Naturally Occurring Radioactivity (NOR) in natural and anthropic environments

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Review of Radioactivity – Radionuclides Concepts

- Atomic Nucleus
- Review of radioactivity and radionuclides concepts
- Radioactive Decay
- Units of Radiation Dose and Exposure

Brief Review of Radioactivity and Radionuclides basic concepts

Atomic Nucleus

Material

Compounds

Elements

Atoms

(Neutrons + Protons) + Electrons
{Nucleus}

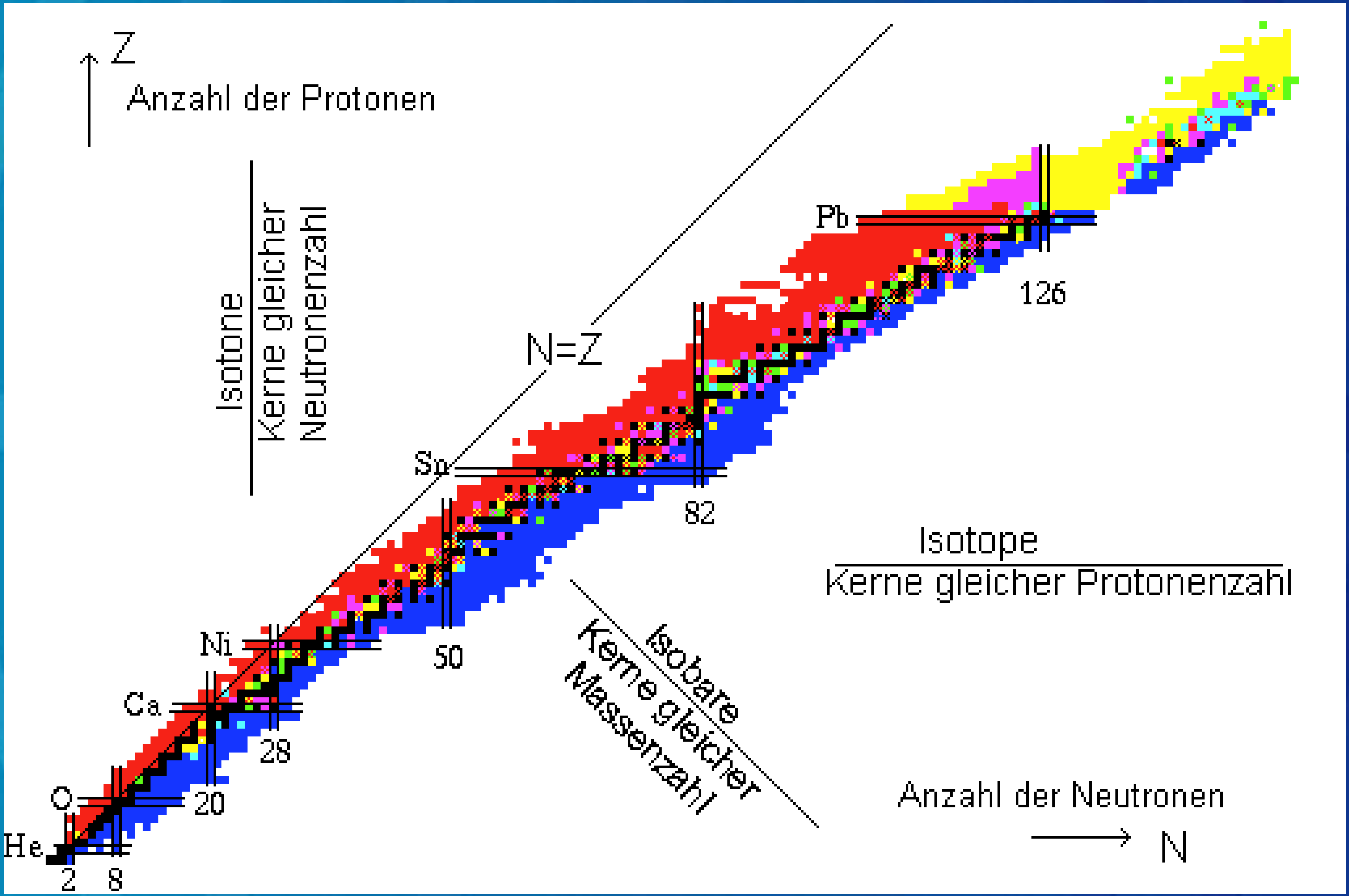
Element X is depicted by

$${}^{A}_{Z}X_{N}$$

A = Mass Number
N = Neutron Number
Z = Atomic Number (Proton Number)

$$A = Z + N$$

Z-N diagram of Nuclides



Review of Radioactivity and …

Radioactive Decay

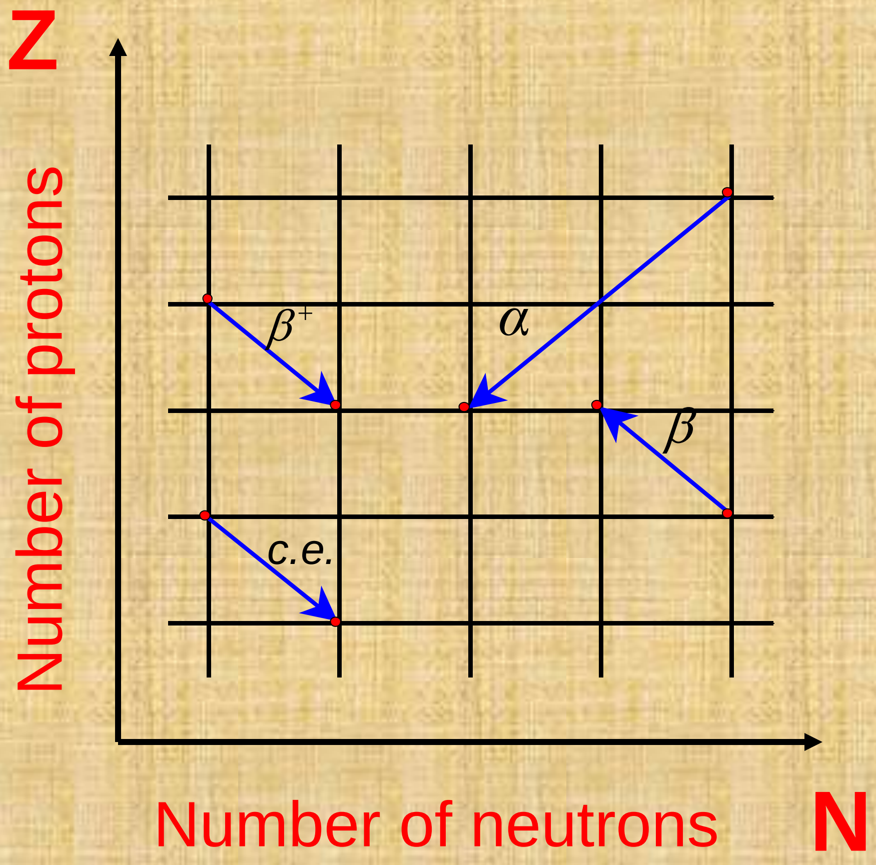
Radioactivity is produced when unstable nuclei decay.
The disintegration of radio-nuclides releases excess energy in the form of nuclear radiations.

Radioactive decay takes place in several ways emitting radiation such as:

- Alpha rays
- Beta (negative and positive) rays
- Gamma rays
- Neutrons
- Neutrinos
- Proton decay
- Internal conversion electrons
- Characteristic x-rays
- Fission fragments

The heavy radioactive elements and their decay products predominantly emit three types of radiation:
Alpha rays, Beta rays, Gamma rays

Radioactive Decays



$$(Z, A) \xrightarrow{\alpha} (Z-2, A-4) + \alpha$$

$$(Z, A) \xrightarrow[\beta^-]{} (Z+1, A) + e^- + \bar{\nu}$$

$$(Z, A) \xrightarrow[\beta^+]{} (Z-1, A) + e^+ + \nu$$

$$(Z, A) + e^- \xrightarrow[c.e.]{} (Z-1, A) + \nu$$

A* = *N* + *Z
c.e.* = *electronic capture

Review of Radioactivity and ...

Alpha decay followed by gamma decay:

Alpha particle is $^{4}_{2}He_{2}$.

$$^{234}_{92}U_{142} \longrightarrow {}^{230}_{90}Th_{140} + \alpha + \gamma .$$

The unstable isotope $^{234}_{92}U_{142}$ decays to $^{230}_{90}Th_{140}$ by alpha and gamma radiation. The atomic number decreases by 2 and mass number by 4.

Review of Radioactivity and …

Alpha decay of ^{234}U to ^{230}Th

Z ↓						
92	U 231 4.2 d	U 232 68.9 y	U 233 1.592E5 y	U 234 2.455E5 y 0.0055	U 235 7.038E8 y 0.720	
91	Pa 230 17.4 d	Pa 231 3.28E4 y	Pa 232 1.31 d	Pa 233 26.967 d	Pa 234 1.17m | 6.7h	
90	Th 229 7340 y	Th 230 7.538E4 y	Th 231 25.52 h	Th 232 1.405E10 y 100	Th 233 22.3 m	
	139	140	141	142	143	← N

Table 1: Alpha decay of ^{234}U to ^{230}Th (shown in the format of chart of nuclides).
The atomic number Z reduces by 2.
The neutron number N reduces by 2.
The mass number A reduces by 4.

Review of Radioactivity and ...

Radioactive Decay

Beta decay followed by gamma decay.
Beta particle is electron ejected by excited nuclei. Their charge can be positive or negative.

$$ {}^{40}_{19}K_{21} \longrightarrow {}^{40}_{20}Ca_{20} + \beta + \gamma. $$

The radioactive isotope ${}^{40}_{19}K_{21}$ decays to ${}^{40}_{20}Ca_{20}$ by beta and gamma radiation. Neutrinos are also emitted. A neutron is transformed into proton. The atomic number increases by 1 and mass number remains unchanged.

Review of Radioactivity and …

Beta decay of ^{40}K to ^{40}Ca

Z							
20	Ca 37 0.181 s	Ca 38 0.440 s	Ca 39 0.859 s	Ca 40 96.941	Ca 41 1.3E5 y	Ca42 0.647	
19	K 36 0. 342 s	K 37 1.23 s	K 38 0.926 s | 7.63 m	K 39 93.258	K 40 1.28E9 y 0.012	K 41 6.73	
	17	18	19	20	21	22	← N

Table 2: Beta decay of ^{40}K to ^{40}Ca (shown in the format of chart of nuclides).
The atomic number Z increase by 1.
The neutron number N reduces by 1.
The mass number A remains unchanged.

Review of Radioactivity and …

Radioactive Decay

- Gamma rays (γ) are emitted when an excited nucleus de-excites, by the transition from an excited energy state to a lower energy state. Gamma-rays have well defined energies and their emission often is accompanied by nuclear reactions and nuclear decays.

- Alpha particles (α) are ^{4}He particles with two protons and two neutrons. The atomic number (Z) of the resultant nucleus is reduced by two units, the mass number is reduced by 4 units.

- Negative Beta particles (β^-) or negatrons are emitted when neutron is transformed into a proton during the nuclear transformation.

  Negative beta particles are electrons formed during nuclear transformation, hence are of nuclear origin.

  The atomic number (Z) of the resultant nucleus is one unit greater, but the mass number is unchanged.

Review of Radioactivity and ...

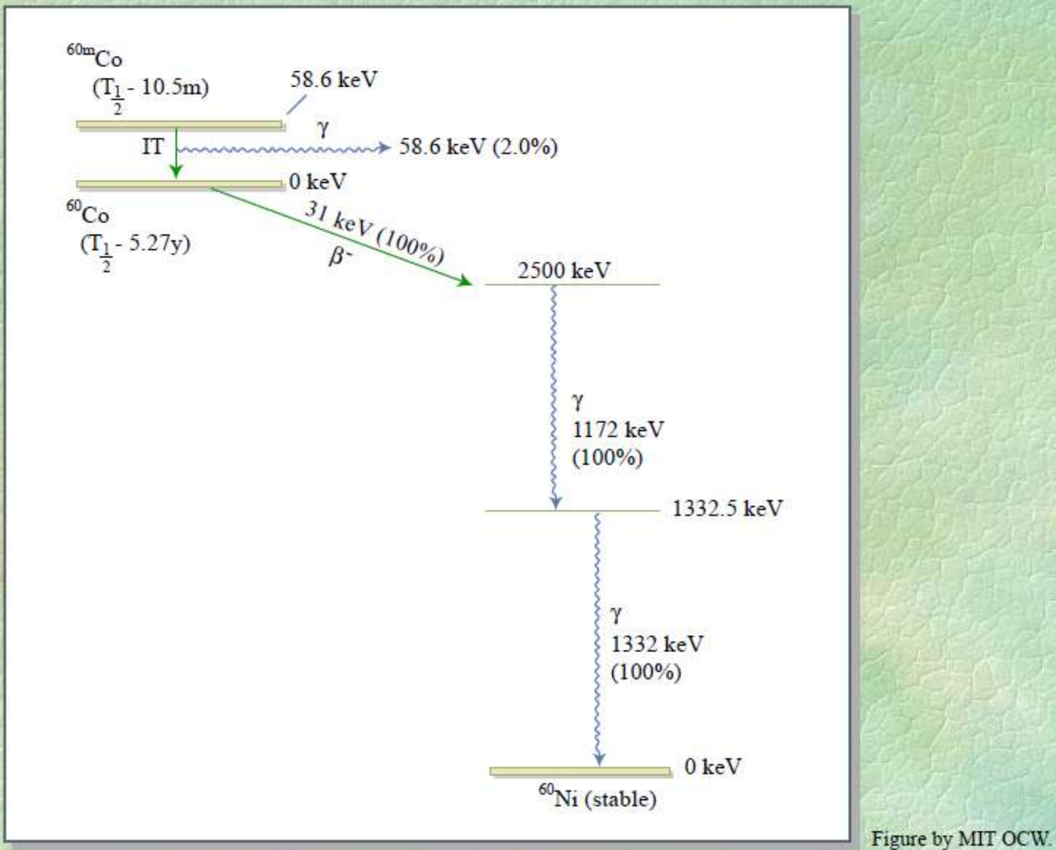
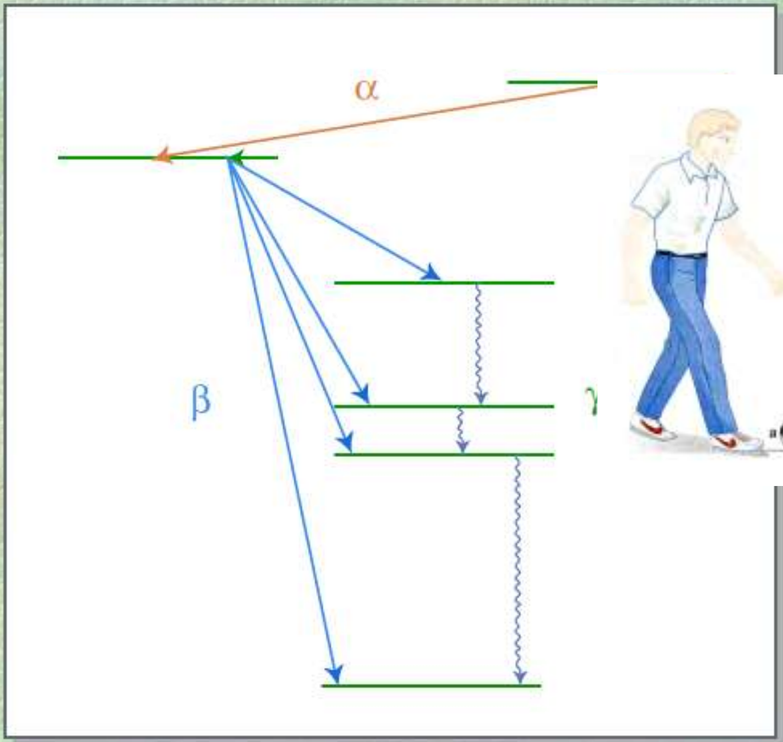


Figure 1: Gamma and beta decay scheme of ^{60m}Co and ^{60}Co.

Review of Radioactivity and ...



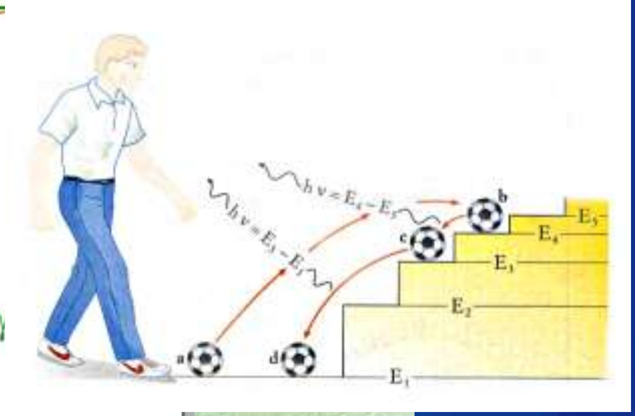
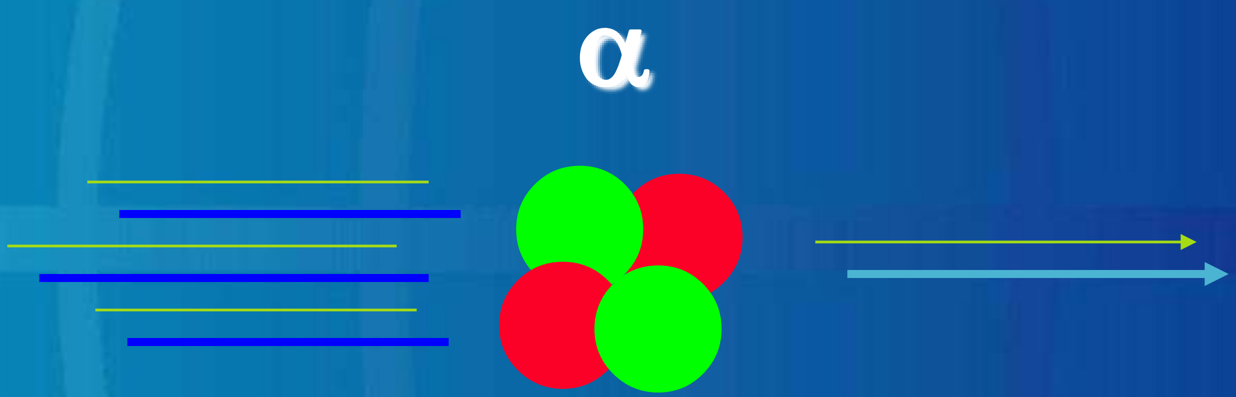


Figure by MIT OCW.

Figure 2: Pictorial depiction of simultaneous alpha, beta and gamma emissions

α Radiation

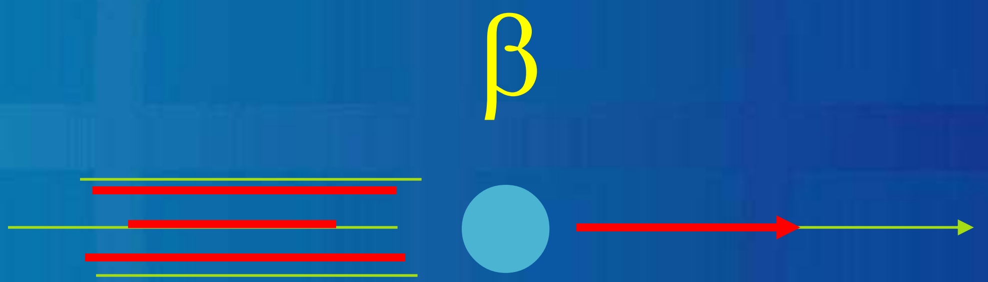


2 PROTONS

2 NEUTRONS

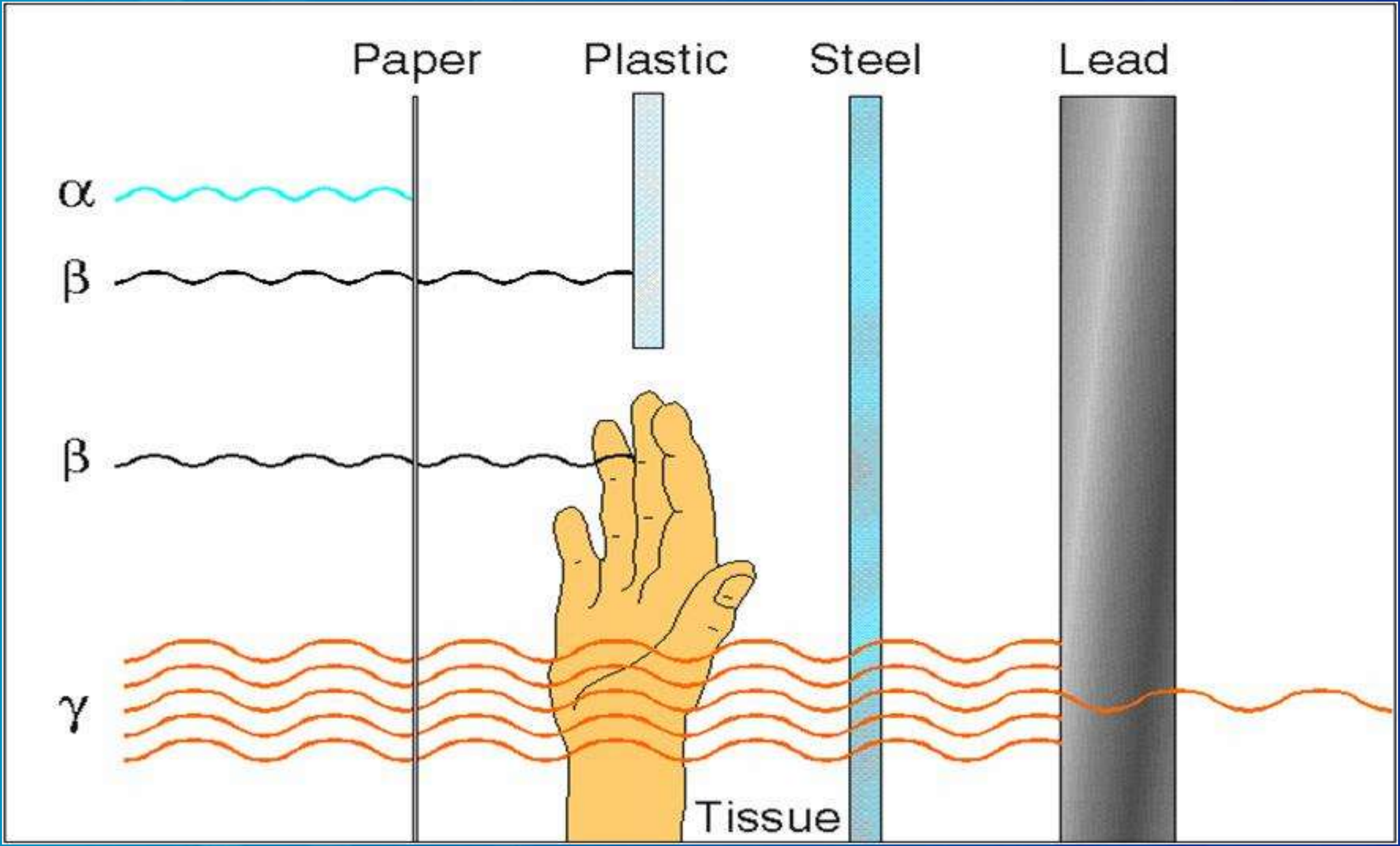
β Radiation

1 ELECTRON



γ Radiation

Relative Penetrating Power



Review of Radioactivity and ...

Units of Radiation Dose and Exposure

- Radioactivity is measured in unit of disintegration per second (dps).

  1 Becquerel is 1Bq = 1 dps

  1 Curie is 1Ci = 3.7×10^{10} Bq **old unit**

Review of Radioactivity and …

Units of Radiation Dose and Exposure

- The amount of radiation is usually referred to as Dose.
- Dose is different from Exposure.
- The quantities and units of Radiation Dose and Exposure are not simple but are complex involving various parameters such as type of radiation, absorbed dose (D), quality factor (Q), any modifying factor (N), etc.
- After going through an evolution in a period of more than a half a century, the current units designated by SI (Système International)

Unit of Dose Equivalent is 1Sievert = 1 Sv (1 Joule/kg)

Unit of Dose is 1 Gray = 1Gy (1 Joule/kg)

1 Gy = 100 rad; 1 rad = 0.01 Joule/kg

1 Sv = 100 rem; 1 rem = rad x quality factor

Note: rad refers to any material and any radiation.

Ref: P126 Basic Nuclear Engineering; P 42 Environmental Radioactivity Merrill Eisenbud and Giesell.

Measurement Units of the radiation energy

The energy of radiation is typically measured in:

electronvolt (eV)

1 eV is defined like the energy that a unitary charge (i.e., an electron) acquires travelling across a potential difference of 1 Volt.

Energy of radiations

- eV multiples:

- **keV** (100 eV) (X-rays)
- **MeV** (10^6 eV), (nuclear processes)
- **GeV** (10^9 eV). (pre-LHC era particle accelerators)
- **TeV** (10^{12} eV) (LHC era)
- **PeV** (10^{15} eV) (cosmic rays)
- **EeV** (10^{18} eV) (cosmic rays)

Review of Radioactivity and ...

- **NORM** - Naturally Occurring Radioactive Material.
- **TENORM** -Technologically-Enhanced Naturally Occurring Radioactive Material.

NORM Definition

- *Naturally Occurring Radioactive Material* (NORM)

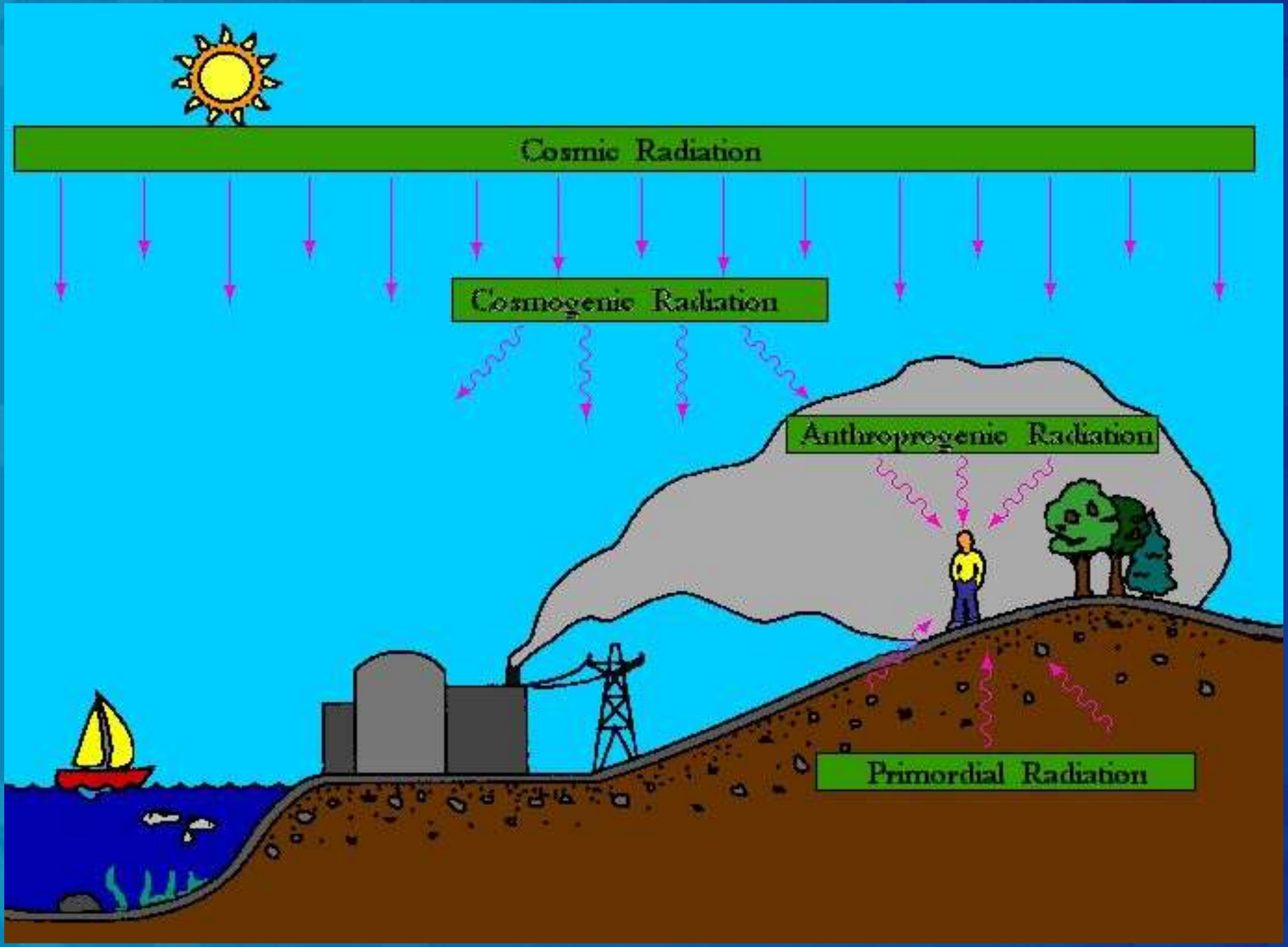
  – any nuclide that is radioactive in its natural state (i.e. not man-made), but not including source, by-product, or special nuclear material. The associated radioactivity is

  Naturally Occurring Radioactivity (NOR)

Naturally Occurring Radioactive Materials (NORM)

- Primordial
- Cosmogenic
- Anthropogenic

Types of NOR



Cosmic Radiation
Cosmogenic Radiation
Anthroprogenic Radiation
Primordial Radiation

Naturally Occurring Radioactive Materials NORM

The earth is radioactive and the world we live in, the environment around is radioactive.

Radioactive elements can be categorized as

- Primordial – present even before or ever since the existence of the Earth.
- Cosmogenic - formed as a result of cosmic ray interactions.
- Anthropogenic - enhanced or formed due to technology, human activities.

Naturally Occurring Radioactive Materials NORM

Characteristics of Primordial elements

- long lived
- most half-lives of the order of millions of years;
- must have been left-over on the earth, because the radioactivity decays to very minute levels usually after 30 half-lives.

Naturally Occurring Radioactive Materials NORM

List of some more Primordial Radio-nuclides

^{209}Bi, ^{113}Cd, ^{142}Ce, ^{152}Gd, ^{174}Hf, ^{115}In, ^{138}La, ^{144}Nd, ^{176}Lu, ^{190}Pt, ^{192}Pt, ^{187}Re, ^{87}Rb, ^{147}Sm, ^{123}Te, ^{50}V

Naturally Occurring Radioactive Materials NORM

The uranium and thorium decay series

Detailed information of radioactive decay of ^{235}U, $^{238}U$and ^{232}Th, and their daughter products, the corresponding half-life of each and the decay sequence are provided in many text books and web sites.

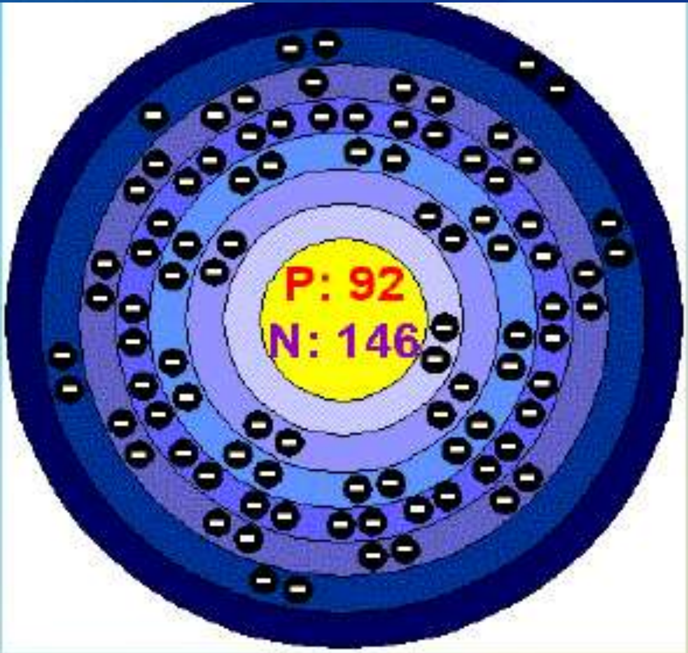
References:

1) Figure 13.1 ^{235}U radioactive decay chain.
Figure 13.2 ^{238}U radioactive decay chain.
Figure 13.3 ^{232}Th radioactive decay chain.
Chapter 13. Nuclear techniques for the determination of uranium and thorium and their decay products,
A hand book of silicate rock analysis, P. J. Potts.
2) http://www.health.state.ny.us/nysdoh/radon/chain.htm

Dominant isotope of U is ^{238}U (99.2%)

- is parent of all other U isotopes.
- is a major alpha emitter.
- $t_{½}$ = 4.47 GA
- ^{238}U = 1.55 x10^{-10}yr^{-1} (decay rate).

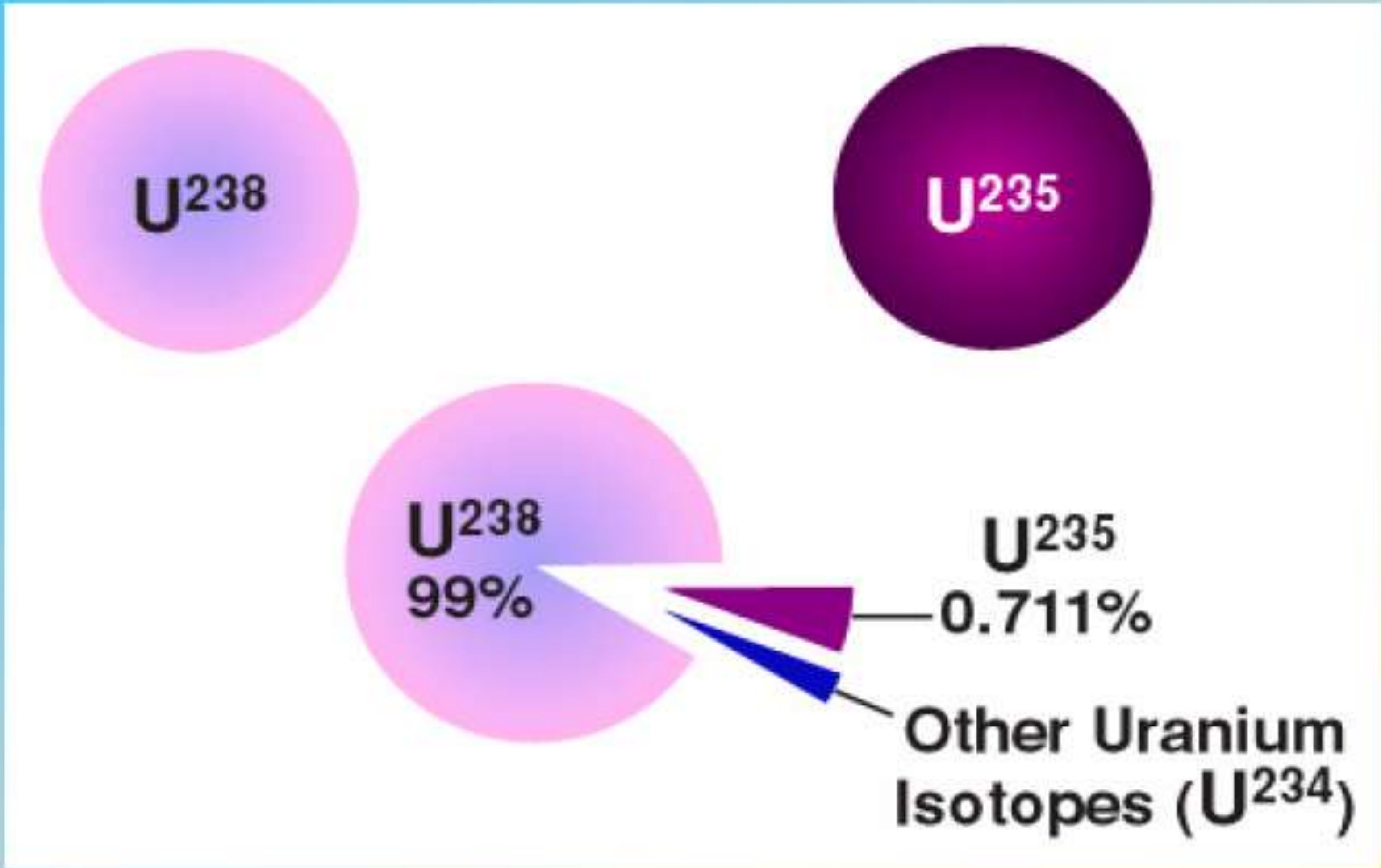
http://www.chemicalelements.com/elements/u.html



Number of Energy Levels: 7

First Energy Level: 2
Second Energy Level: 8
Third Energy Level: 18
Fourth Energy Level: 32
Fifth Energy Level: 21
Sixth Energy Level: 9
Seventh Energy Level: 2

Natural uranium contains 99 percent U-238 and only about 0.7 percent U-235 by weight.



http://www.nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html

	U abundance (ppm)	Pb abundance (ppm)	U/Pb ratio
Meteorites	0.008	2.470	0.003
Primitive mantle	0.021	0.185	0.113
Continental crust	1.4	12.6	0.111

The figure given for the continental crust is an average of the entire crust. Of course, local concentration of uranium can far exceed these values, ranging up to 50 ppm disseminated in some granites, to much higher values in ore deposits. In fact, in the geological past, local concentrations of uranium have occasionally achieved natural criticality, for example the Oklo reactors in Gabon.

http://world-nuclear.org/info/inf78.htm

^{235}U

- also occurs naturally in small quantities; useful b/c it fissions
- present day: $^{238}U/^{235}U = 138/1 = N_{238}/N_{235}$
- $^{235}U \rightarrow t_{1/2}$ = 700 Ma (That's why there is so much less).
- **^{235}U -alpha decay → ^{207}Pb; ^{238}U -alpha, beta decay → ^{206}Pb.**

Companion Decay Series:

- ^{235}U, ^{232}Th → Don't produce nuclides, which are useful tracers for geologic/ environmental processes.
- ^{235}U used in fission bombs because it splits apart more readily than ^{238}U.
- a method to enrich ^{235}U ratio from 1% to 6%, enables manufacture of nuclear weapons (method is gaseous diffusion; ie. Paducah, KY).

→

Uranium goes through a series of gamma and beta decays

^{238}U -alpha beta decay → ^{206}Pb.

Alpha (α) = 2p, 2n → ^{4}He.

Beta ($\beta-$) = e-

– therefore, ^{4}He is a decay product (will sniff ^{4}He while prospecting for U).

Dating technique: $^{206}Pb/^{238}U$ coupled with ^{235}U.

- In the oceans, U is stable and Th is rapidly removed into sediments.

  $^{230}Th = 0$; $^{232}Th = 0$ → $^{230}Th = {}^{230}Th_o e^{-\lambda t}$

  → $t = (-1/\lambda) \ln ({}^{230}Th/{}^{230}Th_o)$

- In corals, look at ^{234}U → ^{230}Th :

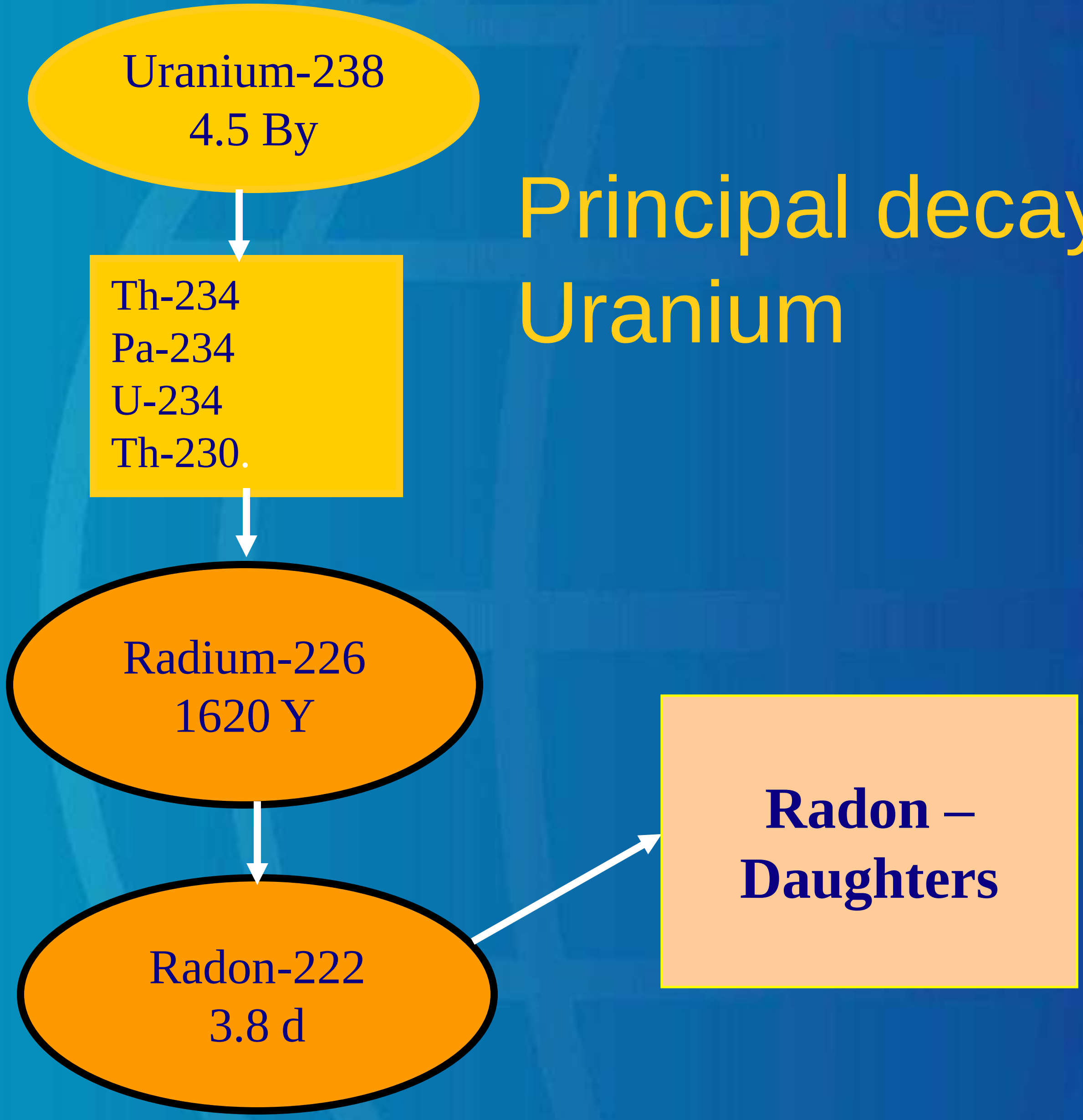
* ^{230}Th chronometer of choice to establish age of corals.

^{234}U useful in age dating of old water.

** Calibration curve relation allows for pretty good estimates up to 100 kyr

→ ^{234}U & ^{230}Th & ^{14}C age versus age reflect climatic conditions

Principal decay Scheme of Uranium



Naturally Occurring Radioactive Materials NORM

Table 3.
K, Th and U
Concentrations and activities in rocks and soils

Material	^{40}K		^{232}Th		^{238}U	
	%	Bq/kg	ppm	Bq/kg	ppm	Bq/kg
Igneous rocks						
Basalt (crustal average)	0.8	300	3.0-4.0	10.0 - 15.0	0.5-1	7.0 - 10.0
Granite (crustal average)	>4	>1000	17	70	3	40
Sedimentary rocks						
Shale sandstones	2.7	800	12	50	3.7	40
Clean quartz	<1	<300	<2	<8	<1	<10
Beach sands	<1	<300	6	25	3	40
Carbonate rocks	0.3	70	2	8	2	25
Continental crust (average)	2.8	850	10.7	44	2.8	36
Soil (average)	1.5	400	9	37	1.8	22
All rocks (range)	0.3 – 4.5	70 - 1500	1.6 - 20	7 - 80	0.5 – 4.7	7 – 60

Based on: Table 6-6, pp 140, Environmental Radioactivity from Natural, Industrial and Military Sources.

Naturally Occurring Radioactive Materials NORM

Natural radioactivity in soil

- Activity levels vary greatly depending on soil type, mineral composition and density. Activities for the ^{40}K, ^{232}Th, ^{238}U, ^{226}Ra and ^{222}Rn using typical numbers may be viewed on the web site:

http://www.physics.isu.edu/radinf/natural.htm

Naturally Occurring Radioactive Materials NORM

Natural Radioactivity in the Ocean

- Activity levels for the ^{40}K, ^{3}H, ^{87}Rb, ^{14}C in Pacific and Atlantic oceans using typical numbers may be viewed on the web site

http://www.physics.isu.edu/radinf/natural.htm

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity

Cosmic radiation:

- ❖**Primary cosmic radiation**
- ❖**Secondary cosmic radiation**

- Primary cosmic radiation:

  Extremely high energy particles (up to 10^{18} eV), and are mostly **protons**, and some larger particles.

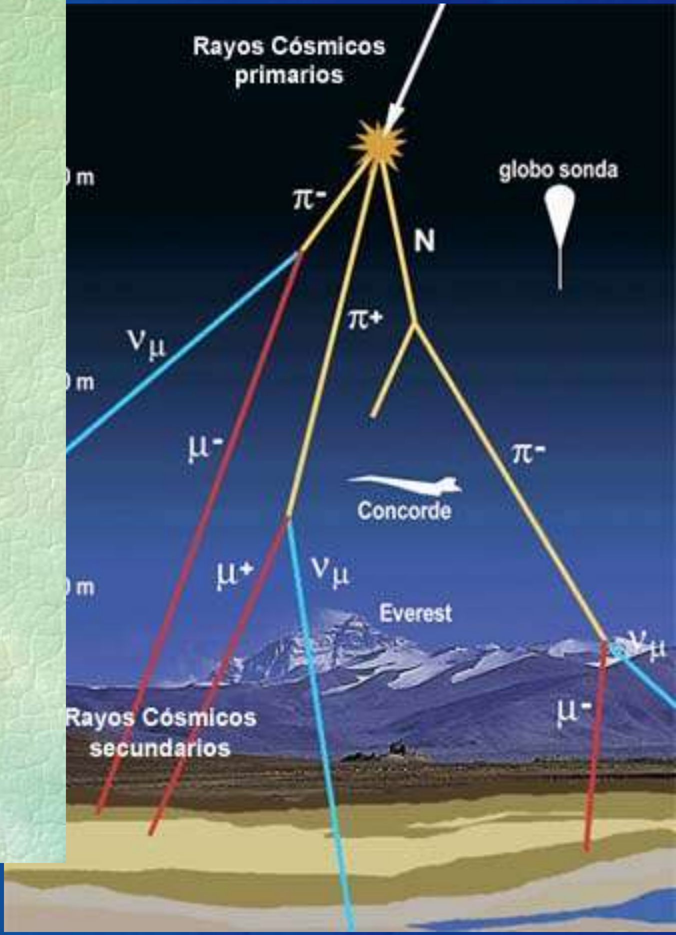
  Major percentage of it comes from outside the solar system and exists throughout space.

  Some of the primary cosmic radiation is from the sun, produced during solar flares.

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity

Cosmic radiation consisting of high speed heavy particles and high energy photons and muons permeates all of space, the source being primarily outside our solar system. The cosmic radiation interacts with the upper atmosphere, and produces cosmogenic radioactive nuclides. They can have long half-lives, but the majority have shorter half-lives than the primordial nuclides.



Naturally Occurring Radioactive Materials NORM

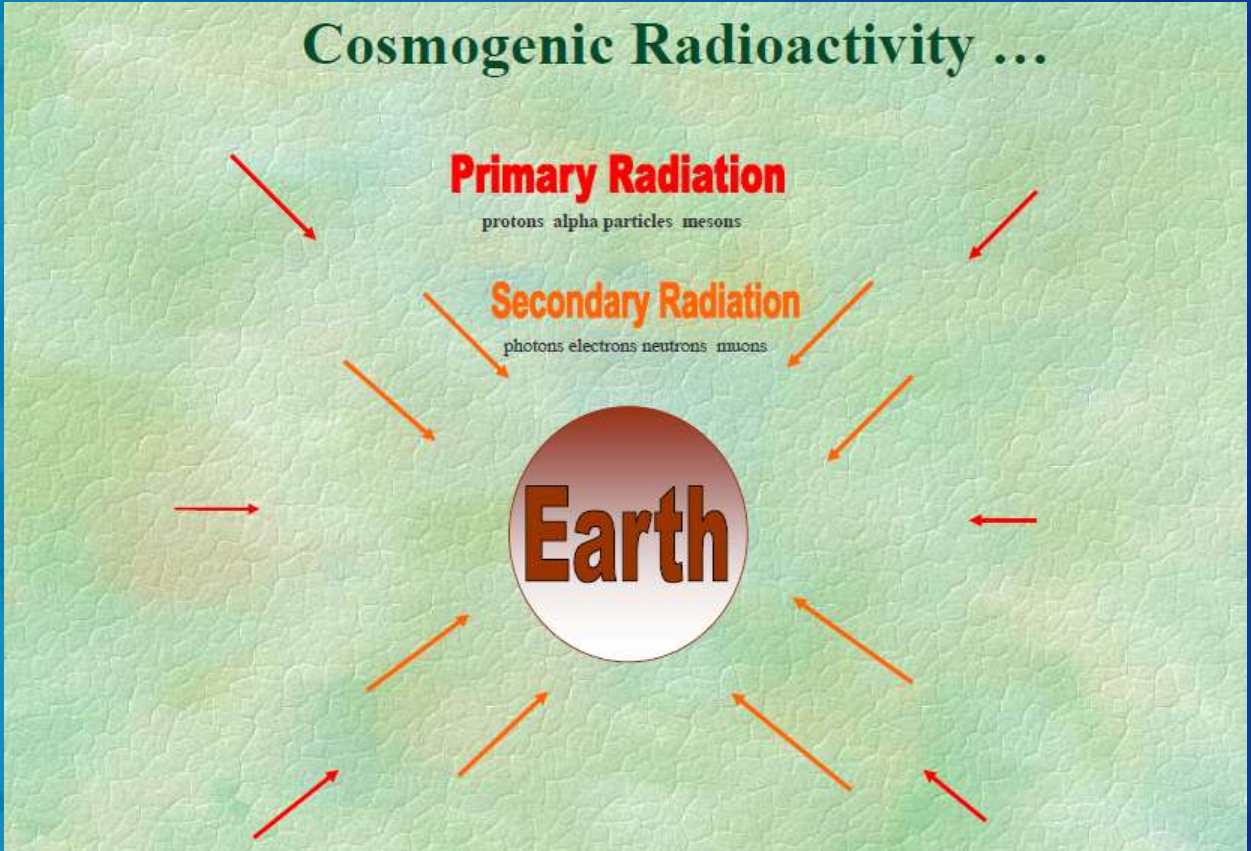


Figure 3 : Conceptual rendering of primary and secondary cosmic radiation isotropically surrounding the Earth. (not drawn to scale)

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity …

- The primary radiation that originate in outer space and impinge isotropically on top of the earth's atmosphere consist of

  85% protons,

  14% alpha particles,

  1% of nuclei between atomic number Z from 4 to 26.

- Primary radiation is highly penetrating with energies in the range 10^{10}eV to 10^{19} eV.

- The major source of cosmic radiation is galactic in origin and a small amount is of solar origin. However, solar flares (in cycles of 11 years) contribute significantly to cosmic radiation.

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity…

- Secondary Radiation:

  Not much of the primary cosmic radiation penetrates the Earth's surface. The vast majority of it interacts with the atmosphere. When the interaction takes place, it produces the secondary cosmic radiation, or that is detected on the Earth. The interactions produce other lower energy radiations in the form of photons, electrons, neutrons, muons, etc. which the surface of the Earth.

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity …

- The atmosphere and the Earth's magnetic fields shield the Earth from cosmic radiation; thereby reduced amount reaches the Earth's surface. Thus the annual dose from cosmic radiation dependent on the **altitude** of the location.
- Dose from cosmic radiation to the U.S., to the average person is about **27 mrem per year; for** every 6,000 foot increase in elevation, the dose roughly doubles .

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity …

- Typical Cosmic Radiation Dose rates:
  - 4 μR/hr in the Northeastern US
  - 20 μR/hr at 15,000 feet
  - 300 μR/hr at 55,000 feet
- There is only about a 10% decrease at sea level in cosmic radiation rates when going from pole to the equator, but at 55,000 feet the decrease is 75%. This is on account of the effect of the earth's and the Sun's geomagnetic fields on the primary cosmic radiations.
- Flying can add a few extra mrem to your annual dose, depending on how often you fly, how high the plane flies, and how long you are in the air.

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity …

Table 4: Some commonly known cosmogenic radioactive nuclides and their activities

Radio -nuclide	Half-life
^{14}C	5730 yr
^{3}H	12.3 yr
^{7}Be	53.28 days

Based on http://www.physics.isu.edu/radinf/natural.htm

Naturally Occurring Radioactive Materials NORM

Cosmogenic Radioactivity …

- Some more cosmogenic radionuclides are ^{26}Al, ^{37}Ar, ^{39}Ar , ^{10}Be, ^{34m}Cl, ^{36}Cl, ^{39}Cl, ^{18}F, ^{80}Kr, ^{38}Mg, ^{24}Na, ^{22}Na, ^{32}P, ^{33}P, ^{31}Si, ^{32}Si, ^{35}S, ^{38}S,

Naturally Occurring Radioactive Materials NORM

Anthropogenic Radioactivity

The use of radioactivity for one hundred years, added to the natural inventories. The ban of above ground testing of nuclear weapons, reduced the amounts and also due to the shorter half-lives of many of the nuclides, have seen a marked decrease.

Naturally Occurring Radioactive Materials NORM

Table 5. Anthropogenic Radio-nuclides

Radionuclide	Half-life
^{3}H	12.3 y
^{131}I	8.04 d
^{129}I	1.57×10^{7} y
^{137}Cs	30.17 y
^{90}Sr	28.78 y
^{99}Tc	2.11×10^{5} y
^{239}Pu	2.41×10^{4} y

Note: Details may be obtained from Environmental radioactivity from natural, industrial, and military scources, 4th edition.

Technologically Enhanced
Naturally Occurring Radioactive Materials
TENORMs

- **NORM - Naturally Occurring Radioactive Material**

- **TENORM – Technologically Enhanced Naturally Occurring Radioactive Material.**

Where anthropogenic Norm & Tenorm?

- ¿Qué es NORM y TENORM?
- Recopilación de industrias afectadas
- Minería y procesado de metales: Al, Cu, TiO_2, Zr, Fe-acero, Sn, oro, arenas de minerales pesados, etc.
- Industrias de minerales
  - Producción de fertilizantes fosfatados
  - Cerámicas y materiales de construcción
- Combustibles:
  - Petróleo y gas
  - Centrales térmicas de carbón
- Otras actividades
  - Producción de energía geotérmica
  - Tratamiento de aguas: potables y residuales

TENORM Contributors

Arranged alphabetically:

Coal Ash
Geothermal Energy Production Waste
Metal Mining and Processing Waste
Oil and Gas Production Scale and Sludge
Paper and Pulp Industry
Phosphate Fertilizers and Potash
Phosphate Industry Wastes
Scrap Metal Release and Recycling
Uranium Overburden and Mine Spoils
Waste Water Treatment Sludge

Identification of industry sectors dealing with NORM

- The industries identified and the relevant radiological considerations are presented in detail in the IAEA Safety Report No. 49 (2006)

1	Extraction of rare earth elements
2	Production and use of thorium and its compounds
3	Production of niobium and ferro-niobium
4	Mining of ores other than uranium ore
5	Production of oil and gas
6	Manufacture of titanium dioxide pigments
7	Phosphate industry
8	Zircon and zirconia industry
9	Production of tin, copper, aluminum
10	Combustion of coal
11	Water treatment

To our surprise, the *combustion of coal* is the most often mentioned industry sector in the questionnaire

Actividades que pueden generar NORM

Minerales y materiales extraídos		Otros procesos
Aluminio	Tierras raras	Tratamiento aguas residuales
Cobre	Estaño	Pasta de celulosa
Yeso	Titanio	Fabricación de cerámica
Hierro	Zirconio	Dióxido de titanio
Mo	Térmicas de carbón	Fundición metales (Fe, Cu, etc.)
Fosfato	Energía geotérmica	Arenas abrasivas y refractarias
Fósforo	Petróleo y gas	Materiales de construcción
		Electrónica

TENORM Sources and Concentrations

http://www.epa.gov/radiation/tenorm/sources.htm

http://www.epa.gov/radiation/tenorm/sources_table.htm

Note:

Please see "TENORM Sources" attached in the lecture notes table.

Please see "TENORM Sources Table" attached in the lecture notes table.

Courtesy of Environmental Protection Agency, USA.

TENORM Summary http://www.epa.gov/radiation/docs/tenorm/402-r-00-001.pdf

- *Note: Please see "TENORM Summary" attached in the lecture notes table.*

Courtesy of Environmental Protection Agency, USA.

Principal radionuclides occurring

Radionucleido	Semivida	Tipo de radiación	Comentarios
^{40}K	$1.28 \cdot 10^{9}$ a	β, γ	No genera cadena
^{238}U	$4.47 \cdot 10^{9}$ a	α, γ	Genera fraccionamiento de 4 subseries con T1/2 alto: ^{238}U, ^{230}Th, ^{226}Ra y ^{210}Pb
^{234}U	$2.5 \cdot 10^{5}$ a	α	
^{230}Th	$7.54 \cdot 10^{4}$ a	α, γ	
^{226}Ra	1600 a	α, γ	
^{222}Rn	3.82 d	α	
^{210}Pb	22 a	β, γ	
^{210}Po	138.4 d	α, γ	
^{235}U	$7.04 \cdot 10^{8}$ a	α, γ	Poco interés radiológico ya que: (^{235}U) = 0.044 (^{238}U)
^{231}Pa	$3.3 \cdot 10^{4}$	α, γ	
^{227}Ac	22 a	α, γ	
^{232}Th	$1.41 \cdot 10^{10}$ a	α, γ	Genera fraccionamiento de 3 subseries con T1/2 alto: ^{232}Th, ^{228}Ra y ^{228}Th
^{228}Ra	5.75 a	β	
^{228}Th	1.91 a	α	

Brief History of NORM in Oil & Gas industry

- **Early accounts of NORM**
  - **Canadian oil field (1904)**
  - **Radium in Russian fields (1930)**
  - **Uranium in gas formations (1953)**
- **NORM in north sea (1985)**
- **Guidelines (API, IAEA, etc.)**
- **Regulations**

- The oil and gas industry is a global industry that operates in many of the Member States of the IAEA.
- There are several sectors in the industry, including:
- (a) The construction sector responsible for manufacturing and fabricating facilities and equipment,
- (b) The exploration sector responsible for finding and evaluating new resources,
- (c) The production sector responsible for developing and exploiting commercially viable oil and gas fields,
- (d) ‘Downstream’ sectors dealing with transport of the raw materials and their processing into saleable products,
- (e) Marketing sectors responsible for the transport and distribution of the finished products.

- Radioactive materials, sealed sources and radiation generators are used extensively by the oil and gas industry, and various solid and liquid wastes containing naturally occurring radioactive material (NORM) are produced.
- The presence of these radioactive materials and radiation generators results in the need to control occupational and public exposures to ionizing radiation.
- Various radioactive wastes are produced in the oil and gas industry, including the following:
- (a) Discrete sealed sources, e.g. spent and disused sealed sources;
- (b) Unsealed sources, e.g. tracers;
- (c) Contaminated items;
- (d) Wastes arising from decontamination activities, e.g. scales and sludges.

- These wastes are generated predominantly in solid and liquid forms and may contain artificial or naturally occurring radionuclides with a wide range of half-lives.
- Work activities and situations which involve potential exposure to ionizing radiation and radioactive materials:

(a) Industrial radiography, including underwater radiography;

(b) Use of installed gauges, including those used to make level and density measurements;

(c) Use of portable gauging equipment;

(d) Well logging, including ‘measurement while drilling’ and wireline techniques;

(e) Work with radiotracers;

(f) Generation, accumulation and disposal of NORM and the decontamination of equipment contaminated by NORM;

(g) Radioactive waste management;

(h) Accidents involving radioactive sources and materials.

EMPLOYEE AND PUBLIC HEALTH IMPACTS – TYPICAL OIL AND GAS OPERATION		
PHASE	EMPLOYEE HEALTH	COMMUNITY HEALTH
Geological Surveys/Seismic	Infectious Disease Foodborne/Waterborne Illness Wildlife & Vector Induced Disease Noise	Infectious Disease Foodborne/Waterborne Illness Wildlife & Vector Induced Disease Noise
Drilling	Chemical/Physical Agent Exposure – Drilling Mud – Petroleum Products – Radioactive sources – Noise	Chemical/Physical Agent Exposure – Drilling Mud – Petroleum Products – Noise
Oil & Gas Production	Chemical/Physical Agent Exposure – Drilling Mud – Petroleum Products – Treatment Chemicals – Radioactive sources – NORM* – Solvents – Metals – Temperature (heat/cold) – Silica/Asbestos – Noise/Vibration – PCB's	Chemical/Physical Agent Exposure – Drilling Mud – Petroleum Products – Solvents – Metals – Noise
Refining	Chemical/Physical Agent Exposure – Petroleum Products** – Solvents – Treatment Chemicals – Metals – Silica/Asbestos – Temperature – Load – Noise/Vibration – PCB	Chemical/Physical Agent Exposure – Petroleum Products – Solvents – Metals – Load – Noise

**NORM – Naturally Occurring Radioactive Material*

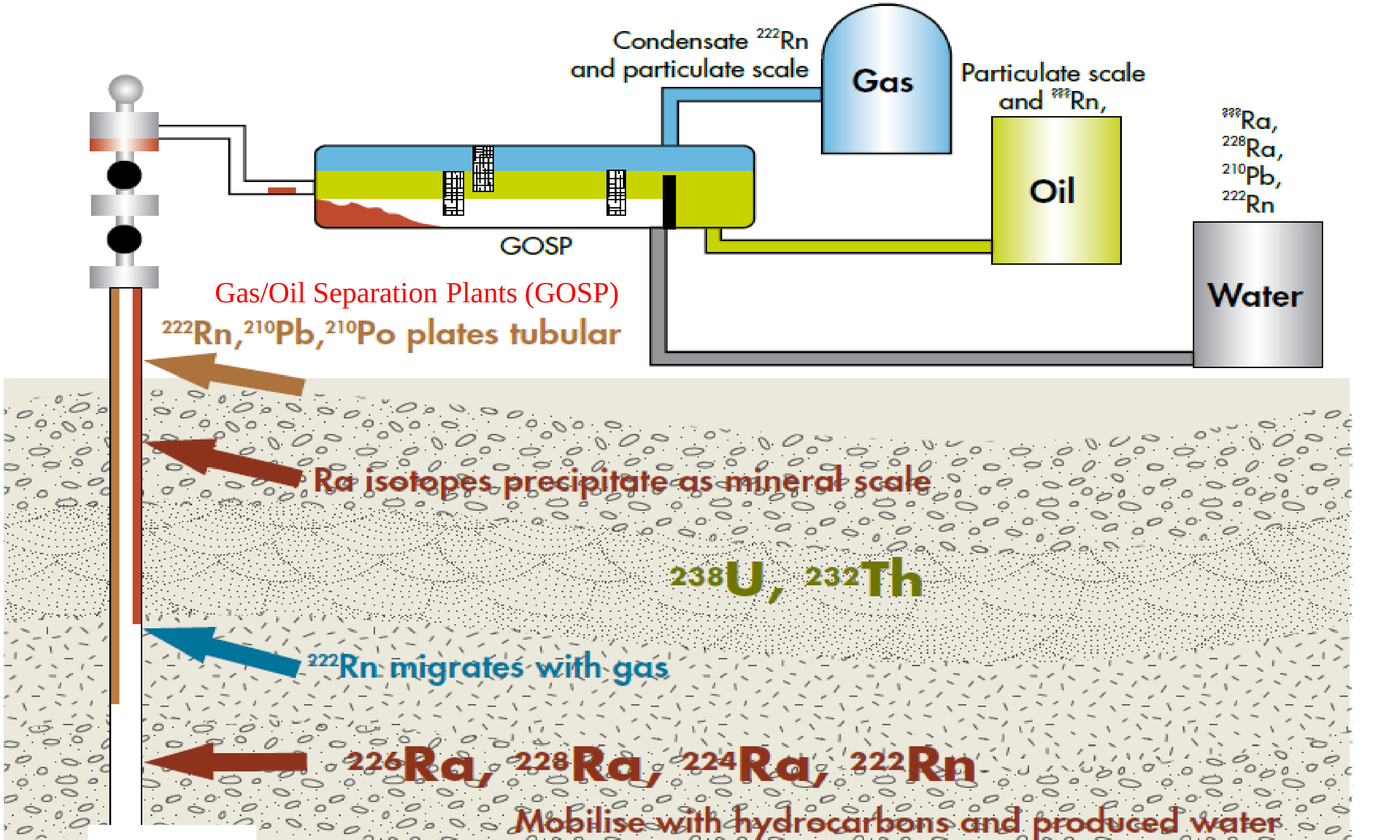
***Refining typically includes a higher concentration of lighter hydrocarbons and, possibly, heavier hydrocarbons such as polycyclic aromatic hydrocarbons*

Which NORM !

NORM nuclides of interest to oil & gas industry

- Radium-226 & Radium-228
- Uranium
- Radon-222
- Lead-210
- Polonium-210

Origins of NORM in the Oil & Gas Industry



Courtesy by International Association of Oil & Gas Producers

Radiation Emitted by NORM

- **Gamma rays**

  Ra-226 and Pb-210

- **Beta particles**

  Ra-228, Pb-210, Bi-210

- **Alpha particles**

  Ra-226,U-238,Po-210 and Pb-210

Summary

- Radioactivty is all around us.
- Radioactive materials exist naturally and also are generated artificially.
- Technological activities enhance natural radioactivity.
- Radioactivity in the environment is from natural, industrial and military sources.

Internet Keywords

- Natural background radiation
- Cosmogenic radiation – primary secondary
- Table of isotopes
- Chart of nuclides
- NORM
- TENORM

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Radioactive Material/ Sources found or used in the Oil and Gas Industry

Offshore Operations

- Naturally Occurring Radioactive Material (NORM)
- Radiography
- Surveys
- Well Logging
- Nucleonic Gauges
- Safety Systems
- Tracers

Naturally Occurring Radioactive Material (NORM)

- Contaminated plant / equipment / pipework sent for cleaning
- Waste removed from vessels and pipelines sent for treatment / disposal
- Samples sent for radiochemical analysis
- Radionuclides present may differ, e.g. -
  - Ra-226, Ra-228 + Daughters
  - Pb-210, Po-210 + Daughters
- Excepted Packages, Industrial Packages and Unpackaged SCO-1
- UN2910, UN2912, UN2915
- Sea, Road and Rail

Where NORM accumulates

NORM may accumulate in the following media:

- Scale
- Scrapings
- Sludge
- Thin films (radon progeny)

NORM in Scale

Photograph courtesy of the Scotoil Group

Courtesy by

ارامكو السعودية
Saudi Aramco

NORM in Scale

- Types of scales
  - Sulfate: $SrSO_4$ and $BaSO_4$ ($RaSO_4$)
  - Carbonate: $CaCO_3$ ($RaCO_3$)
- Effect of water mixing
- Change in pressure/temperature
- Scale accumulates in: production tubing, well head, valves, and pumps
- Scale inhibitors

NORM in Pipelines Scrapings

- Crude pipelines
  (Radium & Pb-210)
- Seawater pipelines
  (Uranium)

Courtesy by
ارامكو السعودية
Saudi Aramco

NORM in Gas Processing Facilities

- **Radon path**
- **Radon progeny**
  - **Pb-210 (22 years)**
  - **Po-210 (138 days)**
  - **Bi-210 (5 days)**

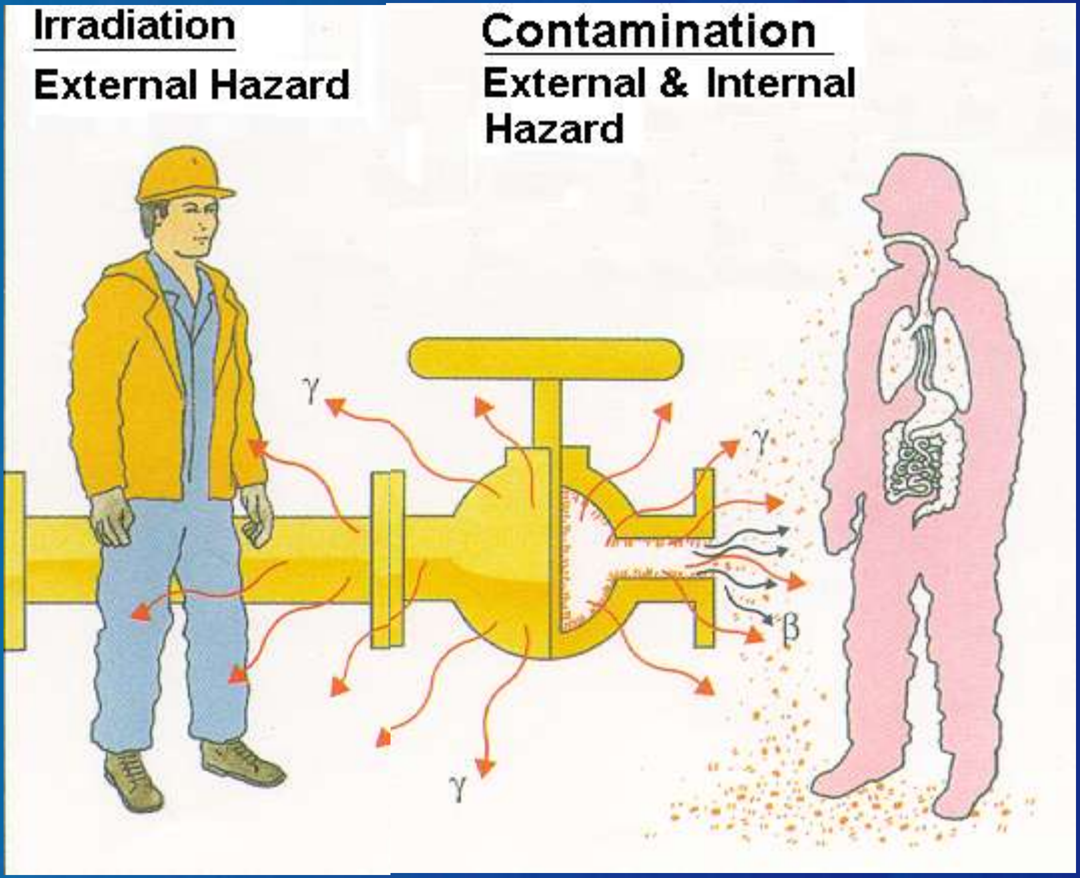
Form thin films on: compressors, reflux pumps, control valves, product lines/vessels.

	Boiling Point (°K, 1 Atm)
Ethane	185
Radon	211
Propane	231

NORM Exposure Scenarios

- **Contamination**
  Inhalation
  Ingestion
  Absorption

- **Irradiation**
  External Exposure



NORM Health Impact

No short-term acute effects

Chronic exposure
(unprotected)

↓

Higher possibility of cancer

NORM Regulations

- **Specifies contamination limits:**
  - **Equipment, waste and soil**
  - **Nuclide dependent**
  - **Country dependent**

Country	Limit of ^{226}Ra (pCi/g)
Canada	8
UK	10
USA	5 to 30

- **EURATOM 96/29**
  "May 2000"

Courtesy by
ارامكو السعودية
Saudi Aramco

NORM Levels

World wide reported levels of NORM

	Specific Activity (pCi/g)		
Nuclide	**Scale**	**Sludge**	**Scrapings**
Ra-226	2.7 – 405000	1.4 – 21600	0.3 – 2000
Pb-210	0.5 – 2025	2.7 – 35100	1.4 – 1350
Po-210	0.5 – 41	0.1 – 4320	2.7 – 108

Courtesy by
ارامكو السعودية
Saudi Aramco

NORM in Natural Gas

- **Radon gas (Rn-222)**
- **EPA limit for Radon in air is 4 pCi/ liter**

Medium	**Specific activity pCi/liter**
Natural gas	0.14 – 5400
NGL	0.27 – 40500
Propane	0.27 – 113400

Courtesy by
ارامكو السعودية
Saudi Aramco

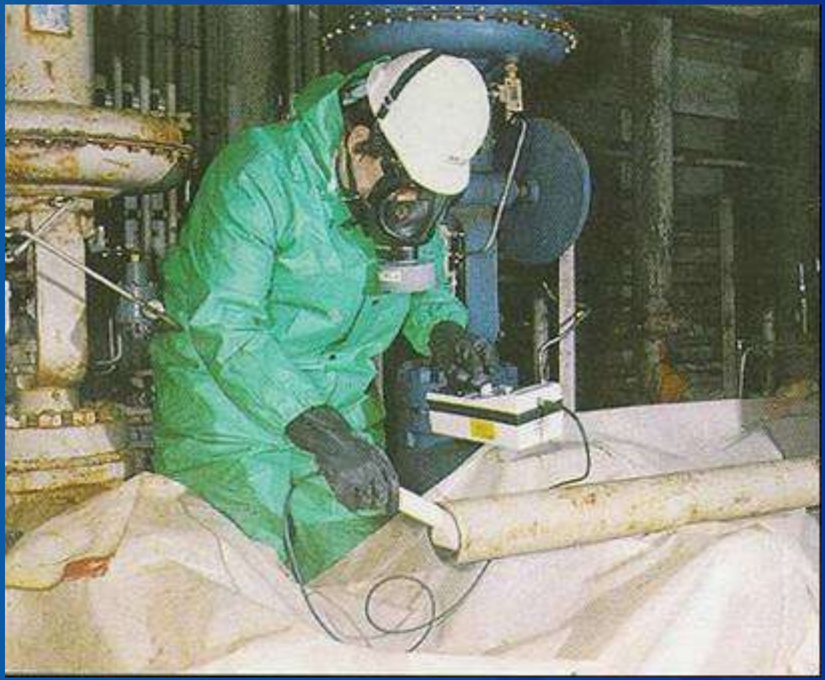
Workers' Radiation Dose

Worker's dose depends on:

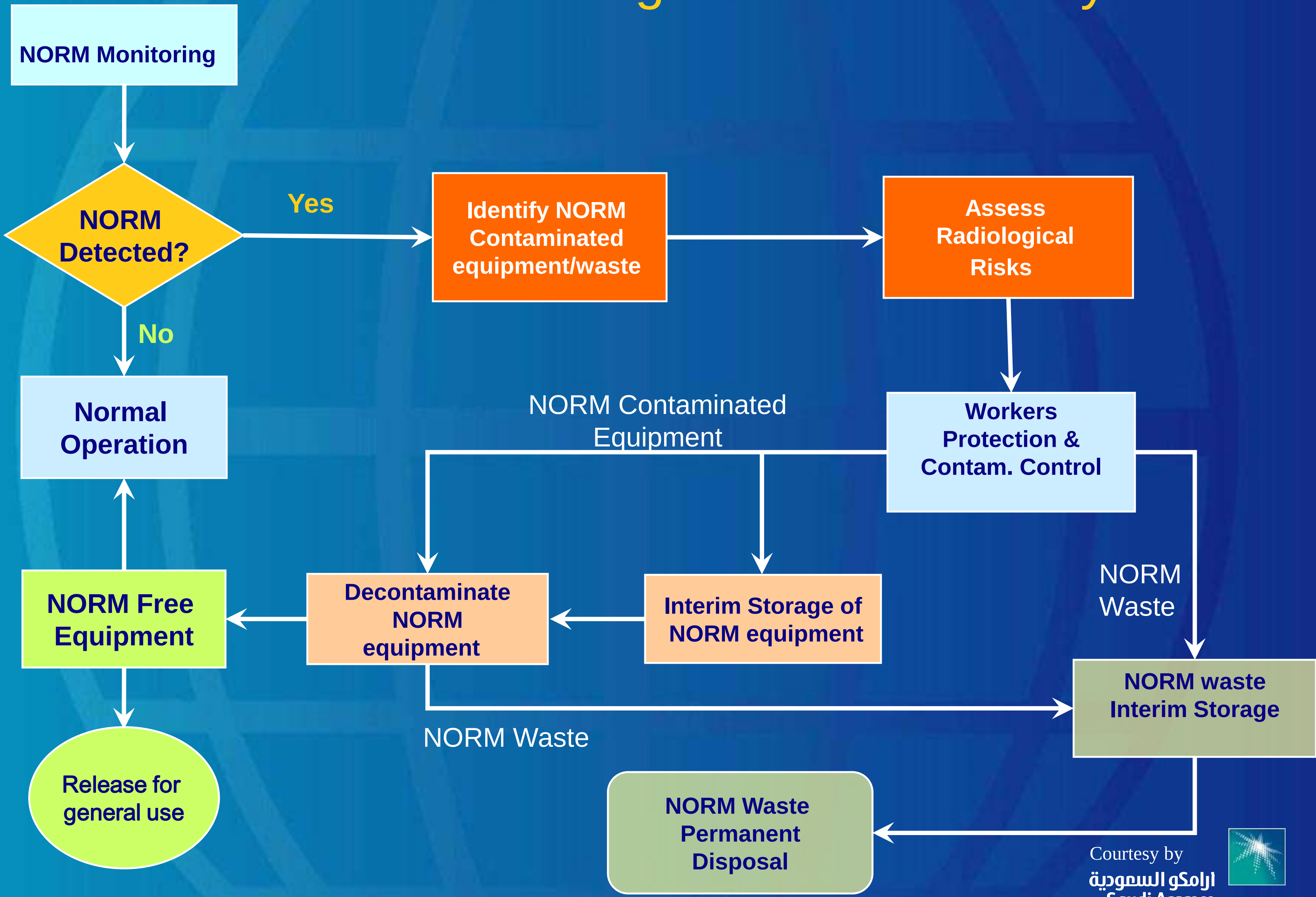
- **Type of work**
  - **Cleaning vessels/tanks**
  - **Maintenance**
- **NORM activity**
- **Time**
- **Protective measures**

Workers Protection

- Awareness/training
- Protective clothes
- Respirators’ use
- Practice good hygiene
- Limited work scenarios



NORM Management Process Cycle



Courtesy by
ارامكو السعودية
Saudi Aramco

Naturally Occurring Radioactive Material (NORM) sent to Drigg

Radiography

- Service companies supply and use source(s)
- Example radionuclides -
  - Iridium-192
  - Selenium-75
  - Ytterbium-169
- Type A and B Packages
- UN3332, UN2916 and UN2917
- Air, Sea and Road

Survey Work

- Service companies supply and use source(s)
- Example radionuclides -
  - Californium-252
  - Caesium-137
- Excepted and Type A Packages
- Road and Sea

Well Logging

- Service companies supply and use source(s)
- Example radionuclides -
  - Am-241 / Be
  - Cf-252
  - Cs-137
  - H-3
- Excepted Packages, Type A and Type B
- Road and Sea

Summary - Packages & Uses

- Excepted Packages
  - NORM samples, smoke detectors, ‘low’ activity sources
- Industrial Packages
  - NORM contaminated equipment and waste
- Unpackaged
  - NORM contaminated tubing / drill pipe
- Type A and B (U) and (M) Packages
  - ‘High’ activity sources

What Next about NORM in industry?

Concluding remarks (P. A. Burns) from

the International Radiation

Protection Association (IRPA), 12th International Congress,

Buenos Aires, Argentina, 19-24 October 2008

What's out there (IRPA 12 cont'd)

- Wide variety of NORM industries:
  - Uranium, Rare Earth minerals;
  - Coal, Oil, Gas;
  - Phosphates, Mineral Processing and others;
- NORM can concentrate in:

Products, by-Products and residues

- Exposure to large populations: small doses
- Exposure to small populations: larger doses
  - Occupational exposure

How to measure it (IRPA 12 cont'd)

Difficult measurement situations:

- Measurement of Activity or activity concentration:
  - Long decay chains – Disequilibrium
  - Hard to measure – radium, radon, thoron, Pb210, Po210.
- Modelling exposure pathways
  - Lot of assumptions
  - Averages adopted for widely varying situations
- Assessing doses to individuals
  - Large uncertainties – internal exposure

What to do about it (IRPA 12 cont'd)

- No one solution to NORM management
- Wide variety of regulatory instruments required
- Graded approach

- Exclusion, exemption, clearance, notification

- Registration, licensing

- Managed as planned or existing exposure situations

- Dose constraints or reference levels

- Numbers of people exposed and magnitude of exposures should be optimised within Dose Bands
- Flexibility required

What about NORM in Europe?

European ALARA Network for
Naturally Occurring Radioactive Materials - **EAN$_{NORM}$**

European ALARA Network for Naturally Occurring Radioactive Materials - NORM

Project of the European Commission, Dec. 2006 - Dec. 2008

Hartmut Schulz, IAF - Radioökologie GmbH (Dresden, Germany), Speaker of the Consortium
Klaus Flesch, IAF - Radioökologie GmbH (Dresden, Germany)
Rainer Gellermann, HGN Hydrogeologie GmbH (Magdeburg, Germany)
Lars Geldner, Robotron Datenbank-Software (Dresden, Germany)
Eckhard Ettenhuber, freelance (Berlin, Germany)

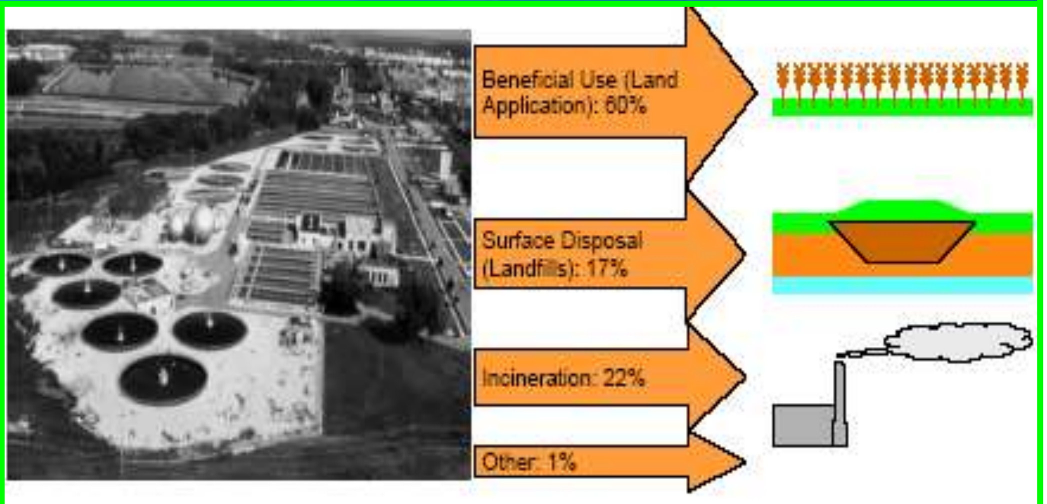
Summary

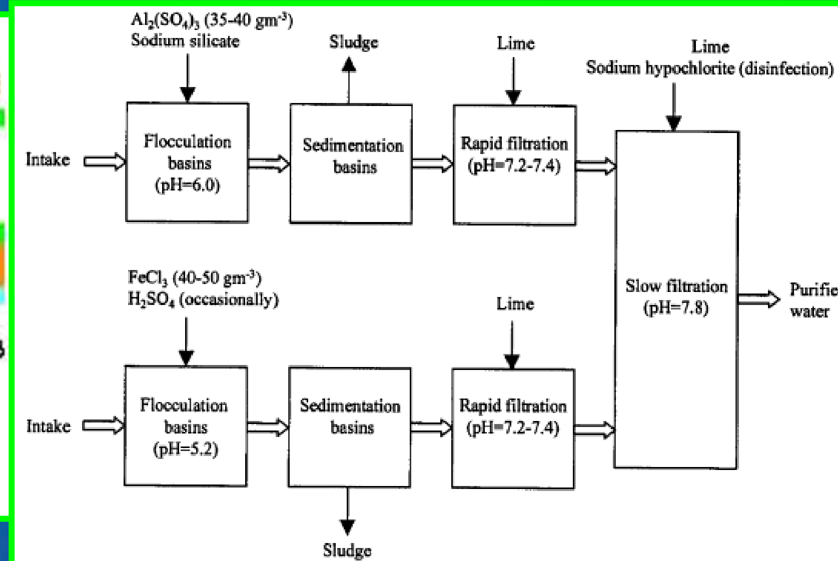
- NORM is a global issue for the oil & gas industry
- NORM health hazards are controllable
- Implementing NORM procedure will not obstruct operations
- NORM limit varies

NATURALLY OCCURRING RADIONUCLIDES IN RAW MATERIALS

Element/mineral	Source	Radioactivity
Aluminium	Ore	250 Bq/(kg U)
	Bauxitic limestone, soil	100–400 Bq/(kg Ra)
	Bauxitic limestone, soil	30–130 Bq/(kg Th)
	Tailings	70–100 Bq/(kg Ra)
Copper	Ore	30–100 000 Bq/(kg U)
	Ore	20–110 Bq/(kg Th)
Fluorspar	Mineral	Uranium series
	Tailings	4000 Bq/(kg Ra)
Iron		Uranium series
		Thorium series
Molybdenum	Tailings	Uranium series
Monazite	Sands	6000–20 000 Bq/(kg U)
		Thorium series (4% by weight)
Natural gas	Gas, average for groups of US and Canadian wells	2–17 000 Bq/(m^3 Rn)
	Gas, individual US and Canadian wells	0.4–54 000 Bq/(m^3 Rn)
	Scale, residue in pumps, vessels and residual gas pipelines	100–50 000 Bq/(kg ^{210}Pb/^{210}Po)
Oil	Brines or produced water	Ranging from mBq to 100 Bq/(L Ra)
	Sludges (scales)	Ranging up to 70 000 Bq/(kg Ra)
		Typically 10^3–10^4 Bq/kg, ranging up to 4×10^6 Bq/(kg Ra)
Phosphate	Ore	100–4000 Bq/(kg $U_{natural}$)
	Ore	15–150 Bq/(kg $Th_{natural}$)
	Ore	600–3000 Bq/(kg Ra)
Potash		Thorium series
		^{40}K
Rare earths		Uranium series
		Thorium series
Tantalum/niobium		Uranium series
		Thorium series
Tin	Ore and slag	1000–2000 Bq/(kg Ra)
Titanium (rutile,	Ore	30–750 Bq/(kg U)
ilmenite)	Ore	35–750 Bq/(kg Th)
Uranium	Ore	15 000 Bq/(kg Ra)
	Slimes	10^5 Bq/(kg Ra)
	Tailings	10 000–20 000 Bq/(kg Ra)
Vanadium		Uranium series
Zinc		Uranium series
		Thorium series
Zirconium (zircon)	Sands	4000 Bq/(kg U)
	Sands	600 Bq/(kg Th)
		4000–7000 Bq/(g Ra)

WATER PROCESSING: DRINKING and WASTE WATERS





ACTIVIDAD (Bq/kg seco) en lodos $Al(OH)_3$ y $Fe(OH)_3$

Lodos	$^{239/240}Pu$	^{232}Th	^{234}U	^{238}U	^{137}Cs	^{210}Pb	^{7}Be
$Al(OH)_3$	0.86	4.53	45.0	61.8	< 2	230	280
$Fe(OH)_3$	0.72	4.54	43.7	62.8	< 2	368	353

EUROPEAN COMMISSION, Sewage Sludge, Directorate General for the Environment, EC, Brussels, http://europa.eu.int/comm/environment/sludge/index.htm.

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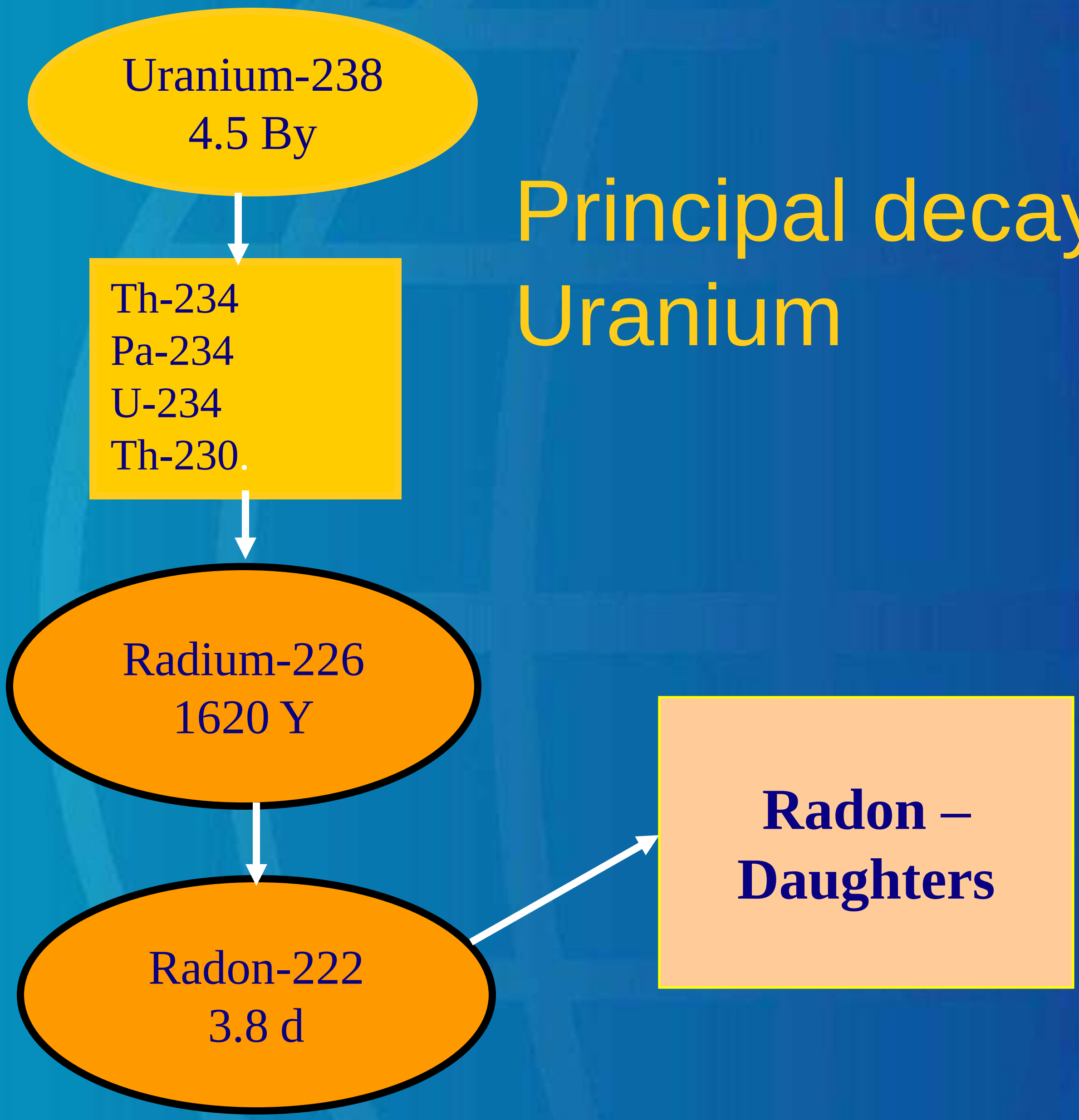
Origins of NORM in Natural Environments

- NORM in earth crust
- NORM in reservoir rock formations
- NORM in Formation water
- NORM in Natural gas
- NORM in Sea water

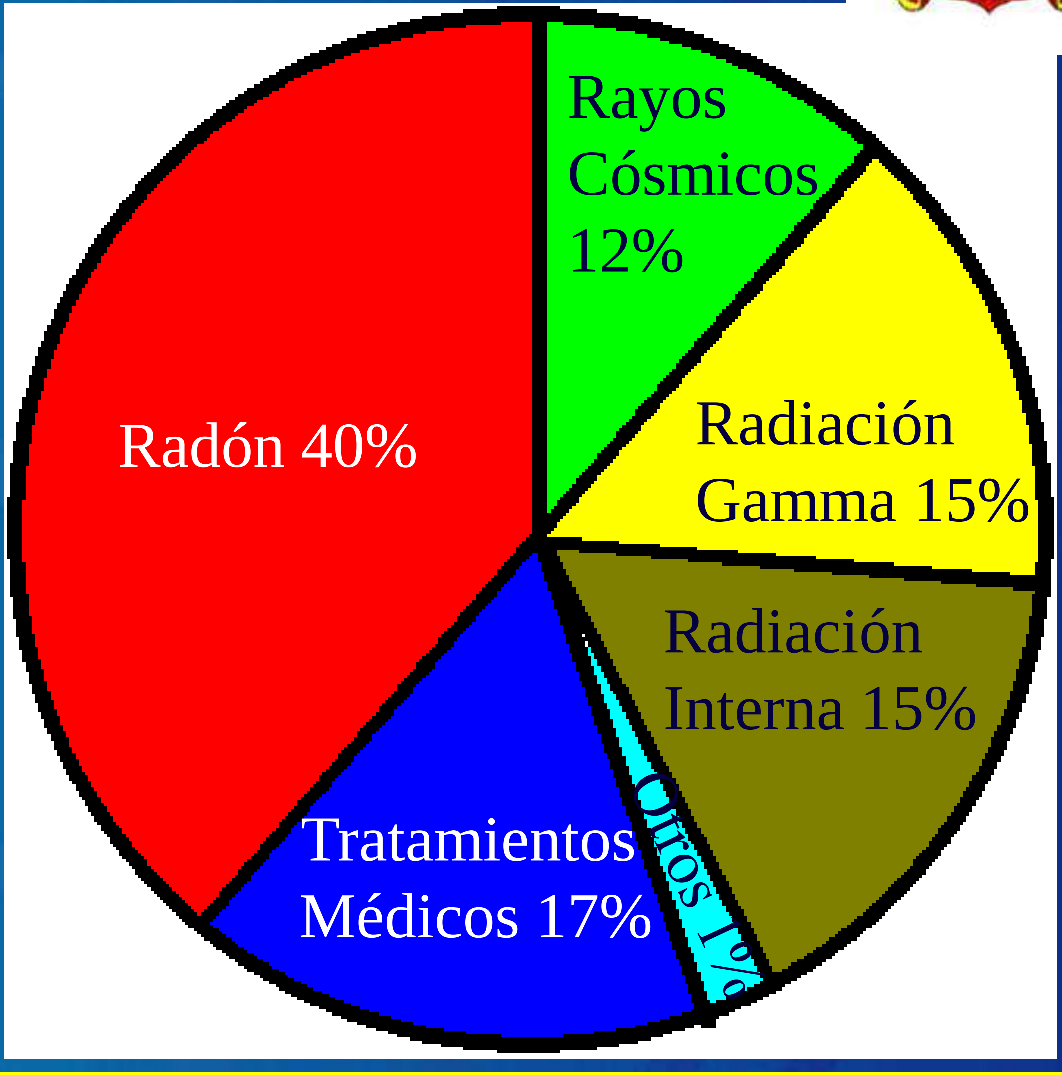
	Uranium ppm	Thorium ppm
Limestone	0.03 - 27	0 - 11
Sandstone	0.1 - 62	0.7 - 227

Principal decay Scheme of Uranium



RADIACTIVIDAD NATURAL

La radiación natural a la que está expuesta la población proviene de la desintegración de isótopos radiactivos en la corteza terrestre, de la radiación cósmica y de los isótopos radiactivos que forman parte de los seres vivos, también llamada radiación interna



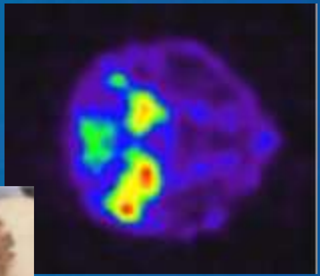
RADIACIÓN EN MEDICINA

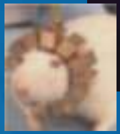
El uso de la radiación en el diagnóstico y el tratamiento de enfermedades se ha convertido en una herramienta básica en medicina. Con ella se ha podido realizar exploraciones del cerebro y los huesos, tratar el cáncer y usar elementos radiactivos para dar seguimiento a hormonas y otros compuestos químicos de los organismos.

Radioterapia

Medicina Nuclear

Diagnóstico Radiológico (Rayos X)





UNIVERSITA' DEGLI STUDI DI SALERNO

Facoltà di Ingegneria

Corso di Laurea in Ingegneria Civile

Building Materials

Radioactiviy Index I :

(Radiation Protection 112, 2000)

$$I = A_{Th}/200 + A_{Ra}/300 + A_{K}/3000$$

granite

brick

Concrete block

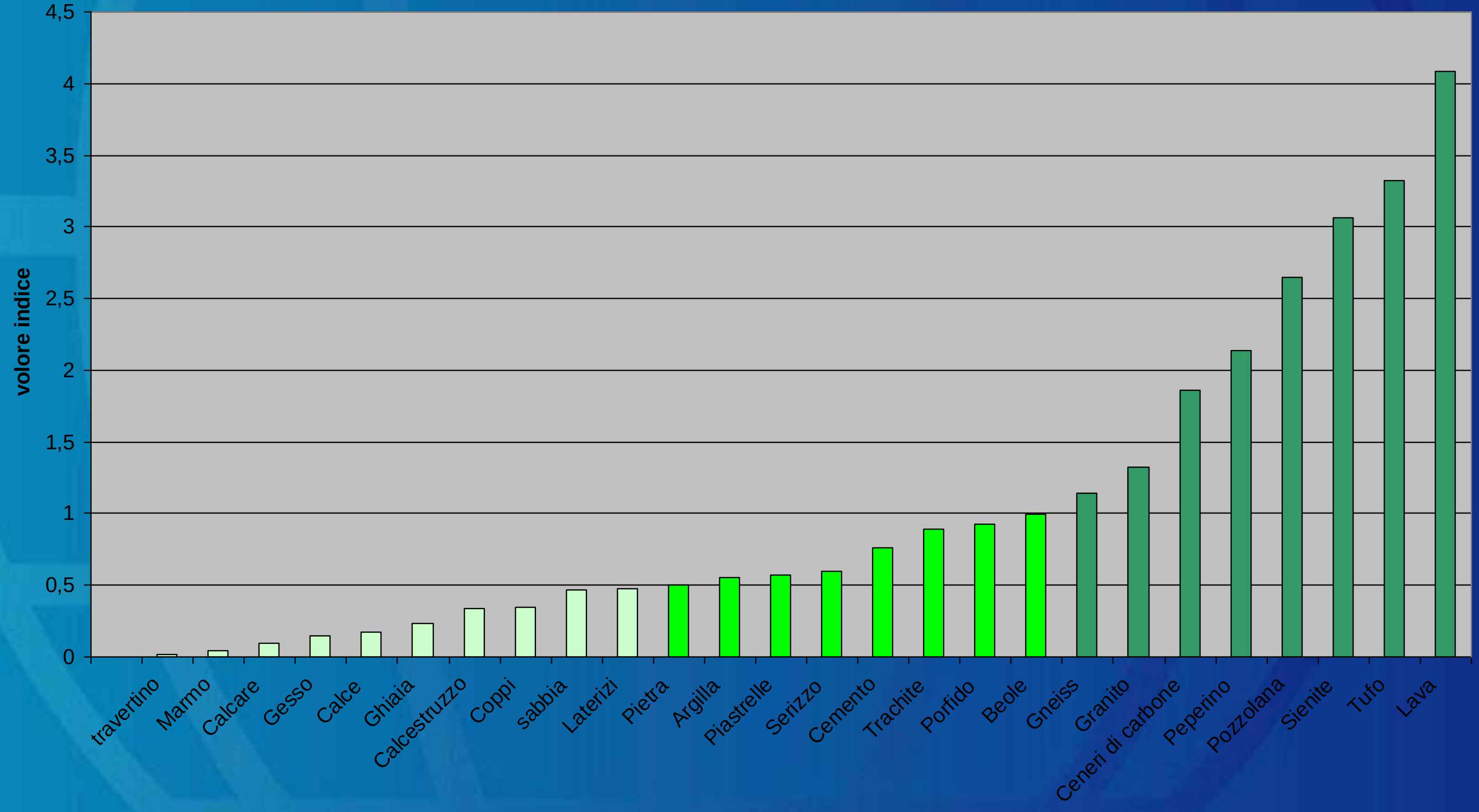
Materiali da costruzione	Concentrazione media di ^{226}Ra (Bq/Kg)	Concentrazione media di ^{232}Th (Bq/Kg)	Concentrazione media di ^{40}K (Bq/Kg)	Indice di Radioattività
travertino	1	0	4	0,004
Marmo	4	1	8	0,021
Calcare	12	1	5	0,046
Gesso	8	3	160	0,095
Calce	9	6	265	0,148
Ghiaia	15	14	157	0,172
Calcestruzzo	22	16	237	0,232
Coppi	59	12	238	0,336
sabbia	18	22	530	0,346
Laterizi	29	26	711	0,463
Pietra	24	37	645	0,48
Argilla	37	40	550	0,506
Piastrelle	43	36	689	0,553
Serizzo	31	42	782	0,574
Cemento	42	66	369	0,593
Trachite	36	52	1154	0,764
Porfido	41	59	1388	0,894
Beole	63	48	1432	0,927
Gneiss	87	71	1040	0,991
Granito	89	**94**	1126	1,142
Ceneri di carbone	160	130	420	1,323
Peperino	159	171	1422	1,859
Pozzolana	164	229	1341	2,138
Sienite	317	234	1255	2,645
Tufo	209	349	1861	3,062
Lava	473	230	1781	3,32
Basalto	208	466	2178	[illegible]

I ≤ 0.5

0.5 < I ≤ 1

I > 1

Radioactivity Index I in building materials



F. Vigorito, Tesi di Laurea in Ingegneria Civile, Università di Salerno, 2006

URANIUM SERIES:

^{238}U → ^{234}Th → ^{234}U → ^{230}Th →

α, $t_{1/2}$ = 4.47Ga β, $t_{1/2}$ = 24 days α, $t_{1/2}$ = 244,000 yr $t_{1/2}$ = 77,000yr

^{226}Ra → ^{222}Rn → ^{218}Po → ^{214}Pb

$t_{1/2}$ = 1600y α, $t_{1/2}$ =3.8 days

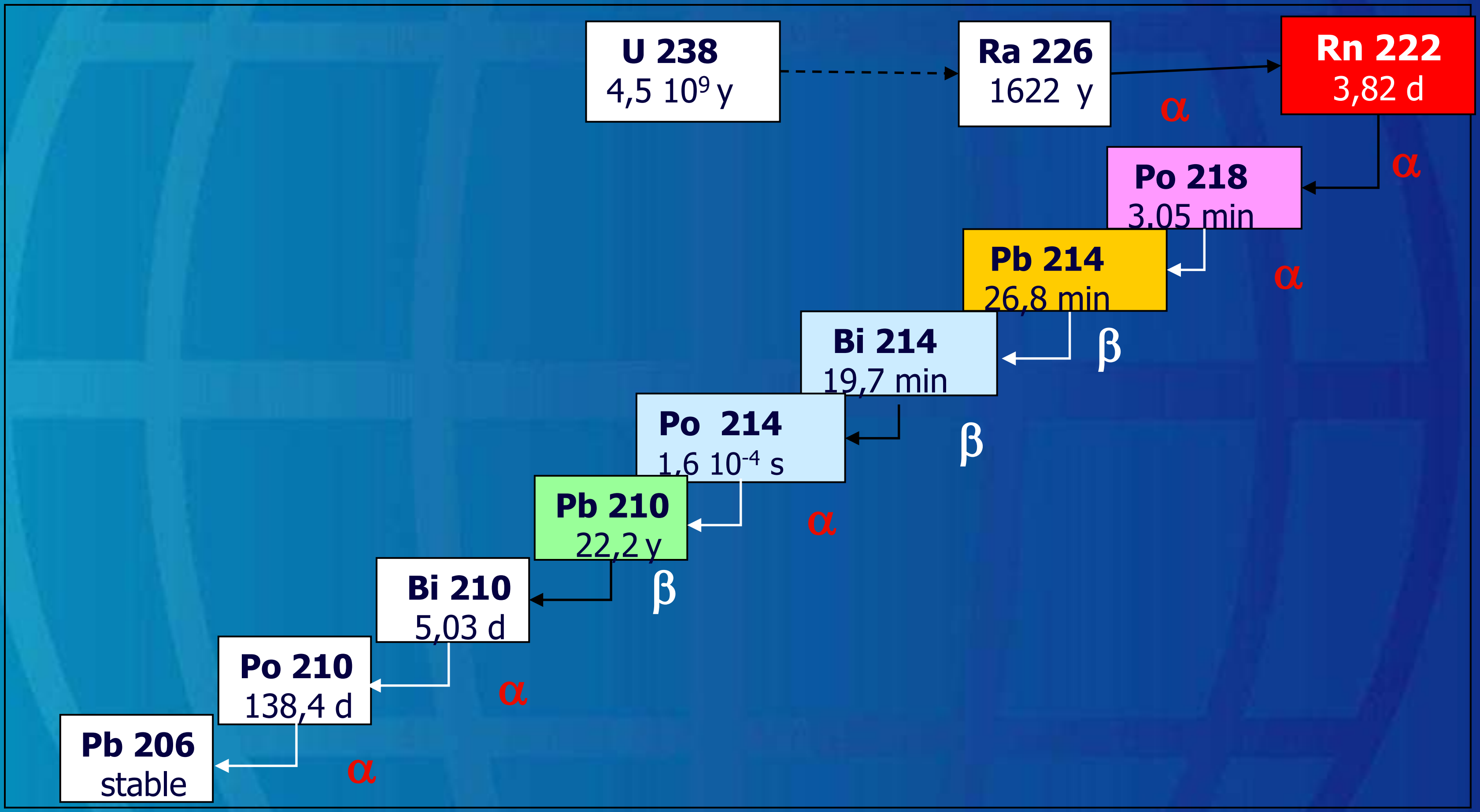
- ^{234}Th : refractory, insoluble in water.
- ^{234}U : stable, U $O2^{++}$.
- ^{226}Ra : alkaline earth, highly mobile, highly soluble in water.
- ^{222}Rn : noble gas, volatile, doesn't react, highly mobile (causes problems).
- ^{218}Po : heavy metal.

→ limited by decay, better off if can be measured directly in mass spec.

Radon: Overview of Properties

- Radon is a unique natural element in being a gas, noble, and radioactive in all its isotopes.
- Radon is the heaviest member of the noble gas family and is colorless, odorless, relatively chemically inert, naturally radioactive, and has the highest melting point, boiling point, critical temperature and critical pressure of noble gases.
- It is soluble in water and has a higher solubility in some organic solvents.
- As a noble gas, it is not immobilized by chemically reacting with the medium that permeates.
- Free radon normally diminishes only by its radioactive decay as it moves from its source.
- Its radioactivity allows radon to be measured with remarkable sensitivity.

The three primary sources for natural radon are the parent isotopes of the two uranium series (^{238}U and ^{235}U) and the Thorium series (^{232}Th).



Radioactive Decay

- Radioactive decay: $$\frac{dN}{dt} = -N\lambda$$
- The solution is: $$N(t) = N_0\, e^{-\lambda t}$$
- λ is related to the half-life: $$\lambda = \frac{\ln 2}{t_{1/2}}$$
- For the general case of A→ B, where both A and B are radioactive , the differential equation describing the production of B from the decay of A and the subsequent radioactive decay of B:

$$\frac{dN_B}{dt} = N_A\lambda_A - N_B\lambda_B$$

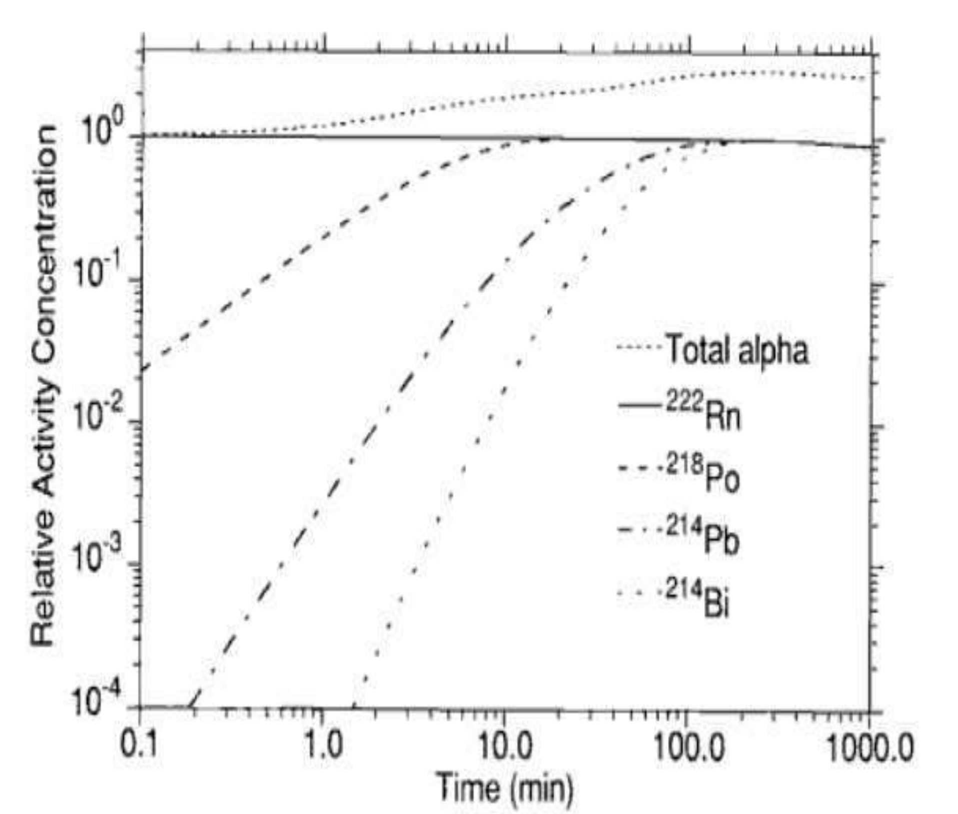
If the half-life of the daughter radionuclide B is much shorter than the half-life of the parent radionuclide A, the decay rate of A, and hence the production rate of B, is approximately constant, because the half-life of A is very long compared to the timescales being considered.

Radon Secular Equilibrium

As Radon has a half-life (3.82 d) much longer than its daughter radionuclides (^{218}Po – 3.05 m, ^{214}Pb – 26.8 m, ^{214}Bi – 19.7 m) a radioactive equilibrium (called secular equilibrium) is achieved after approximatively 3 h.

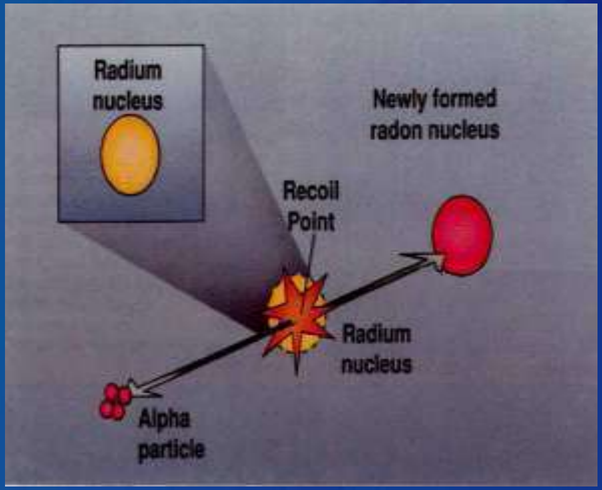
After that time,

the activity concentrations of the short-lived decay products are essentially equal to that of the radon parent.



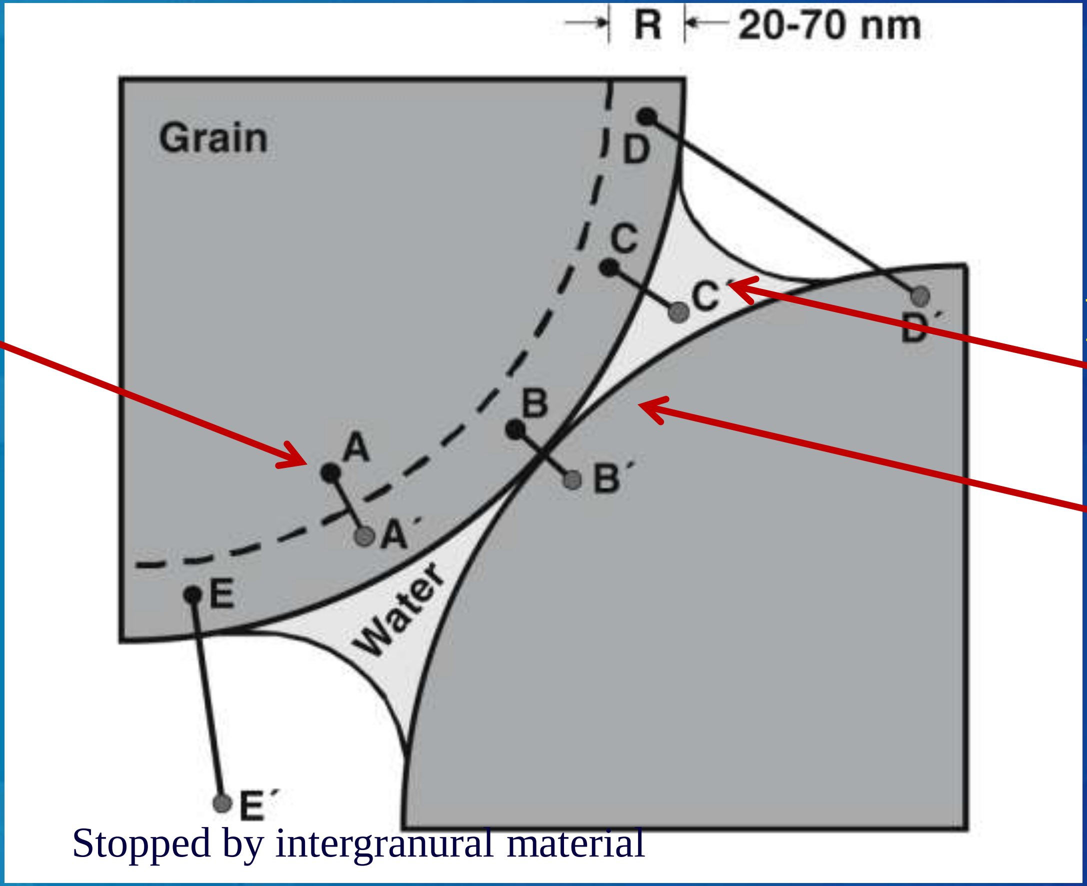
Release Mechanism

- Most radon that is produced by the decay of radium never escapes from the mineral in which it is born.
- The small fraction of radon that escapes is either released promptly as it is born or within the few days before it decays.
- The release mechanism is the direct ejection of the radon atom by recoil from alpha emission.
- Conservation of momentum reveals that emission of an alpha particle with 4.78 MeV by ^{226}Ra gives the ^{222}Rn nucleus a recoil energy of 86 keV.



Release Mechanism

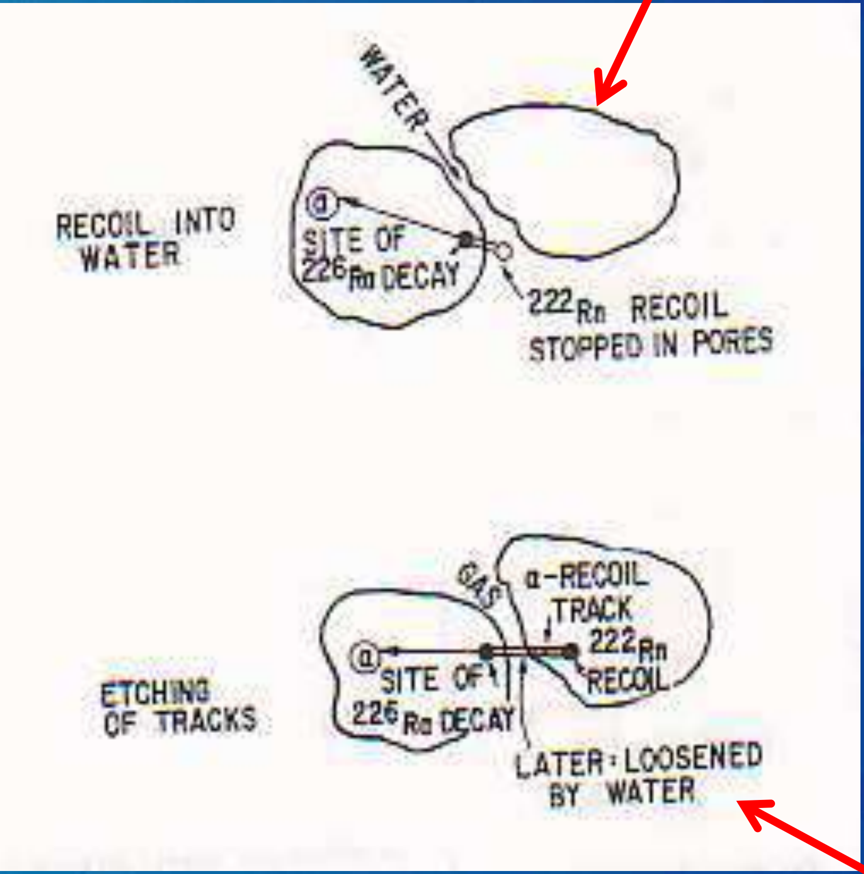
Inside the same mineral grain



From mineral to water

From one mineral to adjacent mineral

If the pore space contains water, the ejected radon atom will rest in the liquid and is free to diffuse from the water or be transported by it.



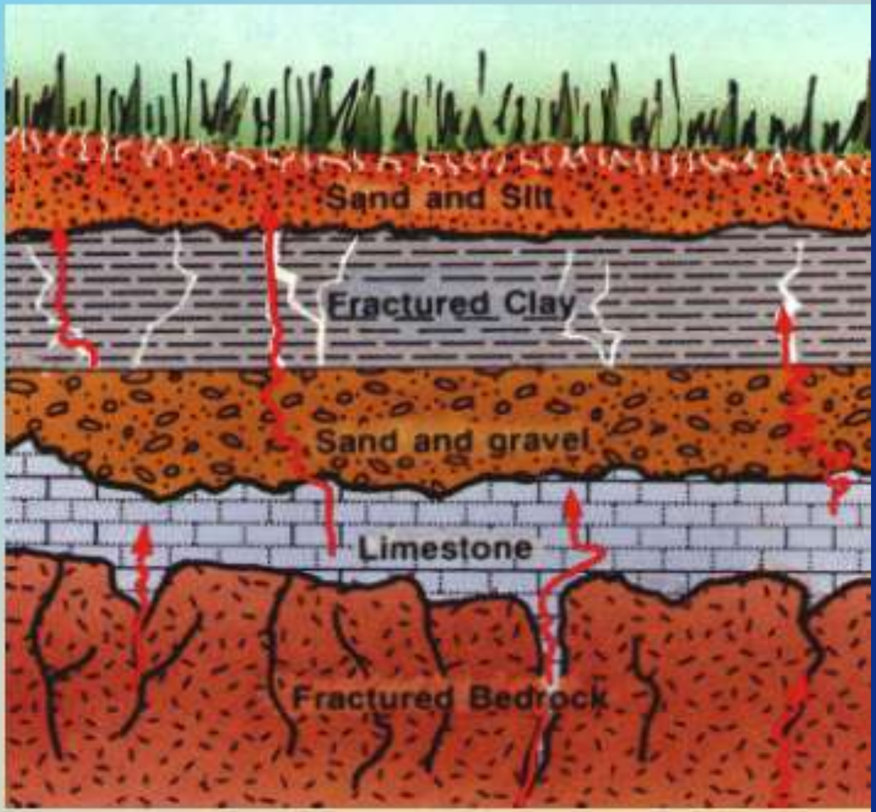
If the interstitial space is dry (i.e. filled only with soil gas) and not wide enough to stop the recoiling radon, it will enter a neighboring grain.

Radon in soil:

1. Mean grain size (lower grain size, higher [Rn]).
2. [U] in soil.
3. Thickness of soil
4. Permeability (sandy soil has high permeability, low [U];
   - clay soil has low air flow, high [U]).

How and where is the ^{238}U molecule situated?

- It doesn't have a site in most common crystal lattices (sedimentary deposits).
- Your house is built on quartz, feldspars, micas, clays, carbonates,
- **Therefore, the ^{238}U is often present along the grain boundaries!!**



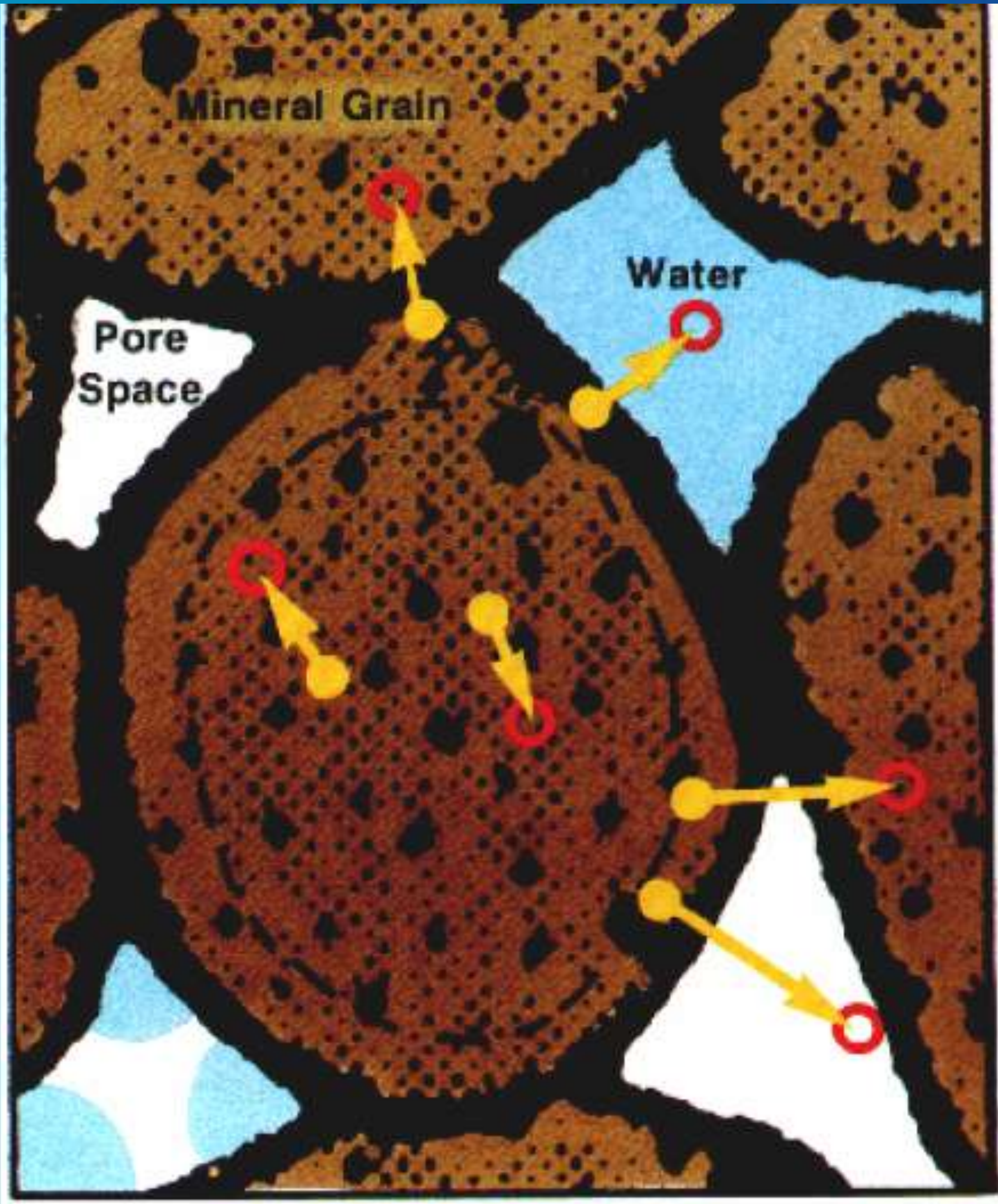
Some radon atoms remain trapped in the soil and decay to form lead: other atoms escape quickly into the air.

http://energy.cr.usgs.gov/radon/georadon/3.html

- ^{234}U, Th - with each decay, nucleus moves a small finite distance due to conservation of momentum.
    - Therefore, there is displacement.

  - Therefore, is 1 ppm U (typical for crustal rocks) --->10,000 Bq/m^3 (1 Bq = 1 dps)
  - If some escapes, still get 10,000 Bq/m^3.
  - Rn can escape from carbonate rocks (porous).

http://energy.cr.usgs.gov/radon/georadon/3.html



Area within a mineral grain from which radon can potentially escape into pore space.

Radium atom before it decays to radon

Newly formed radon atom

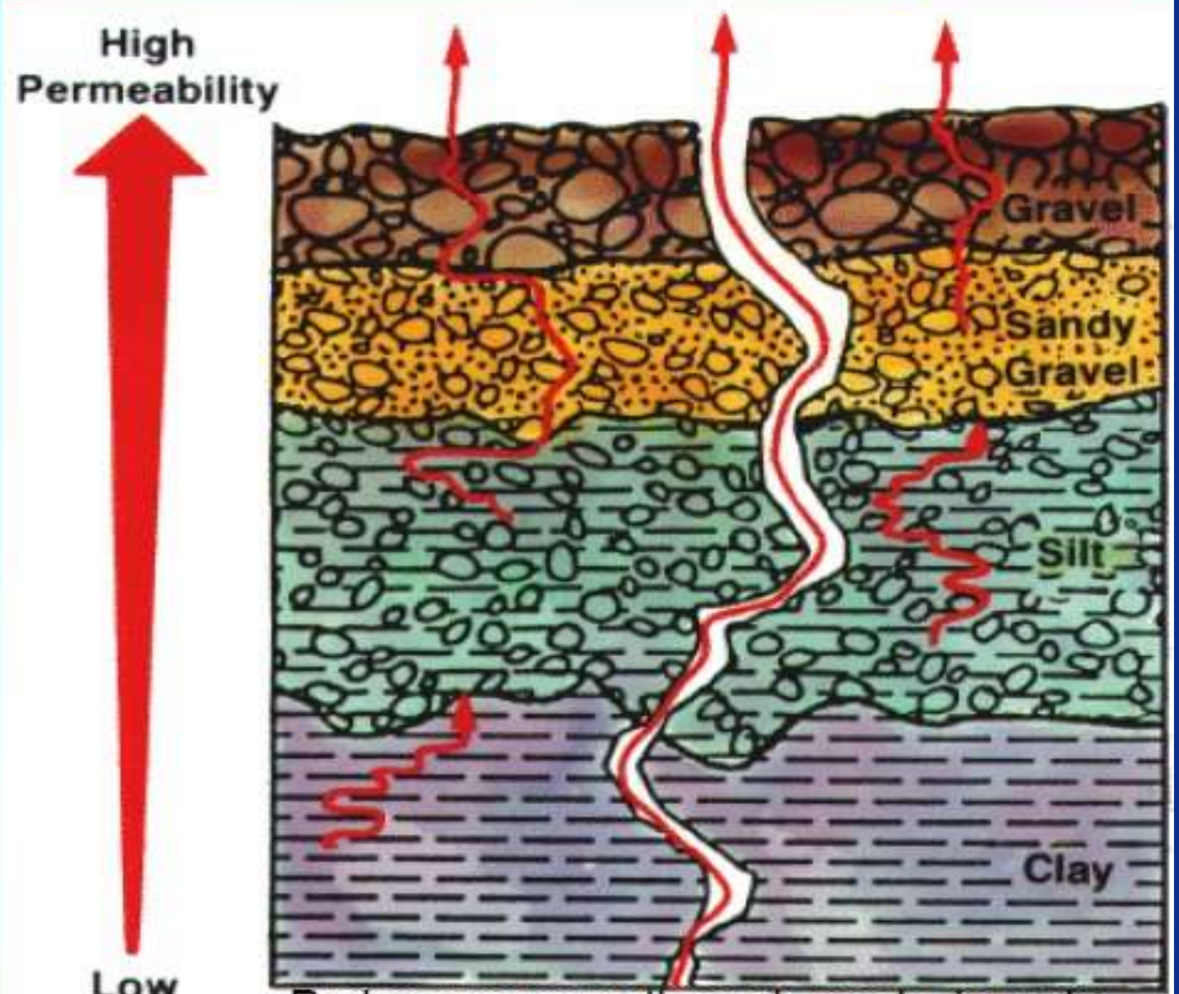
Most of the radon produced within a mineral grain remains embedded in the grain, only 10 to 50 percent escapes to enter the pore space. If water is present in the pore space, the radon atom can more easily remain in the pore space; if the pore space is dry, the radon atom may shoot across the pore and embed in another grain where it cannot move.

Controlling Variables on Radon in soil

1. [^{238}U] in soil.
2. Mean grain size
   - sand vs clay, U is more likely to be located near grain boundary in clay because there is a higher surface area/volume ratio.
   - Rn loss is a function of grain size.

Controlling Variables on Radon in soil

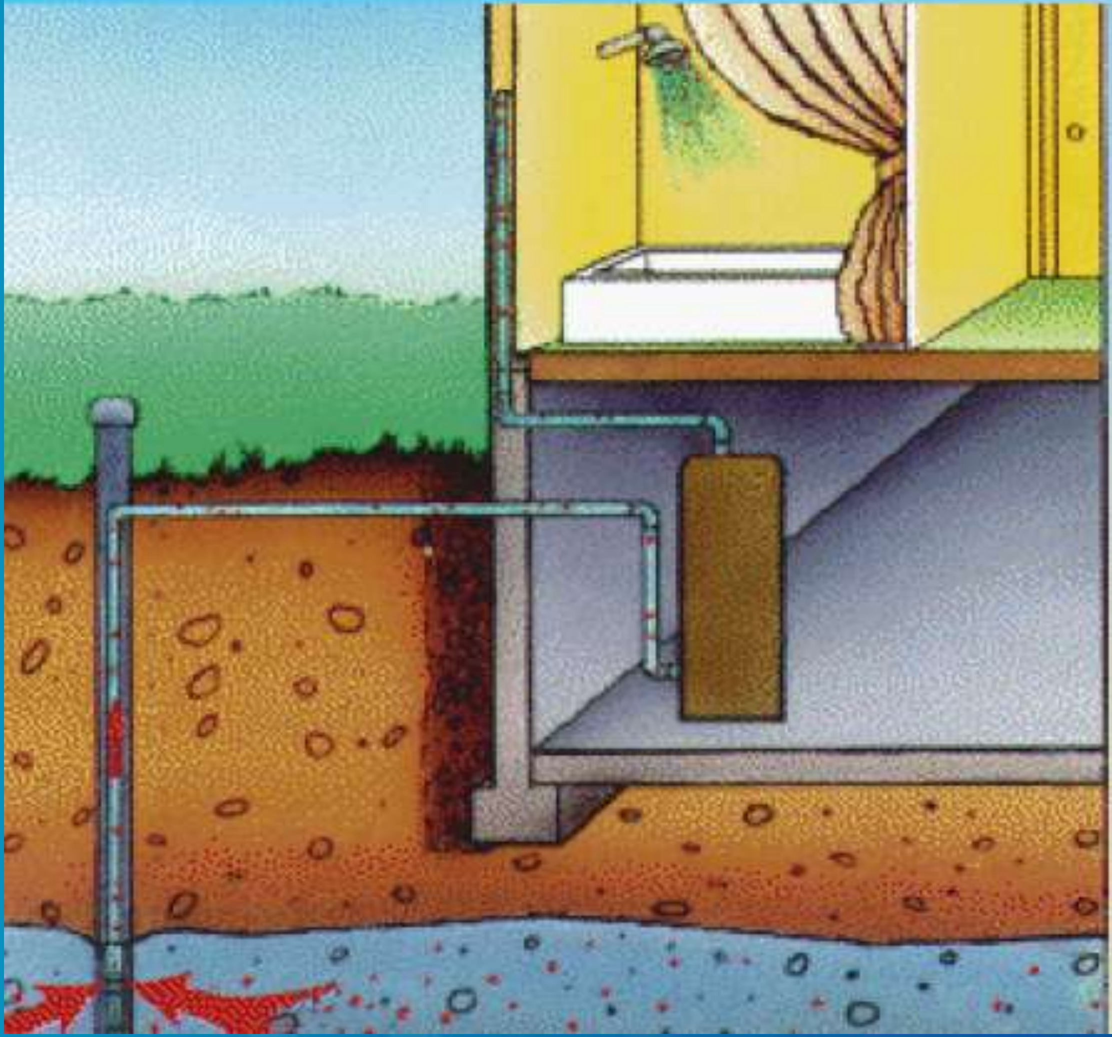
3. Permeability
   - flow → flows are slower in clay than in sand.
   - permeability decreases as grain size decreases.
   - most remediation schemes attempt to reduce permeability.

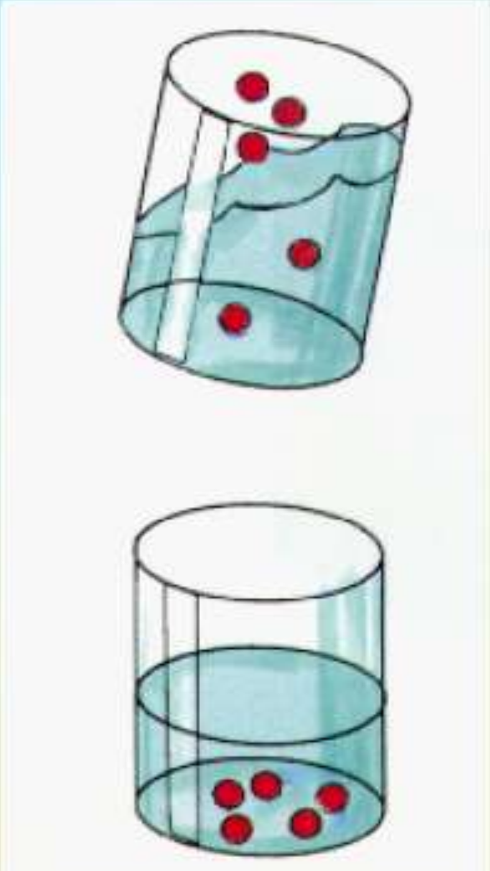


Radon can move through cracks in rocks and through pore spaces in soils.

http://energy.cr.usgs.gov/radon/georadon/3.html

In areas where the main water supply is from private wells and small public water works, radon in ground water can add radon to the indoor air.





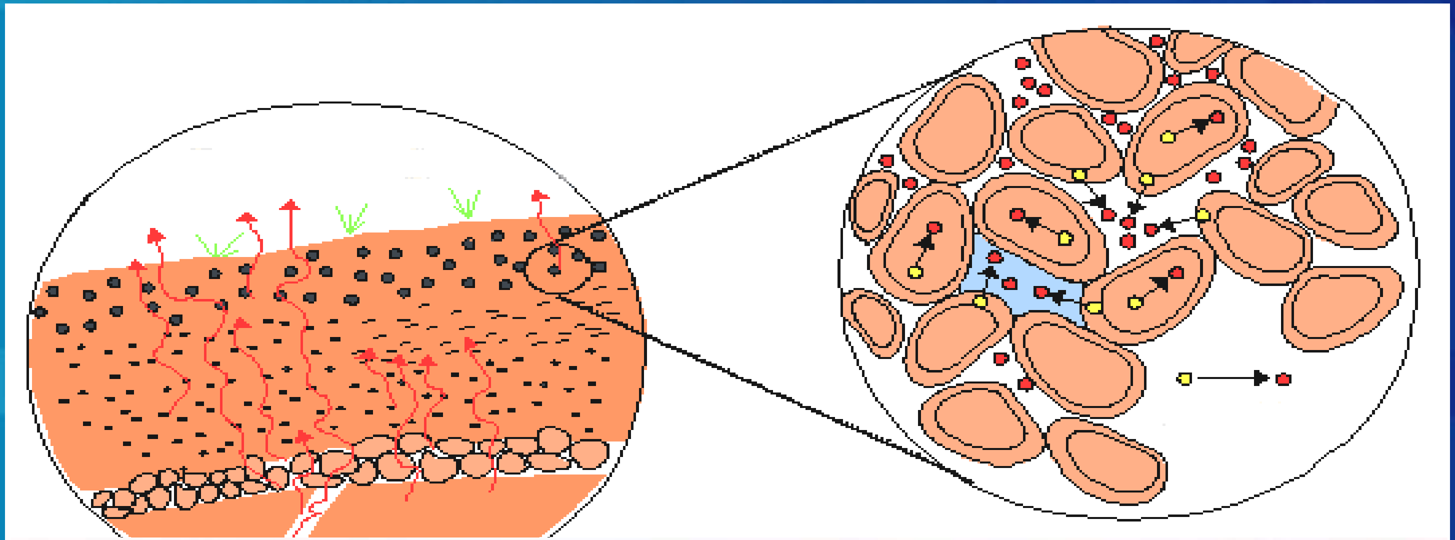
Radon escapes from water when it is agitated.

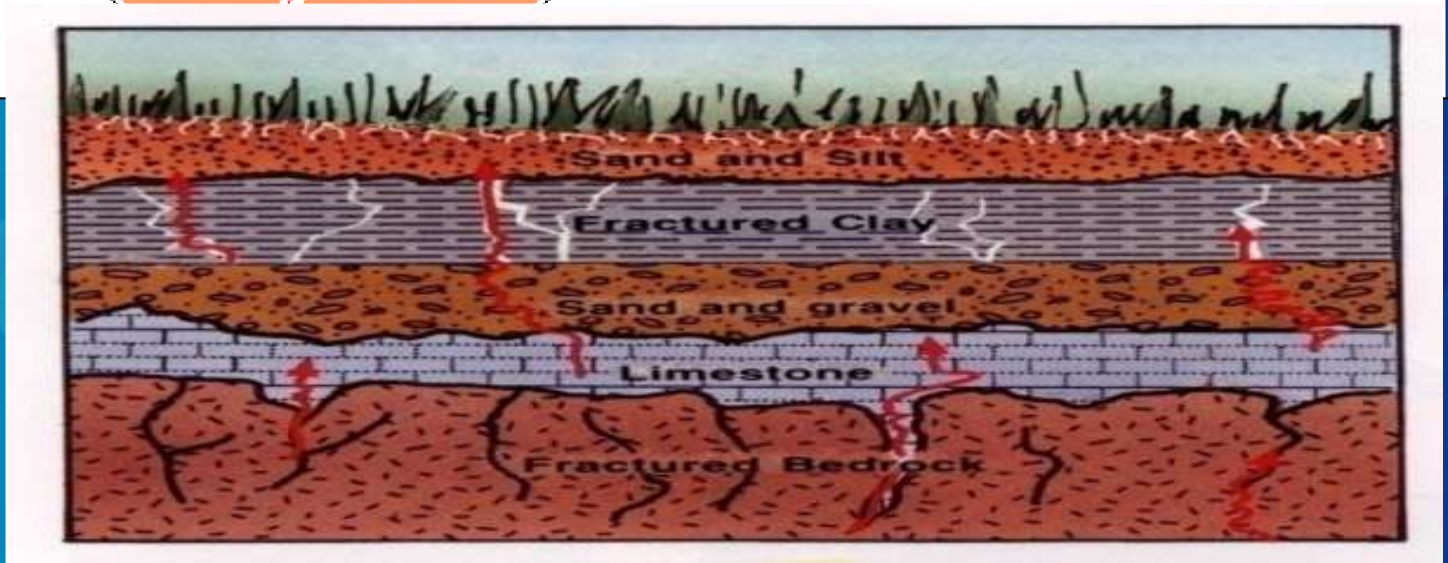
http://energy.cr.usgs.gov/radon/georadon/3.html

Controlling Variables on Radon in soil

4. [Rn] in ground water is not a problem at 0-20 Bq/L, unless used for a domestic source (Rn produced from U decay enters ground water).

^{222}Rn: a Naturally Occurring Tracers for Investigation of transport phenomena in the Litosphere: Emanation and Exhalation

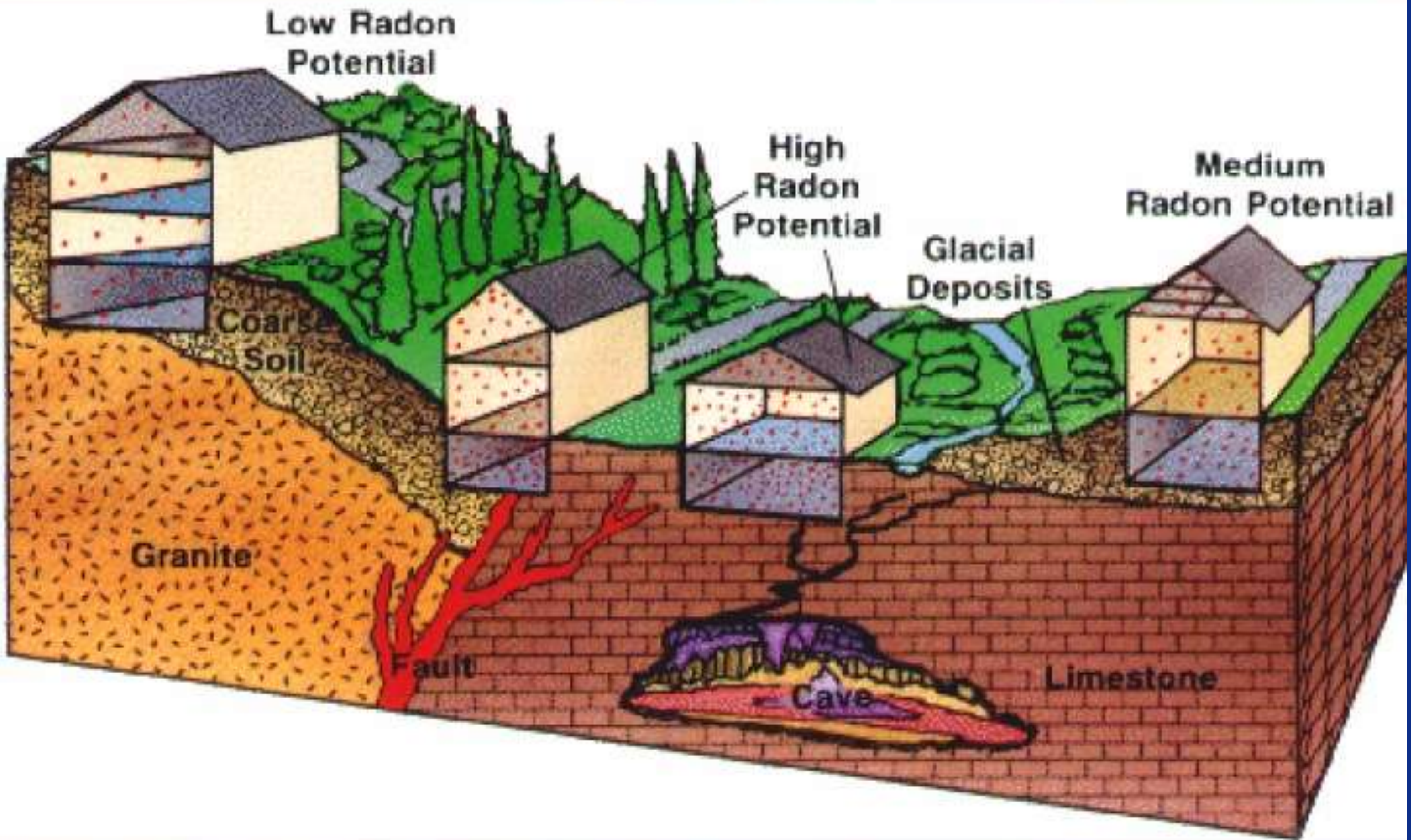




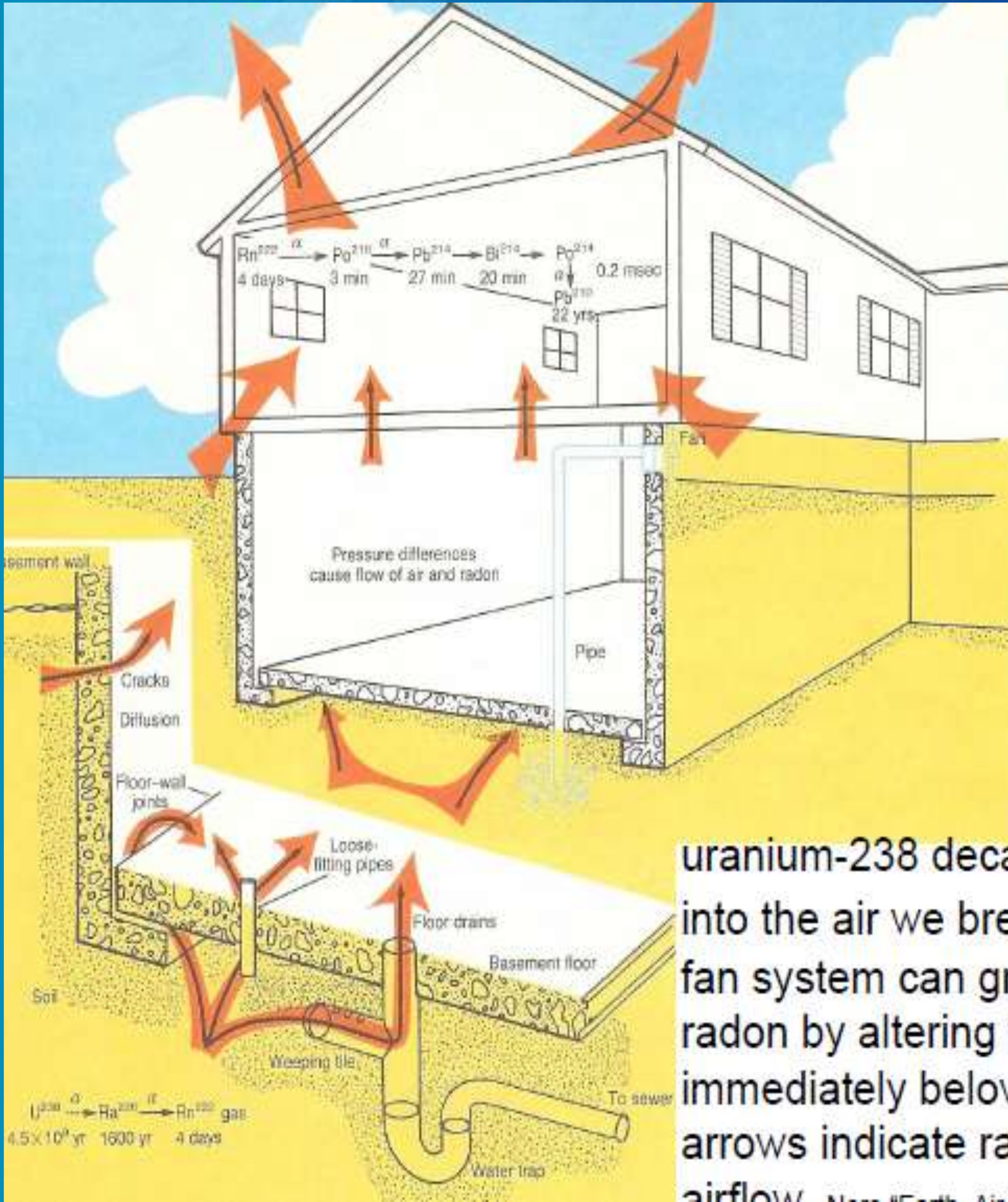
Risk factors?

- only 1-10% Rn present has to leak out to cause problems.
- [^{222}Rn] in soil directly determines the [^{222}Rn] in the house (is a way to remediate this).

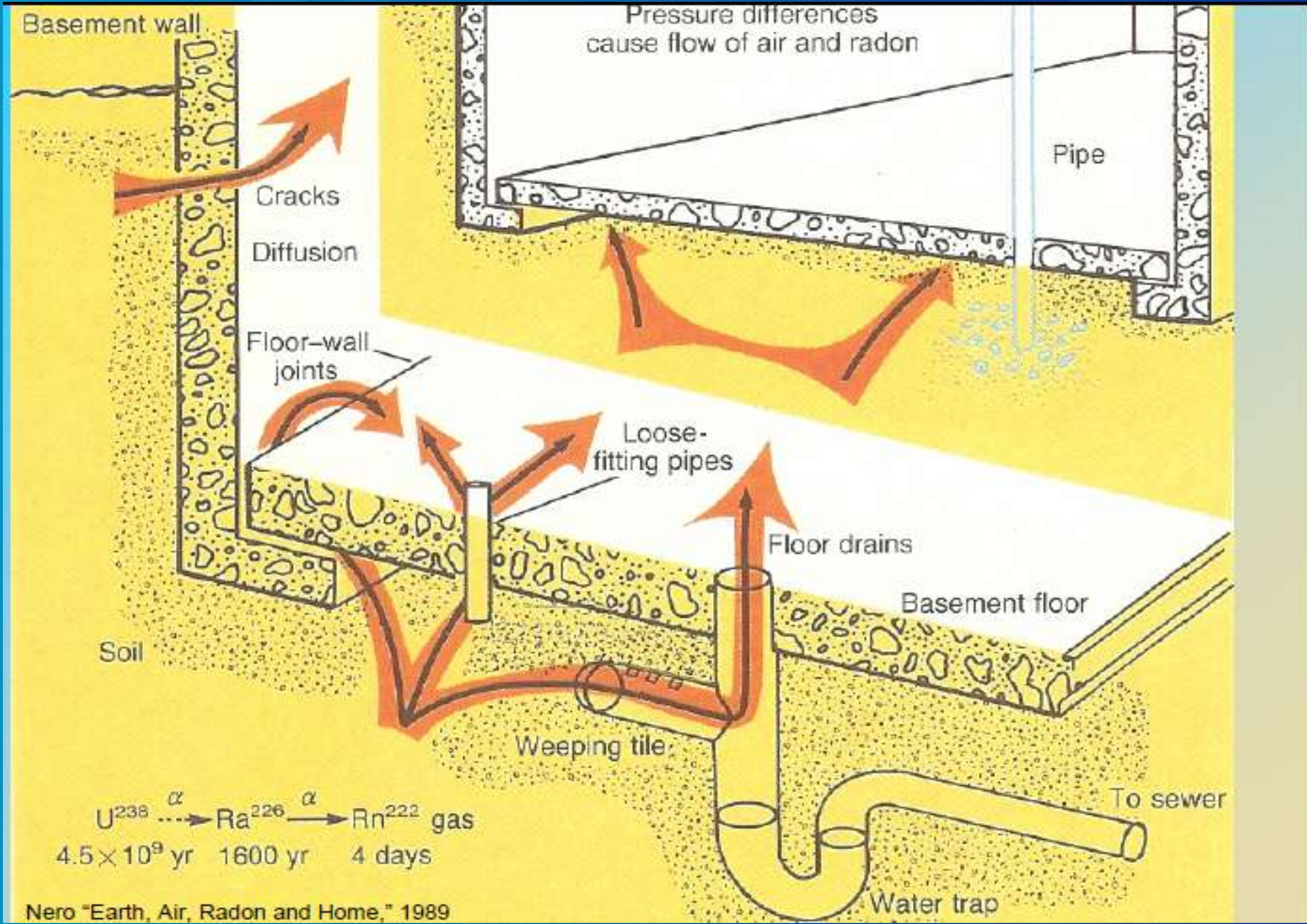
Radon Potential

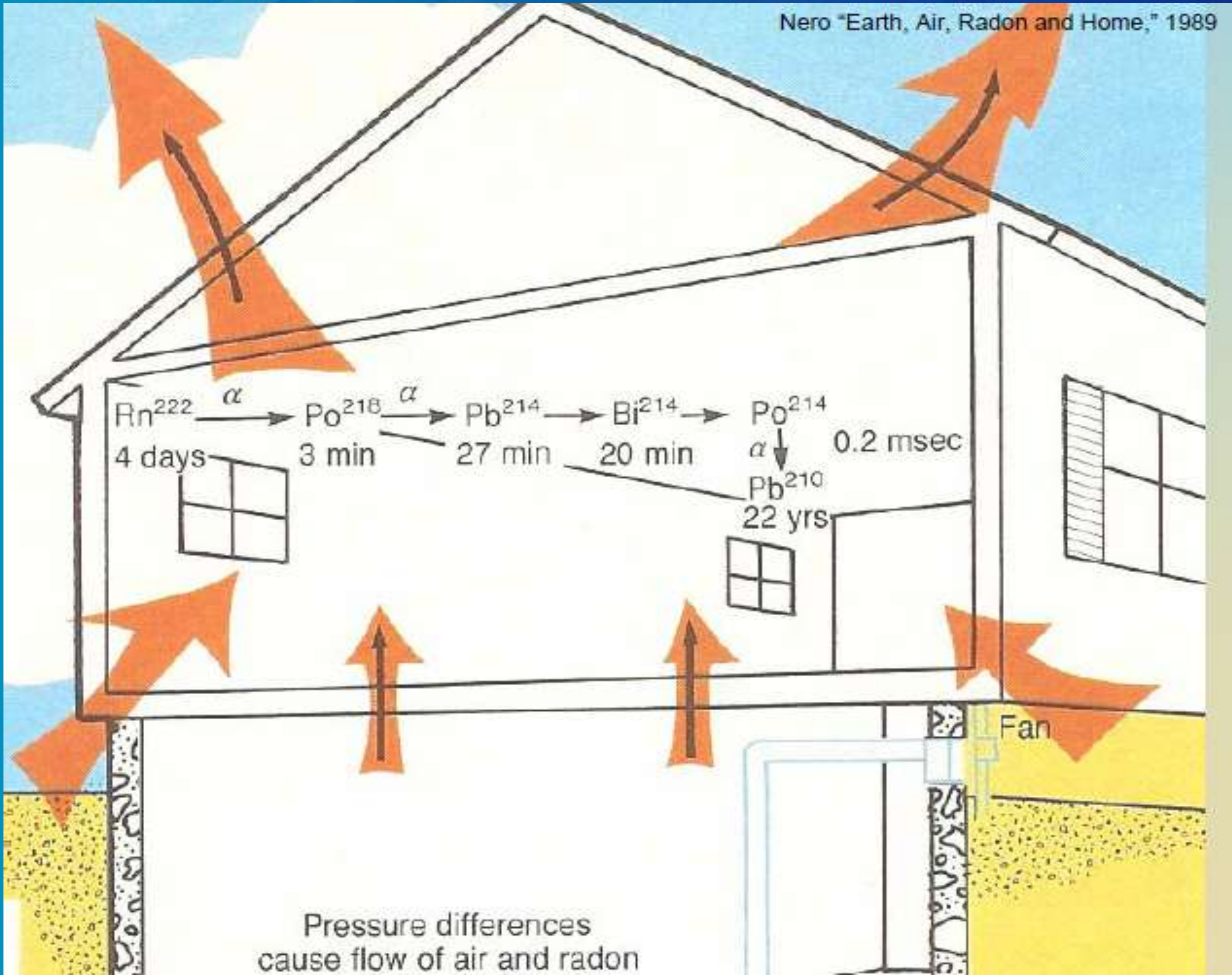


http://energy.cr.usgs.gov/radon/georadon/page4.g



Flow of radon into homes. The primary mechanism is the drawing of soil gas through the ground and understructure by small pressure differences generated by winds and by indoor-outdoor temperature differences. These pressures, which also account for the general bentilation of most homes, effectively transport part of the uranium-238 decay chain from the ground into the air we breathe. A simple pipe-and-fan system can greatly reduce the influx of radon by altering the pressure in the ground immediately below the house. Black arrows indicate radon flow; orange arrows, airflow.

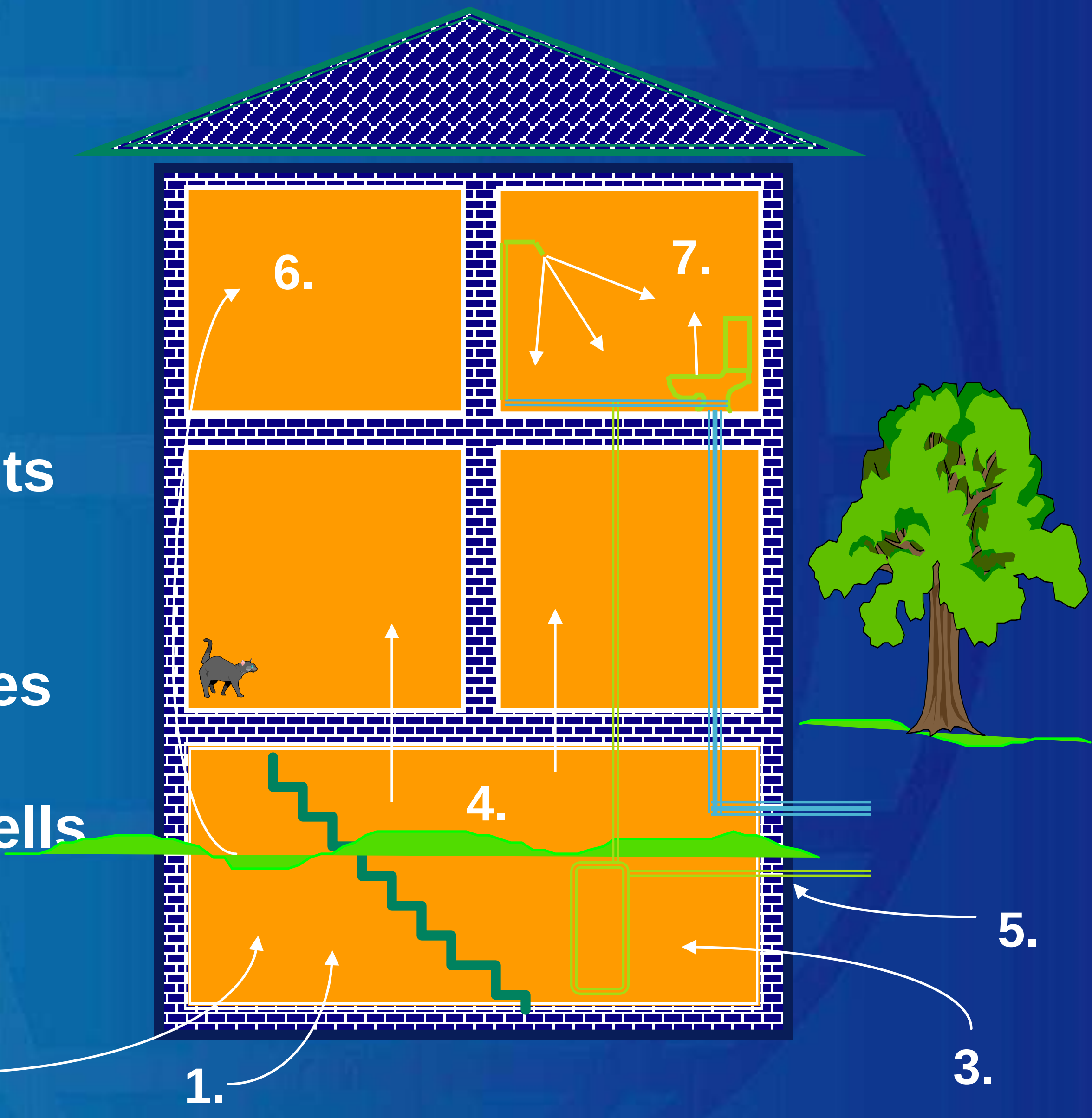

Basement wall
Pressure differences cause flow of air and radon
Pipe
Cracks
Diffusion
Floor–wall joints
Loose-fitting pipes
Floor drains
Basement floor
Soil
Weeping tile
To sewer
Water trap
$U^{238} \xrightarrow{\alpha} Ra^{226} \xrightarrow{\alpha} Rn^{222}$ gas
4.5×10^9 yr 1600 yr 4 days
Nero "Earth, Air, Radon and Home," 1989



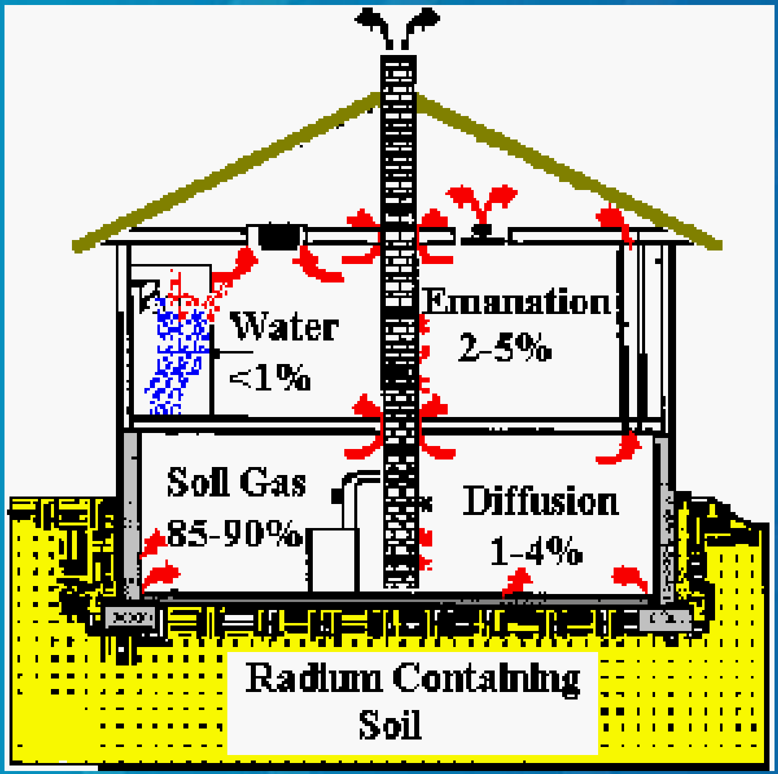
Nero "Earth, Air, Radon and Home," 1989
Rn222 α → Po218 α → Pb214 → Bi214 → Po214
4 days
3 min
27 min
20 min
α ↓ 0.2 msec
Pb210
22 yrs
Fan
Pressure differences
cause flow of air and radon

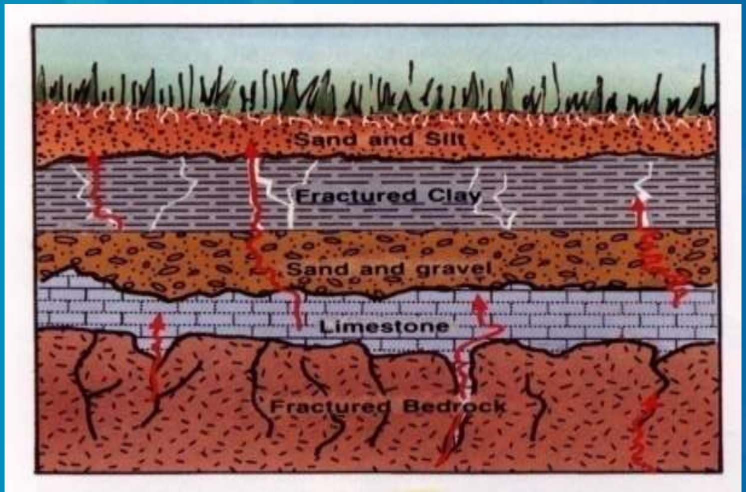
Radon Entry Into a Home

1. Cracks in Solid Floors
2. Construction Joints
3. Cracks in Walls
4. Gaps in Floors
5. Gaps around Pipes
6. Cavities in Walls
7. Water Supply (wells only)



Main sources of Radon in a confined space





building materials 2-5%

water < 1%

soil: 85-90% + diffusion 1-4%

.

$^{222}Rn - \alpha \rightarrow {}^{218}Po - \alpha \rightarrow {}^{214}Pb \rightarrow {}^{214}Bi \rightarrow {}^{214}Po \rightarrow$
$^{210}Pb \rightarrow {}^{210}Po \rightarrow {}^{206}Pb$.

^{222}Rn, $t_{½}$ ~ 3.9 days.

^{218}Po, $t_{½}$ = 3 minutes (carry much energy, don't penetrate -- Gamma particles don't penetrate skin, but can hurt lung linings).

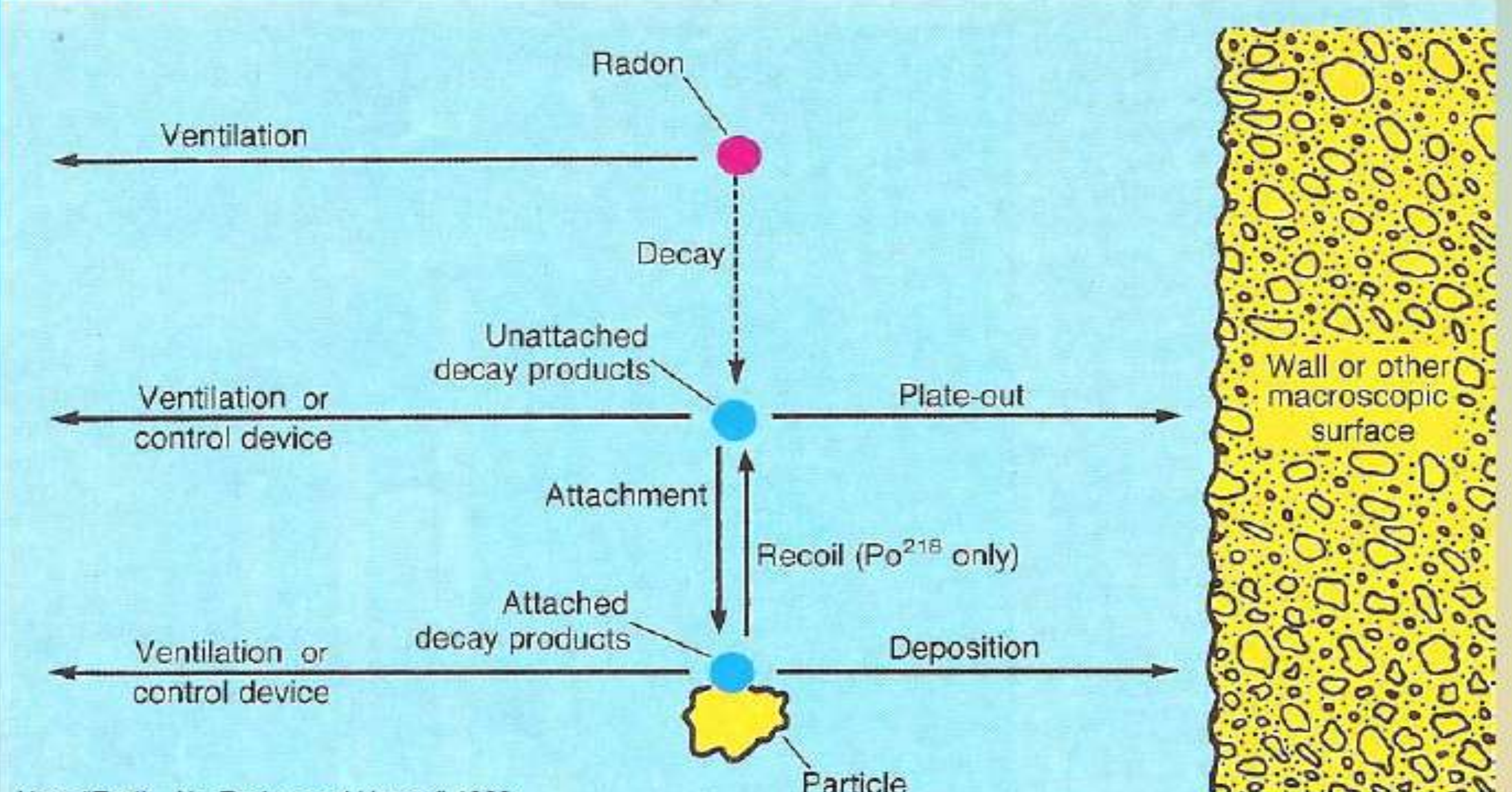
^{214}Bi, $t_{½}$ = 27 minutes.

^{210}Pb, $t_{½}$ = 22 years.

^{210}Po, $t_{½}$ = 138 days.

→**The alpha decays are the bad actors.**

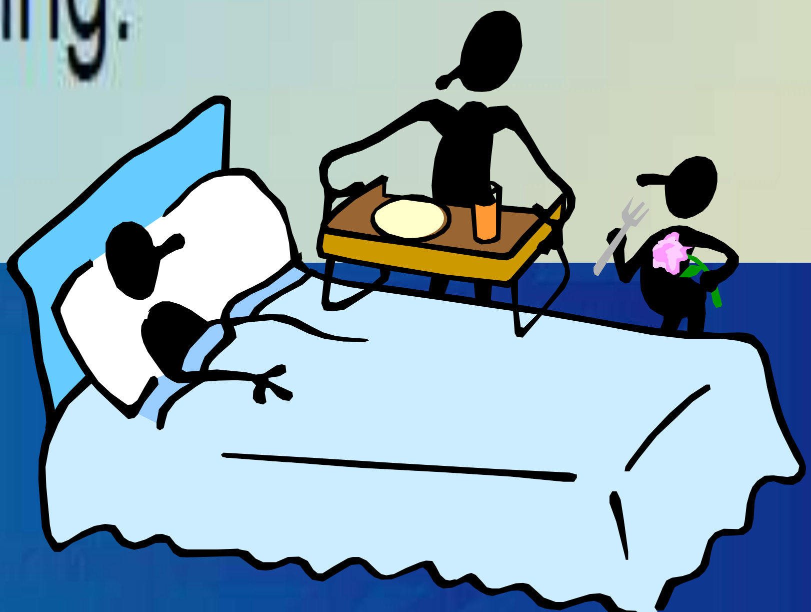
Removal processes. Radioactive decay products leave the indoor air through deposition on walls (wither as "unattached" particles of attached to preexisting particles) and thorugh ventilation or control devices that use processes such as filtration or electrostatic precipitation.



Nero "Earth, Air, Radon and Home," 1989

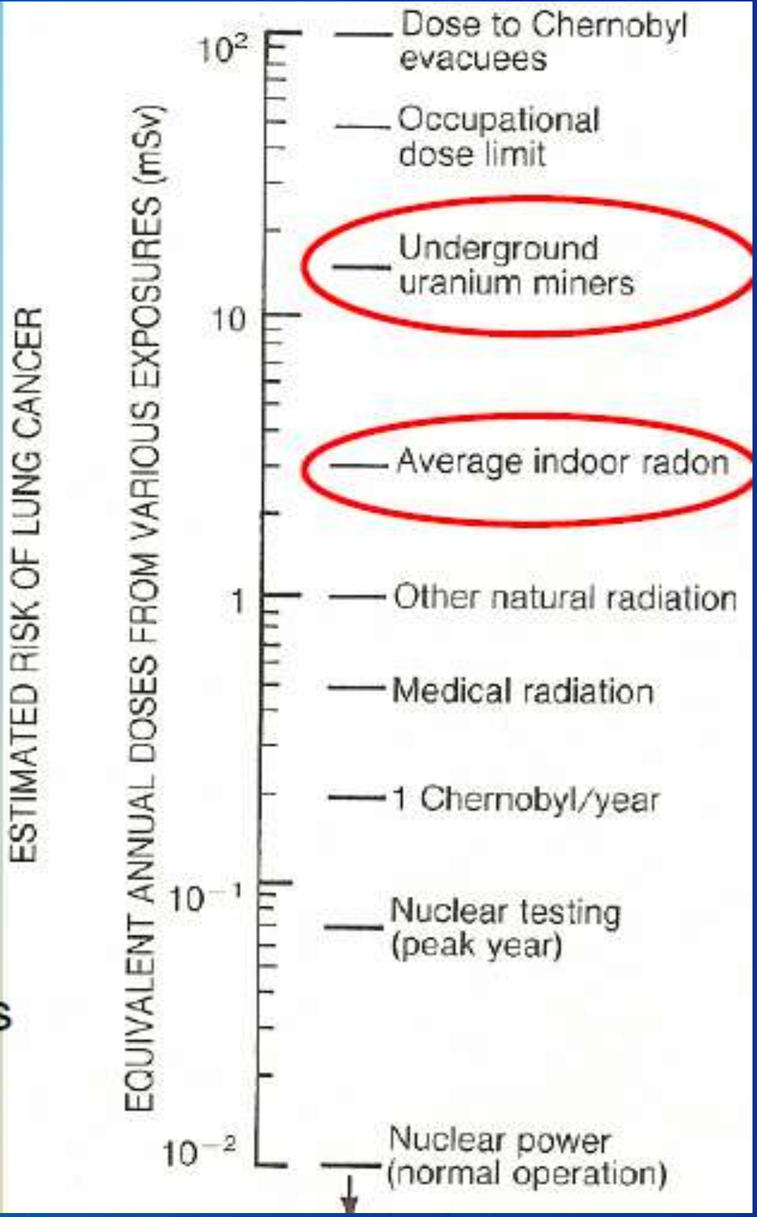
- **There is steady-state [Rn] in your lungs because [^{222}Rn] is about constant in your house** because the decay constant (l) of Rn is about 0.01 hr^{-1}.
- Flux of house air → house exchange/hour.
- [^{222}Rn]house is about constant, whether it comes from soil, or leaky windows/doors.
- **A percentage of Rn in your house will decay in your lungs.**

- Lifetime risk of lung cancer is high with exposure.
- 7% is risk for smoking.

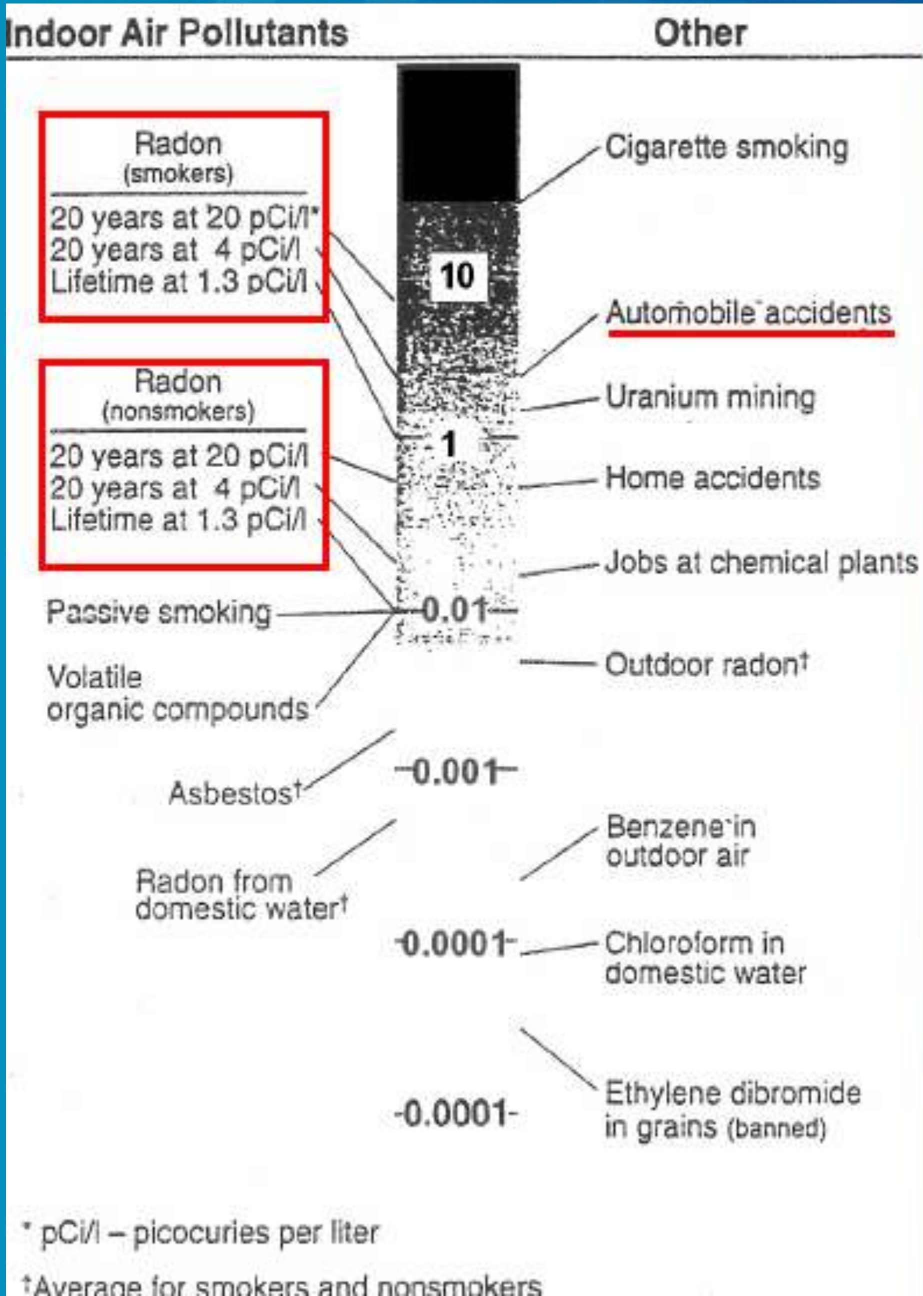


What do the different exposures mean in terms of cancer risk?

- **Average exposure → .5% lung cancer risk**
- **Uranium mining → 5% incidence death from lung cancer.**



Estimates of lung cancer risk for > lifetime occupancy. Radiation doses from other sources are indicated for comparison. Nero "Earth, Air, Radon and Home," 1989



Estimated Lifetime Risk of Premature Death (Percent)

All risks are average for the whole population except where indicated. Radon estimates presume a ten-fold difference between smoker and nonsmoker risks due to synergism, but the exact ratio is not known. In the unlikely event that these actually is no difference between the two groups, the risk for the general population would be just below home accidents for a lifetime at 1.3 pCi/l, somewhat above home accidents for 20 years at 4 pCi/l, and above the risk from auto accidents for 20 years at 20 pCi/l.

Comparison of Annual Cancer Cases due to Indoor Air Pollutants

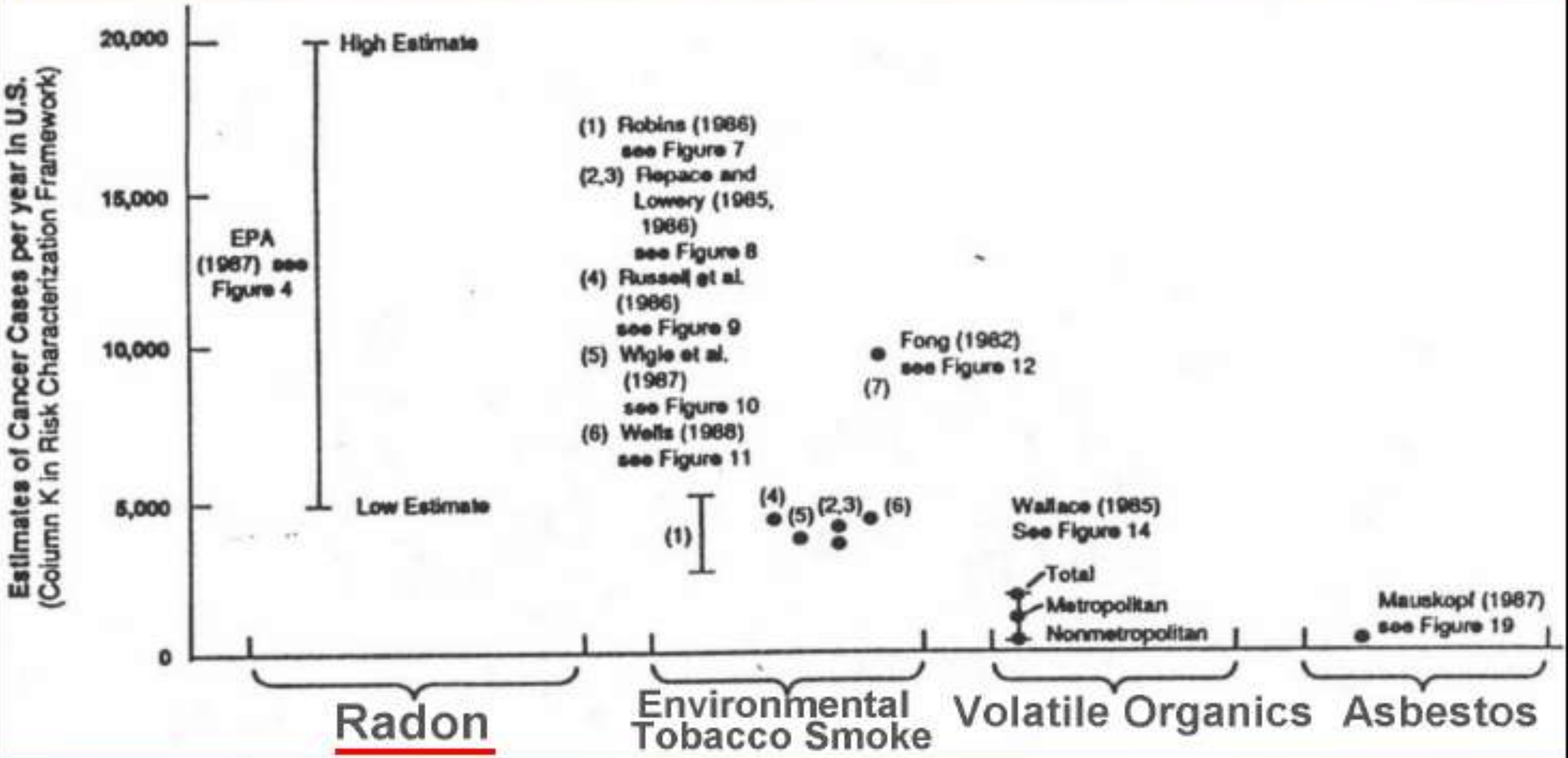


Figure 3. " Indoor Air- Assessment" EPA. 1991

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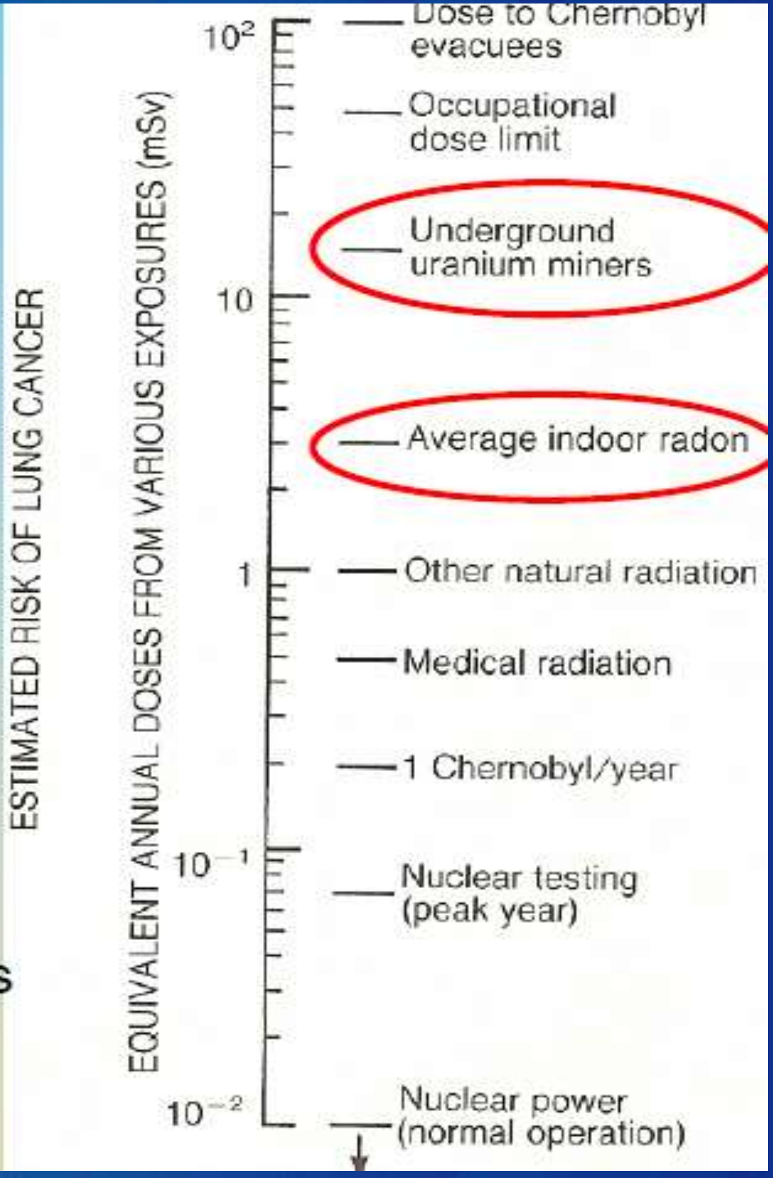
Estimates of lung cancer risk for > lifetime occupancy. Radiation doses from other sources are indicated for comparison. Nero "Earth, Air, Radon and Home," 1989



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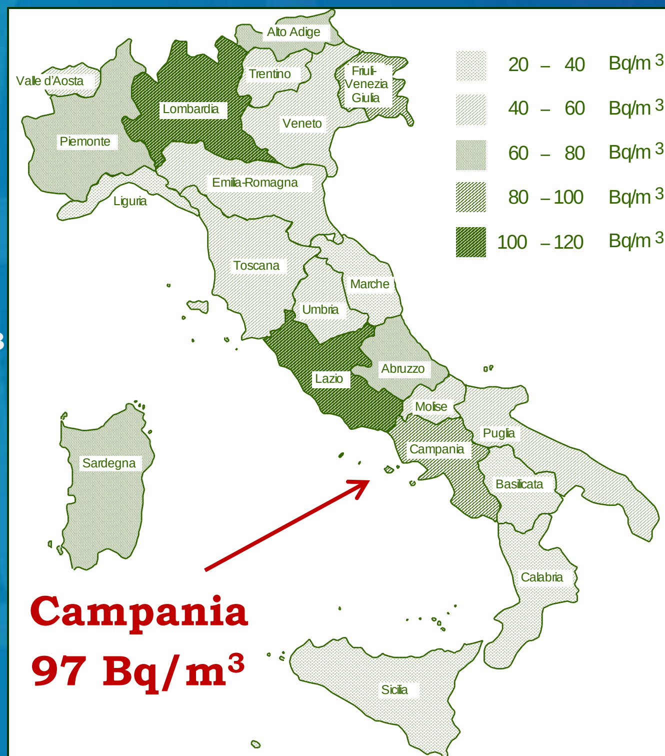
Annual mean concentrations of Indoor Radon



Campania
97 Bq/m³

Italia: 70 Bq/m³

Europa: 59 Bq/m³

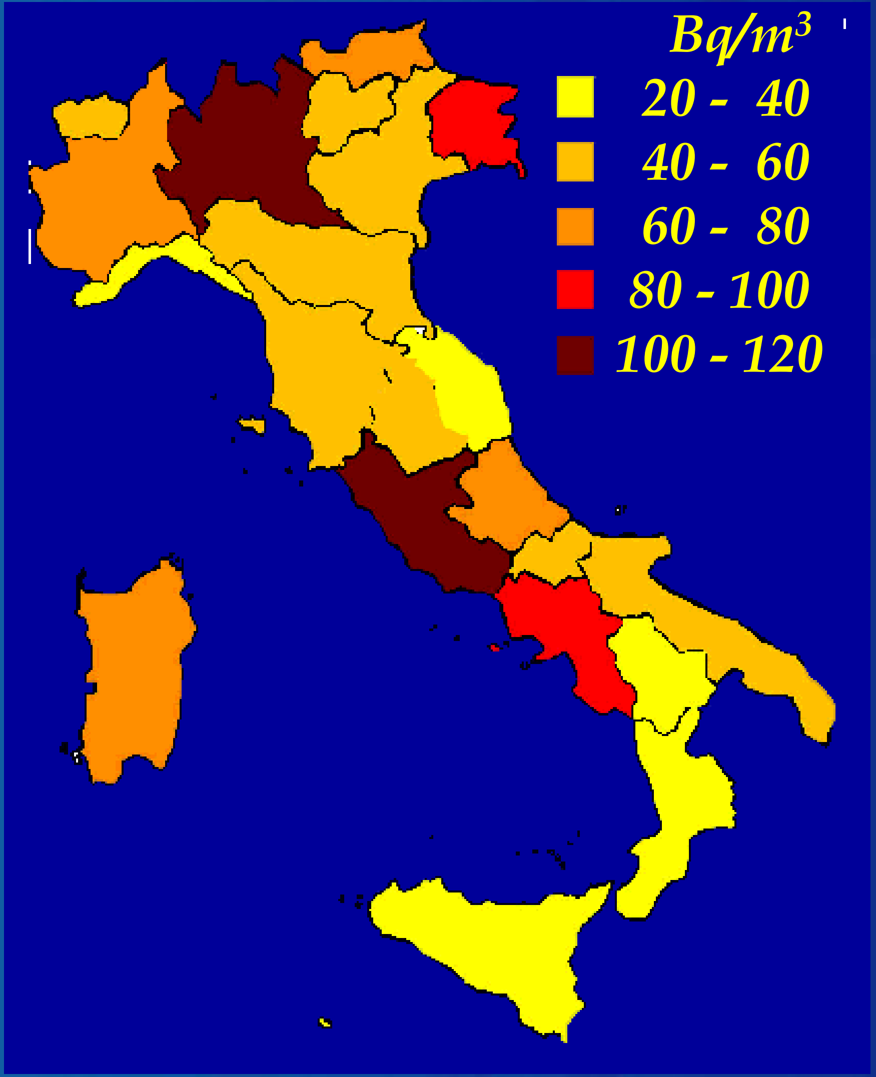
World: 40 Bq/m³

Lithological Map

Indagine nazionale sulla radioattività naturale nelle abitazioni (ANPA, ISS;1989 - 1993)

Indagine nazionale radon (1989-1997)

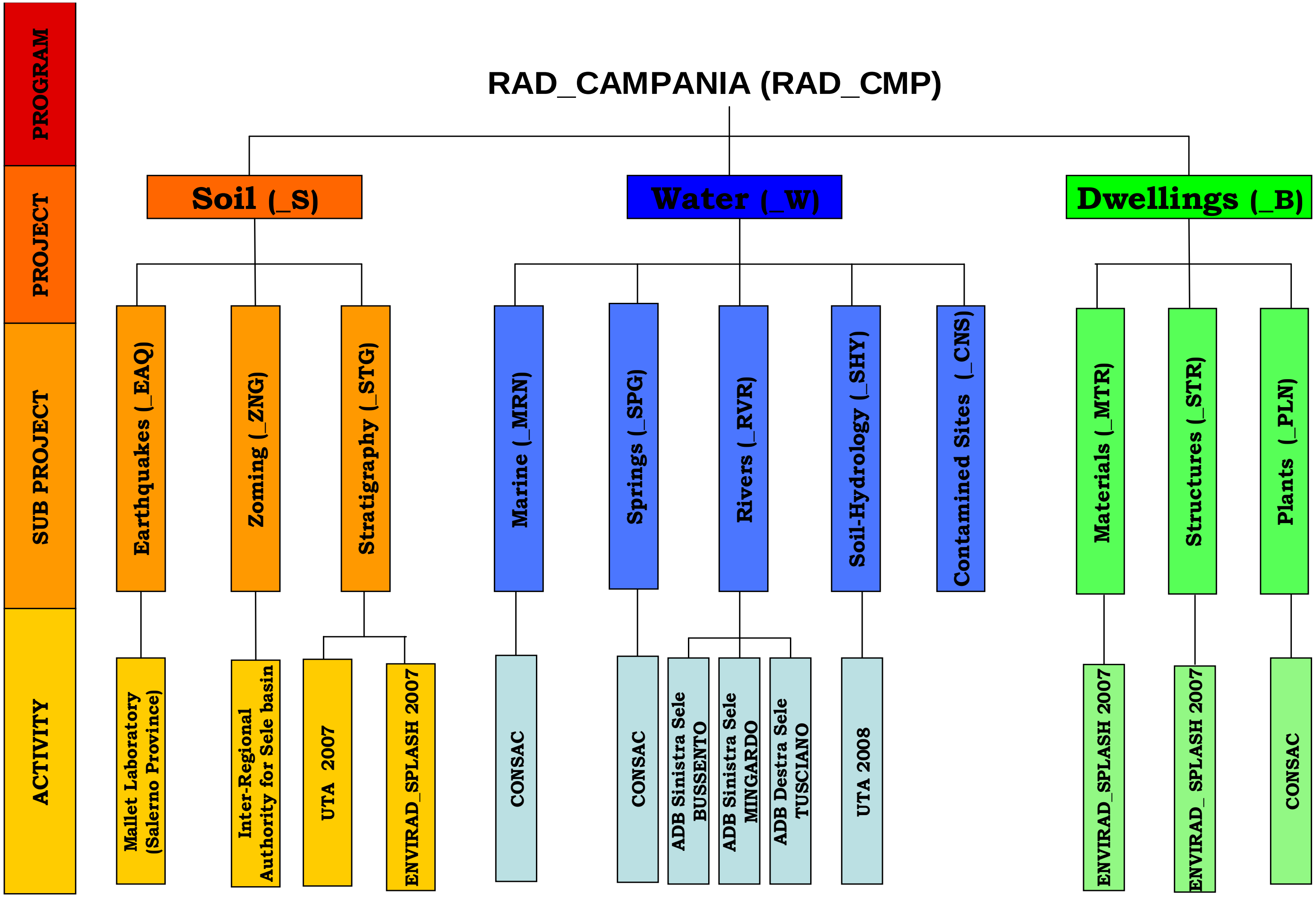
- N. di edifici 5361
- N. di città 232
- Max (Bq/m^3) 1036
- Media aritm. (Bq/m^3) 70
- Std Error (Bq/m^3) 1



Frazione di edifici (totale 20.000.000)

> 200 Bq/m^3	4,1 %	≈ 800.000
> 400 Bq/m^3	0,9 %	≈ 200.000

General Functional Scheme of the Interdepartment Research Programme RAD_CAMPANIA

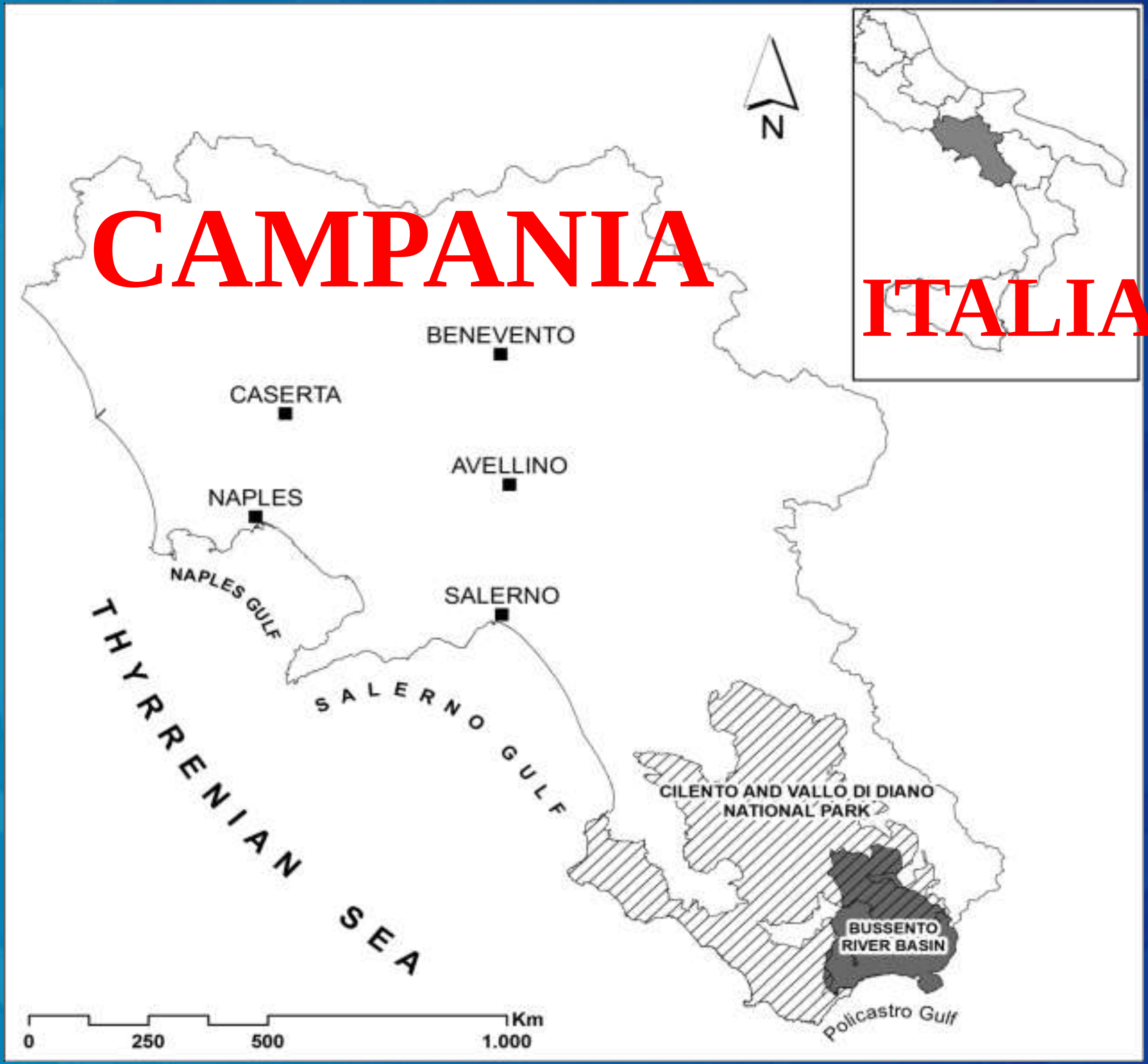


Journal of Technical & Environmental Geology, XVI, 2 (April/June), 38-62, 2008).

in collaboration with

C.U.G.RI., and the Regional Agency for the Environmental Protection ,ARPA Campania

WHERE WE ARE



CAMPANIA
ITALIA
N
BENEVENTO
CASERTA
AVELLINO
NAPLES
SALERNO
NAPLES GULF
THYRRENIAN SEA
SALERNO GULF
CILENTO AND VALLO DI DIANO NATIONAL PARK
BUSSENTO RIVER BASIN
Policastro Gulf
0
250
500
1.000
Km

Multiscalar hierarchical levels for the assessment of the Areas with the highest potential concentrations of exhalated soil-gas Radon (Radon-prone Areas)

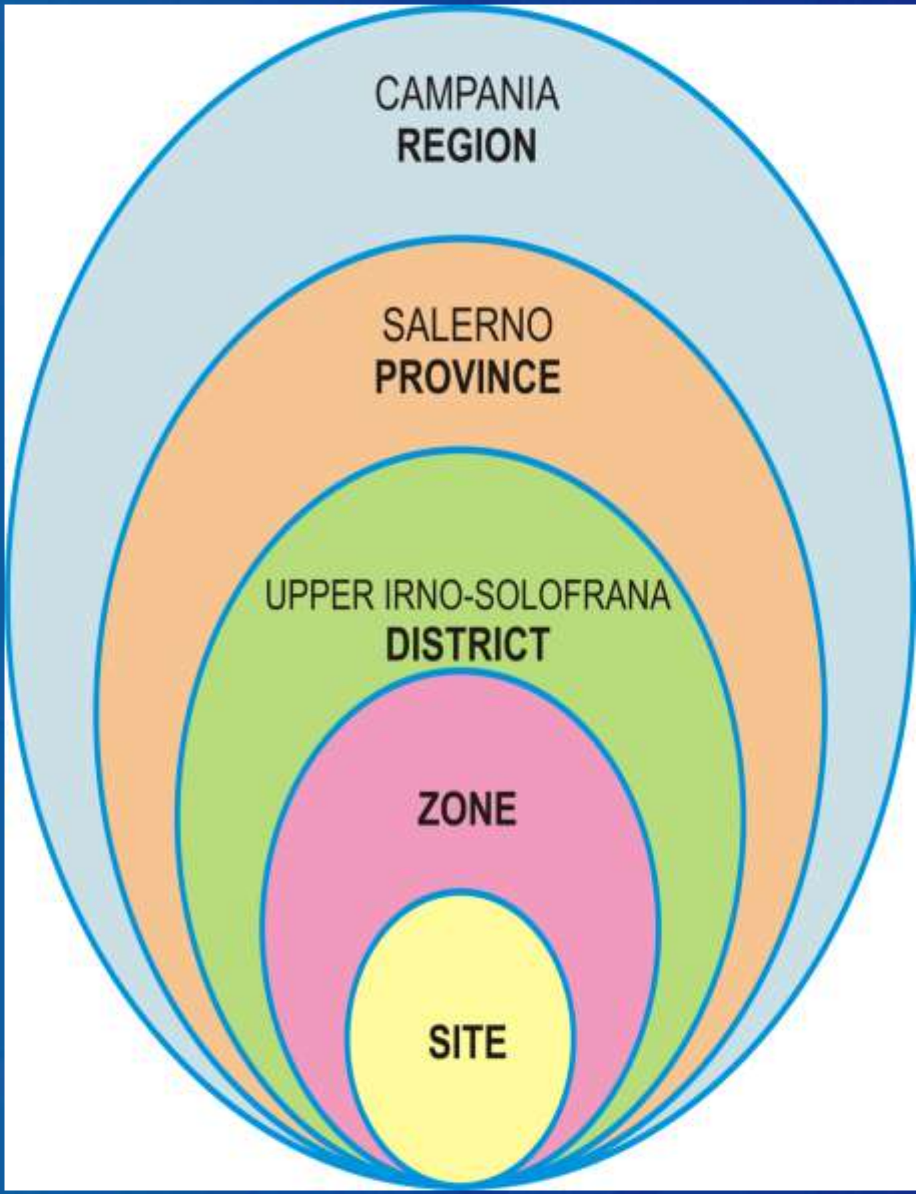
Region Level: scale <1:250,000

Province level: scale <1:100,000

District Level : scale <1:25,000

Zone Level : scale <1:5,000-2,000

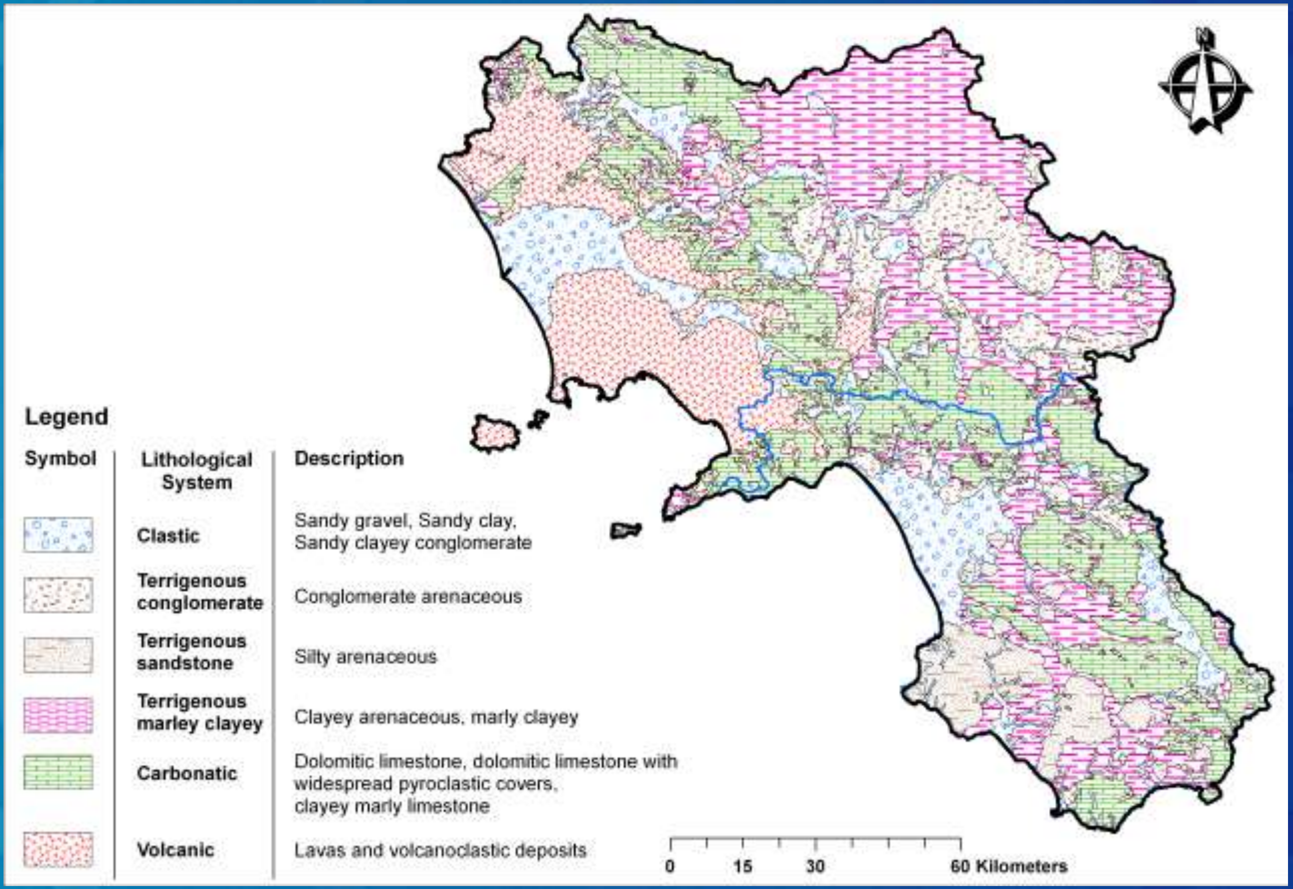
Site Level : scale 1: 2,000



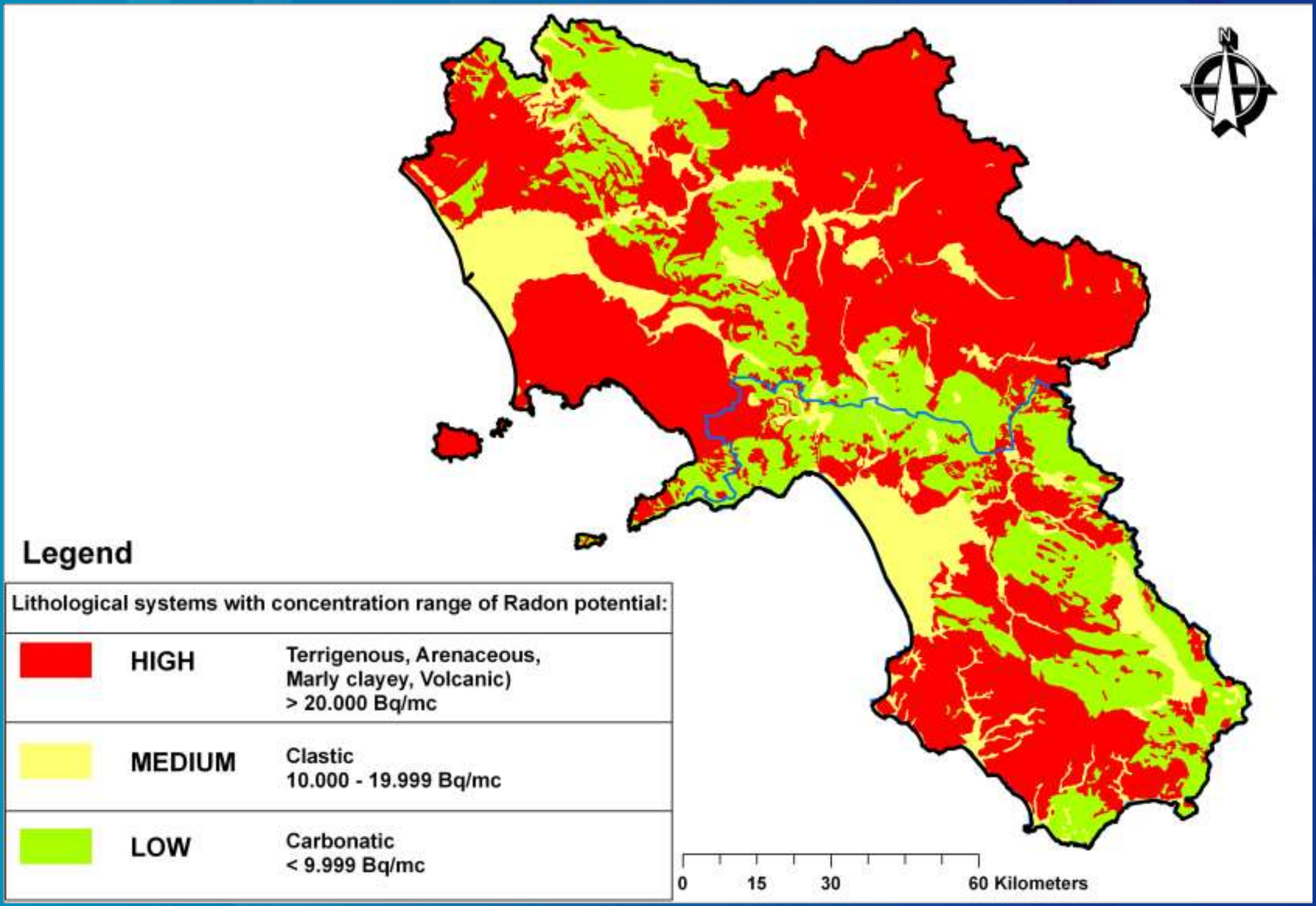
Journal of Technical & Environmental Geology, XVI, 2 (April/June), 38-62, 2008).

Lithological Systems Map of Campania Region

(modified from BLASI C. et al., 2007)

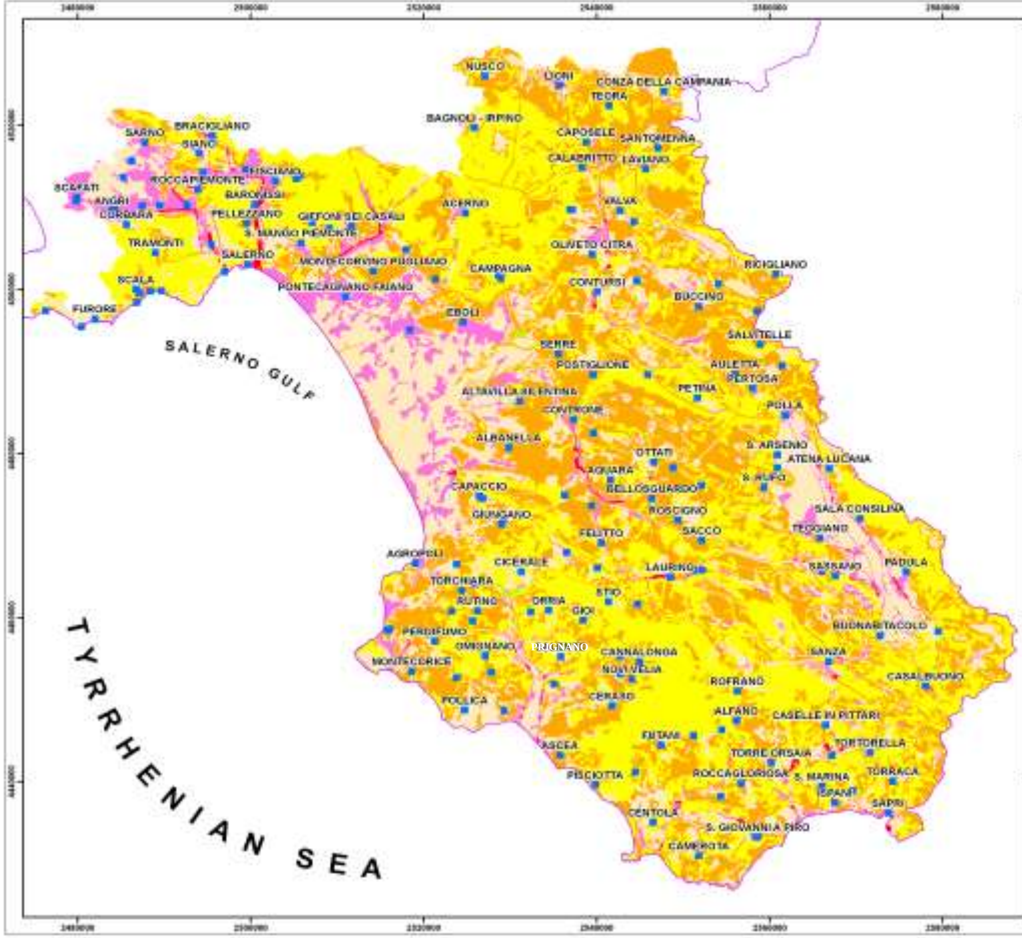


Preliminary assessment from the lithological map and literature



(Cuomo A., Tesi di Laurea in Ing. Civile A&T, 2007; Journal of Technical & Environmental Geology, XVI, 2 (April/June), 38-62, 2008).

Preliminary map of the Radon-prone Areas after the application of the multiscalar hierarchical adaptive approach

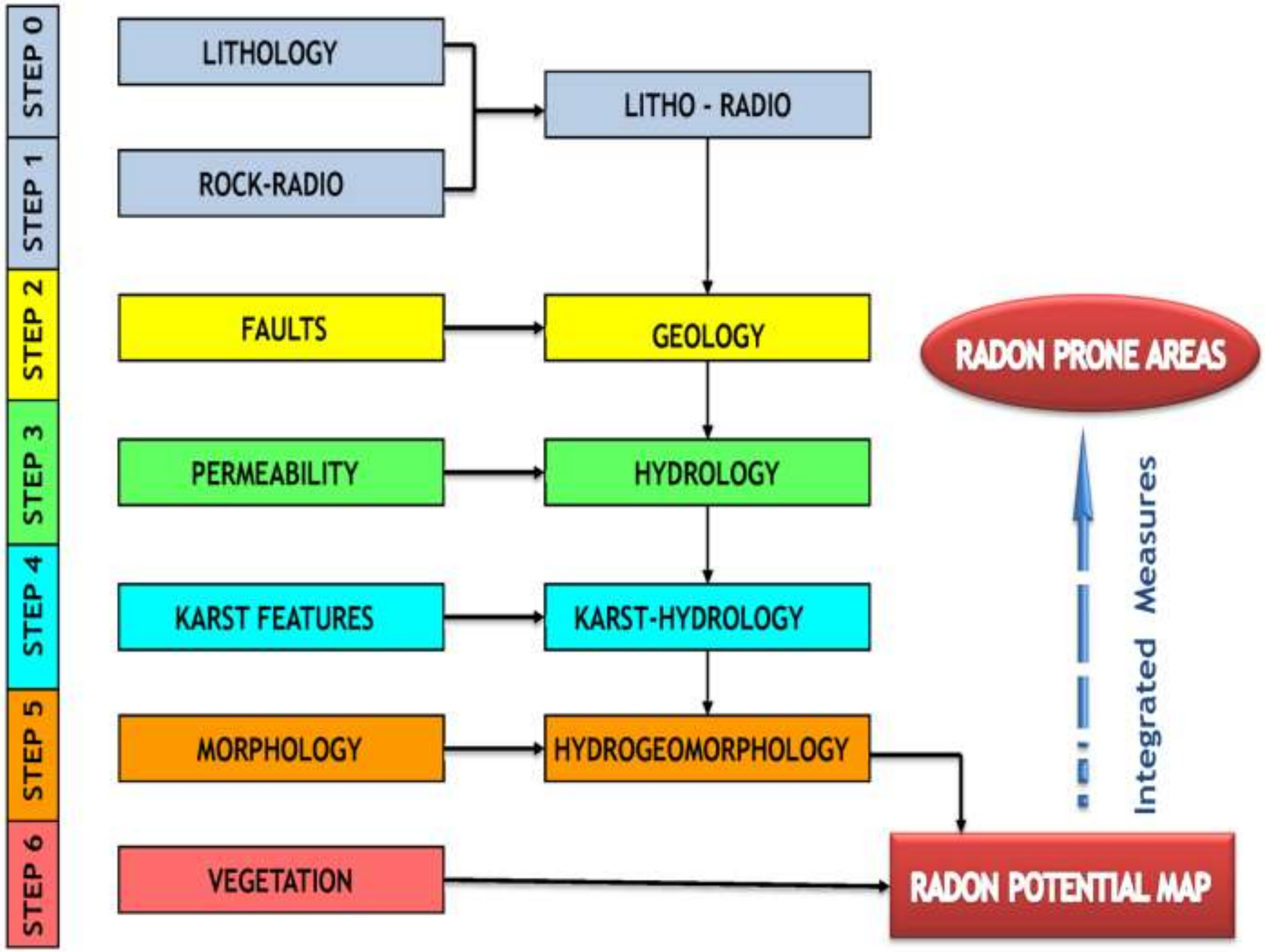


Legend

Symbology	Class	Concentration level	Class range Bq/m^3	Class area Km^2
(green)	1	Very Low	< 1000	2
(yellow)	2	Low	1000 < [Rn-222] < 10.000	1990
(orange)	3	Medium Low	10.000 < [Rn-222] < 20.000	1709
(light beige)	4	Medium	20.000 < [Rn-222] < 30.000	1210
(pink)	5	Medium High	30.000 < [Rn-222] < 50.000	349
(red)	6	High	> 50.000	3

(Cuomo A., Tesi di Laurea in Ing. Civile A&T, 2007; Journal of Technical & Environmental Geology, XVI, 2 (April/June), 38-62, 2008).

Flow-chart diagram showing the applied methodology for the production of the *Radon-prone Areas*.



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Procedura adottata per le misure eseguite con RAD7

(Pelosi A., Tesi di Laurea in Ingegneria, 2007)

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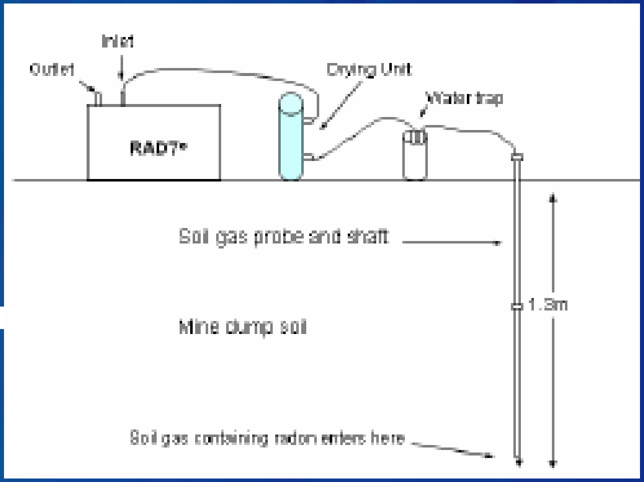
Misura nel suolo con strumentazione attiva: Rad7

- **Lo strumento è stato assemblato;**
- **Si è verificata la percentuale di umidità presente nello strumento e poichè questa superava il 7% allora si è passati all'operazione di purge.**
- **si è infissa la sonda nel punto di misura e costipata la porzione di terreno che la circonda;**
- **è posizionato manometro e si strumento;**
- **si è avviata la menu dello stru**



(L. Serrapica, Tesi di Laurea in Ingegneria, 2007)

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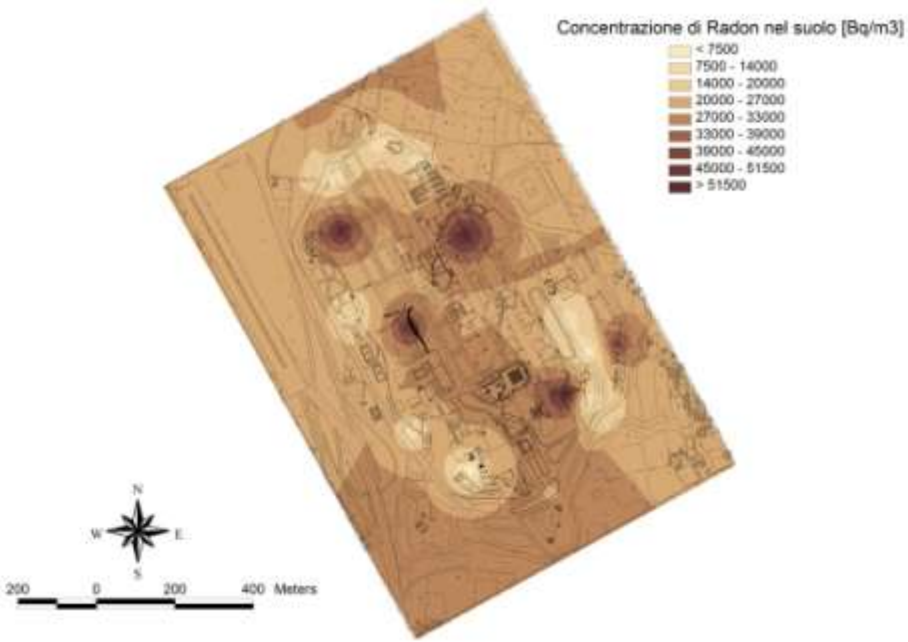
Set di dati a cui sono stati applicati dei criteri di selezione

ID_MIS	COD_S_RN	COD_MIS	DATA	RN_CONC	
1	_01	_01	12/10/2007	913	[Bqm-3]
3	_03	_01	13/10/2007	10.200	[Bqm-3]
4	_04	_01	13/10/2007	51.000	[Bqm-3]
5	_05	_01	13/10/2007	7.870	[Bqm-3]
6	_06	_01	13/10/2007	57.800	[Bqm-3]
7	_07	_01	15/10/2007	55.000	[Bqm-3]
8	_08	_01	15/10/2007	4.120	[Bqm-3]
9	_09	_01	16/10/2007	43.100	[Bqm-3]
10	_10	_01	19/10/2007	56.000	[Bqm-3]
11	_11	_01	20/10/2007	25.800	[Bqm-3]
12	_12	_01	20/10/2007	2.950	[Bqm-3]
13	_13	_01	20/10/2007	9.030	[Bqm-3]
15	_15	_01	27/10/2007	8.370	[Bqm-3]
16	_16	_01	27/10/2007	7.000	[Bqm-3]
17	_17	_01	02/11/2007	4.310	[Bqm-3]

Interpolazione mediante kriging dei dati di concentrazione



(Pelosi A., Tesi di Laurea in Ingegneria, 2007)

Radon as Aqueous Tracer

- Radon is continuously produced via α-decay of its parent nuclide radium, which is commonly found in soil and aquifer material
- Radon is a ubiquitously occurring natural component of groundwater, occurring as dissolved gas
- The chemical and physical properties of radon and its behavior in groundwater allow for its use as naturally occurring aqueous tracer
- It is a natural constituent of groundwater and therefore has not to be injected into the aquifer for the sake of a tracer experiment
- Radon can be detected very precisely also at low concentrations, due to its radioactive nature
- Because of the chemical inertness of Radon, its transport in groundwater systems is controlled only by molecular diffusion and by the flow of groundwater itself
- The only other process that has any significant effect on radon, once it is in solution in groundwater, is outgassing

Work in progress

- Involvement in the

EUROPEAN RADON GEOGENIC MAP PROJECT

(ERGM)

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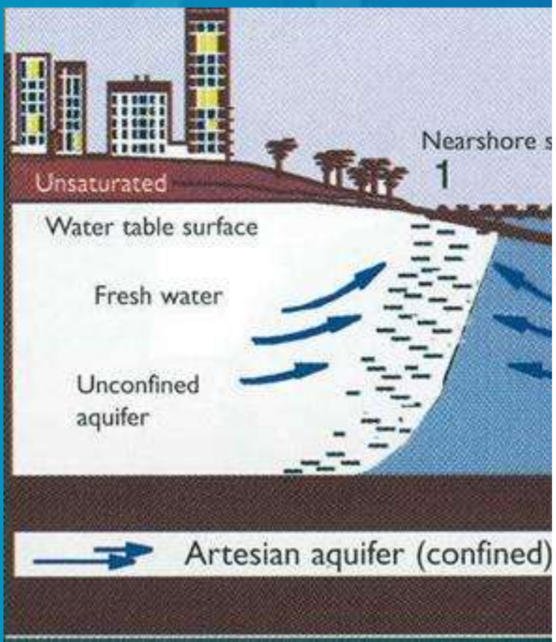
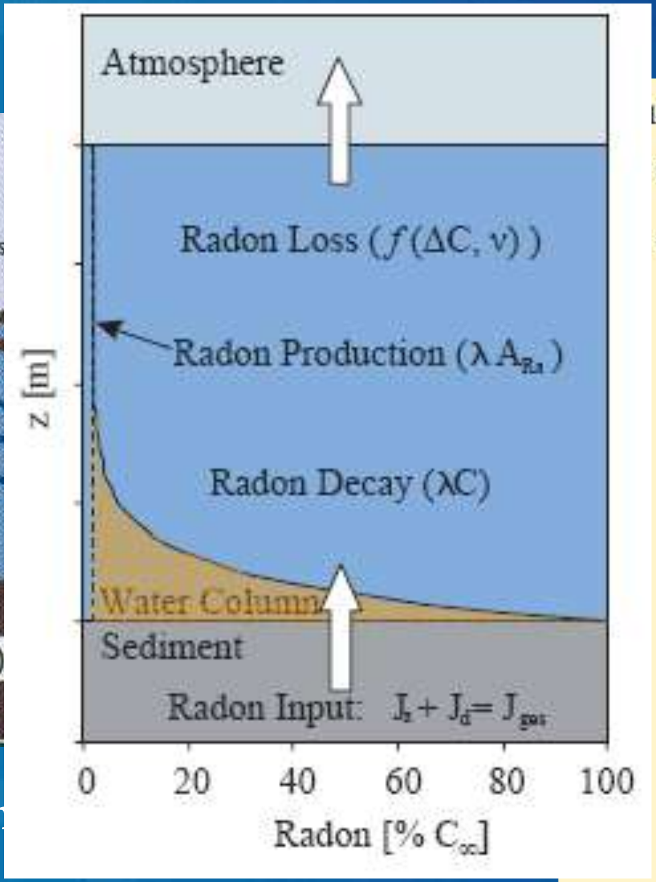
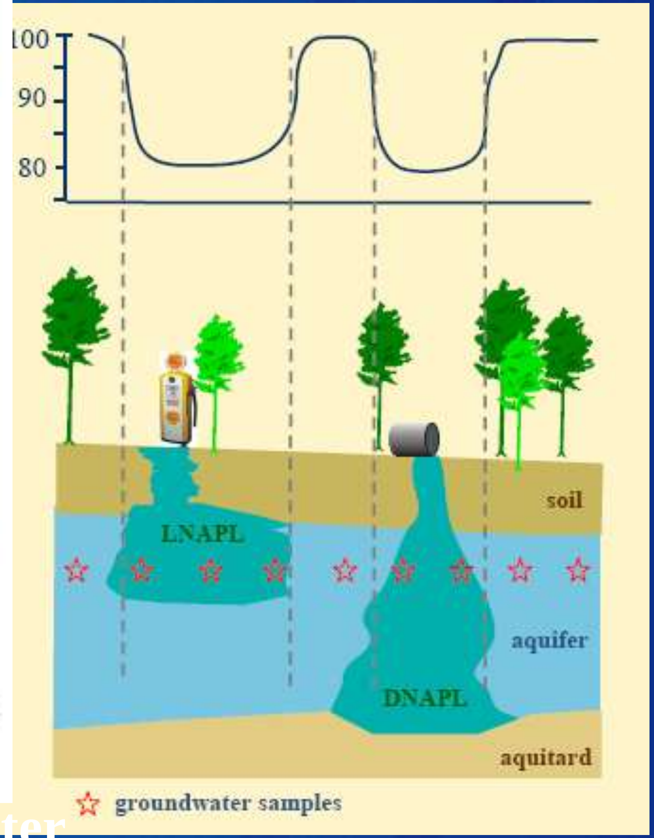
RADON -222 : A Naturally Occurring Radioactive Tracer in Hydrosphere



Assessment of the Submarine Groundwater Discharge (SGD)



Assessment of the Groundwater Discharges in Lakes



Evaluation of the contamination of aquifers

How to measure RADON-IN-WATER: RAD7: Radon Monitor

RAD7 has an internal sample cell of a 0.7L hemisphere with a solid state detector at the center.
The inside of the hemisphere is coated with an electrical conductor which is charged to a potential of 2-4 kV relative to the detector.
Positive charged progeny decayed from 222Rn and 220Rn are driven by the electric field towards the detector.
When a progeny atom reaches the detector and subsequently decays and emits an alpha particle , the alpha particle has a 50% probability of being detected by the detector.
As a result an electrical signal is generated with the strength being proportional to the alpha energy.
RAD7 will then amplify and sort the signals according to their energies.
The RAD7 spectrum is a scale of alpha energies from 0 to 10 MeV, which is divided into 200 channels each of 0.05 MeV width.

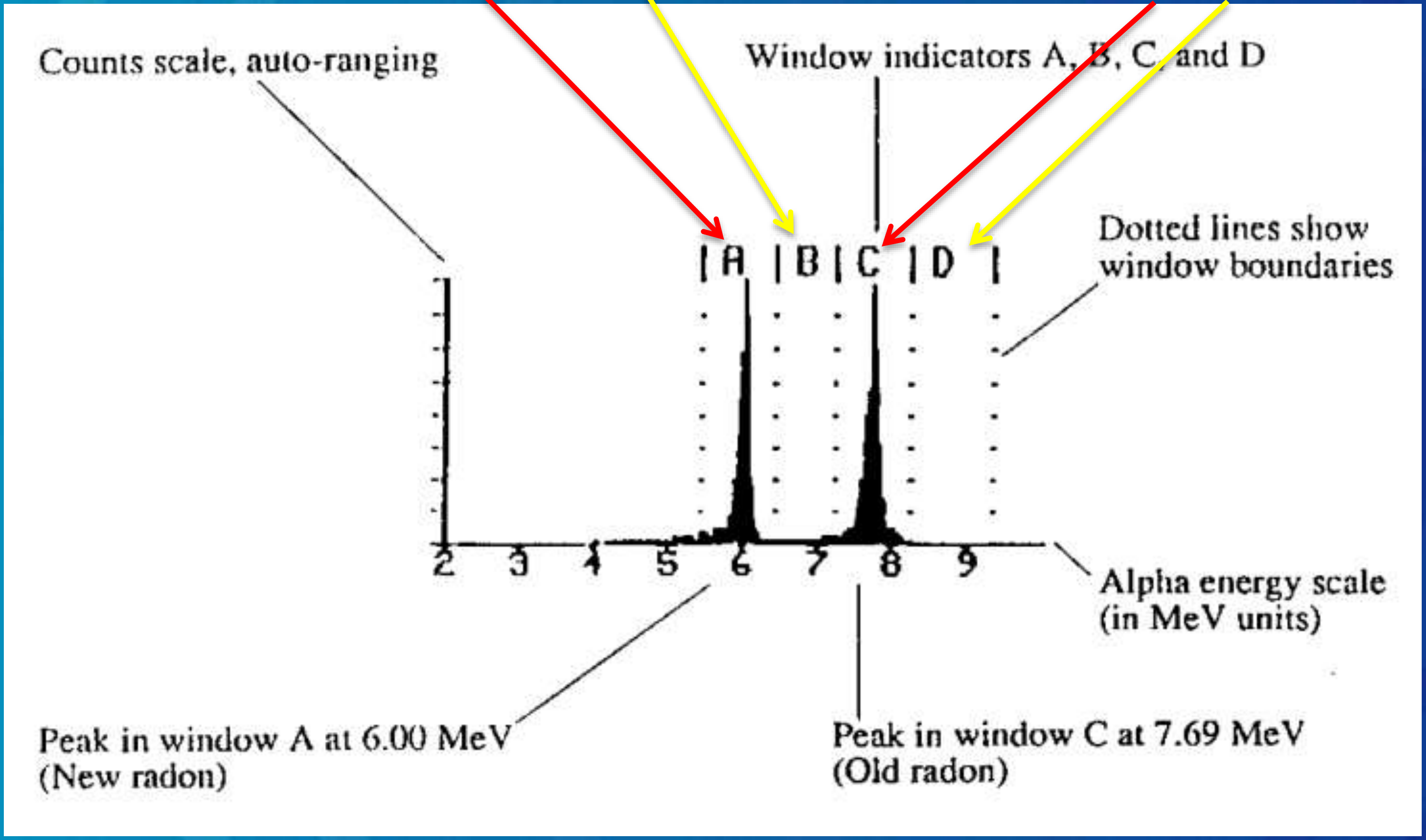
RAD7 Alpha Energy Spectrum

6.00 MeV Alpha from ^{218}Po ($t_{1/2}$ = 3 min)

6.78 MeV Alpha from ^{216}Po ($t_{1/2}$ = 0.15 s)

7.69 MeV Alpha from ^{214}Po

8.78 MeV Alpha from ^{212}Po



The alpha energies associated with ^{222}Rn and ^{220}Rn are in the range of 6-9 MeV. The channels related to them are grouped in 4 energy windows (labeled as A-D)

RADH2O System

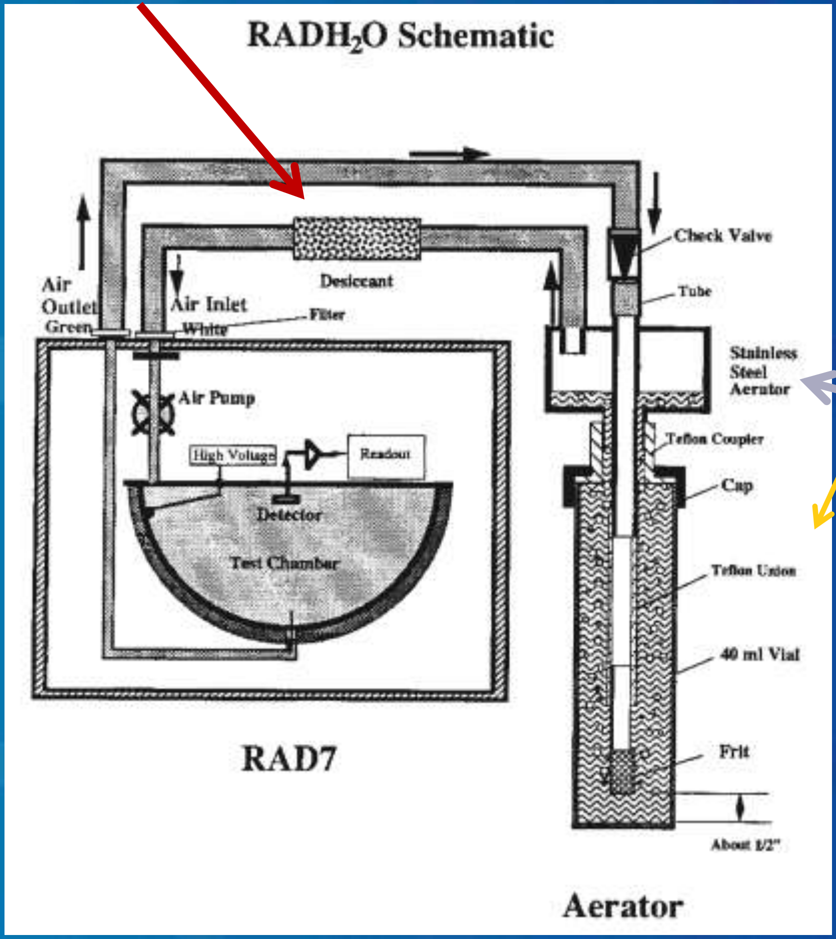
- The RADH2O is an accessory of the RAD7 that allows to measure radon-in-water
- The lower limit of detection is less than 0.3 Bq/L
- It gives results in 30 minutes
- The RADH2O method employs a closed loop aeration scheme in which the air volume and the water volume are constant

RADH2O System

A dessiccant tube is placed before the air inlet of the counter.

Its purpose is to adsorb moisture

- A sample bottle is connected to the RAD7 in a closed loop mode



The sample bottle has a special screw-on cap with two ports.

RADH2O System

The technique consists in bubbling air directly into water

The internal air pump of the RAD7 circulates the air at a flow rate of about 1L/min through the water and continuously extracts the radon

The radon from the water sample circulates through the desiccant column, then through the RAD7's chamber, and then back to water sample until an equilibrium between radon in water and in air is reached

The RADH2O system reaches this state of equilibrium within 5 minutes

After the radon air-water equilibrium is obtained, the radon activity concentration in the air loop is measured by counting alpha particles emitted by radon daughters in the chamber

RADH2O System

- The activity concentration of radon in water is calculated from the distribution factor of radon between water and air given by Weigel:

$$k_w = 0.105 + 0.405 e^{-0.502T}$$

- The actual activity concentration in the water sample is given by:

$$C_{water} V_{water} = C_{air} V_{air} + k_w C_{air} V_{water}$$

As the volumes are fixed, the RAD7 gives automatically the result of C_{water}

- The activity concentration at the sampling istant is given by:

$$C_0 = C(t) e^{\lambda t}$$

where λ is radon's decay constant: $\lambda = 0.1814\ d^{-1}$

Water Probe

Another way to make an air circuit coupled to water, in order to extract radon from it, is to separate water and air through a diffusion membrane.

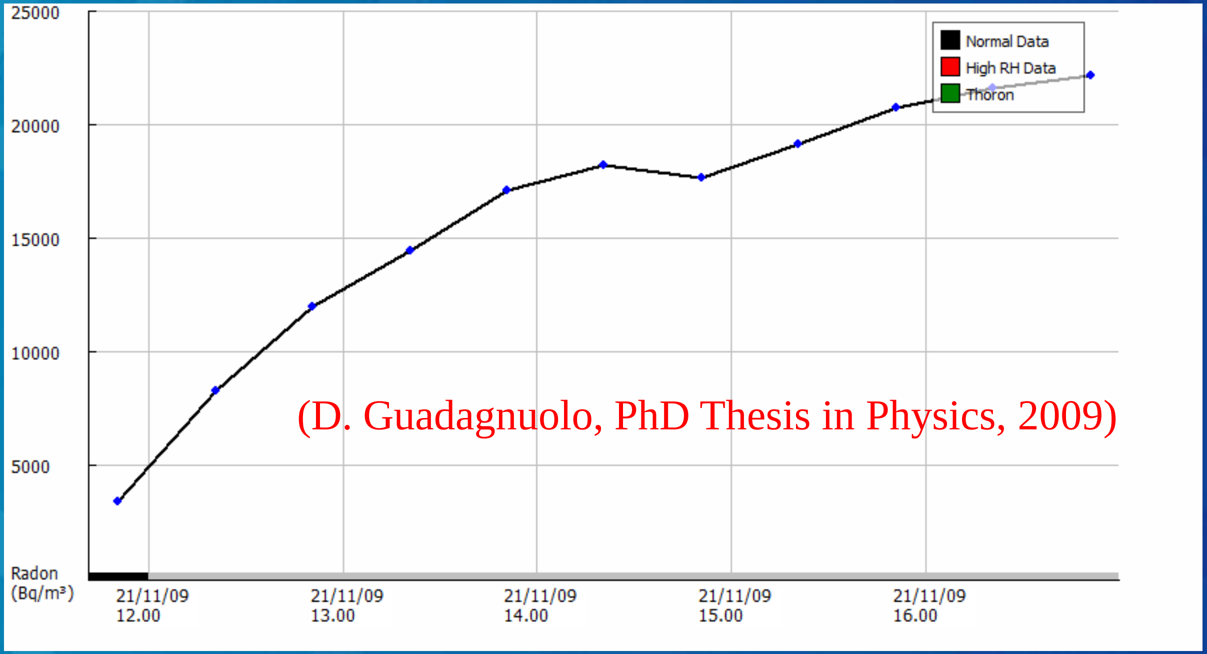
A suitable experimental set-up consists of the Durridge RAD7 in closed loop with a Durridge water probe

The Durridge water probe consists of a semi-permeable membrane tube mounted on an open wire frame.

The probe is placed in a closed loop with the RAD7

- When the probe is lowered into water, radon passes through the membrane until the radon concentration in the air in loop is in equilibrium with the radon concentration in the water
- The equilibrium is given by Weigel's equation and depends on temperature
- The probe has an advantage in that it does not need a pump for the water
- It will, however, take more than three hours to make a spot measurement

Comparison Measurements



Comparison measurements (21/11/09)

C_{water} = 7.5 ± 0.9 Bq/L (RADH2O)

C_{air} = 23000 ± 600 Bq/m^3 (Water Probe)

$K_w = 0.312 \rightarrow C_{water} = K_w \cdot C_{air} = 7.2 \pm 0.5$ Bq/L

Bussento river basin

- The Bussento river drainage basin complex drainage river systems of region
- This complexity is due to the highly conditioning induced by the karst la
- It is characterized by widely and de karst highlands with dolines, lowlar

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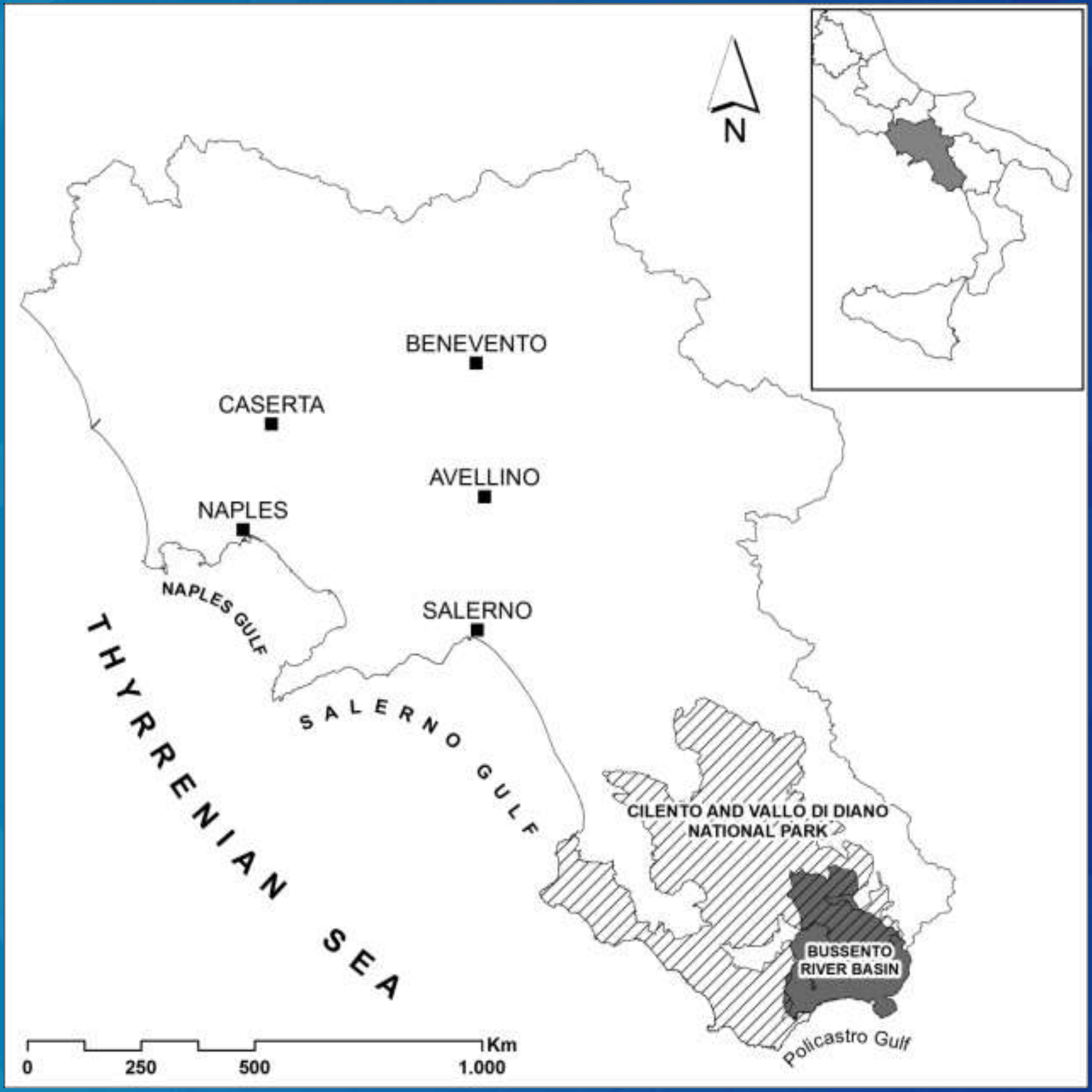
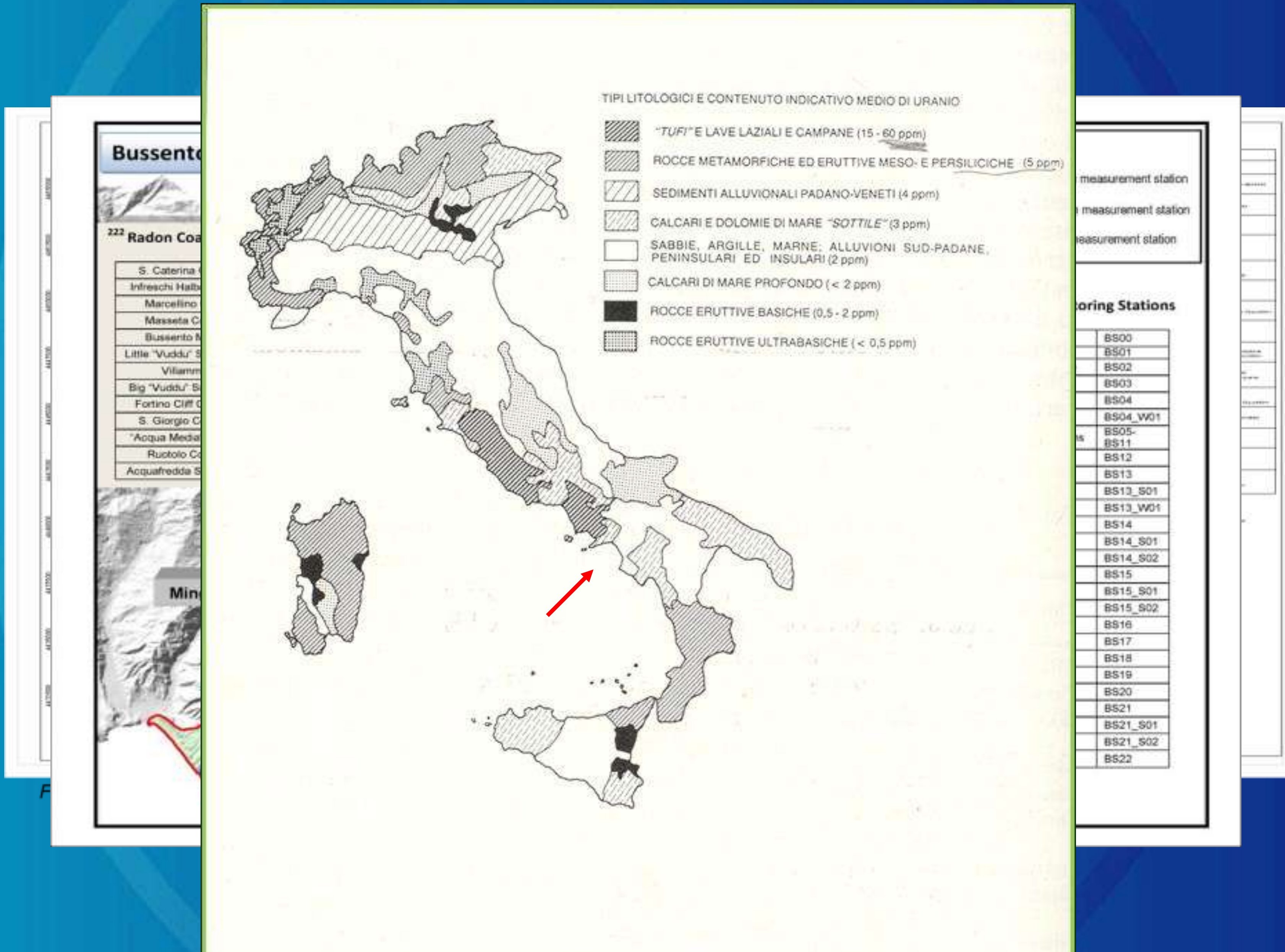
Localization of the Bussento river basin



Bussento River Basin and Policastro Gulf




RIO FREDDO
N
F. BUSSENTO
BS21
BS22
BS20
SANZA
BS19
BS18
ROFRANO
CENTAURINO Mnt
SERRA FORCELLA
F. CALORE
BS10
BS16
F. BUSSENTO
BS07
BS17
BS08
BS06
ALFANO
BS25
CASELLE IN PITTARI
RIO DELLA BACUTA
RIO CASALETTO
V.NE SECCO
BS24
LAURITO
MONTANO ANTILIA
BS11
F. MINGARDO
BS14
BS05
V.NE OLIVA
CASALETTO SPARTANO
BS15
BS04
MORIGERATI
TORTORELLA
BS13
BS23
TORRE ORSAIA
BS12
SERRALUNGA
TORRACA
BS03
ROCCAGLORIOSA
S. MARINA
VIBONATI
CELLE DI BULGHERIA
BS02
ISPANI
BS01
POLICASTRO
PG08
PG07
SAPRI
BS00
PG05
BULGHERIA Mnt
PG09
PG06
COCCOVELLO Mnt
S. GIOVANNI A PIRO
PG10
PG11
PG04
POLICASTRO GULF
CAMEROTA
PG03
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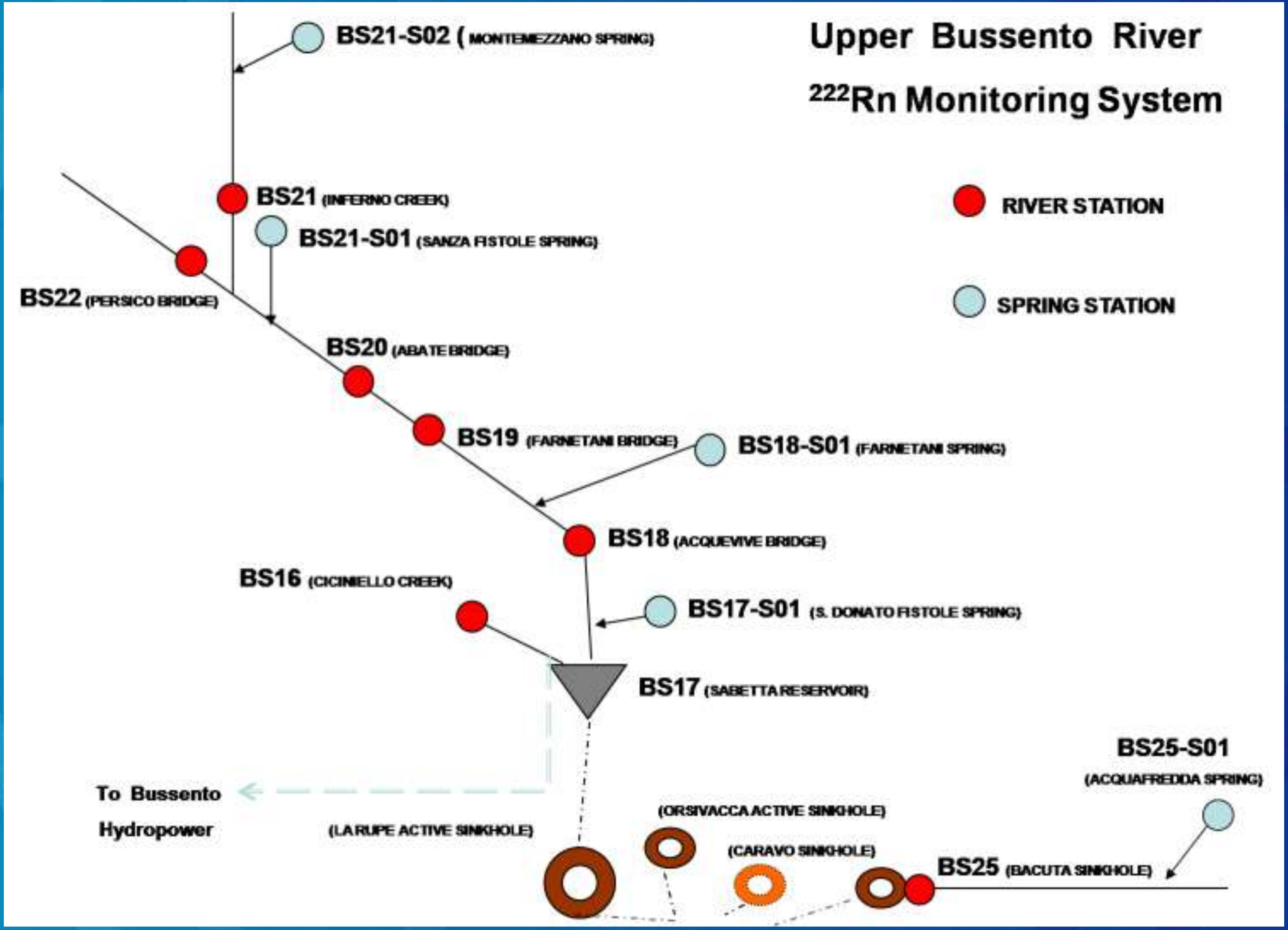
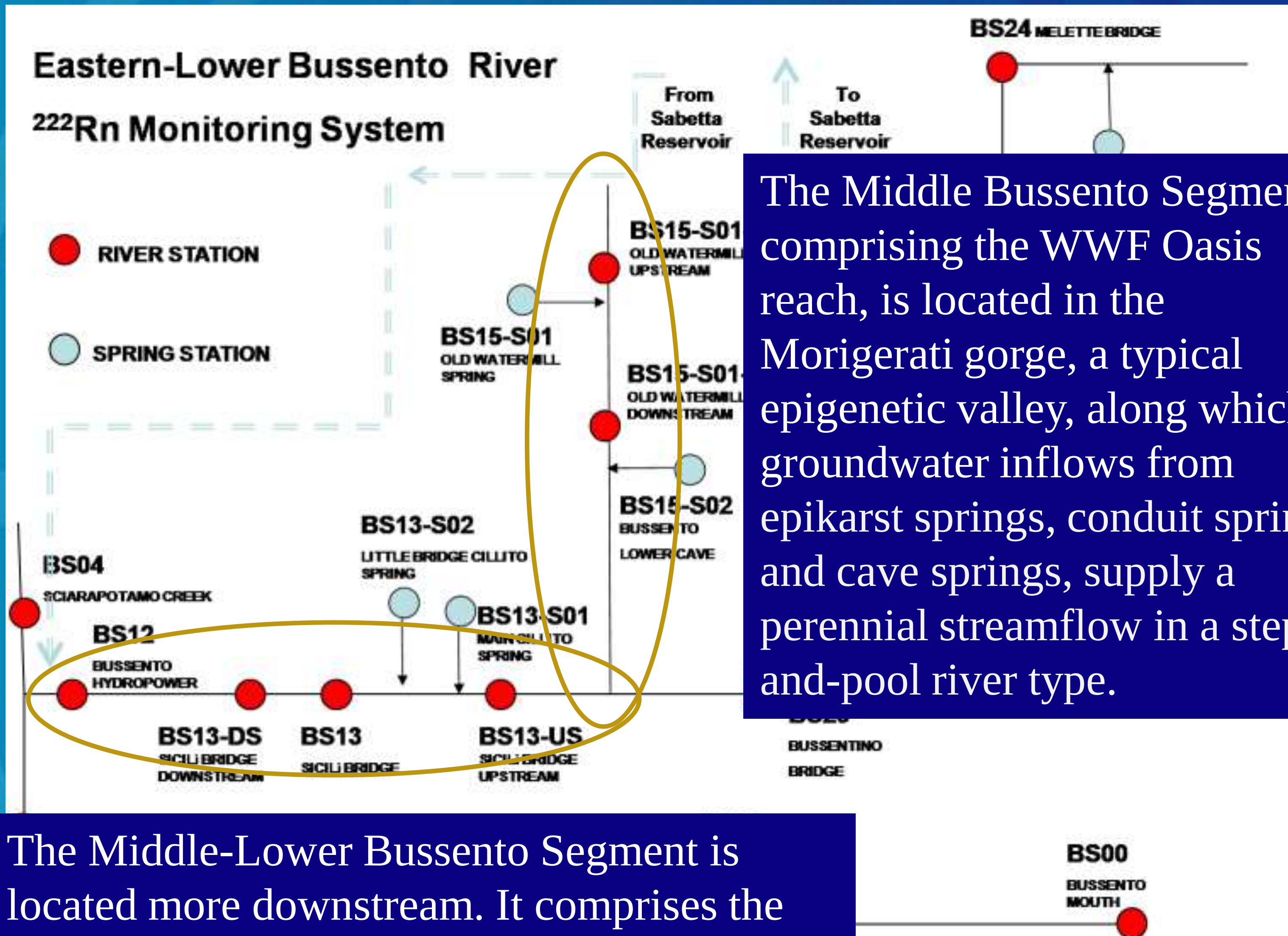
PG01
0 1 2 4 6 8 10
Km
Legend
BS
PG
1
2



Upper Bussento River
222Rn Monitoring System
RIVER STATION
SPRING STATION
BS21-S02 (MONTEMEZZANO SPRING)
BS21 (INFERNO CREEK)
BS21-S01 (SANZA FISTOLE SPRING)
BS22 (PERSICO BRIDGE)
BS20 (ABATE BRIDGE)
BS19 (FARNETANI BRIDGE)
BS18-S01 (FARNETANI SPRING)
BS18 (ACQUEVIVE BRIDGE)
BS16 (CICINIELLO CREEK)
BS17-S01 (S. DONATO FISTOLE SPRING)
BS17 (SABETTA RESERVOIR)
BS25-S01
(ACQUAFREDDA SPRING)
To Bussento
Hydropower
(LA RUPE ACTIVE SINKHOLE)
(ORSIVACCA ACTIVE SINKHOLE)
(CARAVO SINKHOLE)
BS25 (BACUTA SINKHOLE)



The Middle Bussento Segment, comprising the WWF Oasis reach, is located in the Morigerati gorge, a typical epigenetic valley, along which groundwater inflows from epikarst springs, conduit springs and cave springs, supply a perennial streamflow in a step-and-pool river type.

The Middle-Lower Bussento Segment is located more downstream. It comprises the Sicilì Bridge Reference reach, a plane bed river slightly entrenched in alluvial terrace and bedrock.

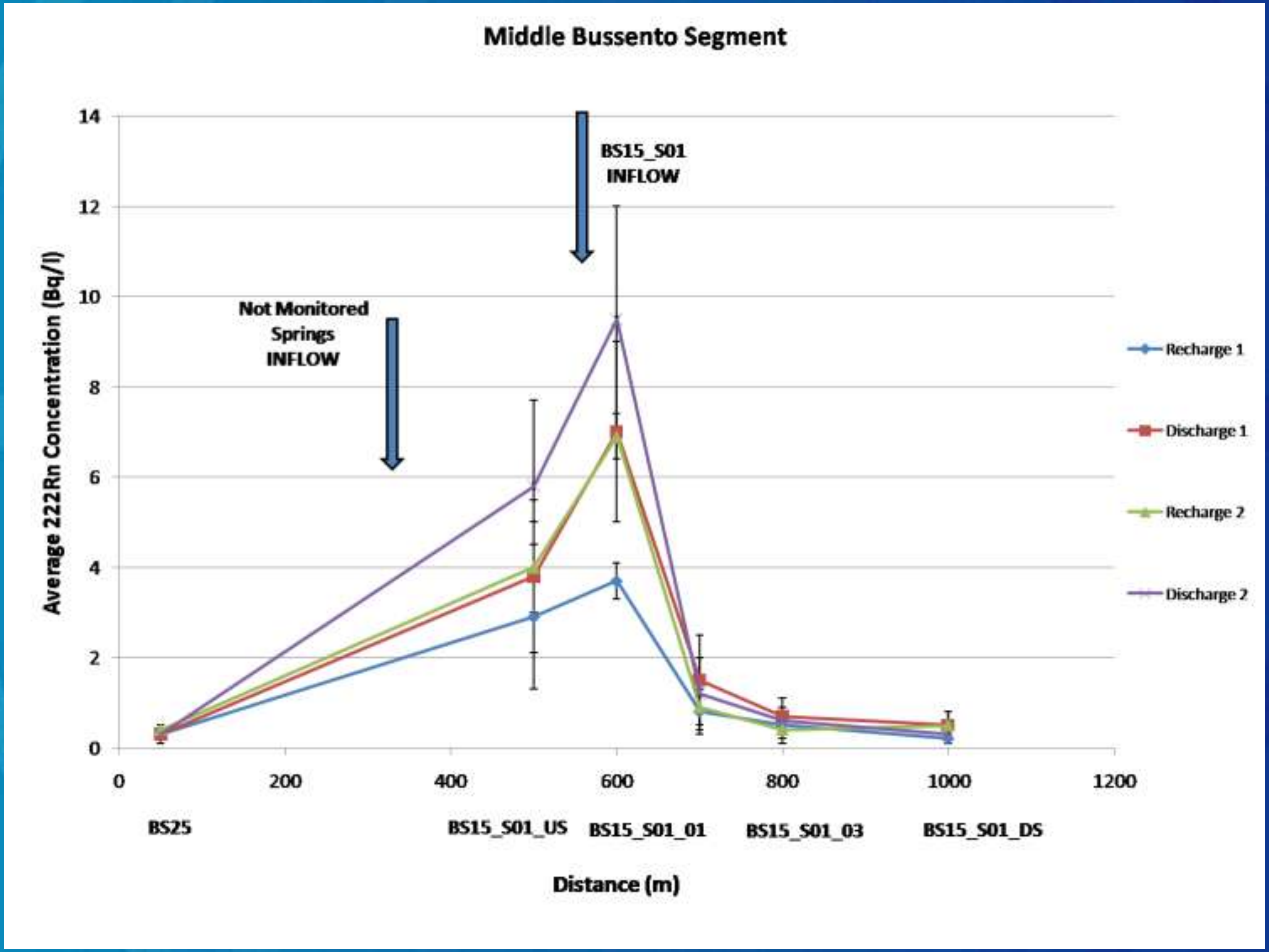
Measurement Protocol

- Identification of the sampling monitoring station (river, spring)
- Collection of the sample and/or measurement in situ
- Measurement of other parameters of interest: river discharge, chemical and physical parameters (pH, dissolved oxygen, temperature…)
- Measurement in laboratory
- Data analysis
- Planning of future campaigns according to the obtained results

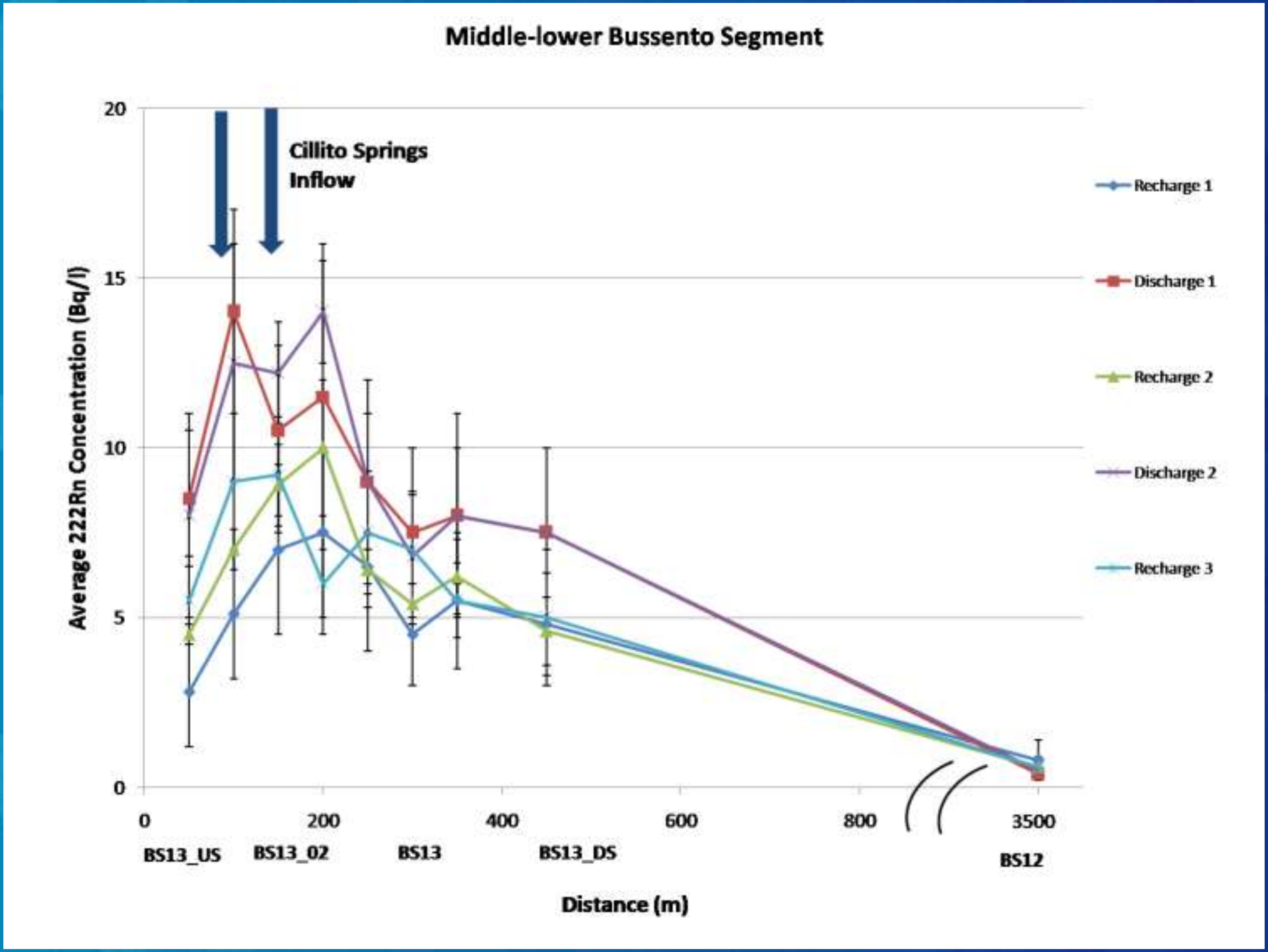
Data Analysis

- The radon activity concentration data have been arranged in relation to the fluvial level hierarchy: at segment scale and at reach scale
- Two main river segment have been analyzed: Middle Bussento and Middle-Lower Bussento
- Two reference reaches have been analyzed: Sicilì Bridge and WWF Oasis
- An analysis of radon activity concentration measured at the springs has brought to the identification of three kinds of karst springs
- An analysis of radon transfer from water to air has been made, applying different models

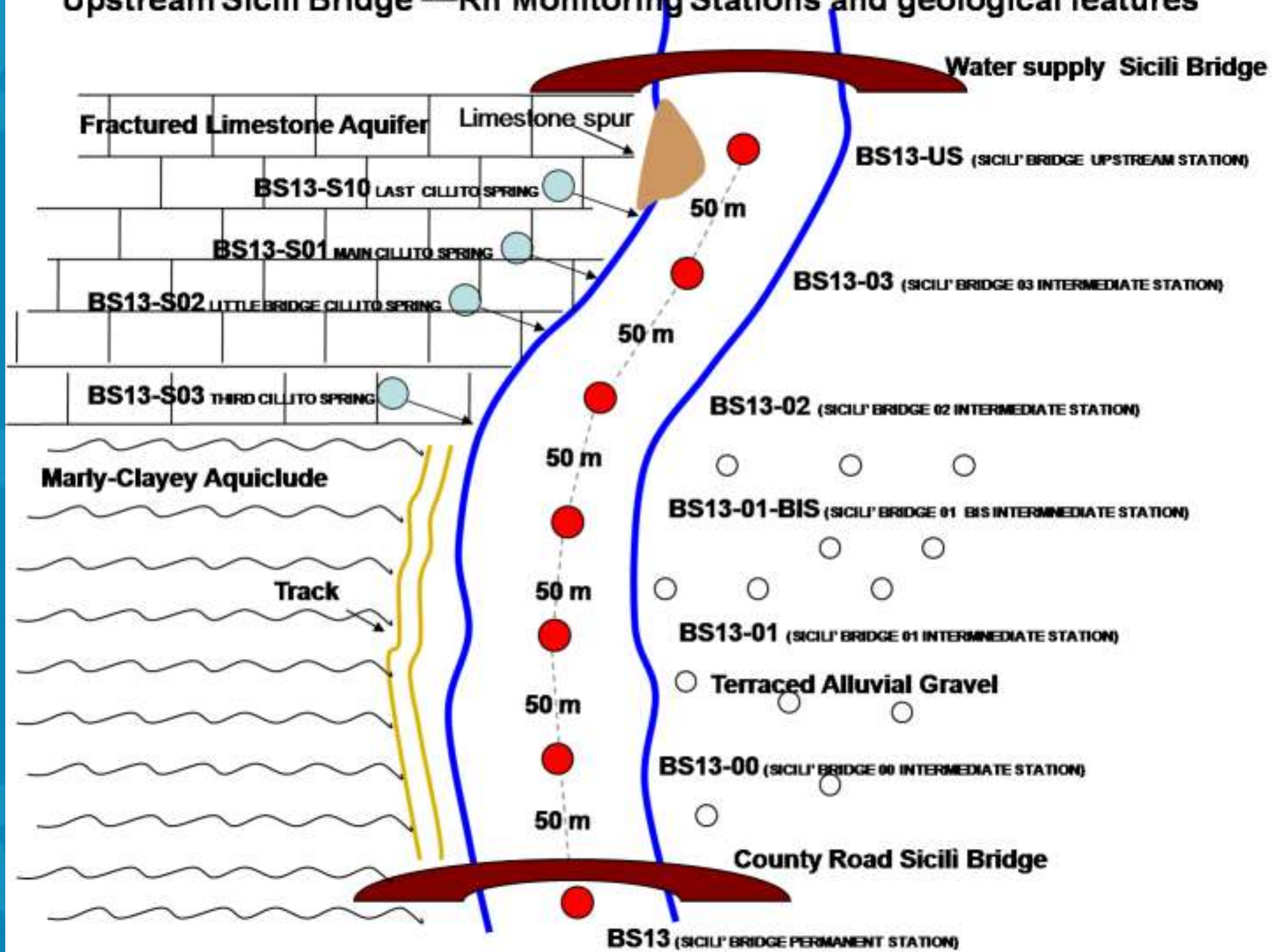
Middle Bussento Segment



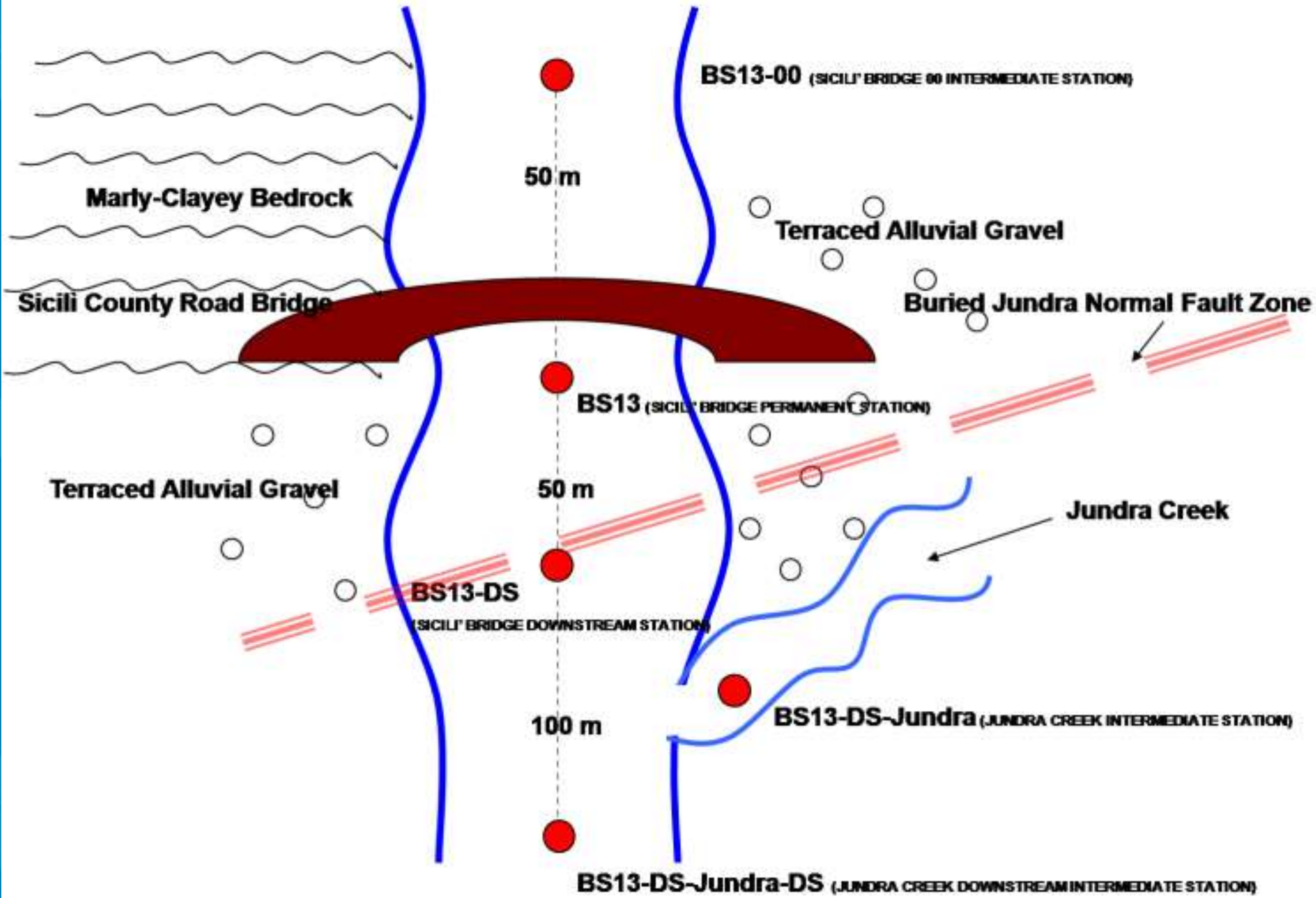
Middle-Lower Bussento Segment

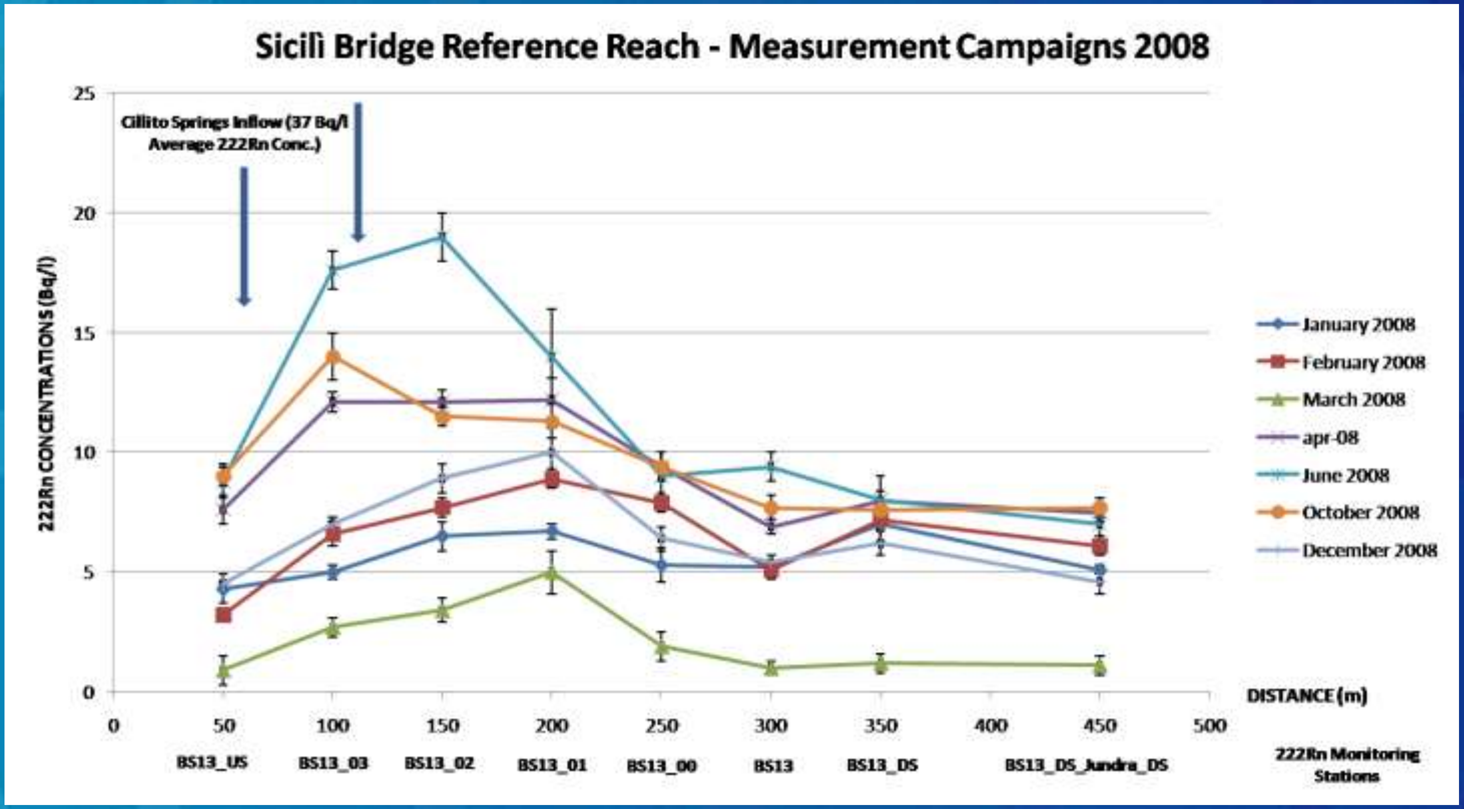


Upstream Sicilì Bridge ^{222}Rn Monitoring Stations and geological features

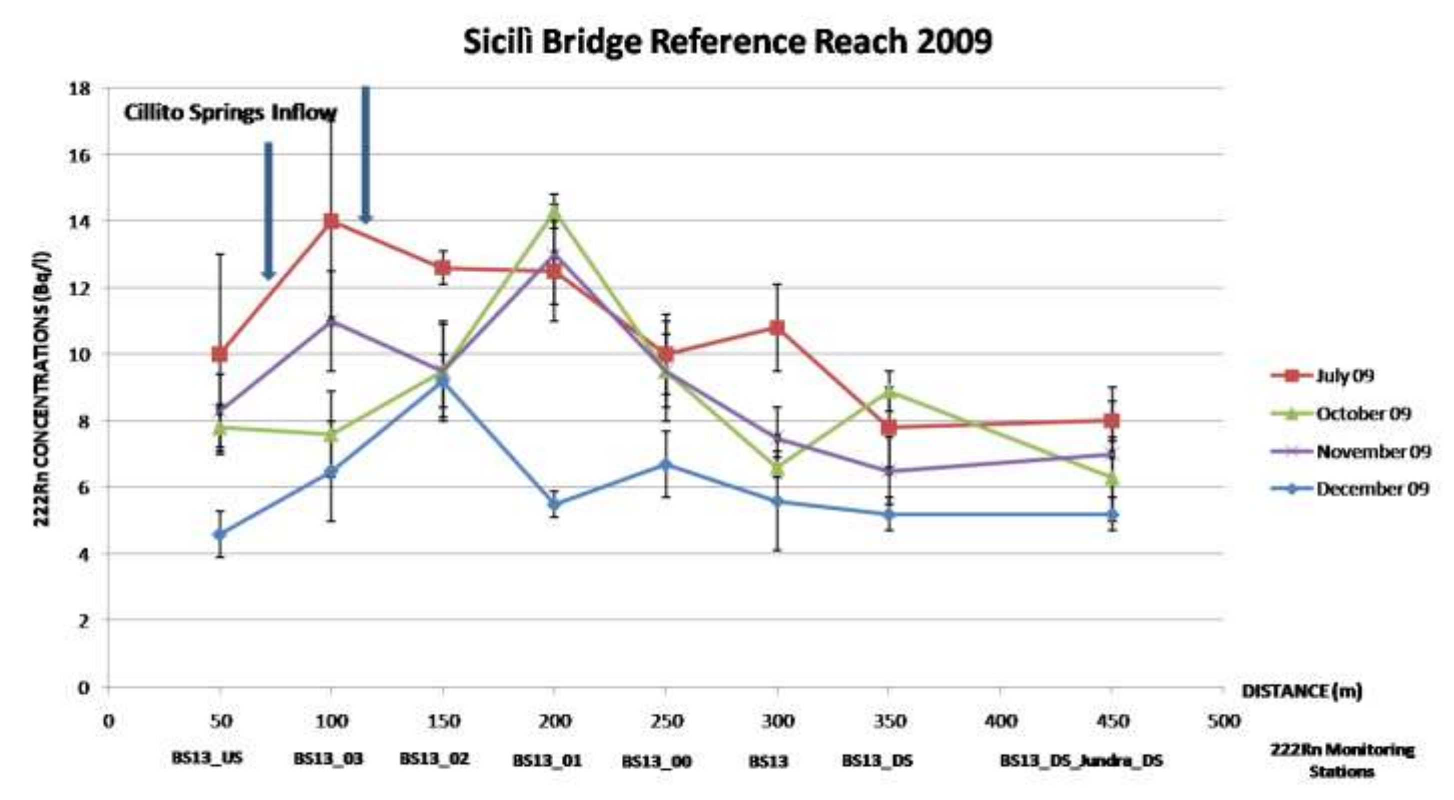


Downstream Sicilì Bridge ^{222}Rn Monitoring Stations and geological features



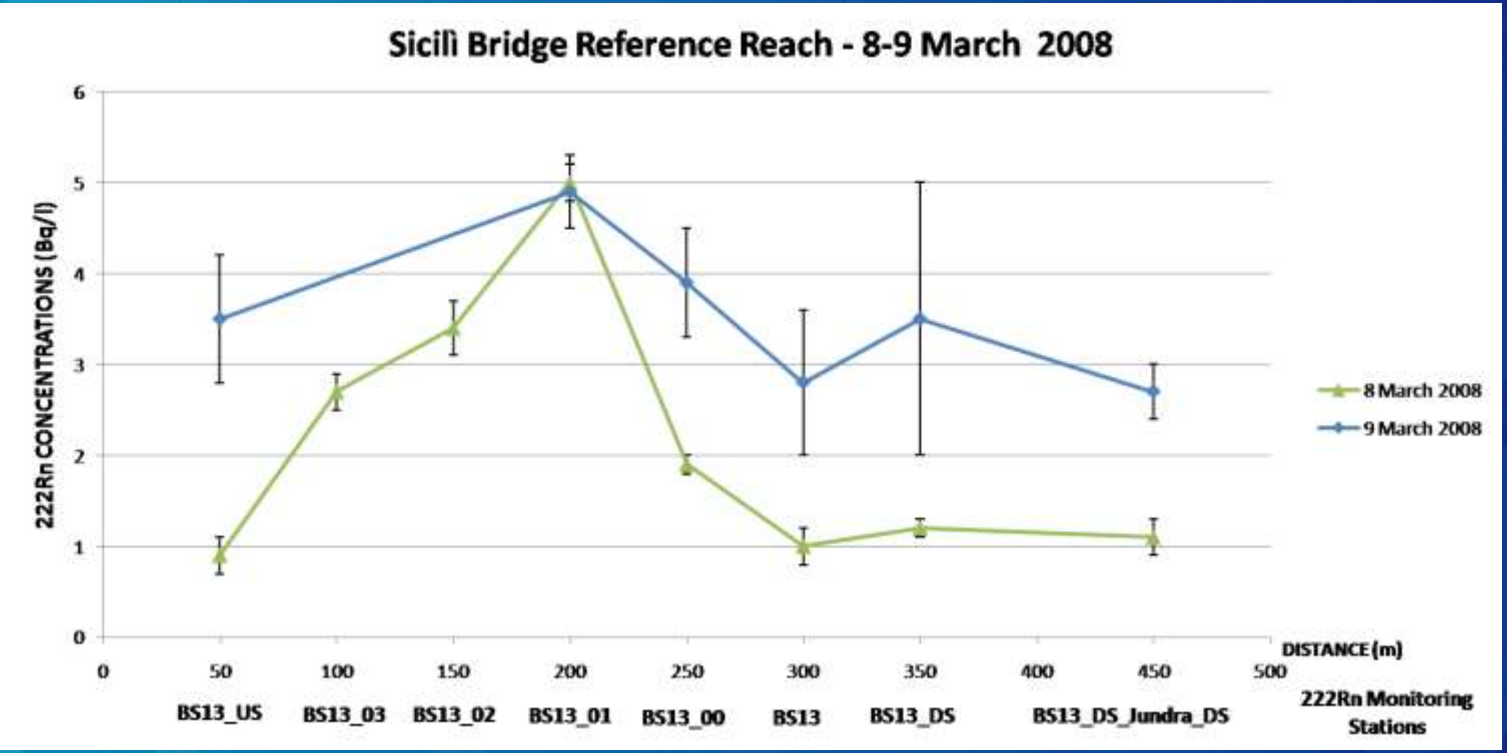


Sicilì Bridge Reference Reach - Measurement Campaigns 2008
Cillito Springs Inflow (37 Bq/l
Average 222Rn Conc.)
222Rn CONCENTRATIONS (Bq/l)
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
500
DISTANCE (m)
BS13_US
BS13_03
BS13_02
BS13_01
BS13_00
BS13
BS13_DS
BS13_DS_Jundra_DS
222Rn Monitoring Stations
January 2008
February 2008
March 2008
apr-08
June 2008
October 2008
December 2008

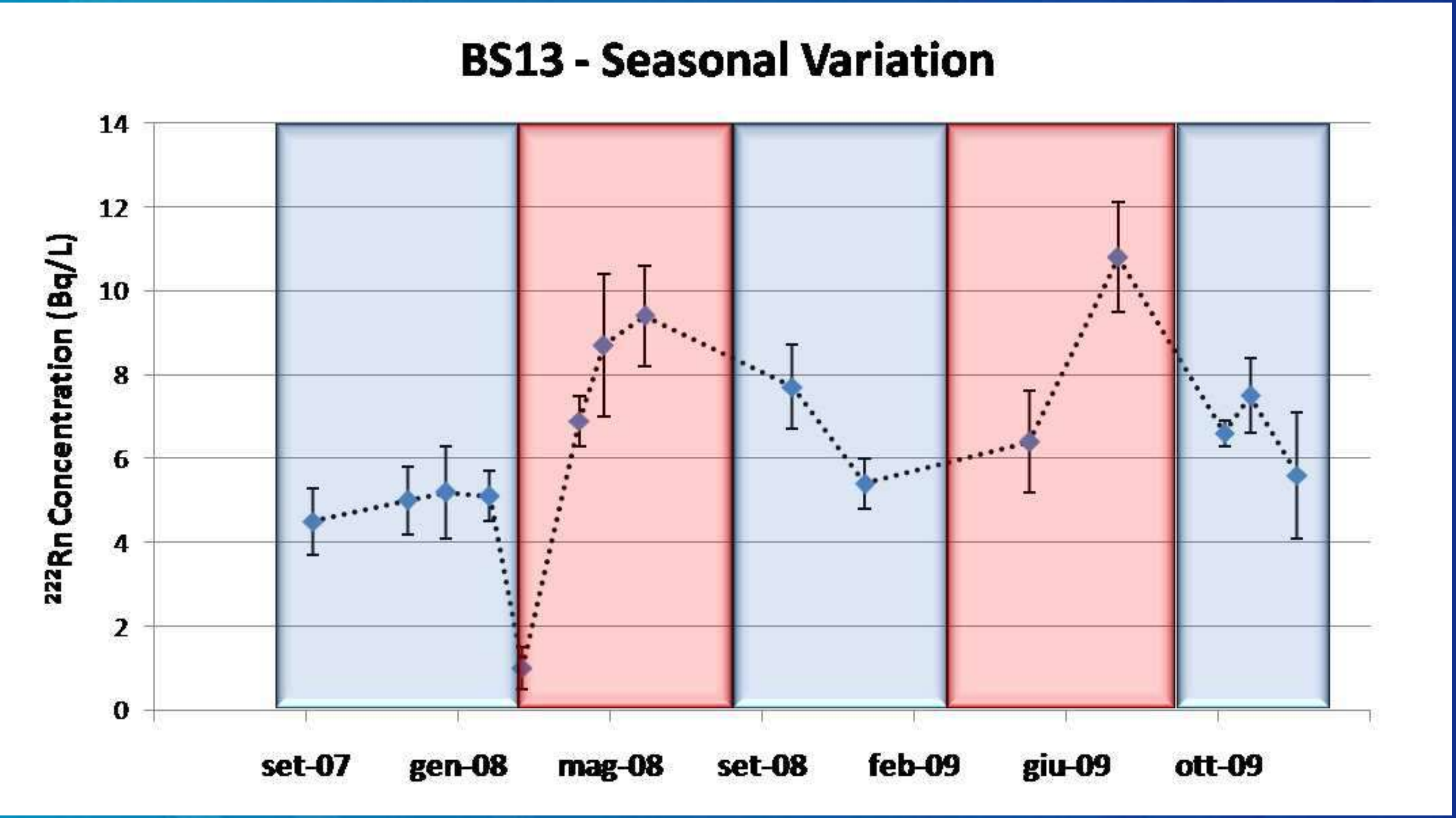


Sicilì Bridge Reference Reach 2009
Cillito Springs Inflow
222Rn CONCENTRATIONS (Bq/l)
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350
400
450
500
DISTANCE (m)
BS13_US
BS13_03
BS13_02
BS13_01
BS13_00
BS13
BS13_DS
BS13_DS_Jundra_DS
222Rn Monitoring Stations
July 09
October 09
November 09
December 09

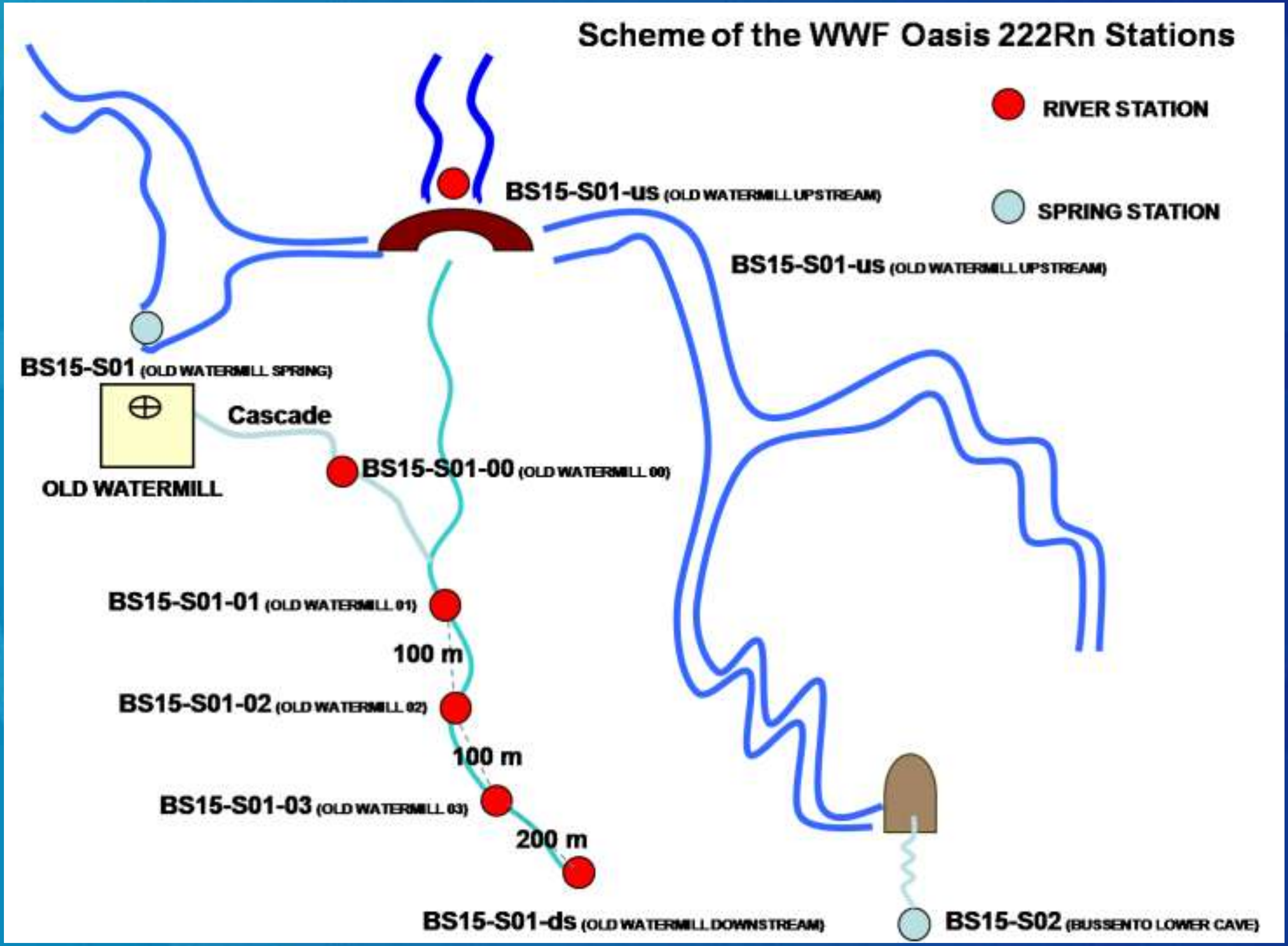
Comparison with the Flood

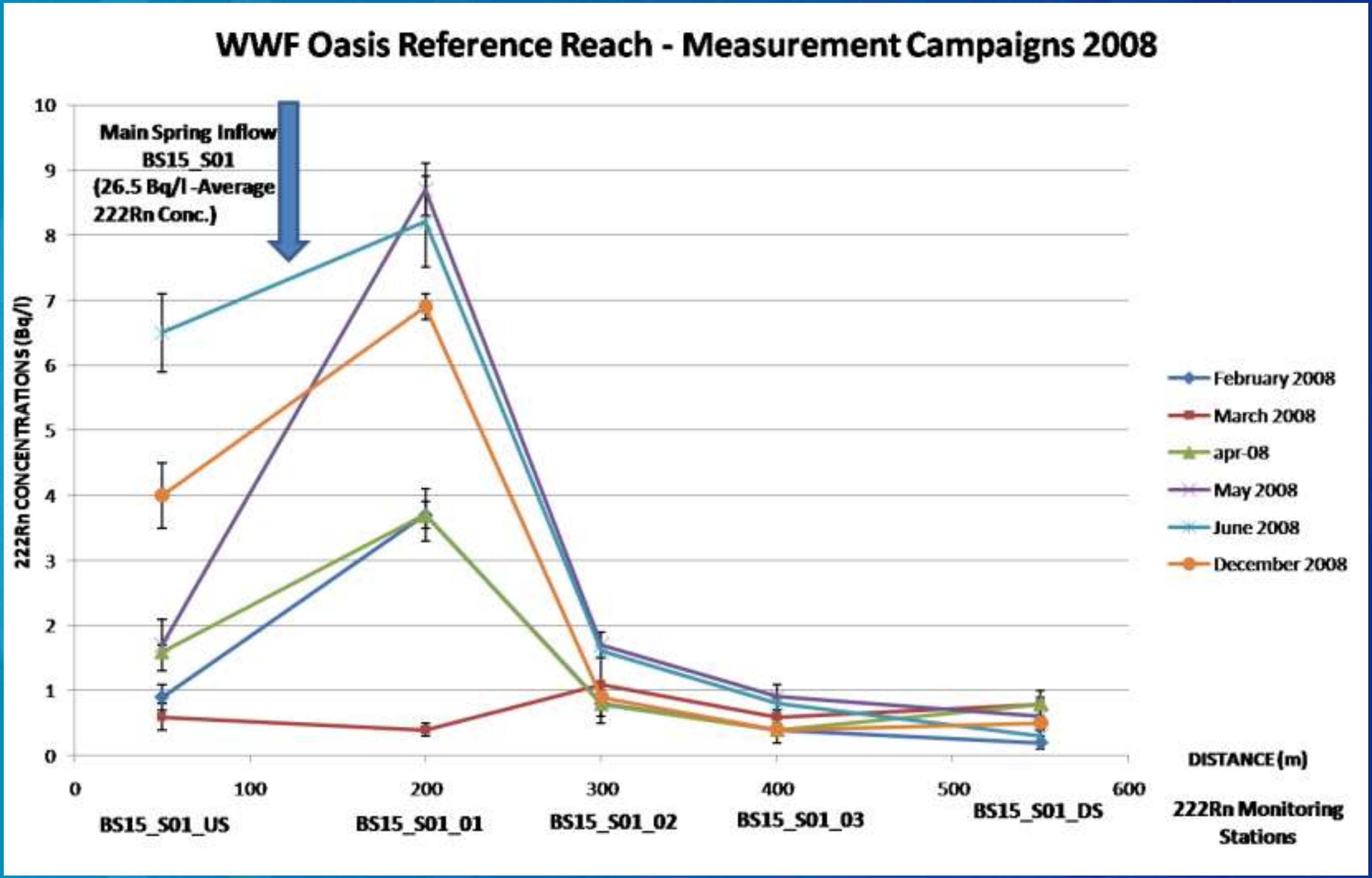


Seasonal Variation

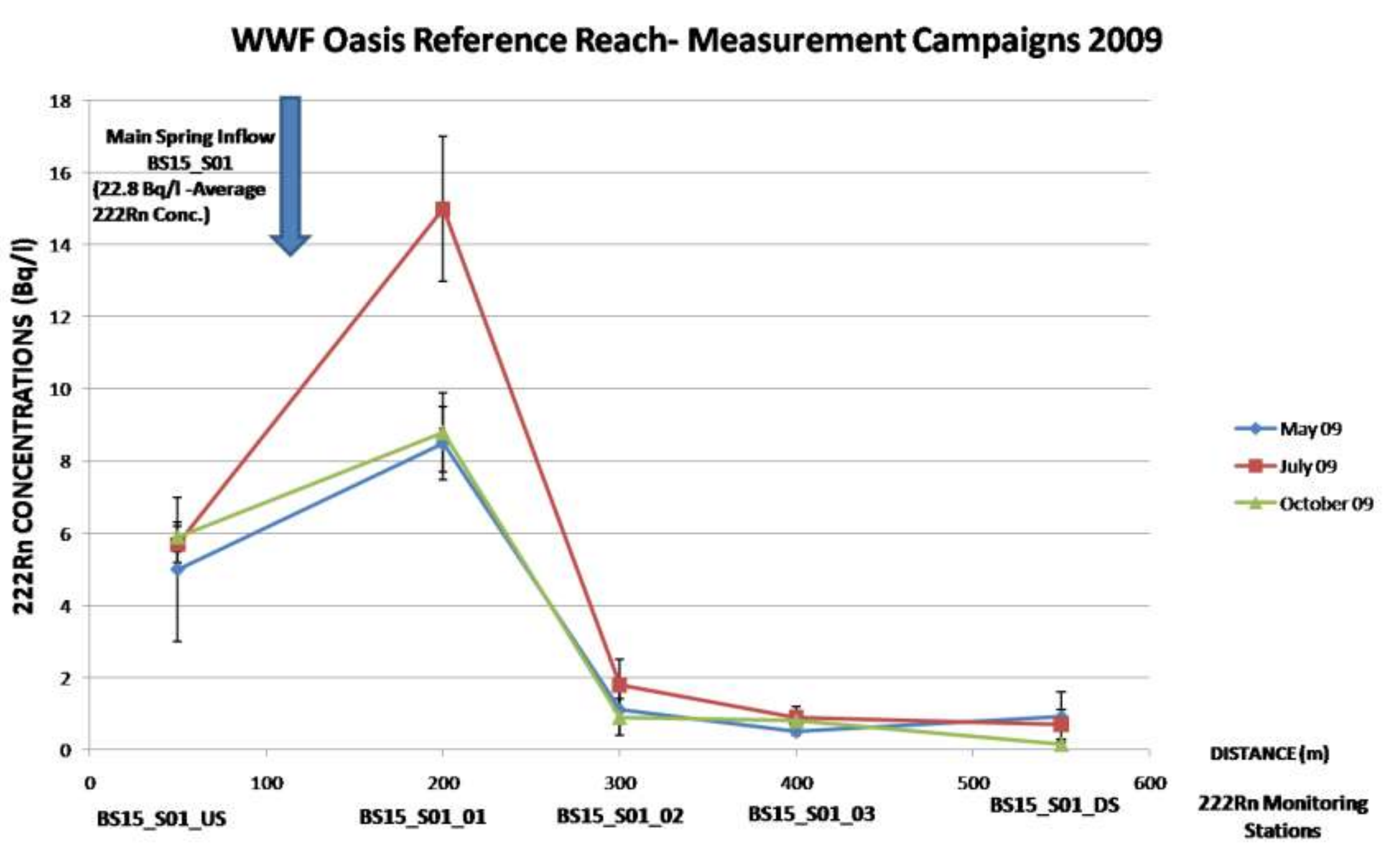


WWF Oasis Reference Reach





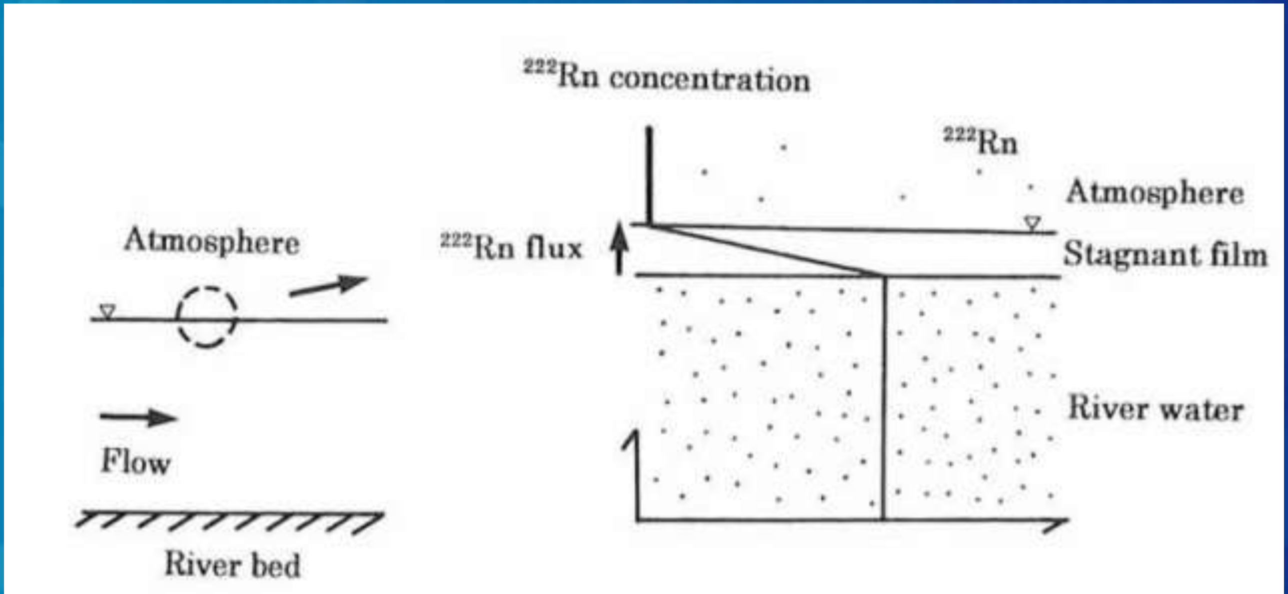
WWF Oasis Reference Reach - Measurement Campaigns 2008
Main Spring Inflow
BS15_S01
(26.5 Bq/l -Average
222Rn Conc.)
222Rn CONCENTRATIONS (Bq/l)
10
9
8
7
6
5
4
3
2
1
0
0
100
200
300
400
500
600
DISTANCE (m)
BS15_S01_US
BS15_S01_01
BS15_S01_02
BS15_S01_03
BS15_S01_DS
222Rn Monitoring Stations
February 2008
March 2008
apr-08
May 2008
June 2008
December 2008



WWF Oasis Reference Reach- Measurement Campaigns 2009
Main Spring Inflow
BS15_S01
(22.8 Bq/l -Average
222Rn Conc.)
222Rn CONCENTRATIONS (Bq/l)
18
16
14
12
10
8
6
4
2
0
0
100
200
300
400
500
600
BS15_S01_US
BS15_S01_01
BS15_S01_02
BS15_S01_03
BS15_S01_DS
DISTANCE (m)
222Rn Monitoring
Stations
May 09
July 09
October 09

Stagnant Film Model

- The radon content of river water is strongly affected by volatilization to the atmosphere
- A model used to characterize the transfer of radon to the atmosphere is the **stagnant film model**
- This model assumes that the rate of exchanges of gases between the water and the atmosphere is controlled by molecular diffusion through a stagnant film, tens of microns thick, at the water-air interface.



•Both the air above and the water below this film are assumed to constitute two well-mixed reservoirs with uniform vertical concentrations separated by the stagnant film of water

Stagnant Film Model

- The thickness of the film is dependent on the degree of agitation of the water surface caused by wind, waves and currents
- The thickness of the stagnant film, z, is estimated by comparing upstream and downstream radon concentrations in a section of the stream where it can be assumed there is no groundwater contribution to the streamflow

$$z = \frac{x\,D}{\ln(C_{US}/C_{DS})\,h\,v}$$

• Two reference stations have been chosen to measure C_{US} and C_{DS}

•From the equation $C_{DS} = C_{US}\, e^{-\alpha x}$

•Where

$$\alpha = D / z\,h\,v$$

Stagnant Film Model

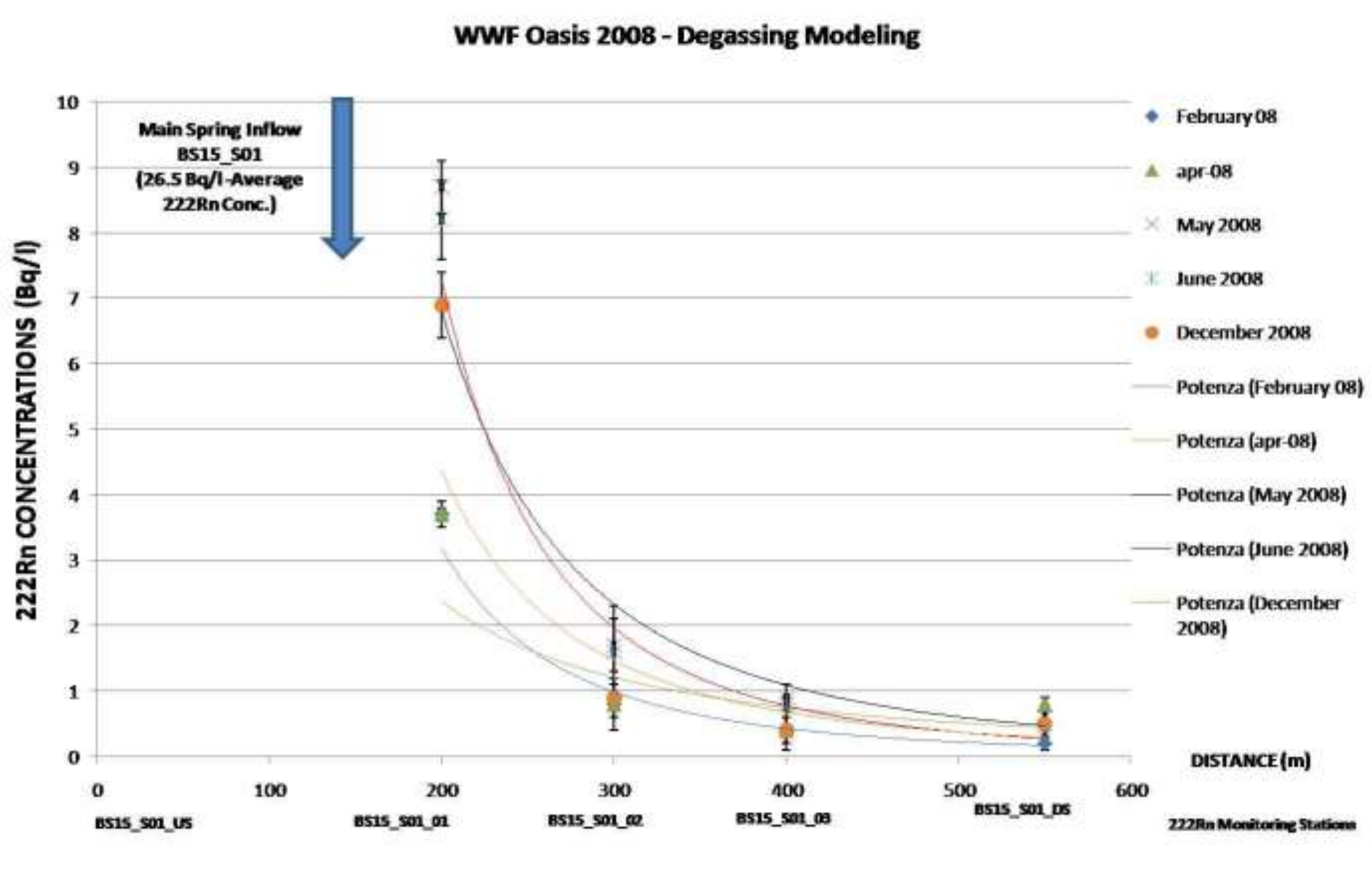
Sicilì Bridge

Measurement Campaign	Degassing Coefficient α $(m^{-1} \cdot 10^{-3})$	Stagnant Film Thickness z (μm)
January 08	0.8 ± 0.1	15 ± 2
February 08	0.8 ± 0.1	15 ± 2
March 08	3.8 ± 1.1	3.2 ± 1.0
April 08	1.4 ± 0.2	9.0 ± 1.0
June 08	3.3 ± 6	3.6 ± 0.7
October 08	1.7 ± 0.3	7.0 ± 1.1
December 08	2.2 ± 0.5	5.5 ± 1.1
May 09	2.6 ± 1.0	4.6 ± 1.8
July 09	1.6 ± 0.5	7.5 ± 2.5
October 09	1.4 ± 0.5	9 ± 3
November 09	1.3 ± 0.6	9 ± 4
December 09	1.9 ± 0.4	6.5 ± 1.5

WWF Oasis

Measurement Campaign	Degassing Coefficient α $(m^{-1} \cdot 10^{-3})$	Stagnant Film Thickness z (μm)
February 08	8 ± 5	1.4 ± 0.8
March 08	1.3 ± 0.8	9 ± 6
April 08	4 ± 1	2.7 ± 0.7
May 08	7.6 ± 1.8	1.6 ± 0.4
December 08	7.5 ± 2.0	1.6 ± 0.4
May 09	6 ± 4	2.0 ± 1.5
July 09	9 ± 6	1.4 ± 1.0
October 09	12 ± 10	1.2 ± 1.0

Gas Exchange Analysis



$$y = K\,x^{-\delta}$$

A very sudden and sharp decrease can be observed

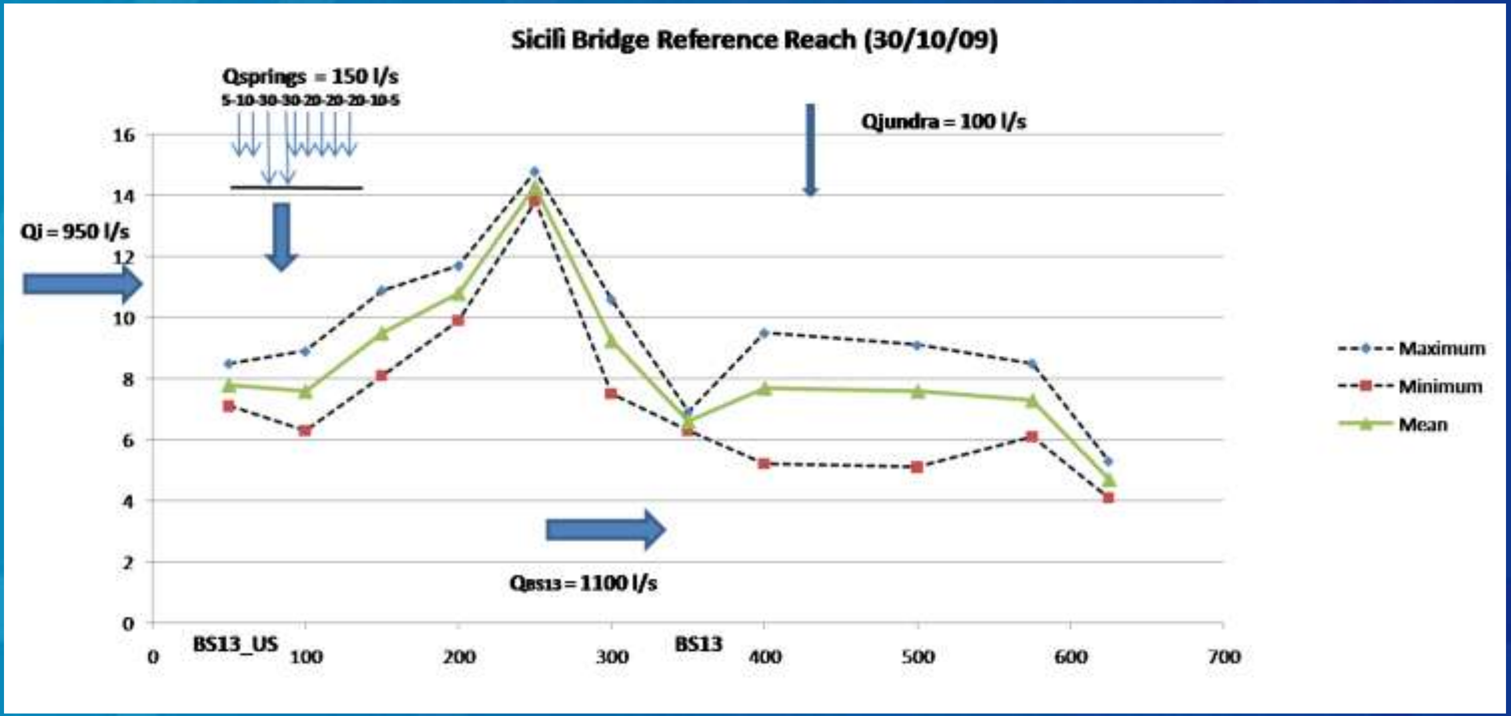
The best fit curve has turned out to be a Power Law

δ is a coefficient that indicates how quickly radon outgassing happens

• The values are mainly included in the range between 2.5 and 3.5

Measurement Campaign	K	δ	R^2 Curve Fitting
February 08	10^7	2.87	0.979
April 08	$1.6 \cdot 10^4$	1.66	0.578
May 08	$9 \cdot 10^6$	2.65	0.938
June 08	$2 \cdot 10^8$	3.22	0.989
December 08	$7 \cdot 10^6$	2.69	0.795
May 09	10^6	2.35	0.673
July 09	10^8	3.04	0.886
October 09	$3 \cdot 10^9$	3.76	0.938

Gas Exchange Analysis

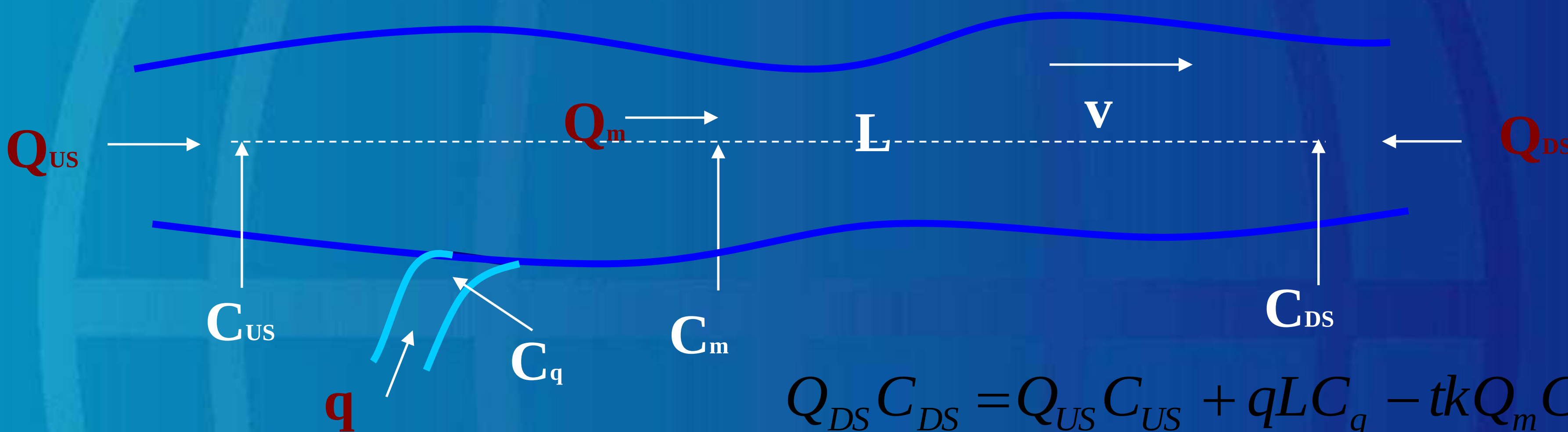


$$Q_{DS}C_{DS} = Q_{US}C_{US} + qC_q - k\,t\,Q_{avg}C_{avg}$$

Measurement Campaign	Q_{US} (l/s)	Q_{BS13} (l/s)	$q_{springs}$ (l/s)	Mean Stream Velocity (m/s)	k (s^{-1})
October 09	950	1100	150	0.5	$(5 \pm 2) \cdot 10^{-4}$
November 09	1100	1450	300	0.5	$(12 \pm 4) \cdot 10^{-4}$
December 09	2600	3700	400	0.7	$(6 \pm 2) \cdot 10^{-4}$

Modello di Kies-Hofmann et al.

per la valutazione della portata delle acque sorgive profonde

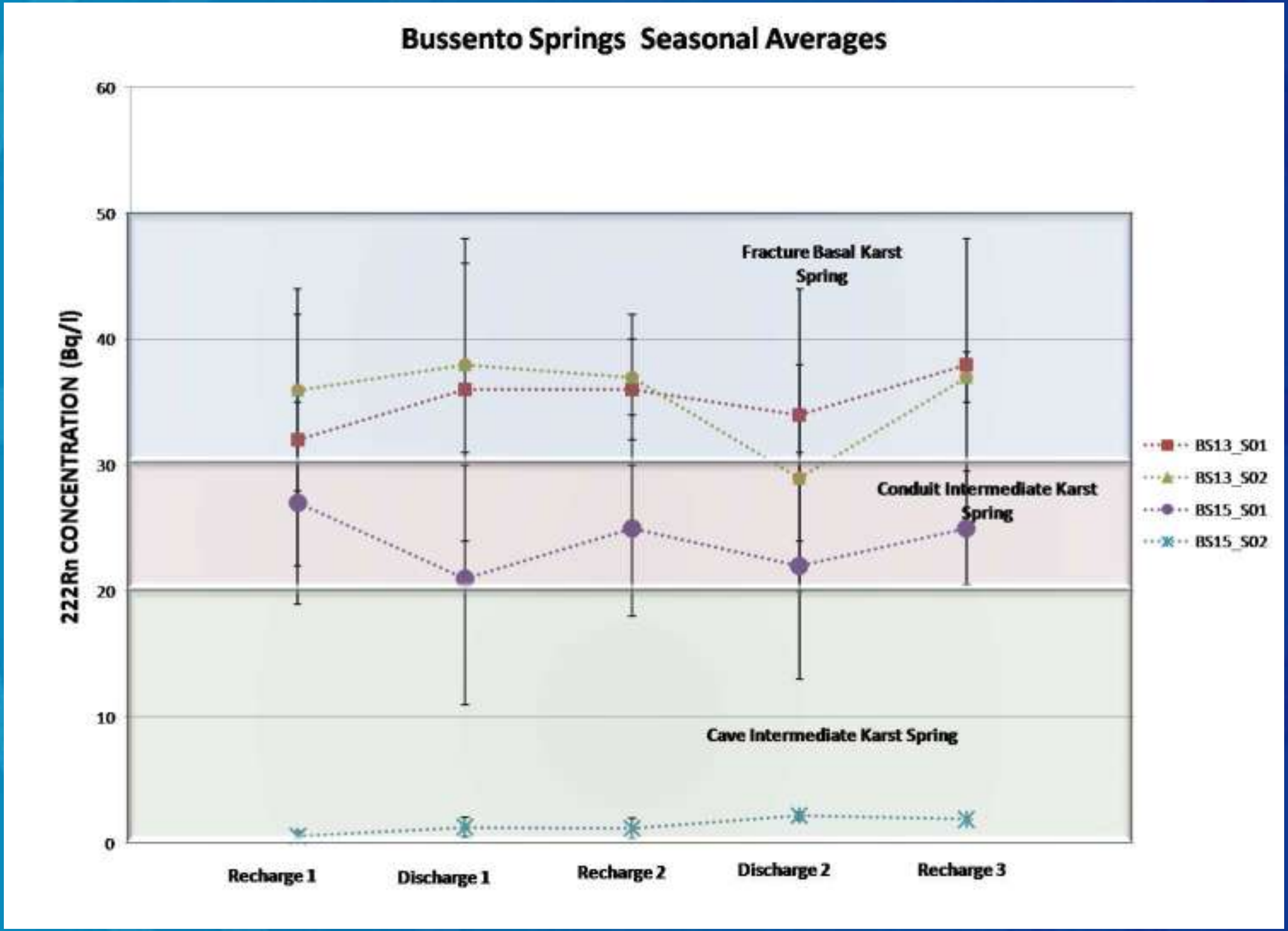


$$Q_{DS}C_{DS} = Q_{US}C_{US} + qLC_q - tkQ_mC_m$$

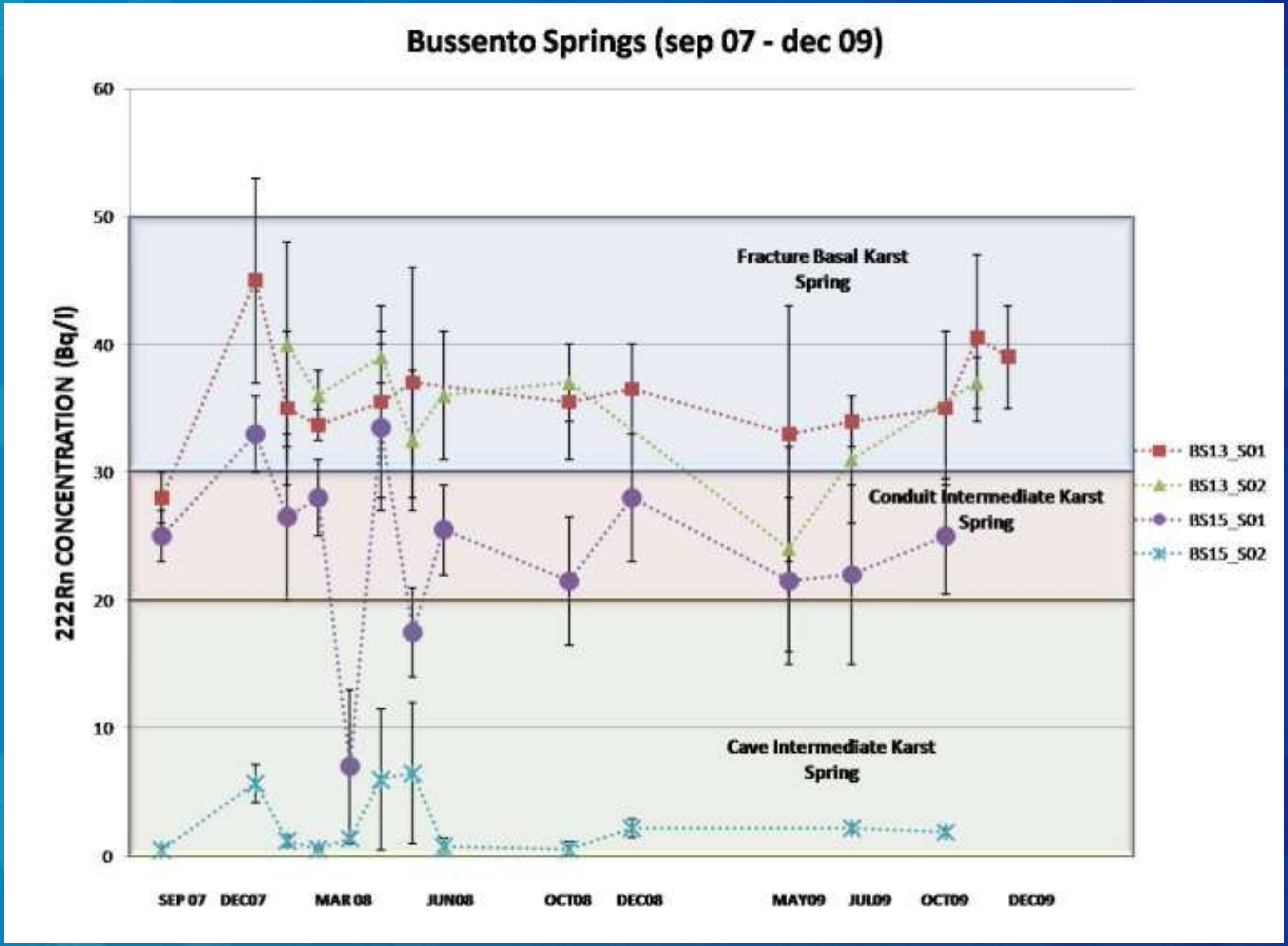
Grandezze da misurare:

1. C_{US} C_{DS} C_m C_q **Concentrazioni Upstream, Downstream, Media e di Immissione Laterale**
2. Q_{US} Q_{DS} Q_m **Portate Upstream, Downstream e Media**
3. **L** **Distanza tra le 2 stazioni di misura Upstream e Downstream**
4. **v** Velocità del flusso per ricavare il tempo **t**

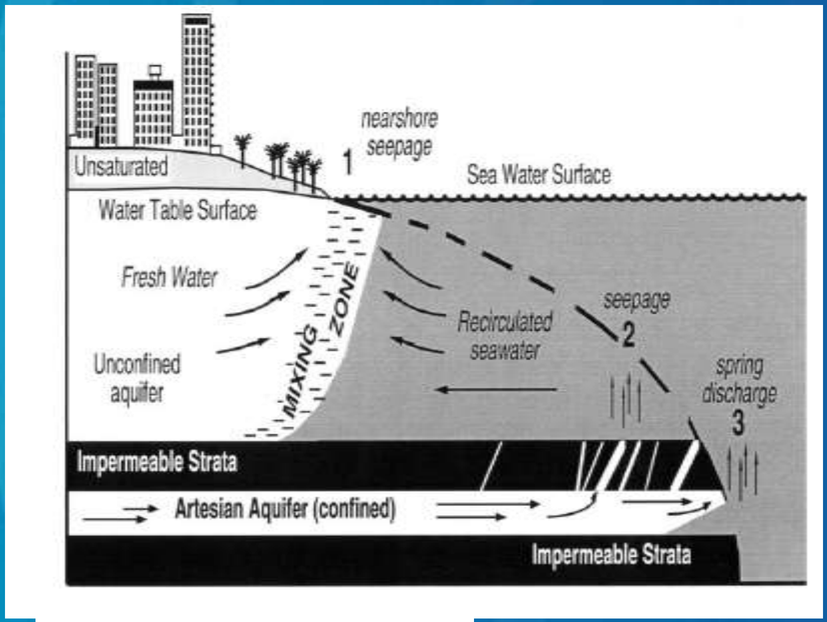
Karst Springs Analysis



Karst Springs Analysis



Submarine Groundwater Discharges (SGD)



SGD

Figura 9.3 - Carta delle Stazioni di Monitoraggio Radon-222 in alveo

Submarine Groundwater Discharges (SGD)

SGD "Vuddu", Villammare, Policastro, Cilento
(> 5mc/s)

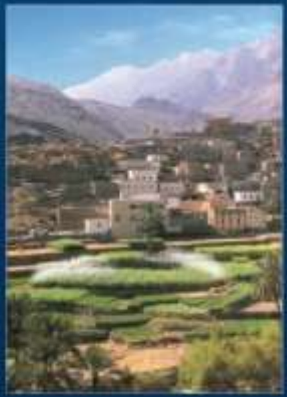
Submarine Groundwater Discharge

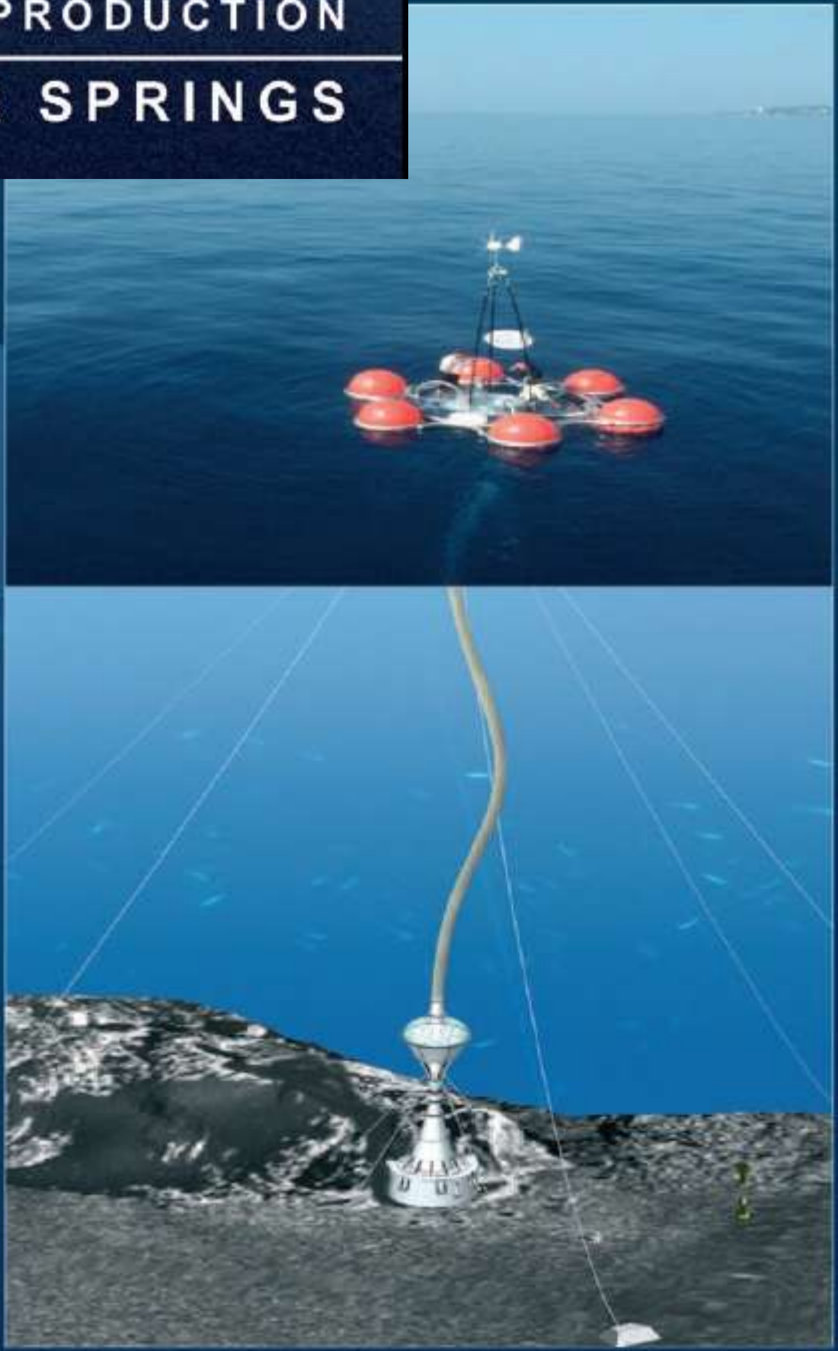
O' Vuddu (boiling water), Policastro., Italy

EXPLORATION-PRODUCTION

SUBMARINE FRESH WATER SPRINGS

Water for all uses





Courtesy of NYMPHEA WATER

Why to be concerned about Karst Aquifers?

PATHWAYS FOR POLLUTION

- Sinkholes
- Cave Entrances
- Cracks and Crevices
- Filtration through Soil
- Soil Macropores

In karst landscapes, water can enter the aquifer through large openings, thus very little or no filtration occurs.

PATHWAYS FOR POLLUTION

- Sinkholes
- Cave Entrances
- Cracks and Crevices
- Filtration through Soil
- Soil Macropores

Large openings (caves and crevices) are often continuous for the entire length of the aquifer (from inputs via sinks to exits at springs or wells).

PATHWAYS FOR POLLUTION

- Sinkholes
- Cave Entrances
- Cracks and Crevices
- Filtration through Soil
- Soil Macropores

Once in the aquifer, water and contaminates can move quickly…

to both known and unpredictable locations!

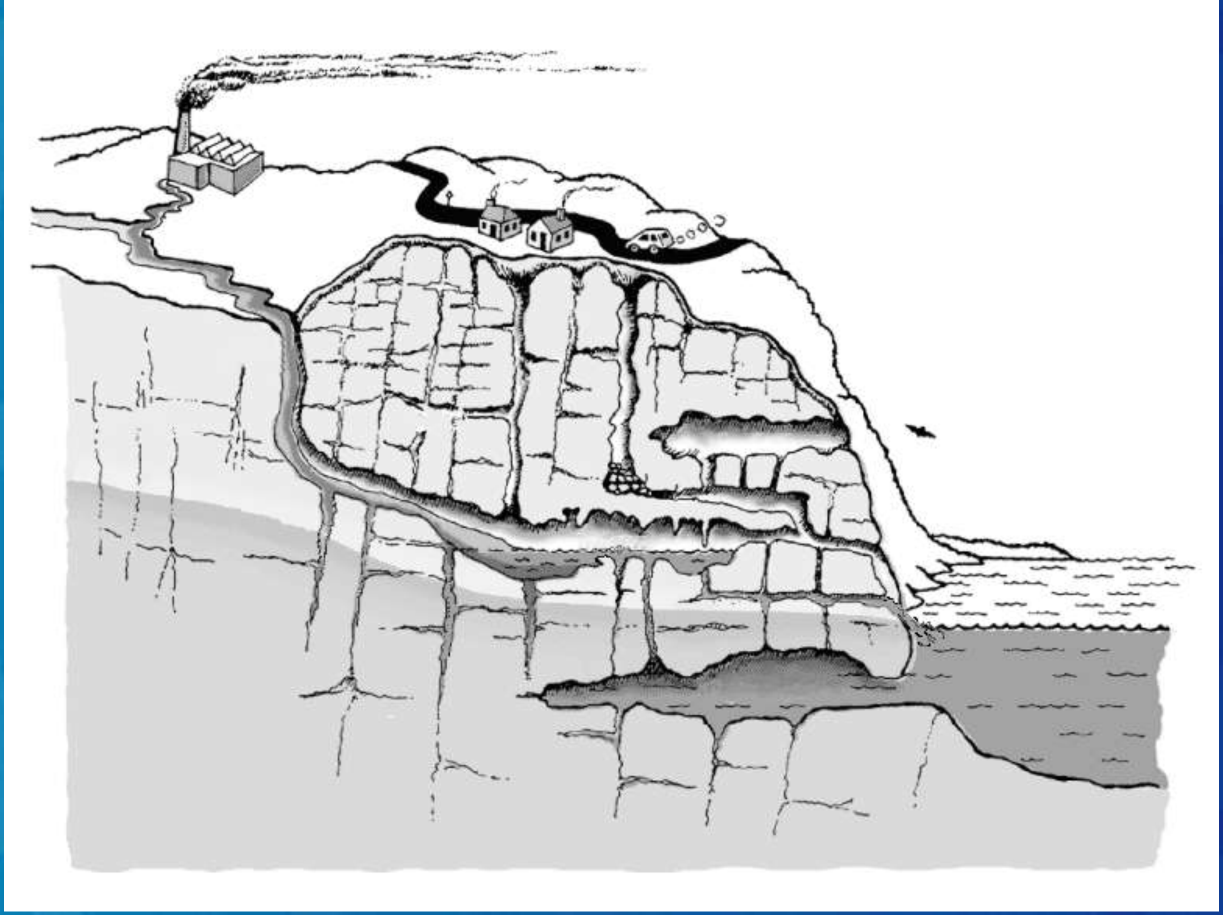
Karst groundwater is extremely susceptible to pollution…

Urban pollution of groundwater: sewage, pavement runoff containing petrochemicals, trash, domestic and industrial chemicals

Rural pollution of groundwater: sewage, fertilizers, pesticides, herbicides, dead livestock, and trash

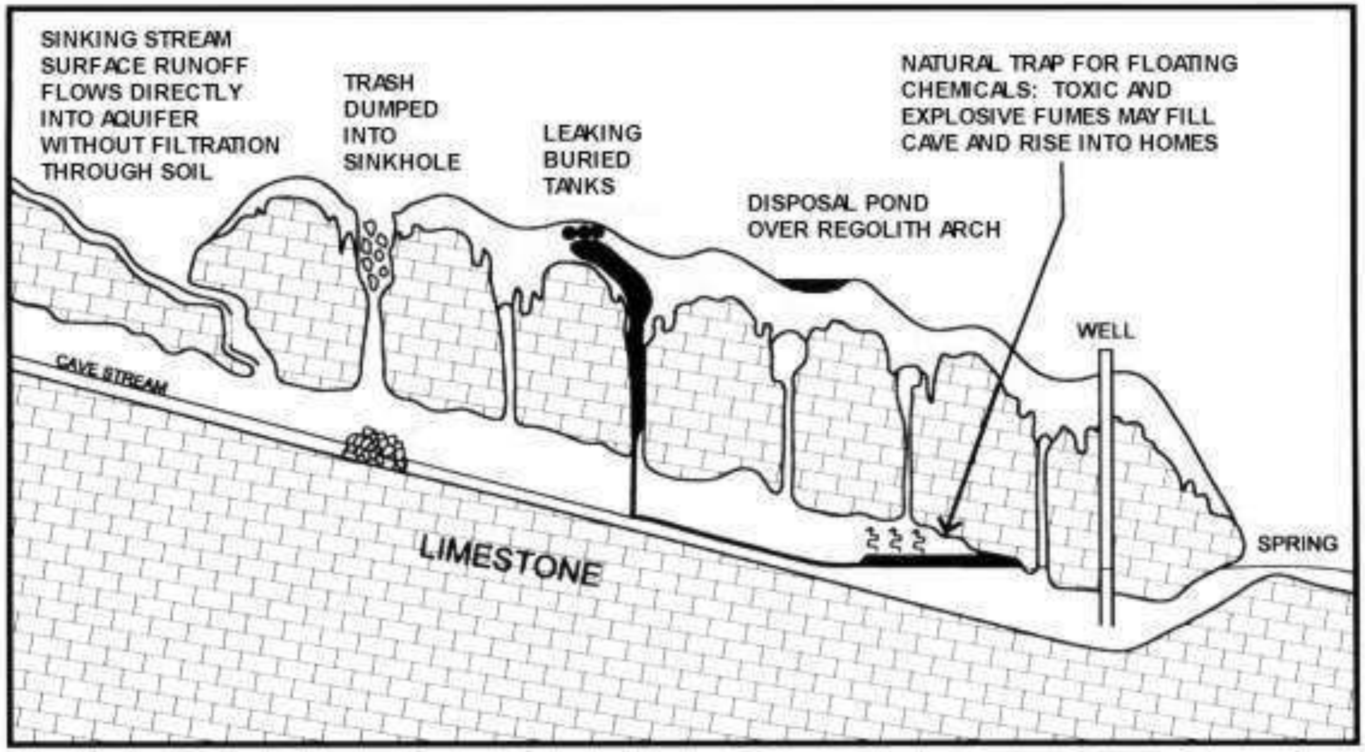
Contaminants associated with agricultural activities, such as nitrates, bacteria from livestock waste, and pesticides, are common in karst groundwater. Also, contaminants associated with urban runoff, such as lead, chromium, oil and grease, and bacteria from pet-animal wastes may be a threat to people using karst water supplies and to aquatic cave life.

Karst landscape: a very complex network for groundwater



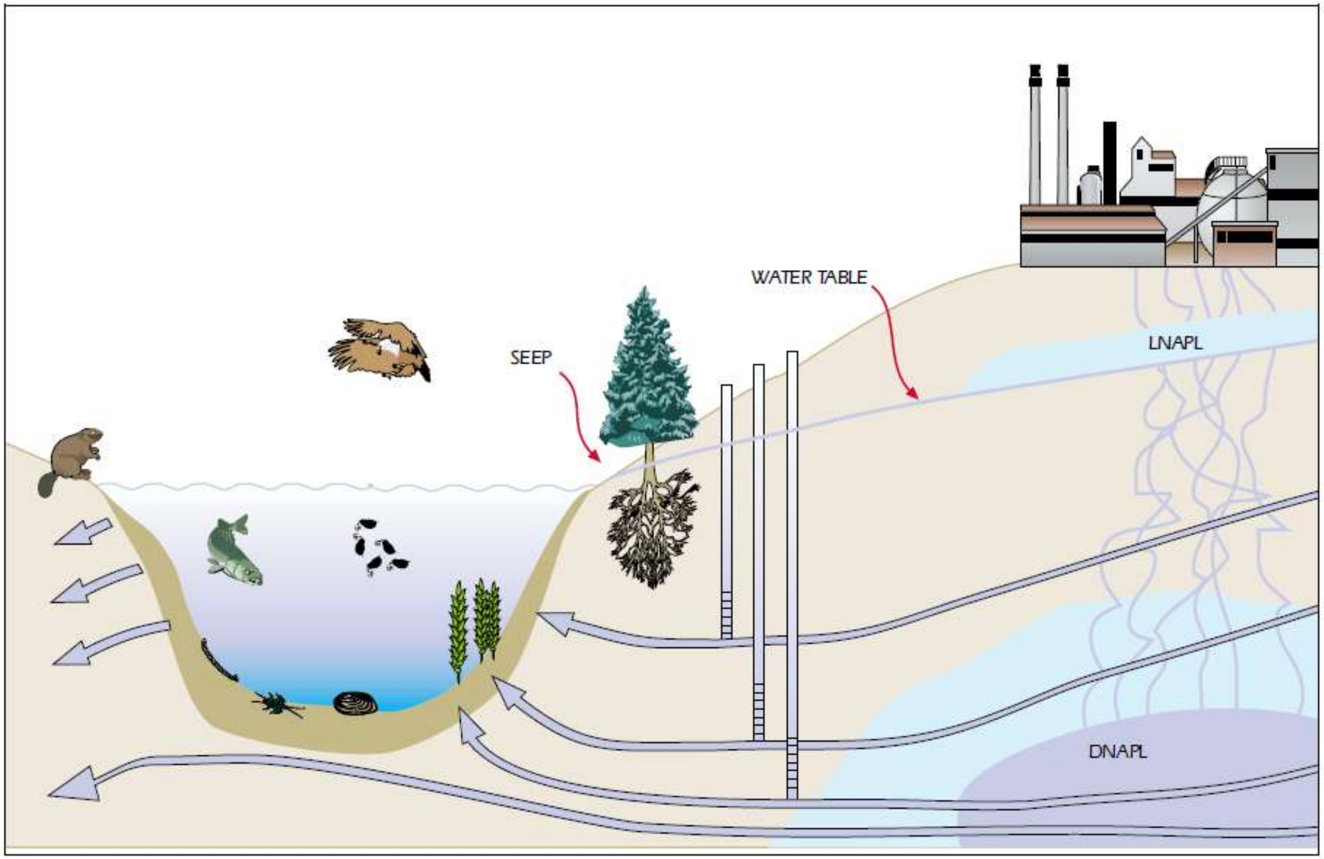
From: USGS (2002) Exploring Caves, Washington, D.C., pp. 61.

Karst aquifers and contamination



Profile view of karst aquifer showing sources of groundwater contamination

© 2002, Nick Crawford
Center for Cave and Karst Studies


WATER TABLE
SEEP
LNAPL
DNAPL

Flooding

Catastrophic collapse:

- regolith (soil) collapse
- bedrock (cave) collapse

Construction problems:

- stabilization of land for buildings and roads

Courtesy by J. Alan Glennon
Department of Geography
University of California, Santa Barbara

Water-supply development

- quantity and quality

Environmental Health Issues

- radon
- acute contaminant exposure
- medical geology

What can be done about all these problems?

- Study karst environments and apply information to solutions
- Make Informed Choices and Plans (Gather Information)
- Implement plans with an understanding of ongoing processes
- Know typical behavior for karst landscapes; prepare for it – budget for it

Conclusions

- The implementation of radon measurement techniques has confirmed the perspective of using these methodologies to investigate the interaction between streamflow and groundwater in a river
- Different measurement techniques have been tested and compared
- Experimental data have been acquired during monthly measurement campaigns
- Data have enabled to individuate a spatial and temporal variability of radon activity concentration along the river
- Three typologies of karst springs have been identified
- A flood event has been investigated comparing radon activity concentration during and after the flood
- A preliminary investigation and modeling of radon diffusion from water to air has been made

SGDCILERAD

"Submarine Groundwater Discharge assessment on the interregional coastal areas of Cilento, southern Italy, with measurements of natural isotopic tracers like 222-Radon"

Our Project is funded by:

University of Salerno

Istituto Nazionale di Fisica Nucleare

C.U.G.RI.

Consorzio inter-Universitario
per la Previsione e Prevenzione dei Grandi RIschi
Università di Salerno - Università di Napoli "Federico II"

Regional Water Authority – Autorità di Bacino in Sinistra Sele

National Park of Cilento and Vallo di Diano

CONSAC – Consorzio Acquedotto del Cilento

Provincia di Salerno – Assessorato all'Ambiente

Possibility of 2 Marie Curie EU FP7

starting from summer 2012.

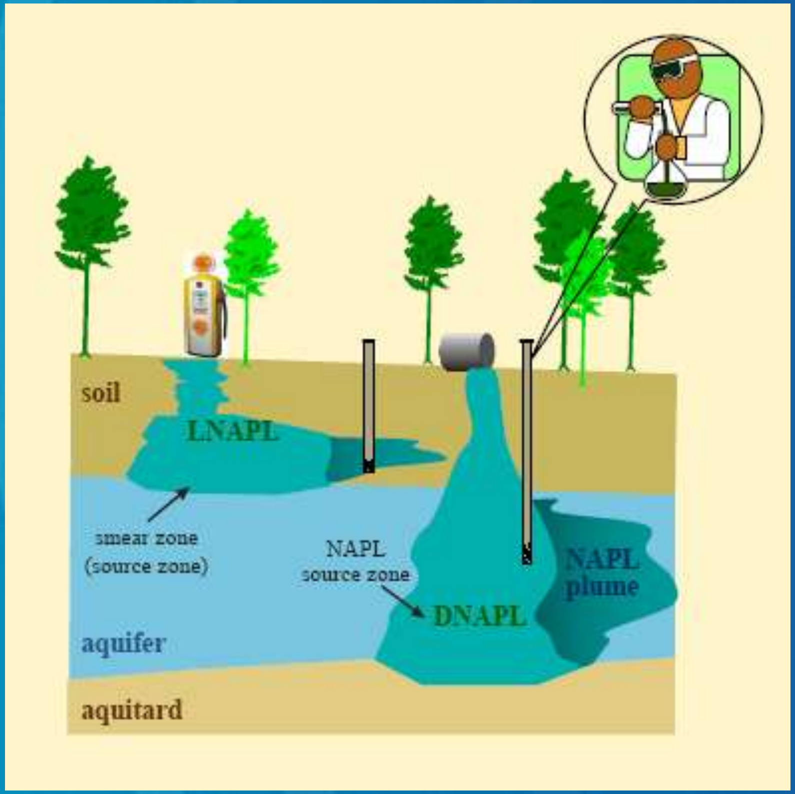
Researchers who already have a Ph.D. degree

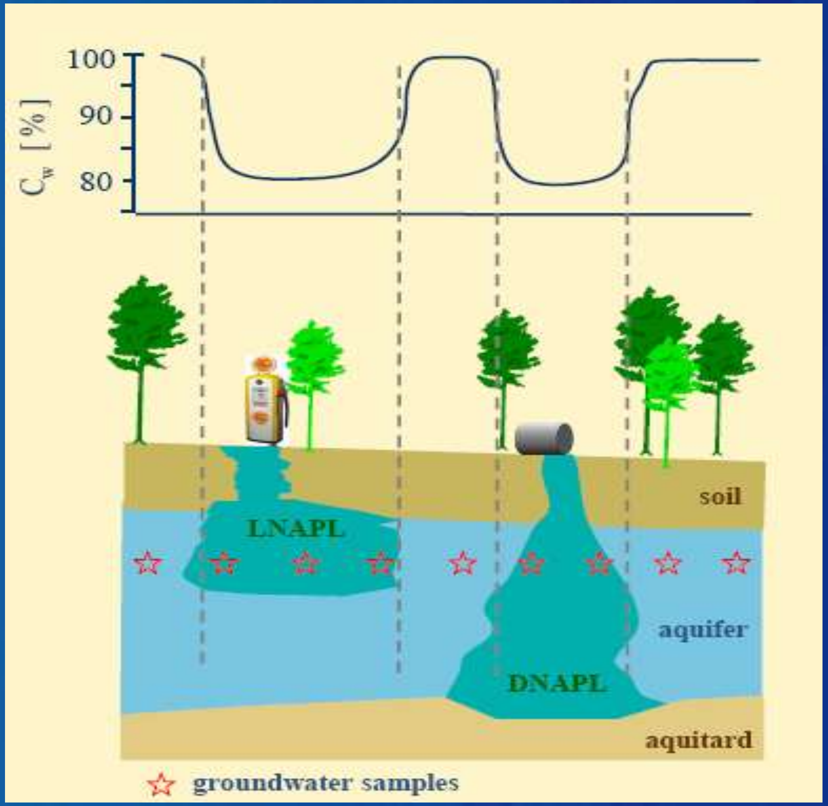
Deadline: August 2011

Contact: prof.Michele Guida

guida@sa.infn.it

USE OF RADON-222 AS NATURALLY OCCURRING TRACER FOR RESIDUAL NAPL-CONTAMINATION OF AQUIFERS



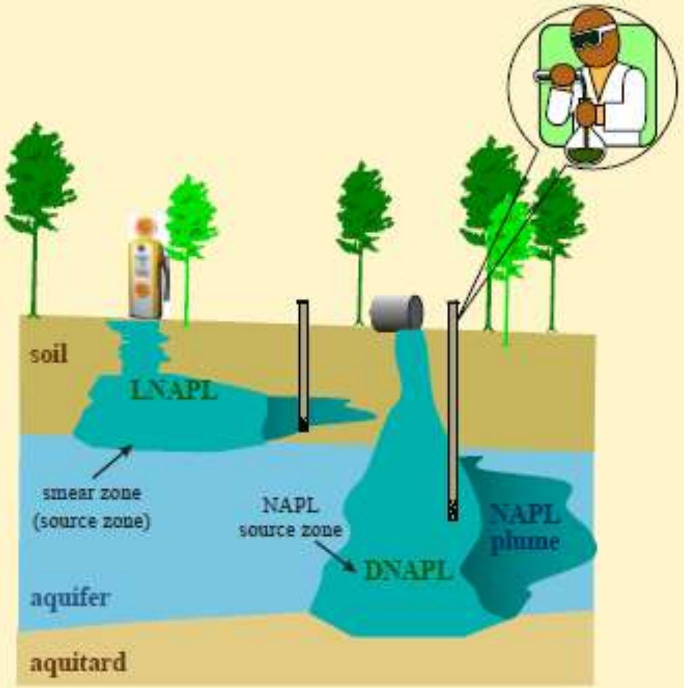


In collaboration with C.U.G.RI., ENI and Michael Schubert, UFZ Leipzig
Helmholtz Centre for Environmental Research – UFZ Leipzig, Germany

The NAPL Problem

Localisation and assessment of NAPL - Source Zones (at petrol stations, airports, military bases …)

conventionally on-site surveys include
- aquifer material sampling
- groundwater sampling



⬇

direct analysis of samples for NAPLs

aquifer samples:
☹ point values only

groundwater samples:
☹ water-soluble NAPL only

➡

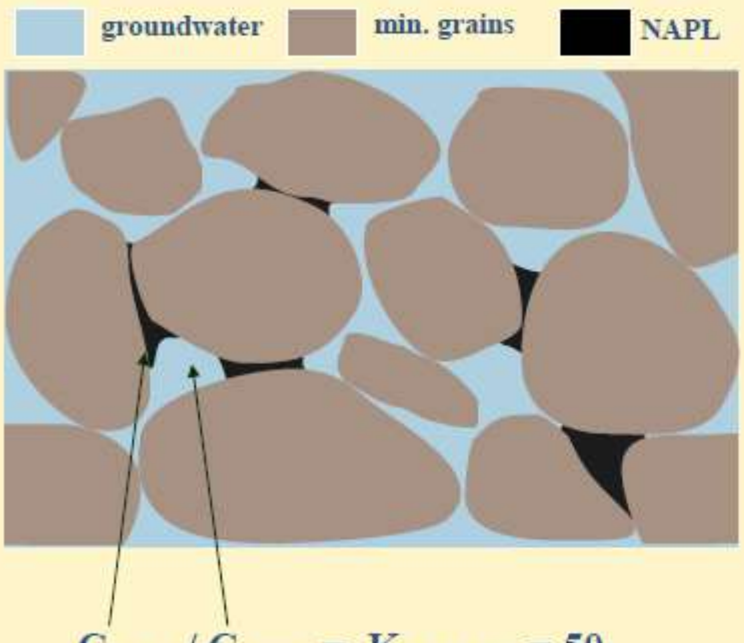
expensive, time consuming, inaccurate …

… complicates site assessment and remediation planning

An Indirect Approach

Central Facts

1. ^{222}Rn is a naturally occurring component of the groundwater.
2. Radon is a radioactive noble gas, which can be detected selectively and very precisely.
3. Radon exhibits a very good solubility in a wide range of NAPLs and gets therefore "trapped" in residual phase.



$$C_{NAPL} / C_{water} = K_{NAPL/W} = 50$$

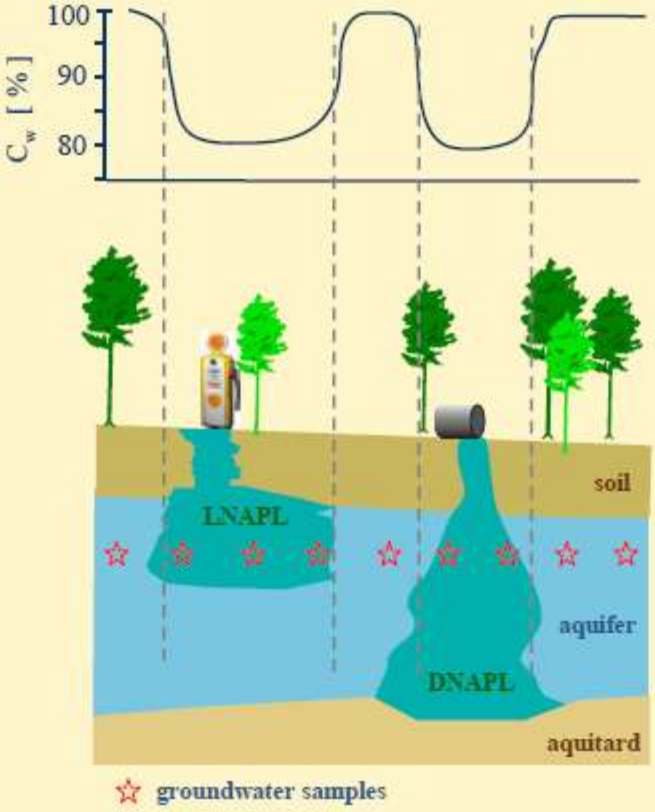
NAPL/water partition coefficient

An Indirect Approach

Central Idea

Residual NAPL gives rise to locally **reduced radon concentrations** in the groundwater.

Rn deficit is a **qualitative indicator** which allows indirect localization of NAPL – Source Zones.



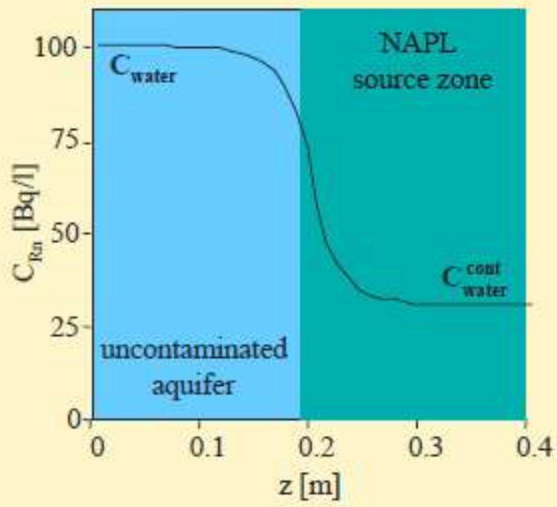
An Indirect Approach

Central Idea

Residual NAPL gives rise to locally **reduced radon concentrations** in the groundwater.

Rn deficit is a **qualitative indicator** which allows indirect localization of NAPL – Source Zones.

If $K_{NAPL/W}$ is known, the Rn deficit is a **quantitative indicator** for the NAPL saturation of the pore space (S_{NAPL}).



$$C_{water}^{cont} = \frac{C_{water}}{1 - S_{NAPL} - K_{NAPL/W} S_{NAPL}}$$

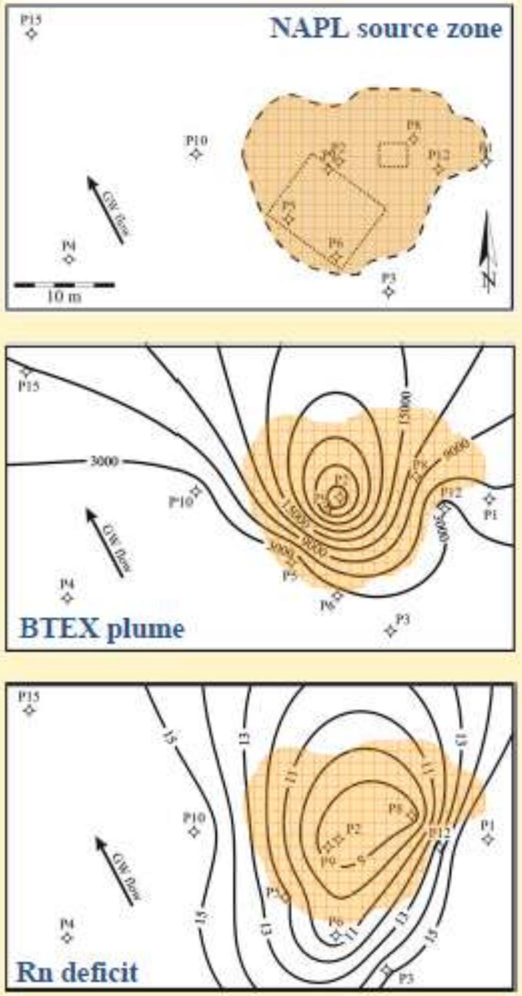
Radon Survey – Example

- abandoned gas station
- source zone covers ca. 400 m²
- homogeneous geology (sandy gravels)
- residual contamination with diesel fuel
- GW samples from 11 monitoring wells analyzed for Rn and BTEX
- BTEX plume down gradient of source zone

➡ good correspondence

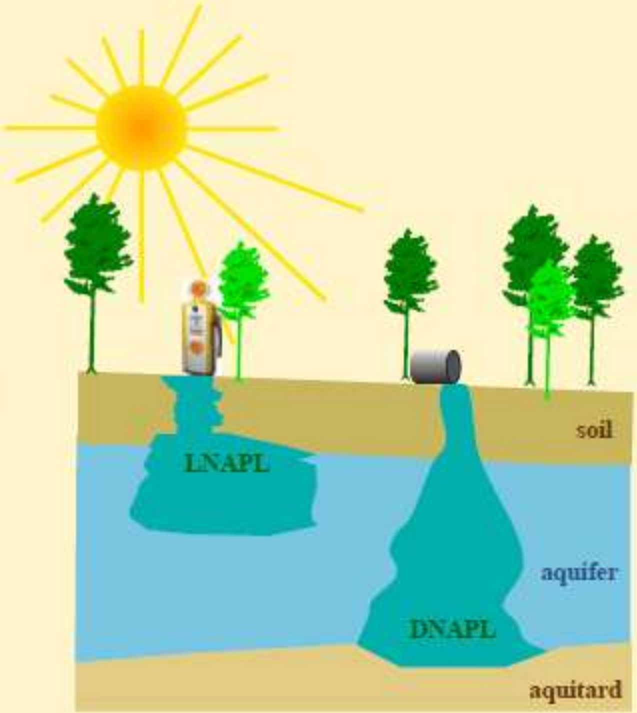
➡ distinguishing between source zone and NAPL plume was possible

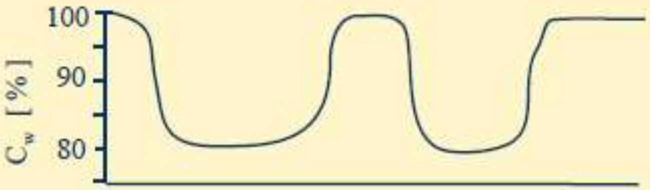
➡ Quantitative assessment revealed a NAPL saturation of about 3%.



Conclusions

1. NAPL source zones can be **localized** using locally reduced radon concentrations as indicator.
2. Residual NAPL saturation can be **quantified** using the radon deficit as indicator.
3. Since preliminary results are available directly on-site a first assessment of the situation is possible **immediately** .
4. The method is more **cost efficient** than conventional methods.





some literature

- 8° International Symposium on the Natural Radiation Environment (NREVIII), Buzios, Rio de Janeiro, Brasile, 07 – 12 Ottobre 2007;
- International Workshop on “Measurement and Application of Radium and Radon Isotopes in Environmental Sciences”, Venezia, 07 – 11 Aprile 2008;
- European Geosciences Union (EGU) General Assembly, Vienna, 13 – 18 Aprile 2008;
- Giornate di studio: “Il rischio da contaminazione radioattiva: i casi radon e uranio impoverito”, Paestum, 29 – 30 Apr. 2008.

International Collaborations:

- Grup de Fisica de les Radiacions, Universitat Autonoma de Barcelona, Spagna;
- Department of Oceanography, Florida State University, Tallahassee, Florida, USA;
- LARAMG - Laboratory of Radioecology and Global Changes, Universidade do Estado do Rio de Janeiro, Brasile;
- Institut de Protection et de Sŭreté Nucléaire (I.R.S.N.), IRSN - DEI - SARG - LERAR, Francia;
- Helmholtz Centre for Environmental Research – UFZ, Leipzig, Germania;
- Laboratoire de l'environnement marin, Département des sciences et des applications nucléaires, IAEA, Monaco.
- Alexander Makarenko, National Technical University, Kyiv, Ukraine

C.U.G.RI.

C.U.G.RI.
Centro Universitario per la Previsione e Prevenzione dei Grandi Rischi
University Centre for the Prediction and Prevention of Large Hazards

www.cugri.unisa.it

Prof. Eugenio Pugliese Carratelli
Director

Barcellona 2009

Università degli Studi di Napoli “Federico II”

C.U.G.RI.

is a Consortium between the University “Federico II” of Naples and the University of Salerno.

It was established in 1993 by the Italian National Law

Università degli Studi di Salerno

Goals and operation

CUGRI acts as a **front end** for the **two founding Universities** in the fields of the prediction and prevention of large hazards, natural and industrial.

It works – mostly – **under contracts** from public bodies and private companies, by carrying out **applied research**, **consultancy** and field **monitoring** activities

It **also** operates with its **own funds** (Italian Ministry of Research) to perform **basic research**.

All **the staff** from the two Universities can operate within CUGRI

But it **also** operates in association with **Private Companies**, other **Universities**, and other **Scientific Institutions**

SECTORS

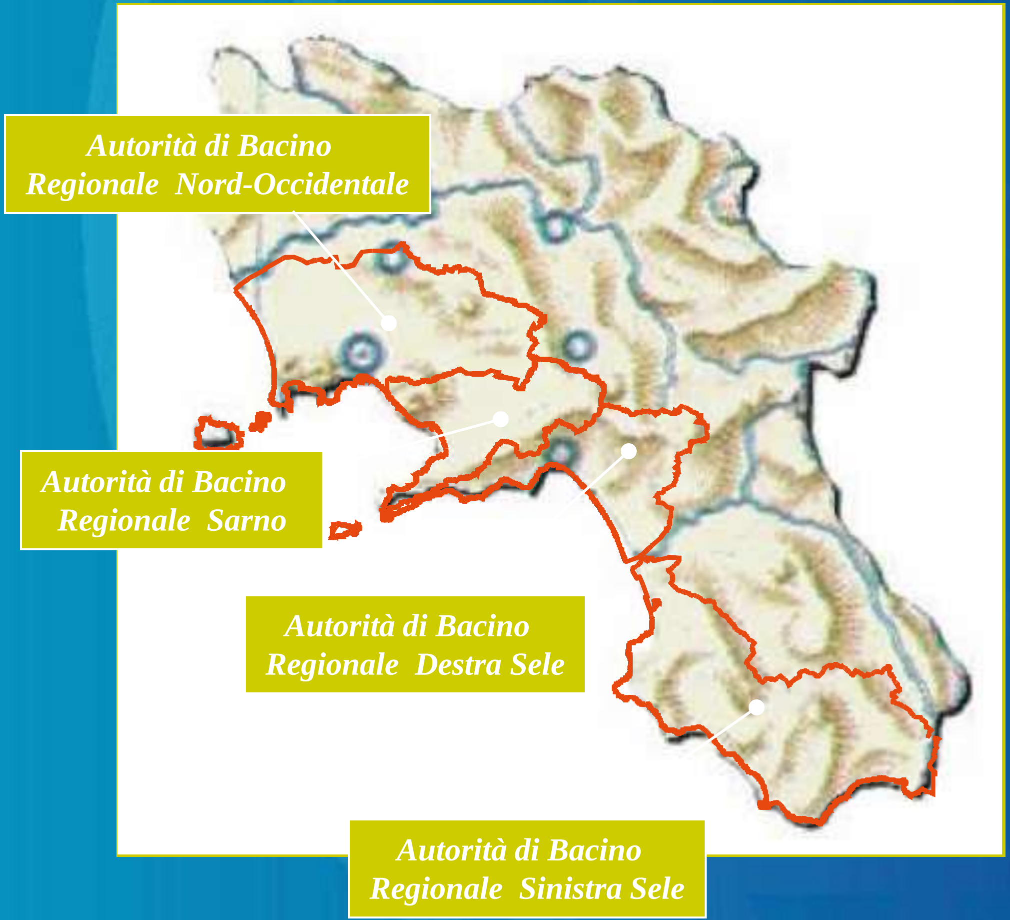
- Hydrogeology
- Coastal and Marine
- Volcanic
- Earthquake
- Chemical-industrial and environmental
- Radioactivity and Radioprotection

OWN PROJECTS

- *Flood Risk*
- *Landslide Risk*
- *Meteo-marine risk*
- *Soil mechanics actions for land protection*
- *Hydraulic infrastructures and risks*
- *Landslide hazards within the specific geology of the Campania Region*
- *Building vulnerability and structural consolidation techniques*
- *Safety and the environment*
- *Parallel computing in environemental engineering*
- ***Assessment of the impact of the Natural Radioactivity on a regional scale.***

International Cooperation … so far

- *Institute of Geological Science, Jagellonian University, Krakòw, Polonia.*
- *M.I.T. (Massachusetts Institute of Technology - Cambridge, U.S.A.).*
- *Hydraulics Research Ltd. Wallingford, Oxfordshire, U.K.*
- *CUJAE- Technical University of Havana (Cuba)*
- *:----*



Regional Autority

Risk Prediction:

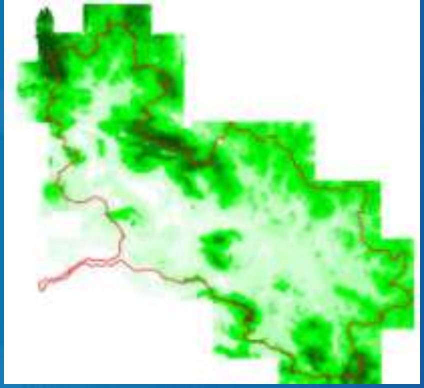
- **Landslides hazard**
- **Coastal hazards and Coastal erotion**
- **Flood hazard**

Comune di Napoli

Management of the hydrogeologic emergency in the City of Naples
Technical and scientific support to the analysis of the hydrogeologic hazard and to the definition of a strategy for hazard mitigation.

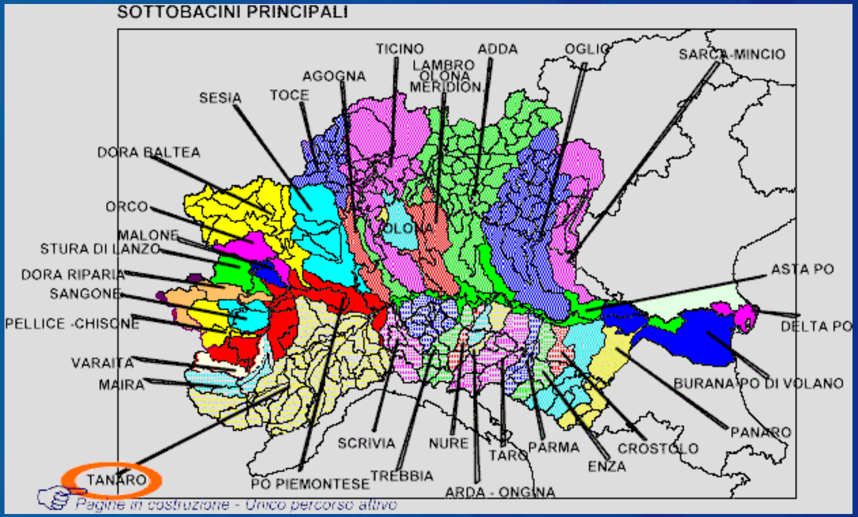
Autorità di Bacino dei Fiumi Liri - Garigliano e Volturno

Outline of the Geografic Information System for Liri-Garigliano and Volturno River Catchments, in the hydraulic and geological hazard mitigation field



REGIONE ***PIEMONTE***

Hydrological studies for the hydro-meteorological flood risk assessment



Priola 05 November 1994
Pictures from the flooding of Alta Valle Tanaro e surroundings

Evaluation of the studies about artificial flood waves produced by dam gates operation or by dam break events

SERVIZIO NAZIONALE DIGHE

Dipartimento Servizi Tecnici Nazionali

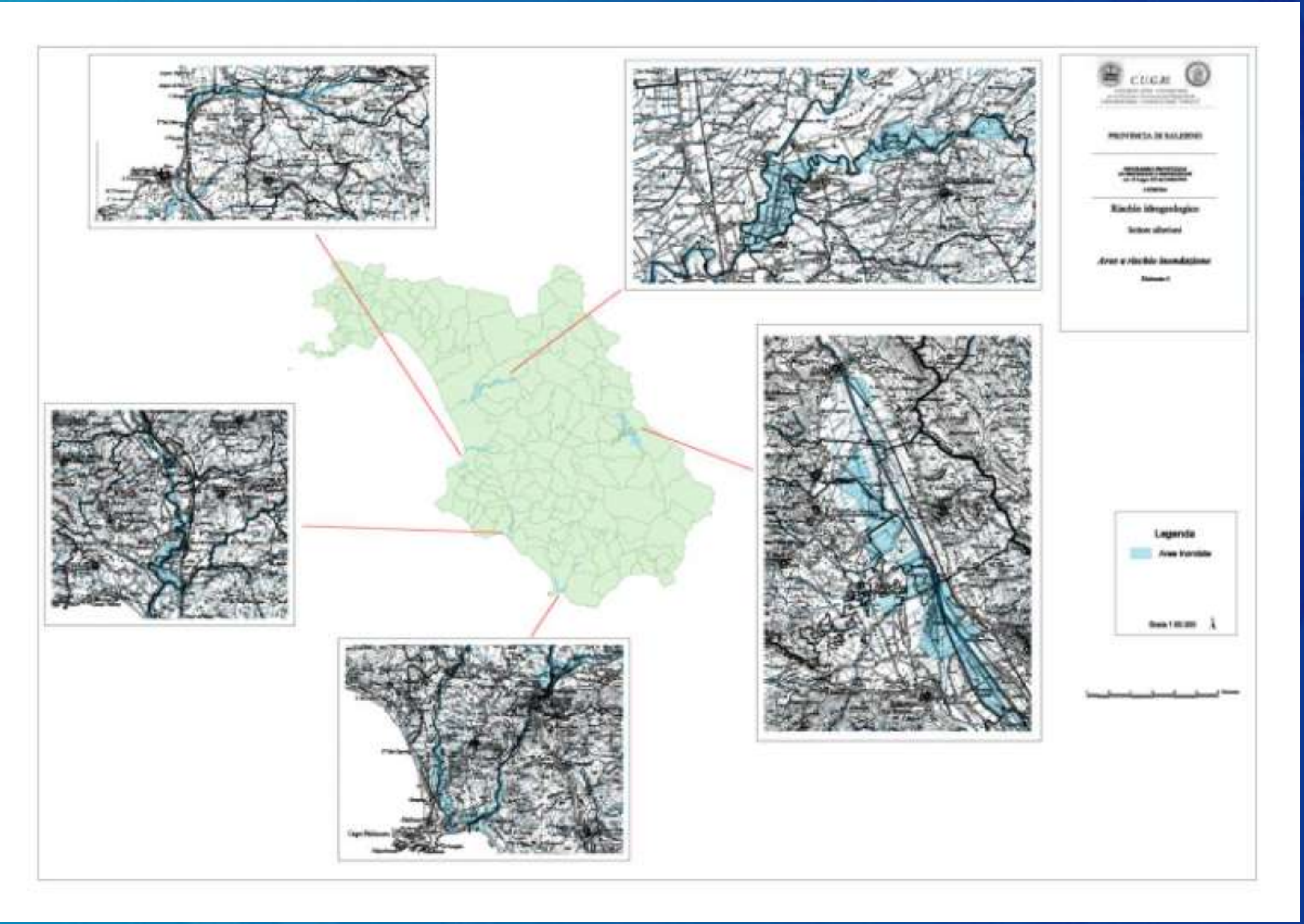
Dipartimento dei Servizi Tecnici Nazionali

Breached dam during the Oder flood in 1998. View looking downstream, through the breached dam section.

ITALIAN NATIONAL DAM MONITORING AND REGULATING AUTHORITY

Provincia Salerno

Scientific support in the development of the Risk Prevention Plan



European Project

EUROTAS
Flood risk mitigation

European Commission Directorate General XII Science, Research and Development, Environment and Climate, Contract number ENV4 CT97-0535

OBJECTIVE OF EUROTAS:

The objective of EUROTAS is to develop and demonstrate tools and procedures for the assessment and management of flood risk, including the effects of environmental change.

Courtesy of: Delft Hydraulics, The Netherlands

WHAT IS EUROTAS?

*The **Eur**opean **R**iver Flood **O**ccurrence and **T**otal Risk **A**ssessment **S**ystem (EUROTAS) project has been funded from the second call of the EC Fourth Framework Programme under the Hydrological Risks component of the Environment and Climate programme.*

EUROTAS is being undertaken by fifteen organisations from nine countries - Denmark, France, Germany, Greece, Italy, the Netherlands, Spain, Czech Republic and the UK. HR Wallingford is the project co-ordinator.

A special thought to a very special friend and colleague Sandro Pietrofaccia that recently left us and whose human and professional virtues will be forever a very important example and reference


Working very hard
on the field
Having fun with scientific research

Thanks to all the guys from the RAD_Campania group

Albina Cuomo (Environmental Engineer)

Mariella De Piano (Environmental Engineer)

Davide Guadagnuolo (Experimental Physicist)

Domenico Guida (Geomorphologist)

Michela Iamarino (Pedologist)

Simona Mancini (Civil Engineer)

Anna Pelosi (Environmental Engineer)

Lucia Pergamo (Civil Engineer)

Nicoletta Pisacreta (Civil Engineer)

Enrico Sicignano (Architect, Building Engineer)

Vincenzo Siervo (Geologist , GIS expert)

A very special one to the CUGRI staff:

E. Pugliese Carratelli (Scientific Director), G. Benevento (Technical Director), P. Meloro (Administration Responsible)

Last but not least: nothing would have been possible without the warm and friendly encouragement of Aldo De Marco, Pasquale Persico Fabio Rossi