Romanian underground laboratory

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The context

Romania is rich in natural deposits of salts, mainly encountered in the sub-Carpathian region which have been exploited since ancient times housing many active and in conservation salt mines. One of these is located in Slanic-Prahova. Slanic-Prahova is located in the outer Carpathians area (Prahova County), 40 km NE of Ploiesti, about 100 km N from Bucharest and 150 km SE from Brasov. The town is placed in Slanic River valley, tributary of Varbilau River.

Slanic is mainly a center for salt exploitation and a tourist resort. Here is the Salt Mountain which is unique in the world and, also the largest salt mine in Europe. The town is surrounded by picturesque landscapes and provides accommodation, treatment and various entertainment conditions. The population of Slanic town is about 7000 inhabitants.





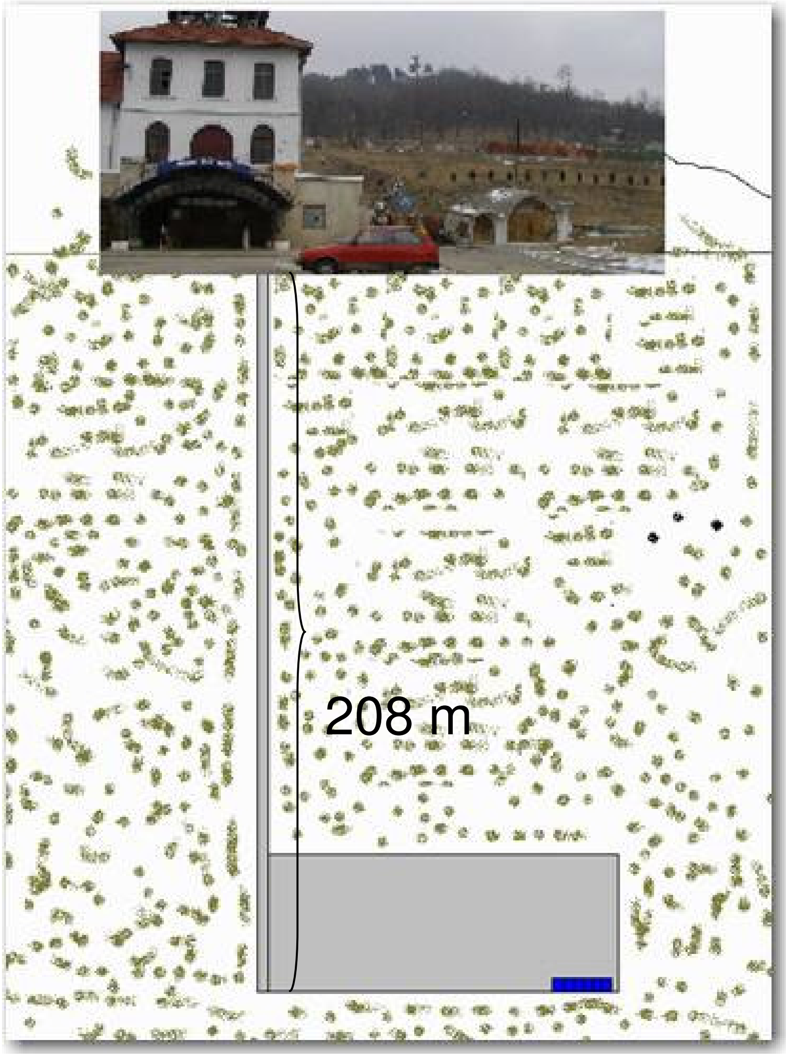
MINA UNIREA

The geology of salt massif

From geological point of view, the salt massif belongs to the post-tectogenetic cover of Tarcău Nappe, one of the most important ones cropping out in the Eastern Carpathians. It includes Cretaceous, Paleogene and lower Miocene sedimentary successions. Towards Prahova County, this nappe ends on two main anticlines, Homoraci and Valeni, separate by two synclines, Slanic and Drajna, both filled with Miocene molasse. The post-tectogenetic sedimentary cover of Tarcău Nappe begun to accumulate in early Miocene (23.7 Ma) and ended in Sarmatian (5.3 Ma).

The sedimentary environment in the region of actual Slanic Prahova was dominated by the Middle Badenian evaporitic condition, covering the interval from the last stage of carbonates precipitation to halite, however, without reaching the stage of K and Mg salt precipitation.

During evaporitic condition, authigenic minerals such as carbonates, sulfates and halite precipitated simultaneously with a certain amount of sediments from the adjacent areas whose presence can be remarked as interbedded layers in the salt formation.



The Unirea salt mine environment:

temperature: 12.0 -13.0 ^oC

humidity: 65-70 %

excavated volume: 2.9 million m^3

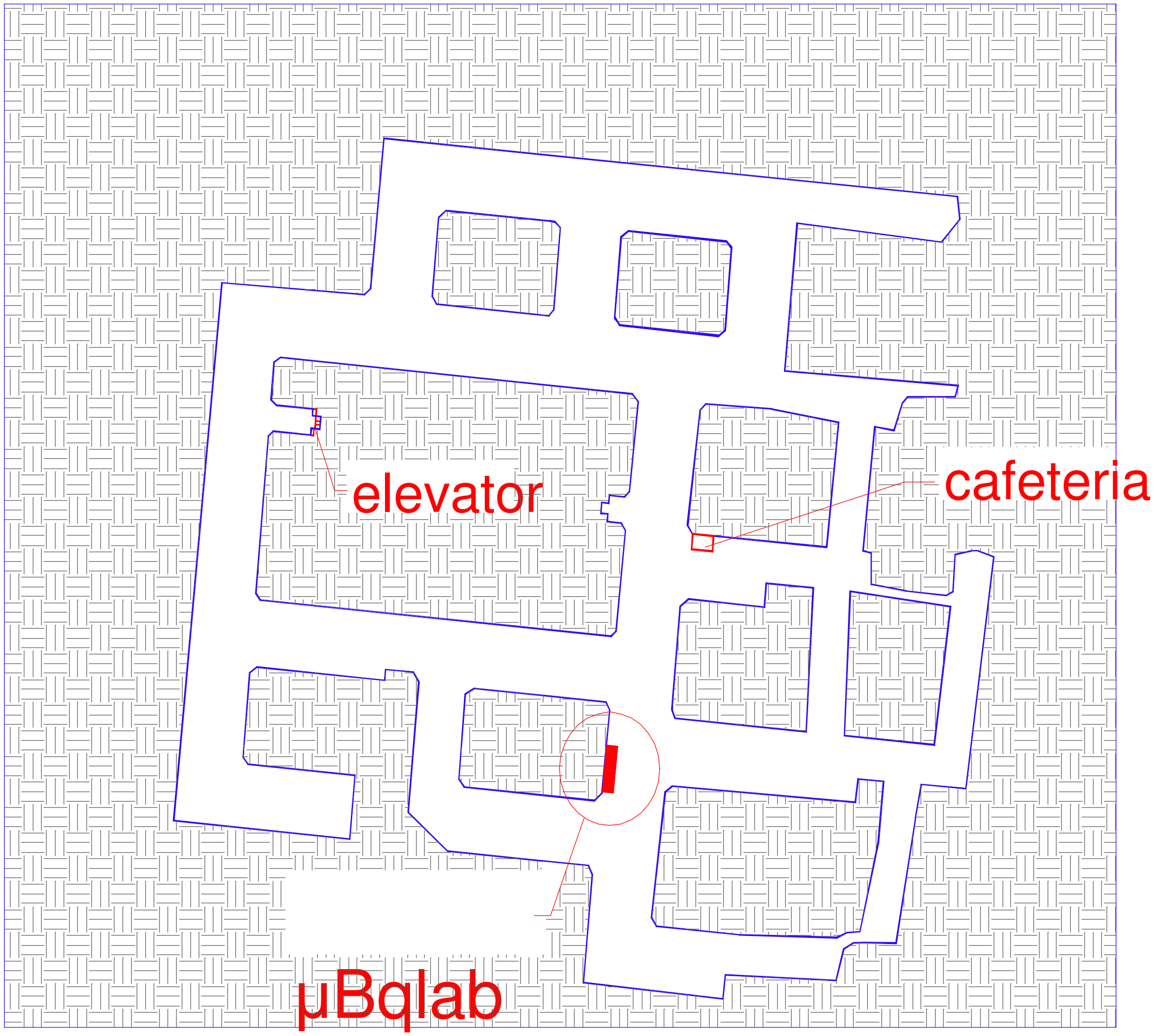
floor area: 70000 m^2

average high: 52-57 m

width 32-26 m

Existing infrastructures

The Unirea salt mine is connected to electricity, roads, railway, phone, internet, GSM networks. The entrance into the galleries is assured by an elevator.
From Slanic downtown to Unirea salt mine entrance there are about 500 m.



UNIREA salt mine gallery

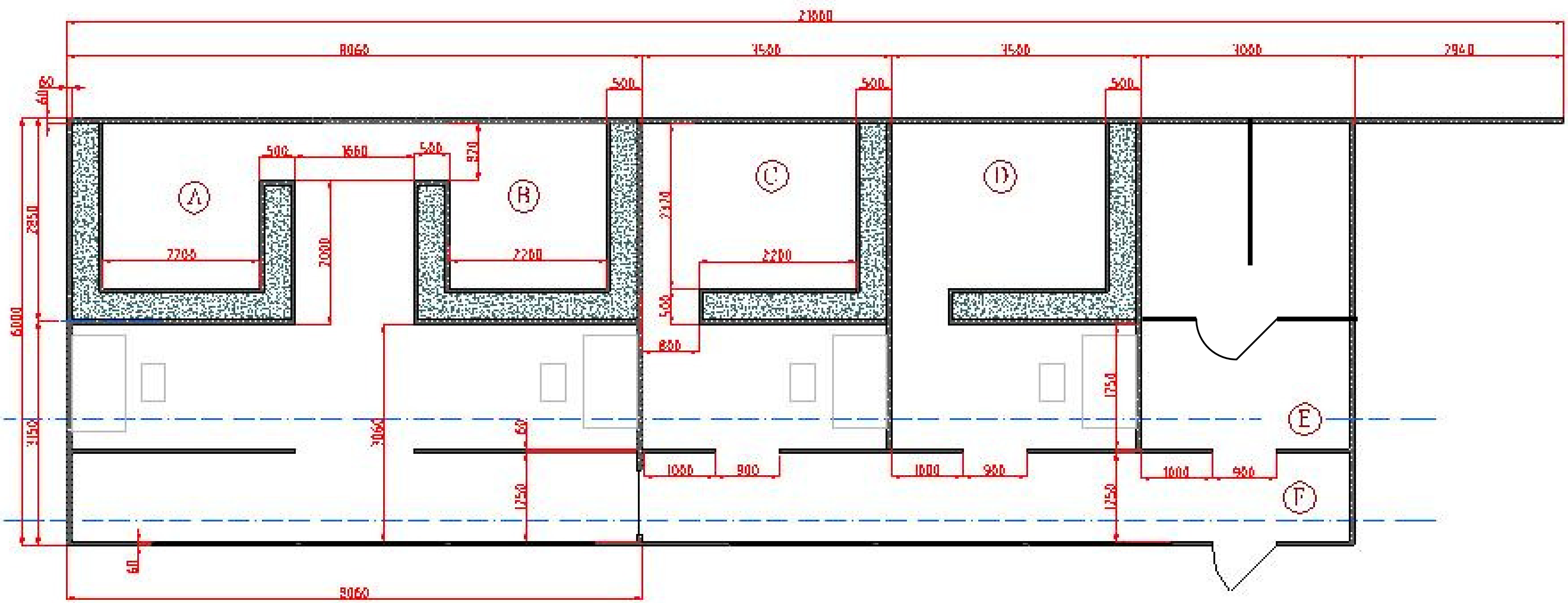
Underground laboratory realization stages:

I. – conception, design, constructor selection, material selection;

II. – material conditioning, transportation and construction;

III. – leveling the mine floor under laboratory using granulated salt,

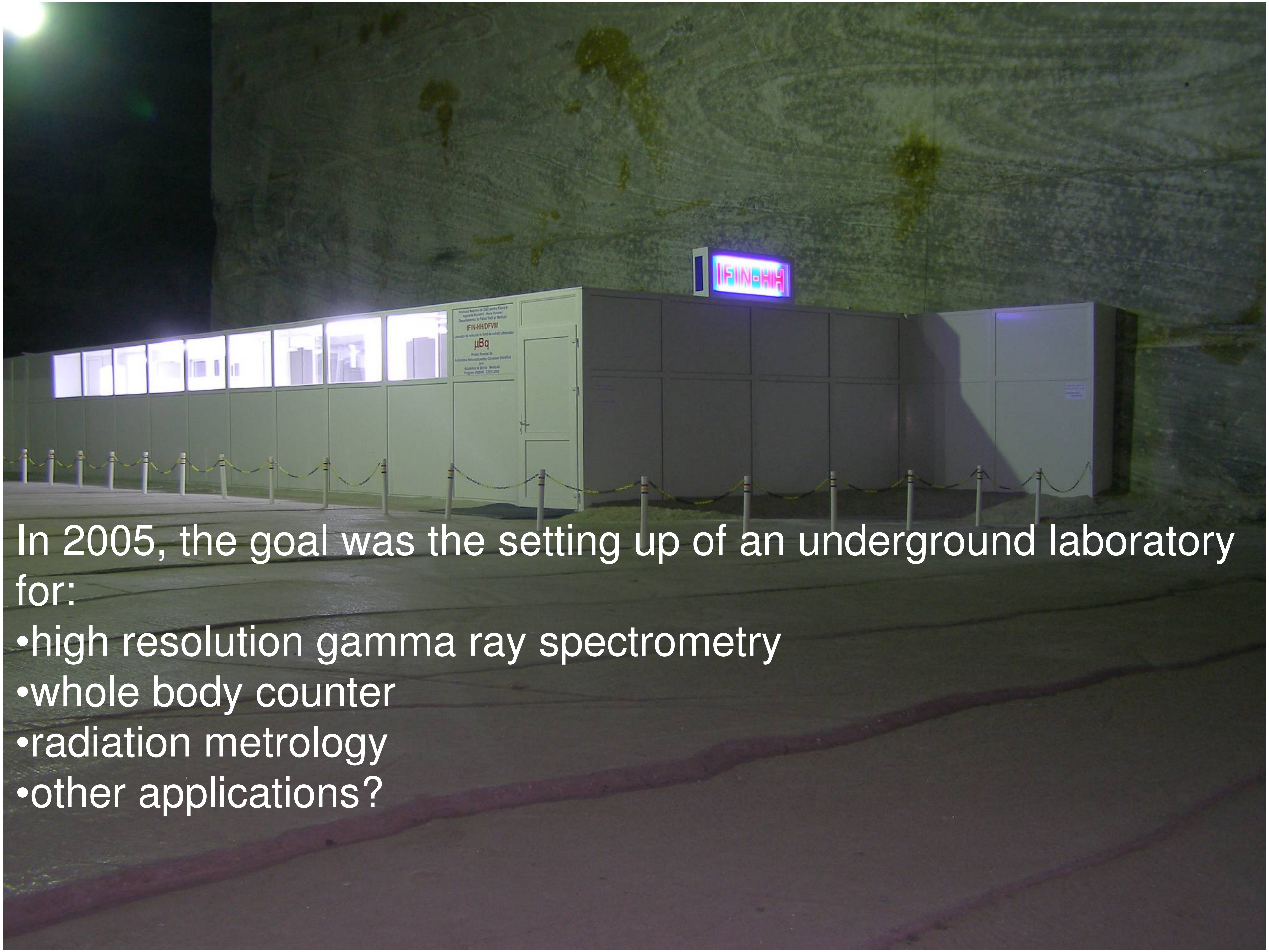
IV. – measurement systems purchasing



UNDERGROUND LABORATORY


IESIRE
EXIT



In 2005, the goal was the setting up of an underground laboratory for:

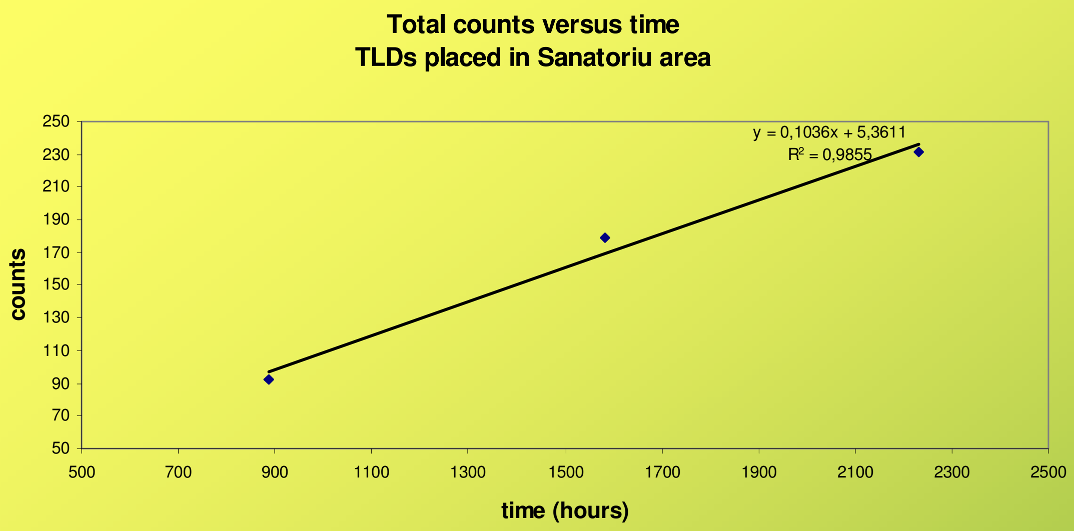
- high resolution gamma ray spectrometry
- whole body counter
- radiation metrology
- other applications?

The initial work

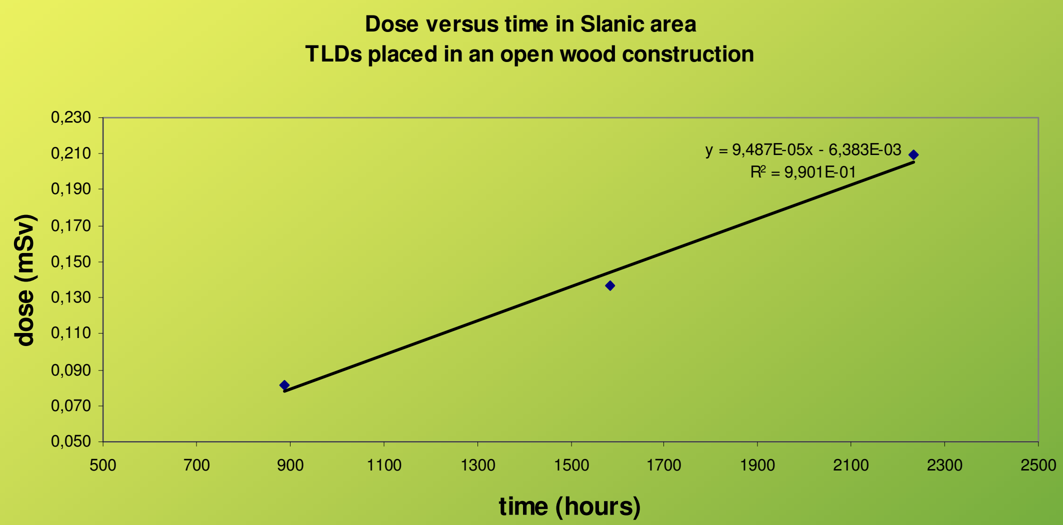
Dose rate measurement in the laboratory area

Measurement of radiation background with high resolution gamma detectors

Testing the whole body counter

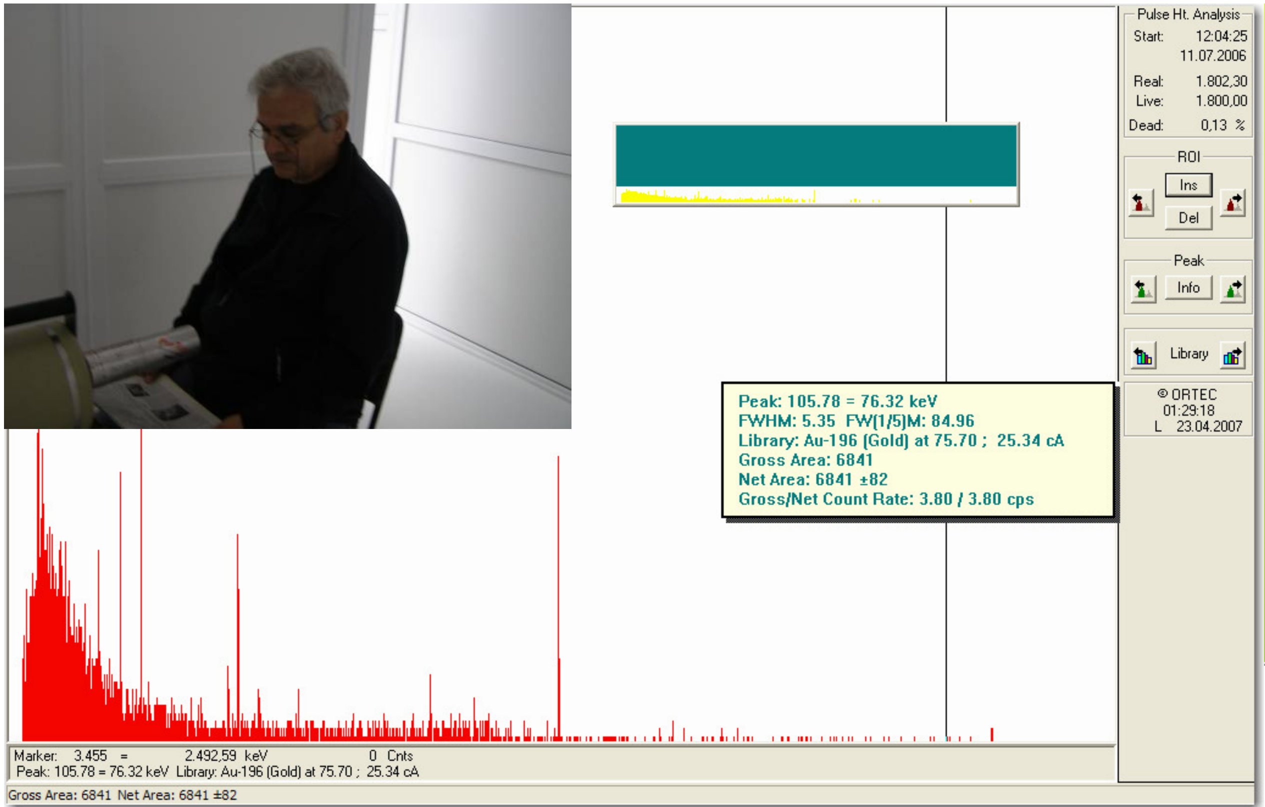


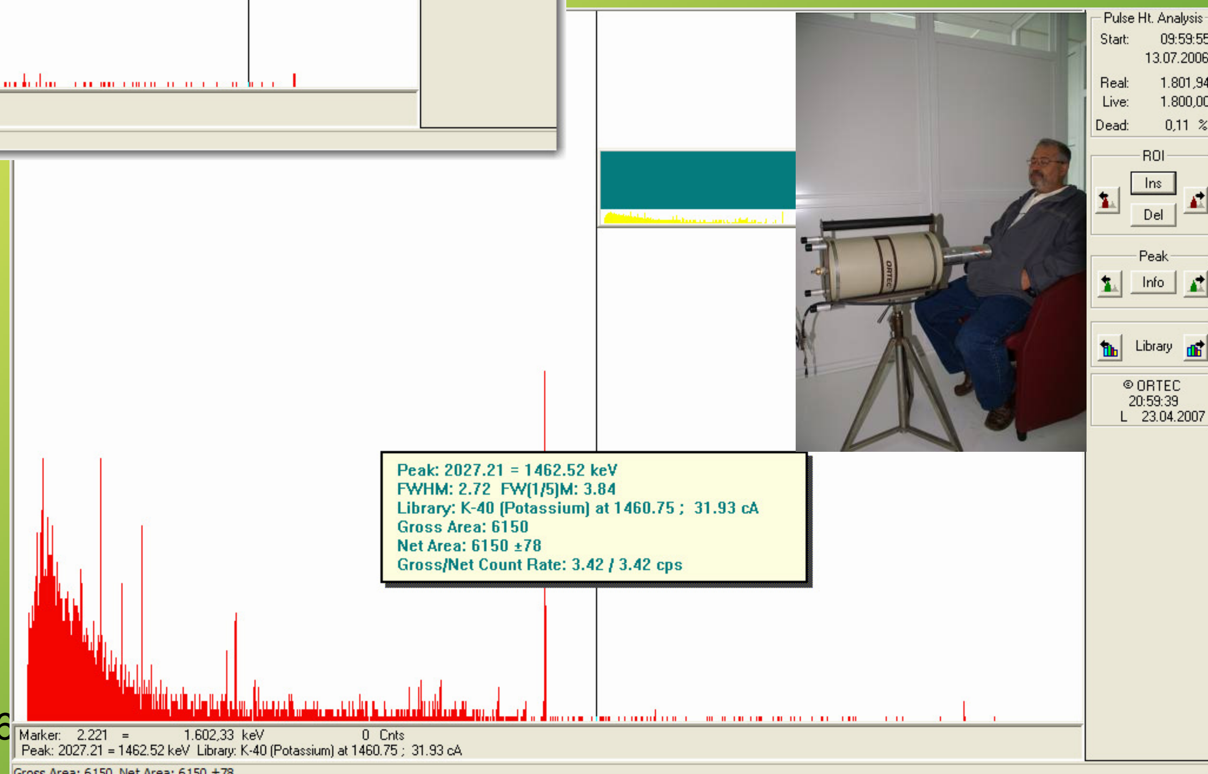
dose rate: 0.2 – 2.0 nSv/h

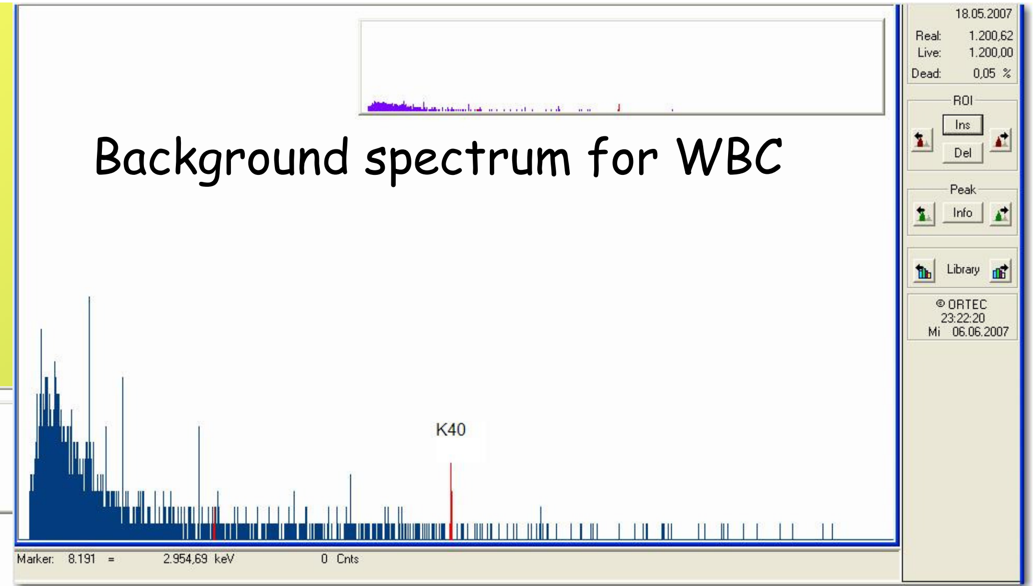


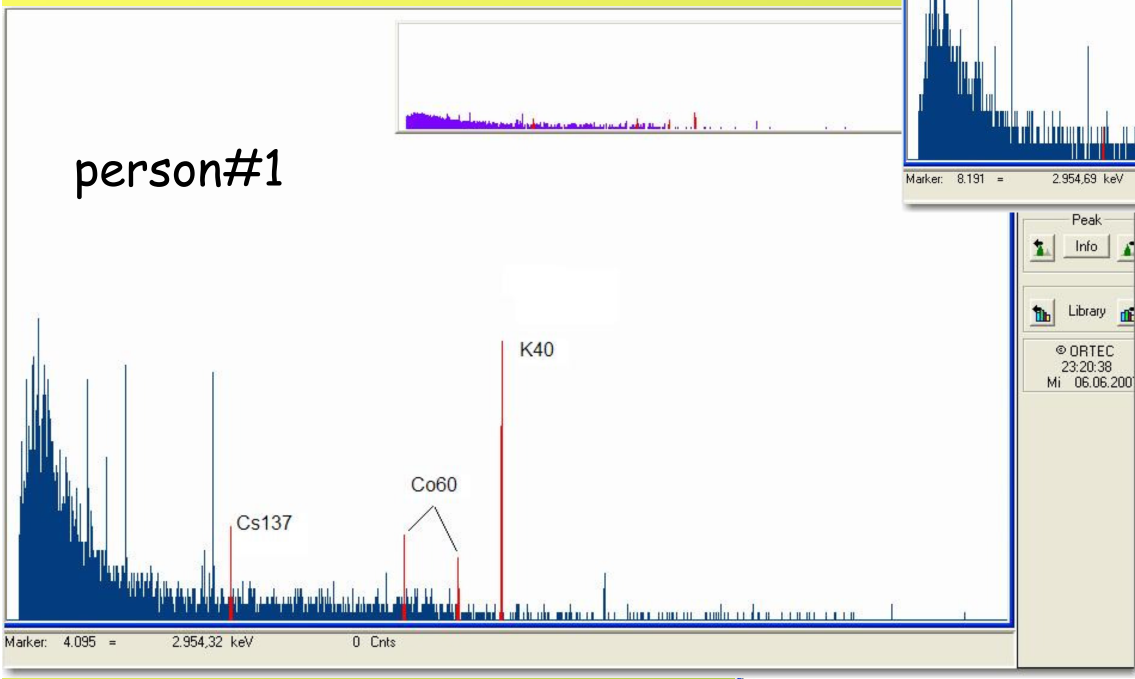
dose rate: 82 – 94 nSv/h

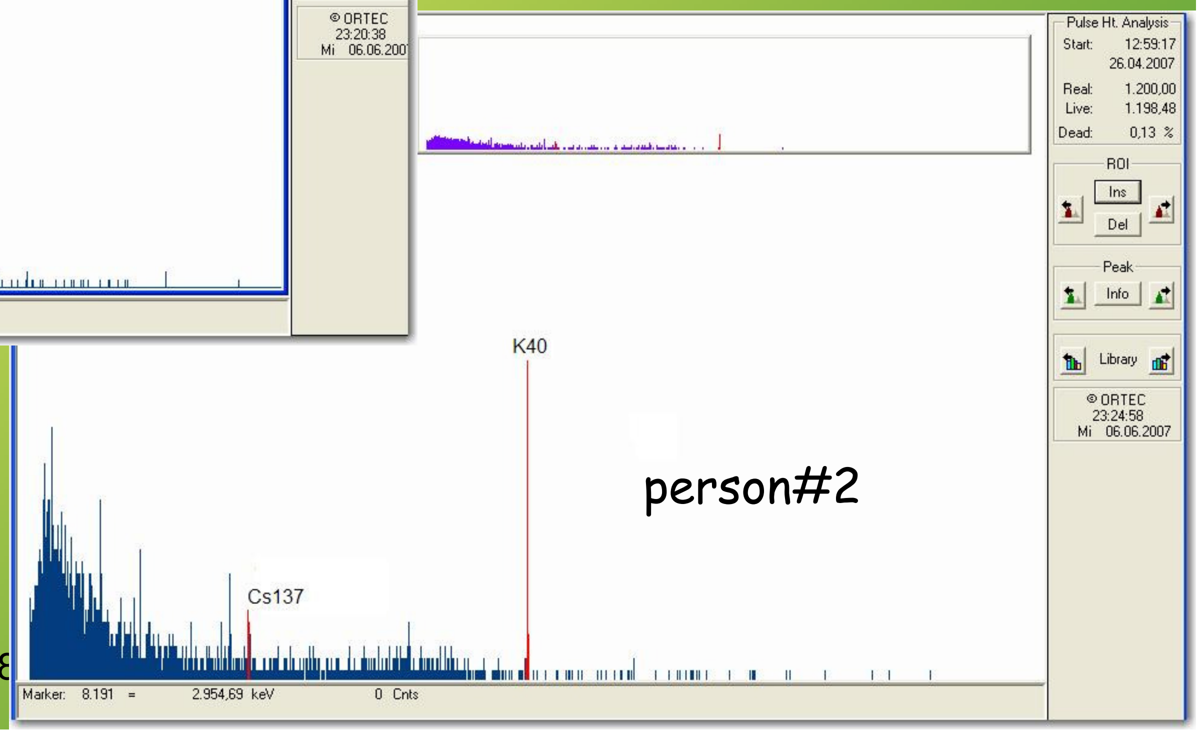
Whole body counter



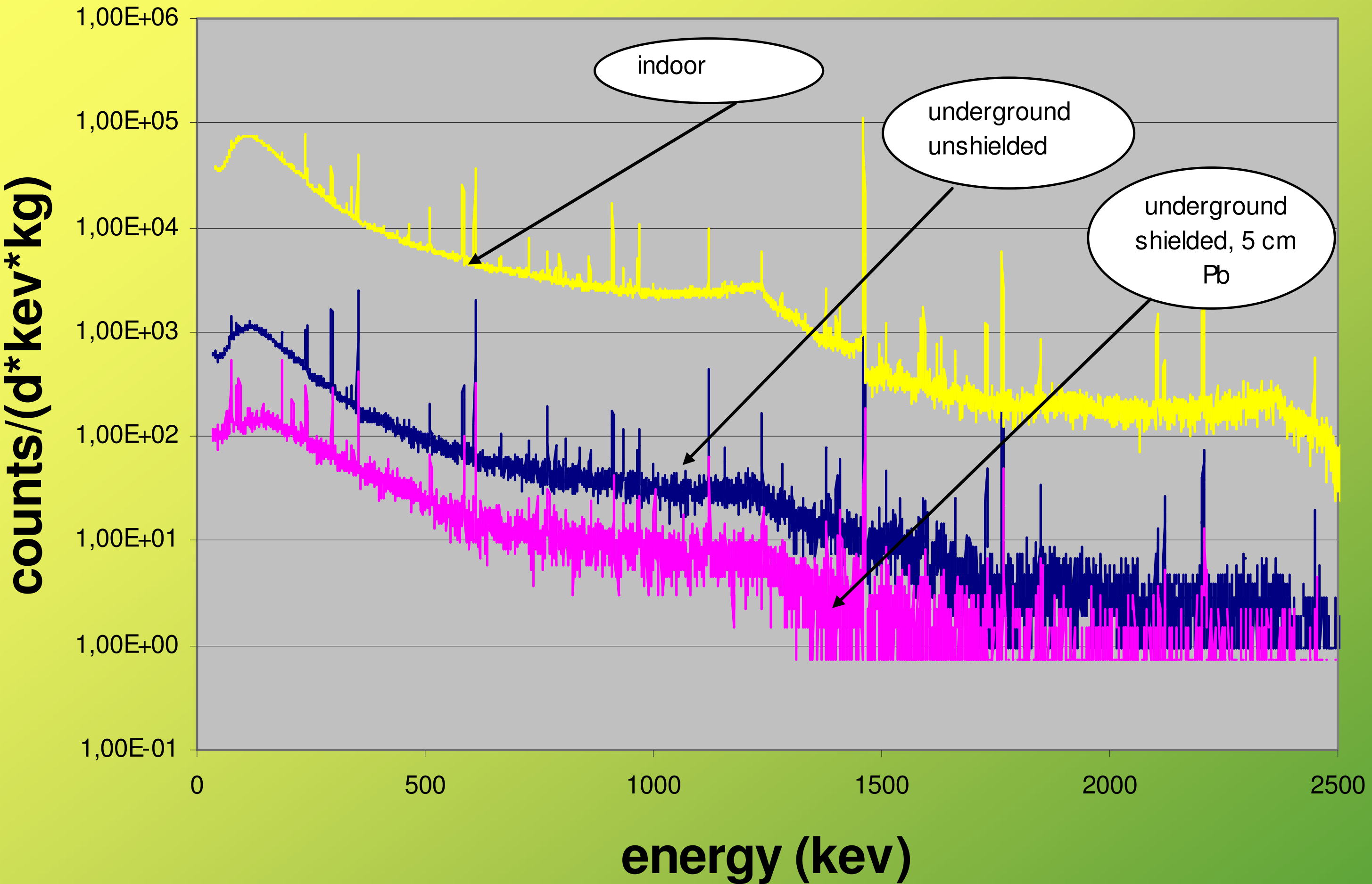



Background spectrum for WBC
K40
Marker: 8.191 = 2.954,69 keV 0 Cnts
18.05.2007
Real: 1.200,62
Live: 1.200,00
Dead: 0,05 %
ROI
Ins
Del
Peak
Info
Library
© ORTEC
23:22:20
Mi 06.06.2007

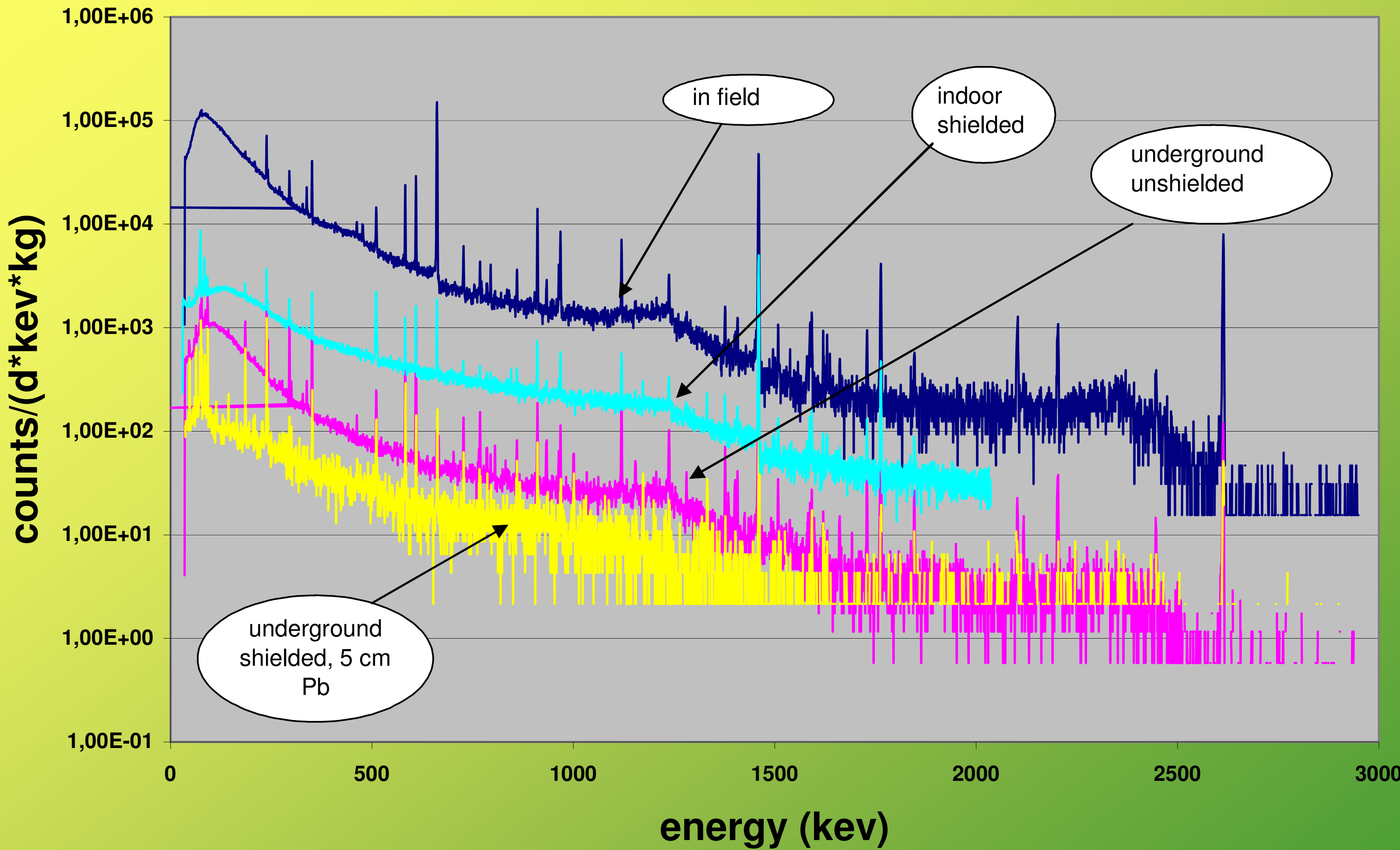

person#1
K40
Co60
Cs137
Marker: 4.095 = 2.954,32 keV 0 Cnts
Peak
Info
Library
© ORTEC
23:20:38


person#2
K40
Cs137
Marker: 8.191 = 2.954,69 keV 0 Cnts
Pulse Ht. Analysis
Start: 12:59:17
26.04.2007
Real: 1.200,00
Live: 1.198,48
Dead: 0,13 %
ROI
Ins
Del
Peak
Info
Library
© ORTEC
23:24:58
Mi 06.06.2007

Background spectra collected with a CANBERRA GeHP detector with 22.8% rel. efficiency



Background spectra collected with an ORTEC GeHP detector with 33% rel. efficiency



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The Slanic-Prahova (ROMANIA) underground low-background radiation laboratory

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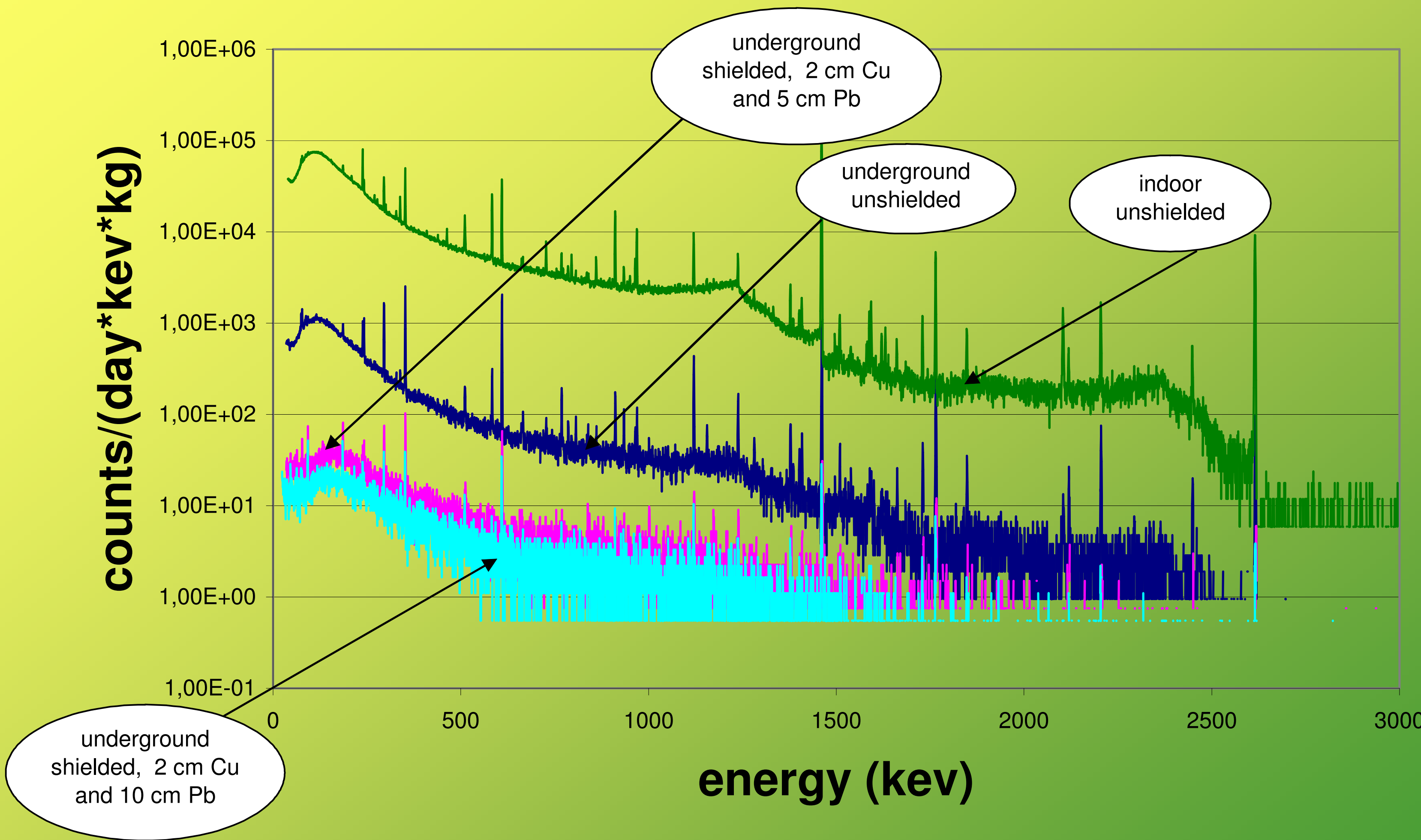
Low-level radiation metrology

ABSTRACT

A low-background radiation laboratory was constructed and fully commissioned in 2006 in the former Unirea (Slanic-Prahova) salt mine at 208 m below surface (estimated to 560 m water equivalent). Preliminary measurements showed a global reduction of the absorbed dose due to natural factors of about 39 times compared to level on the surface, reaching inside the mine 1.17 ± 0.14 nGy/h. The total gamma background spectrum between 40 KeV and 3 MeV was 100 times smaller at laboratory level with respect to the same spectrum recorder at surface, in open field. All these experimental facts recommend the Slanic-Prahova low-background radiation laboratory, at present time fully operational, as very suitable for various measurements needing a low background.

Background spectra collected with a CANBERRA GeHP detector with 22.8% rel. efficiency



Radiochim. Acta **97**, 333–337 (2009) / **DOI** 10.1524/ract.2009.1622

Epithermal neutrons activation analysis, radiochemical and radiometric investigations of evaporitic deposits of Slanic-Prahova (Romania) salt mine

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Activation analysis / Halite / Trace element / Natural radioactivity / Underground laboratory

cess potassium chloride as well as other heavy metals salts are substantially removed and the presence of natural radionuclides is considerably diminished [11]. This makes salt

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External dose rate in Unirea salt mine, Slanic-Prahova, Romania

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A R T I C L E I N F O

Keywords:
Low-level background laboratory
External dose rate
Salt mine

A B S T R A C T

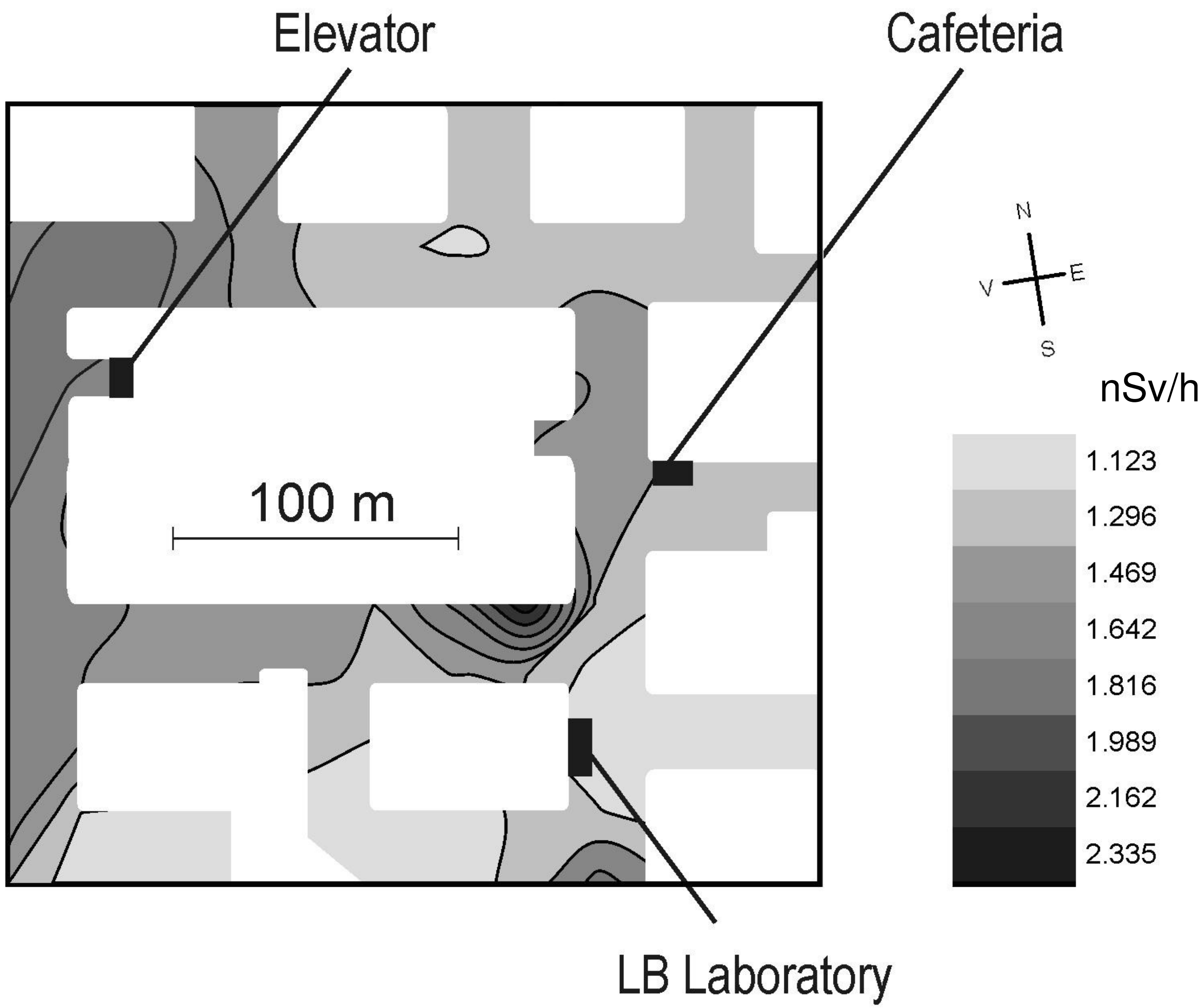
The distribution of the external dose rate within the former Unirea salt mine, host of the Low-Level Background Laboratory was determined and compared with calculated values based on the experimentally determined content of natural radioactive elements in the mine walls. The average external dose rate was found to be 1.3 ± 0.3 nSv h^{-1}, close to calculated one of 1.4 ± 0.2 nSv h^{-1}.

Neutron activation analyses of salt from UNIREA salt mine

Element	Neutron activation analyses
Uranium	<1ppm
Kalium	ND
Thorium	ND

Neutron activation analyses of salt impurities from UNIREA salt mine

Element	Neutron activation analyses
Uranium	6.4 ppm
Kalium	15400 ppm
Thorium	5.5 ppm


Elevator
Cafeteria
N
V
E
S
nSv/h
1.123
1.296
1.469
1.642
1.816
1.989
2.162
2.335
100 m
LB Laboratory

DOSE RATE

The measurement of external dose rate gave:

•in different places in Unirea salt mine - 1.1 ÷ 2.3 nSv/h, average 1.3 nSv/h

•in underground laboratory - 1.6 ± 0.3 nSv/h.

The external dose rate was measured with an EBERLINE FH40G-L10 calibrated by producer.
The separation walls from laboratory, filled with salt, contain 1mg/kg $K_4[Fe(CN)_6]3H_2O$.
In this condition the external dose rate due to $K_4[Fe(CN)_6]3H_2O$ is about 0.35 nGy/h.

calculated dose

Radionuclide	External dose rates (nGy/h)
K40	0,41
Th 232 series	0,28
Ra 236 series	0,71
Total	1,40

Radon concentration in Unirea salt mine gallery

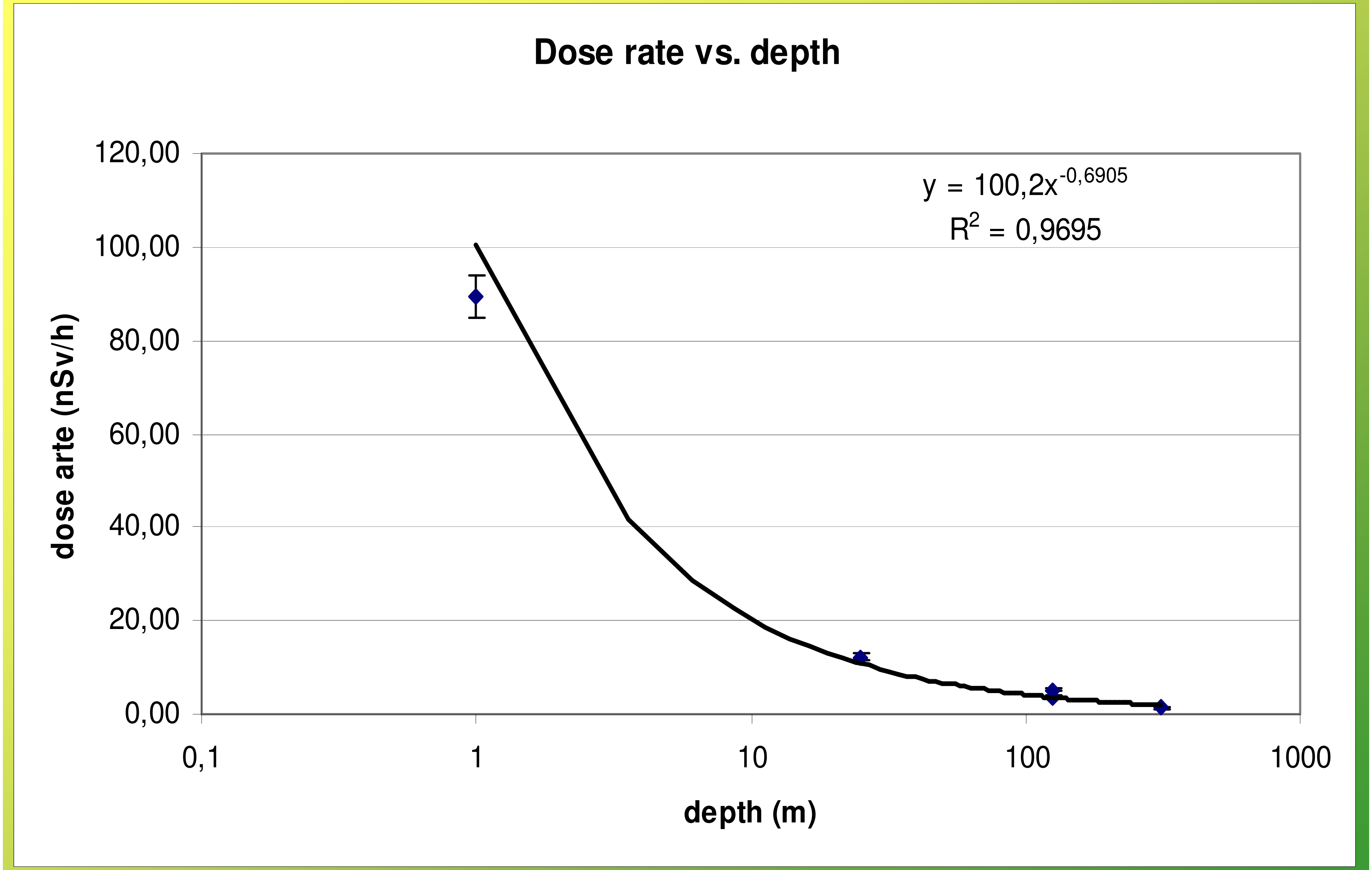
Detector	N tracks	density [tracks/mm^2]	corrected density	Rn conc. [Bq/m^3]*
A112	53	1,132	0,817	11
A439	48	1,026	0,711	9

*uncertainty ~40%

Other measurements are in progress, especially for detectors background correction

minimum = 0,09 mm^{-2} and maximum: 0,55 mm^{-2}, average=0,31 $\pm$ 0.16 mm^{-2}

Measurements performed by Prof. C. Cosma from UBB Cluj Napoca


Dose rate vs. depth
y = 100,2x-0,6905
R2 = 0,9695
dose arte (nSv/h)
120,00
100,00
80,00
60,00
40,00
20,00
0,00
0,1
1
10
100
1000
depth (m)

Applied Radiation and Isotopes 67 (2009) 961–963

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Activity measurements of technically enhanced naturally occurring radionuclides (TENORM) in phosphogypsum

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A R T I C L E I N F O

Keywords:
Phosphogypsum
TENORM
Gamma-ray spectrometry
Activity

A B S T R A C T

Phosphogypsum is a by-product of the phosphoric acid based fertilizer industry; it can be used in agriculture and to make building materials. Phosphogypsum is radioactive due to the presence of technically enhanced naturally occurring radionuclides (TENORM) and its environmental impact is a major concern of the public authorities. The Radionuclide Metrology Laboratory from IFIN-HH participated at the IAEA-CU-2007-06-CCRI(II)-S5 Supplementary Comparison for the Determination of TENORM in phosphogypsum. The measurement procedures and the discussion of results and problems encountered are presented.

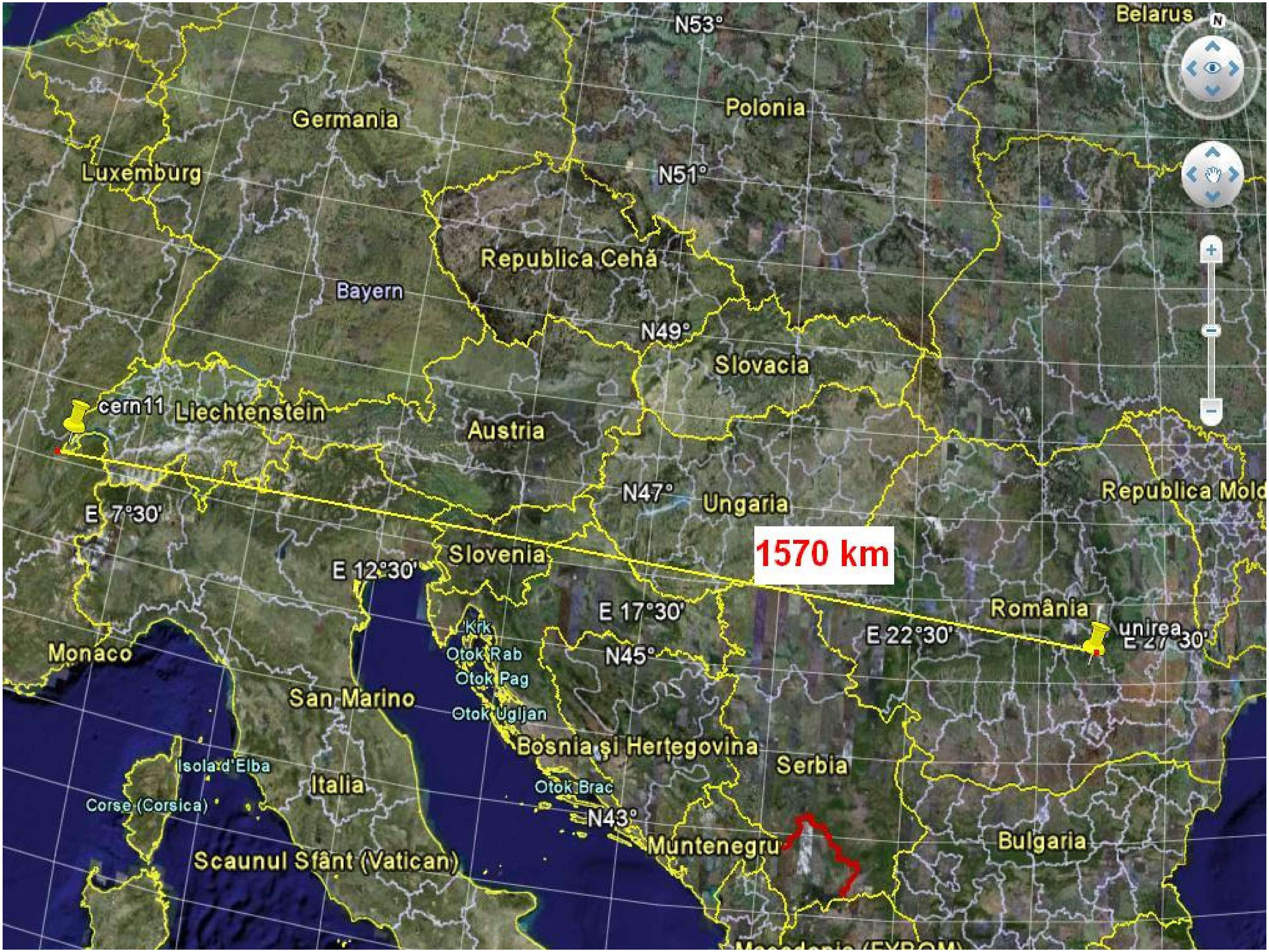
Results expressed in relative values (to the ^{226}Ra activity) obtained for the IAEA-CU-2007-06-CCRI(II)-S5 Supplementary Comparison for the Determination of TENORM in phosphogypsum.

Radionuclide	Individual activity determinations dry mass (relative to ^{226}Ra) (%)						Estimates	
	Sample 1	Unc.1[a]	Sample 2	Unc.2[a]	Sample 3	Unc.3[a]	Average value (%)	Total Unc[a] at 1σ level
^{210}Pb	150	19	–	–	–	–	150	19
^{214}Pb	72	10	73	10	71	10	72	10
^{214}Bi	44	5	42	5	42.4	4.9	42.8	4.9
^{226}Ra	100	13	–	–	–	–	100	13
^{234}Th	46	7	–	–	48	12	47	7
^{235}U	2.86	0.46	–	–	–	–	2.86	0.46

[a] Standard uncertainty of individual determination expressed in % (for example, in the case of sample 1, the activity ratio between ^{214}Pb and ^{226}Ra is (72$\pm$10)%).

Slanic laboratory in LAGUNA project

Due to the depth of Unirea salt mine, about 600 mwe, the only experiment which could be considered to be installed in Slanic is GLACIER.

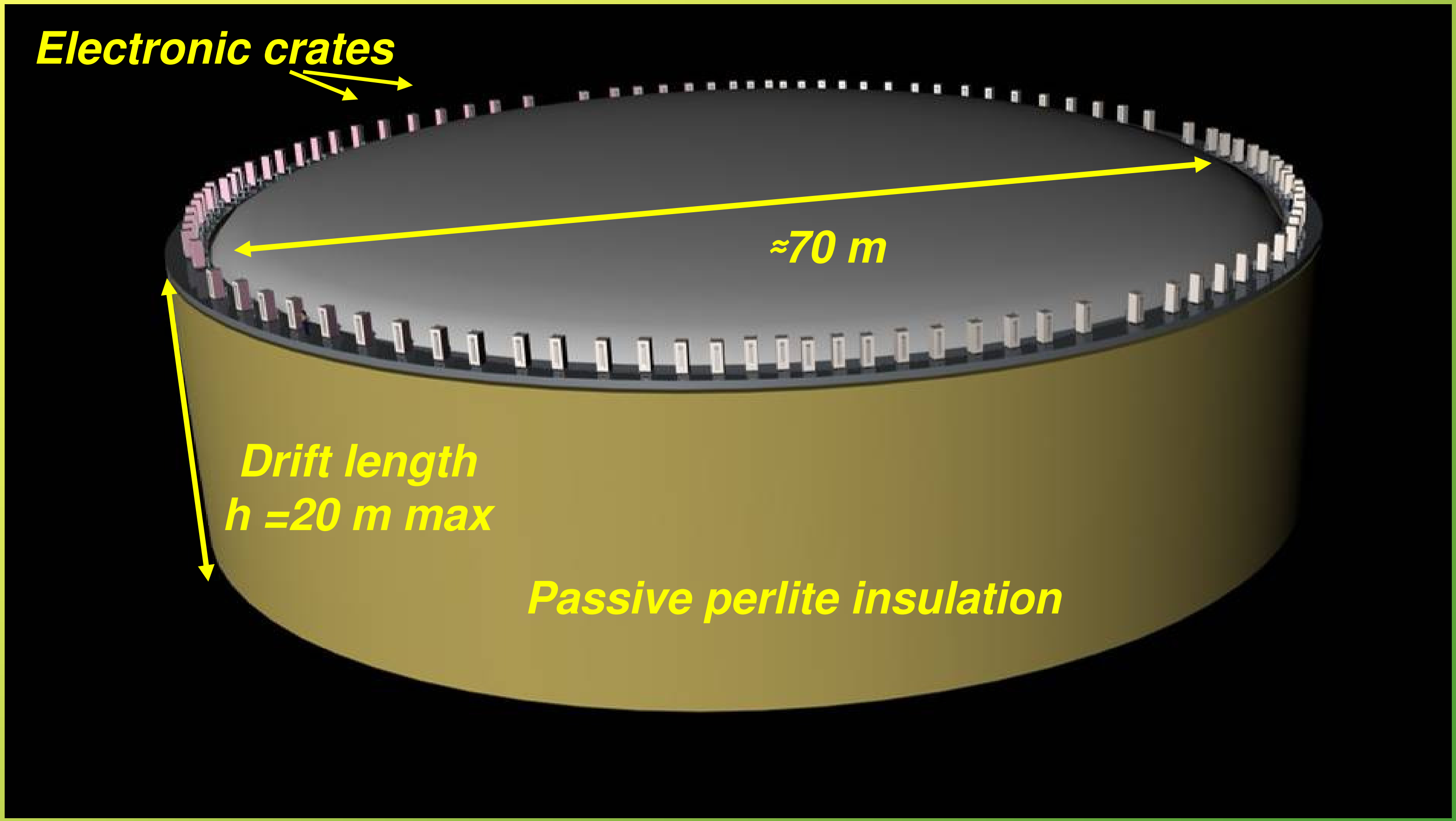


Belarus
N53°
Germania
Polonia
Luxemburg
N51°
Republica Cehă
Bayern
N49°
Slovacia
cern11
Liechtenstein
Austria
N47°
Ungaria
Republica Mold
E 7°30'
1570 km
Slovenia
E 12°30'
E 17°30'
România
unirea
E 22°30'
E 27°30'
Krk
Otok Rab
Monaco
N45°
Otok Pag
San Marino
Otok Ugljan
Bosnia și Herțegovina
Isola d'Elba
Serbia
Italia
Otok Brac
Corse (Corsica)
N43°
Muntenegru
Bulgaria
Scaunul Sfânt (Vatican)

GLACIER

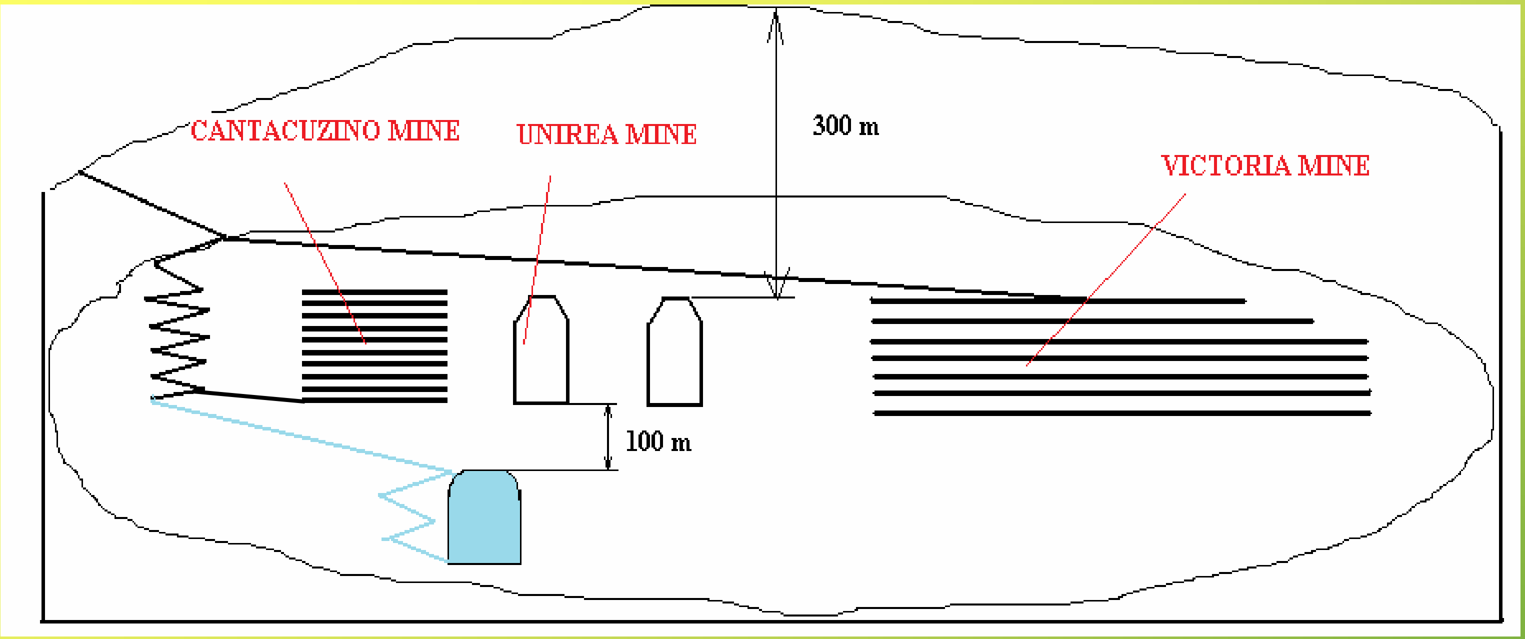
Giant Liquid Argon Charge Imaging ExpeRiment

possibly up to 100 kton



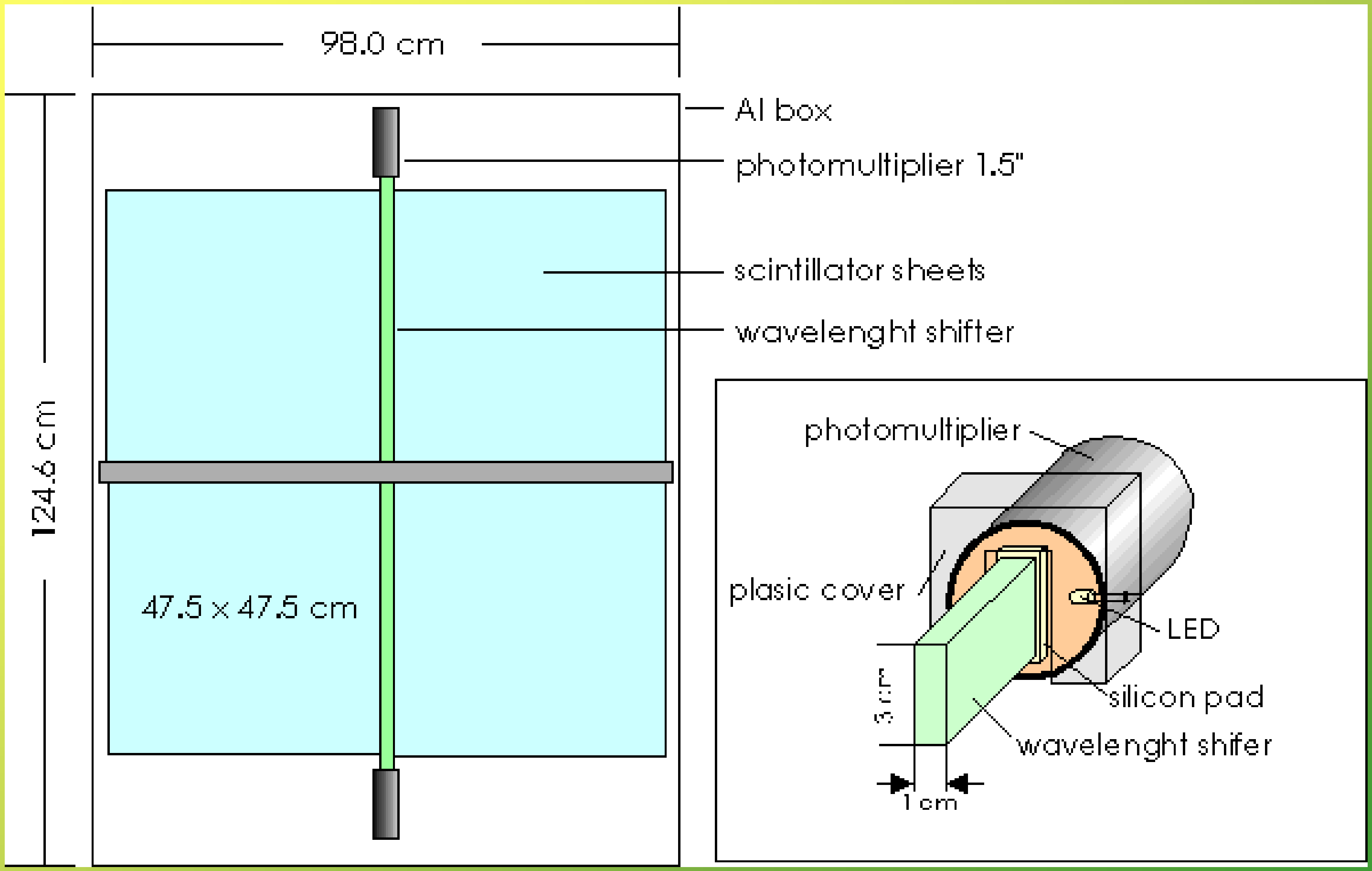
A. Rubbia hep-ph/0402110
Venice, Nov 2003

The muon flux measurement in underground



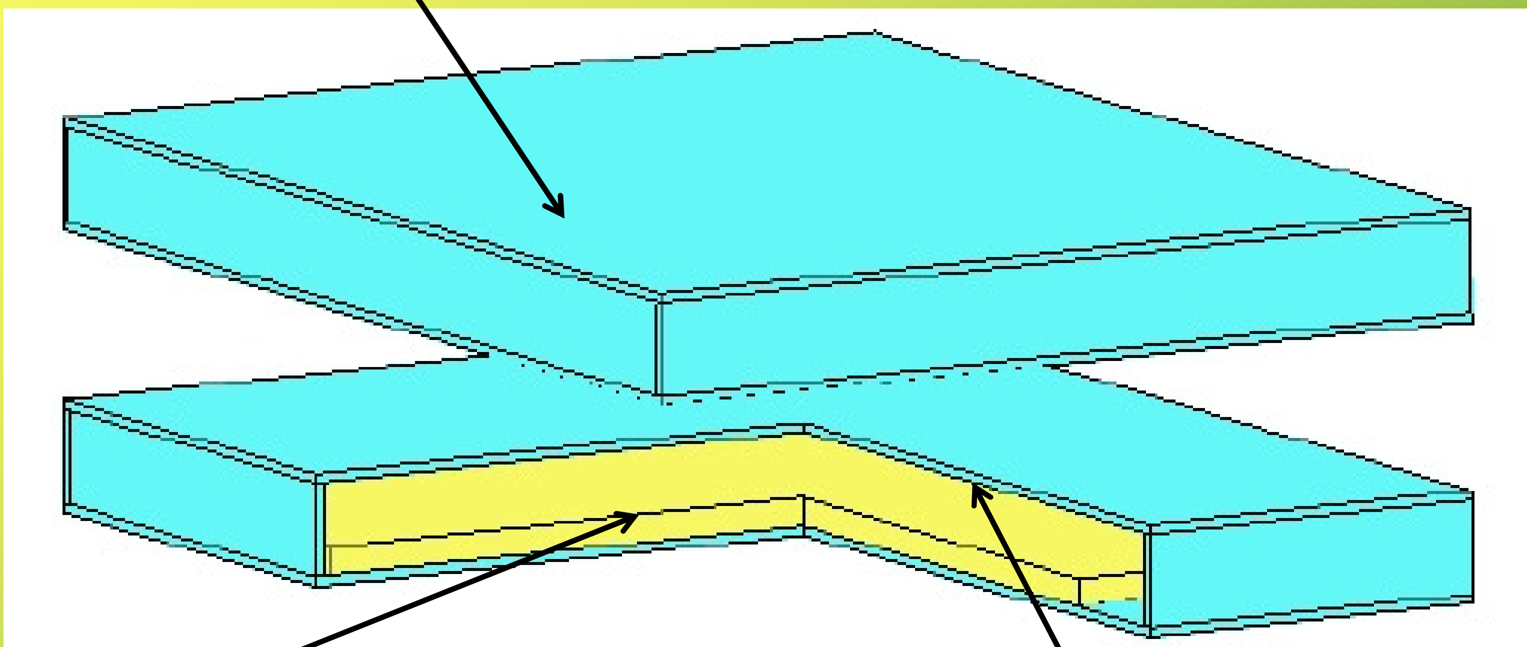
The mobile muon detector

Detection system



GEANT simulation of the detector

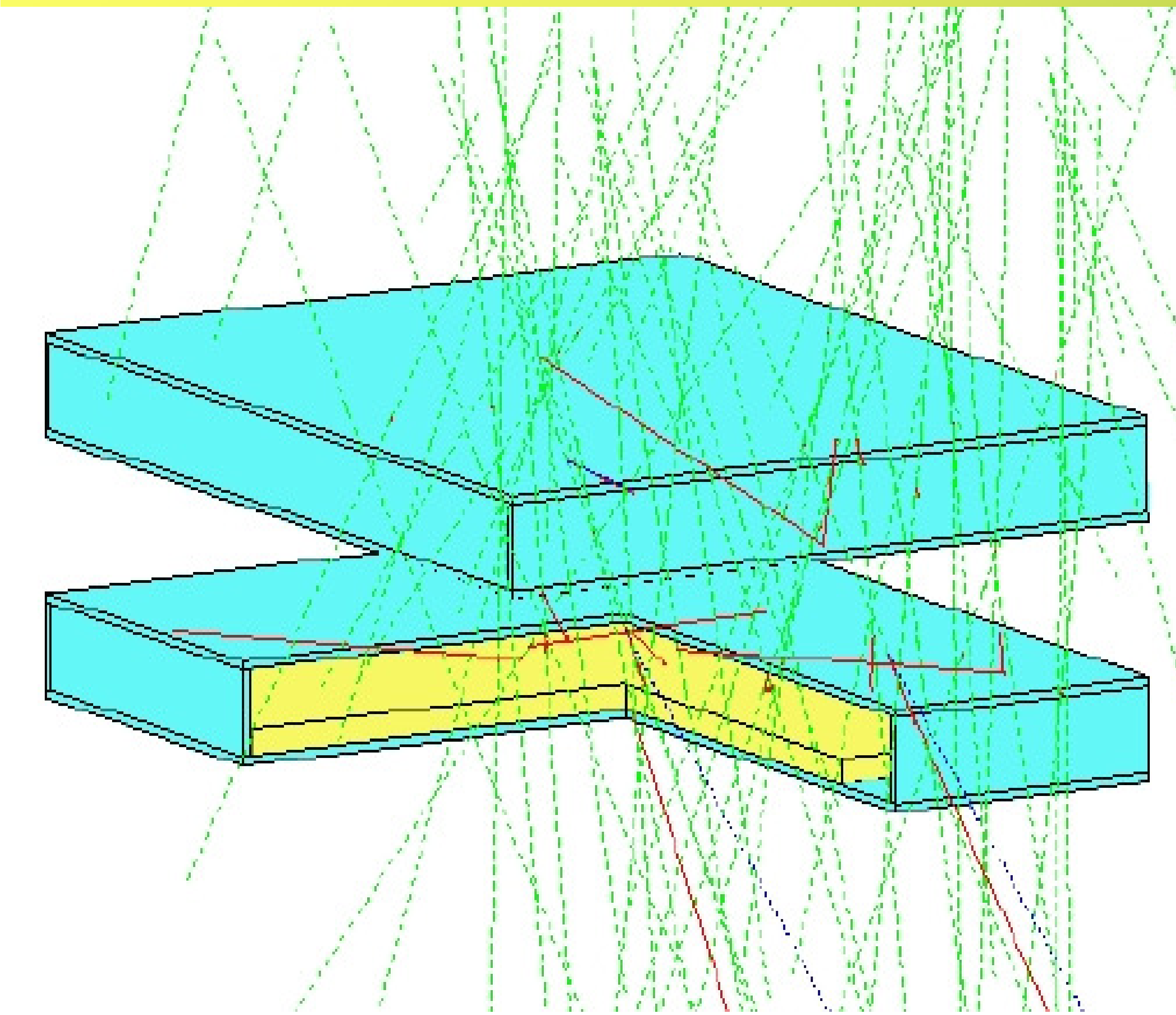
Detection Module



Scintillator plate (NE 114)

Aluminuim box

GEANT simulation of the detector



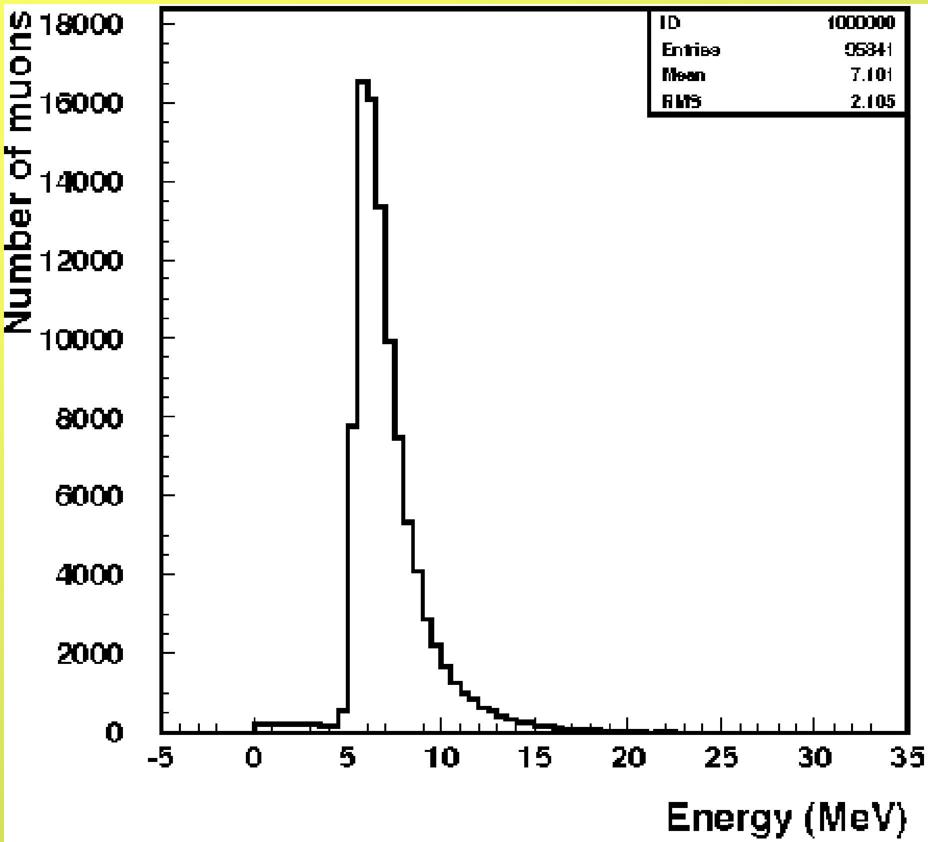
GEANT 3.21

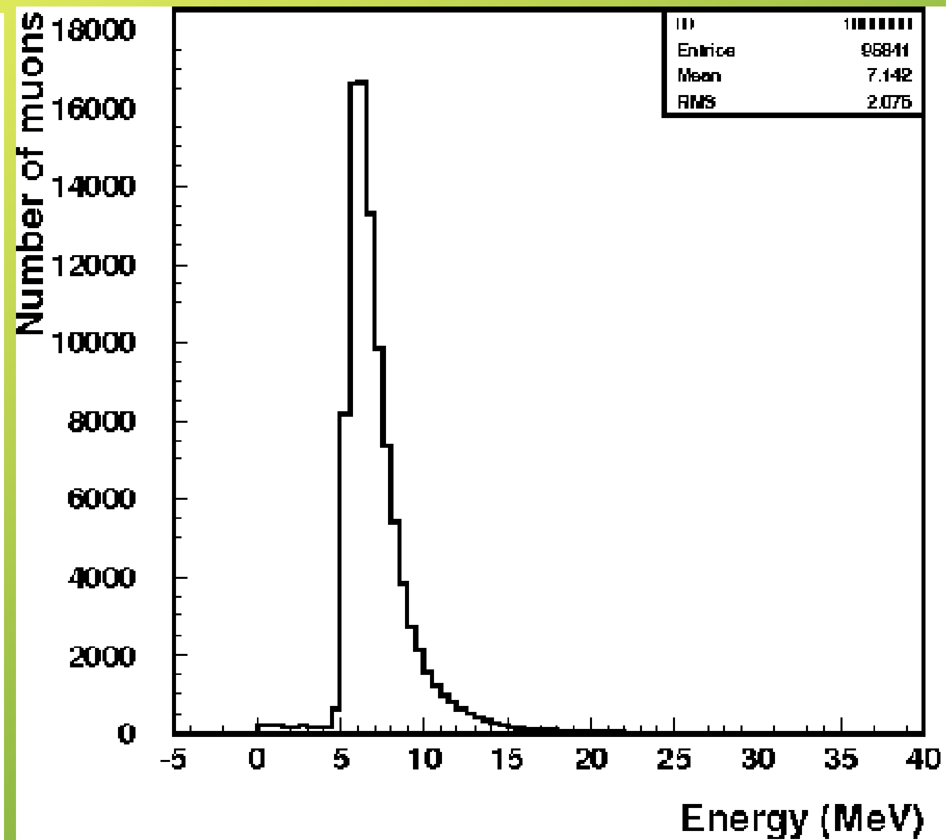
1.Muon`s interaction with the detector is simulated

2.Estimation of the energy deposit in the detector by the muons and secondary particle

3.The correction factor of the muon rate is estimated at 22%

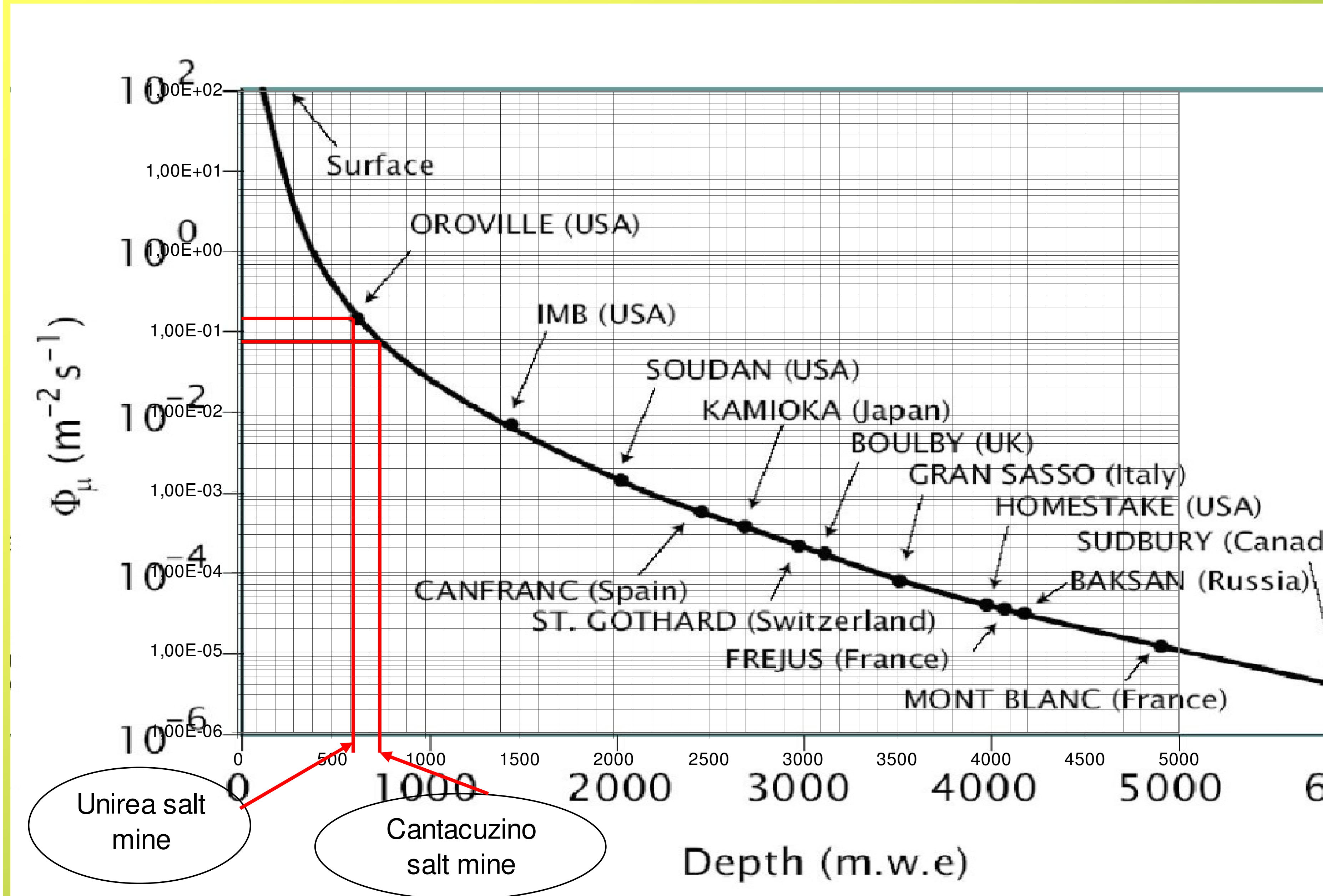
Deposited energy by muons in scintilators (GEANT)





Mesuremenst of the muon intensity in underground

Place	Level (m)	Muon rate (muon/m^2s)
UNIREA MINE	- 208	0.18
CANTACUZINO Oriz. 8	- 188	0.19
CANTACUZINO Oriz. 12	- 210	0.09



10^{2}
1,00E+02
1,00E+01
10^{0}
1,00E+00
1,00E-01
10^{-2}
1,00E-02
1,00E-03
10^{-4}
1,00E-04
1,00E-05
10^{-6}
1,00E-06
Φ_μ ($m^{-2}s^{-1}$)
Surface
OROVILLE (USA)
IMB (USA)
SOUDAN (USA)
KAMIOKA (Japan)
BOULBY (UK)
GRAN SASSO (Italy)
HOMESTAKE (USA)
SUDBURY (Canada
BAKSAN (Russia)
CANFRANC (Spain)
ST. GOTHARD (Switzerland)
FREJUS (France)
MONT BLANC (France)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
1000
2000
3000
4000
5000
6
Unirea salt mine
Cantacuzino salt mine
Depth (m.w.e)

Tank construction alternatives

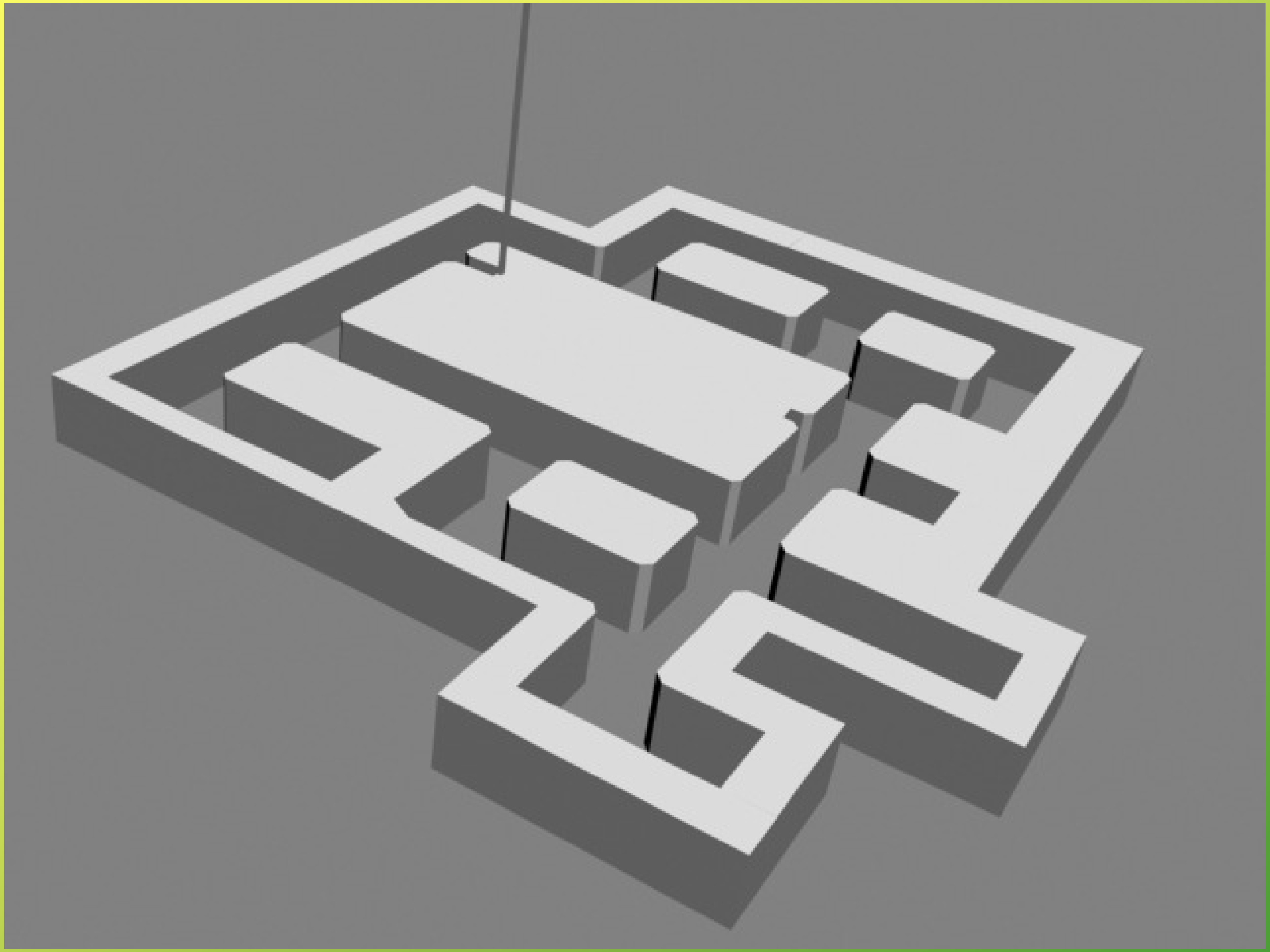
For the underground infrastructures and engineering, for GLACIER type detector, three situations were investigated:

- A crown type detector placed around one of the pillars in Unirea salt mine, with a volume of about 80500m^3,
- 3 smaller tanks placed at the cross of different galleries with a total volume of about 81000 m^3.
- excavation of a new gallery able to host a tank of 72 m in diameter and about 37 m height

In the existing galleries we have two options, namely:

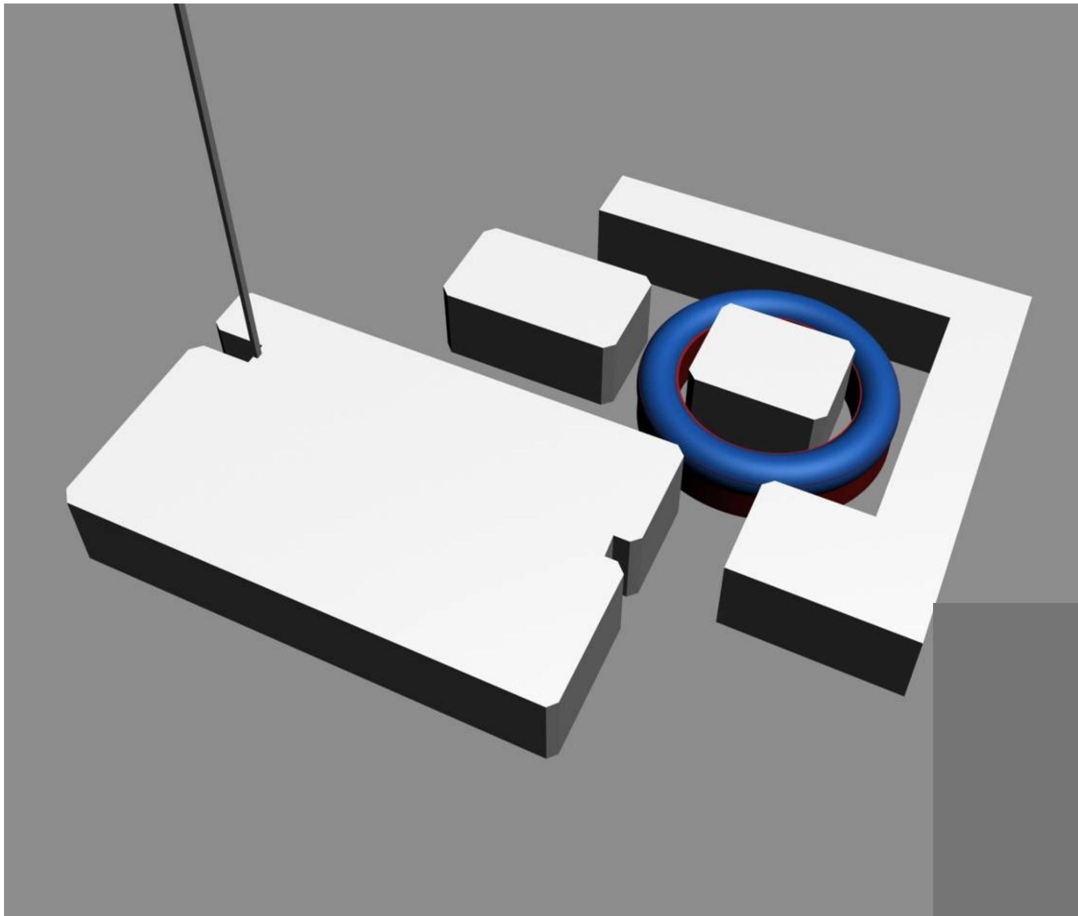
Option 1 - 1 tank of 80.000 m^3 Crown detector with: R=54m, r=37,6m, h=26m height

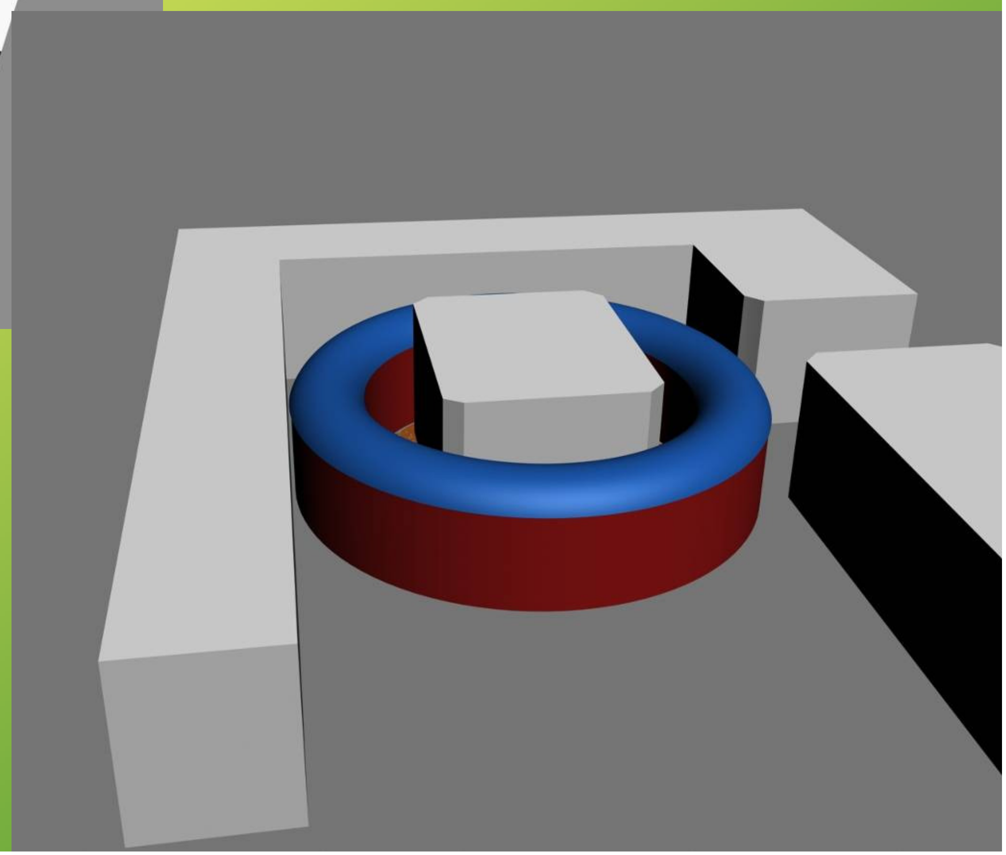
Option 2 - 3 tanks of 26.000 m^3 each with R=22 m, h = 25 m height



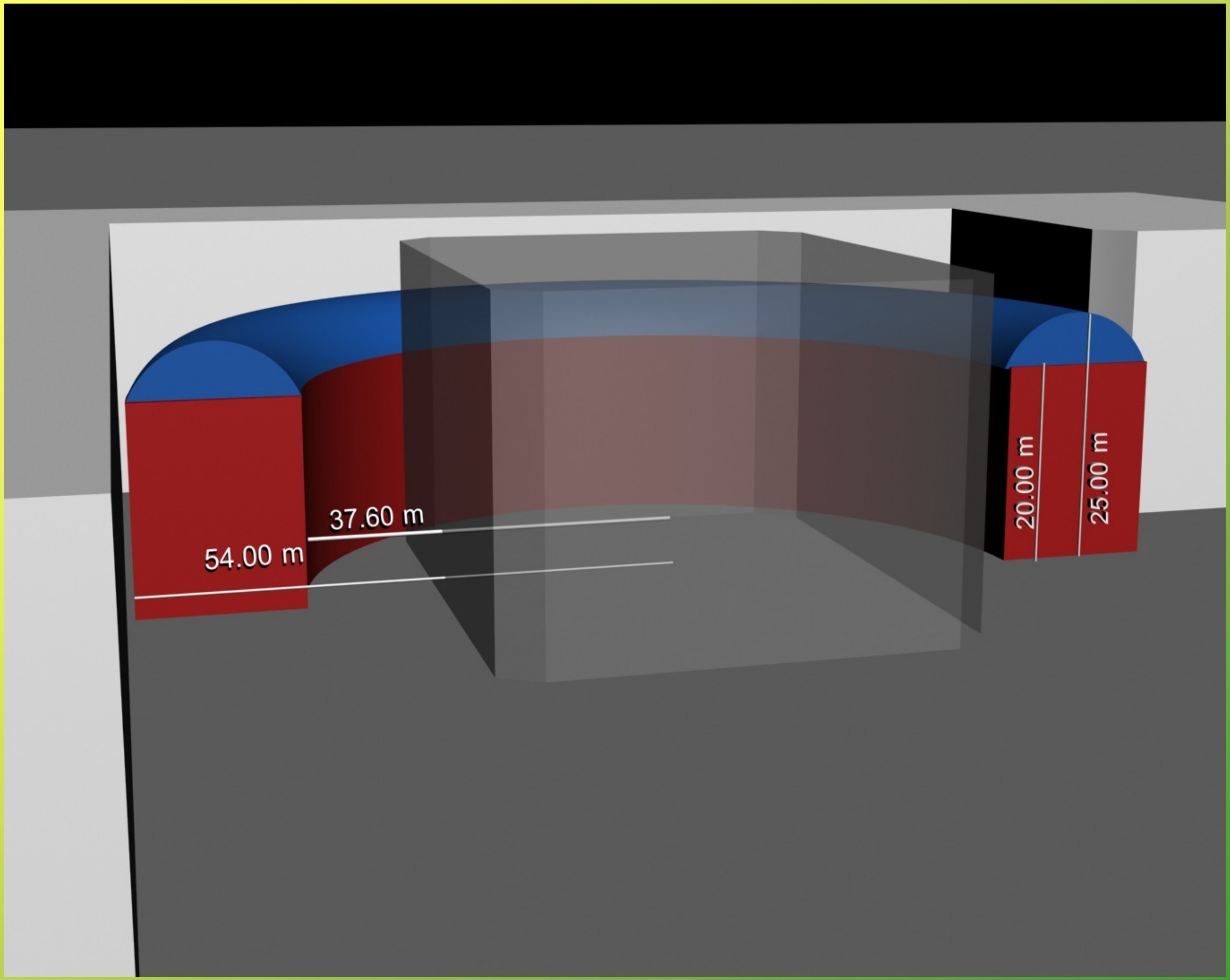
OPTION#1

CROWN DETECTOR

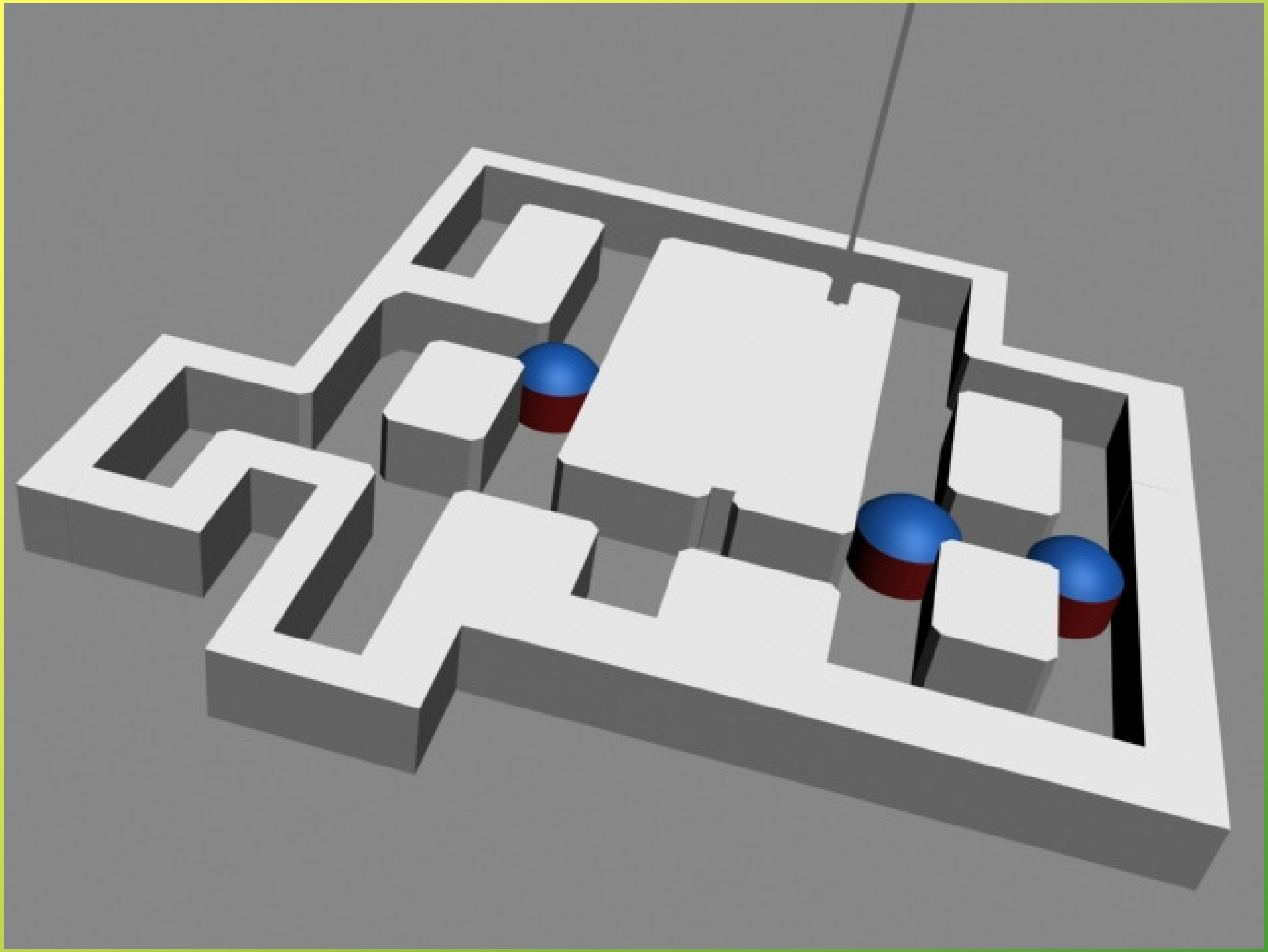




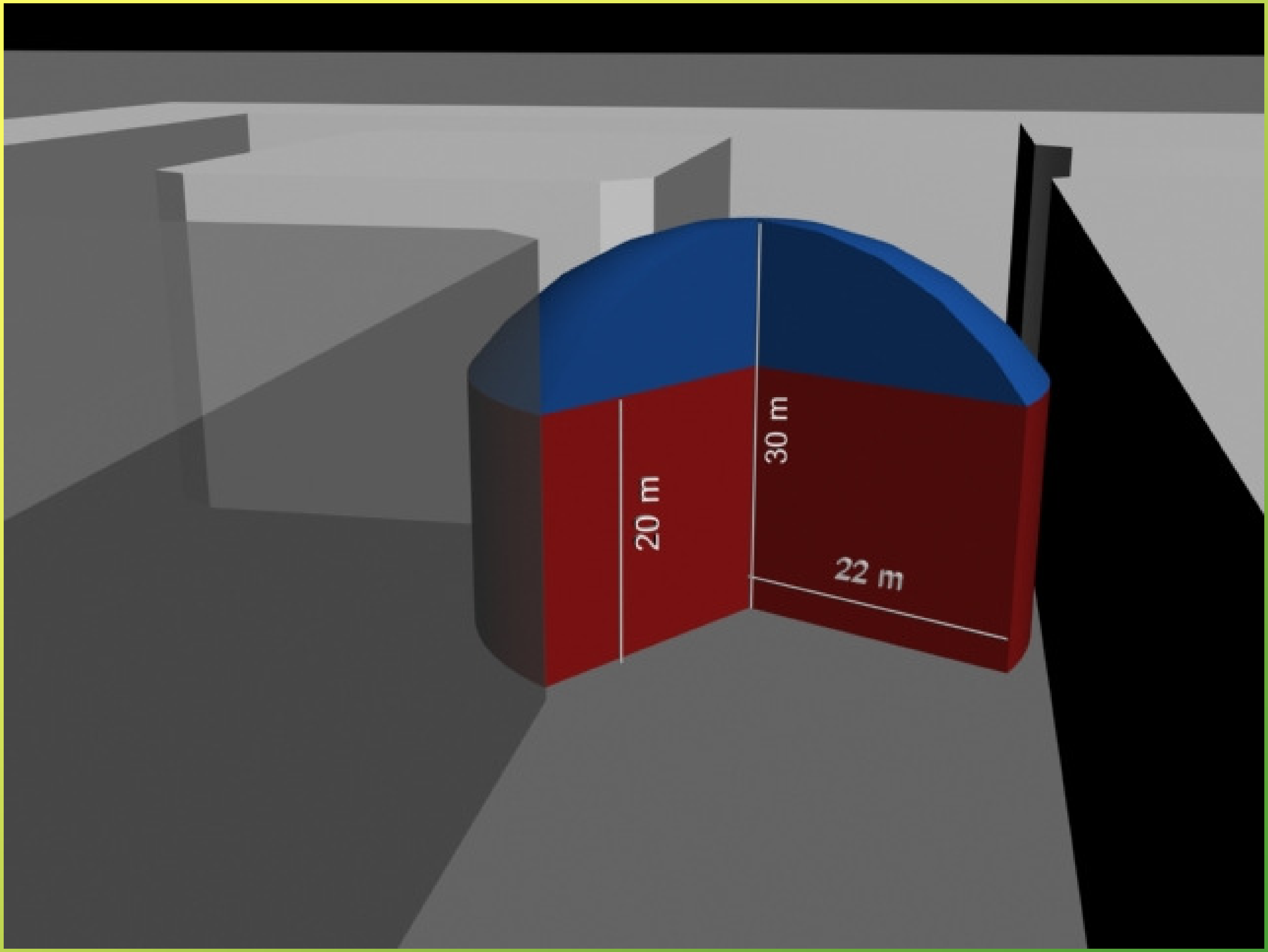
Crown detector dimensions



OPTION#2 - 3 smaller detectors

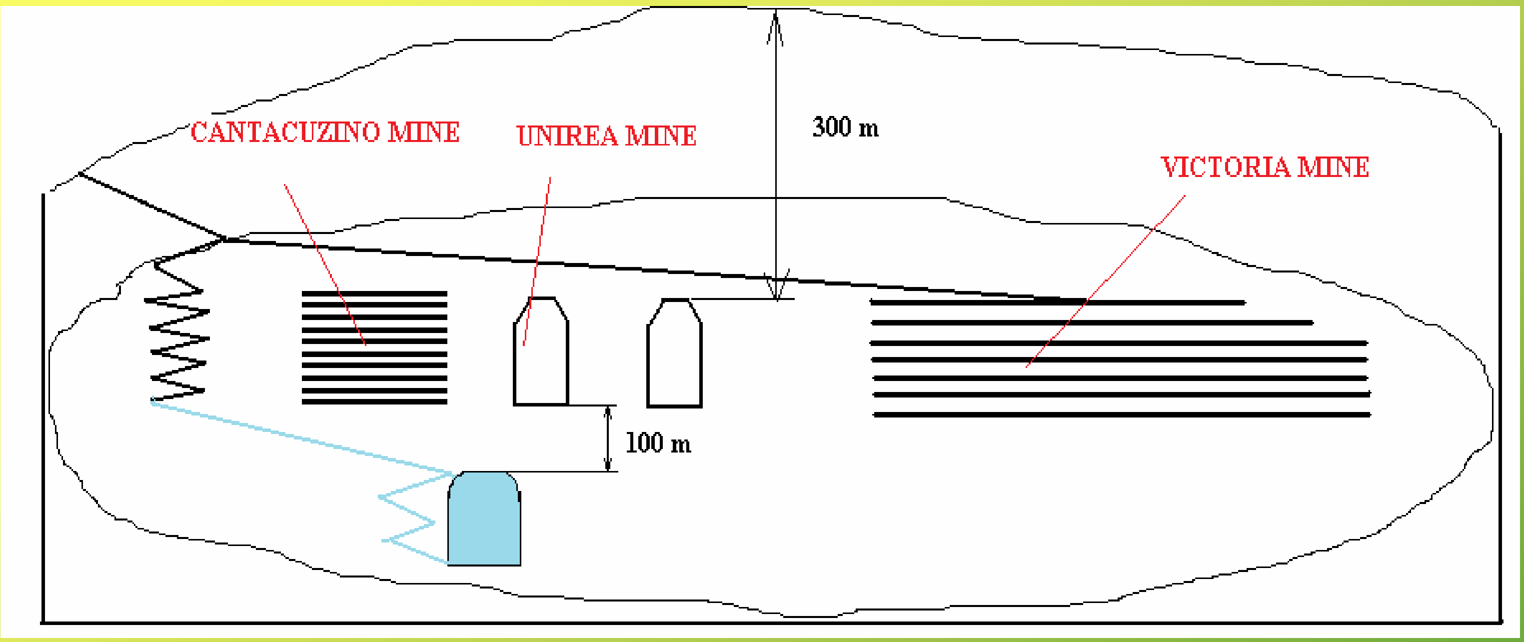


Tank dimensions for the second option



Option#3

Excavation of a new gallery about 100 m below the present excavation



The calculations were performed by Prof. V. Arad and his coworkers from University of Petrosani, Faculty of Mine, Department of Mining Engineering and Industrial Safety

GEOMECHANICAL CHARACTERIZATION OF THE SALT FROM SLANIC-PRAHOVA

The measurement of geomechanical characteristics in laboratory

The important physical properties for the stability of the underground excavation determined are: specific density (γ), volumetric density, (γ_a) and porosity (n).

The relevant mechanical properties for the stability of the underground excavations are: uni-axial compressive strength, traction strength, shears strength, cohesion and internal friction strength

Geomechanical characteristics of salt in massif

Along with direct measurement of salt parameters in laboratory, for simulating the salt behavior in Slanic-Prahova massif, software for geotechniques based on Hoek-Brown crack criterion was used. Hoek-Brown crack criterion is generally accepted and it is world wide applied giving accepted engineering results.

The engineering practice offers the possibility to choose for the salt massif, considering the geological structure, a GSI ranging from 98 to 87, namely an intact structure with few discontinuities zones.

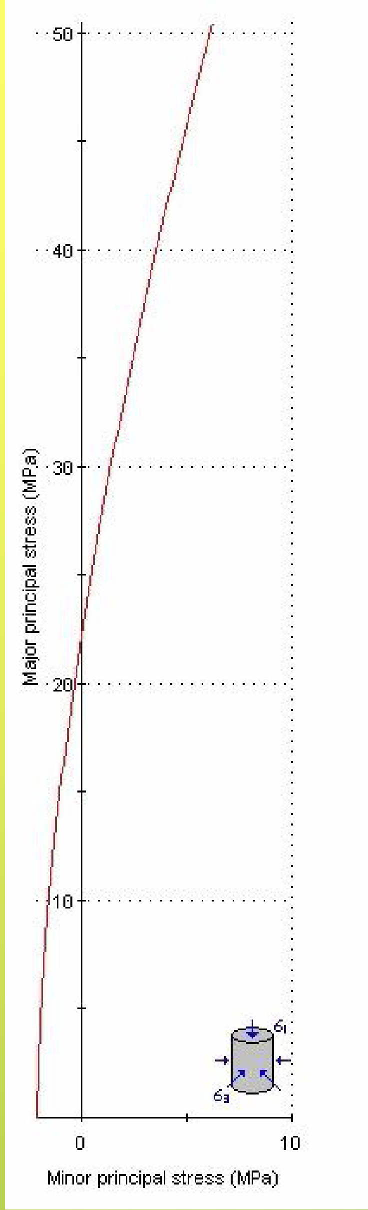
Simulations for GSI=98 have been performed, namely the salt massif almost intact, well structured by internal bonds, consisting from cubic blocks intersected by discontinuities.

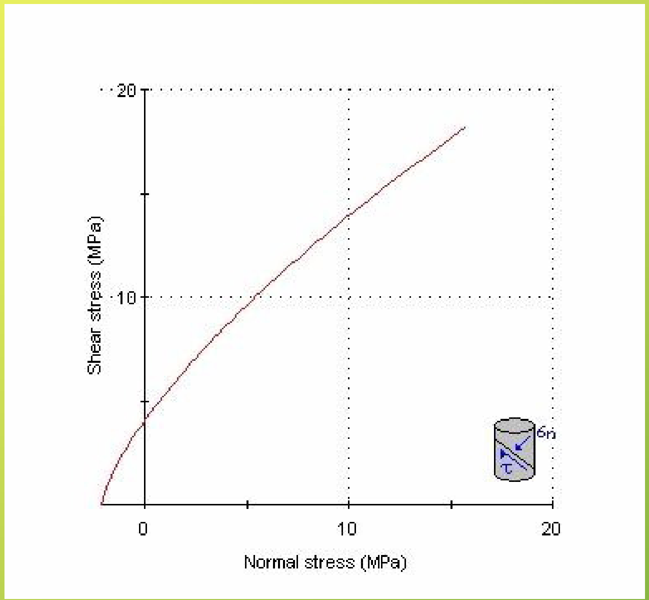
For the salt rocks from Slanic, knowing the geo-morphological characteristics and the literature recommendations, the structural index m_i has been chosen to range in (10 $\pm$ 2). Simulations for m_i=10 and m_i=8 have been performed, the best behavior of salt massif occurs at m_i=10.

A specialized computer code **RocLab** was used, the parameters and properties of rock salt from Slanic Prahova were given in input.
The code generates tables and charts for estimating uni-axial compression stress of intact rock, (σ_{ci}), material parameters m_i and GSI index.
Characteristics values of the massif and those determined for the critical stress for samples from Slanic Prahova salt determined in the laboratory are presented in next table.

parameter	**MU.**	**Average value**	
		mi=8	**mi= 10**
compression strength, σ_{rc} (lab)	MPa	28,868	28,868
compression strength in massif	MPa	22,371	22,371
traction strength in massif	MPa	2,688	2,151
cohesion in massif	MPa	4,462	4,56
internal friction angle	[^{o}]	43,79	42,69
Young's modulus	MPa	1937,18	2926,55

Major and minor principal strength dependency for m = 10





Hoek-Brown Classification

intact uniaxial compressive strength = 25 MPa

GSI = 98 mi = 10 Disturbance factor = 0

Hoek-Brown Criterion

mb = 9.311 s = 0.8007 a = 0.500

Mohr-Coulomb Fit

cohesion = 4.566 MPa friction angle = 42.69 deg

Rock Mass Parameters

tensile strength = -2.150 MPa

uniaxial compressive strength = 22.371 MPa

global strength = 20.846 MPa

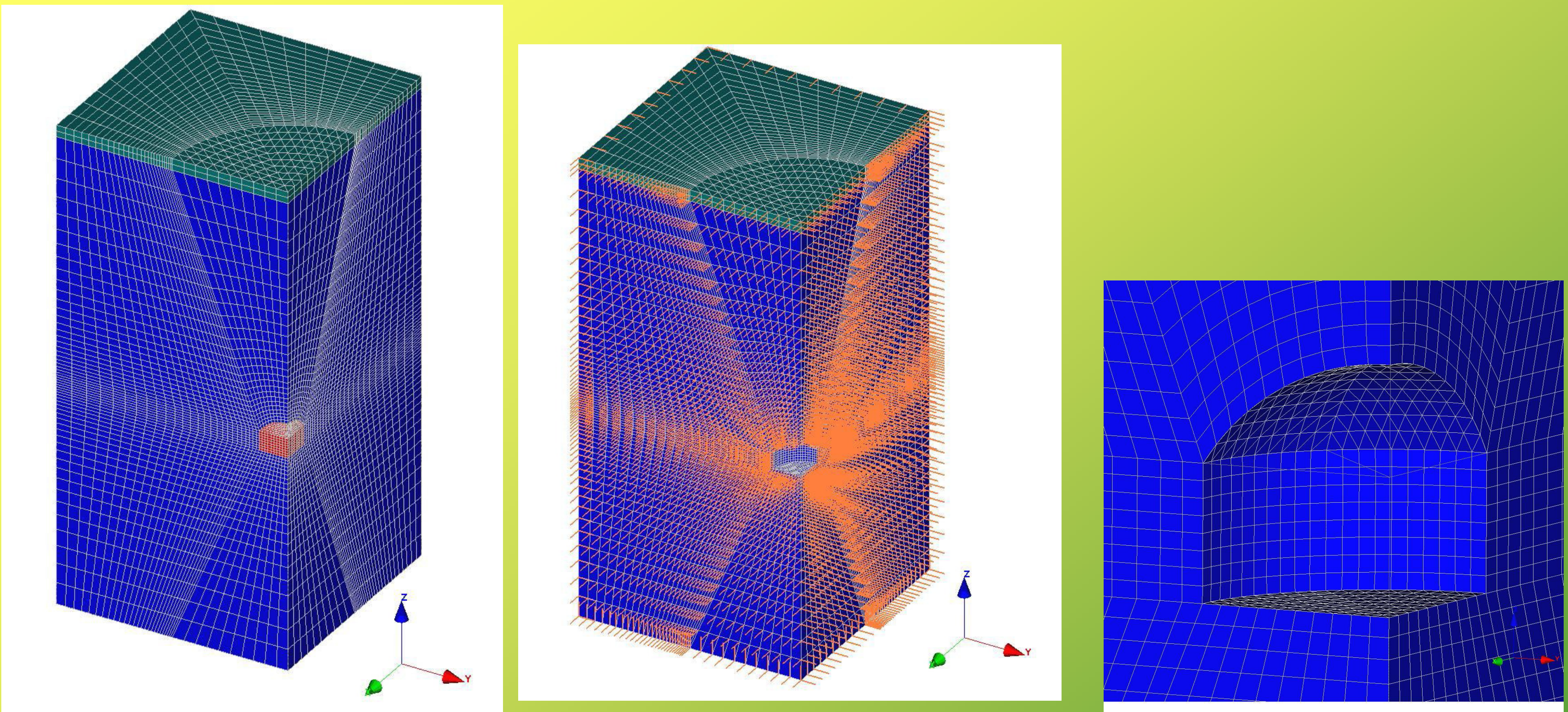
modulus of deformation = 2926.55 MPa

Analysis by finite element method of stresses and strains developed around an excavation in salt massif in Slanic Prahova

Regarding the FEM, several computer codes for analyzing structures by finite element method have occurred. The CESAR code, whose development began in 1981, is the successor of ROSALIE code developed by the Central Laboratory of Bridges and Roads in Paris. CESAR is a general computer code that is based on finite element method, which addresses the following areas: structures, soil and rock mechanics, heat transfer, hydrogeology.

CESAR-LCPC code 2D and 3D version 4, which is composed of processor Cleo2D respectively Cleo3D completed the Option C0 (linear and nonlinear static Mechanics & Diffusion)

The goal of modeling with FEM using CESAR-LCPC 3D computer code is an excavation located at an average depth of approx. H = 300m, measured from its upper surface. The excavation consists of a lower part vertical cylinder of diameter d = 74m and horizontal height h = 25m and an upper hand in the form of spherical caps height h1 = 20m and radius of approx. R = 44m, stabile for more than 50 years



a) b) c)

Model geometry:
a) Meshing the model, b) conditions to the limit, c) Detail of mesh with excavation

The calculation base

Geomechanical characteristics considered the criterion elastic-plastic Mohr-Coulomb type without hardening

Geomechanical characteristics	U.M	Rock salt	Surrounding rocks
Apparent specific density, γ_a	[N/m^3]	22000	25000
Young's modulus, E	[kN/m^2]	3000000	1800000
Poisson's coefficient, μ		0,25	0,25
Cohesion, C	[kN/m^2]	4500	1000
Angle of internal friction, φ	[º]	35	30
Expantion angle, ψ	[º]	35	30

Results

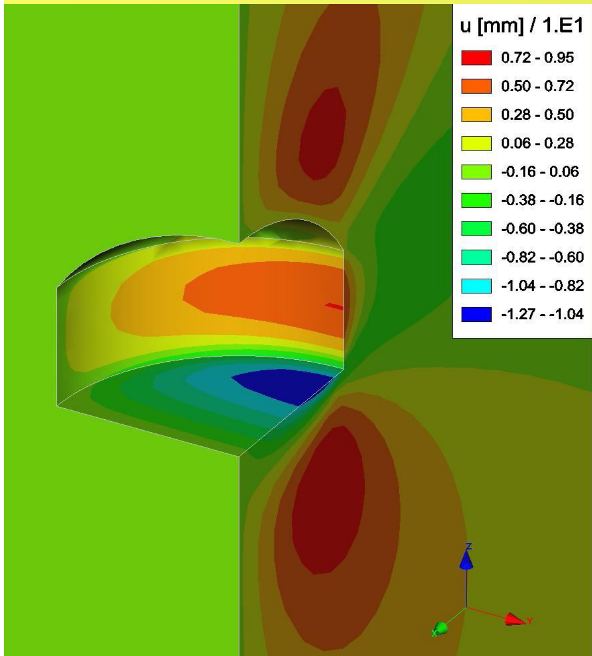
Variation of horizontal u and v and vertical w displacements, [mm]

displacements [mm]		
u	v	w
+ 9,4 ÷ -12,7	+ 9,4 ÷ -12,7	+ 115 ÷ -78
strains [%]		
ε_u	ε_v	ε_w
0,0000343÷0,000254	0,0000343÷0,000254	0,000254÷ 0,0021

Variation of stresses

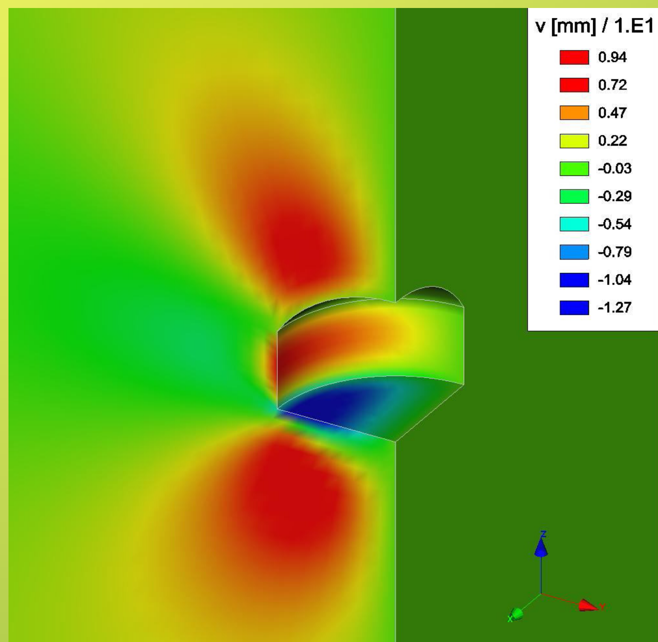
Stresses, [kN/m^2]					
σ_{xx}	σ_{yy}	τ_{zz}	τ_{xy}	τ_{yz}	τ_{zx}
+2260÷-8330	+2260÷-8330	+500÷-17000	+1380÷-1740	+5640÷58	+5640÷589
σ_1	σ_2	σ_3	τ_{max}	σ_c	σ_t
+2290÷-5250	+2260÷-6490	+2260÷-6490	+7920÷0	0÷-19500	+2290÷0

Displacements



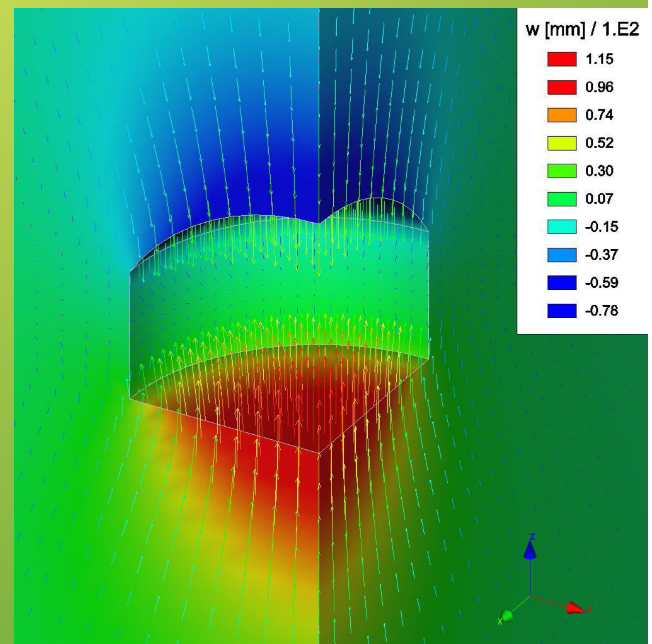
Horizontal displacement

u, in mm



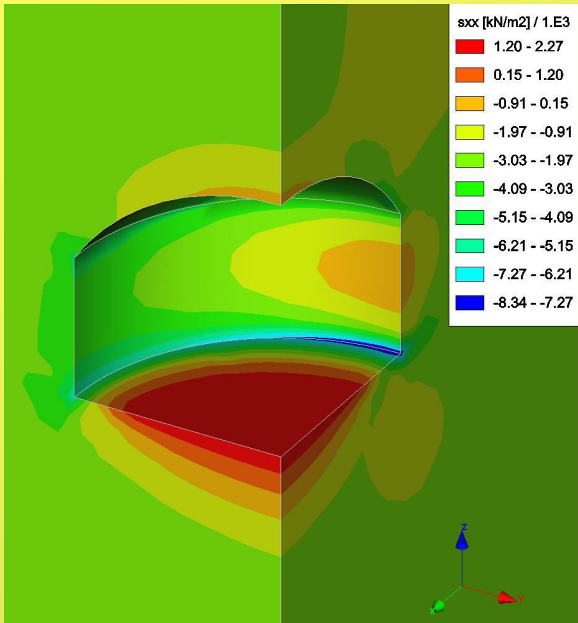
Horizontal displacement

v, in mm

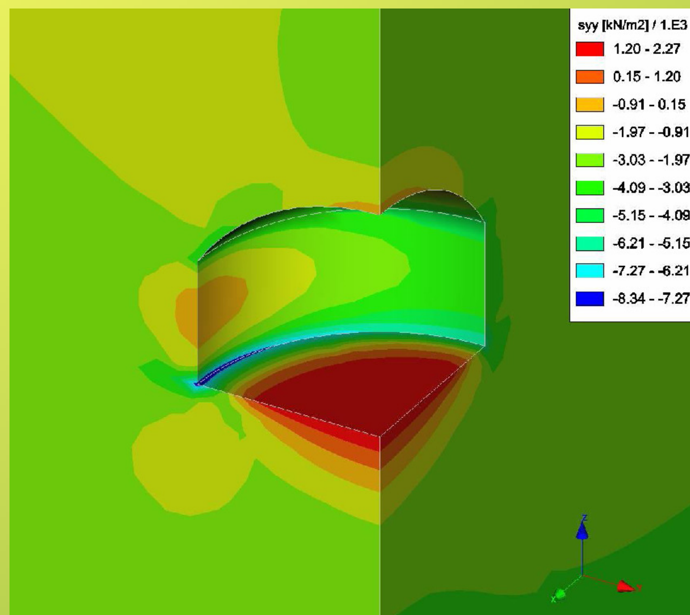


Vertical displacement w in mm

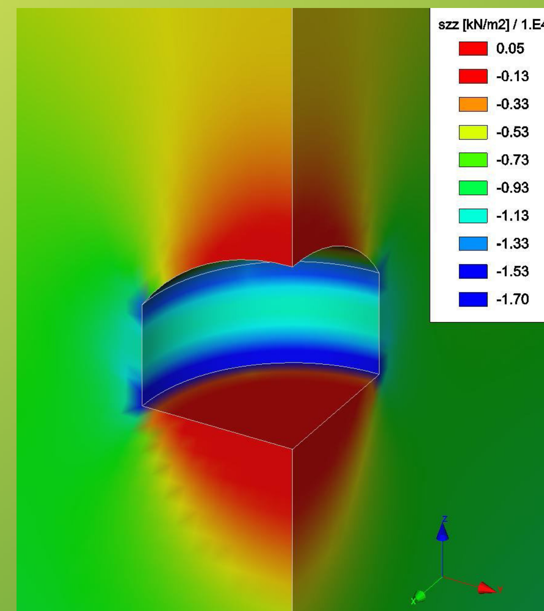
Stresses



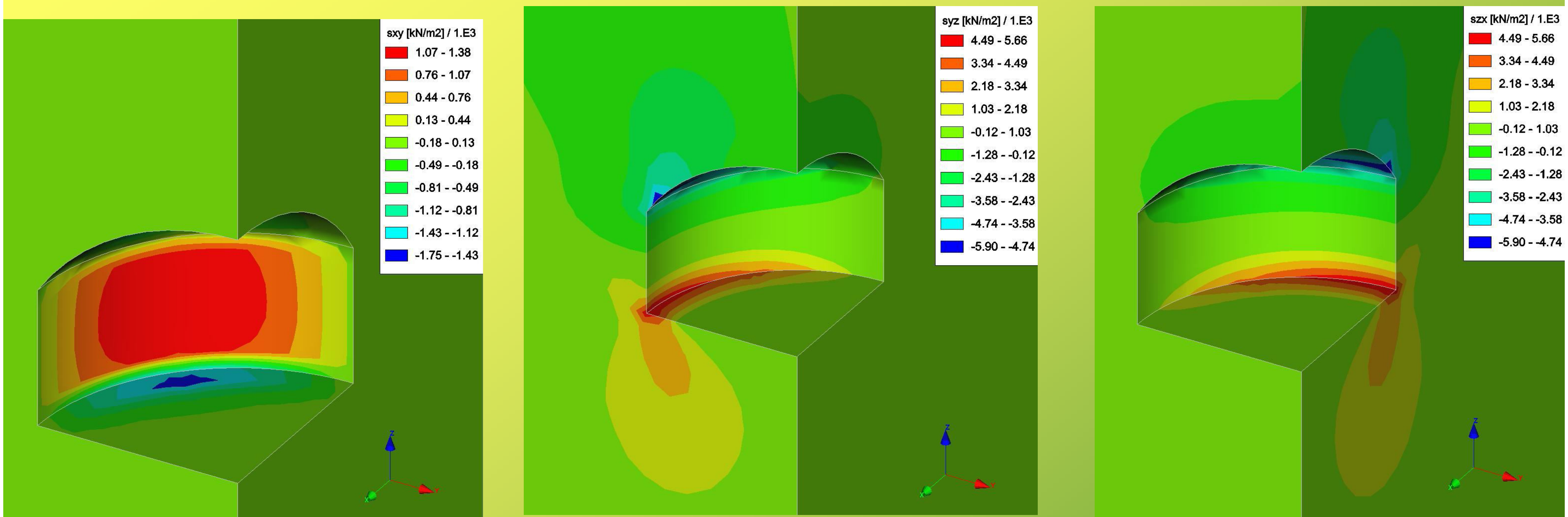
Horizontal stresses σ_{xx}, in kN/m^2



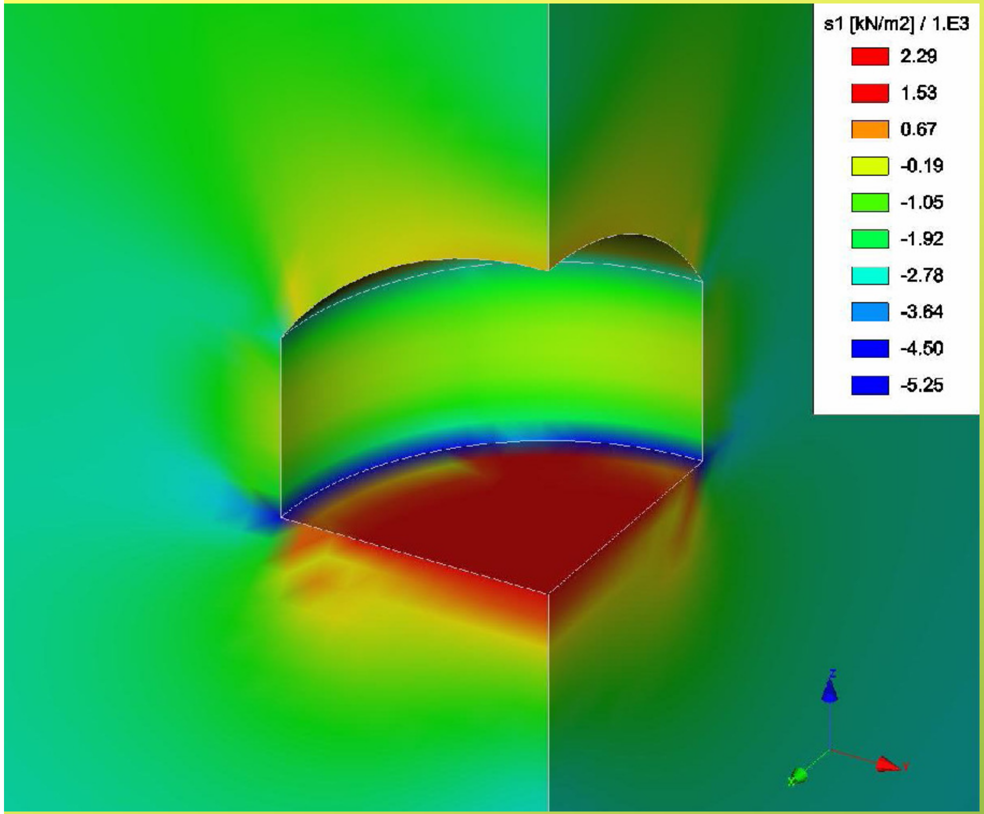
Horizontal stresses σ_{yy} , in kN/m^2

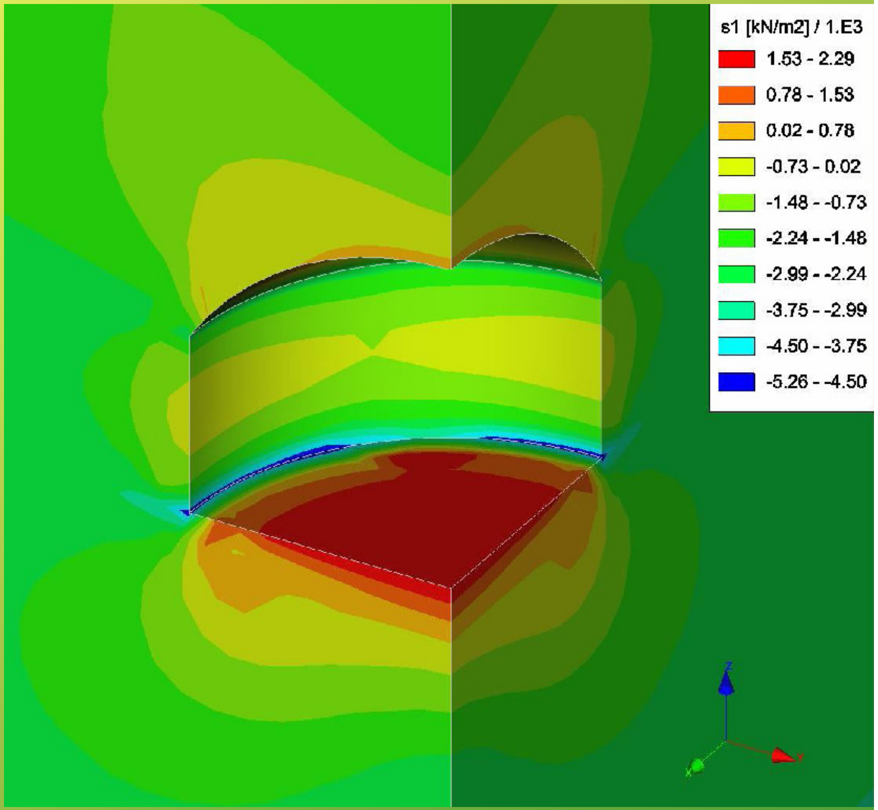


Vertical stresses σ_{zz}, in kN/m^2

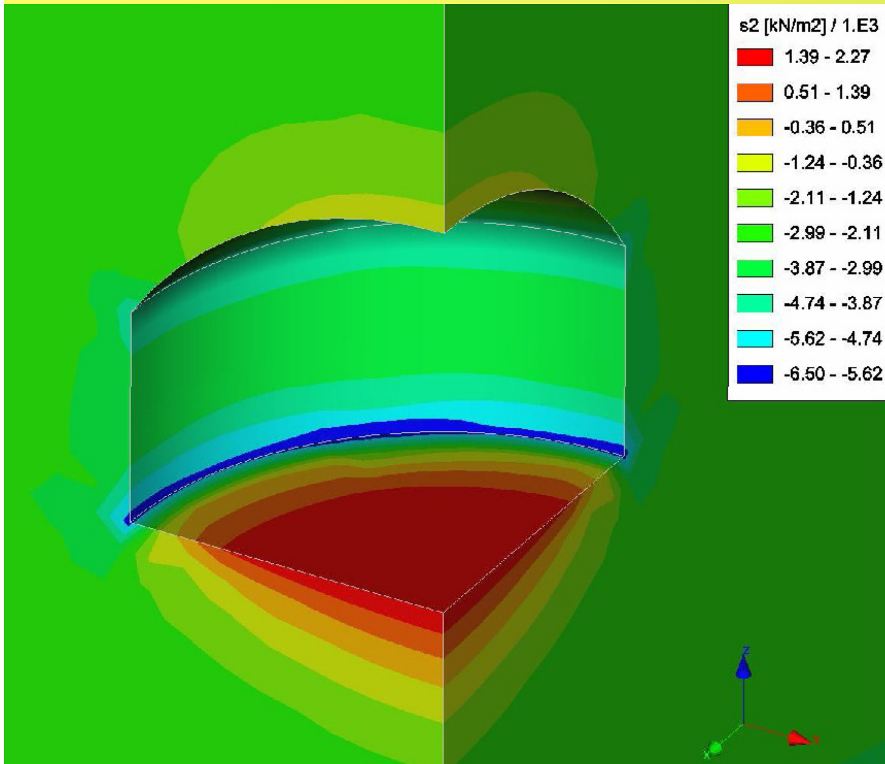


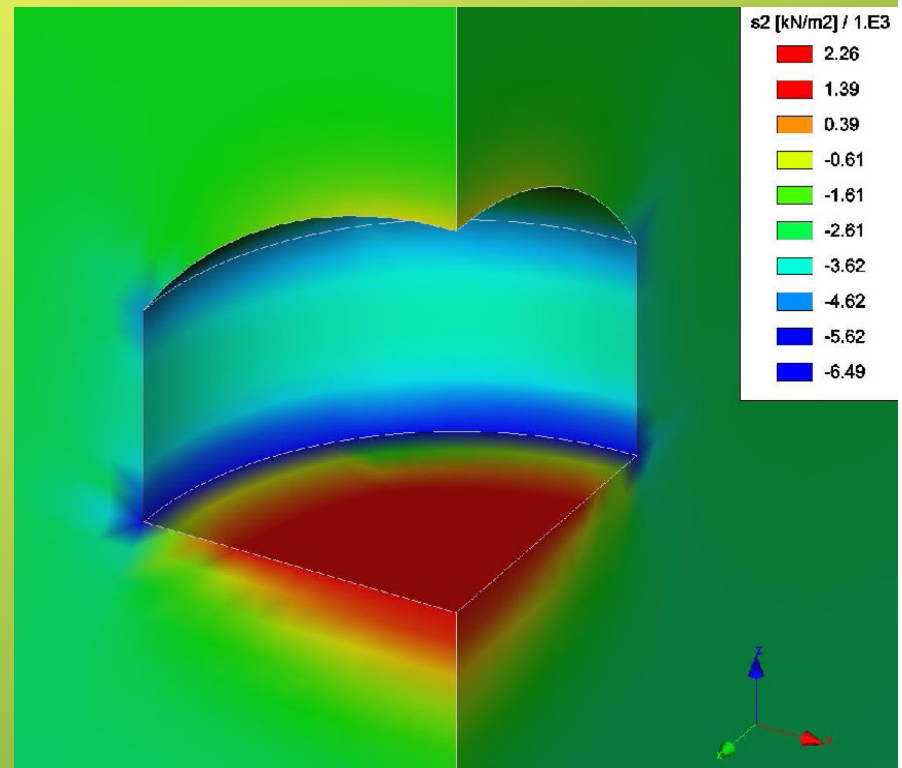
Tangential stresses τ_{xy} , τ_{yz} , τ_{zx} , in kN/m^2



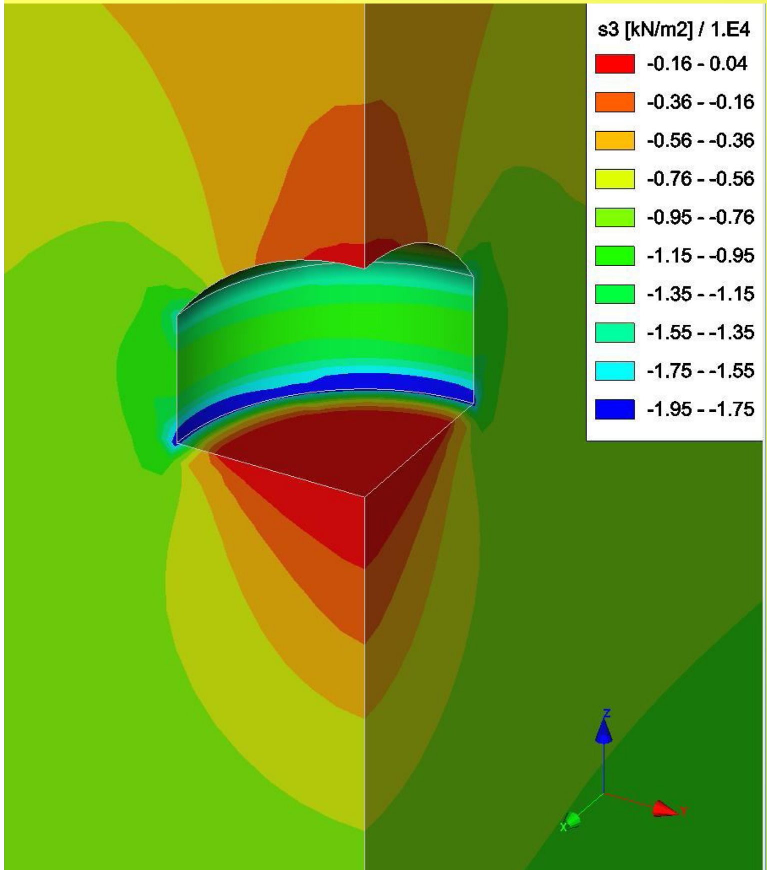


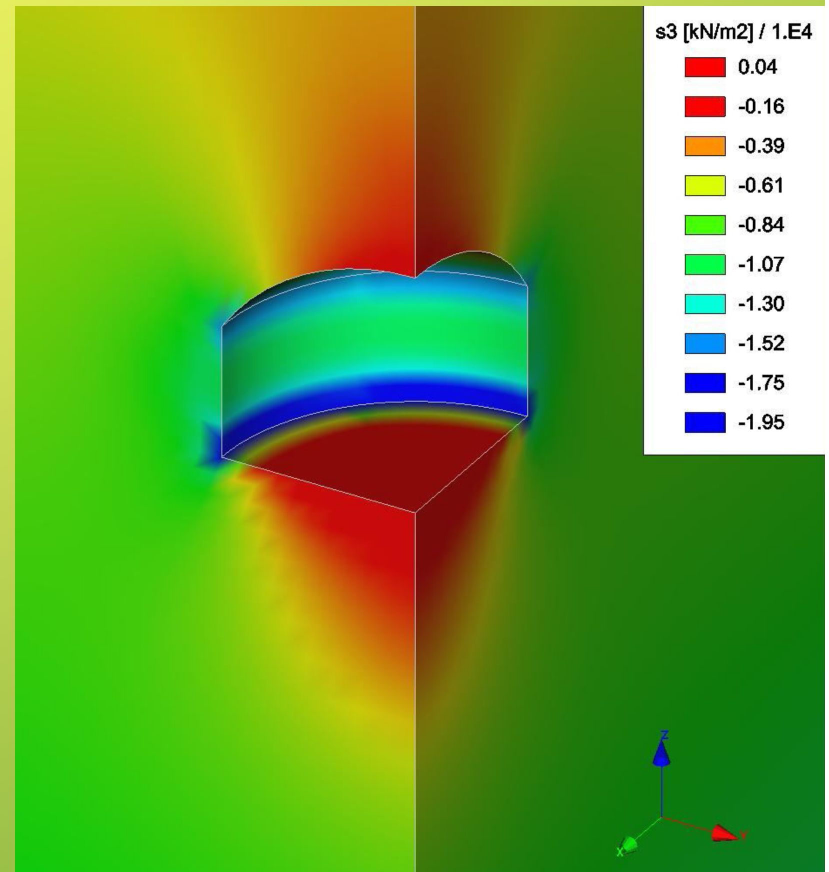
Major principal stresses σ_1, in kN/m^2



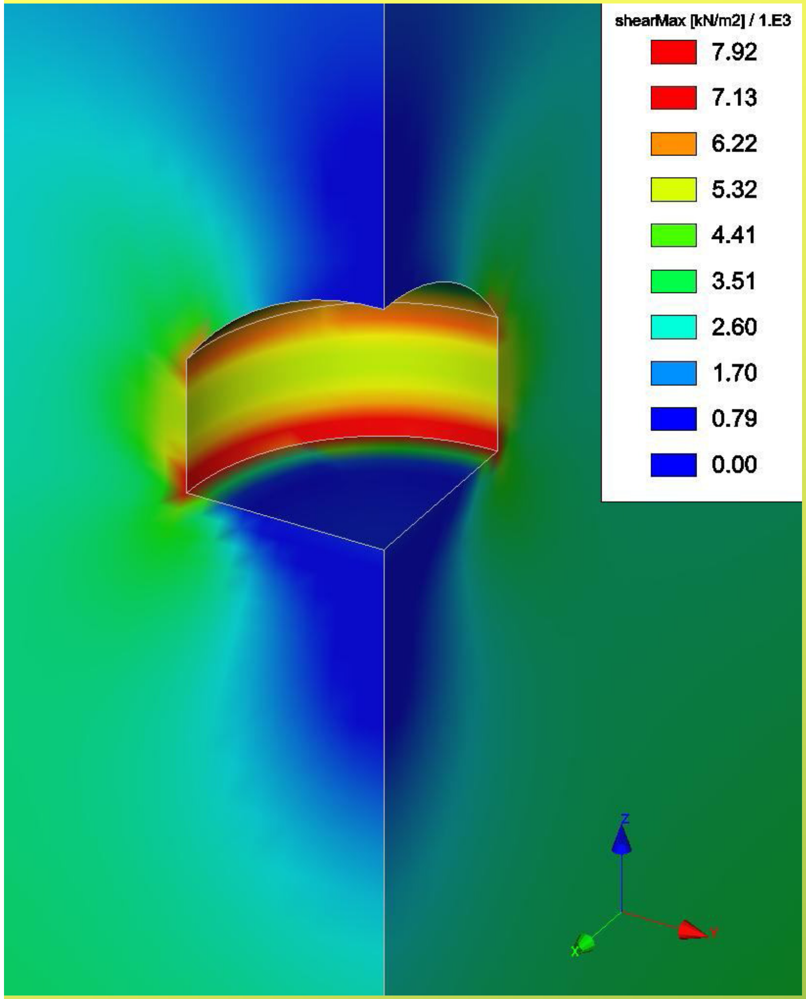


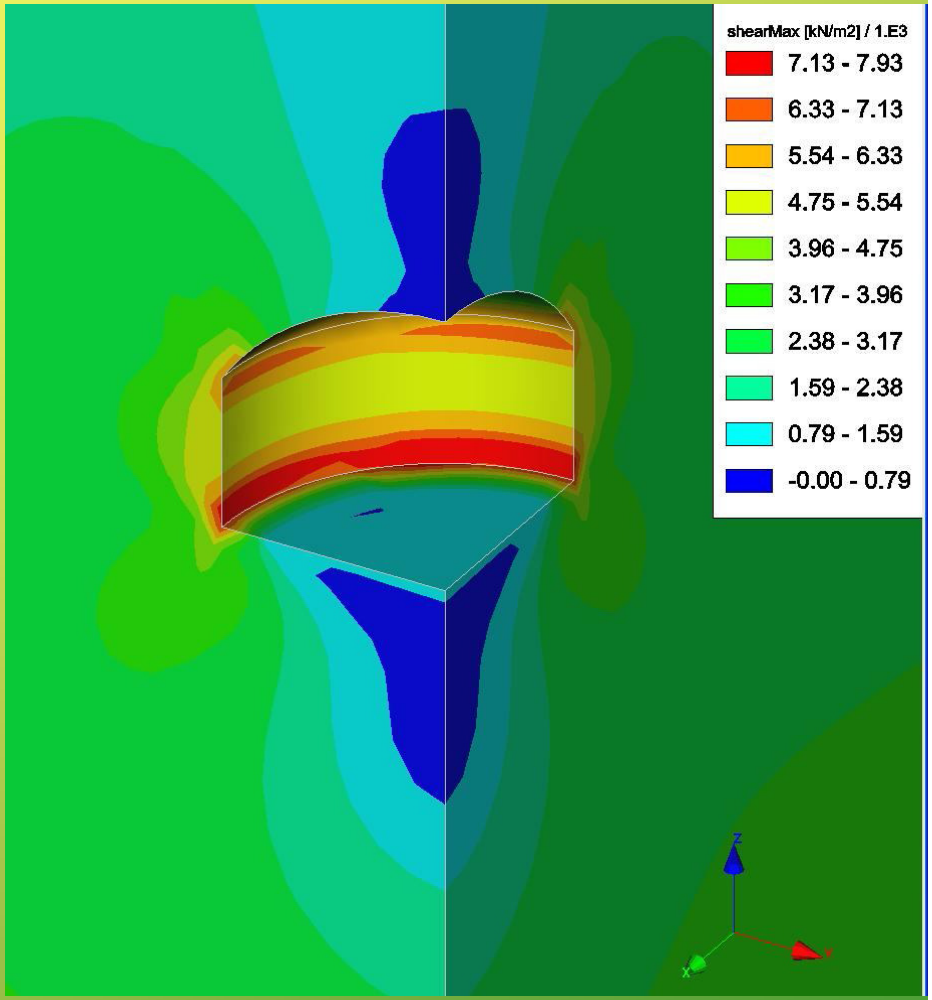
Average principal stresses σ_2, in kN/m^2



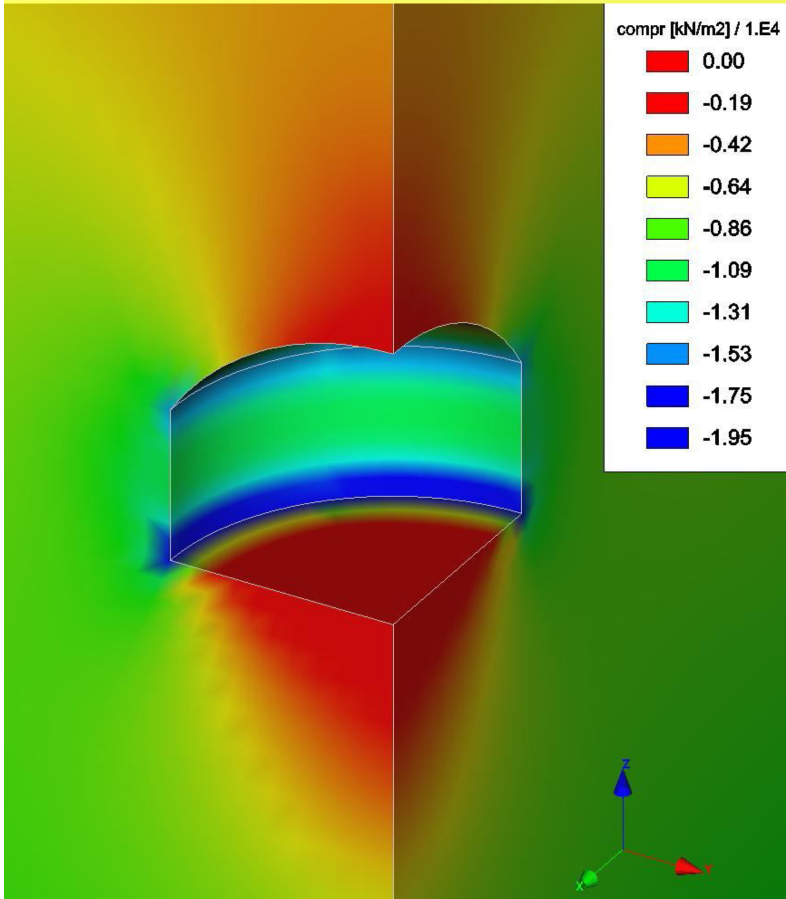


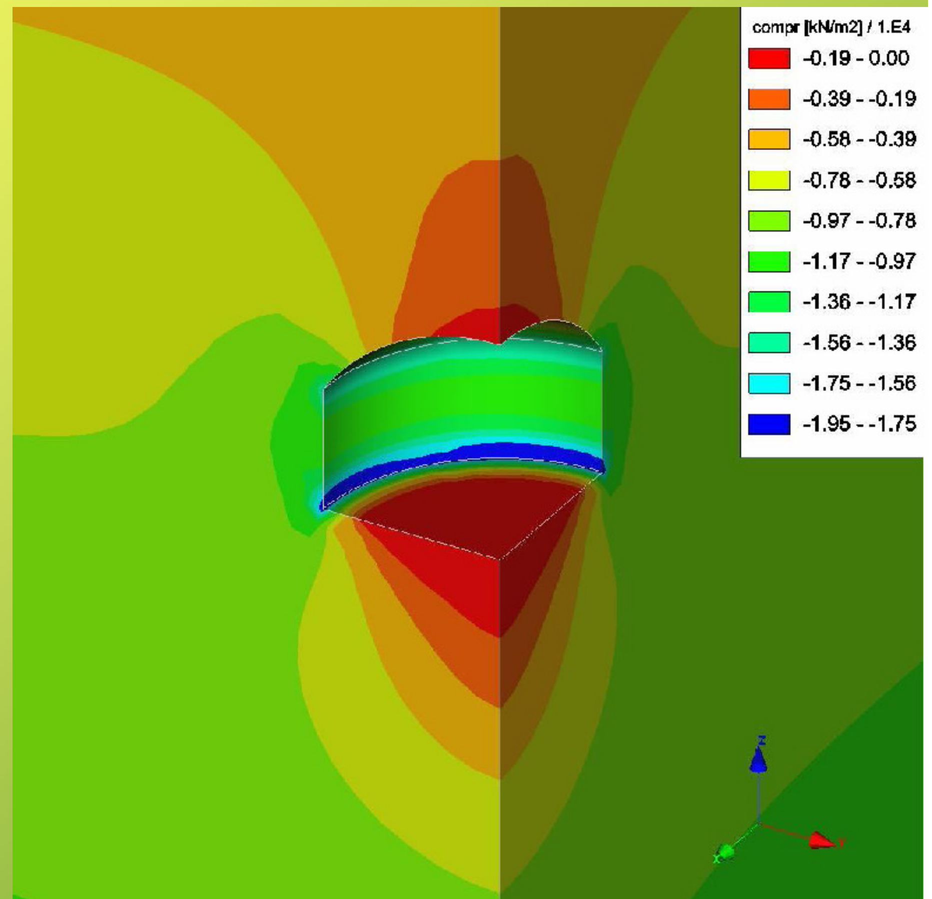
Minor principal stresses σ_3, in kN/m^2





Major shear stresses τ_{max}, in kN/m^2





Compression stresses σ_c, in kN/m^2;

Stability analysis

Excavation walls are subjected to compression stresses, which increases from the vault (-14819 kN/m²) to the floor (-19308 kN/m²), the compression strength value of salt rock (28876 kN/m²). In the walls major shear stresses are developed with highest values near the corners of the vault and the floor, ranging from 7130 to 7930 kN/m², less than the breaking strength of shear salt which is 10500 kN/m². Note that the maximum compression stresses -19308 kN/m², are lower than long-term strength limit, which is 19800 kN/m². Also maximum traction stress is 7930 kN/m², lower than long-term traction strength limit of 11460 kN/m².

Permanent reinforcement

Permanent reinforcement of the cavern from Slanic could be realized from fiberglass anchors with a diameter of 18-20 mm or iron ribbed with Φ 28 mm fixed with synthetic resins, geo-synthetic net for fixing the salt around the cavern, shotcrete for consolidation to avoid the adverse phenomenon which influence the microclimate (air and moisture).

Conclusions

Any salt mine could be a suitable place for an underground laboratory in low radiation background.

The price of the construction without equipments is from thousands to tens of thousands of euros.

By its natural conditions, the Slanic underground laboratory is comparable with the other underground laboratories. The measurements showed a global reduction of the absorbed dose due to natural factors of up to 80 times, which reached a value of $1.2 \div 1.3$ nGy/h, comparable with similar laboratories.

The integral gamma spectrum between 40 and 3MeV was at the laboratory level 1600 times lower compared with the spectrum collected in the open field.

At the same time, the gamma spectrometry unit to be full comparable with other similar laboratories will need a careful selection of supplementary shielding.

Conclusions (continued)

All experimental facts recommend the Slanic-Prahova laboratory, at present time fully operational, as very suitable for various measurements needing low-radiation background.

Experimentally, the water equivalent depth of Slanic Mine was established at:

- ~ 600 mwe (Unirea Mine)
- ~ 750 mwe (Cantacuzino Mine – horizon 12)

The new cavern 100 m below the present excavation could offer a shielding of about 1000 mwe.

The Slanic site is feasible for LAGUNA (GLACIER), either in Unirea salt mine or in a new cavern 100 m bellow Cantacuzino mine.