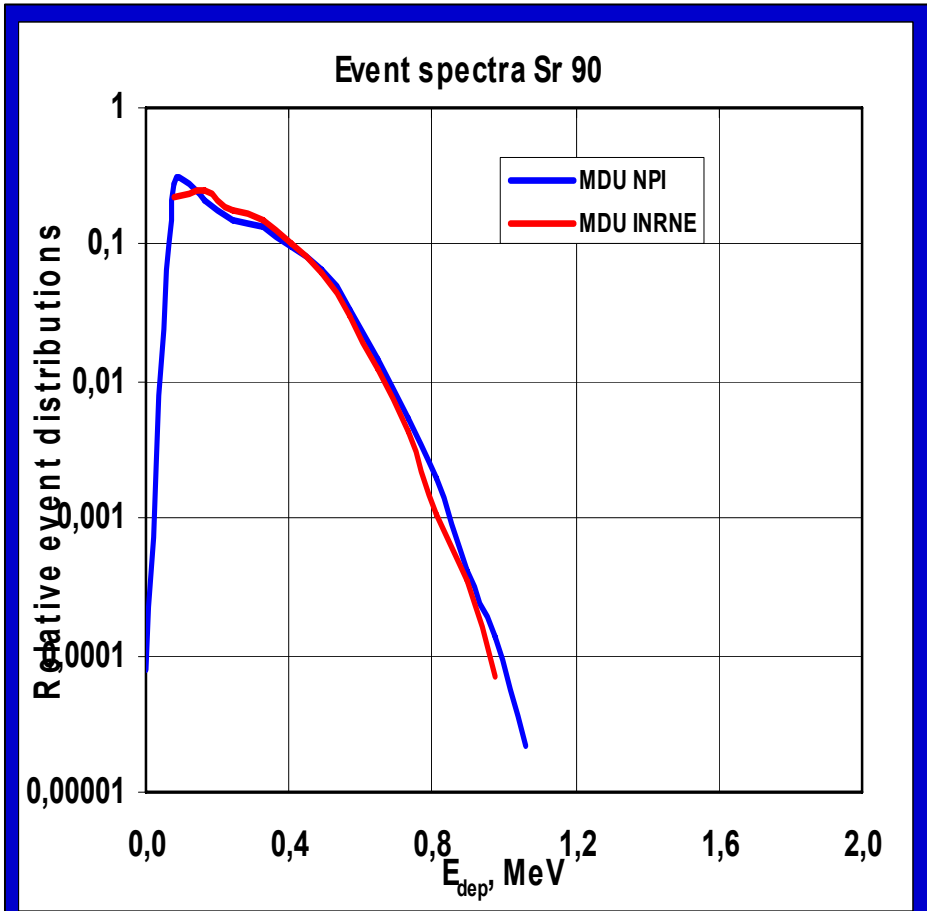
Cosmic neutrons at some stations as measured inside a moderator sphere

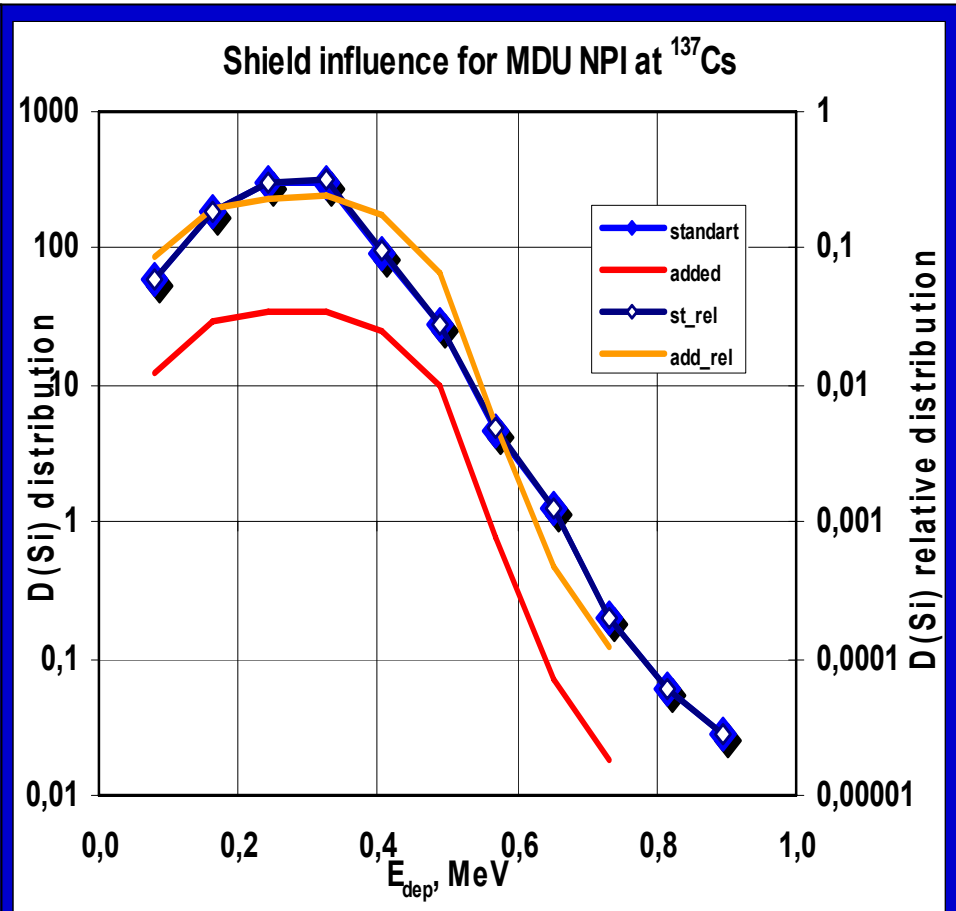


Comparison of NPI and INRNE MDU equipments - 1

- INRNE – acquisition spring 2006;
- Difference: shield of Si-diode different (air gap 5mm!), and also 5 times thicker for INRNE unit;
- Comparison performed at Sr-Y, PuBe, Cs sources, and measuring background

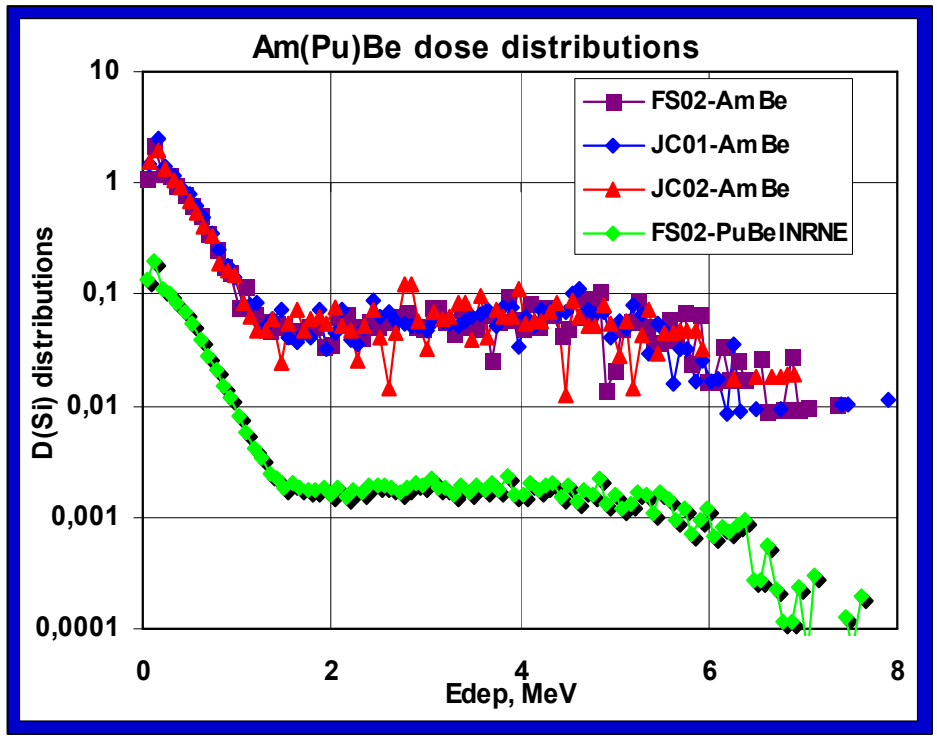
Comparison of NPI and INRNE MDU equipments – results 1





Comparison of NPI and INRNE MDU equipments – results 2

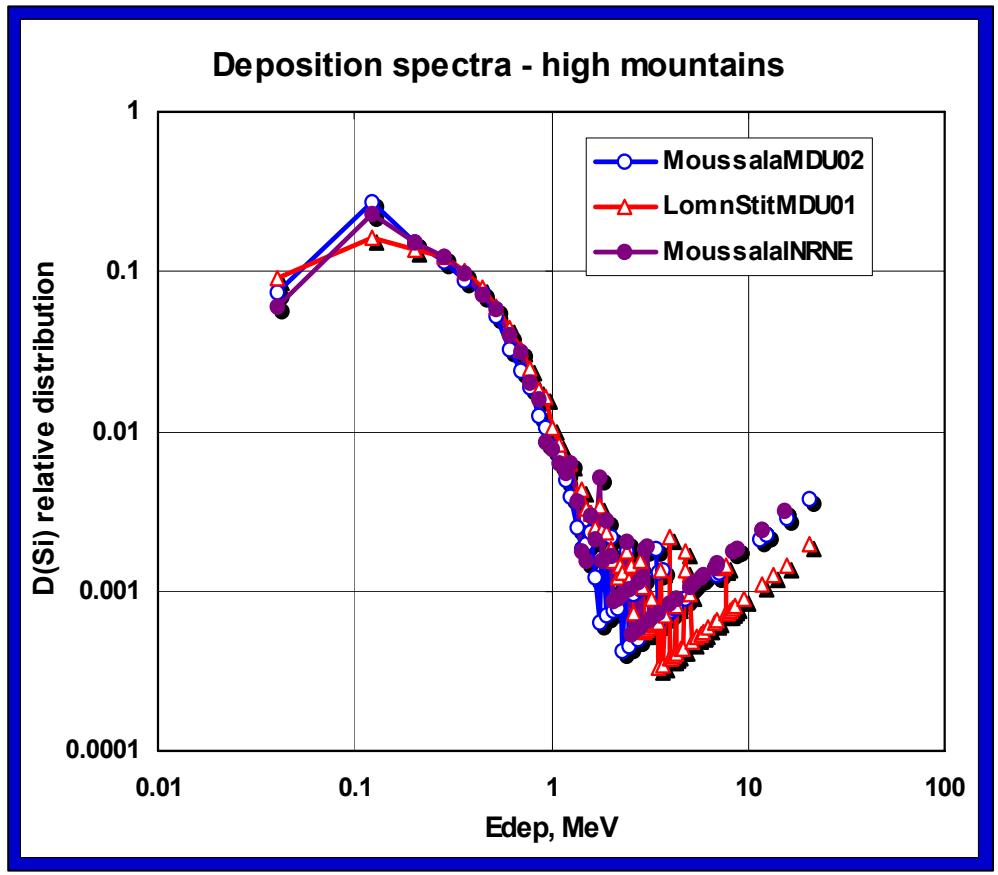
- For Sr-Y: D(Si) twice less for INRNE unit;
- For ^{137}Cs in contact with the unit surface: D(Si) six times less for INRNE unit;
- For PuBe source: D(Si) about 30 % lower for INRNE unit; spectra similar
- Background: D(Si) about 20 % lower for INRNE unit



MDU equipment's common studies at BEO Moussala, and at Lomnický Štít - 1

MDU 02 unit of the DRD NPI AS CR positioned close to the unit of the INRNE:

- 07/10/06 (12:00 UTC) to the 09/10/06 (06:00 UTC)
- Si - detectors units of both equipments were placed at the upper floor of the main building of the station, precisely the server room and near the north-west wall.



Results - neutron component of cosmic radiation – Comparison of BEO Moussala

Table 1: D(Si) annual values, (μGy) measured at Moussala with two MDU

MDU unit	$D(Si)_{low}$	$D(Si)_{high}$	$D(Si)_{total}$
INRNE	1121.1.	111.7	1232.8
NPI	1199.0	92.3	1291.3

Table 2. Comparison of annual apparent ambient dose equivalent values, in μSv, at BEO Moussala, obtained from MDUs data when using conversion factors (CF) established for DRD NPI MDU 01 and 02 units.

MDU unit	CF from	$H_{app}(10)_{low}$	$H_{app}(10)_{high}$	$H_{app}(10)_{total}$
INRNE	MDU02	1793.7[1)]	725.9	2519.6
	MDU01	1681.6	681.2	2362.8
DRD NPI02	MDU02	1932.4	626.7	2559.1

[1)] Relative uncertainties (1s) about ±10 % for low energy deposition component, ±20 % for high energy deposition component, resp. ±15 % for $H_{app}(10)_{tota}$

Results - neutron component of cosmic radiation – Lomnický štít

Table 3: Annual values of radiation protection quantities as established at Lomnický štít observatory by means of MDU spectrometers.

Run floor	Unit	Annual $H_{app}(10)$, μSv		
		low LET	neutrons	total
08/2004	MDU 01	1790 ± 32[1)]	860 ±85	2650 ± 72
bottom	MDU 02	1850 ± 52	740 ± 48	2590 ± 78
12/2005	MDU 01	1400 ± 47	444 ± 48	1840 ± 85
-2 floor	MDU 02	1490 ± 48	435 ± 51	1920 ± 83
03/2006	MDU 01	1640 ± 30	815 ± 44	2460 ± 44
bottom	MDU 02	1720 ± 30	979 ± 111	2650 ± 105
- 1 floor	MDU 02	1605 ± 16	532 ± 55	2140 ± 56
-2 floor	MDU 02	1490 ± 17	426 ± 52	1920 ± 54

[1)] Only statistical uncertainties

Neutron component of cosmic radiation – comparison Moussala-Lomnický štít

1. **Low energy deposition component practically impossible to compare. This component is composed as a sum of cosmic radiation contribution (~ 600-650 μSv for both observatories) and that of "terrestrial" contribution not exactly known in both cases.**

1. **As far as the neutron (high-energy deposition) component, its contribution could be estimated on the base of the last UNSCEAR Report, we have estimated it as close to 600-700 μSv per year at both stations**

- **When these figures are considered, it seems that the interpretation of INRNE data by using MDU 01 CF is closer to the realistic estimated values.**
- **In such case (see Table 2), the low energy deposition contribution is for INRNE MDU unit about 10-15% lower that that established with DRD NPI unit. It is in realistic agreement with expected underestimation of this component due to thicker shield of Si-diode, seen in previous results.**

TLD studies:

LET dependence of the relative response

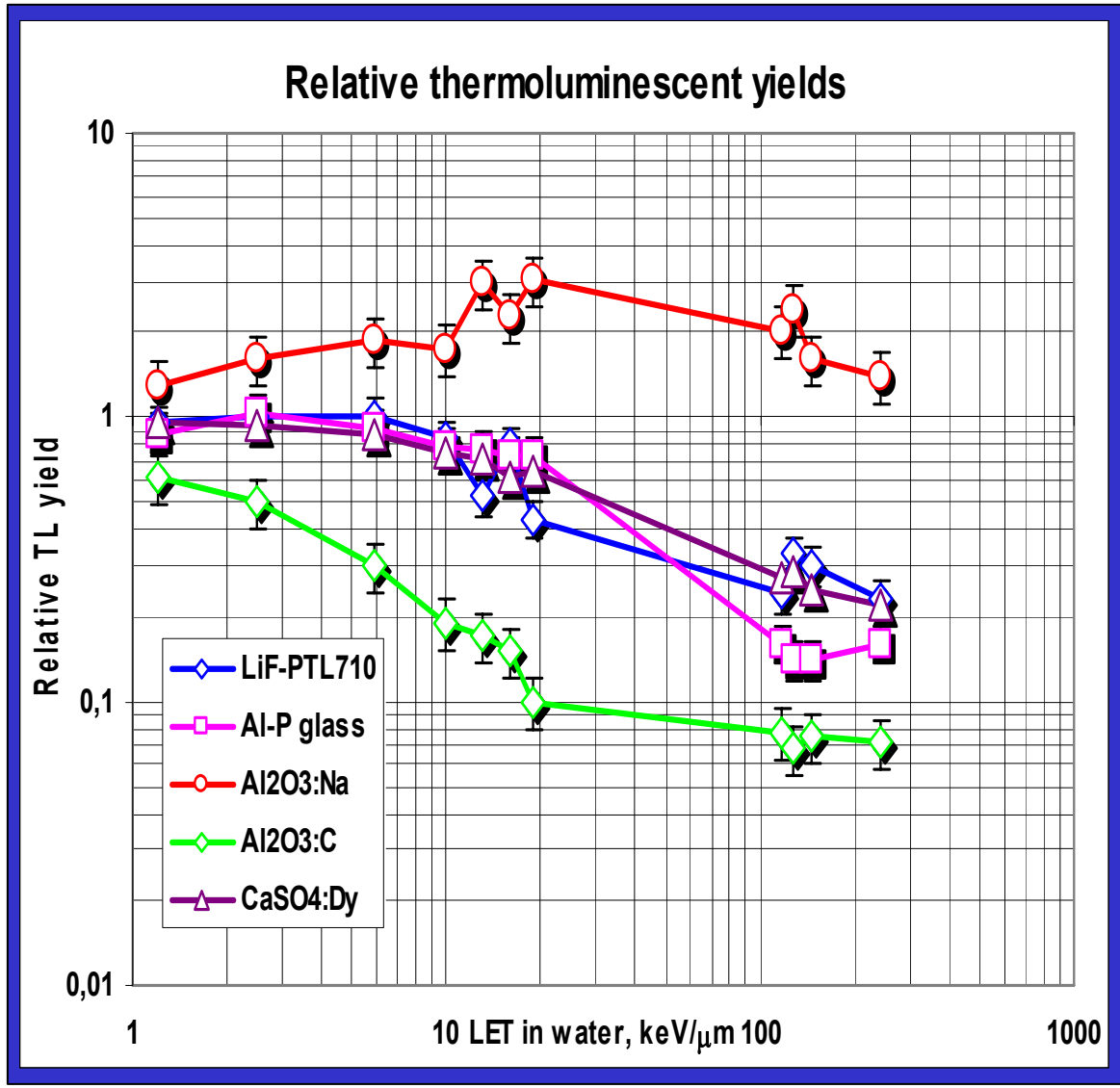
Beam	Actual energy	Actual LET	RR for		
	MeV/n	keV/µm	Al_2O_3:C	Al-P glass	$CaSO_4$:Dy
He	150	2.16	0.77±0.05	0.94±0.08	1.01±0.09
He/PMMA	61[1)]	4.2	1.10±0.08	1.37±0.11	1.63±0.12
O	395	20.0	0.47±0.04	0.92±0.07	0.95±0.06
O/PMMA	268[1)]	25.0	0.47±0.04	0.92±0.08	0.94±0.07
Ar	440	92	0.32±0.02	0.64±0.05	0.59±0.04
Ar/PMMA	377[1)]	108	0.34±0.03	0.68±0.05	0.62±0.04
Fe	130	411	0.25±0.02	0.58±0.04	0.44±0.03
Fe/PMMA	105[1)]	445	0.35±0.03	0.77±0.05	0.57±0.04

[1)] Calculated with SRIM code on the base of the energy for bare beam and the thickness of shield

Response of $CaSO_4$:Dy TLD to high energy charged particles - 3

Comments:

The values of RR for AlP glass and $CaSO_4$:Dy are for all beams rather similar, those of Al_2O_3:C are in all cases lower. Such behavior observed for TLD's already in previous studies (Spurny, 2004–see Figure)



TLD studies: Response of $CaSO_4$:Dy in radiotherapy proton beam-1

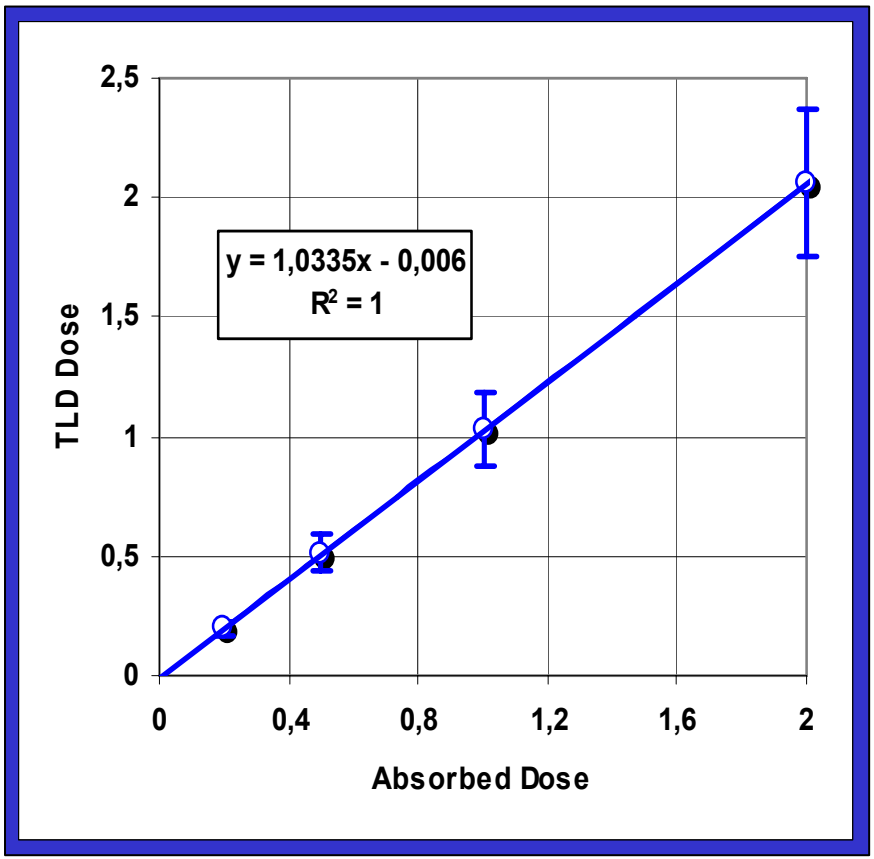
1. **Entrance proton energy – 171 MeV**

2. **Depth of Bragg peak ~ 194 mm**

3. **Studies performed**:

- Linearity (0.2 to 2 Gy)
- Depth dependence of the response

TLD studies: Response of $CaSO_4$:Dy in radiotherapy proton beam-2



Linearity of response - 145 MeV very good

Depth, mm of H_2O	E_{res} MeV	LET_{aver} keV/µm	Relative response
12	166	0.52	1.05[1)]
52	148	0.57	1.01
74.5	106	0.72	0.98
115	93	0.80	1.00
165	64	0.95	1.08
194	Bragg peak	3.1	1.20

Depth, proton energy, and LET dependence of the RR - negligible

[1)] Relative uncertainty ± 12 % (2 s)

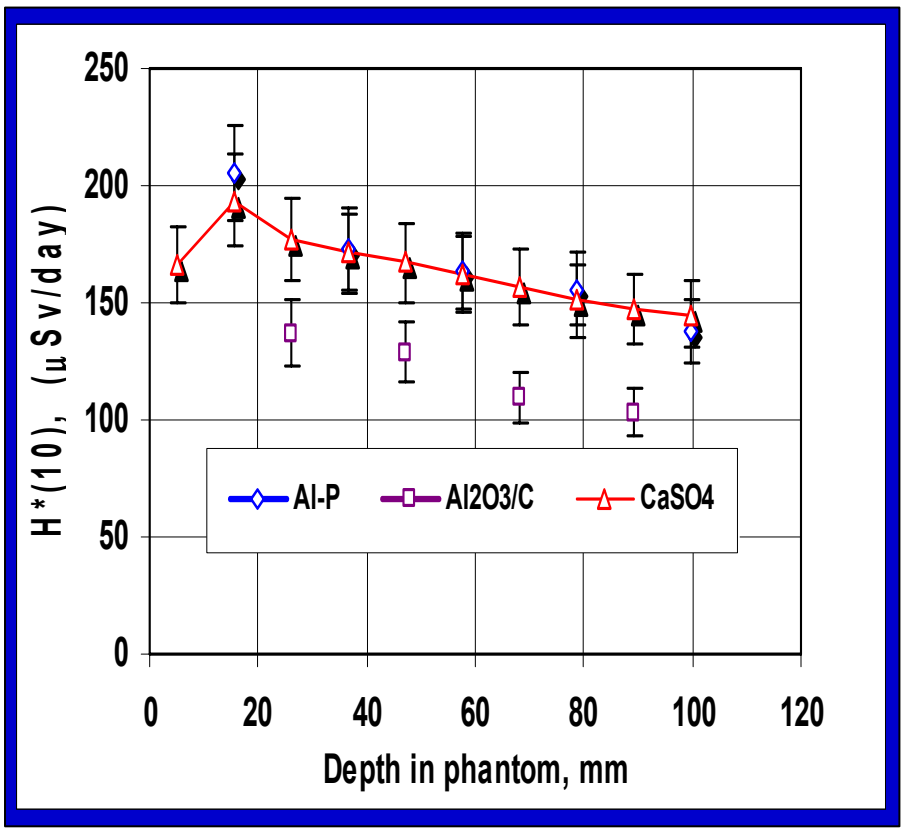
Onboard aircraft exposure

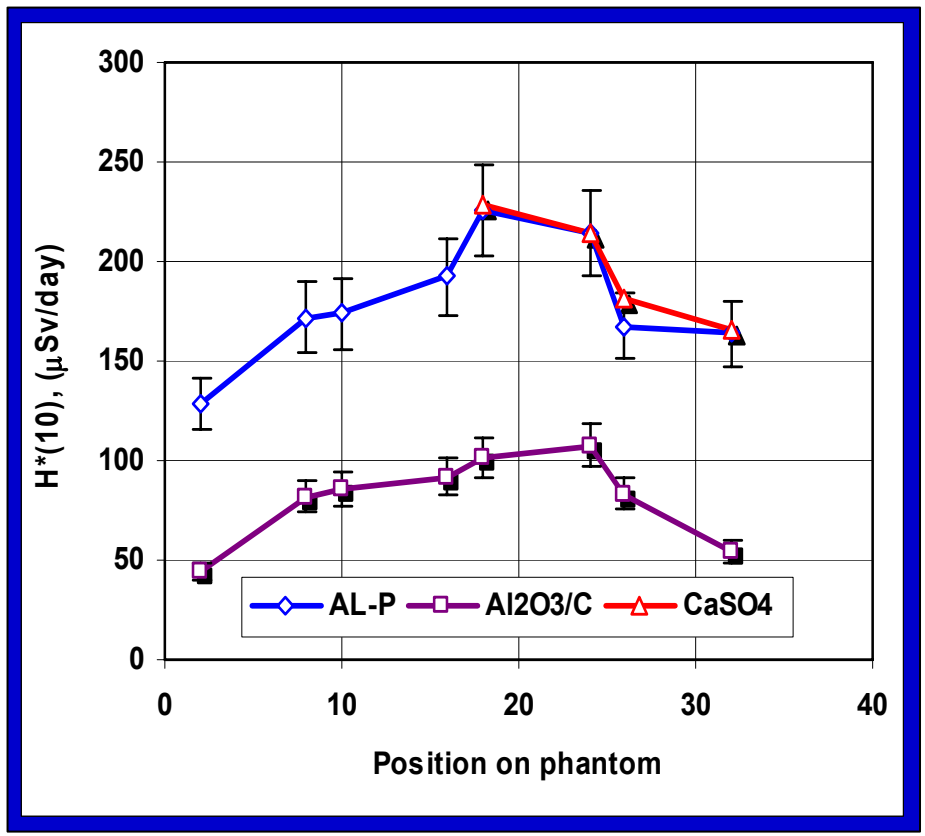
- 25/08 to 31/12/05 - A310-300 (Czech Airlines)
- Basic monitoring equipment - MDU
- On its body, several types of passive detectors were fixed, among them also CaSO4:Dy TLD's.
- Calculation – EPCARD 3.2. code

Dosimetry method	Quantity	Value, mSv
EPCARD 3.2. - calculation	Ambient dose equivalent H*(10)	2.22
MDU –from measurements	Apparent H*(10)	2.6±0.3
$CaSO_4$:Dy – TLD, measured	H*(10)	2.2±0.2

Onboard spacecraft exposure

- Onboard International Space Station, 15/12/05 to 15/09/06
- On and inside MATRJOSHKA-R phantom (30 cm diameter sphere)
- CaSO4:Dy of INRNE together with AlP-glass, and Al_2O_3:C





Further S&T cooperation NPI related to BEOBAL

1. Rn detection and dosimetry:

- In soil – comparison of TLD and track etch detectors
- Rn concentration in air at BEO Moussala, and at INRNE territory: 4-5 $Bq.m^{-3}$
- Automation of track counting by means of a scanner – transfer of procedure, comparison of results

2. Radioactivity in the environment

- Consulting concerning ^{14}C monitoring at NPS
- Measuring and evaluation methods for LSC
- Equipment and evaluation for ^{14}C monitoring in air
- Transfer of technology (free of charge) from NPI to INRNE, for CO_2 sampling from air

S&T equipment – renewal, upgrading

- **Lent from NPI for long-term**
  - **Universal stand for multiple electrochemical etching;**
  - **LSC Tricarb 1050 - in preparation**

- **Detector's calibration**
  - **TLD – NPI calibration facilities; high energy heavy charged particles (HIMAC, Chiba, Japan);**
  - **Comparison of TED ECE evaluation procedures – by eye, and/or with a scanner;**

Improvement of Human Resources- 1

- Stays for PhD students in NPI:

➢ **30 + 21 days – advances in TED method, particularly for Rn detection and dosimetry – done**

➢ **30 + 7 days – advances in radioactivity measurements, particularly for ^{14}C and T measurements by LSC - planned 2006/2007 - done**

- Seminars to advanced topics:

➢ **Track etch detectors and their use for environmental dosimetry and other studies - done**

➢ **Methods and equipment for external exposure in the environment; their metrology – done**

Improvement of Human Resources - 2

- **Visit in NPI (7 days) with the goal to estimate the use of INRNE ion implantator as AMS for ^{14}C analysis;**

- **Consultation of NPI expert on ^{14}C determination by means of LSC (3 x 7 days;**

- **Consultation of NPI expert in course of the preparation of the project on ^{14}C-dating (BAS received ~ 150 k€)**

Future

1. Cooperation will continue in the frame of bilateral Academy agreement;
2. Search (common) for other international sources of support:

- Prolongation of BEOBAL type of program?;
- EURADOS activities (WG 2 on the harmonisation of individual monitoring);
- Research program of the JINR Dubna – TLDs studies in high energy charged particle beams;
- Other possibilities to be searched for

Thank you for your attention !