THE NTUA RADON CHAMBERS AND THE RADIOACTIVITY OF GREEK BUILDING MATERIALS

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USING RADON CHAMBERS (I)

Radon Chambers enable controlled environment in terms of temperature, humidity, air-exchange rate, radon concentration, particle concentration, aerosol size distribution, radon progeny concentration etc, thus providing scientists with a tool for conducting thorough experimental studies on radon and radon progeny

USING RADON CHAMBERS (II)

Radon Chamber experiments include studies on radon progeny behavior and especially unattached radon progeny behavior, attachment processes to aerosol particles and recoil and deposition phenomena.

Most of such experiments are Chamber volume depended

USING RADON CHAMBERS (III)

Such Radon Chamber experiments are useful in the interpretation of indoor environment experimental data, in understanding the synergism between factors influencing radon progeny behavior and in the development of radon progeny behavior models.

USING RADON CHAMBERS (IV)

Other Radon Chamber experiments may be used to evaluate radon and radon progeny measurement techniques, calibrate active and passive radon measurement instrumentation and certify the compatibility of measurement methods and protocols as well as the compatibility of models based on chamber experimental results.

USING RADON CHAMBERS (V)

The ultimate scope of using Radon Chambers is:

To provide sound predictions and control techniques of indoor radon and indoor radon progeny concentration by evaluating the influence and synergism of factors such as:

USING RADON CHAMBERS (VI)

Air-exchange rate

Particle removal by deposition on walls and other surfaces

Filtration

Incomplete mixing

Thermal and electrical effects

Building materials as a source of indoor radon

USING RADON CHAMBERS (VII)

The quantitative tools employed to this end are the measurements of:

Potential Alpha-Energy Concentration (PAEC)

Unattached fraction

Equilibrium Factor (EQF)

Raw building materials exhalation rate and emanation coefficient

Exhalation rate and emanation coefficient of structural modules

USING RADON CHAMBERS (VIII)

Radon Chambers are also used to study the effectiveness of remediation techniques, such as :

- *Epoxy sealants,*
- *Membranes, and*
- *Concrete*

as radon barriers

USING RADON CHAMBERS (IX)

Furthermore, a Radon chamber may be used in animal studies lung-dose experiments and in relevant measurements for Thoron and Thoron Progeny

NTUA – Nuclear Engineering Section, Laboratory Building

THE NTUA RADON CHAMBERS (I)

Designed and constructed in Greece by the NTUA Nuclear Engineering Laboratory

- ✓ Radon chamber 1.8 m^3
- ✓ Radon chamber 8.5 m^3

Made of stainless steel, Air-tight and Radon-tight

Computer controlled environmental conditions

(Temperature 12-45 ^{o}C,

Humidity 15 –95% non-condensing)

$1.8m^3$ RADON CHAMBER TECHNICAL DATA

LENGTH: 1.2m, WIDTH: 1.0m, HEIGHT: 1.5m

DOOR: 1.1m HIGH, 0.6m WIDE

This chamber is primarily suitable for Radon exhalation measurements

THE 1.8 m^3 RADON CHAMBER

FRONT SIDE VIEW

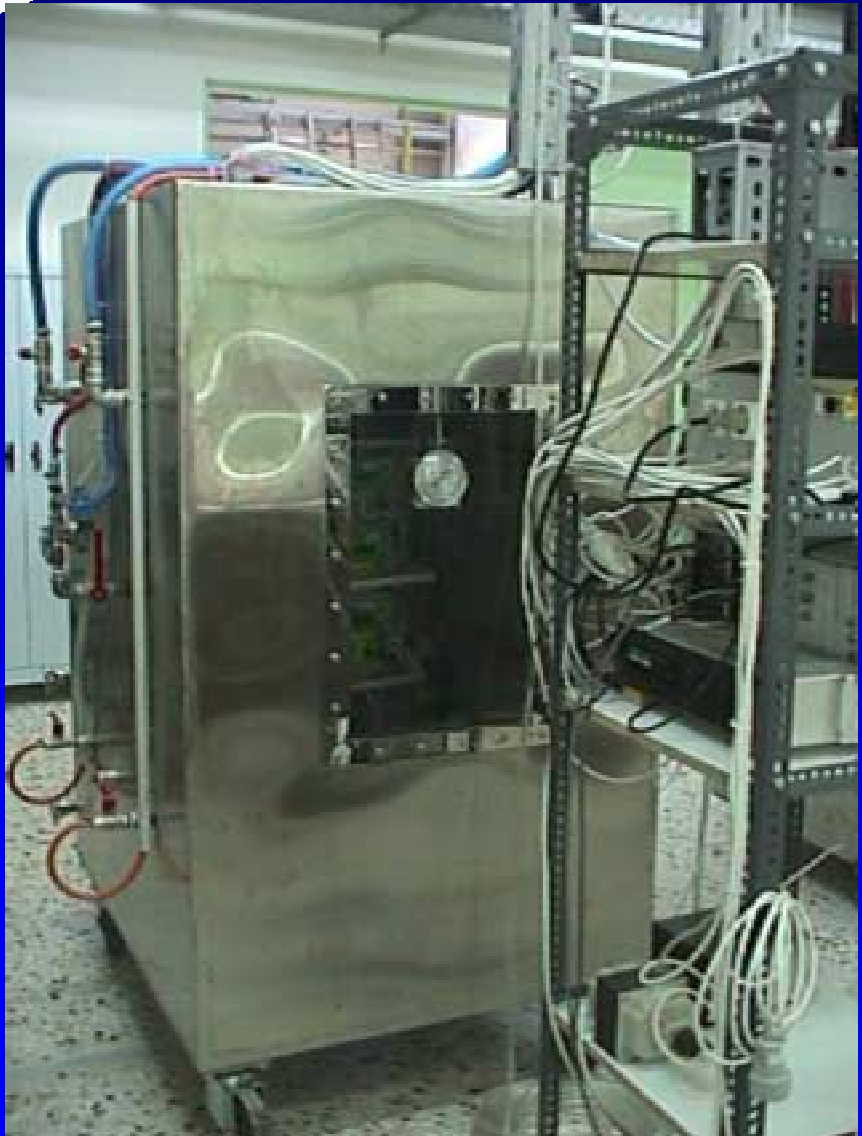
THE 1.8 m^3 RADON CHAMBER

LEFT SIDE VIEW

THE 1.8 m^3 RADON CHAMBER

RIGHT
SIDE
VIEW

THE 1.8 m^3 RADON CHAMBER



REAR SIDE VIEW

RADON-TIGHT DOOR DETAIL

THE 1.8 m^3 RADON CHAMBER

CONTROL PANEL

8.5m^3 RADON CHAMBER TECHNICAL DATA

LENGTH: 2.4m, WIDTH: 1.7m, HEIGHT: 2.1m

DOOR: 1.1m HIGH, 0.6m WIDE

The surface-to-volume ratio is such that an equilibrium factor of about 0.4-0.5 may be maintained for a long period of time without using air circulation or aerosol production.

THE 8.5 m^3 RADON CHAMBER

FRONT SIDE VIEW

THE 8.5 m^3 RADON CHAMBER

LEFT
SIDE
VIEW

THE 8.5 m^3 RADON CHAMBER

REAR SIDE VIEW

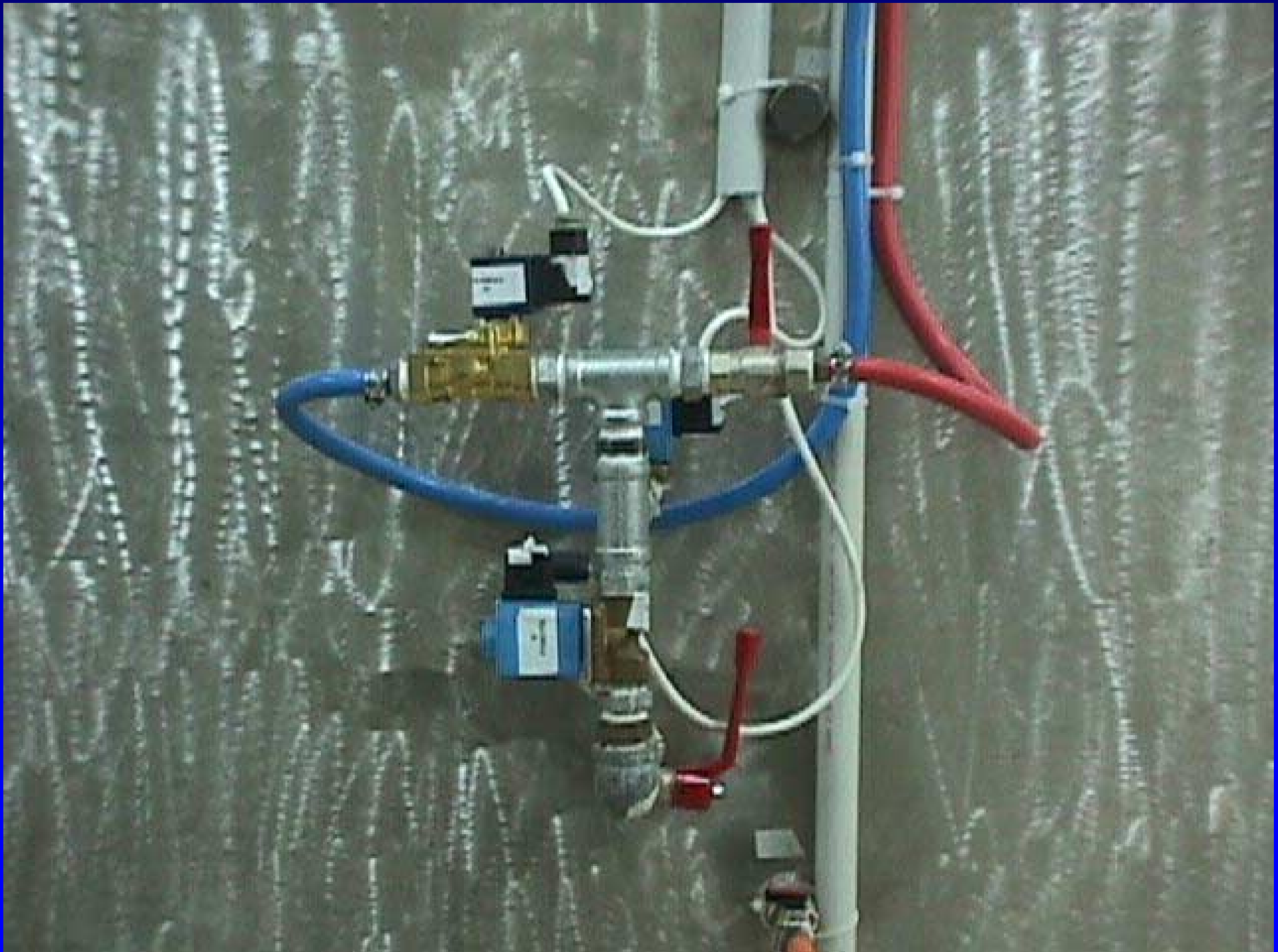
THE 8.5 m^3 RADON CHAMBER

RADON-TIGHT DOOR DETAIL

THE 8.5 m^3 RADON CHAMBER

CONTROL
PANEL

PIPING DETAIL



THE NTUA RADON CHAMBERS (II)

ENVIRONMENTAL MONITORING

Thermometers

Thermocouples

Hair Hygrometers

Relative Humidity Transducers

Pressure Transducers

RELATIVE HUMIDITY TRANSDUCER CONTROL PANEL

CHAMBER PRESSURE MONITORING

PRESSURE TRANSDUCER 1

PRESSURE TRANSDUCER 2

THE NTUA RADON CHAMBERS (III)

ENVIRONMENTAL CONTROL

Humidifier

Heater

Aerosol Generator

Air Circulator

Ioniser

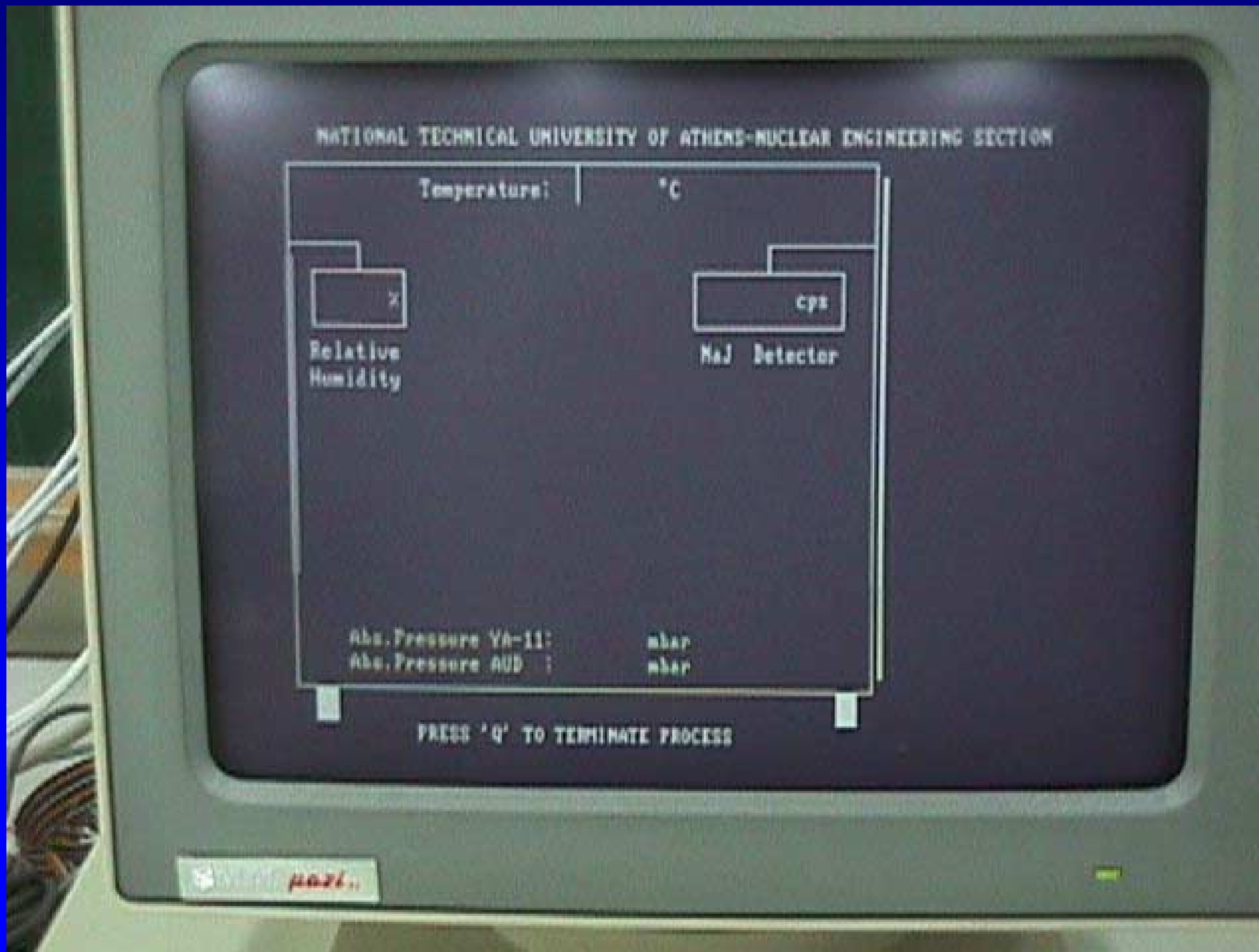
PC Controlled Environmental Data Acquisition using more than 10 transducers per chamber

HUMIDIFIER, HEATER, AEROSOL GENERATOR and IONISER

AIR CIRCULATOR (FAN)

PC CONTROLLED ENVIRONMENTAL DATA ACQUISITION (I)

PC CONTROLLED ENVIRONMENTAL DATA ACQUISITION (II)



PC CONTROLLED ENVIRONMENTAL DATA ACQUISITION (III)

RADON CONCENTRATION ESTABLISHMENT

TWO CERTIFIED DRY ^{226}Ra RADON SOURCES (100% EMANATING POWER)

- ✓ PYLON 102.8 kBq
- ✓ CZECH METROLOGICAL INSTITUTE 274.3 kBq

RADON IS INTRODUCED IN THE CHAMBERS USING IN-LINE EXTERNAL CIRCULATION and INTERNAL CIRCULATION

RADON IS INTRODUCED IN THE CHAMBERS USING :

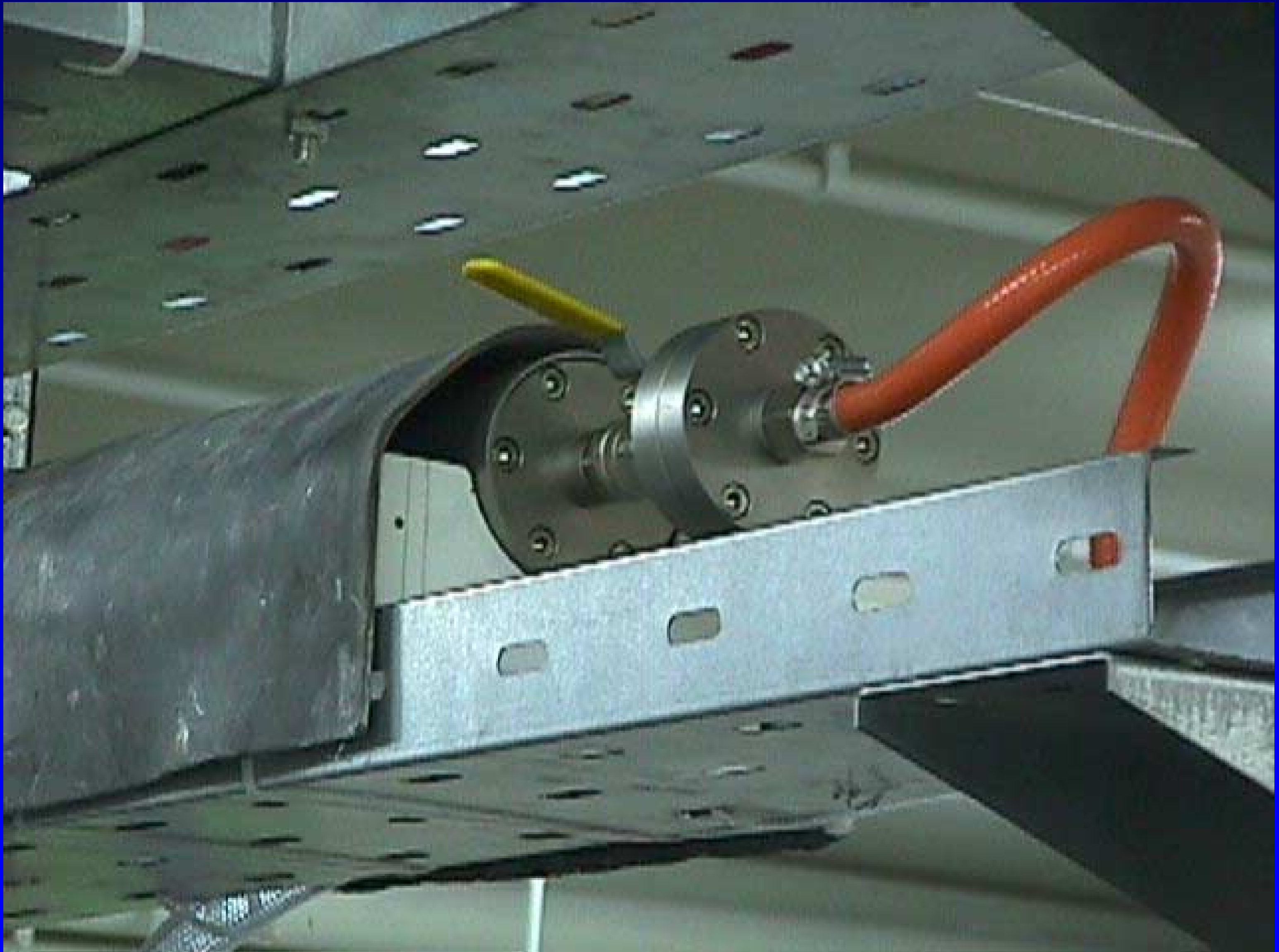
- ✓ In-line external circulation
- ✓ A small container containing the source, positioned inside the chamber, with an externally controlled solenoid valve

IN-LINE EXTERNAL CIRCULATION

PYLON SOURCE IN-LINE CIRCULATION CONTAINER

CIRCULATION CONTAINER DETAILS

CZECH SOURCE IN-LINE CIRCULATION CONTAINER



IN-LINE RADON CIRCULATION PUMP

Small container with solenoid valve

RADON DEGASSING

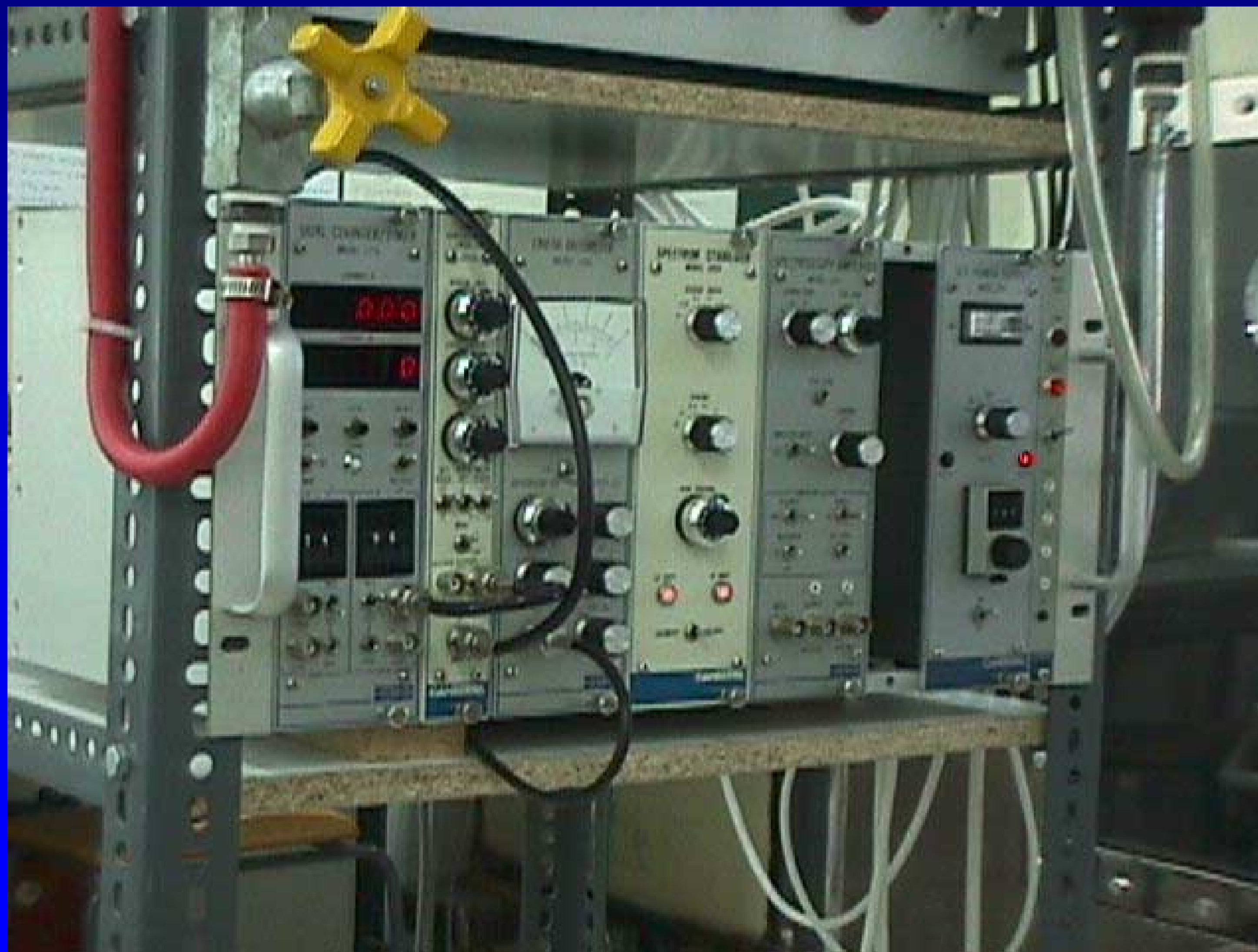
HEAVY DUTY AIR-COMPRESSOR

RADON CONCENTRATION MONITORING (I)

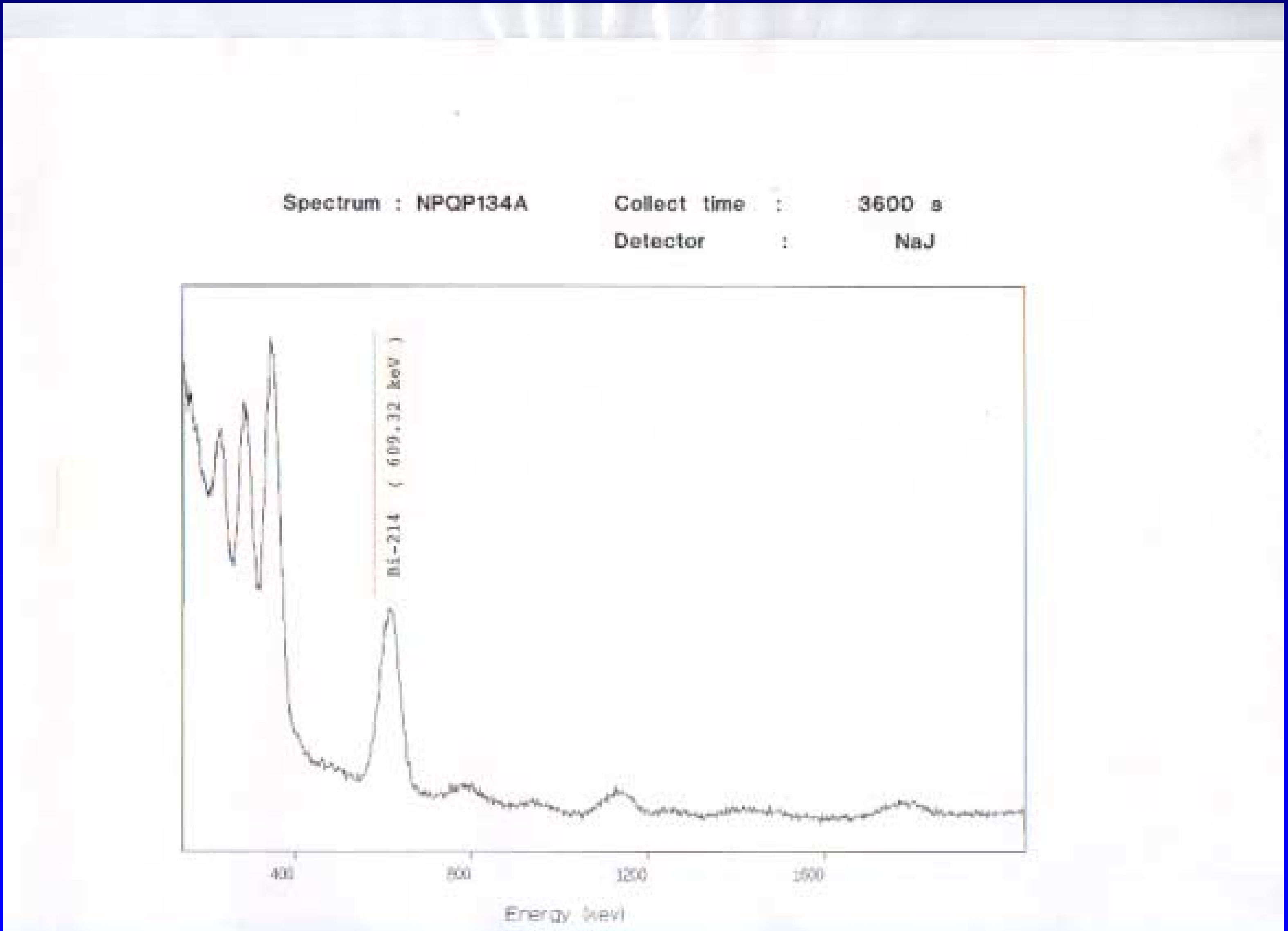
- In-situ continuous Radon progeny concentration measurements using NaI detectors placed inside the chambers.
- Grab sampling, using controlled flow-rate, of a small portion 2 – 10% of chamber gas through filters, which are then analysed for Radon progeny using alpha or/and gamma spectroscopy.

NaI DETECTOR

NaI DETECTOR ELECTRONICS SETUP



NaI DETECTOR SPECTRUM



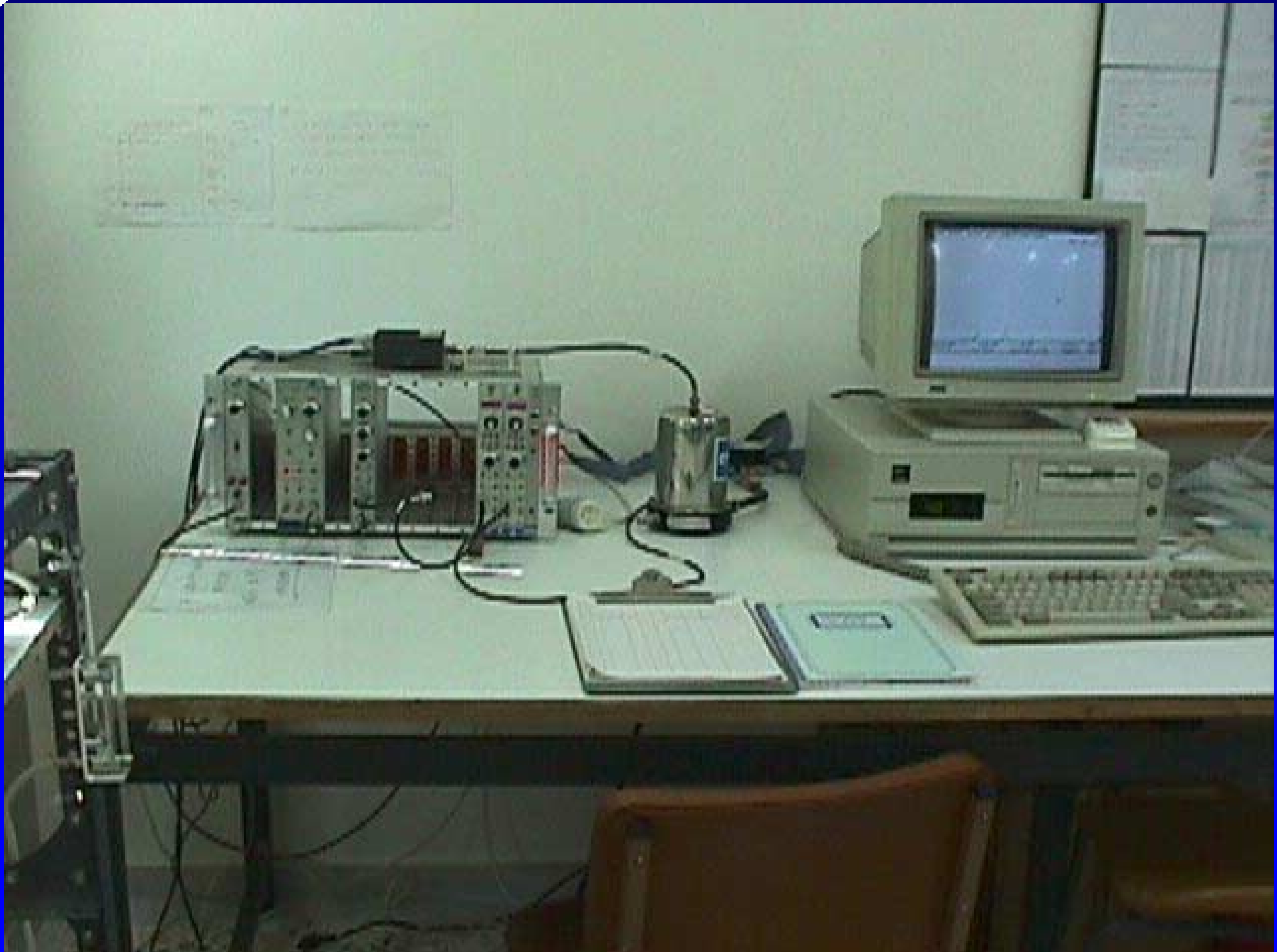
PNEUMATICALLY CONTROLLED OPENING AND CLOSING GRAB SAMPLING PORT HOLES

Filter holding probe

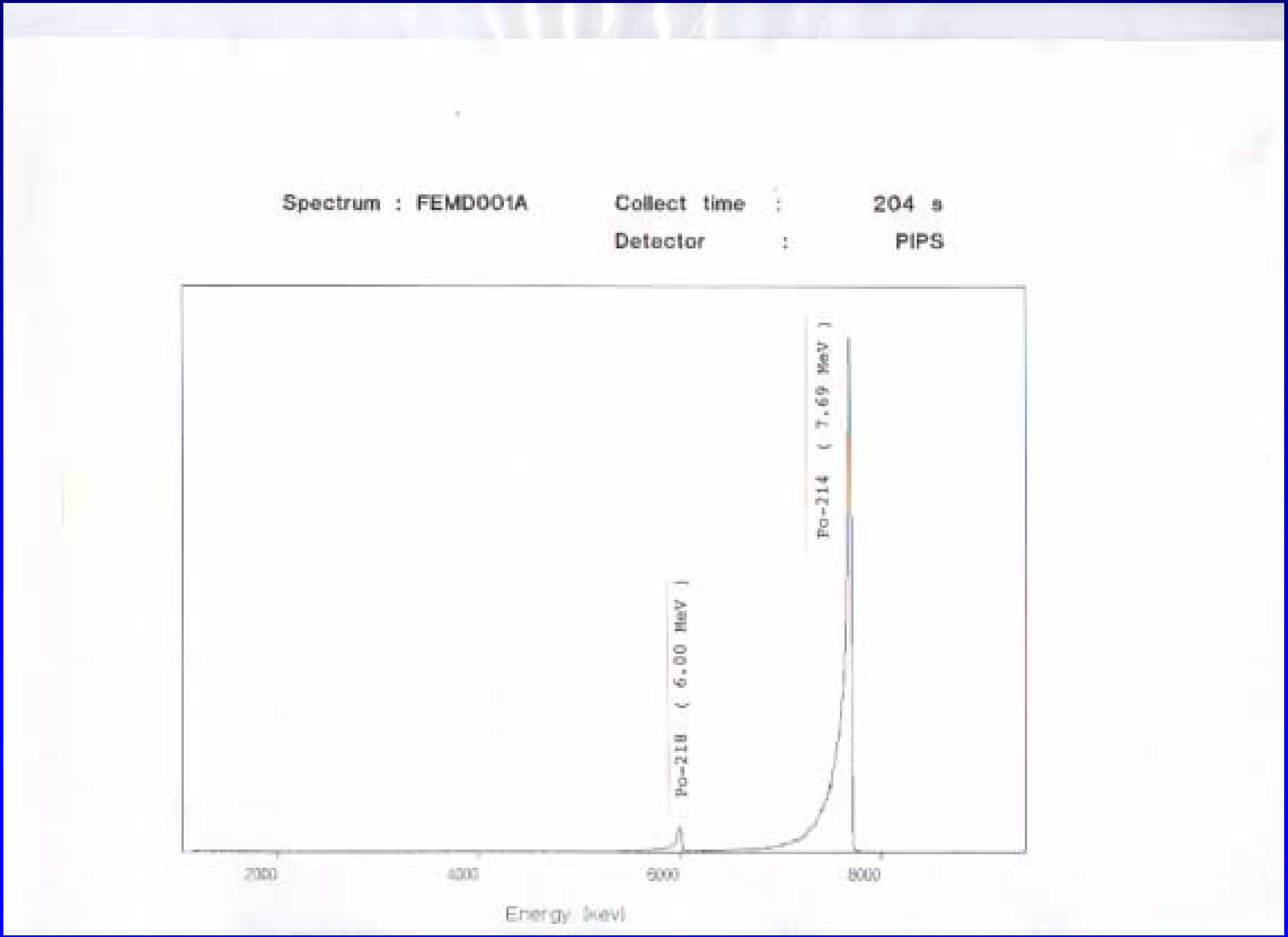
PUMPING UNIT FOR ALPHA FILTERS

ALPHA SPECTROSCOPY SETUP (I)

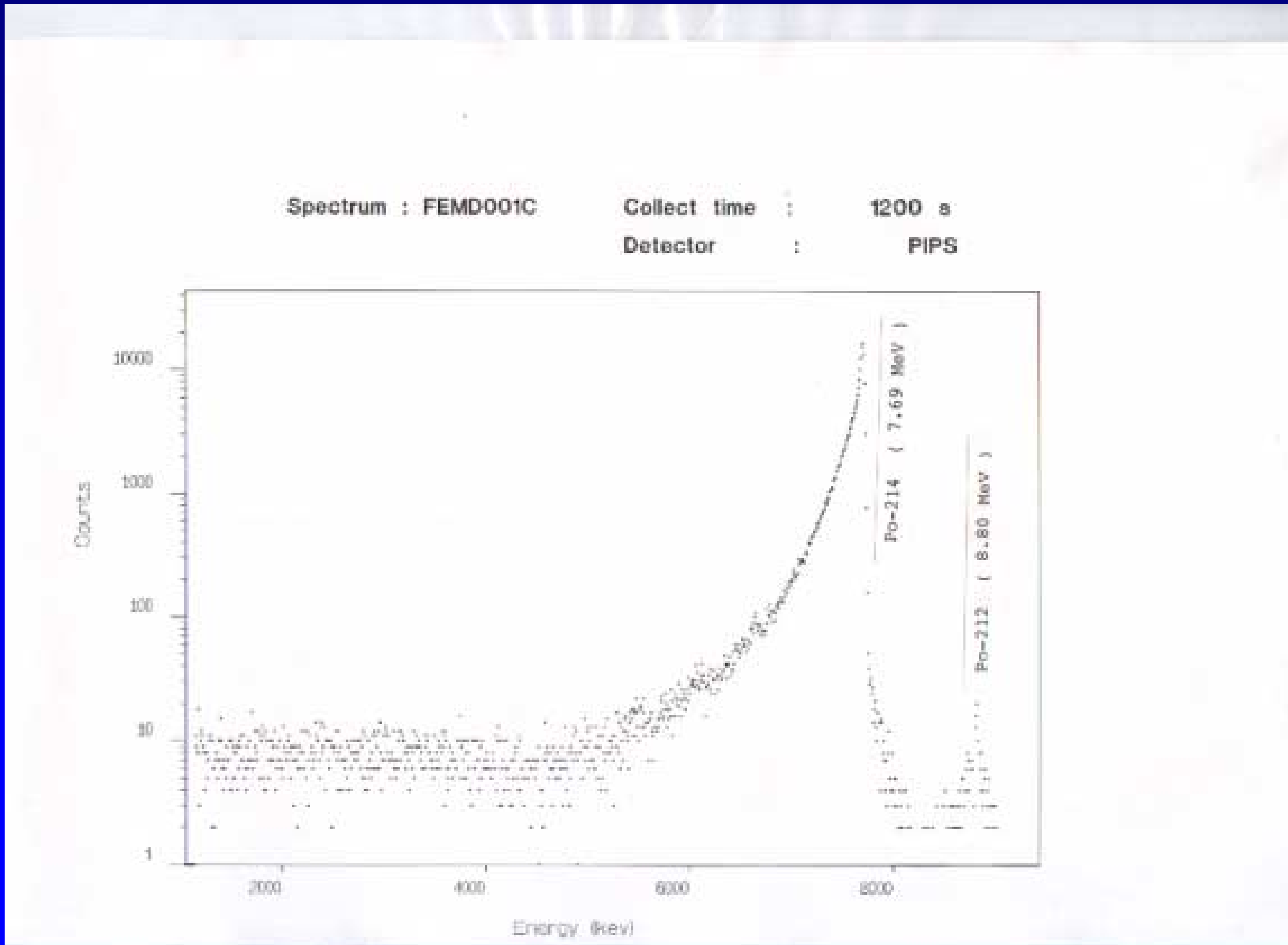
ALPHA SPECTROSCOPY SETUP (II)



FILTER ALPHA SPECTRUM

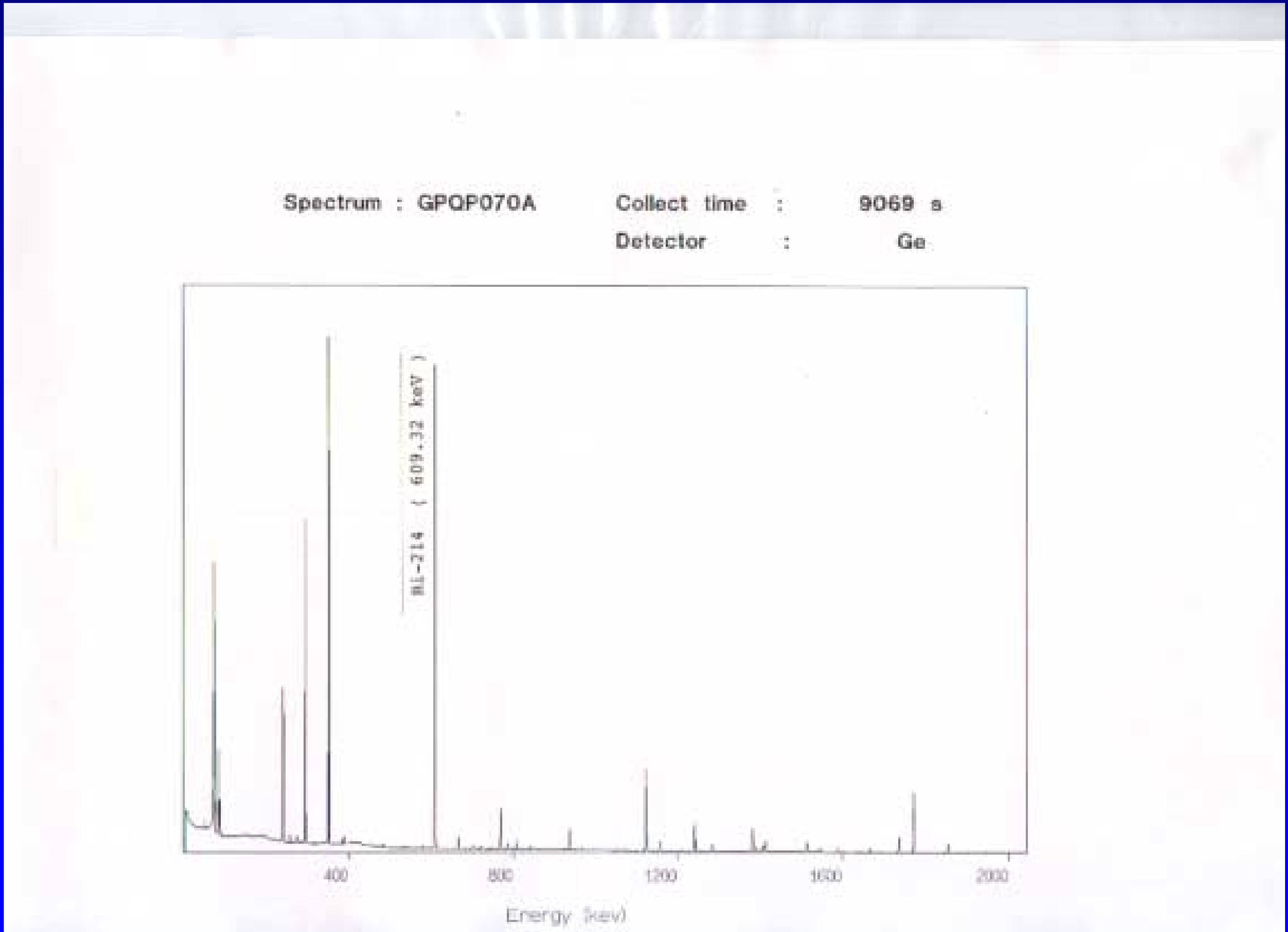


FILTER ALPHA SPECTRUM (THORON)



PUMPING UNIT FOR GAMMA FILTERS

FILTER GAMMA SPECTRUM



RADON CONCENTRATION MONITORING (II)

Continuous or quasi-continuous Radon concentration measurements using active instrumentation, placed either inside the chambers or in-line connected to them.

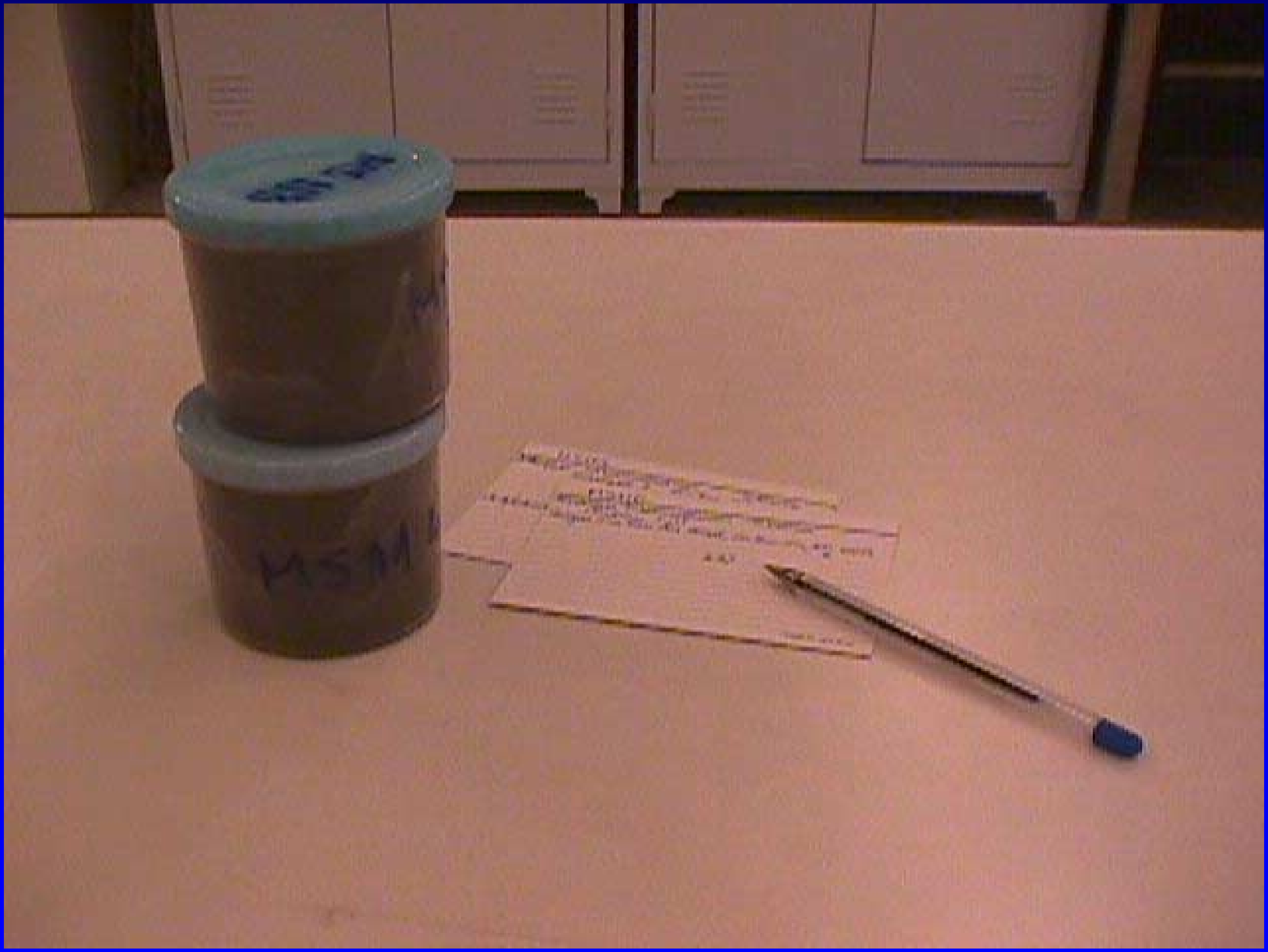
QUASI-CONTINUOUS RADON CONCENTRATION MONITORING

Measuring the gamma radioactivity of building materials in Greece

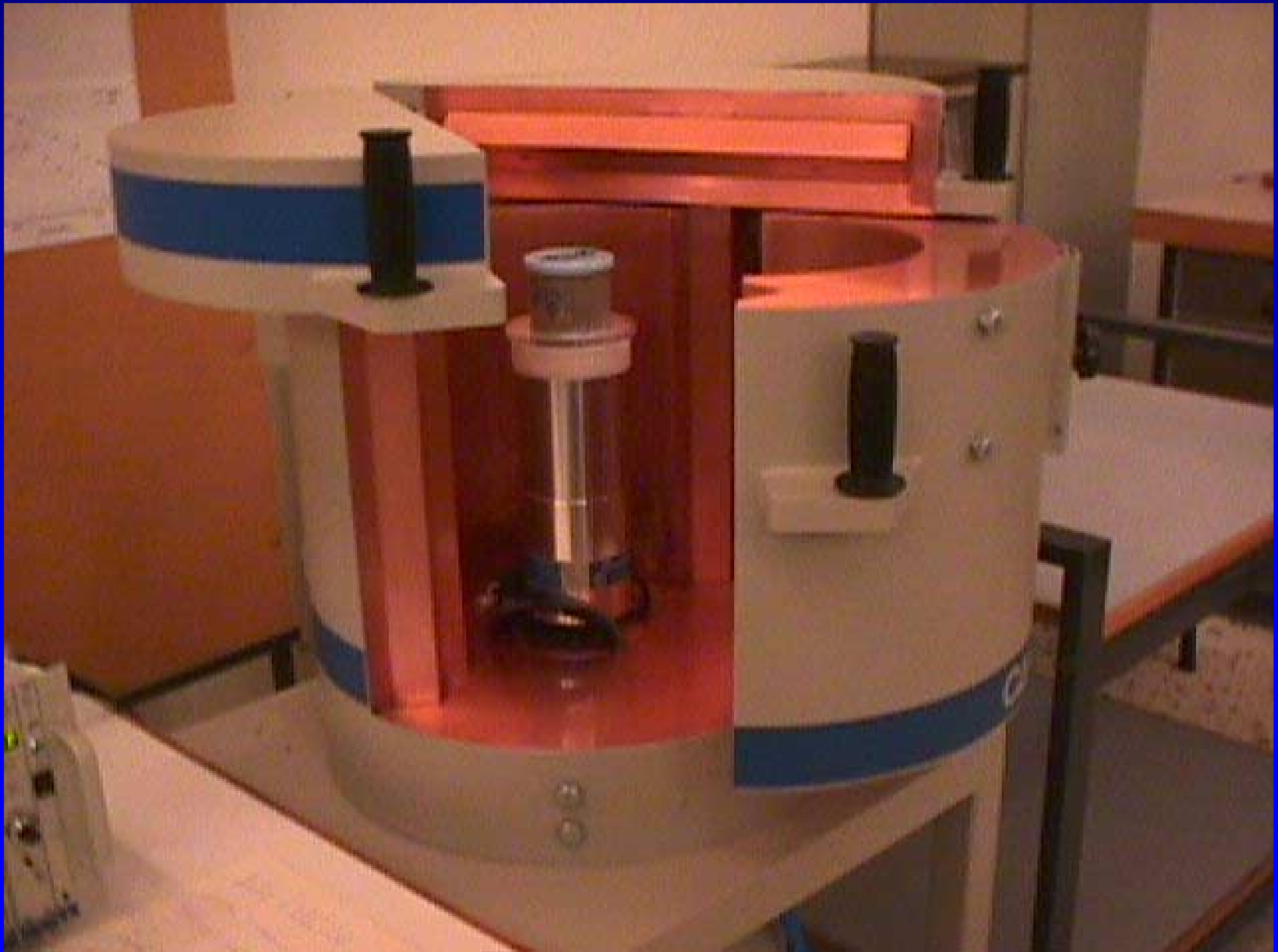
Gamma Radioactivity Lab

SOME
BUILDING
MATERIALS
SAMPLES

SAMPLE PREPARATION

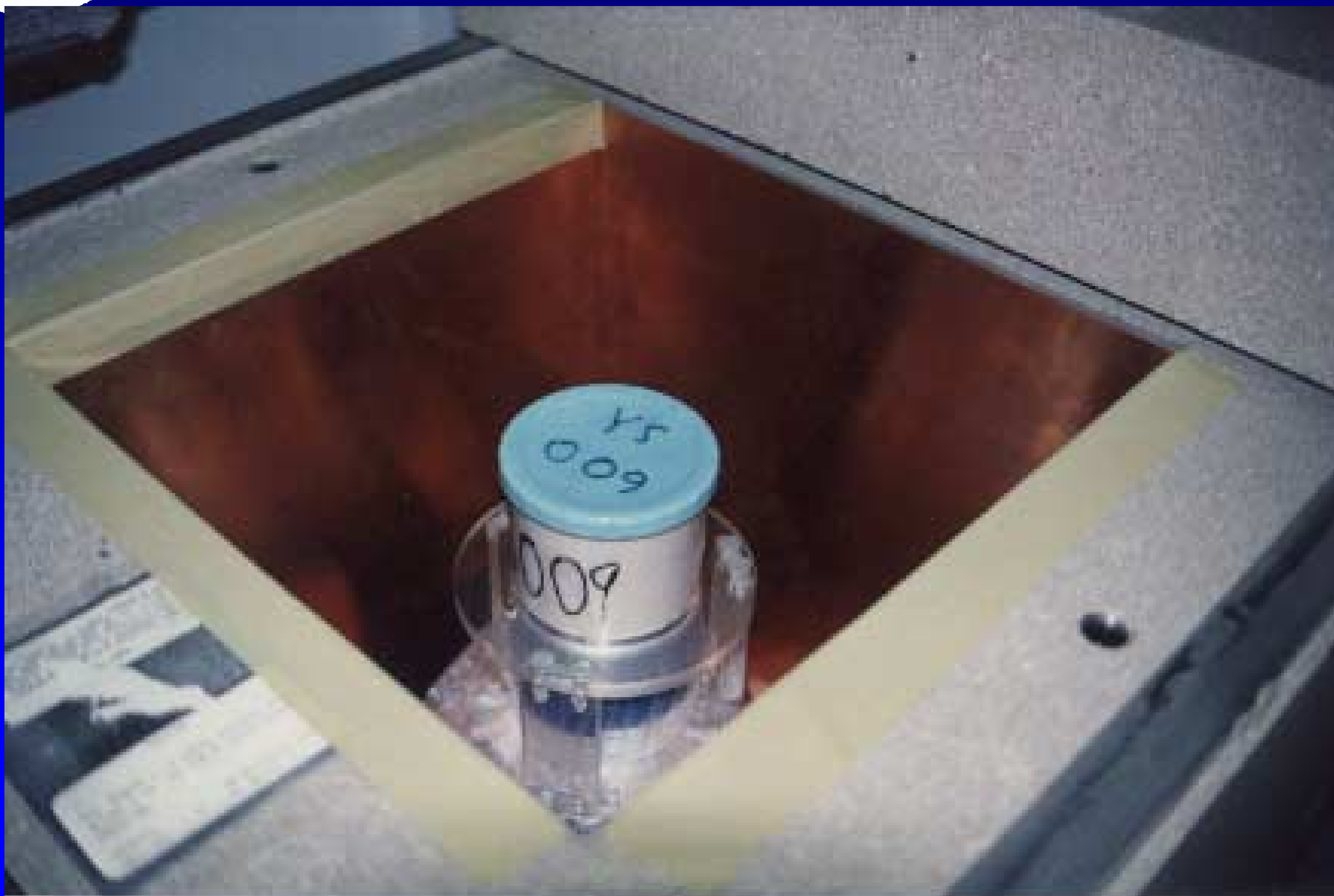


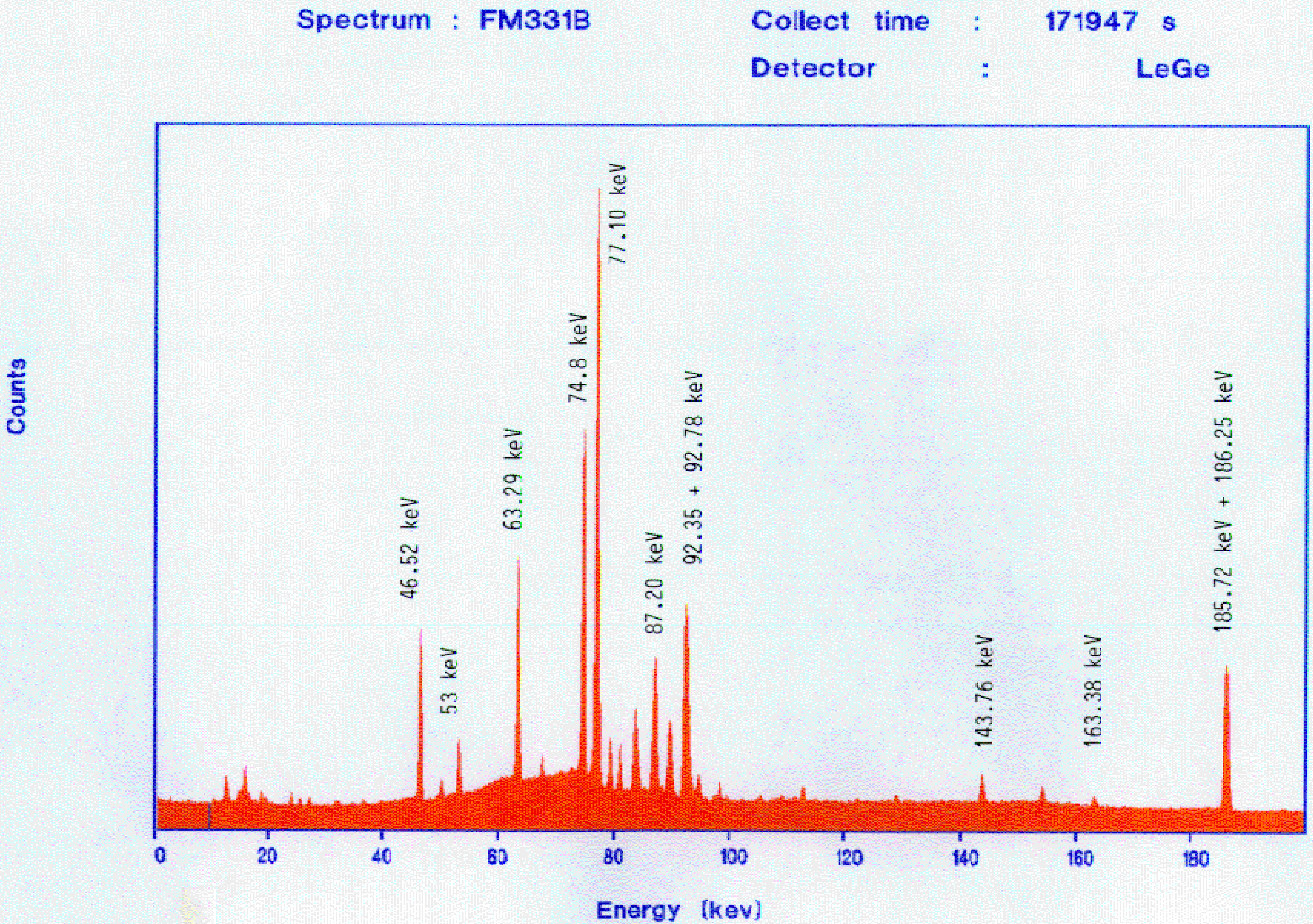
SAMPLE MEASUREMENT IN XtRa Ge DETECTOR



SAMPLE MEASUREMENT IN XtRa Ge DETECTOR

SAMPLE MEASUREMENT WITH HPGe DETECTOR





Spectrum : FM331B
Collect time : 171947 s
Detector : LeGe
Counts
Energy (kev)
0
20
40
60
80
100
120
140
160
180
46.52 keV
53 keV
63.29 keV
74.8 keV
77.10 keV
87.20 keV
92.35 + 92.78 keV
143.76 keV
163.38 keV
185.72 keV + 186.25 keV

NATURAL RADIONUCLIDES ANALYSIS REPORT

of sample PM4P023

Isotope	Energy (kev)	Activity		(Bq/kg)	pCi/gr
Pb-210	46.52	3985.9	±	.60%	107.728
Pb-214A	295.22	1213.8	±	.90%	32.804
Pb-214B	351.99	1213.1	±	.73%	32.785
Pb-214	(W.Mean)	1213.3	±	.56%	32.793
Bi-214A	609.32	1130.5	±	.56%	30.555
Bi-214B	1120.28	1163.7	±	1.80%	31.453
Bi-214C	1764.51	1169.4	±	1.78%	31.607
Bi-214	(W.Mean)	1136.2	±	.51%	30.707
Ra-226	(W.Mean)	1168.7	±	.38%	31.586
Ra-226	186.25				
Th-234	63.29	1345.5	±	1.43%	36.364
U-238E	185.99	1484.5	±	1.00%	40.121
U-238C	185.99	1221.3	±	1.00%	33.007
U-235	185.72				
U-238L					
Ac-228A	338.40	60.1	±	12.19%	1.624
Ac-228B	911.07	49.0	±	14.73%	1.323
Ra-228	(W.Mean)	54.4	±	9.44%	1.471
Pb-212B	238.63	55.7	±	7.39%	1.506
Tl-208A	583.14	50.5	±	10.54%	1.364
Th-228	(W.Mean)	53.8	±	6.06%	1.453
Th-232	(W.Mean)	54.0	±	5.10%	1.458
K-40	1460.75	384.7	±	6.99%	10.397

Natural radioactivity results of building materials used in Greece

Calculations of the gamma-ray dose rate from terrestrial origin radionuclides in building materials are usually based upon the assumption that:

there exists radioactive equilibrium:

- ***among the nuclides of the ^{238}U series***
- ***among the nuclides of the ^{232}Th series***

Radioactive disequilibrium among the nuclides of the uranium series in soil and soil-origin materials usually exists among :

^{238}U ($T_{½}$ = 4.47 10^9y),

^{226}Ra ($T_{½}$ = 1600y) and

^{210}Pb ($T_{½}$ = 22.2y)

Soil-origin materials with natural radioactive disequilibrium

- Fossil fuels, due to leaching and geochemistry.
- By-products of industrial processes, due to different physicochemical properties.
- Ashes from thermal power plants due to different physicochemical properties.
- Building materials for the production of which by-products of industrial processes are used.

γ-spectroscopic determination of ^{226}Ra (indirect)

Indirectly from short-lived radon decay products. The sample should be shielded to obtain radioactive equilibrium in ~25 days. Isotopes detected :

^{214}Pb (295.22, 351.99 keV)

^{214}Bi (609.31, 1120.28, 1764.51 keV)

γ-spectroscopic determination of ^{226}Ra directly from 186.25keV photons (1) :

Problem

The photopeak at 186.25 keV is a multiplet with that at 185.72 (^{235}U)

γ-spectroscopic determination of ^{226}Ra directly from 186.25keV photons (2) :

What it is needed

- ✓ **High resolution detector**

  (e.g LEGe with fwhm=530eV at 122keV)

- ✓ **Sensitive γ-spectroscopic analysis software**

- ✓ **Good statistics of the multiplet photopeak**

γ-spectroscopic determination of ^{238}U and ^{210}Pb

- ✓ ^{210}Pb from 46.54keV photons
- ✓ ^{238}U from 63.29keV photons of ^{234}Th
- ✓ A detector such as a planar Ge, LEGe or XtRa Ge, with appropriate efficiency
- ✓ The intense self-absorption of the photons emitted inside the sample should be taken into account

Material	Sample Size	Range (Min-Max) -$Bqkg^{-1}$				
		^{238}U	^{226}Ra	^{210}Pb	^{232}Th	^{40}K
Black Cement	83	up to 173	29-147	up to 183	13-30	172-331
White Cement	10	---	14-26	---	7-13	5-67
Clay Bricks	13	---	25-48	---	27-56	476-895
Sea Sand	6	---	7-13	---	8-16	145-302
Sand	13	---	1-5	---	up to 3	1-37
Marble Powder	10	---	up to 1	---	up to 1	up to 25
Mosaic	7	---	1-4	---	1-3	up to 23
Gypsum	6	---	6-17	---	up to 10	5-40
Pumice Stone	5	up to 361	50-874	up to1003	54-60	1048-1158
Quicklime	2	---	9-32	---	up to 1	---
Perlite	1	---	46	---	56	1048
Wall tiles	1	---	58	---	46	409
Fly-ash	~350	up to 1443	273-1377	up to 3986	41-65	143-661
Bottom-ash	~60	up to 715	102-743	up to290	20-49	111-480

Results of cement samples analysis

Sample	Activity in $Bq kg^{-1}$			Activity ratio	
	^{226}Ra	^{210}Pb	^{238}U	$^{210}Pb/^{226}Ra$	$^{238}U/^{226}Ra$
1	31	4.4	49	0.14	1.58
2	63.3	39	88	0.62	1.39
3	95.6	100	127	1.04	1.33
4	98.9	99	129	1.0	1.30
5	105	99	127	0.94	1.21
6	134	153	166	1.14	1.24
7	136	163	165	1.2	1.21
8	138	159	167	1.15	1.21
9	142	160	170	1.13	1.20
10	143	159	173	1.19	1.21
11	147	161	165	1.1	1.12
mean	112 ± 38	118 ± 55	138 ± 40	0.89 ± 0.41	1.27 ± 0.13

Conclusions from building materials analysis

- Radioactive equilibrium in most analyzed building materials is observed.
- An excess of ^{238}U is usually observed in black cement samples. The ratio of $^{238}U/^{226}Ra$ ranged from 1.12 –1.58 with a mean value of 1.27.
- Radioactive equilibrium between ^{226}Ra and ^{210}Pb is observed in black cement, with few exceptions.
- High ^{238}U activity (up to $1 kBq kg^{-1}$) and significant disequilibrium among ^{238}U, ^{226}Ra and ^{210}Pb may exist in building materials of volcanic origin, such as pumice stone ($^{238}U/^{226}Ra = 2.9$, $^{210}Pb/^{226}Ra=1$).

RADON EXHALATION RATE FROM GREEK BUILDING MATERIALS AND STRUCTURAL MODULES

	^{226}Ra Content ($Bqkg^{-1}$)	Exhalation Rate
Cement	142	0.01 $mBqkg^{-1}s^{-1}$
Fly-ash	1000	0.1 $mBqkg^{-1}s^{-1}$
Concrete slab	24	3 $mBqm^{-2}s^{-1}$
Clay Brick Wall	29	0.3 $mBqm^{-2}s^{-1}$
Pumice Stone Wall	48	0.8 $mBqm^{-2}s^{-1}$