Portable gamma ray spectrometer

- a short introduction

István Dunkl

http://www.sediment.uni-goettingen.de/staff/dunkl

Focus:

units of radioctivity, principle of measurement,

case studies

methodology, demo of GR-135

exploration of K and U - outlook of atomic power

Dimensions

Becquerel (Bq = 1 decay per second)

Curie (Ci = 3.7×10^{10} decays per second)

Gray (Gy = J/Kg) (adsorbed radiation dose)

Sievert (1 Sv = J/Kg) **= 100 Rem** (*roentgen equivalent in man)*

total gamma ray count for the NGS can be approximated by the simple formula

$$GR(API) = 4 \cdot Th(ppm) + 8 \cdot U(ppm) + 16 \cdot K(\%) \qquad (2.7.5)$$

Therefore, the compensated gamma ray CGR is calculated as

$$CGR(API) = 4 \cdot Th(ppm) + 16 \cdot K(\%) \qquad (2.7.6)$$

[Luthi (2001) Geological well logs]

Principle

All rocks and soils are naturally radioactive, & contain various proportions of a variety of radioactive elements.

The natural decay of these elements produces a variety of types of radiation (alpha, beta, gamma) at specific energy levels.

Only gamma ray radiation has sufficient energy to be useful for geological mapping or exploration. (penetration)

Portable gamma spectrometer has good resolution of the gamma photon energies in the 0.3 to 3 MeV range.

Variables

Meteorological conditions, humidity

Topography of the survey area

Cosmic-ray background

Height of the sensor above ground

Speed of data acquisition

Data processing

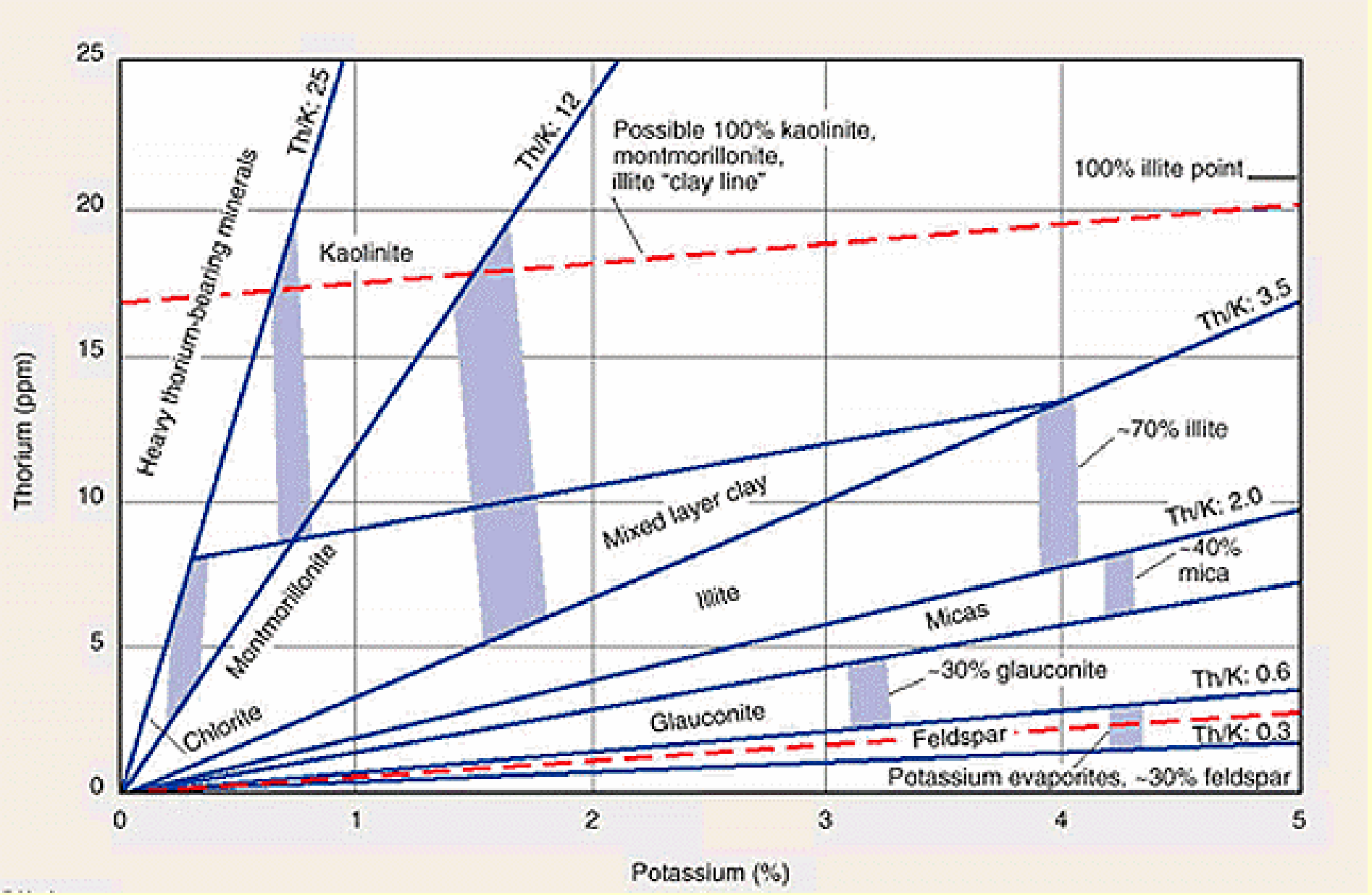
István: Geometry, geometry & geometry !!!

Typical U, Th and K concentrations

Mineral	U-Gehalt in ppm	Th-Gehalt in ppm	K-Gehalt in %
Montmorillonit	2 …5	14 …24	0 … 4.9
Chlorit		3 …5	0 … 0.35
Kaolinit	1.5 … 9	6 …42	0 … 0.6
Illit	1.5	10 … 25	3.5 … 8.3
Glaukonit		< 10	3.2 … 5.8
Bentonit	10 …36	4 … 55	
Hornblende	1 … 30	5 …50	< 0.5
Biotit	1 … 40	0.5 … 50	6.2 … 10.1
Muskovit	2 … 8	10 … 25	7.9 … 9.8
Mikroklin			10.9
Orthoklas			11.8 … 14
Plagioklas	0.2 … 5	0.5 … 3	
Sylvinit			52.4
Carnallit			15.1
Polyhalit			14.1
Monazit	500 … 3000	25000 … 200000	13.4
Zirkon	300 … 3000	100 … 2500	

[Hentschke]

Th / K ratio of some minerals & rocks



[Widijanto, 2006]

Uranium

continental rocks: 2-4 ppm

mafic rocks: < 1 ppm

sediments: 5-10 ppm

soils are usually depleted

ocean water: 3.3 ppb

Aqueous mobility by Uranyl:
U adsorption on organic matter, clays, zeolites, FeOOH

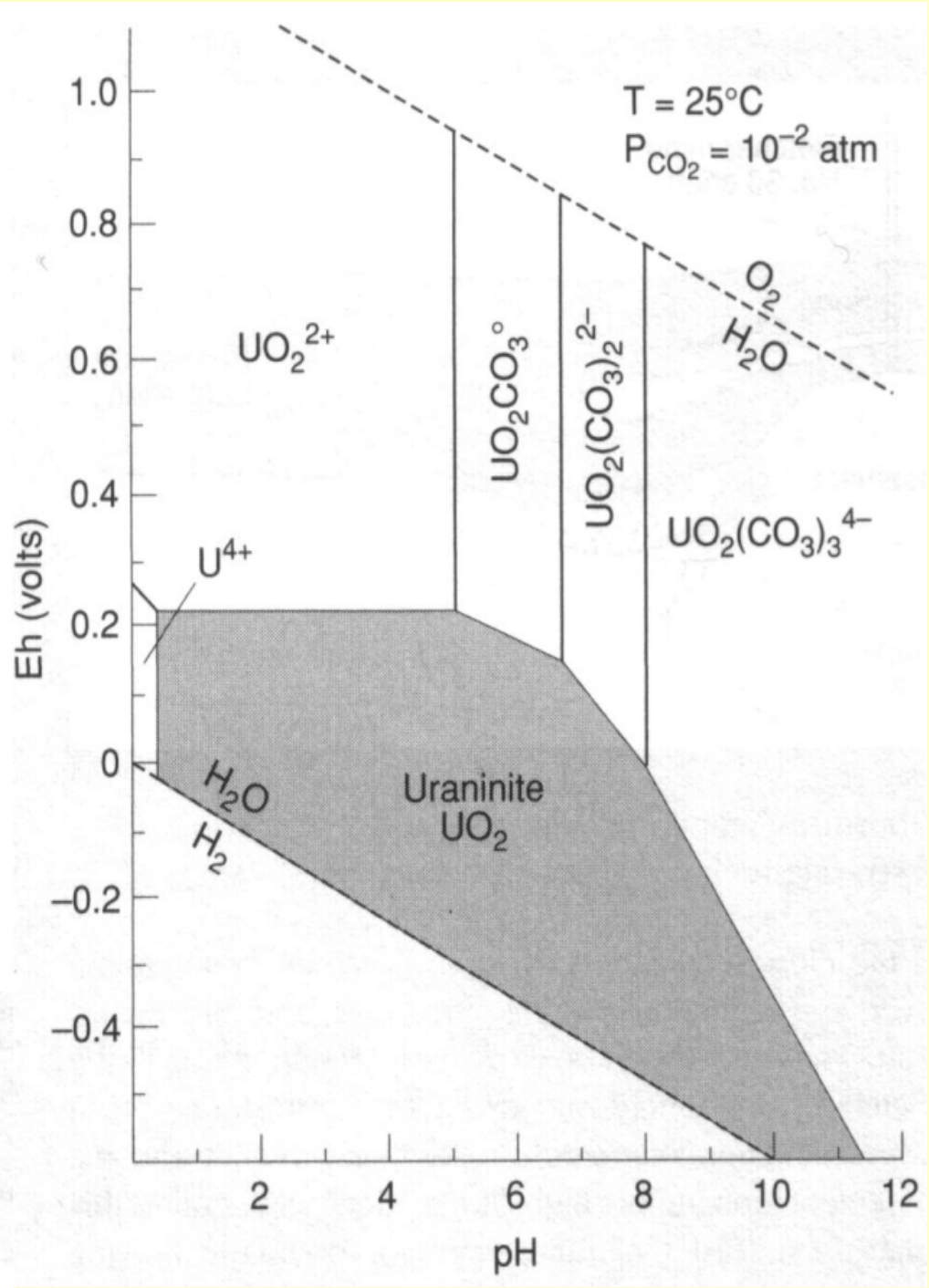
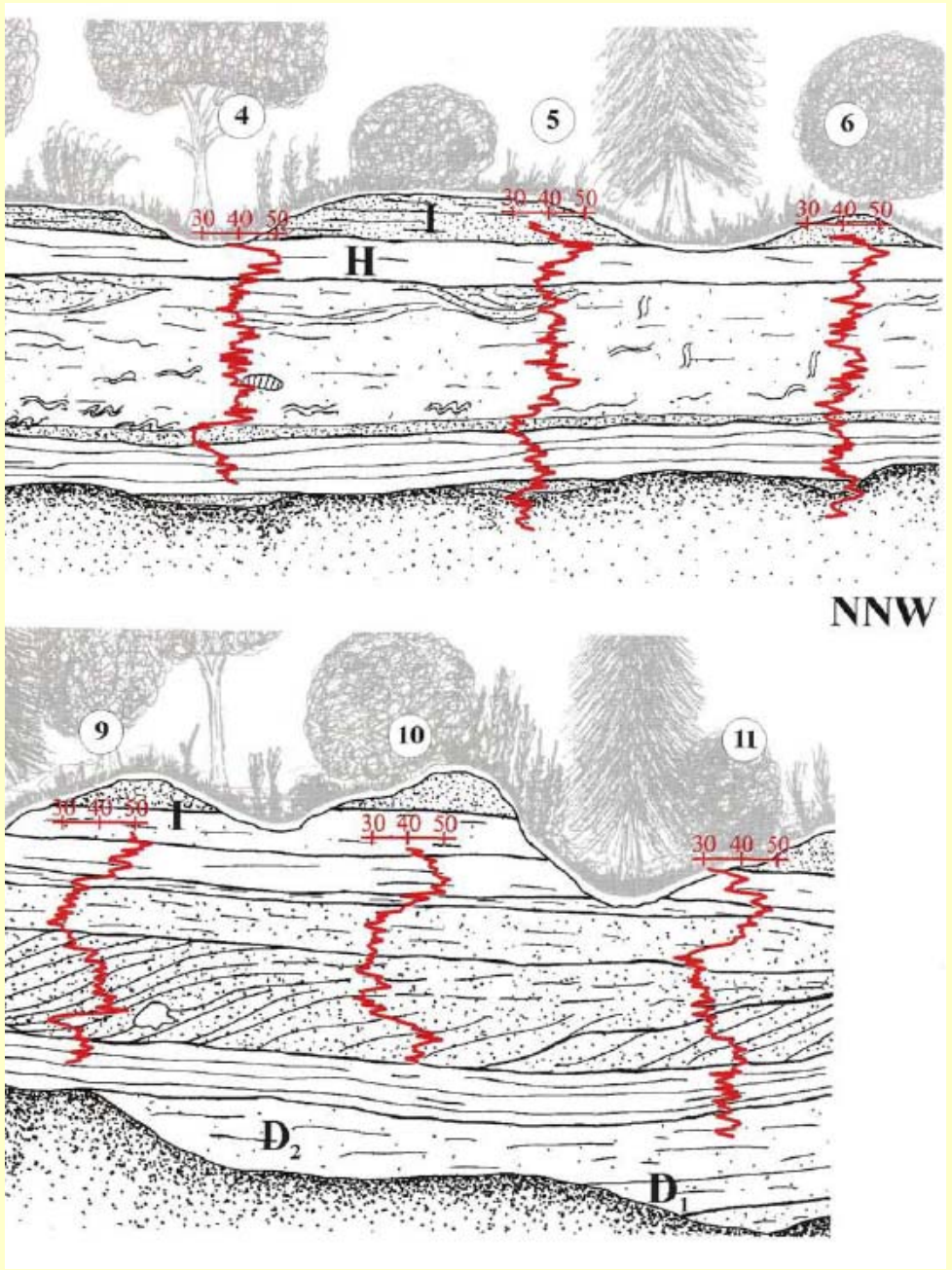


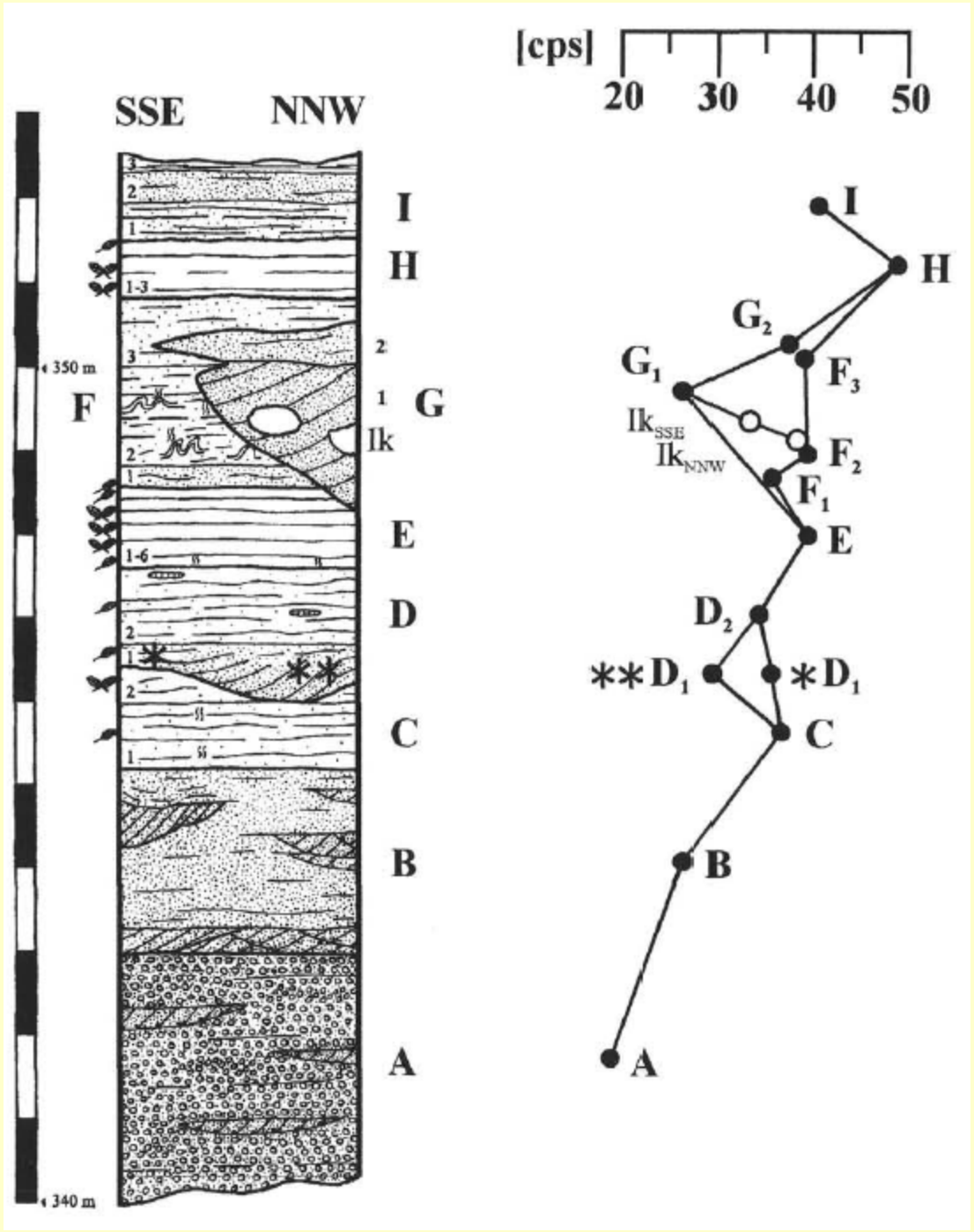
Figure 3.35 Eh–pH diagram showing relevant aqueous uranium species for the conditions specified. For most meteoric waters in the near neutral pH range, the dominant aqueous species are likely to be U^{6+}-oxide or -carbonate complexes. These will be precipitated from solution by a reduction of Eh to form U^{4+}-oxide, or uraninite (after Langmuir, 1978).

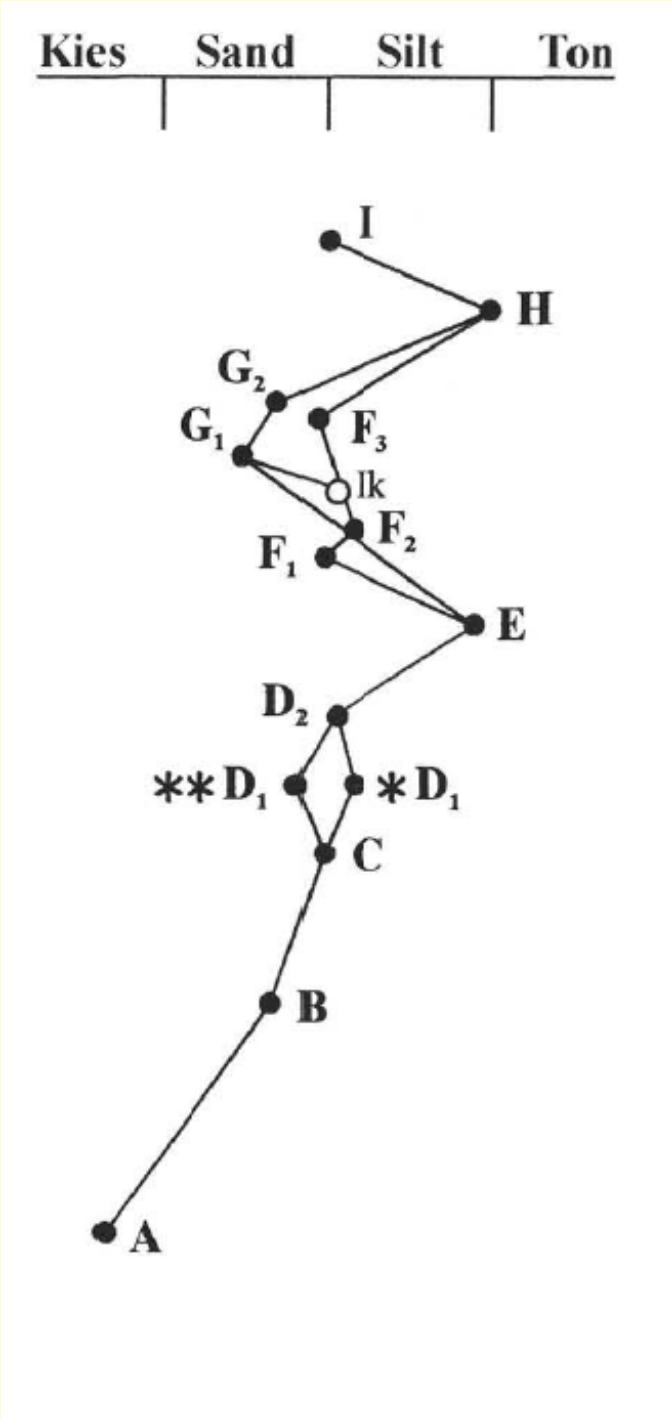
[Robb, 2005]

Facies analysis by gamma log



[Gross et al., 2000]





[Gross, Reisinger, Hubmann, 2000]

Well log

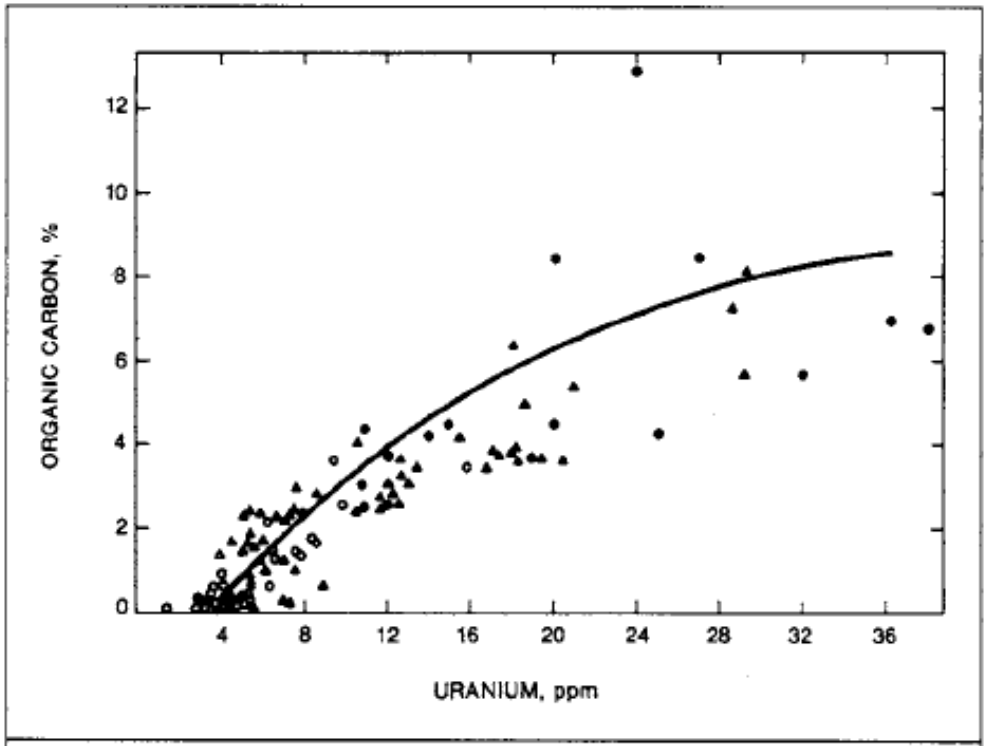


Fig. 4—Uranium content vs. organic-carbon content in Devonian black shales in West Virginia, Kentucky, and New York.[8]

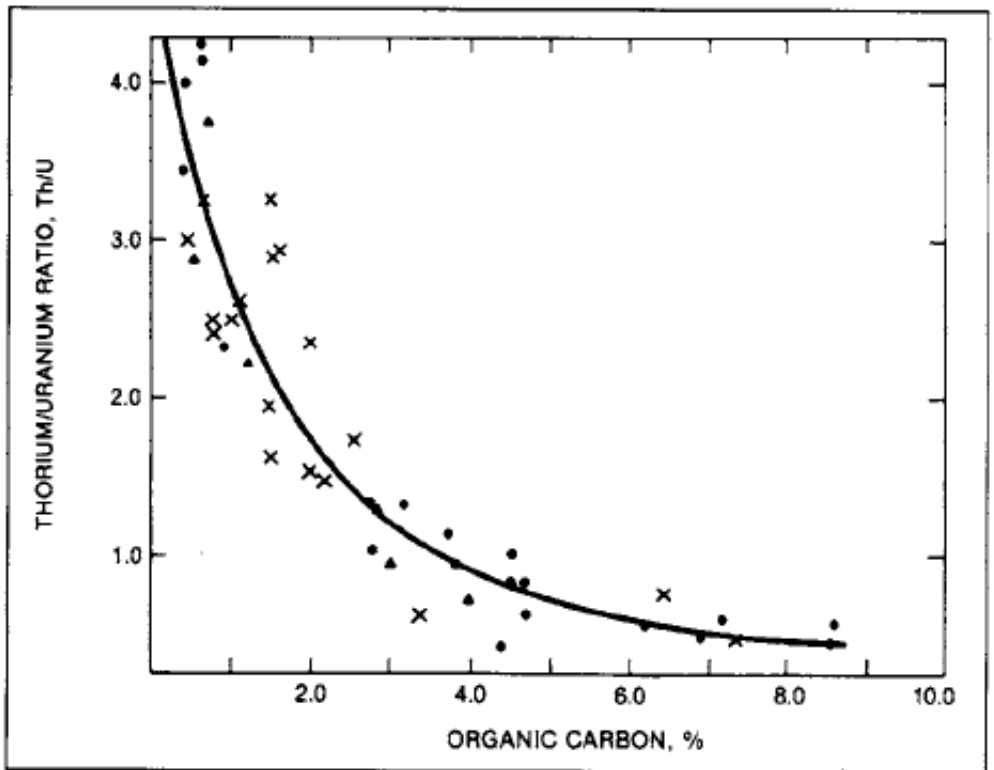
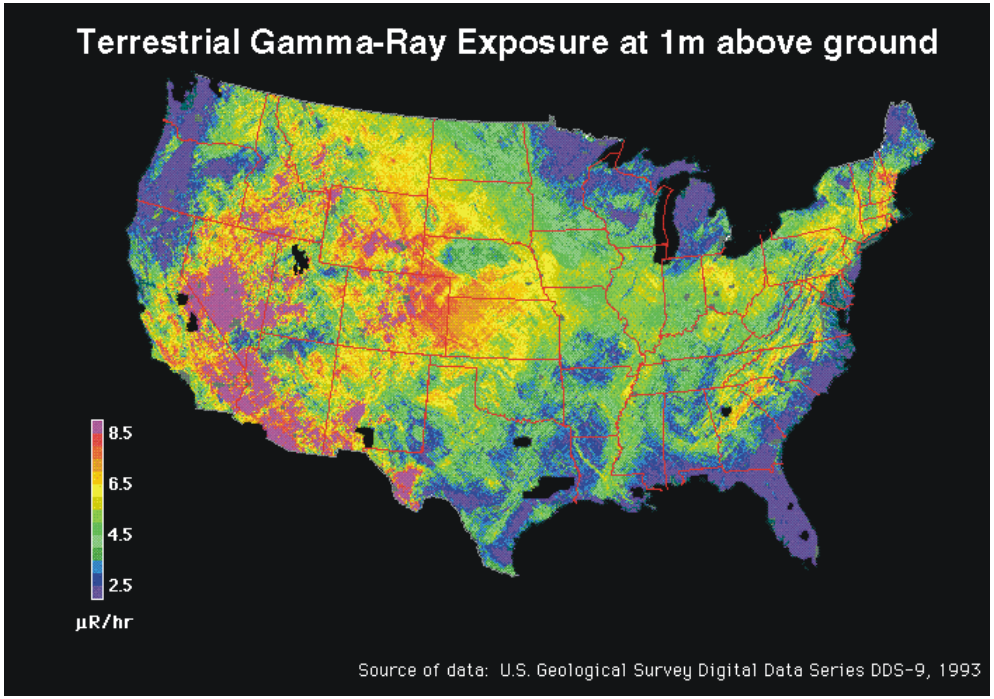
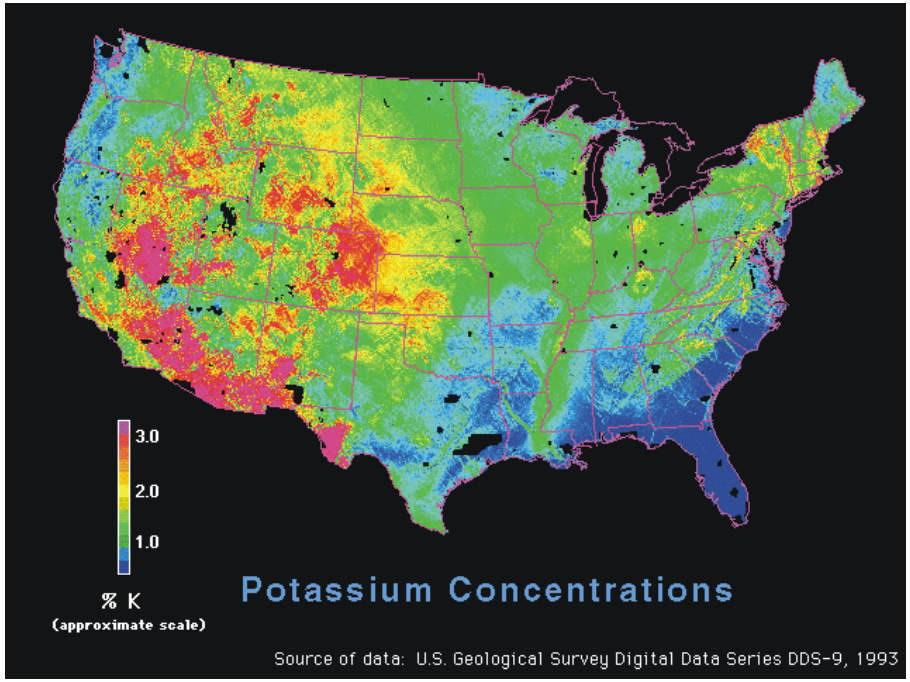
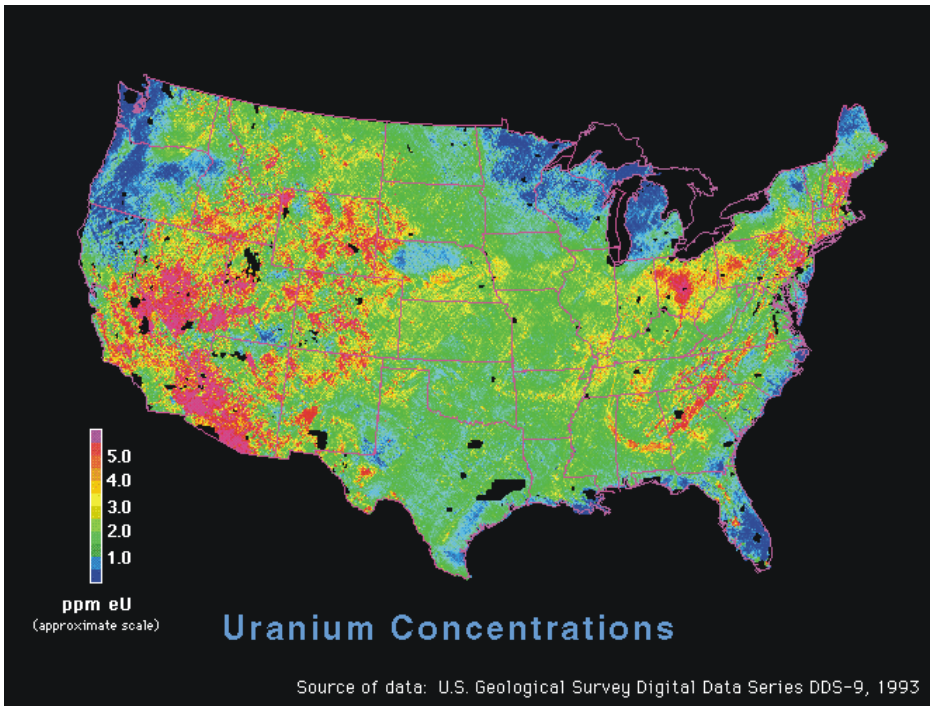


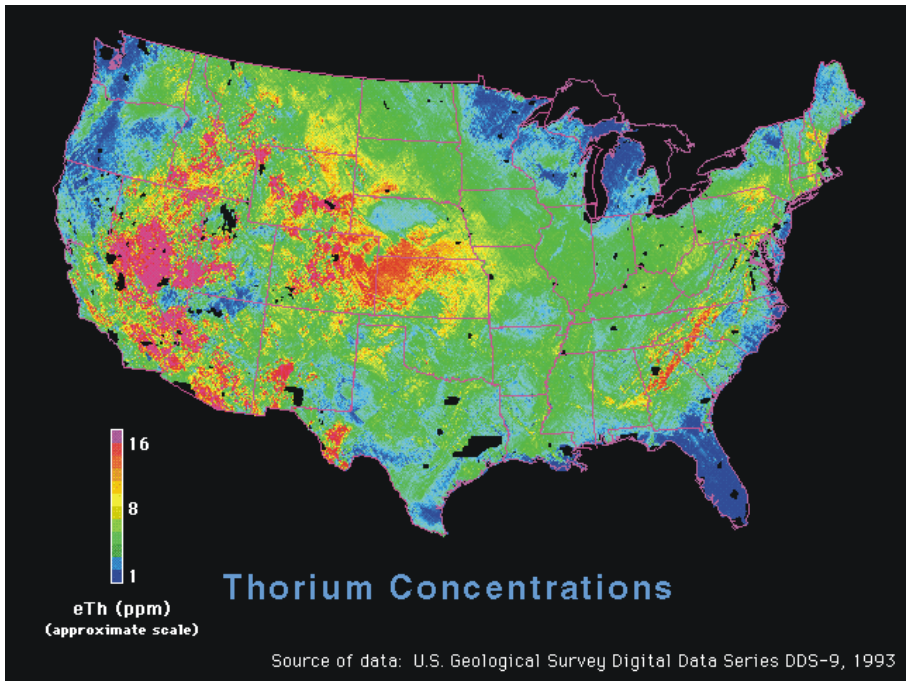
Fig. 5—Organic-carbon content vs. the Th/U ratio in Devonian black shales in West Virginia and Kentucky.[4,8]

[Fertl & Chillingar, 1988]


Terrestrial Gamma-Ray Exposure at 1m above ground
8.5
6.5
4.5
2.5
µR/hr
Source of data: U.S. Geological Survey Digital Data Series DDS-9, 1993

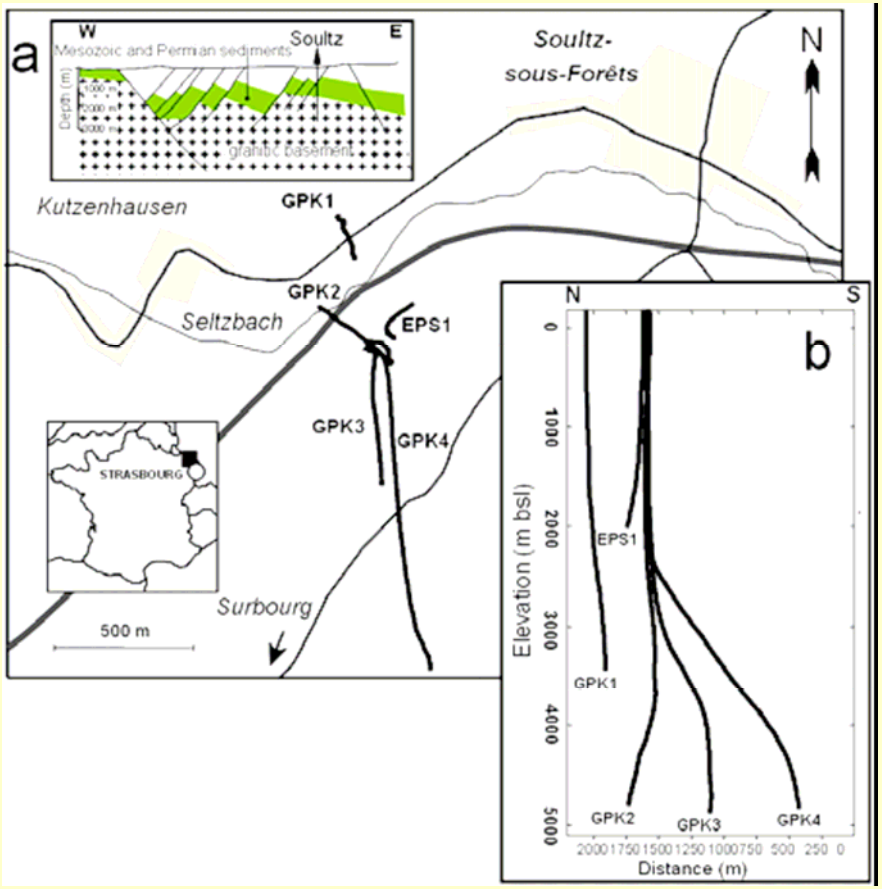

3.0
2.0
1.0
% K
(approximate scale)
Potassium Concentrations
Source of data: U.S. Geological Survey Digital Data Series DDS-9, 1993


5.0
4.0
3.0
2.0
1.0
ppm eU
(approximate scale)
Uranium Concentrations
Source of data: U.S. Geological Survey Digital Data Series DDS-9, 1993


16
8
1
eTh (ppm)
(approximate scale)
Thorium Concentrations
Source of data: U.S. Geological Survey Digital Data Series DDS-9, 1993

[USGS]

Soultz geothermal experiment (fracture connectivity)



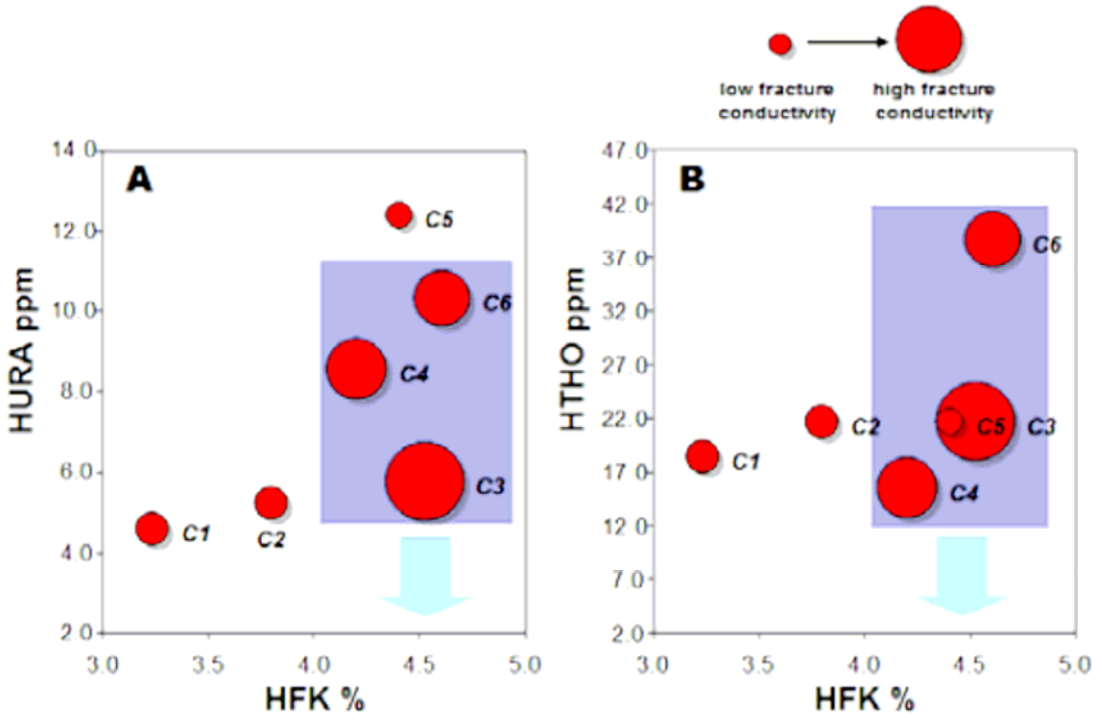


Figure. 5. Cross-plots A) Uranium (HURA ppm) – Potassium (HFK %) and B) Thorium (HTHO ppm) – Potassium (HFK %). Sizes of the dots are proportional to fracture conductivities. Red squares shows the Potassium ranges where high fracture conductivities are observed.

[Sausse et al., 2008]

ET

Geochemical interpretation of the results of measuring gamma-radiation of Mars

Yu. A. Surkov, L. P. Moskalyova, O. S. Manvelyan, A. T. Basilevsky, and V. P. Kharyukova

[Surkov, 1980]

Techniques

Thallium activated NaI

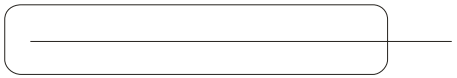
vs.

CsI

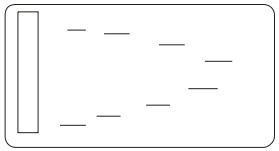
Major techniques for detection of ionizing irradiation

Gas ionisation detectors

Ion chambers
Proportional counter
Geiger-Müller tube



Scintillacion counter



Solid state detectors

TL Termoluminescent dosimetry

(TC thermal current)
(TSEE thermally stimulated exoelectron emission)

LiF : Mg, Ti
$CaSO_4$: Dy
CaF_2 : Mn
BeO : Li

→ oven

RFL Radio-fotoluminescent dosimetry

Ag in glass → UV

Film dosimetry

AgBr, AgI

(from 0.4 mGy up)

shielded parly by plastic, Cu 0.06 mm, 0.5 mm, Cd 1mm, Pb 1mm.....

Track detectors

alpha-sensitive plastic foils

Basic properties of a device

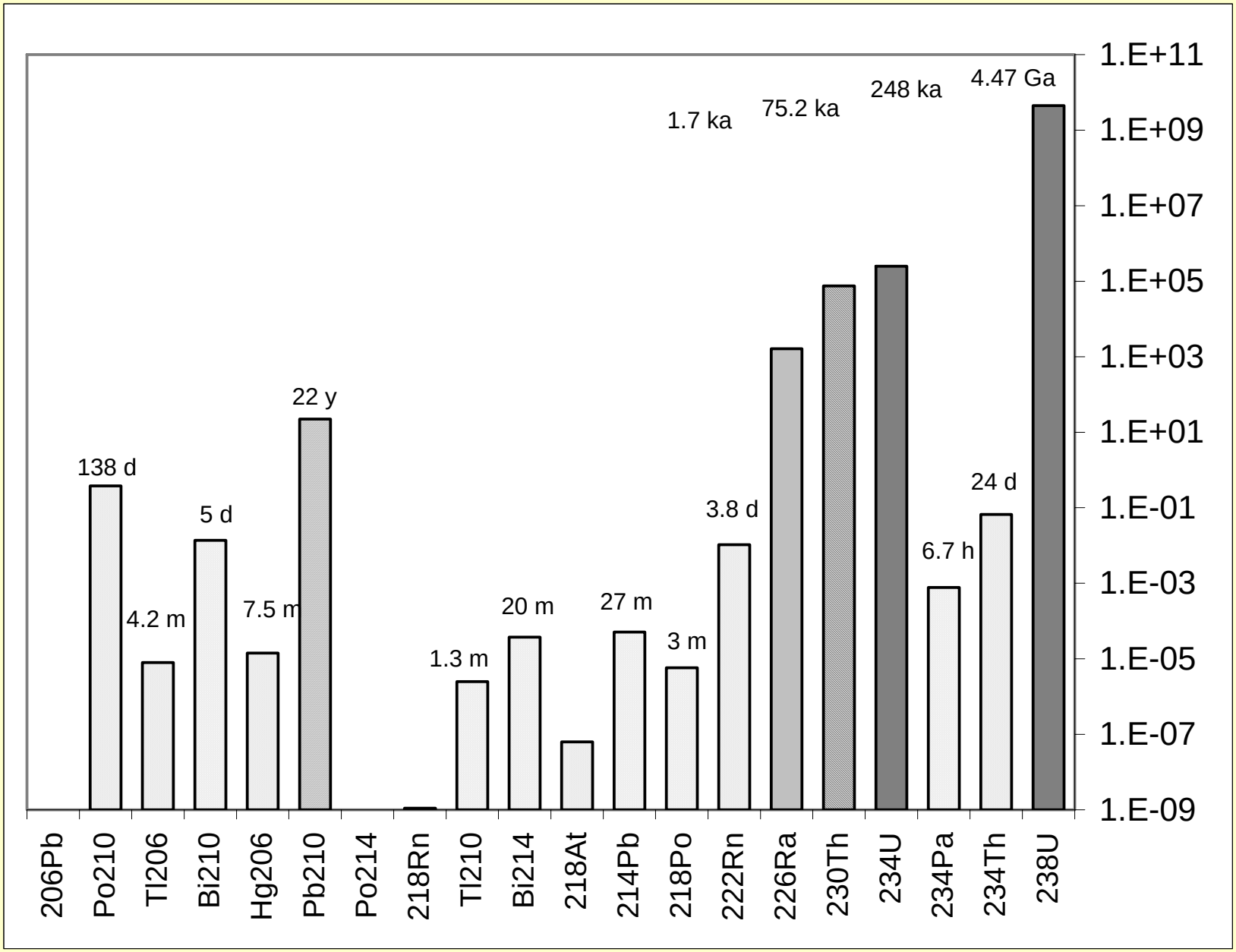
Size of the NaI crystal

Detector efficiency: cps/Bq

Number of channels

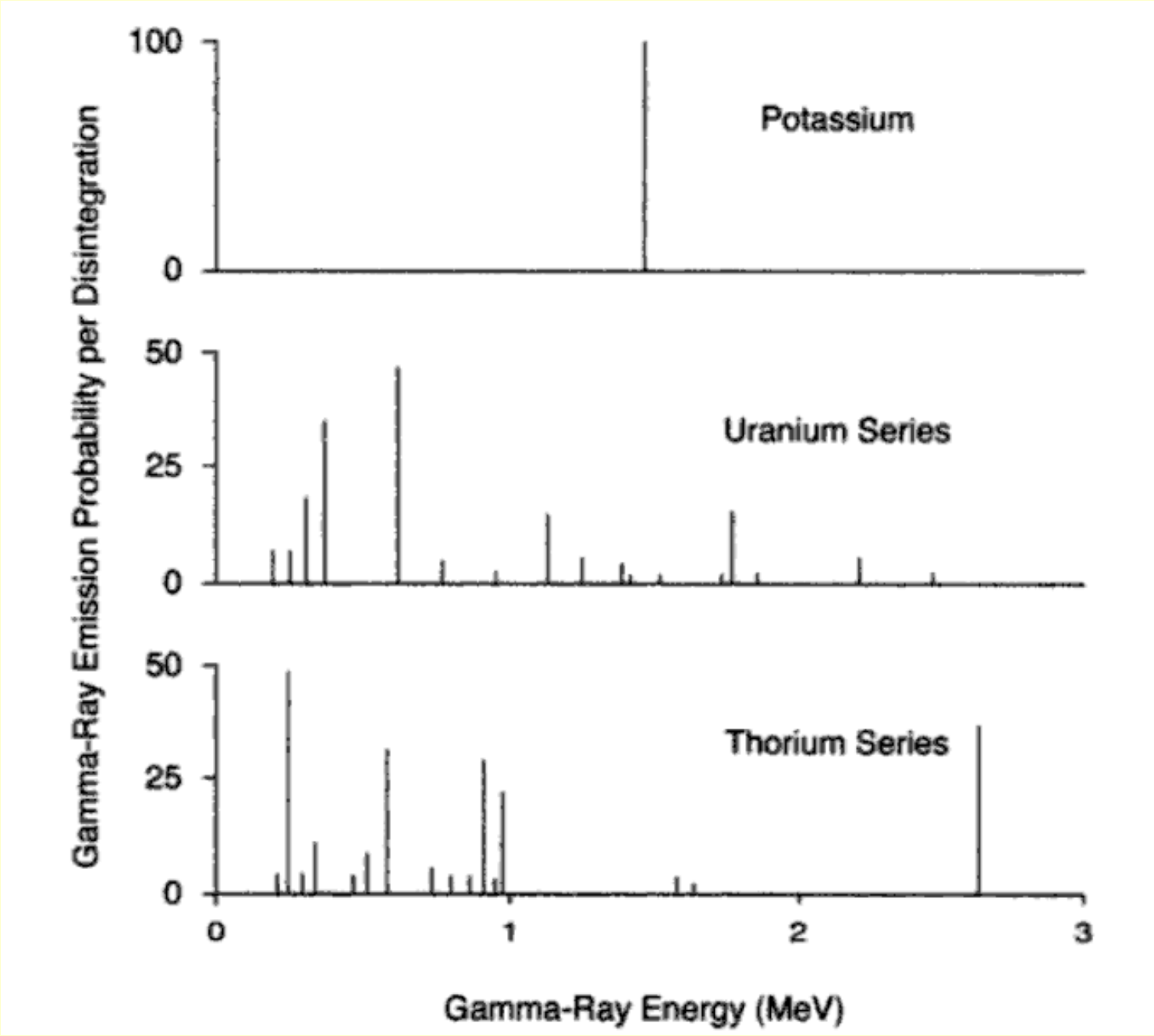
Detector resolution: full width at half maximum (FWHM)

Half-lifes of the U decay chain



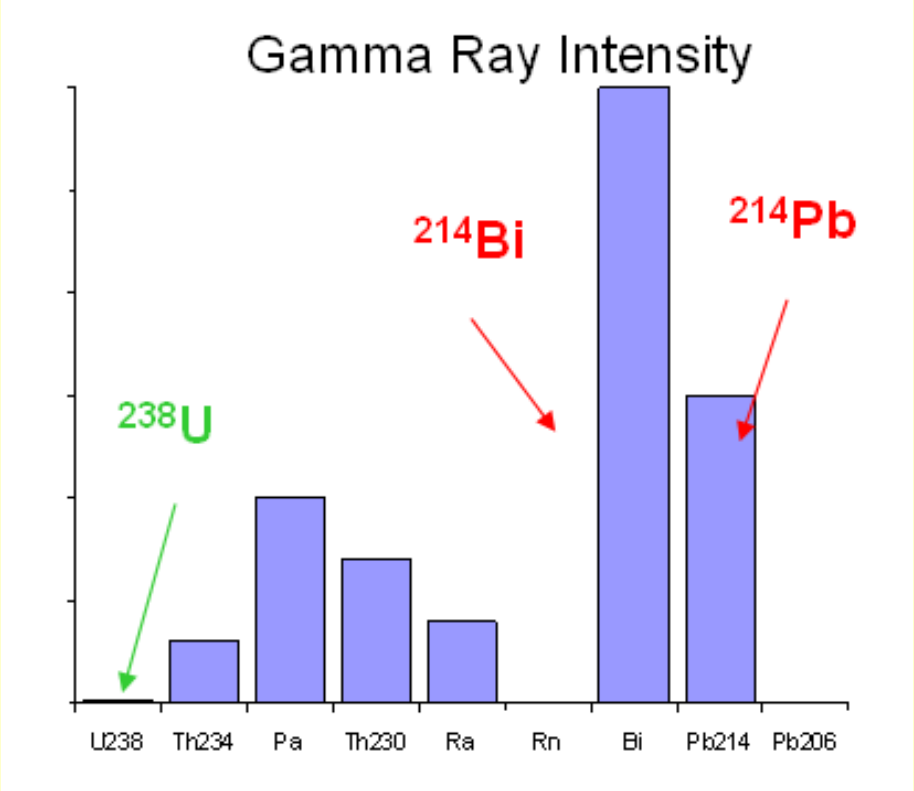
[IAEA]

Gamma ray spectra



[Luthi (2001) Geological well logs]

U_e and Th_e

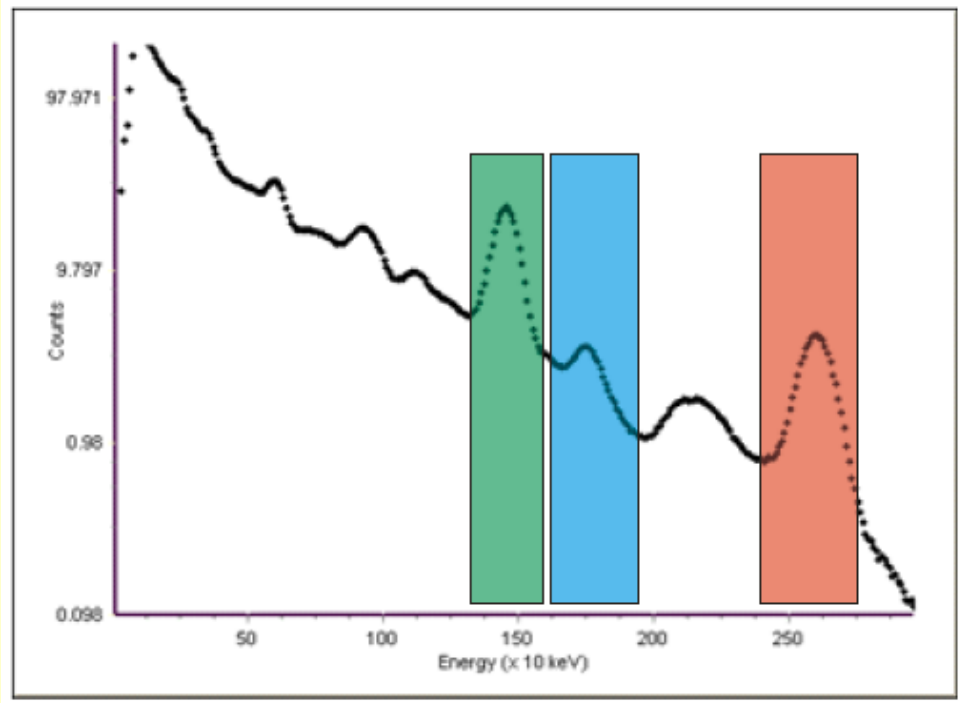


K concentration is measured directly,
U & Th indirectly from measurements of daughter products, hence the use of the term **equivalent**

[SXR Corp.]

What to do with the spectrum?

Classic analysis uising windows for K, U, Th



Full Spectrum Analysis (FSA) incorporates virtually all of the data present in the measured gamma spectrum

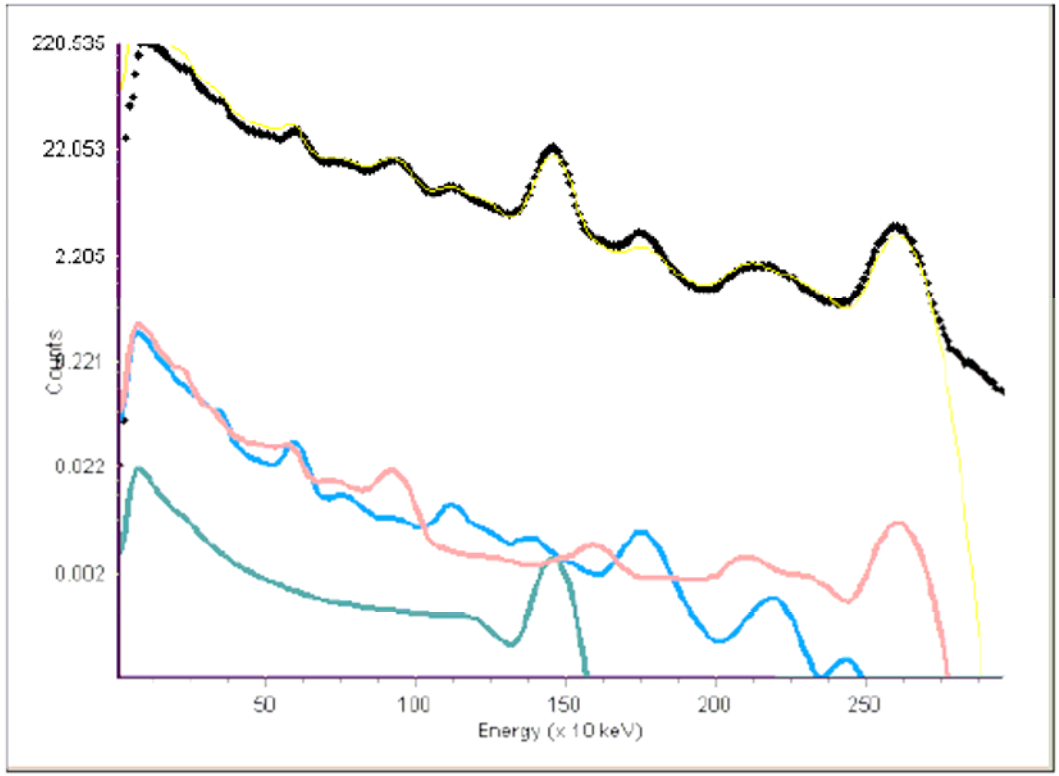


Figure 3. FSA analysis of a natural gamma spectrum. The measured spectrum (black dots) is approximated by a fitted curve (yellow). The green ,blue and red curves are the Standard Spectra for K, U and Th respectively.

[Koomans et al., 2007]

What to do with the spectrum?

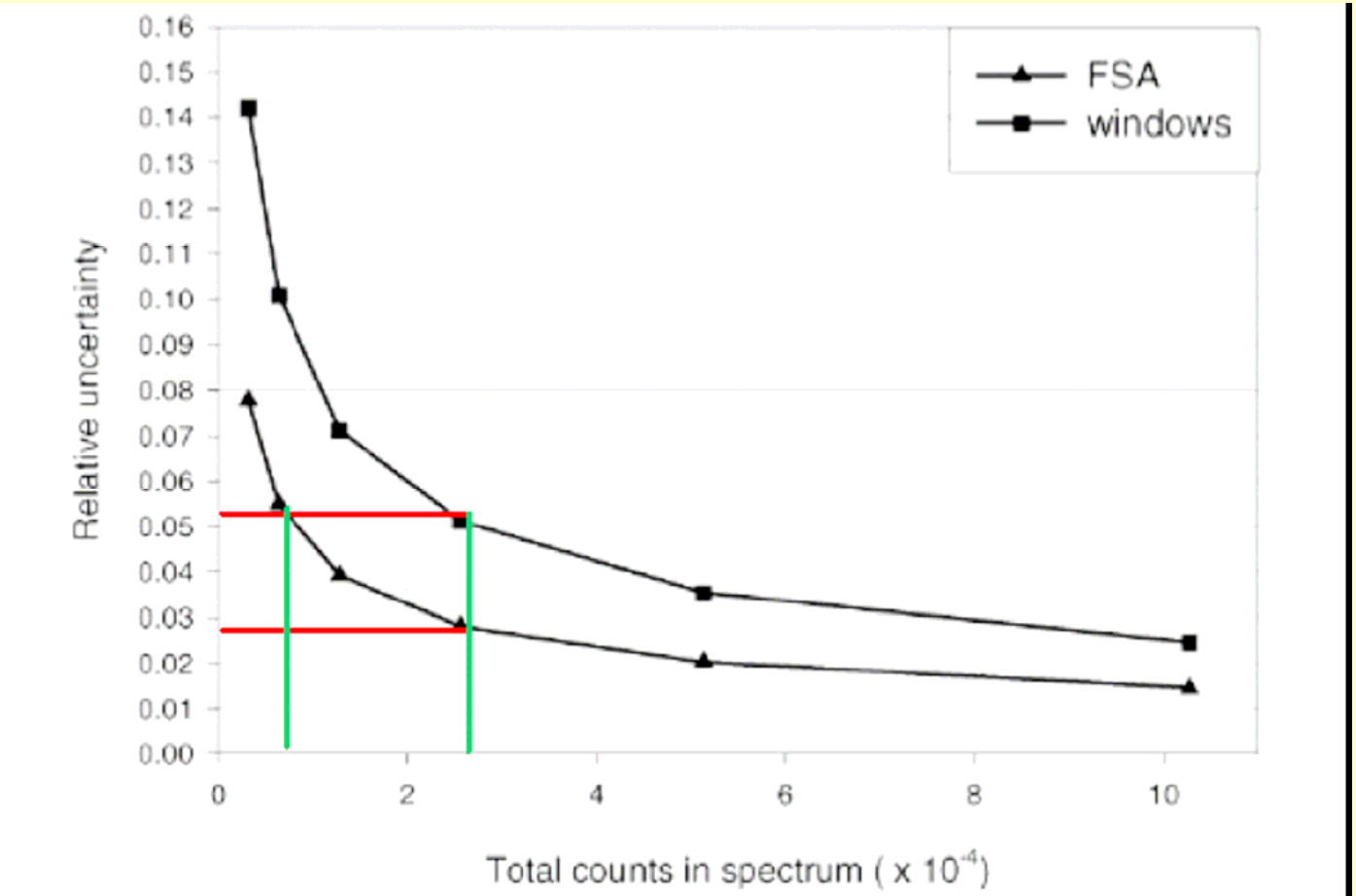
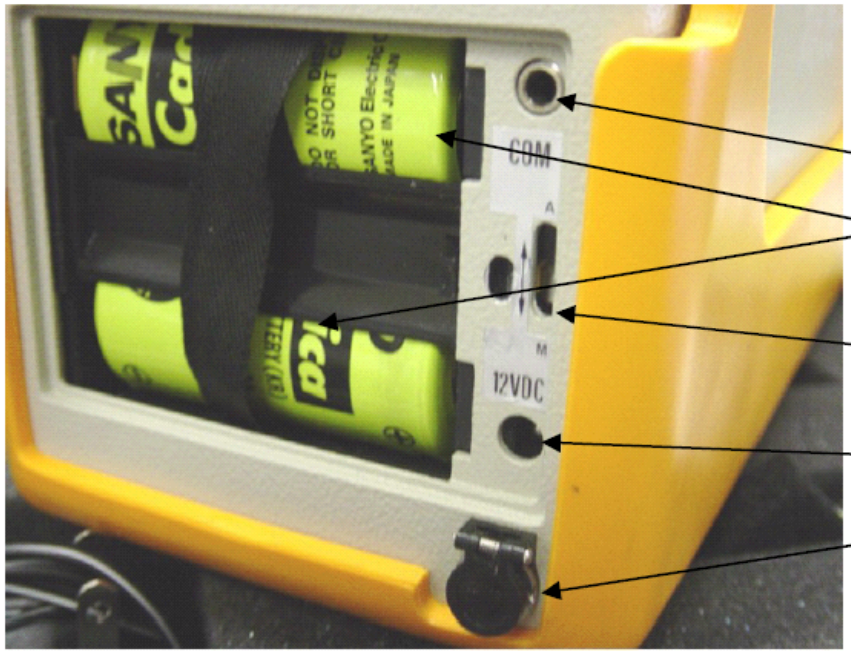


Figure 4. The relative uncertainty in the activity concentrations of ^{232}Th spectra analysed according to the full-spectrum analysis (triangles) and traditional windows analysis (squares) as a function of counts in the spectrum [taken from hendriks].

[Koomans et al., 2007]

GR-135

2.2 CONNECTIONS – BATTERY COMPARTMENT



Rear View with Battery Door Removed

COM - RS-232 Communication Connector

BATTERIES

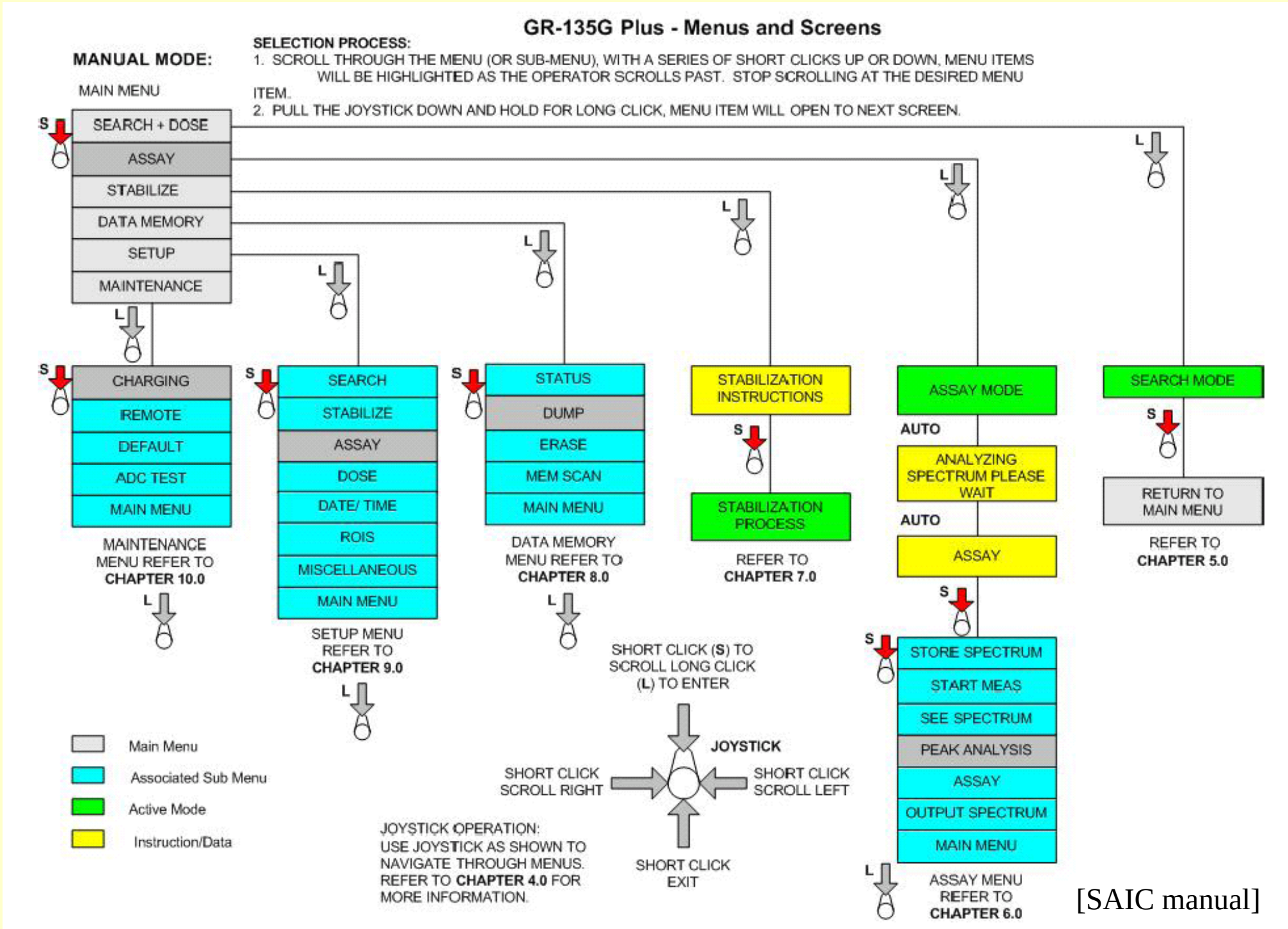
AUTOMATIC/ MANUAL SWITCH

12V DC – Battery Charging Connector

EARPHONE JACK

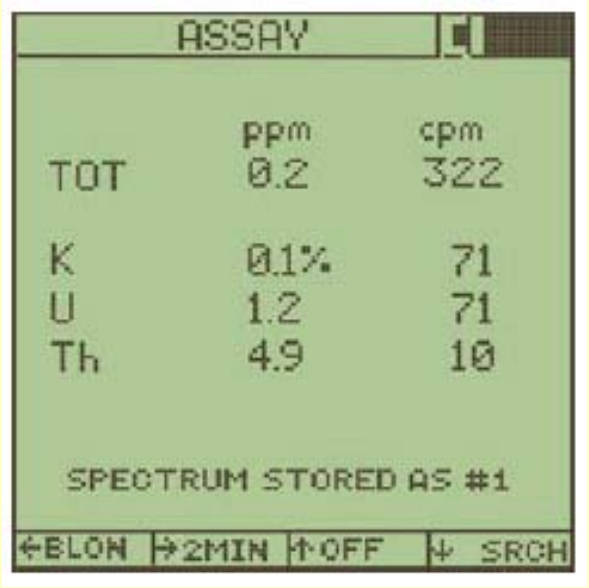
[SAIC manual]

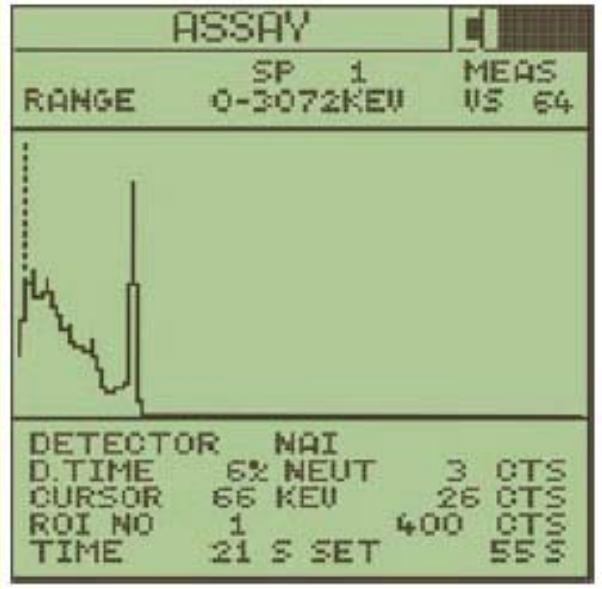
Menu structure of GR-135



[SAIC manual]

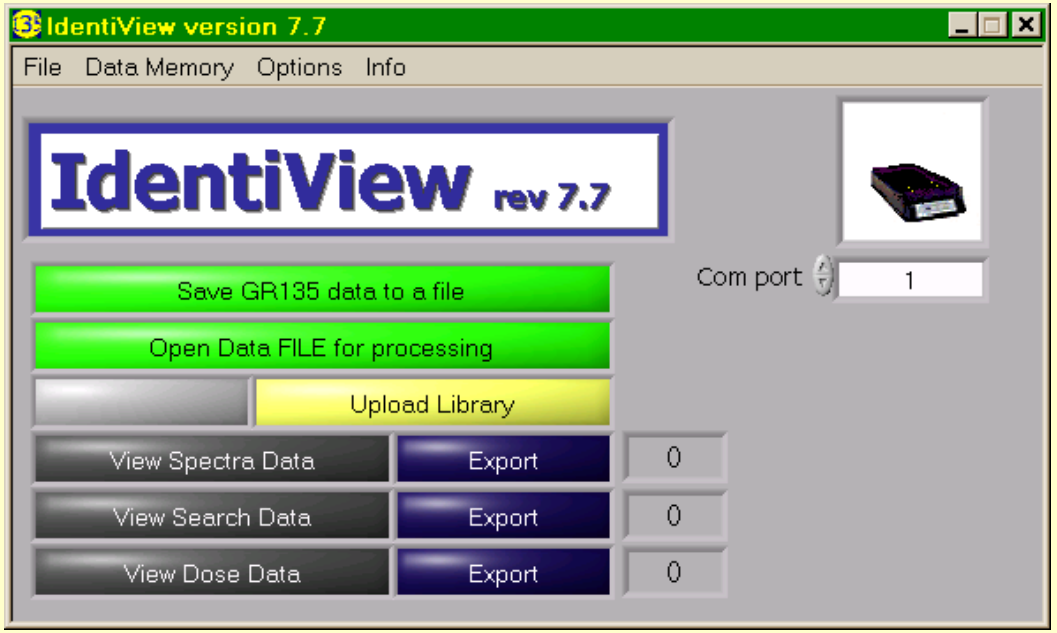
The most important screens (on-line evaluation)

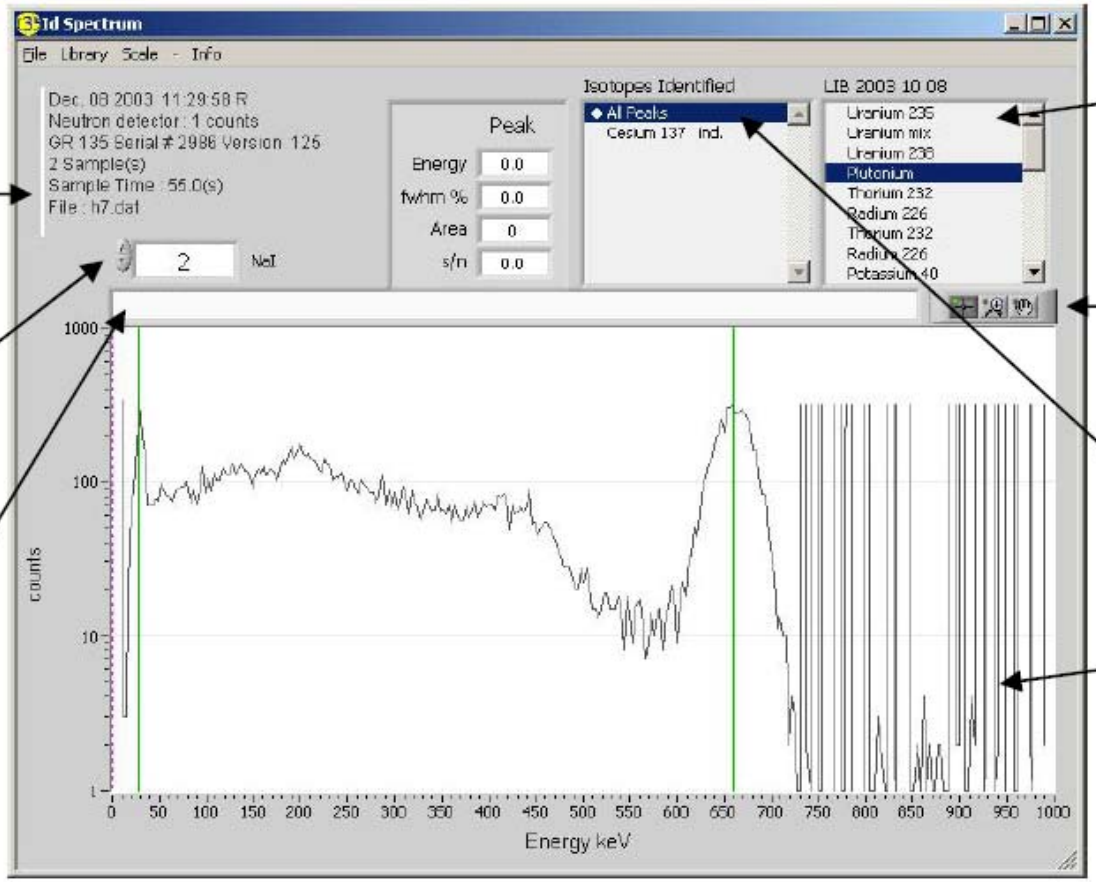




[SAIC manual]

Off – line evaluation





Identifies the GR-135 unit, firmware version, sample time, and date and time of the spectrum. Each specific has its own date/time stamp.

Select spectrum # using up/down arrows. This box goes RED when the last spectrum is reached.

Optional user text box where custom comments can be entered (for printing purposes only)

Current library in use.

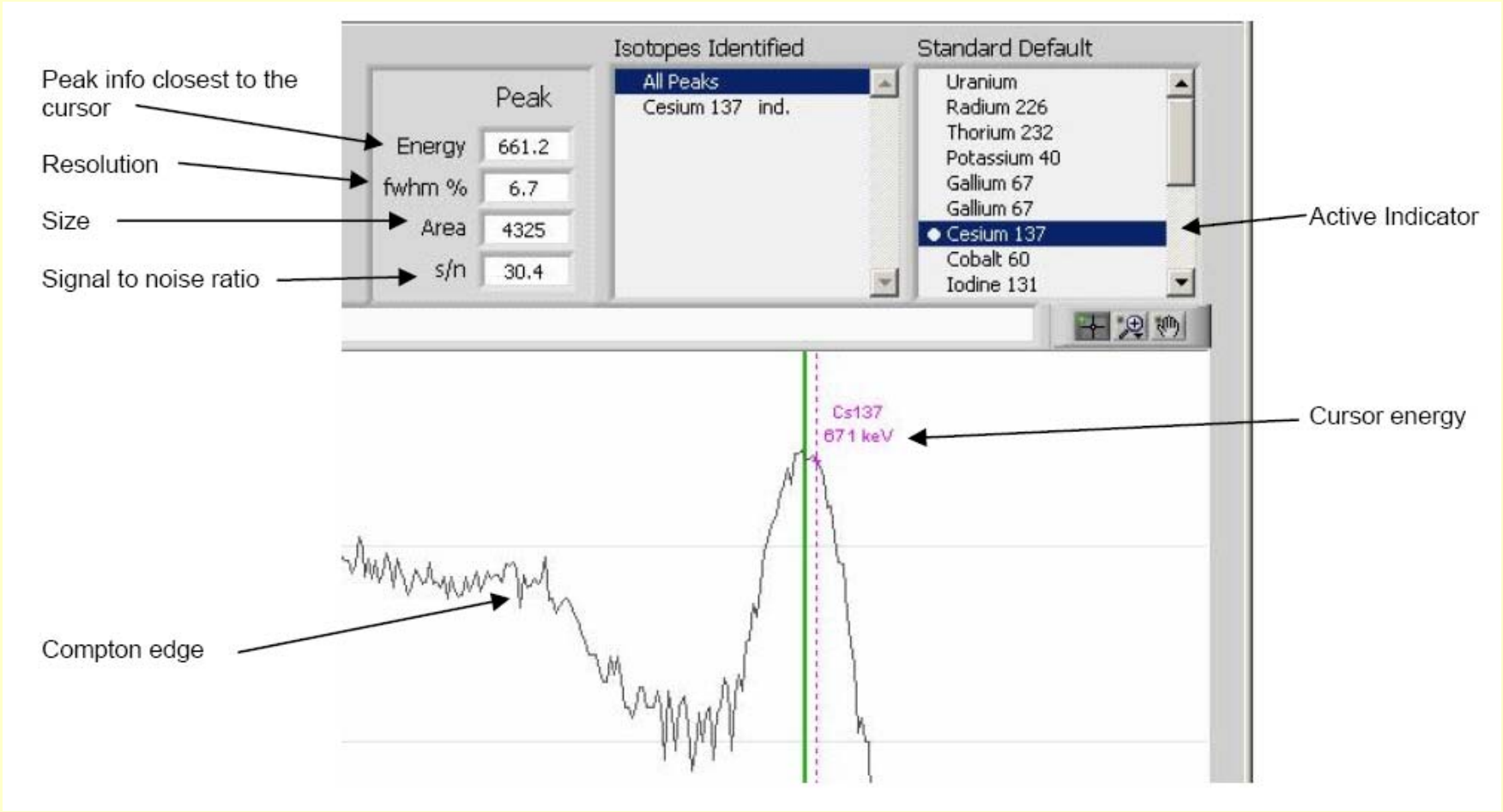
Graph palette with cursor and search functions.

Active indication (double click to force All peaks)

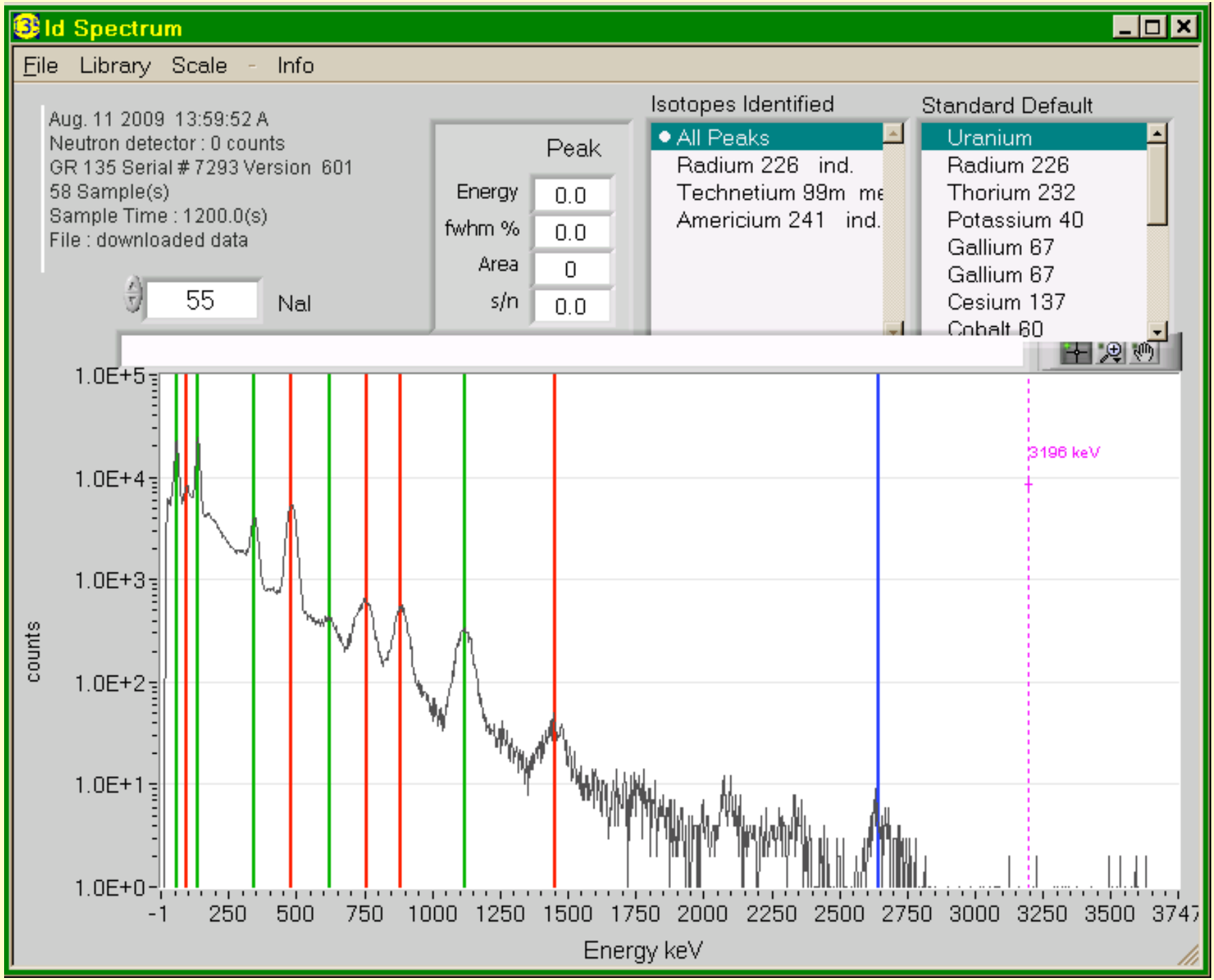
Right Click Mouse on the graph to view the Context Menu.

[SAIC manual]

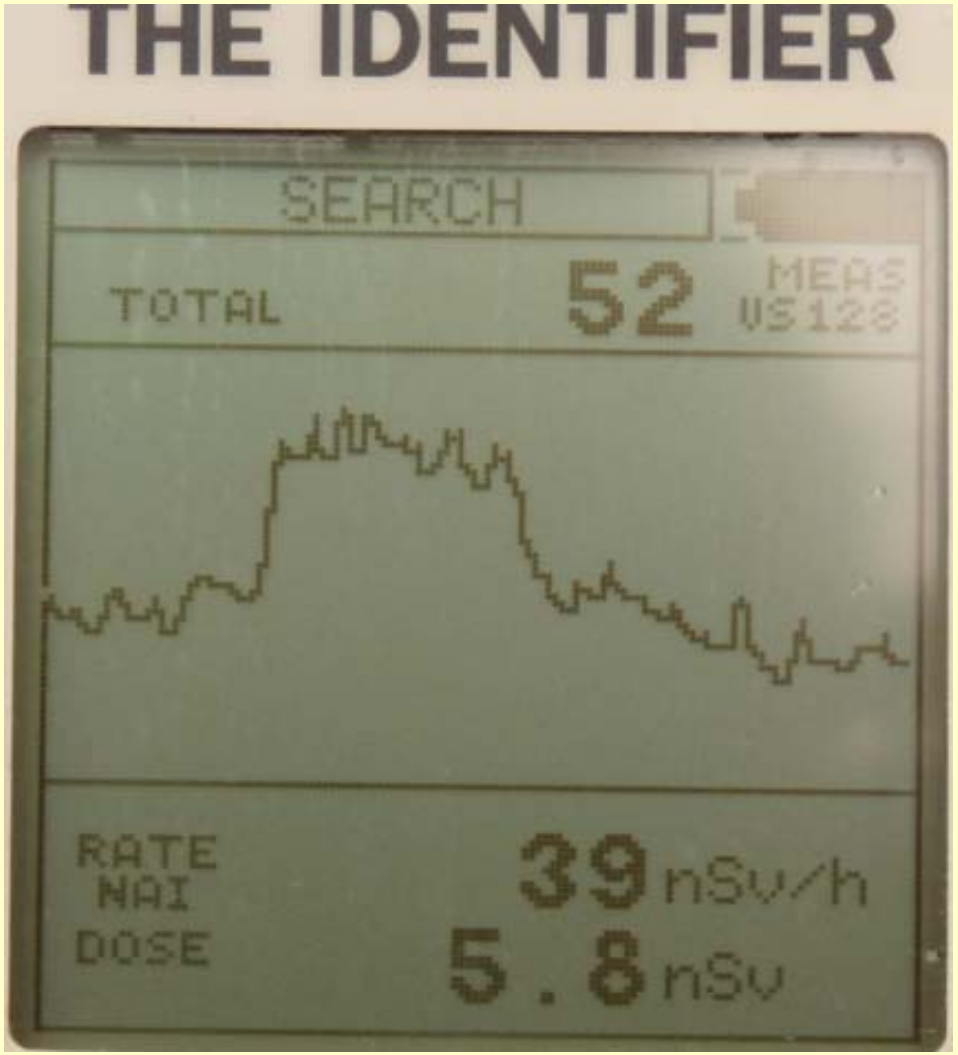
Off – line evaluation

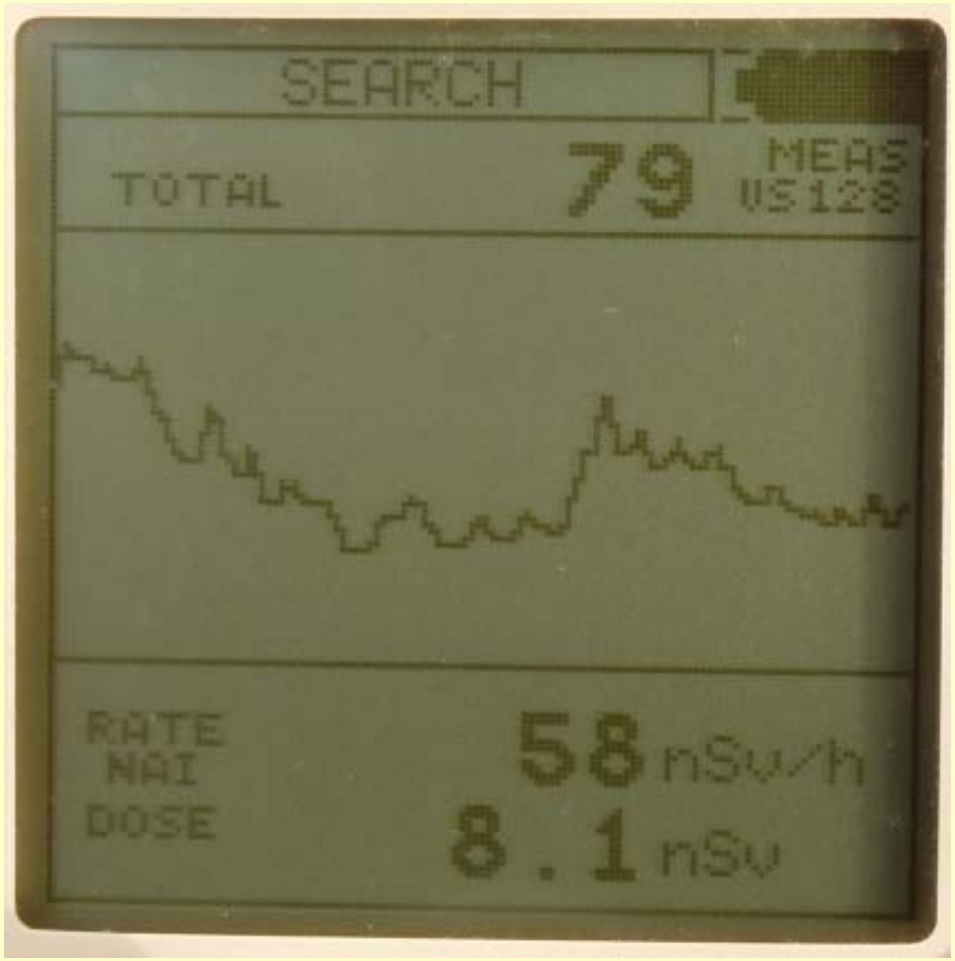


[SAIC manual]

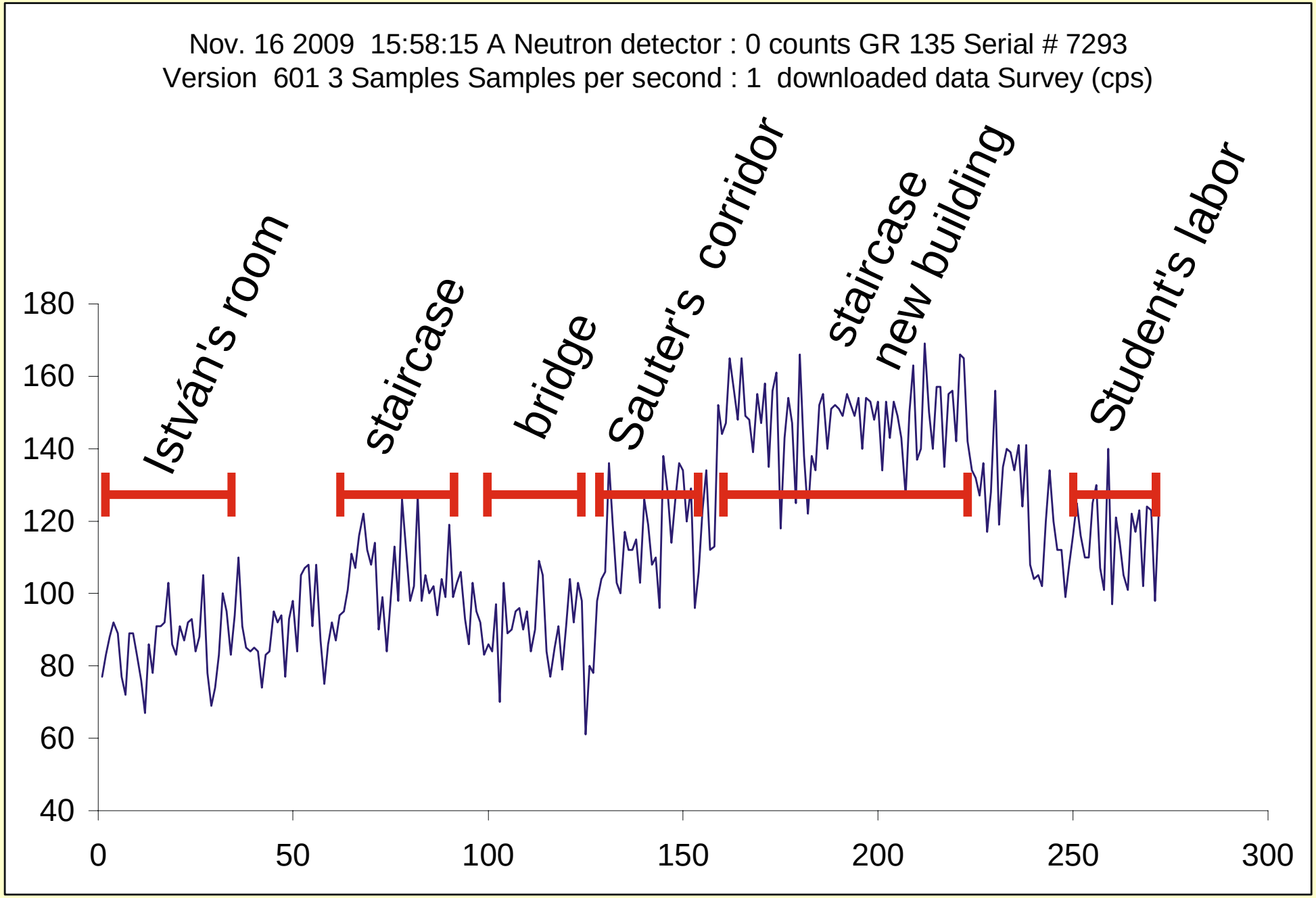

Id Spectrum
File Library Scale - Info
Aug. 11 2009 13:59:52 A
Neutron detector : 0 counts
GR 135 Serial # 7293 Version 601
58 Sample(s)
Sample Time : 1200.0(s)
File : downloaded data
55
NaI
Peak
Energy 0.0
fwhm % 0.0
Area 0
s/n 0.0
Isotopes Identified
All Peaks
Radium 226 ind.
Technetium 99m me
Americium 241 ind.
Standard Default
Uranium
Radium 226
Thorium 232
Potassium 40
Gallium 67
Gallium 67
Cesium 137
Cobalt 60
3196 keV
1.0E+5
1.0E+4
1.0E+3
1.0E+2
1.0E+1
1.0E+0
counts
-1 250 500 750 1000 1250 1500 1750 2000 2250 2500 2750 3000 3250 3500 3747
Energy keV

Demonstration: distinction of dolomite from soil-covered dolomite during field work

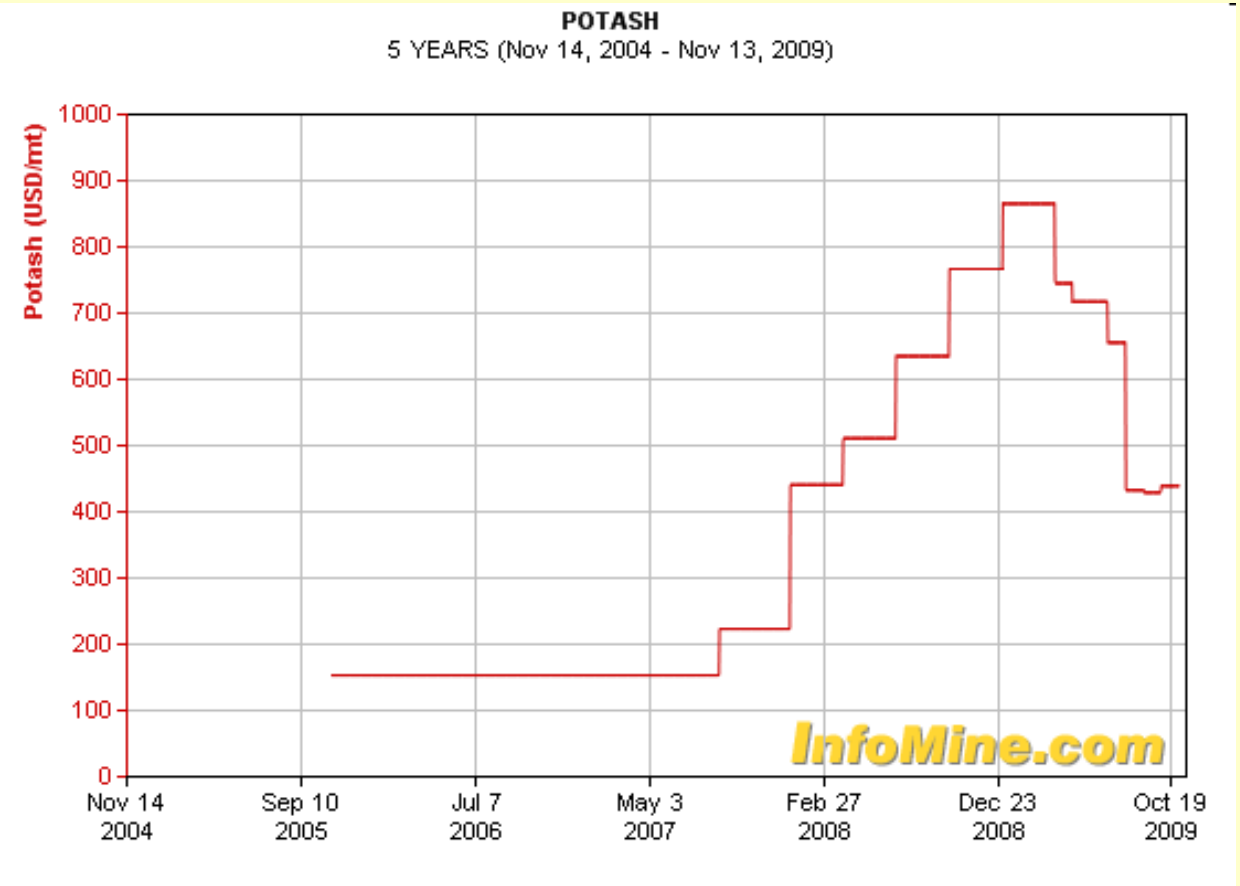




Demonstration: „indoor field-work”

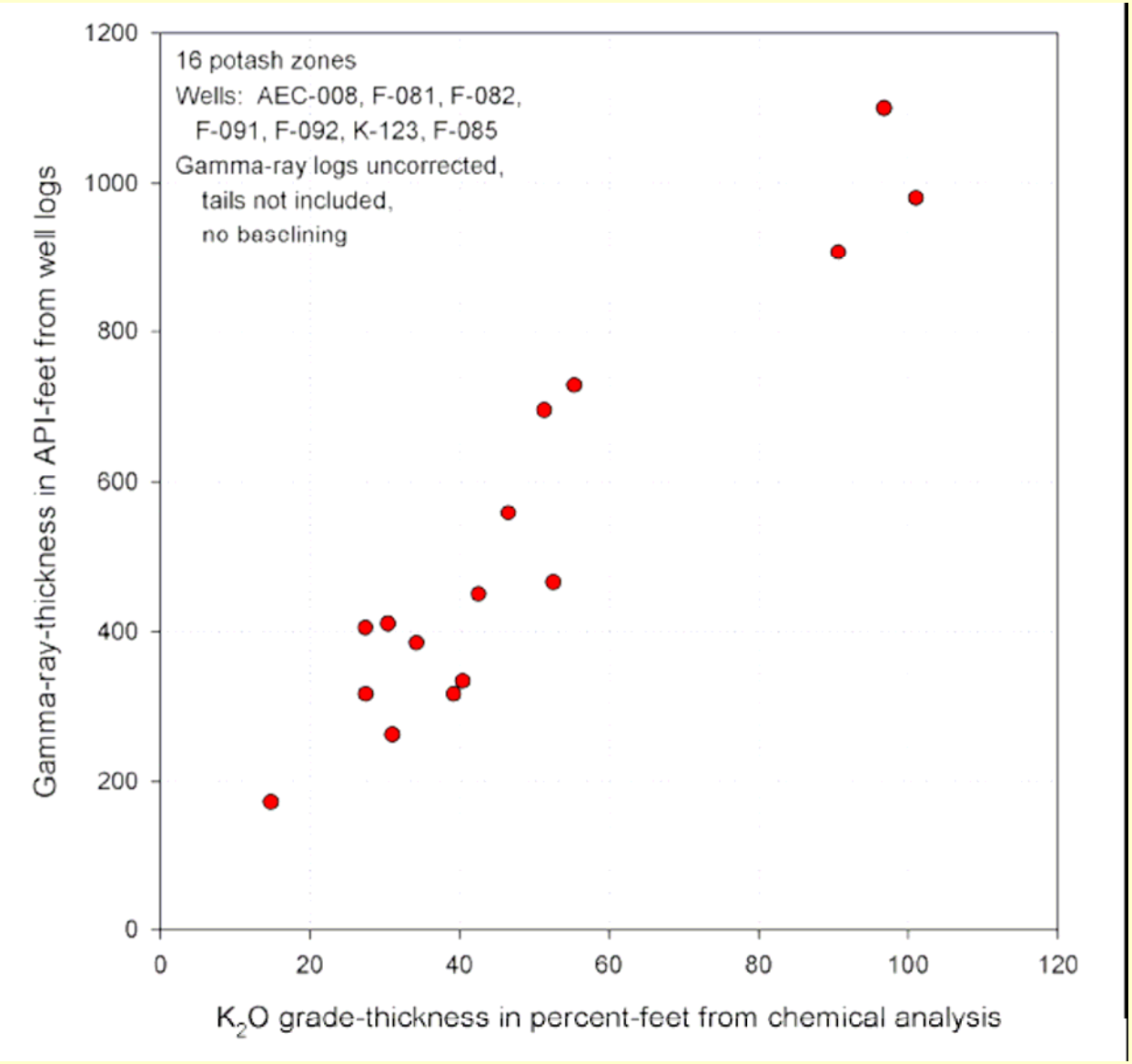


Economy, prospection



[infomine.com]

Potash grade with gamma-ray logs



[Nelson, 2007]

Placers

Monazite (~10 % ThO_2),

Zircon (500-1500 ppmU)

expanding REE market

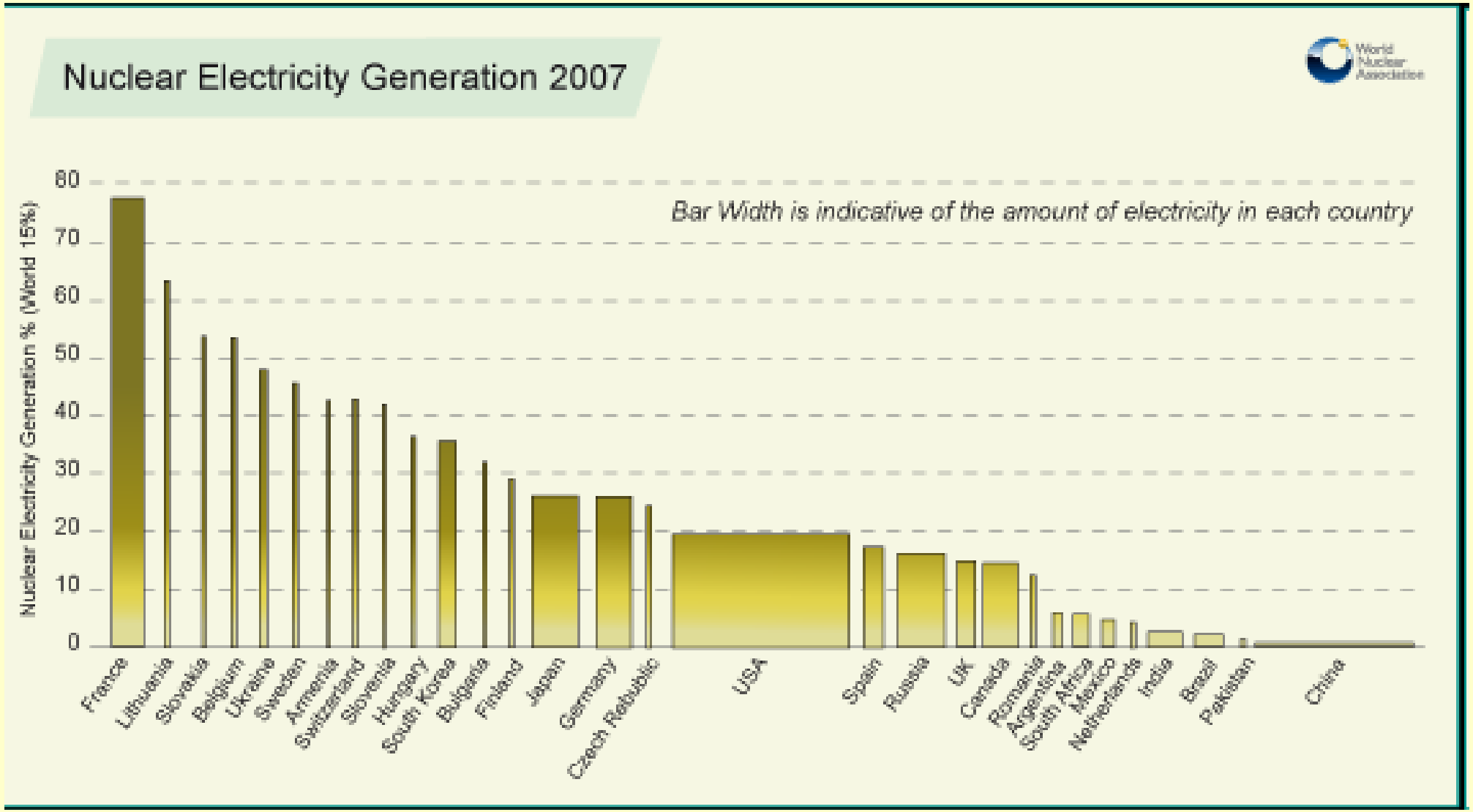
U exploration

[infomine.com]

Uranium production & requirements !!!

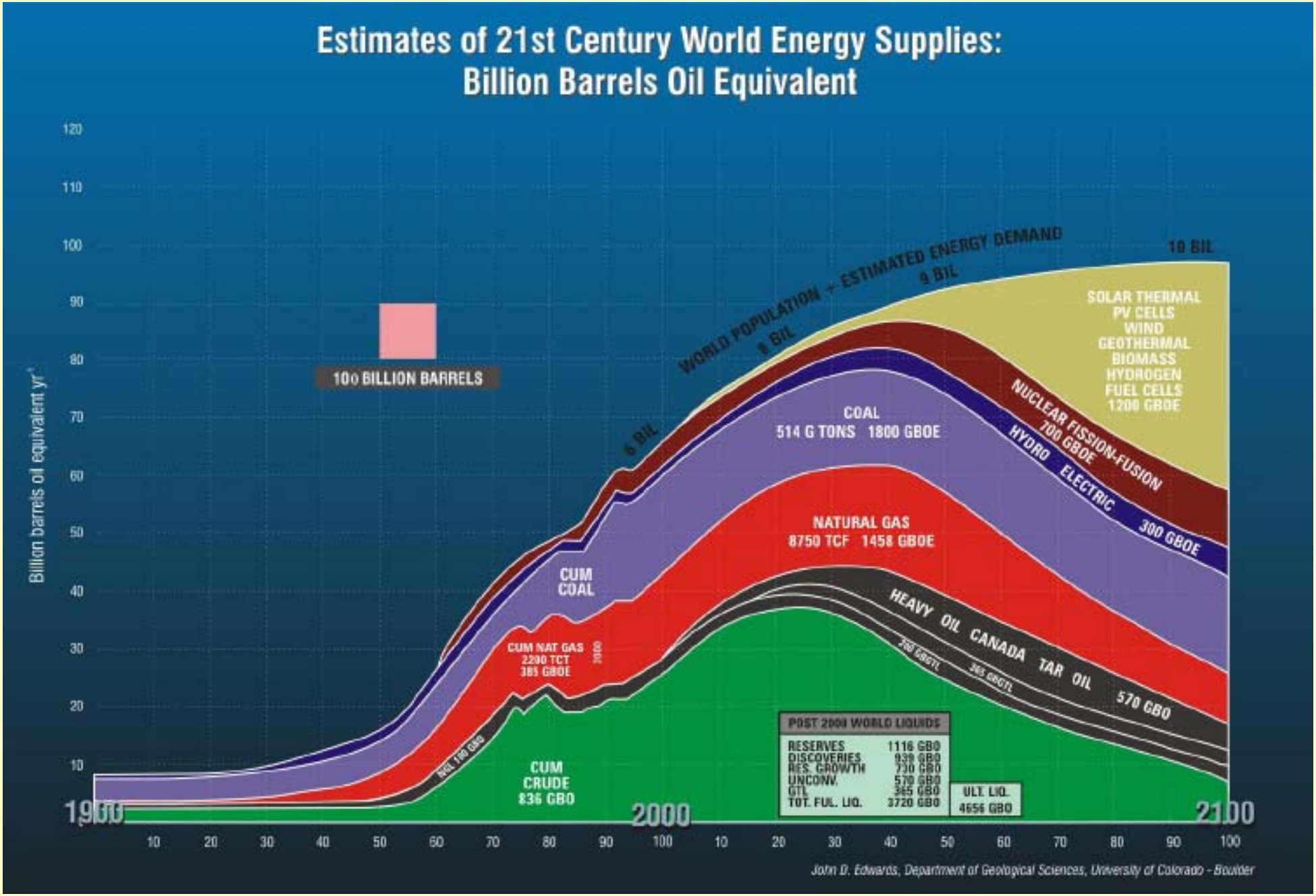
Figure 12. **Annual Uranium Production and Requirements**
(1945-2004)

[IAEA, 2005]


Nuclear Electricity Generation 2007
World Nuclear Association
Bar Width is indicative of the amount of electricity in each country
Nuclear Electricity Generation % (World 15%)
80
70
60
50
40
30
20
10
0
France
Lithuania
Slovakia
Belgium
Ukraine
Sweden
Armenia
Switzerland
Slovenia
Hungary
South Korea
Bulgaria
Finland
Japan
Germany
Czech Rebublic
USA
Spain
Russia
UK
Canada
Romania
Argentina
South Africa
Mexico
Netherlands
India
Brazil
Pakistan
China

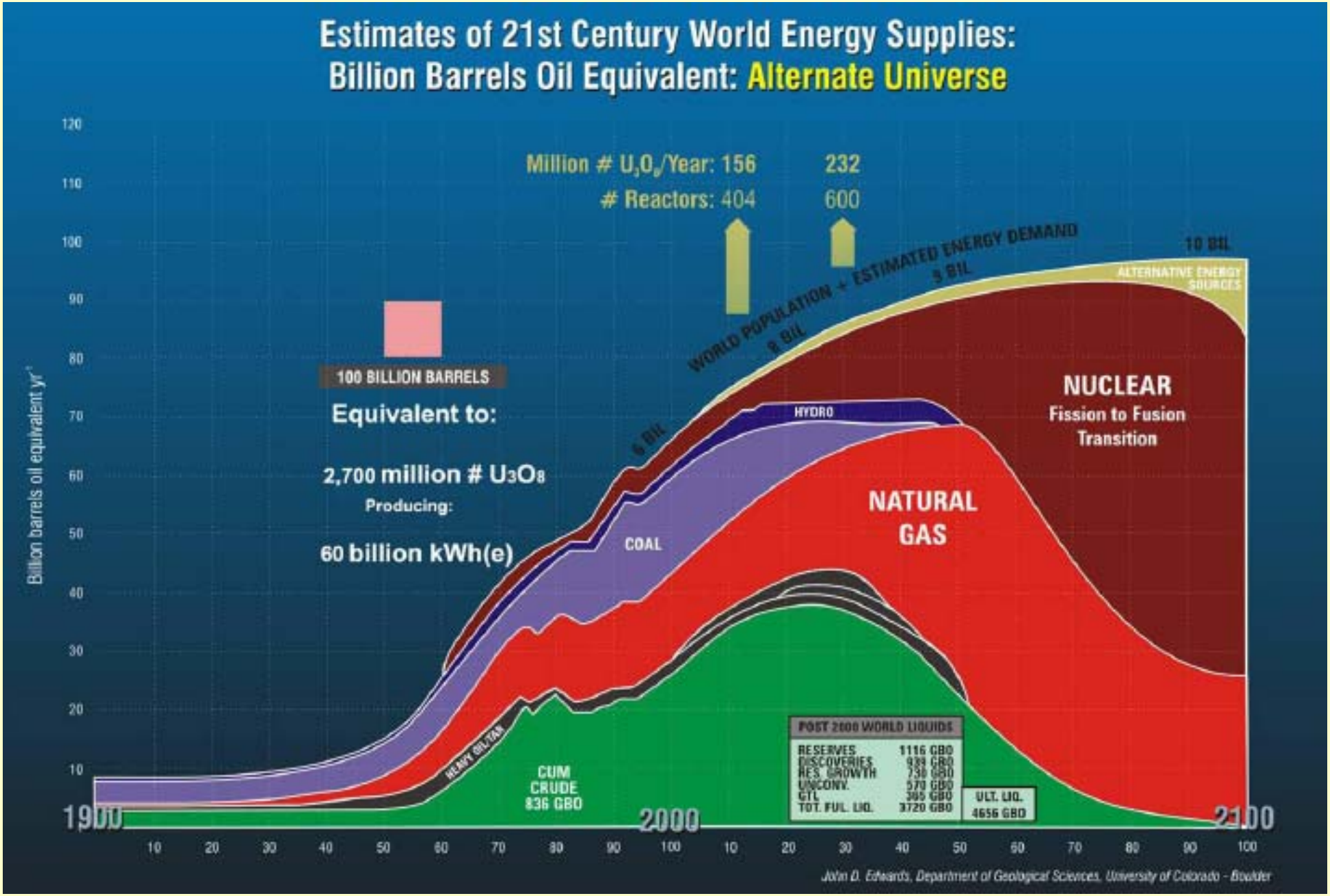
[WNA]

Future 1



[Campbell and Campbell, 2005]

Future 2



[Campbell and Campbell, 2005]

The future looks like absolutely not ‘atomic-free’

WNA NUCLEAR CENTURY OUTLOOK							
MAJOR NUCLEAR PROGRAMMES*	2008	2030 Low	2030 High	2060 Low	2060 High	2100 Low	2100 High
Units - 1GWe							
Belarus	0	2	5	5	8	5	10
Belgium	6	6	8	8	10	8	22
Brazil	2	10	30	40	100	70	330
Bulgaria	2	4	7	5	7	5	7
Canada	13	20	30	25	40	30	85
China	9	35	100	150	750	500	2800
Czech Republic	3	5	7	5	12	5	15
Finland	3	5	7	8	10	8	11
France	63	65	75	80	110	80	130
Germany	20	20	50	40	80	80	175
Hungary	2	4	5	4	8	5	12
India	4	20	70	60	350	200	2750
Japan	48	55	70	80	140	80	200
Lithuania/ Latvia/ Estonia	1	4	6	5	8	5	8
Netherlands	1	1	5	7	20	10	35
Romania	1	4	10	5	20	10	25
Russia	22	30	70	75	180	100	200
Slovakia	2	3	4	4	5	5	7
Slovenia	1	1	1	1	2	1	2
South Korea (and North Korea)	18	25	50	45	80	70	145
Spain	7	8	20	20	50	25	60
Sweden	9	10	15	10	18	10	18

[World Nuclear Association]

Summary

Easy usage, good reproducibility

Quick U-Th-K assay *(equivalent is measured!)*

But!: - Detection geometry
- Background extraction
- Topography and '*micro-topography*'

Nuclid identification

Fields of usage

Mapping, logging profiles (planetology ;-)
Correlation, facies analysis
Radioactive heat production
ESR, TL, OSL dating
U and placer prospection
Evaluation of potash grade

NOT for dosimetry