ASPERA Workshop

The next generation projects in Deep Underground Laboratories

June 30 – July 2, 2011, Zaragoza & Canfranc, Spain

Interdisciplinary research in Underground laboratories

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• Very sensitive detectors measuring ultra-low radioactivity also find applications for environmental and hydro-geological measurements, radiochronology, and the control of the origin of manufactured products.

• The existence of large underground facilities for astroparticle physics is *also* an opportunity to address central questions in other science fields, in particular in modern earth science, biology and engineering.
The subsurface environment is complex, with characteristics that set it apart from other materials. Understanding the coupled thermo-, hydro-, mechanical, chemical and biological properties of rock at depths of a few hundred to several thousand meters or more is increasingly important in a wide range of key studies and applications, from understanding the earthquakes, to understanding the role of underground microbial life in the development of all life.

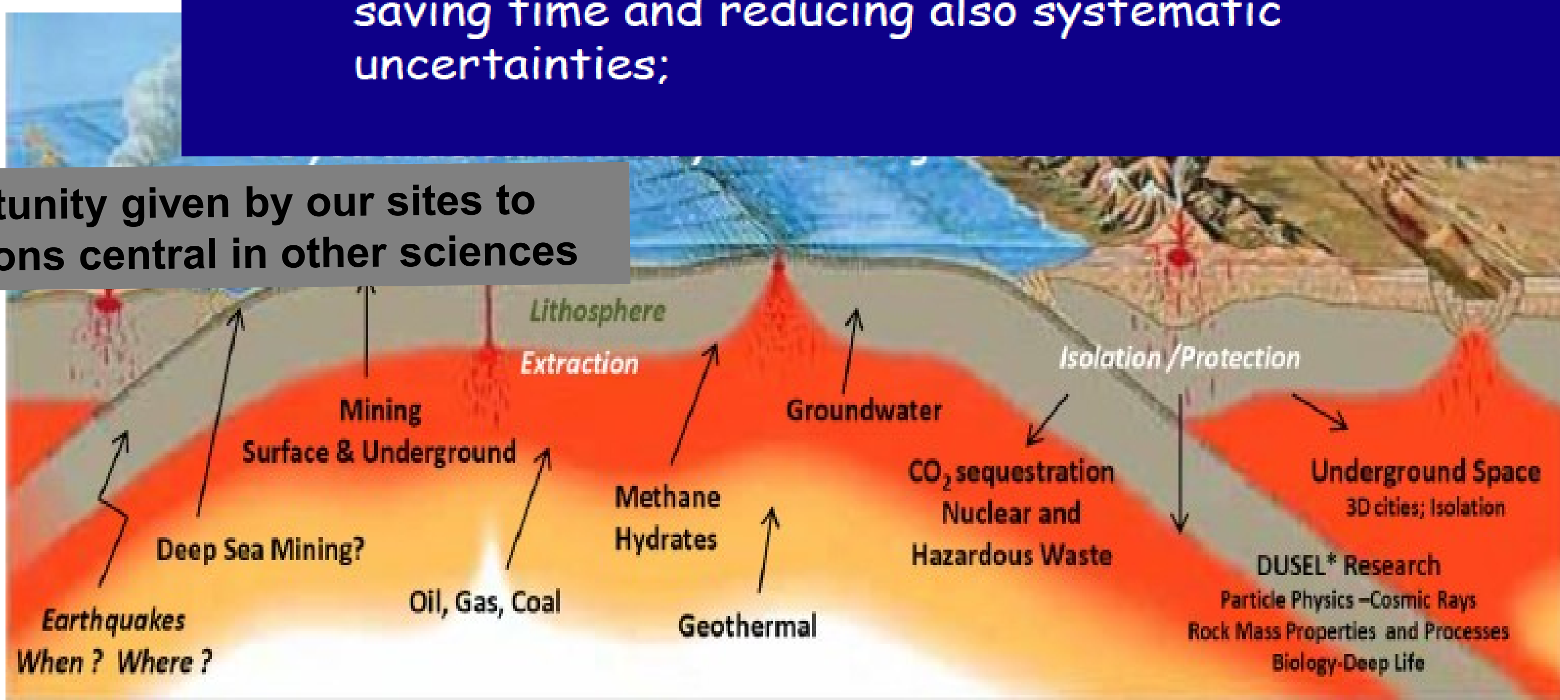
I will report on the present non-astroparticle physics activities in underground laboratories and will discuss the possibility of the future development of these facilities as multidisciplinary platforms.

Applications
of our instruments

Why does one go underground?

- measurements of environmental samples in an ultra low background laboratory are useful, because the data is more robust due to the practically constant very low background level;
- measurements of environmental samples in an ultra low background laboratory can be considered as almost background free reducing systematic uncertainties;
- measurement times can be drastically reduced, saving time and reducing also systematic uncertainties;

Opportunity given by our sites to questions central in other sciences

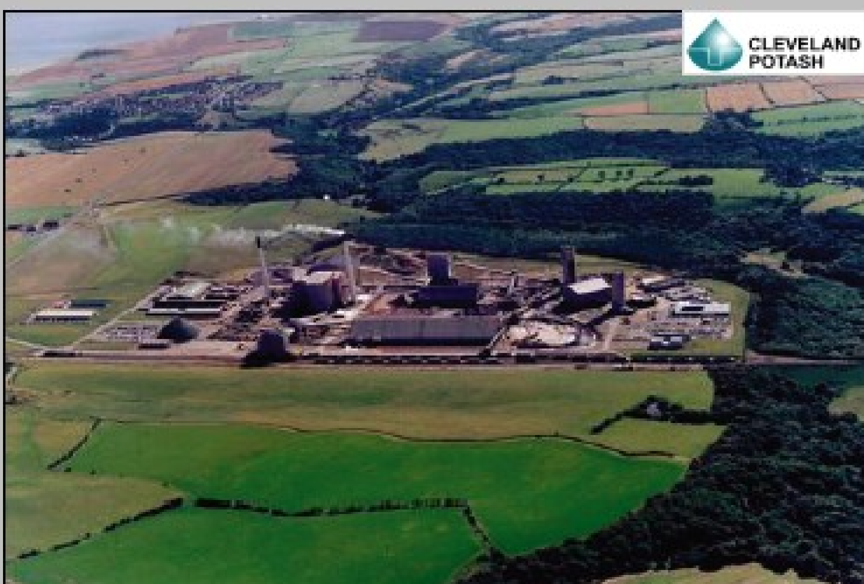


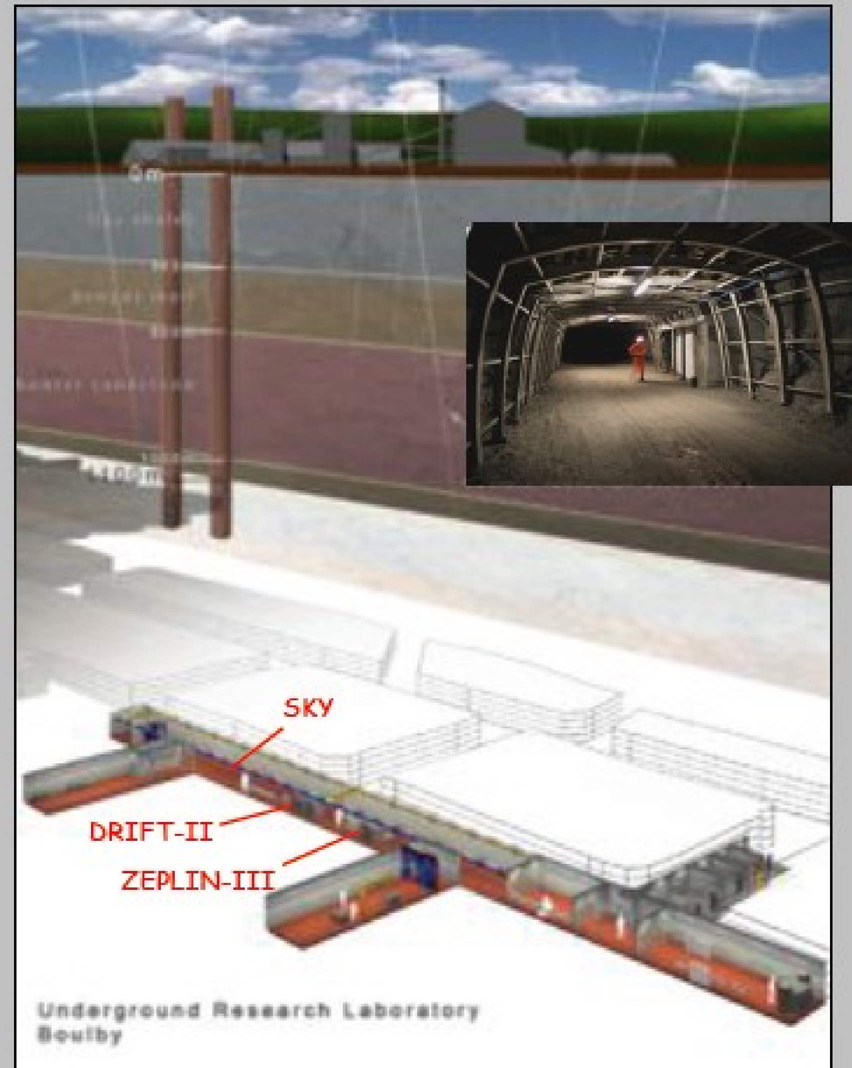
Boulby Underground Laboratory

A working potash and rock-salt mine on the North East coast of England

1100m deep (2805mwe) – **Cosmic ray muon flux reduced by 10^6**

Surrounding Rock Salt naturally low in Uranium & Thorium giving **low gamma, neutron and Radon backgrounds**.





JIF Lab - Opened 2003

Interdisciplinary Science @ Boulby

- **NEW - €850k over 3 years (2011-2014) funding secured specifically to develop inter-disciplinary science at Boulby.**

- ‘Low- background’ interdisciplinary projects...
  - SKY Cosmo-climatology project: Studying the link between atmospheric ionisation, aerosol production and climate.
  - Ultra-low Background Gamma Spectroscopy: Wider exploitation of ultra-low background gamma spectroscopy projects for environmental applications and beyond.

- ‘Other’ deep underground interdisciplinary projects...
  - Extremophiles, geomicrobiology and astrobiology.
  - Carbon capture and storage studies...
  - Muon tomography for geological survey...
  - Etc etc etc...

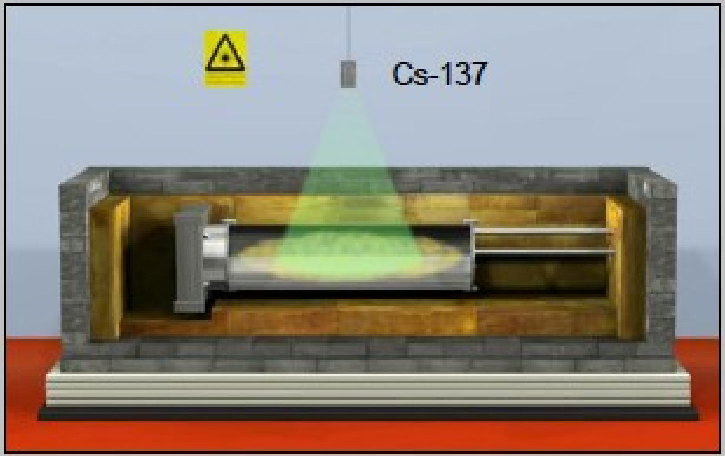
The SKY Project

An Danish/UK (**EPSRC**) study of the effect of ions on aerosol nucleation in the atmosphere - the 1st study in an ultra-low background environment.

Important in climatology: Ionisation from cosmic rays may have an influence on cloud production and mean cloud clover

SKY @ Boulby

Do Cosmic Rays play a role in cloud formation and global climate?



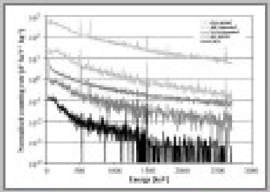
SKY-ZERO: 2008-2010. Primary science runs @ Boulby completed. **1 paper published – 2 more submitted.**

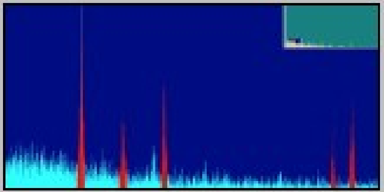
Next steps: A bigger & better SKY experiment (**SKY-PLUS?**) for 2012-2014. **Construction funding already secured**. Wider UK collaboration & funding now being sought.

Participants: Sheffield University, Danish National Space Institute.

Gamma Spectroscopy

Ultra-low background gamma spectrometry for material selection & Environment studies





Deeper = better. At 1.1km below ground at Boulby backgrounds are reduced by a factor **1000**.

Towards a National Ultra-Low Background Facility supporting rare event studies, industry, defense & the environment

Gamma spectrometry for Environmental research:

- Pb210, Si32 dating
- Cs137 in marine waters
- Many more...

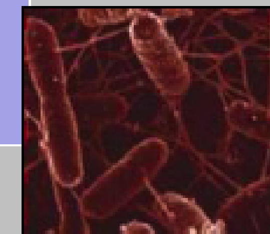
Future plans:

- Continue to development of use of gamma spectroscopy for rare-event studies.
- Engage wider science communities – industry, defence and the environment.
- Towards a national ultra-low background counting facility

Strong support & interest in the UK radio-ecology community

Other Underground Projects

Continuation and expansion of existing interdisciplinary 'Geoscience' projects underway at Boulby...



Geo-microbes

Improved mining technologies
    E.g. enhanced extraction but reduced subsidence?
Rock deformation studies
    E.g. salt deformation and oil reservoirs?
Carbon Capture and Storage (CCS)
    E.g. how can we store waste (e.g. CO_2) underground?
Seismology
    E.g. how does stress change induce earthquakes?
Extremophiles.
    E.g. how do microbes survive in extreme environs?
Geological survey techniques
    E.g. Muon Tomography for survey of geo-structures?

Geochemistry

Rock deformation & subsidence

Carbon Capture & storage (CCS)

Following £1M stage 1 funding received 2009: 18 month Boulby geo-science proof-of-concept study

one NORTH EAST

Durham University

Laboratoire Souterrain de Modane

Depth: **4800 m.w.e.**

Surface: **400 m2**

Volume : **3500 m^3**

Muon flux: **4 10^{-5} $\mu.m^{-2}.s^{-1}$**

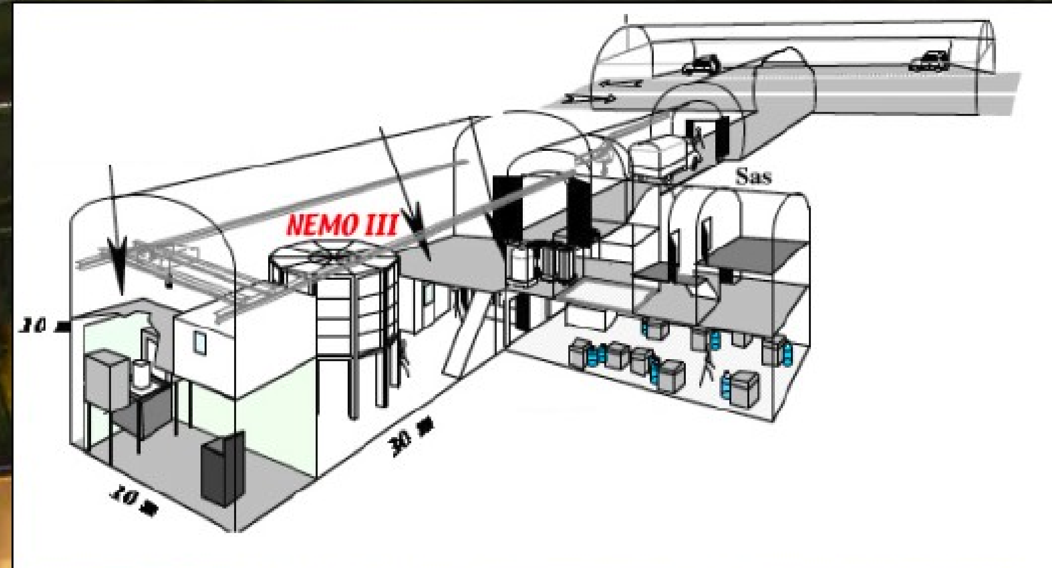
Neutrons:

Fast flux: 4 10^{-2} $n.m^{-2}.s^{-1}$

Thermal flux: 1.6 10^{-2} $n.m^{-2}.s^{-1}$

Radon: **15 Bq/m^3**

Access : **horizontal**



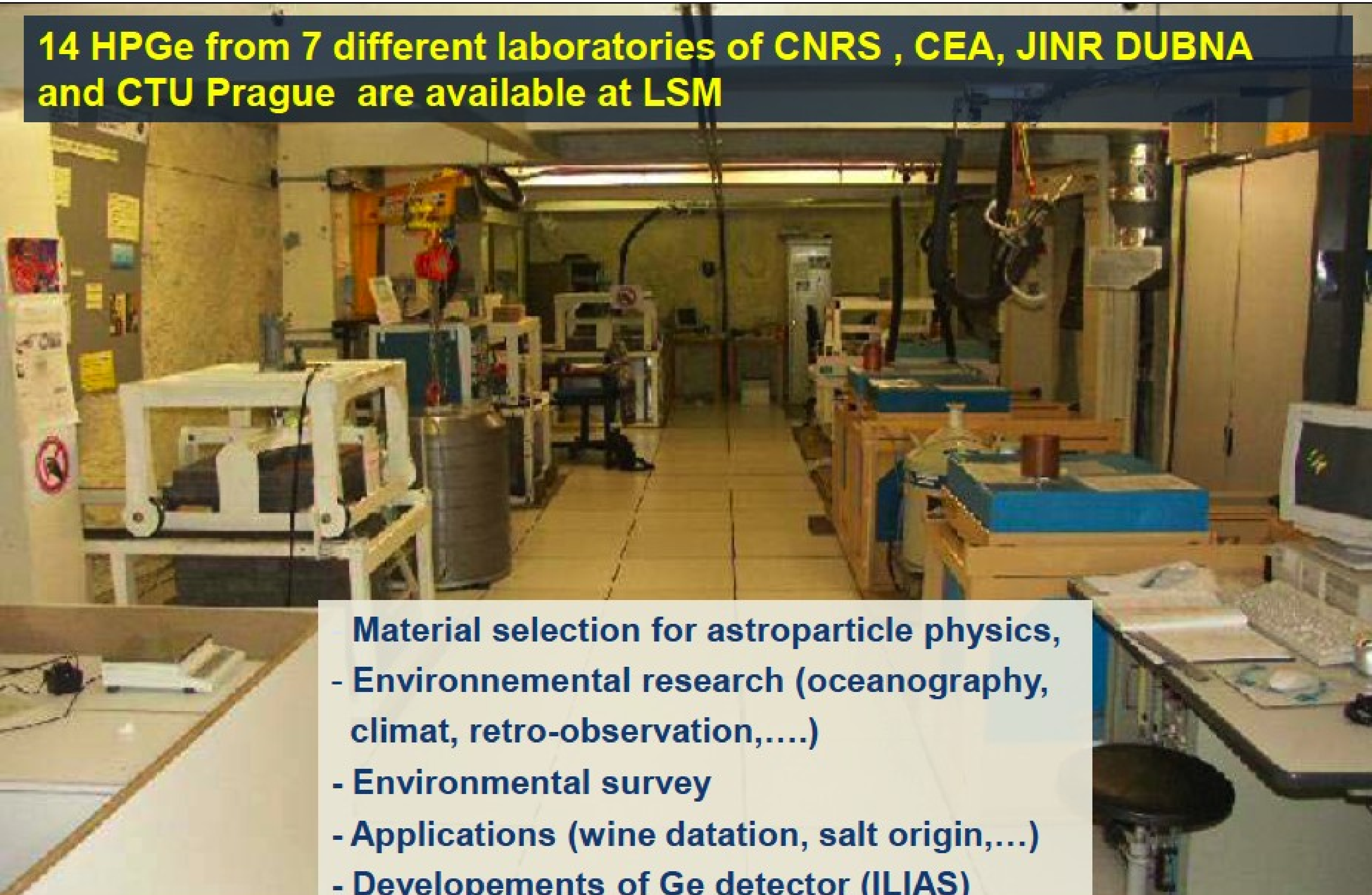
Budget (full cost): **1 M€/yr**

Staff:
- 3 Physicists
- 3 Engineers
- 7 Technicians

International associated laboratory agreement with JINR Dubna (Russia) and CTU Prague (Czech Republic)

Gamma ray spectroscopy @ LSM

14 HPGe from 7 different laboratories of CNRS , CEA, JINR DUBNA and CTU Prague are available at LSM



- Material selection for astroparticle physics,
- Environnemental research (oceanography, climat, retro-observation,….)
- Environmental survey
- Applications (wine datation, salt origin,…)
- Developements of Ge detector (ILIAS)

Interdisciplinary @ LSM

Use of the ulta-low gamma-ray spectroscopy

Radio-isotopes are used as tracers in the environment or as chronometers for dating of glacial or sedimentary layers.

They are used also for archaeological objects which sometimes require non-destructive measurements

Some exemples:

- Environmental survey
- Characterization the age of the suspended solids and pollutants associated with them in rivers
- Marine and continental geochemistry
- Characterization of water masses, their origin and age in the ocean
- Retro-observation (effects on human activities on the environment)
- Radioactivity in the atmosphere

Applications :

- Charaterisation of water (lakes, rivers, underground water) EU directive
- For drug and food administration ex. wine dating, marine salt origin
- Judicial expertises
- Mean age of crustacean livestock for fishing regulation
- ......

Developemnt of a national ultra-low radioactivity platform measurements with

EDYTEM (University of Savoie/CNRS), LGGE (University of Grenoble / CNRS), LSCE (CNRS/CEA), LPSC (University of Grenoble / CNRS) and LSM

The scientific and societal usefulness of recent (< 250 years) Alpine lake sediment studies

An overview on LSM – Université de Savoie joint scientific progresses in paleolimnology

Fabien Arnaud
Charline Giguet-Covex
Bruno Wilhelm

Jean-Louis Reyss

Marie-Elodie Perga

Laboratoire EDYTEM
Environnements, Dynamiques et Territoires de la Montagne

LSCE

CARRTEL
Centre Alpin de Recherche sur les Réseaux Trophiques et Ecosystèmes Limniques

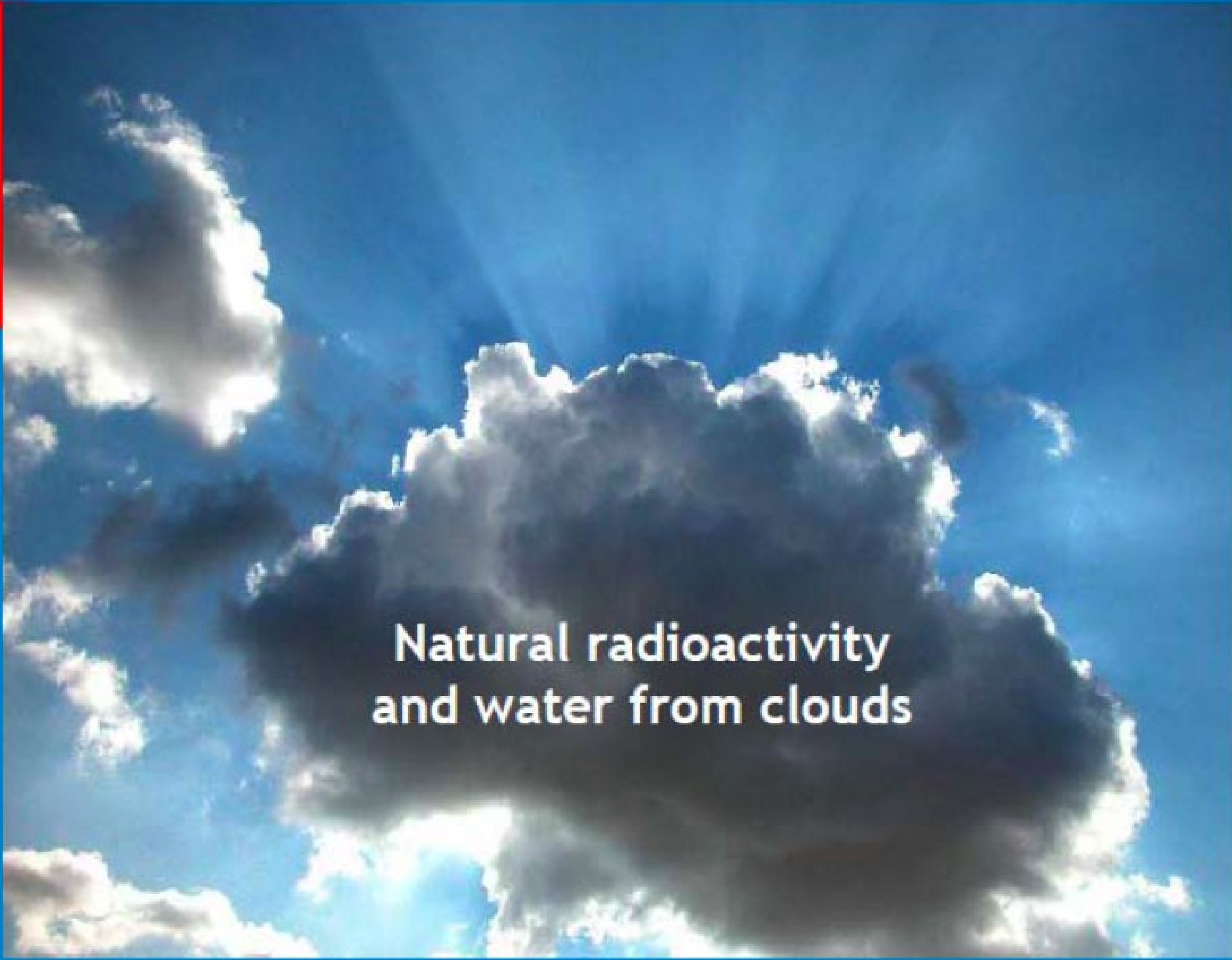
Current global changes are hard to assess due to lack in monitoring data

Lake sediment may have archived some environmental variables (climate, trophic state, pollutant inputs, erosion etc.)

Their study may thus bring useful information to evaluate the effect of past land-use and the efficiency of management policies

From a scientific point of view, such a “retro-observation” is crucial to assess the intensity and kinetics of global changes compared to a measured (i.e. non-hypothetical) “reference state”

IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE



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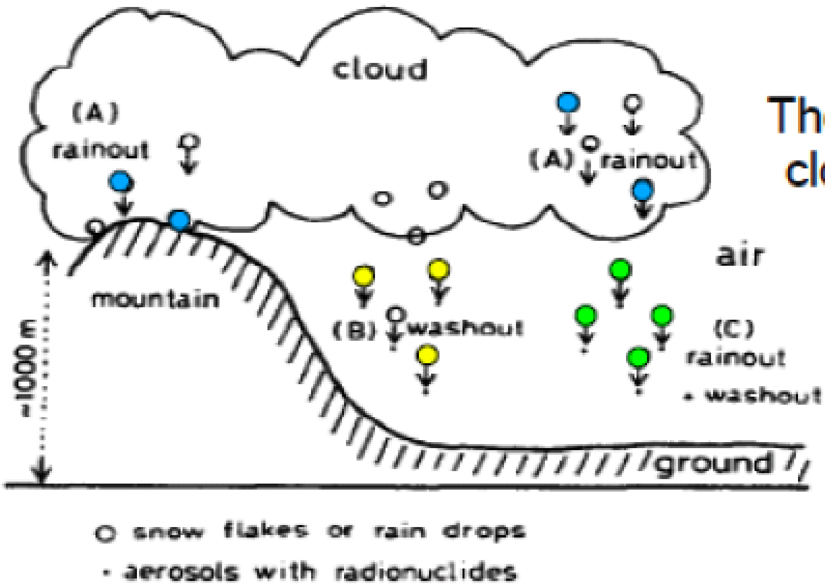
As part of its mission of environmental monitoring, IRSN carries out studies on the environmental processes that can explain the transfer and the evolution in time of natural and artificial radionuclides present in the atmosphere

The process of leaching of aerosols can explain 90% deposition of radionuclides in the event of accidental release into the atmosphere

Scavenging of radionuclides in air



These processes are carried out under the cloud but also <u>in</u> the cloud and are called the wash ("rainout")

Given their size, collection efficiency is 10 to 100 times greater for droplets in the cloud as raindrops that precipitate,

Intra-cloud washing accounts for 25% of total wet deposition from an altitude> 800 m (Lange, 2003)

The IRSN has instruments to collect cloud water at the station's scientific study of the atmosphere at the summit of the Puy de Dome (OPGC / Laboratoire de Météorologie Physique)

The volumes collected are very low (few tens of milliliters or less).

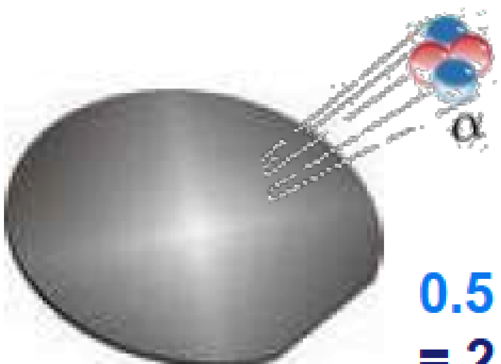
After evaporation, the solids content is set for a measurement geometry XXL long in the detector wells installed at the IRSN LSM

The level of artificial radionuclides in the water droplets in clouds are sampled equivalents (a few mBq / l) to those obtained in rainwater collected in plain

Soft-Error Rate (SER) Characterization of SRAM circuits induced by alpha-particle emitter contamination

IM2NP-CNRS laboratory has conducted since 2007 a series of underground experiments to quantify the importance of alpha-particle emitter contamination in advanced SRAM memories

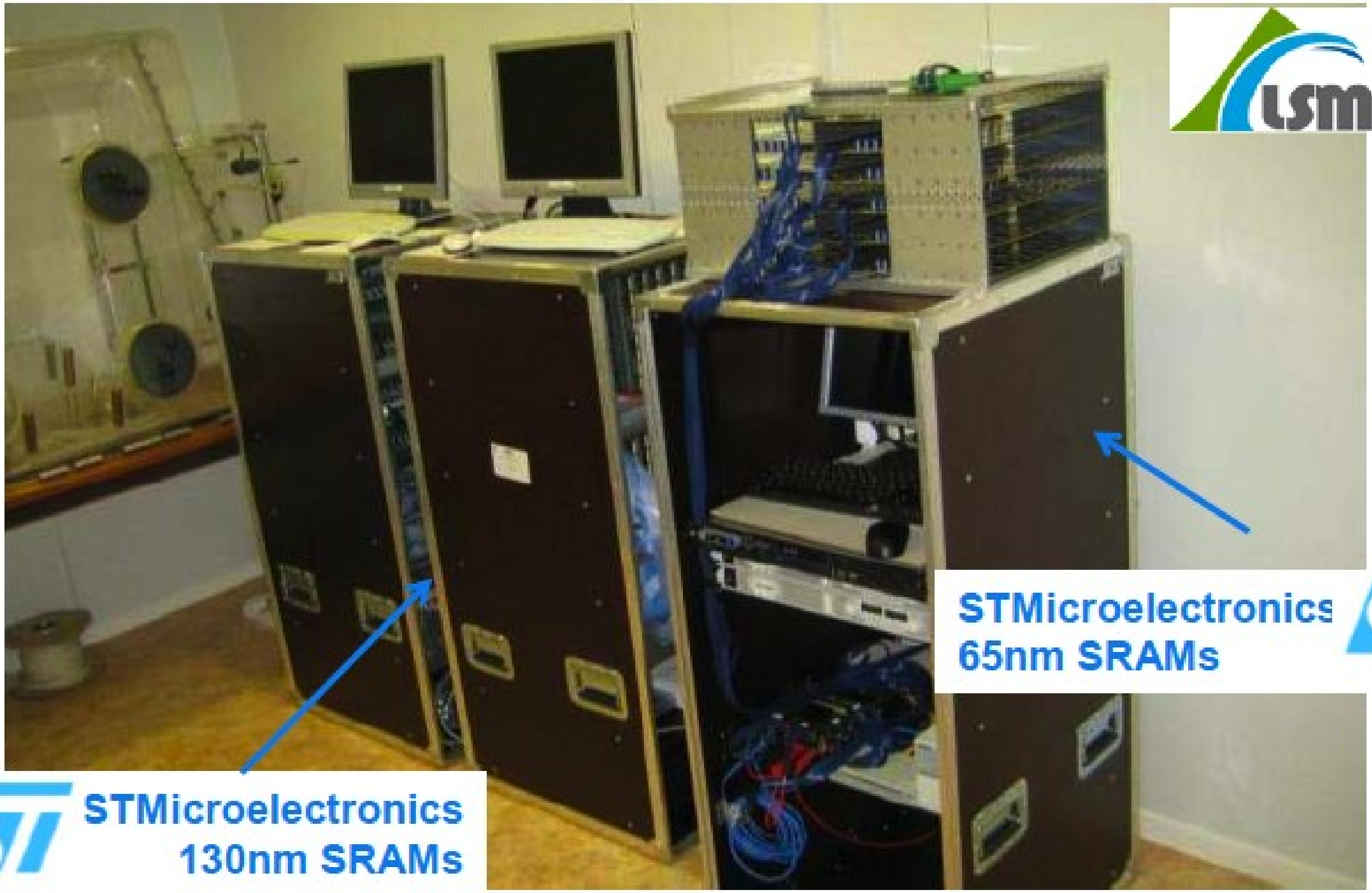
Silicon wafers, ceramic packages and contact bumps are contaminated with Uranium and Thorium elements at ppb concentration levels



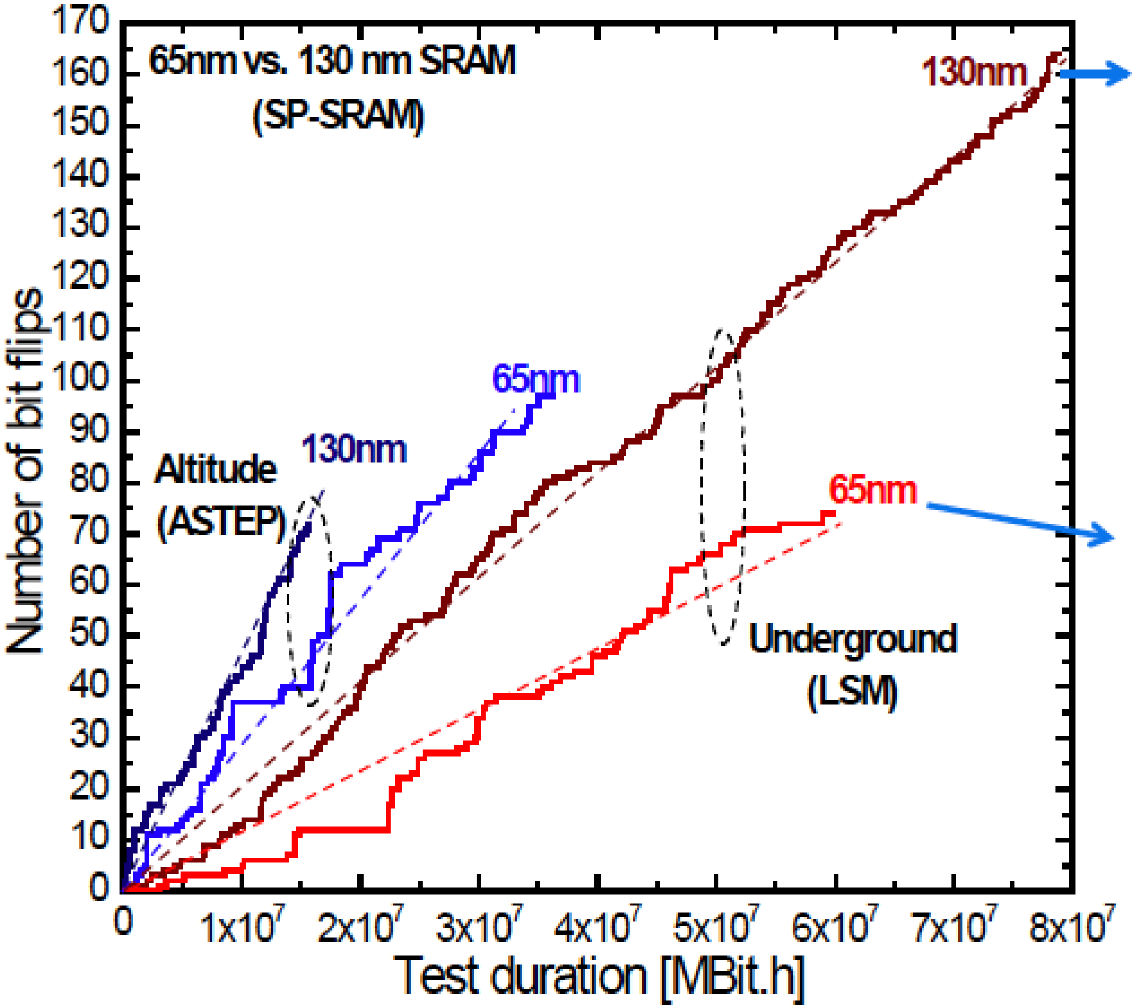
0.5 ppb of ^{238}U in Silicon
= 425 Bq/m^3
= 0.18 Bq/kg

0.5 ppb of ^{238}U in Silicon
= 2.28×10^{-3} α/cm^2/h

- **Real-time experiments** : ***long-term (several months) exposure of a large amount (Gbits) of circuits to the natural radiation environment***
- ***Underground**: to remove the atmospheric neutron contribution (observed soft-errors are expected to be due to alpha particles)***



Underground results for 130nm and 65nm SRAM technologies

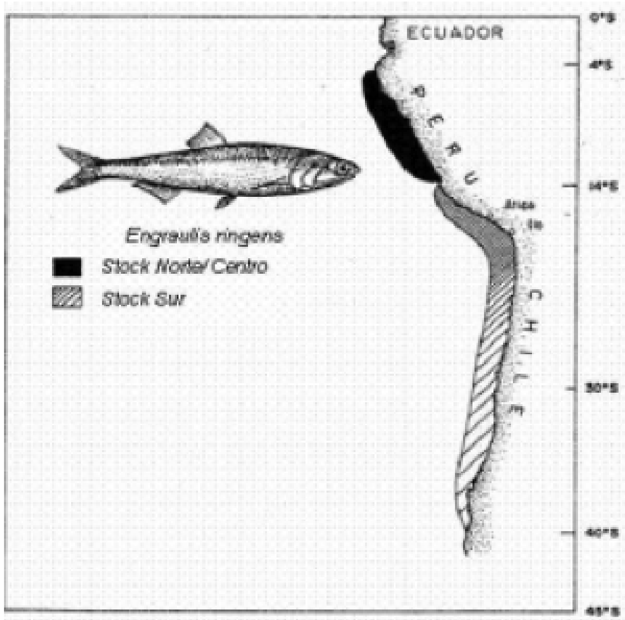


$4\ 10^{-3}\ \alpha/cm^2/h$

$9\ 10^{-4}\ \alpha/cm^2/h$

= result of a substantive work performed at technological process integration level (elimination of some materials subjected to alpha emitter contamination).

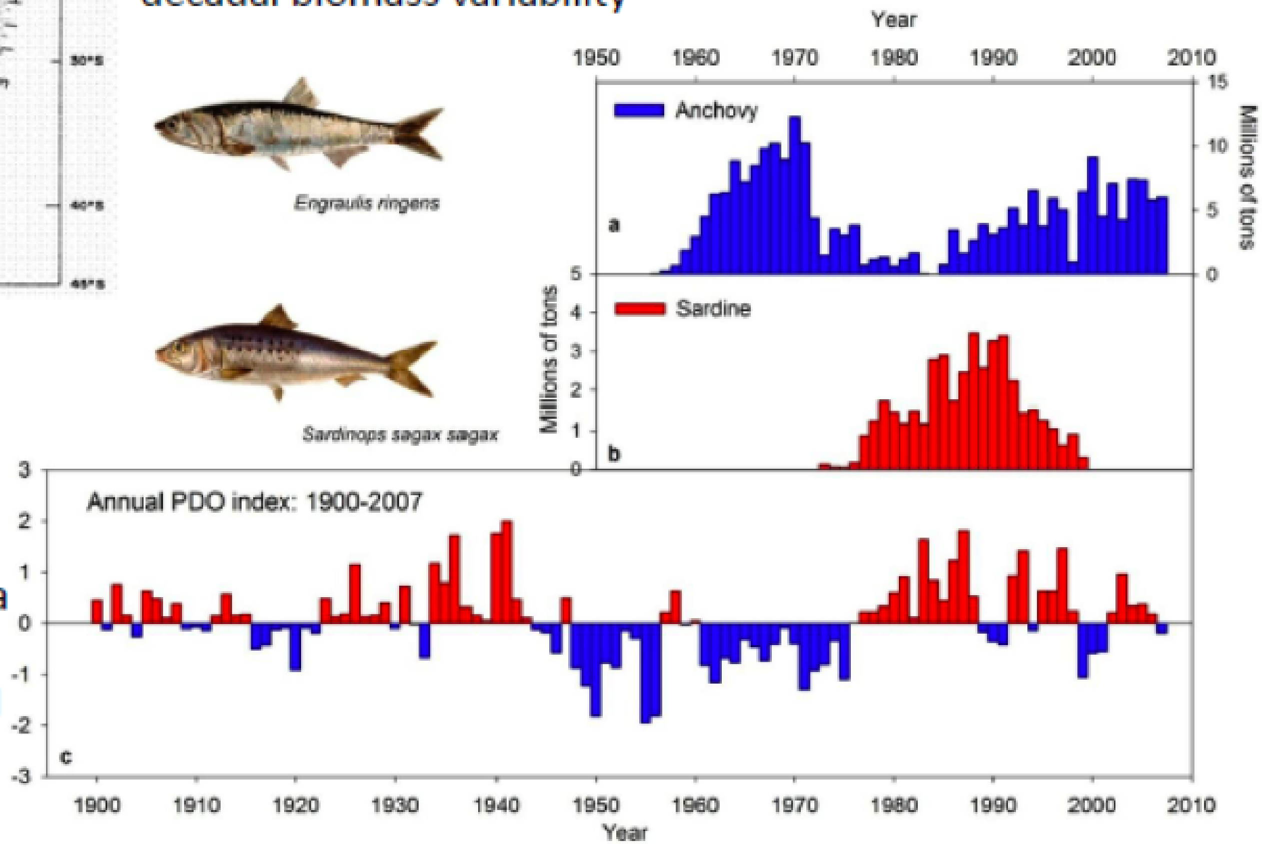
The Humboldt Upwelling Ecosystem is characterized by strong ENSO variability and the highest pelagic fish productivity



-Continuous coastal upwelling throughout the year

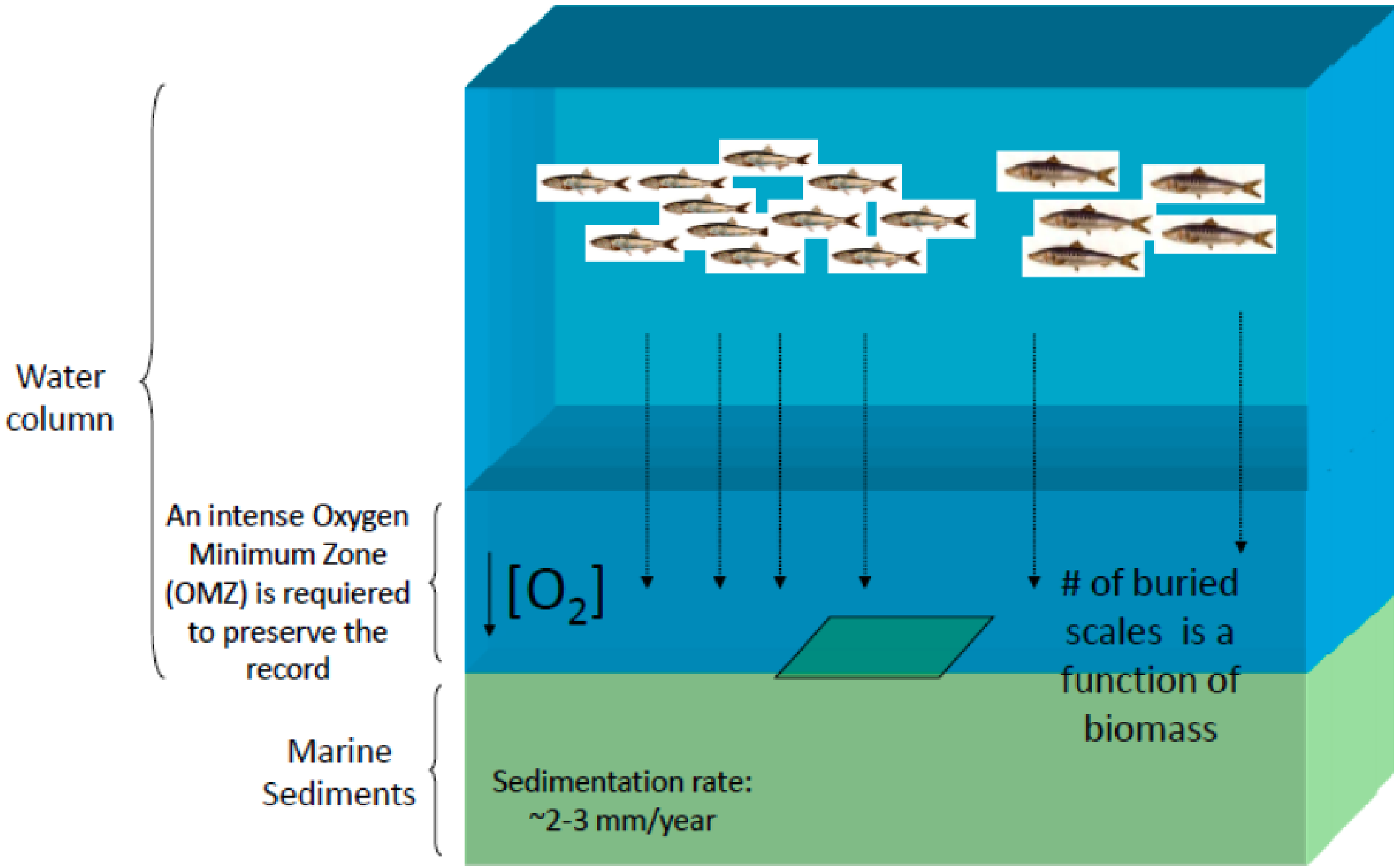
-The northern Humboldt Current System off Peru presently produces about 10% of the world fish catch based primarily on anchovy.

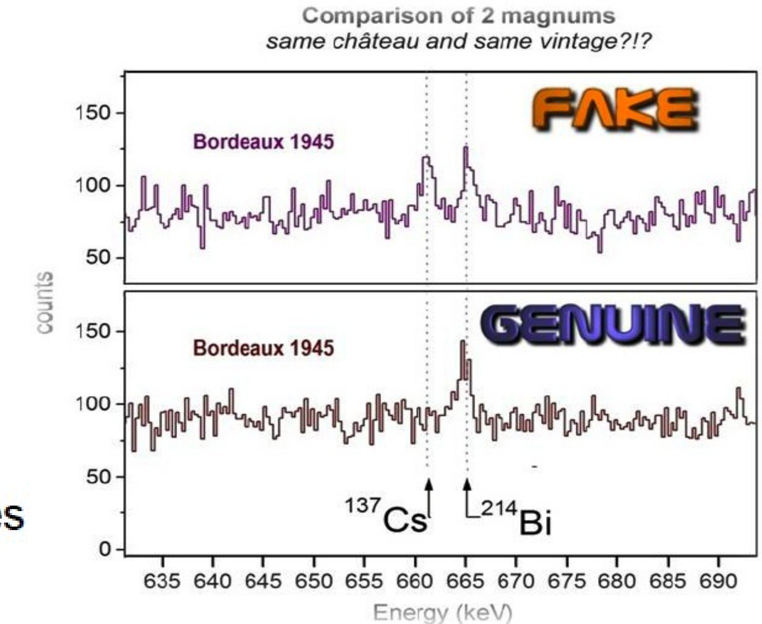
-Anchovy and sardine landings show strong annual and decadal biomass variability



The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period).

Fish scales buried in marine laminated sediments can provide a record of populatior variability of small pelagic fishes prior to the development of the fisheries





Wine datation by 137Cs measurement

Developed by Ph. Hubert (Centre d'etudes Nucleaires

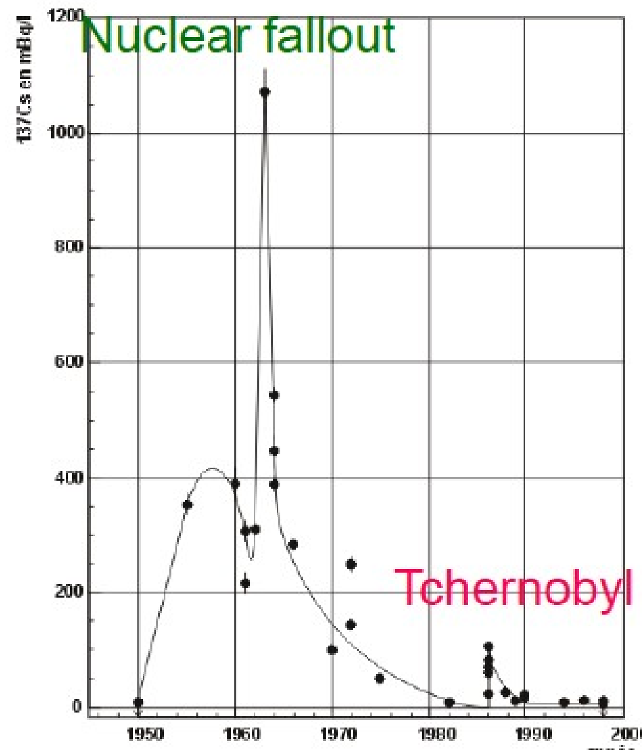
Châteaux

"Lafite"

&

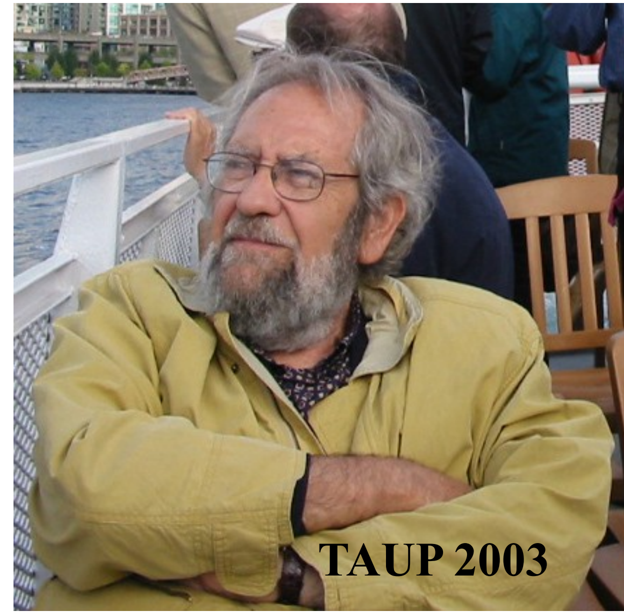
"Margaux"

1900 ?



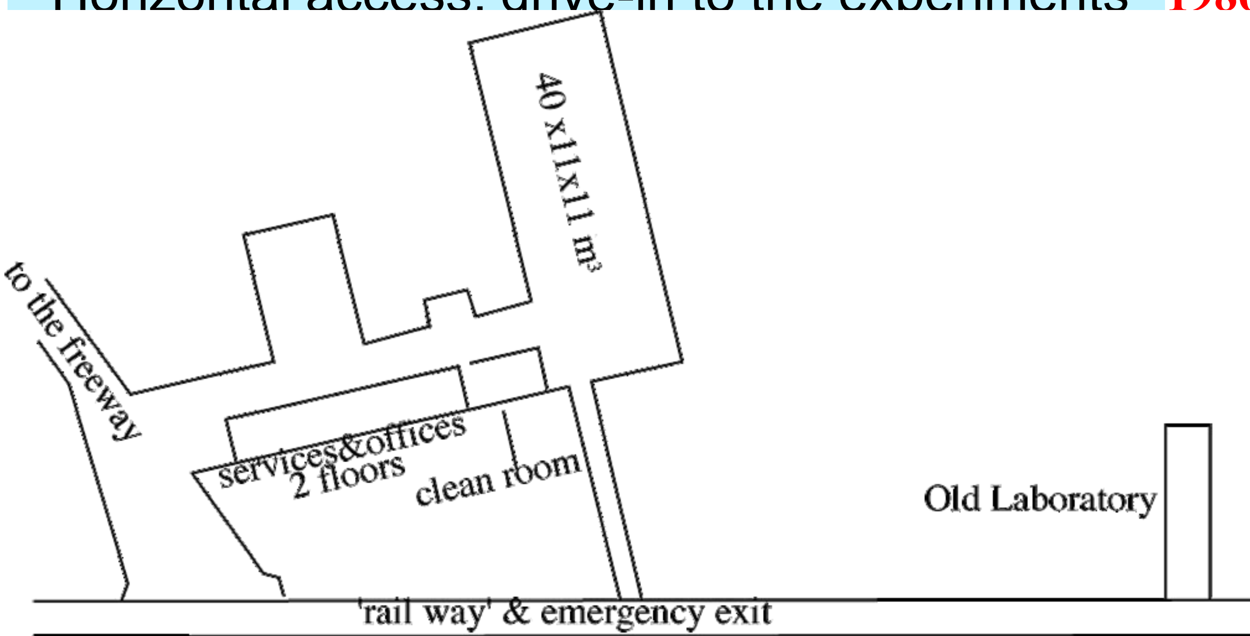
Laboratorio Subterraneo de Canfranc. LSC

- 850 m rock overburden (2.4 km w.e.)
- Neutron flux = 2×10^{-2} $m^{-2}s^{-1}$
- μ flux = 2-4 $\times$ 10^{-3} $m^{-2}s^{-1}$ (site dependent)
- γ flux= $1.9\pm0.2 \times 10^{4}$ $m^{-2}s^{-1}$
- Radon 50-80 Bq/m^3
- Ventilation: 11 000 m^3/h (one volume in 40')
- Underground area 1000 m^2
- Support facilities on the surface under construction
- Scientific programme being defined
- Horizontal access, drive-in to the experiments



1986 A. Morales creates the first
ranc Laboratory (≈100 m^2)
: to a non-used railway tunnel

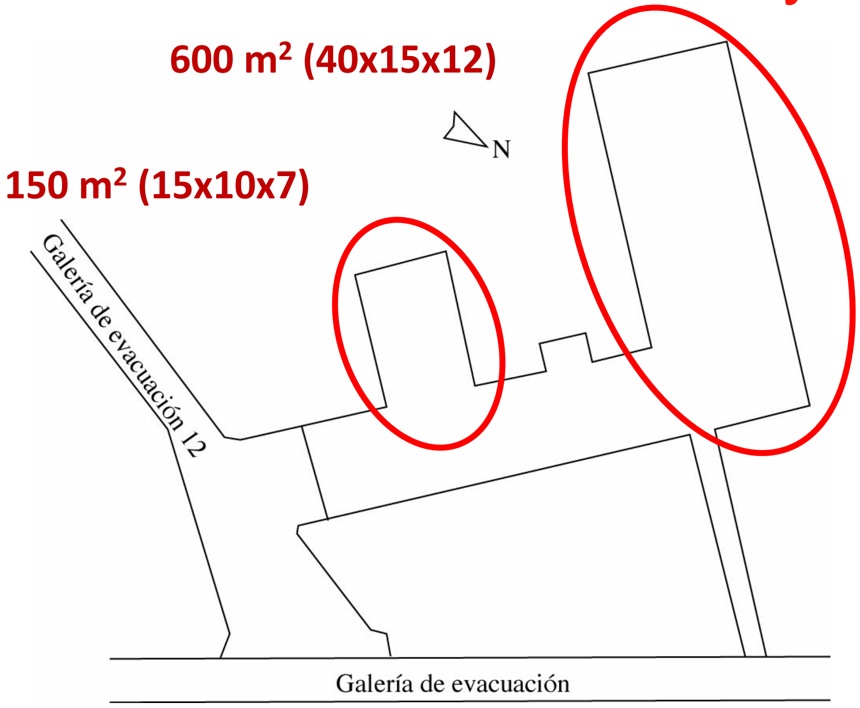
Morales compeltes the new
atory between the new free
tunnel and the railway tunnel



ld lab (since 1986)
NAIS. DM. Modulation with NaI
OSEBUD. DM. R&D for EURECA
ther R&D, low radioactivity
ieasurements

CANFRANC Experimental halls A, B

Ready July 2010

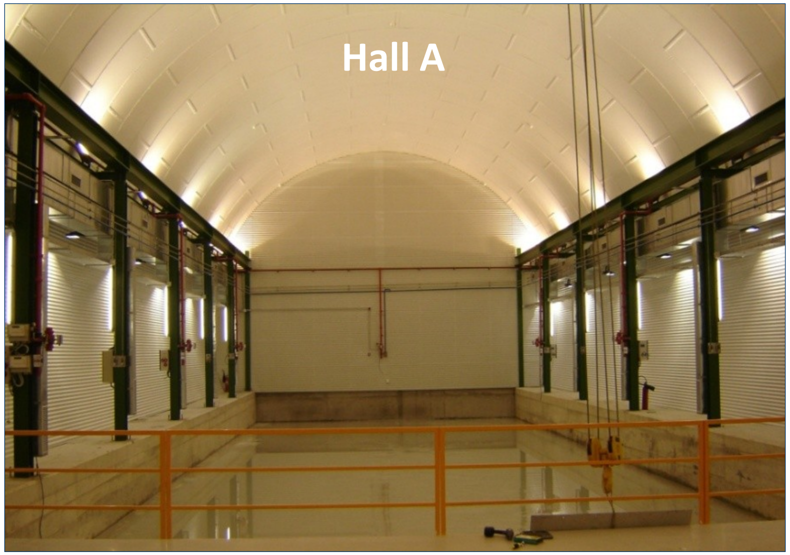


Depth: 800 m, access horizontal

Muons: 0.47 x 10^{-2} m^{-2} s^{-1}

Neutrons: 2×10^{-2} m^{-2} s^{-1}

Radon: 50-80 Bq/m^3



GEODYN: A Geodynamic Observational Facility in the Canfranc Laboratory

The facility is proposed to consist of :
-a two-component strain-meter to measure small scale deformation over distances of 100 m inside the Earth

-a broad band seismometer, which will measure data at low noise and of unusually high quality

- a seismic accelerometer for measuring strong-motion
two GPS stations, which will be continuously recording surface movement, which can be correlated to the strain measurements and the local seismic activity.

The facility will be a high-class observatory for five study themes:

1. Measurement of seismic phase velocities, which holds the potential of widening our understanding of how seismic waves actually propagate in the real Earth

2. Slow earthquakes, a challenging aspect with broad perspectives, not least seem in relation to the recent discovery of similar type of earthquakes from fast moving glaciers.

3. Strain seasonal changes. Related to new high quality measurements of Earth gravity changes from satellite, this aspect may further the understanding of the processes responsible for the temporal changes in gravity, of utmost importance for studies of the water resources on Earth.

4. Tectonic deformation. The continuous real time recording of in-situ deformation inside the Pyrenean orogen and coincident, continuous real-time measurement of the surface deformation may provide significant data for understanding the processes related to orogenic deformation. The installation of continuous GPS instruments at the surface will provide link between the small scale deformation inside the crust and the movement of the Earth's surface. The outcome of these studies will undoubtedly provide background for significant contributions to TopoEurope, which presently is the major European Earth Science programme.

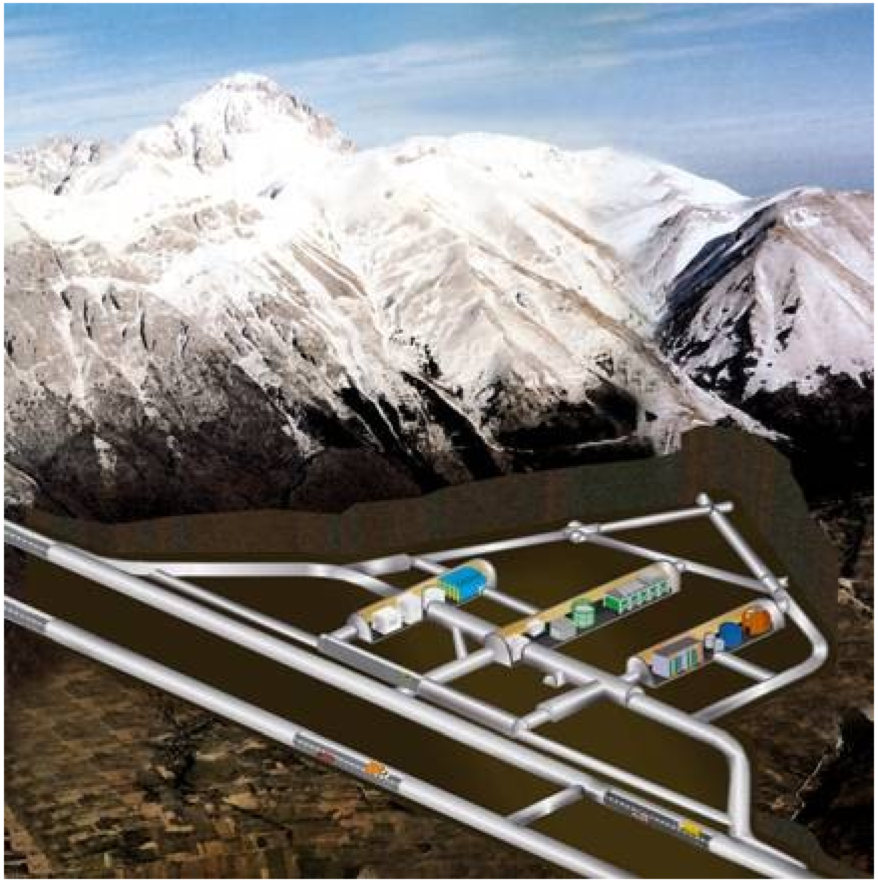
5. Strong motion studies are most often carried out after the recoding of major earthquakes. Here the recordings will be made throughout the whole sequence of a seismic event, and supplemented by information on actual deformation in the crust.

LNGS: the world largest underground laboratory

Laboratori Nazionali del Gran Sasso

Broad Research activities

- Neutrino physics
- Dark matter
- Nuclear reactions of astrophysics interest
- Fundamental Physics
- Geophysics
- Biology



- Opening: 1987
- 1400 m rock coverage
- Muon flux = 3.0×10^{-4} s^{-1} m^{-2}
- Neutron flux = 3.8±0.3 10–2 m–2s–1
- Experimental Area = 3 halls 17300 m^{2}; Volume 180 000 m3, ISO 14001
- Access: horizontal through the highway tunnel
- γ flux= 1 10^4 m–2s^{-1}
- Ventilation: 1 lab volume/3 h
- Radon in air 50-120 Bq/m3 (less @ experiments)
- The largest international scientific community
- Permanent staff = 80 permanent +23

Roman lead for CUORE @LNGS

- **120 ingots of Roman Lead (4 tons)**

from an ancient ship that sunk off the Sardinia coast have arrived in LNGS and are safely installed underground. With the previous 170 they are sufficient for the internal shield of CUORE.

- *Borexino and geo-antineutrinos*
- *Low background γ spectroscopy facility:*

  STELLA = SubTErranean Low Level Assay
- *Environmental Radioactivity Monitoring for Earth Sciences @ LNGS*
- *The Gran Sasso geodetic interferometers*

Geo-ν: a unique direct probe of the Earth interior

The radioactive isotopes inside the Earth generate heat.

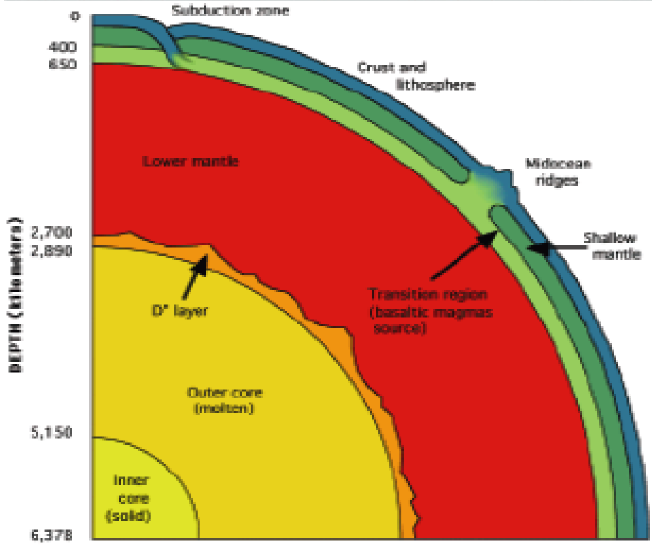
The Earth shines in anti-ν

$^{238}U \rightarrow {}^{206}Pb + 8\,\alpha + 8\,e^- + 6\,\bar{\nu}_e + 51.7$ MeV

$^{232}Th \rightarrow {}^{208}Pb + 6\,\alpha + 4\,e^- + 4\,\bar{\nu}_e + 42.8$ MeV

$^{40}K \rightarrow {}^{40}Ca + e^- + 1\,\bar{\nu}_e + 1.32$ MeV

Earth structure



Only two detectors (Kamland,Borexino) are presently able to detect Geo- ν

Relevance of geoneutrinos study: A new probe of the Earth interior

The movement of the heat within the Earth is central in the theory of plate tectonics

- *What is radiogenic contribution to the Earth energy budget (50%??)?*

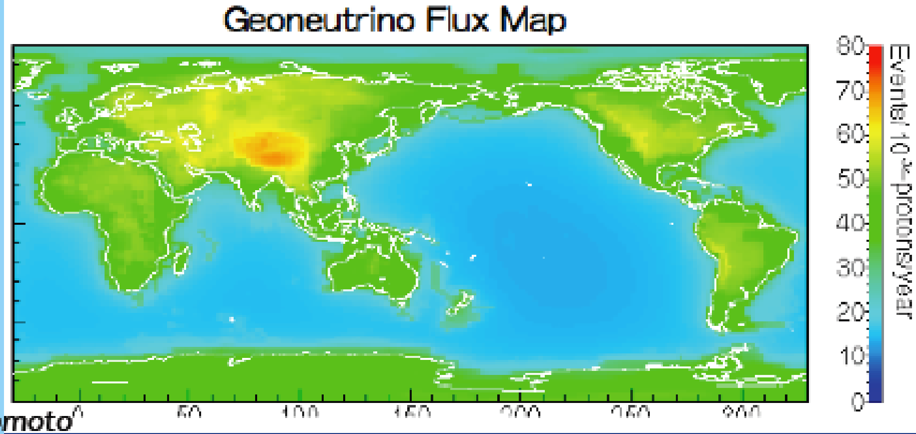
- *What is the distribution of the radiogenic elements?*

• *How much in the crust and how much in the mantle?*

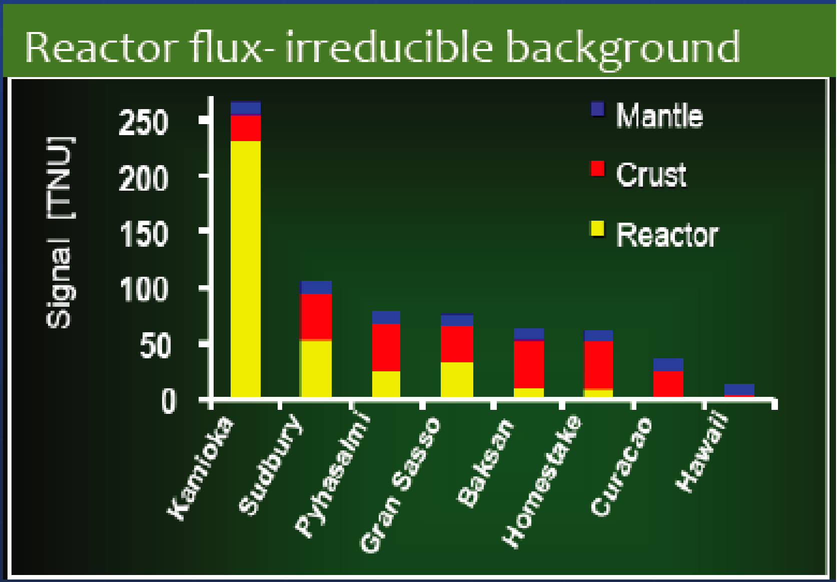
Geo-ν: expected fluxes

Flux not omogeneous
Strong contribution from local geology
Geoneutrino community needs regional models based on:

- **γ-ray spectroscopy (surface)**
- **seismology + geochemistry (wholecrust)**
- **Heat flow (whole crust)**



Enomoto



Mantovani (TAUP 2007)

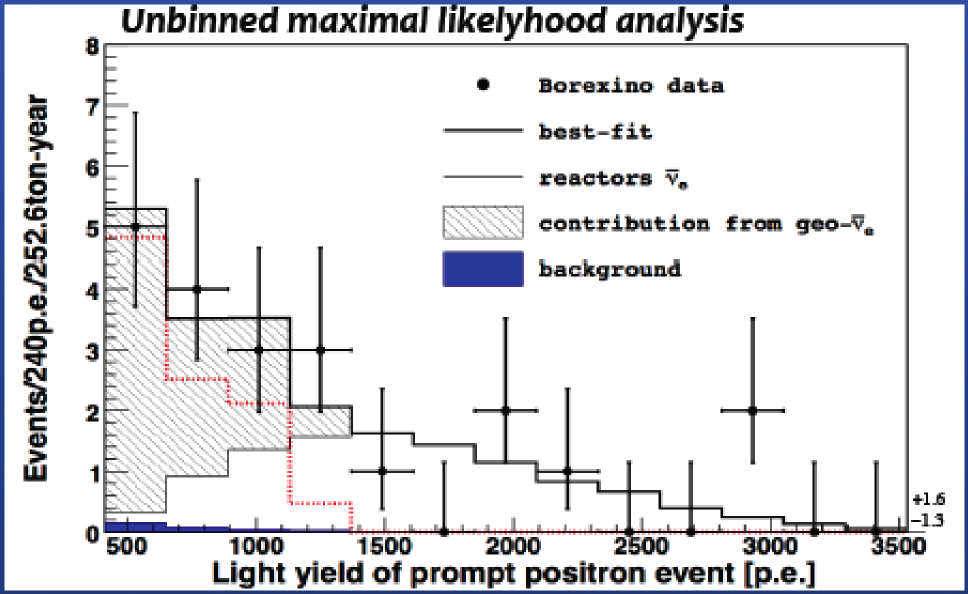
Need of multi-site measurements
-Continental sites (Borexino,Kamland, SNO+…)
- Oceanic site (Hanohano???)

Borexino:

- ✓ Low intrisic radioactivity;
- ✓ Far from reactor plants;
- ✓ Underground site: $\Phi(\mu)$ reduced by ~ 10^6.

Geo-ν: the observation of the geo-ν signal

BOREXINO



Our best estimates are:

$$N_{geo} = 9.9^{+4.1}_{-3.4}\ {}^{+14.6}_{-8.2}$$

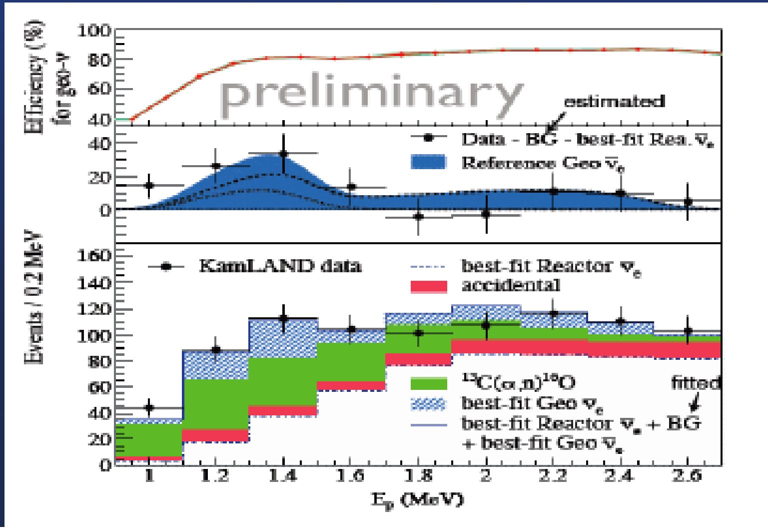
$$N_{react} = 10.7^{+4.3}_{-3.4}\ {}^{+15.8}_{-8.0}$$

@ 99.73% C.L

@ 68.3% C.L

Null geo-ν hypothesis rejected at 4.2 σ

Background in the geo-ν energy window: 0.31 ± 0.05



KAMLAND 2010

S/B ≈ 4:1 in Borex

S/B ≈ 1:7 in Kamland

STELLA

low background γ spectroscopy Facility

- Underground experiments aim to detect very weak processes and very rare events.
- They have to fight against background of different origin.
  - cosmic radiation
  - particles of nuclear decays
  - intrinsic natural radioactivity

low background γ spectroscopy @ L.N.G.S.

STELLA = SubTErranean Low Level Assay

Why does one go underground?

- measurements of environmental samples in an ultra low background laboratory are useful, because the data is more robust due to the practically constant very low background level;
- measurements of environmental samples in an ultra low background laboratory can be considered as almost background free reducing systematic uncertainties;
- measurement times can be drastically reduced, saving time and reducing also systematic uncertainties;

Examples of activities

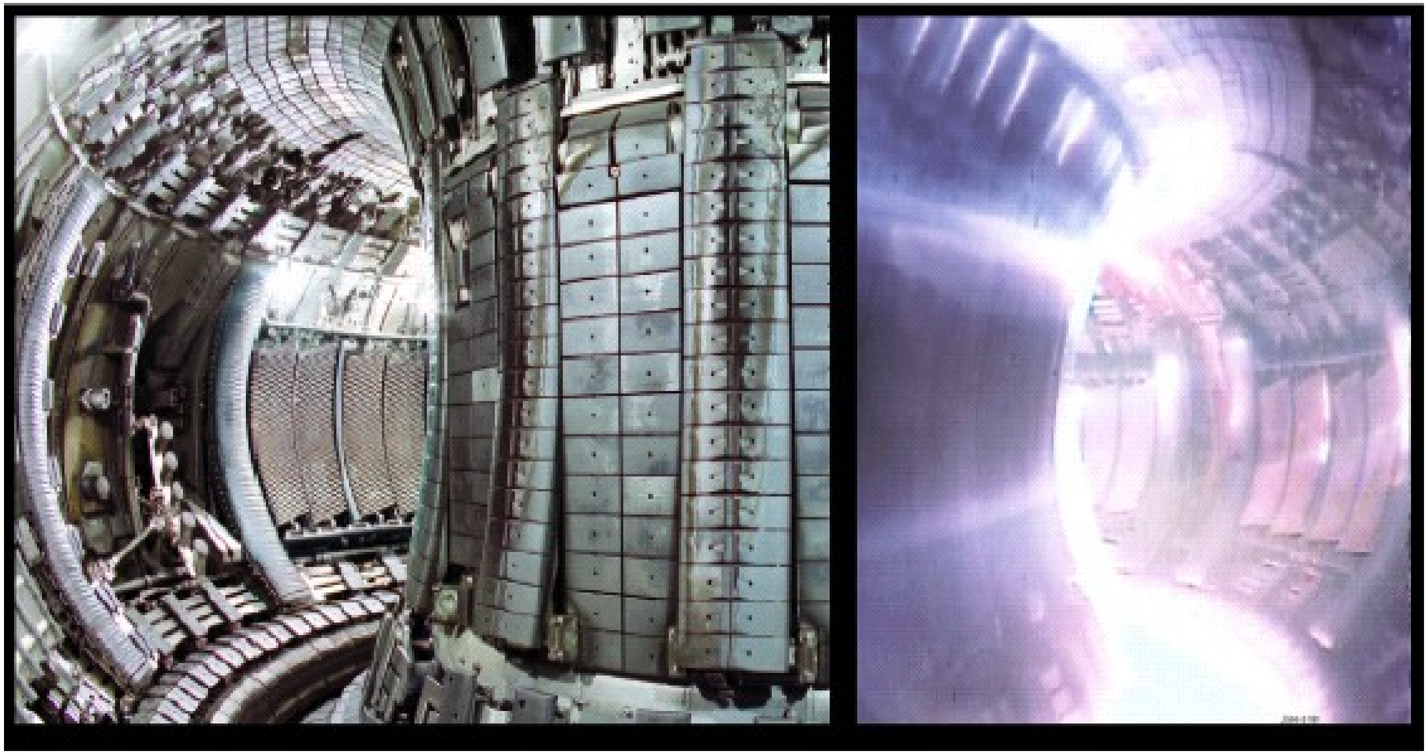
- CELLAR: samples from JET (Joint European Torus; fusion experiment)

CELLAR
Collaboration of European Low-level underground LAboRatories

- meteorite measurements (Jesenice (Slovenia), Maribo (Denmark), Bunburra Rockhole (Australia), Almahata Sitta (Sudan))

Use of activation technique to be able to determine the loss of charged particles from the plasma

ULGS measurements : need low background due to **very low activity & small samples**.



- Analyse also short lived radionuclides like V-48 (16 d) and Sc-47 (3.4 d) and Cr-51 (28 d)
- Use 18 detectors (2 samples for one week on each detector)

in meteorites

size determination of parent body through measurement of

^{26}Al (7.16x10^{5} a)

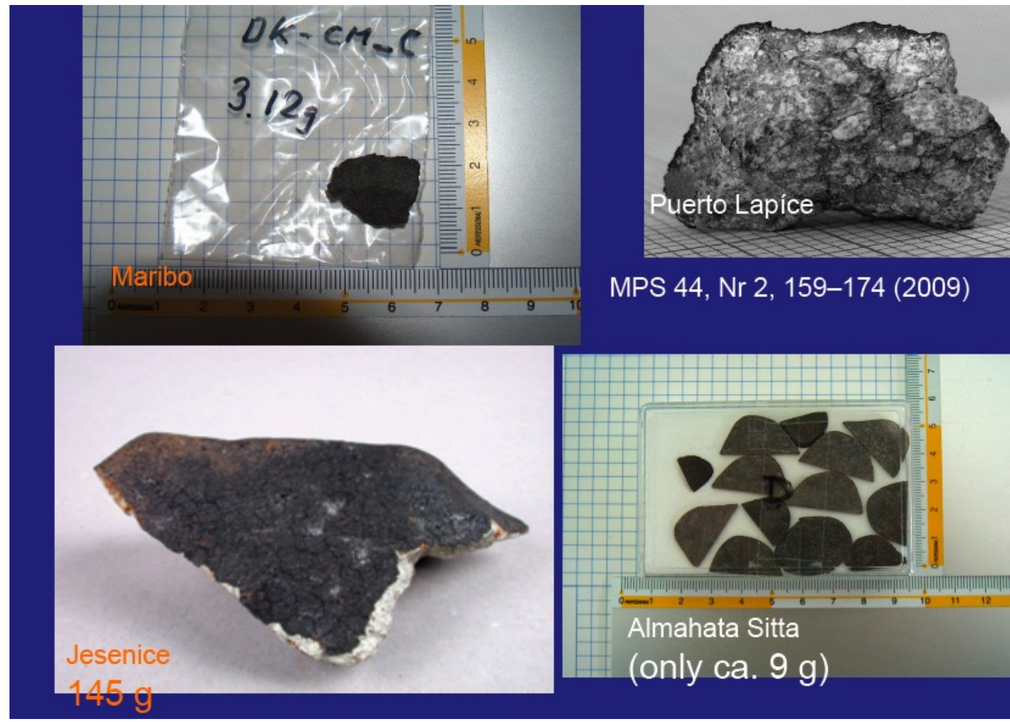
^{22}Na (2.602 a)

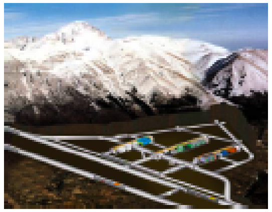
^{60}Co (5.27 a)

^{54}Mn (312.15 d)

exposure age determination through

^{26}Al (7.16x10^{5} a)





ERMES

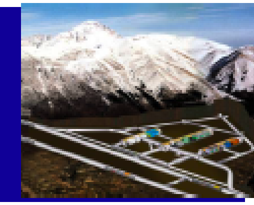
Enviromental Radioactivity Monitoring for Earth Sciences

Environmental Radioactivity Monitoring for Earth Sciences at the deep underground Gran Sasso National Laboratory, Italy

INFN

Istituto Nazionale di Fisica Nucleare

Sources for the neutron background



The sources for neutron background considered are the interaction between cosmic muons with rock or detectors, the radioactivity in the rock and the structural coating in cement, and recently at LNGS its percentage of water: in the latter case, the water acts only as moderator for neutron flux.

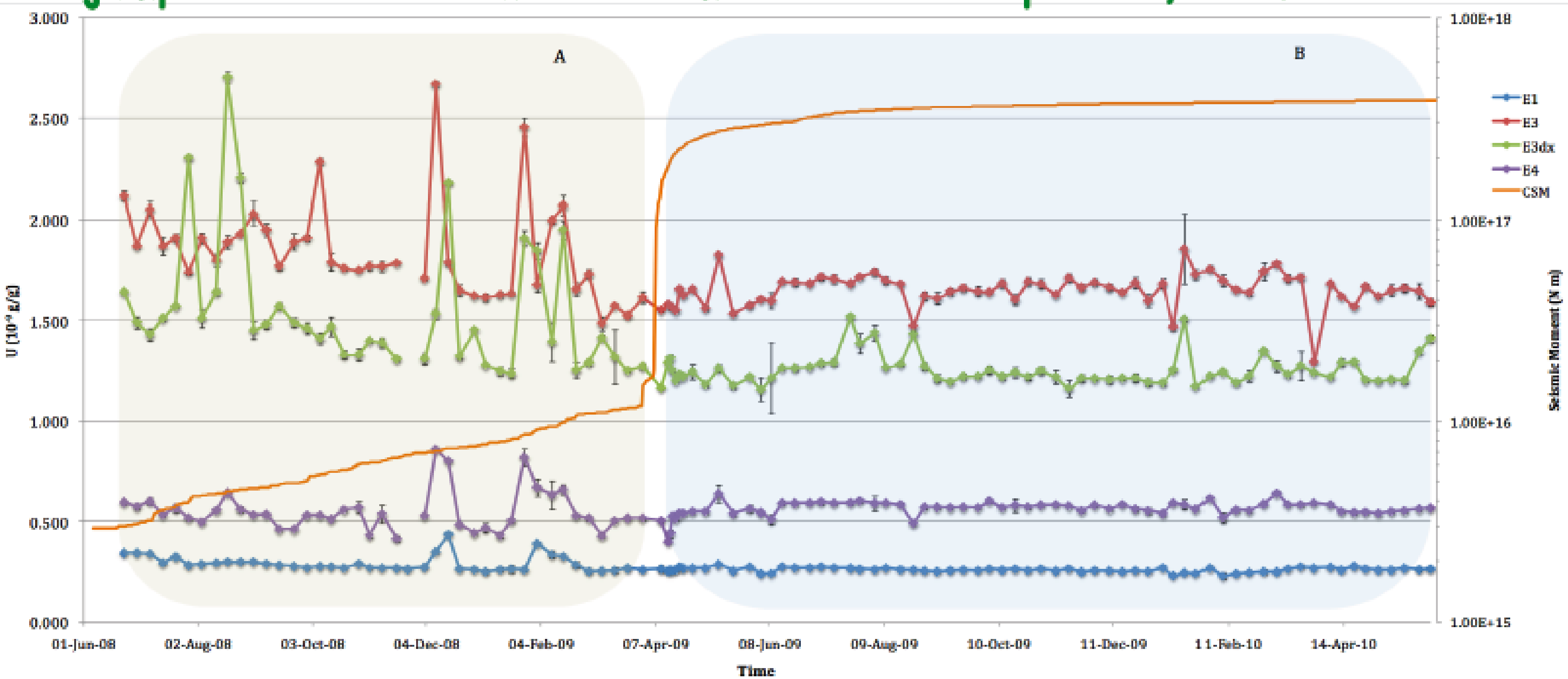
The possibility of a spatial-temporal variation of the neutron flux induced by the hydrogeological properties of the Gran Sasso aquifer, and the groundwater radioactivity due to water-rock interaction and geochemical variations in solubility of Uranite and Thorianite are studied by ERMES

The (LNGS-INFN) is located inside the largest aquifer of central Italy……. and in a seismogenic area.

Time variation of U concentration in groundwater sampled at E1, E3, E3dx, E4 from June 2008 to May 2010

Period A, from June 2008 to 31st March 2009 (seismic swarm):
A clear short-term 40-80% peak structure

Period B, from 10th April to May 2020:
Systematic peak structure for U no longer present
The cumulative seismic moment (CSM) estimated from seismic data shows a clear jump in coincidence with the main shock on April 6th, 2009



Plastino, W. *et al.* Uranium groundwater anomalies and active normal faulting, J. Radioanal. Nucl. Chem., in press.

ERMES Outlooks

Neutron Flux Background

★The studies on neutrons performed until now are not conclusive and the characterization of this background requires new measurements and analyses of the natural radioactivity in water over a suitable time-space range.

★The spatial-temporal variations of ground water radioactivity could induce a neutron flux modulation due to water-rock interaction and hydrological properties of the Gran Sasso aquifer.

★The work shows that there are two types of water with different uranium concentrations at the LNGS-INFN.

★Further neutron monitoring activities and numerical simulations will be scheduled to better characterize the neutron flux background at the LNGS-INFN.

ERMES Outlooks (cont)

Geodynamic Processes in the Earth's Lithosphere and Mantle

★More attention should be devoted to the pre-earthquake and volcanic eruption studies of geodynamic processes, especially on characteristics of fluids filling the fractures before the main shock and eruption.

★Uranium in groundwater has been tested as a potential indicator of pre-earthquake processes as it may be associated with geodynamics of preparation phases of earthquakes.

★Another possible physical process during the pre- and post-phases of the earthquake could be investigated: the first stage seems to be characterized by U variations in groundwater that can modulate the radon concentration, the second one (after the main shock) do not show any U anomalies, justifying the different radon patterns before and after the main shock.

Agreement INFN- INGV

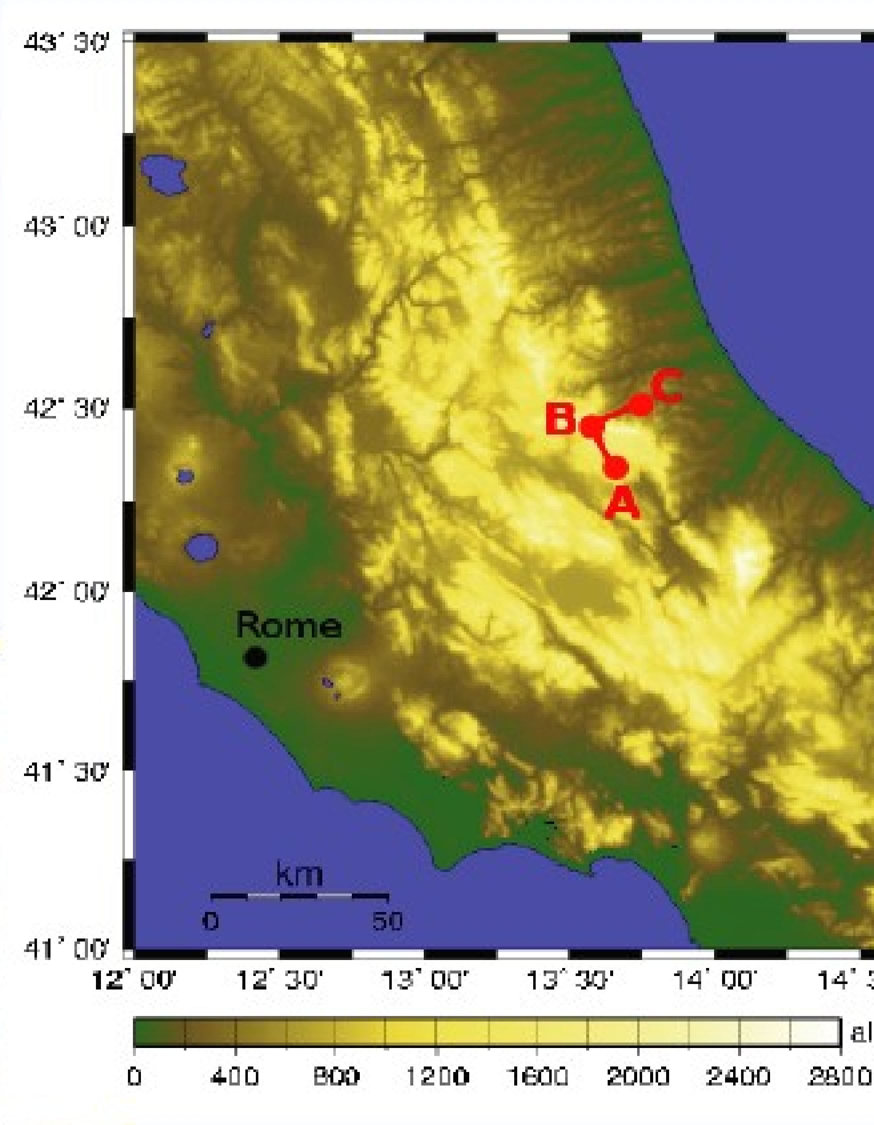
dependent components of the strain tensor (BA
C distance changes);

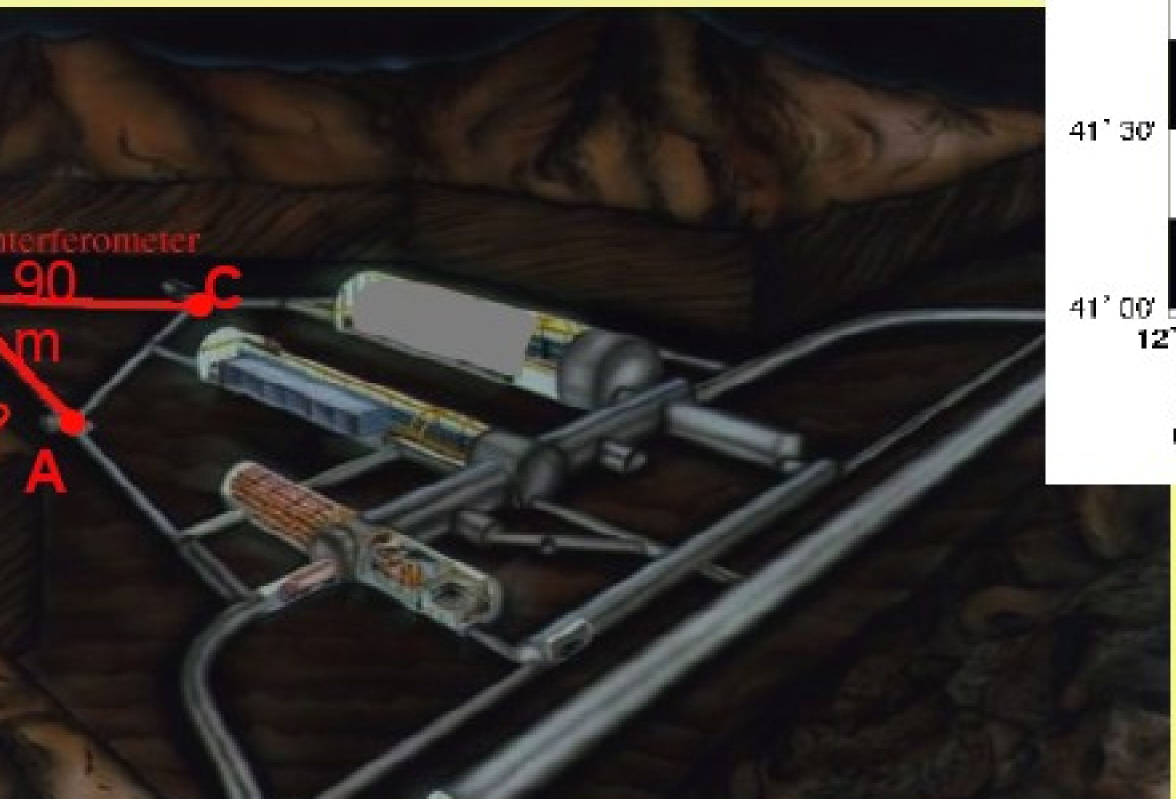
10^{-12} (nominal resolution)

num $\Delta l/l$: nominally unlimited

al bandwidth ≈ 200 Hz to 0 Hz

num strain rate: few 10^{-7} s^{-1} (easily increasable)





Two geodetic extensometers:
unequal arms interferometers
90-m long measurement arm
<40-cm long reference arm
HeNe laser source

The Free Core Resonance on diurnal tides

e Free Core Nutation is the result of the fact that the rotation axes of the co
d mantle of the Earth are not precisely aligned. It causes a resonance on th
rth response to tidal forcing whose period T_{FCR} (situated in the diurnal tidal
nd) and quality factor Q depend on the core-mantle boundary (CMB) ellipti
e Earth's inelasticity, and the viscomagnetic coupling of the CMB. The FCN
riod and Q are usually estimated using VLBI (astronomical interferometry) a
avity tide data. After long-standing controversies, the joint analysis of long
cords (many years) from several stations gave (Ducarme et al., 2009)

$_{CR} \approx$ 430 sidereal days;   Q ≈ 15000

milar results have been obtained using only few years of data from the Gran
sso interferometers.

Amoruso, and L. Crescentini, Free Core Resonance Parameters From Strai
es Recorded by Paired Extensometers at Gran Sasso, Italy, *Eos Trans. AG*
53), Fall Meet. Suppl., Abstract G33B-0700, 2008.

Amoruso, and L. Crescentini, Free Core Resonance parameters from strain
a: results from the Gran Sasso (Italy) extensometers, in preparation

v earthquakes

v earthquake is a discontinuous, earthquake-like event that releases energy
a period much longer than usual earthquakes. Slow earthquakes may play
portant role in the stress redistribution process.

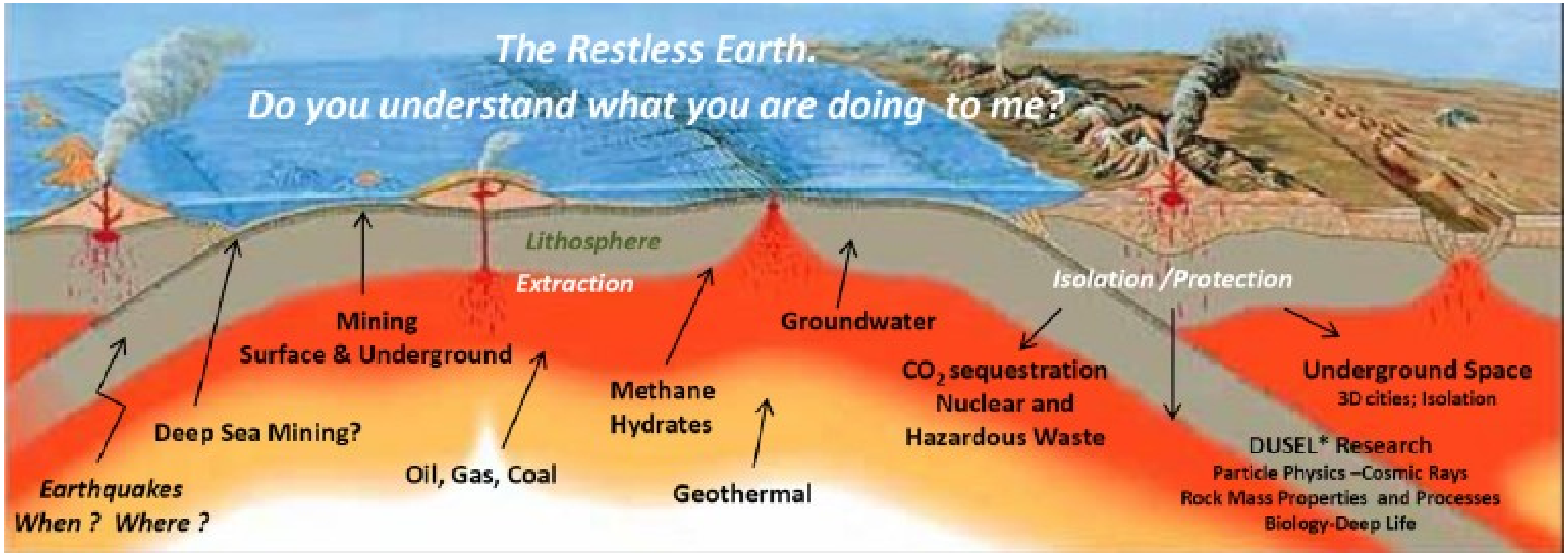
ported the first observation of a swarm of slow earthquakes. We first
nized that slow earthquakes are probably characterized by a "diffusive"
e propagation, differently from regular earthquakes (recently confirmed in
ork by Ide et al., *Nature*, 2007).

scentini, A. Amoruso, and R. Scarpa, Constraints on Slow Earthquake
nics from a Swarm in Central Italy, *Science*, **286**, 2132, 1999.

oruso, L. Crescentini, A. Morelli, and R. Scarpa, Slow rupture of an
nic fault in a seismogenic region of Central Italy, *Geophys. Res. Lett.*, **29**
219, 2002.

oruso, L. Crescentini, M. Dragoni and A. Piombo, Fault slip controlled by
rheology: a model for slow earthquakes, *Geophys. J. Int.*, **159**, 347,

Considerations on future
Engineering, Geoscience and Bioscience experiments



* What are the interactions among subsurface processes?

* Are underground resources of drinking water safe and secure?

* Can we reliably predict and control earthquakes?

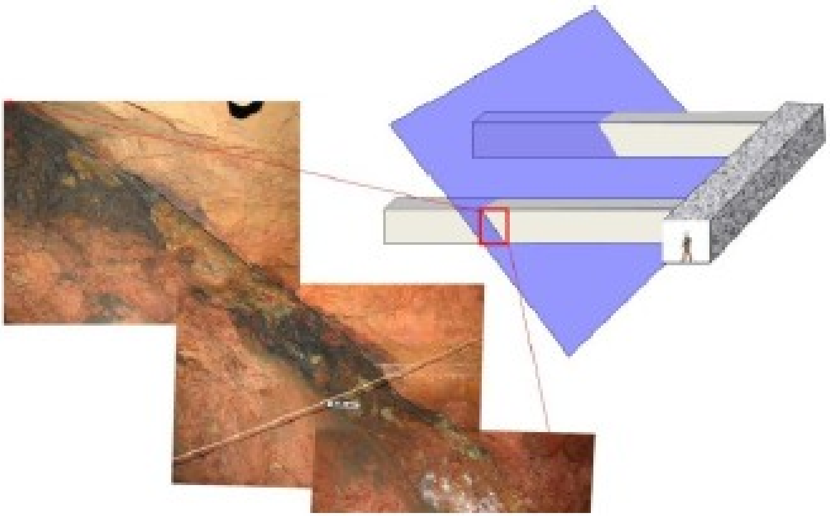
* Can we make the earth "transparent" and observe underground processes in action?

“We do not understand the strength of a rock mass”

Reply by Professor Leopold Muller to the question “Why do we need an International Society for Rock Mechanics?” posed during a radio interview in Salzburg, May 24, 1962- when he officially registered the ISRM as a Society.

QuickTime™ and a
decompressor
are needed to see this picture.

Coupled Thermo-Hydro-Mechanical-Chemical Processes



Faults are important features that cut across the geosciences

Understanding the nucleation and rupture of earthquakes on faults is a central theme of seismology, rock mechanics and structural geology.

Faults affect preferential pathways to fluids at all lengths and time scales. An important fraction of Earth's heat flow is carried by hydrothermal circulation through faults.

Faults can also be a locus for microbial life. Hydrogen released during the faulting process may have sustained the earliest life on the planet, and it may continue to be important to the deep biosphere.
Fluid transport and chemical reactions are important contributors to microbial life, and the microbes likely facilitate chemical reactions. The ensemble chemical reactions alter permeability and affect fluid pressures, which in turn control fluid flow and mechanical stability.
Damage during an earthquake rupture can be healed and resulting changes in permeability can be sealed by chemical reactions, thereby influencing subsequent fault slip.

Despite their significance, studying Earth stresses and strain deep in the subsurface and their interaction with preexisting or growing fractures, moving or static fluids, and chemical or biochemical reactions are restricted to sparse point measurements in deep boreholes and deep mines

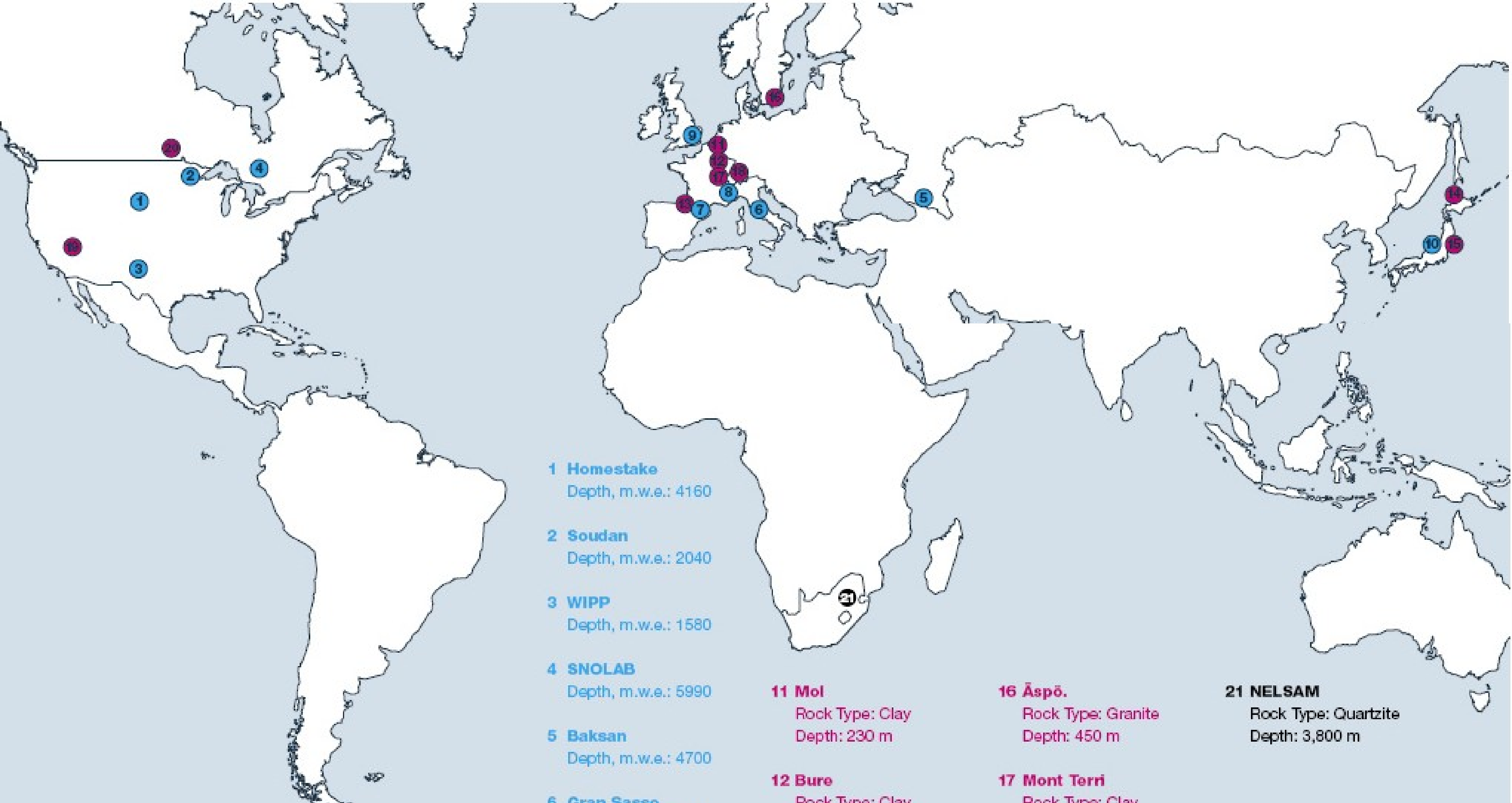
Fractures are commonly too small and widely spaced to be effectively sampled by boreholes.
Operating mines provide access to the underground but do not usually allow for long-term studies.

The most desirable subsurface experimental setting therefore includes observations at large scales (hundreds of meters to kilometers) and for long periods of time (years to decades)

One consistently high profile area for biological advance, is the discovery of new microbes that expand our knowledge of the strategies and limits of life, such as microbes that harvest new sources of energy, live at even higher temperatures or pressures or exhibit new biochemical reactions some of which may have biotechnological or pharmaceutical value.

> C.f., Schulz, H. N., T. Brinkhoff, T. G. Ferdelman, H. Hernandez Marine, A. Teske, and B. B. Jorgensen, 1999. Dense populations of a giant sulfur bacterium in Namibian shelf sediments. Science 284: 493-495

The discovery of these organisms often occurs in samples from unusual habitats where unique biology may have evolved. An Underground Lab will necessarily access unique subsurface material that could reasonably harbor unique biology.
Major biological question on energy sources, energy efficiency, evolution of small populations, horizontal gene exchange as well as mechanisms of mineral weathering could be addressed with access enabled by Underground Labs.



http://www.deepscience.org/

Figure 1: Underground laboratories worldwide. Physics laboratories (blue) are listed with their depths in meters water equivalent. Laboratories for research into the long-term (~million-year) isolation of high-level nuclear waste, shown in red, are listed with actual depth. The NELSAM laboratory (black) is for earthquake research.

1 Homestake
Depth, m.w.e.: 4160

2 Soudan
Depth, m.w.e.: 2040

3 WIPP
Depth, m.w.e.: 1580

4 SNOLAB
Depth, m.w.e.: 5990

5 Baksan
Depth, m.w.e.: 4700

6 Gran Sasso
Depth, m.w.e.: 3030

7 Canfranc
Depth, m.w.e.: 2450

8 Fréjus/Modane
Depth, m.w.e.: 4150

9 Boulby
Depth, m.w.e.: 2805

10 Kamioka
Depth, m.w.e.: 2050

11 Mol
Rock Type: Clay
Depth: 230 m

12 Bure
Rock Type: Clay
Depth: 450 m

13 Tournemire
Rock Type: Clay
Depth: 300 m

14 Horonobe
Rock Type: Sedimentary
Depth: 1,000 m

15 Tono (Mizunami)
Rock Type: Granite
Depth: 1,000 m

16 Āspö.
Rock Type: Granite
Depth: 450 m

17 Mont Terri
Rock Type: Clay
Depth: 300 m

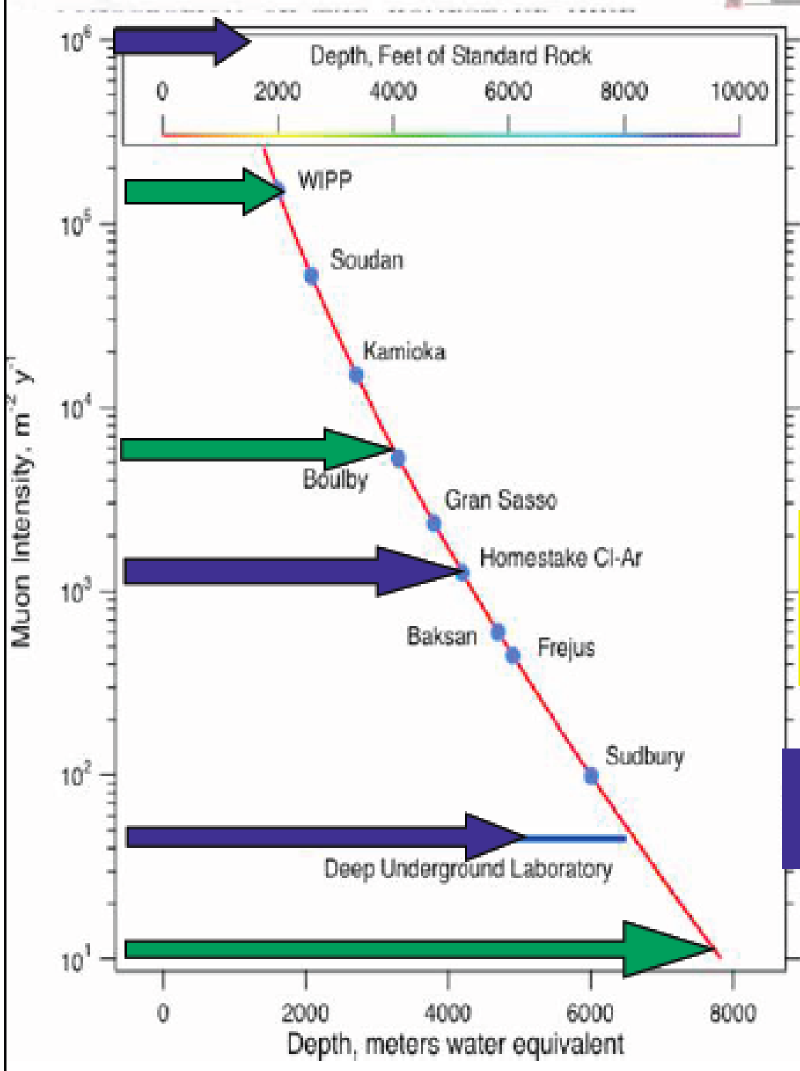
18 Grimsel
Rock Type: Granite
Depth: 450 m

19 Yucca Mountian
Rock Type: Volcanic tuff
Depth: 300 m

20 Pinawa
Rock Type: Granite
Depth: 450 m

21 NELSAM
Rock Type: Quartzite
Depth: 3,800 m

Plans for Research Campuses Optimized for Science



300L R&D E&O 10k ft^2

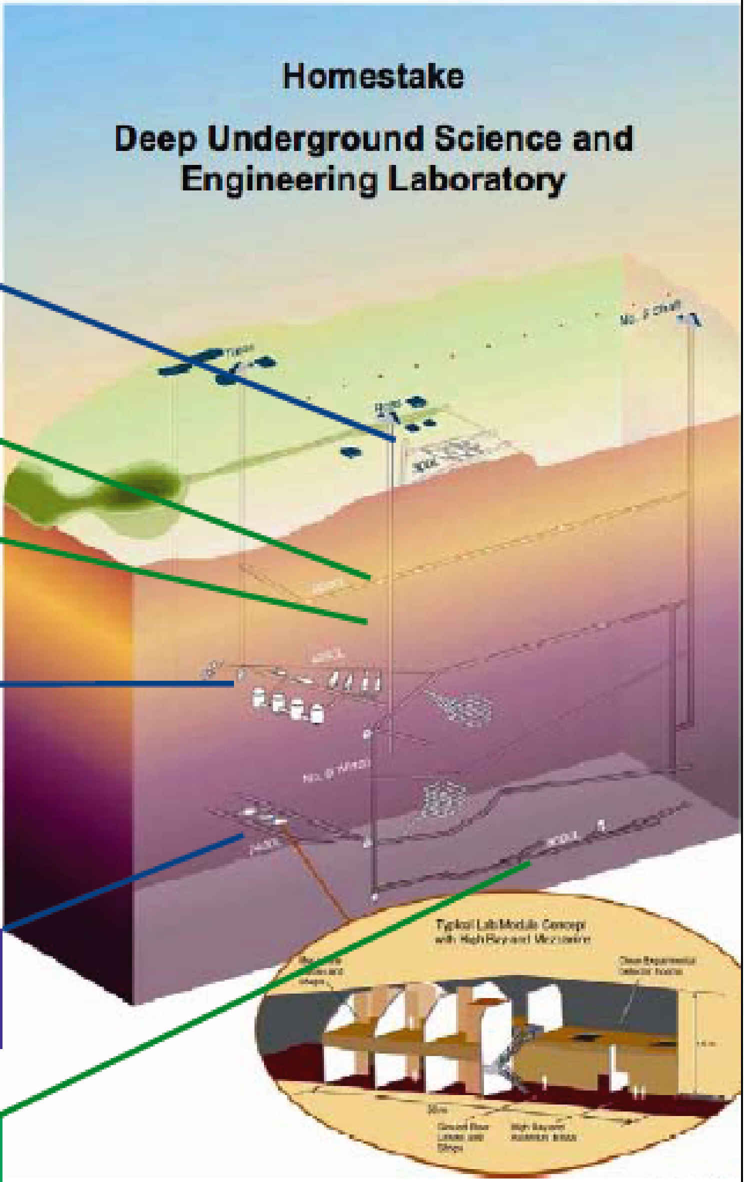
2000L BGE Level

3800L BGE Level

4850L Campus $100k\ ft^2$ + Mega Cavities

7400L Campus 65k ft^2

8000L BGE Lab



A broad classes of engineering, geoscience and bioscience experiments could be accomplished in future

• Scale effects and coupled thermo-hydro-mechanical processes

Stimulated by the proposal to construct a large cavity for Megaton scale detector. Such an underground cavity is unprecedented and provides a unique opportunity for engineering research on the effects of scale on rock deformation

• Subsurface imaging (Transparent Earth);

Explore the potential of a variety of geophysical techniques to make the rock more 'transparent' and beat its opaque nature

• Mechanics of induced fracturing and fault slip;

New tests on hydraulic fracturing (used extensively in the oil and gas industry); investigate rock strain as a function of time and position near faults

• Biology

Investigate the microbiological role in the rock weathering processes and explore unknown aspects by access to a unique habitat.

Any single underground site has important limitations.

This is true for geo-engineering and geoscience research as well as for biology: owing to important variations in rock types, loading conditions, temperature and fluid regime, investigations at many sites are likely to yield the most valuable insights.

Thus interdisciplinary research would be benefited by international cooperation and a strategy of several subsurface sites.