Introduction to terrestrial gamma ray background

natural & artificial nuclides present in environment

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Natural radioactivity (about 60 isotopes)

1. $T_{1/2}$ > 500 mln lat (^{238}U, ^{235}U, ^{232}Th, ^{40}K, ^{147}Sm, ^{87}Rb, ^{138}La, ^{176}Lu....)

Natural nuclear reactor: Oklo (Gabon)!

2. Daughters of above (^{234}U,^{226}Ra, ^{228}Ra, ^{234}Th, ^{230}Th, ^{222}Rn, ^{220}Rn, ^{210}Po, ^{210}Pb....)

{Series U, Th, Ac, (Np)}

1+2 – common name: „terrestrial radionuclides”

3. Cosmogenic (^{3}H,^{7}Be,^{10}Be, ^{14}C, ^{22}Na, ^{24}Na, ^{26}Al, ^{35}S, ^{36}Cl, ^{129}I, ...)

Series U

Z Element	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146
92 uranium																			^{234}U 0.3 Ma, α				^{238}U 4.5 Ga α
91 protactinium																				^{234}Pa 1 min β^-			
90 thorium																	^{230}Th 75 ka lα				^{234}Th 24 d β^-		
89 actinium																							
88 radium															^{226}Ra 1622 a, α								
87 fransium																							
86 radon													^{222}Rn 3.8d α										
85 astatium										^{218}At 1.3 s α													
84 polonium			^{210}Po 138d α				^{214}Po 0.2ms α				^{218}Po 3min. α,β^-												
83 bismuth				^{210}Bi 6 d β^-,α				^{214}Bi 20min β^-,α															
82 lead	^{206}Pb stable				^{210}Pb 22 a lβ^-,α				^{214}Pb 27min β^-														
81 talium		^{206}Tl 4min β^-				^{210}Tl 1.3m β^-																	
80 mercury			^{206}Hg 9min β^-																				

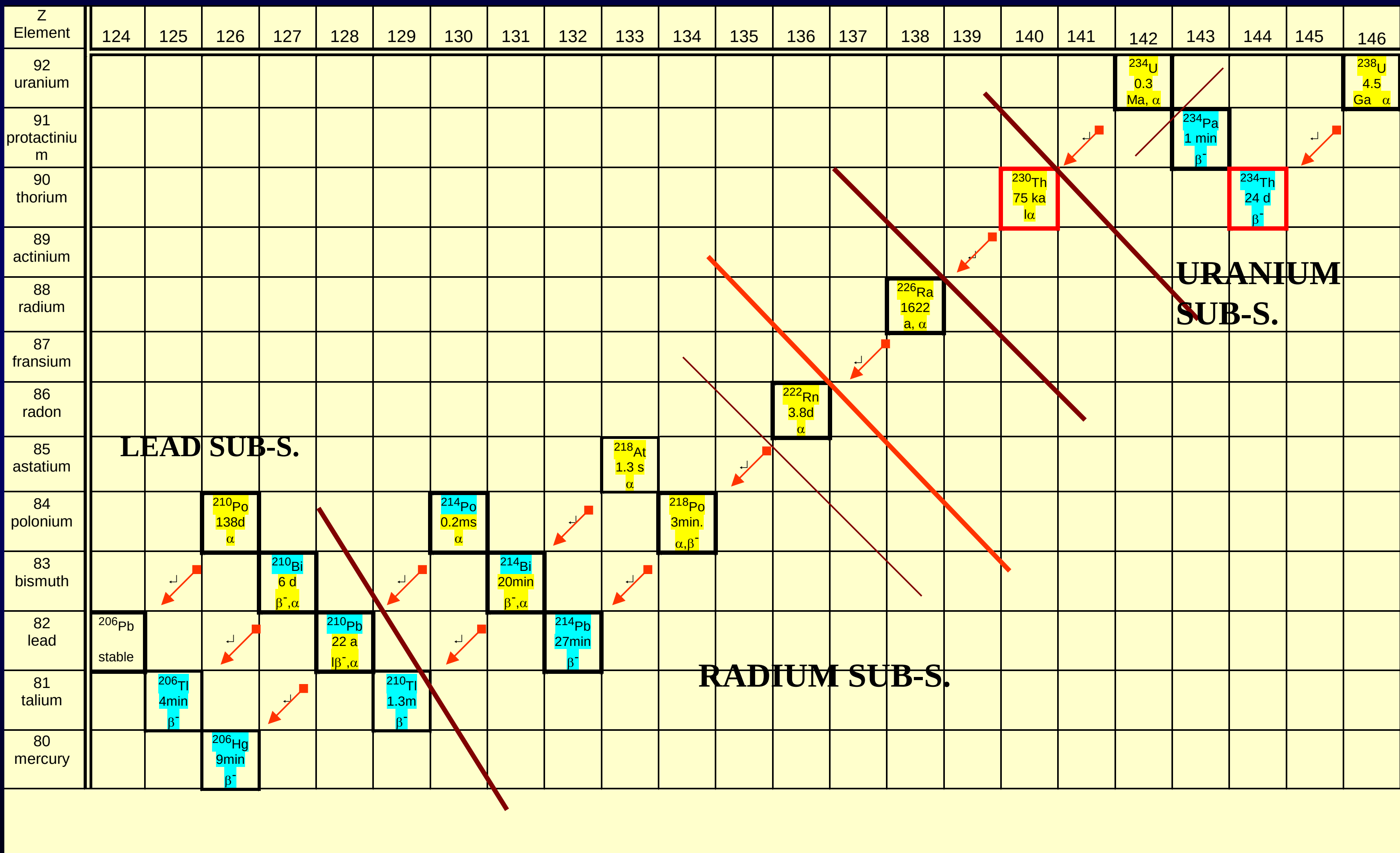
Are activities in series equal? - secular equlibrium

Is parent in equilibrium with daughter?

- <NO>: (relatively low total activities)
- <YES>: whole serie equilibrated (high total activities)
- <Partial> fragments of serie equilibrated
  $^{238}U+^{234}Th+^{234m}Pa$, ^{234}U (so called sub-series)

Spectrum analyses needed

Series U



Z
Element
124
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144
145
146
92
uranium
91
protactinium
90
thorium
89
actinium
88
radium
87
fransium
86
radon
85
astatium
84
polonium
83
bismuth
82
lead
81
talium
80
mercury
234U 0.3 Ma, α
238U 4.5 Ga α
234Pa 1 min β-
230Th 75 ka lα
234Th 24 d β-
226Ra 1622 a, α
222Rn 3.8d α
218At 1.3 s α
210Po 138d α
214Po 0.2ms α
218Po 3min. α,β-
210Bi 6 d β-,α
214Bi 20min β-,α
206Pb stable
210Pb 22 a lβ-,α
214Pb 27min β-
206Tl 4min β-
210Tl 1.3m β-
206Hg 9min β-
URANIUM SUB-S.
LEAD SUB-S.
RADIUM SUB-S.

Series Th :

Z Element	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142
90 thorium													^{228}Th 1.9 y α				^{232}Th 14 Ga lat, α
89 actinium														^{228}Ac 6.1 h β			
88 radium											^{224}Ra 3.7 d, α				^{228}Ra 6.7 a β		
87 fransium																	
86 radon									^{220}Rn 55s α								
85 astatium																	
84 polonium			^{212}Po 0.3µs α				^{216}Po 0.156 s α										
83 bismuth				^{212}Bi 6min β^-,α													
82 lead	^{208}Pb stable				^{212}Pb 11 h β^-												
81 talium		^{208}Tl 3min β^-															

URANIUM (U)- isotopes

- Z=92
- A=234,235,238, ...
- 0.0058%,0.71%,99.28% of mass
- $^{234}U\ T_{1/2}$ =244 ka, alpha
- $^{235}U\ T_{1/2}$=700 Ma alpha, gamma
- $^{238}U\ T_{1/2}$=4.6 Ga, alpha

Examples of U activities

For 1 M (238 g) U, (without Ra):

2.9 MBq alpha, + 2x2.9 MBq beta (+gamma)

1 ppm U = 12 Bq/kg (x18 if equilibrated with whole series)

In uranium glasses (green dye):

Up to 1% U = 10000 ppm U=120 000 Bq/kg

U in environment

In rocks (as 160 minerals):

vulcanic:

  basic < 1 ppm (< 12 Bq/kg)

  acidic: 2.5-6 ppm (30-72 Bq/kg)

sedimental:

  clay and silts 3-4 ppm (36-48 Bq/kg)

  sands ~0.5 ppm (~6 Bq/kg)

  carbon ~2.5 ppm (~30 Bq/kg)

In sea – (~3 ppb) ~3.3 μBq/dm^3

Soil – 0.3-11 ppm (4-130 Bq/kg)

Human body– 10-20 ppb, mainly in kidneys (200 mBq)

Thorium (Th) - isotopes

Z= 90

^{232}Th – alpha, 14 Ga (Th ser.)

^{230}Th – alpha, 80 ka (U ser)

^{228}Th – alpha, 1.9 a (Th ser.)

^{234}Th – beta minus, gamma, 24 d (U ser.)

^{227}Th – alpha, 18 d (Ac ser.)

^{231}Th – beta minus, 26h, (Ac ser.)

Chemical properties similar to Ce or other REE

Thorium (Th):

Abundance (mean for Earth):

2.4 ppm (1 ppm ^{232}Th=5 Bq/kg)

Minerals

- Euksenite $(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)_2O_6$
- Monazite $(Ce,La,Th).PO_4$
- Sartorite $PbAs_2S_4$
- Torianite ThO_2
- Xenotime YPO_4

Radium (Ra):

Z= 88

Isotopes:

^{226}Ra – alpha, gamma, 1622a (U ser.)

^{228}Ra – beta minus, 6.7 a (Th ser.)

^{224}Ra – alpha, 3.64 d (Th ser.)

^{223}Ra – alpha, 11.4 d (Ac ser.)

Second group metal (like Ca, Sr)

In general not in equilibrium with parent if it is U nor Th

Radon (Rn):

Z= 86

- Isotopes:
- ^{222}Rn – alpha, 3.84 d (U ser.)
- ^{220}Rn – alpha, 55 s (Th ser.)
- ^{219}Rn – alpha, 4s (Ac ser.)

Noble gas

Polonium (Po):

Z=84

Isotopes:

- ^{218}Po - alpha, 3.05 min (U ser.)
- ^{216}Po – alpha, 0.16 s (Th ser.)
- ^{215}Po – alpha, 1.7 ms (Ac ser.)
- ^{214}Po – alpha, 26.8 m (U ser.)
- ^{212}Po – alpha, 0.3 μs (Th ser.)
- ^{211}Po – alpha, 0.52 s (Ac ser.)
- **^{210}Po -** alpha **, 138 d (U ser.)**

Metal, similar to selenium

Bismuth (Bi)

Z=83

Izotopy:

- ^{214}Bi – beta minus, alfa 19.7 min, (U szer.)
- ^{210}Bi – beta minus, 5 d (U szer.)
- ^{212}Bi – beta minus, alfa, 60.5 m (Th szer.)
- ^{211}Bi – alfa, beta minus, 2.16 min   (Ac szer.)
- ^{209}Bi – stabilny, nieradiogeniczny

Ciężki, toksyczny metal z grupy azotanowców – gromadzi się w kościach

Lead (Pb):

Z=82

Isotopes:

- ^{214}Pb – beta minus, gamma, 26.8 min (U szer.)
- ^{210}Pb – beta minus, gamma, 22 a (U ser.)
- ^{206}Pb – stable (U ser.)
- ^{212}Pb – beta minus, gamma, 10.6 h (Th ser.)
- ^{208}Pb – stable (Th ser.)
- ^{211}Pb – beta minus, gamma, 36 min (Ac ser.)
- ^{207}Pb – stable (Ac ser.)

Toxic heavy metal

Potassium (K) & rubidium (Rb):

^{40}K (1.26 Ga), beta minus 89%, EC 11%

Abundance 0.0117% (32 Bq/g potassium)

^{87}Rb (48 Ga), beta minus,

Abundance 27%, ~1 kBq/g Rb

First group metal, K –important macro-nutrient, Rb toxic, in traces.

REE

^{138}La (112 Ga), beta minus+gamma

^{147}Sm (105 Ga), alpha

+^{144}Nd, ^{142}Ce, ^{148}Sm,^{146}Sm,^{152}Gd, ^{156}Dy, ...

Cosmogenic radionuclides (main)

IZOTOP	$T_{1/2}$	Radiation E [MeV]	AKTYWNOŚĆ [Bq/m^3]
^{3}H	12 a	β^- , (0.0186)	$3.5\cdot10^{-4}$
^{7}Be	54 d	EC, γ (0.477)	0.003
^{10}Be	**1.6 Ma**	**β^- (0.555)**	**$1.2\cdot10^{-9}$**
^{14}C	**5.7 ka**	**β^- (0.156)**	**0.04**
^{22}Na	2.6 a	β^+(0.545), γ (1.275)	$3\cdot10^{-7}$
^{24}Na	15 h	β^- (1.4), γ (1.37, 2.75)	-
^{26}Al	**7.2 Ma**	**β^+(1.2), γ (1809)**	-
^{32}P	14 d	β^- (1.71)	$7\cdot10^{-5}$
^{33}P	24 d	β^- (0.246)	$4\cdot10^{-5}$
^{35}S	88 d	β^- (0.167)	$4\cdot10^{-5}$
^{38}S	2.84 h	β^- (1.1), γ(1.88)	-
^{36}Cl	**0.3 Ma**	**β^- (0.714)**	**$2.5\cdot10^{-10}$**
^{38}Cl	37 min	β^- (4.91), γ (1.60, 2.17)	-
^{39}Cl	55 min	β^- (1.91), γ (0.25, 1.27)	-
...			

dla beta - E max.

Production rate in atmosphere

Depends on

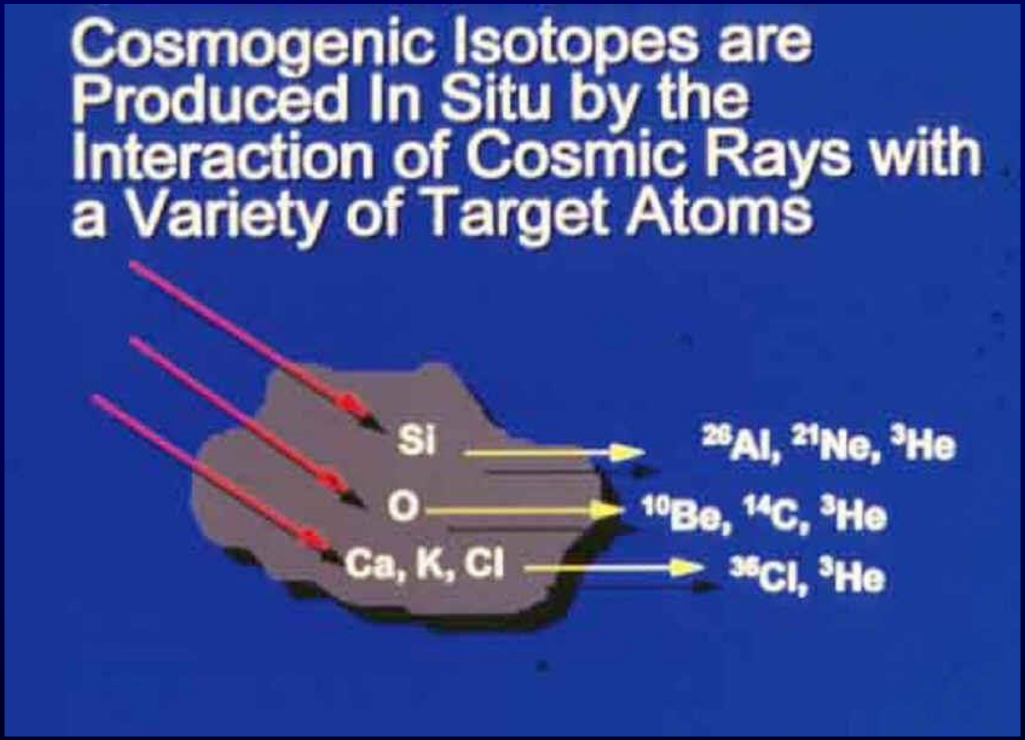
- Altitude – about 2/3 on stratosphere
- Geomegnetic latitude

IZOTOP	Produkcja $(cm^2 s)^{-1}$ Troposfera	Whole atmosphere
^{3}H	$8.4 \cdot 10^{-2}$	$2.5 \cdot 10^{-1}$
^{7}Be	$2.7 \cdot 10^{-2}$	$8.1 \cdot 10^{-2}$
^{10}Be	$1.5 \cdot 10^{-2}$	$4.6 \cdot 10^{-2}$
^{14}C	1.1	2.5
^{22}Na	$2.4 \cdot 10^{-5}$	$8.6 \cdot 10^{-5}$
^{26}Al	$3.8 \cdot 10^{-5}$	$1.4 \cdot 10^{-4}$
^{32}P	$2.7 \cdot 10^{-4}$	$8.1 \cdot 10^{-4}$
^{33}P	$2.2 \cdot 10^{-4}$	$6.8 \cdot 10^{-4}$
^{35}S	$4.9 \cdot 10^{-4}$	$1.4 \cdot 10^{-3}$
^{36}Cl	$4.0 \cdot 10^{-4}$	$1.1 \cdot 10^{-3}$

/D.Lal, SAHRA Workshop, New Mexico, 22-23.III.2001/

Production rate *in situ*

„*in situ*” (on Earth’s crust {rocks, waters, soil} surface) –



Variation of production rate

- Sun activity

Revers mode (antiproportional)

- Size of Earth’s Magnetosphere

Revers mode (antiproportional)

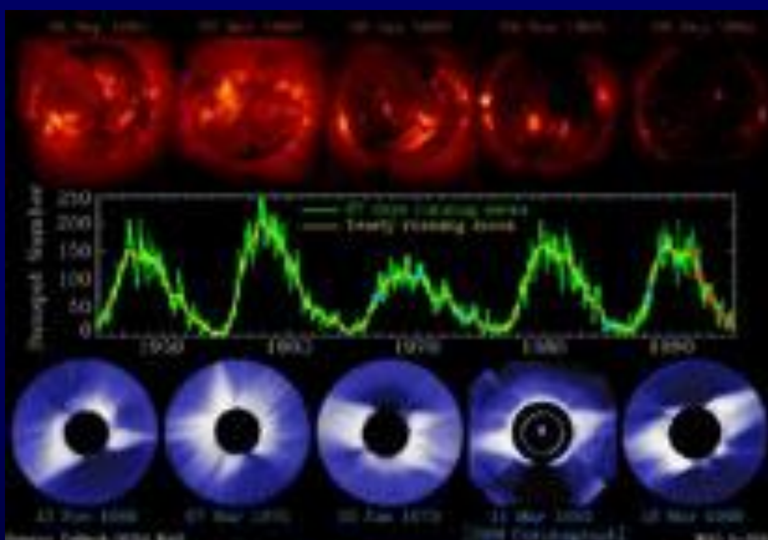
- Cosmic rays flux

Proportional

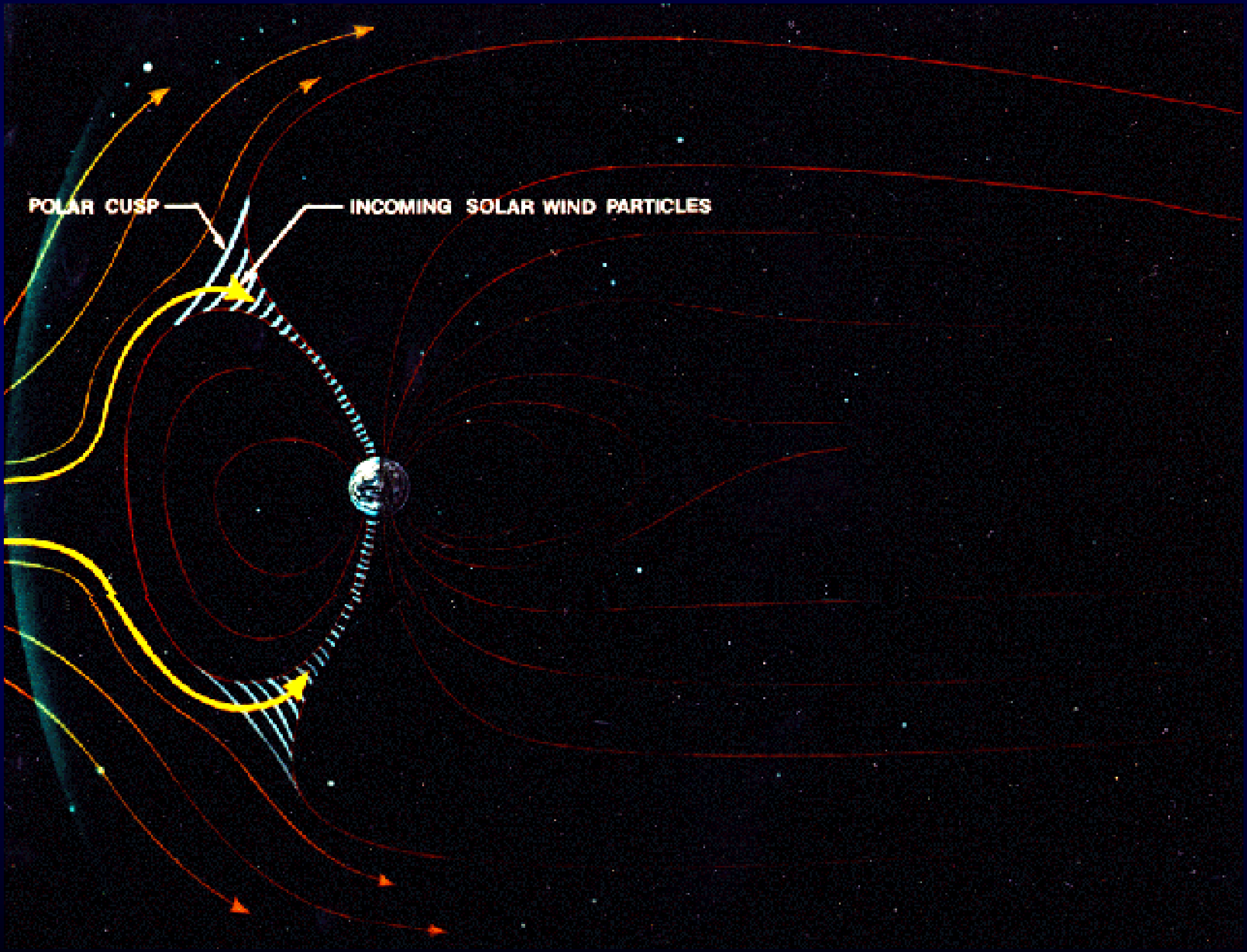
Sun activity

A set of phenomenons (sunspots, solar wind flux, ...)

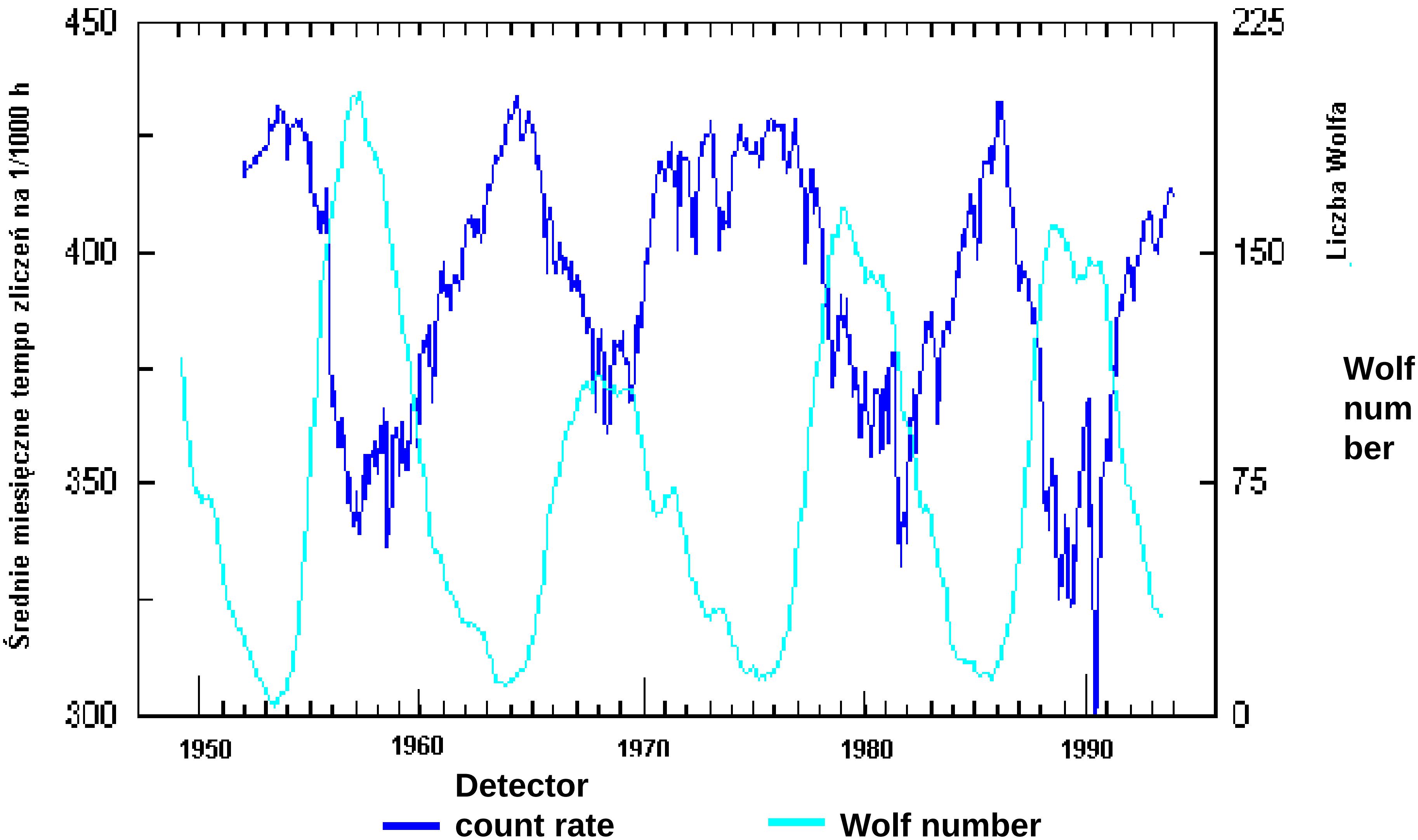
Main cycle - 11 years period



Earth magnetosphere and solar wind



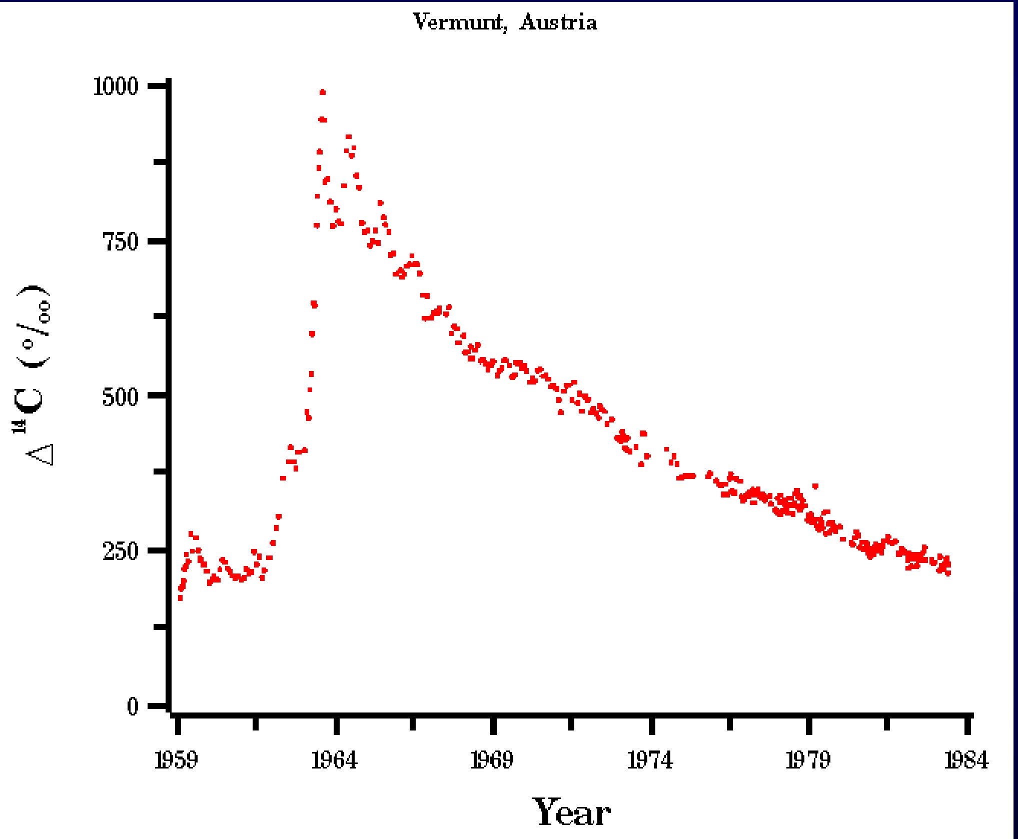
Cosmic radiation & Sun activity



Man made cosmogenic radionuclides: ^{3}H, ^{14}C & ^{85}Kr (year 2000)

Nuclide	$T_{1/2}$ [years]	Natural PBq	Global fallout PBq	Nuclear Energy PBq	Fuel Reprocess. PBq
^{3}H	12.33	1275	22 000	150	150
^{14}C	5730	12 750	213	-	-
^{85}Kr	10.76	0.09	~17	10	4800

Excess of C14 due to nuclear explosion



Source: I. Levin, B. Kromer, H. Schoch–Fischer, M. Bruns, M. Minnich, D. Berdau, J.C. Vogel, and K.O. Minnich (University of Heidelberg)

Typical environmental activities

Isotopes	Material	Activity [Bq]
^{14}C	Man, body	~2000
^{40}K	Man, body	~3000
^{40}K	Milk , 1 L	40
^{40}K	Soil, 1 kg	100-1000
^{238}U	Soil, 1 kg	30-100
^{226}Ra	Soil, 1 kg	30-100
^{7}Be	Air, m^3	$\sim 10^{-3}$
^{222}Rn	Air, m^3	Od <1 do 10^6
^{22}Na	Air, m^3	$\sim 10^{-6}$

Man-made radionuclides in enviroment

MAIN

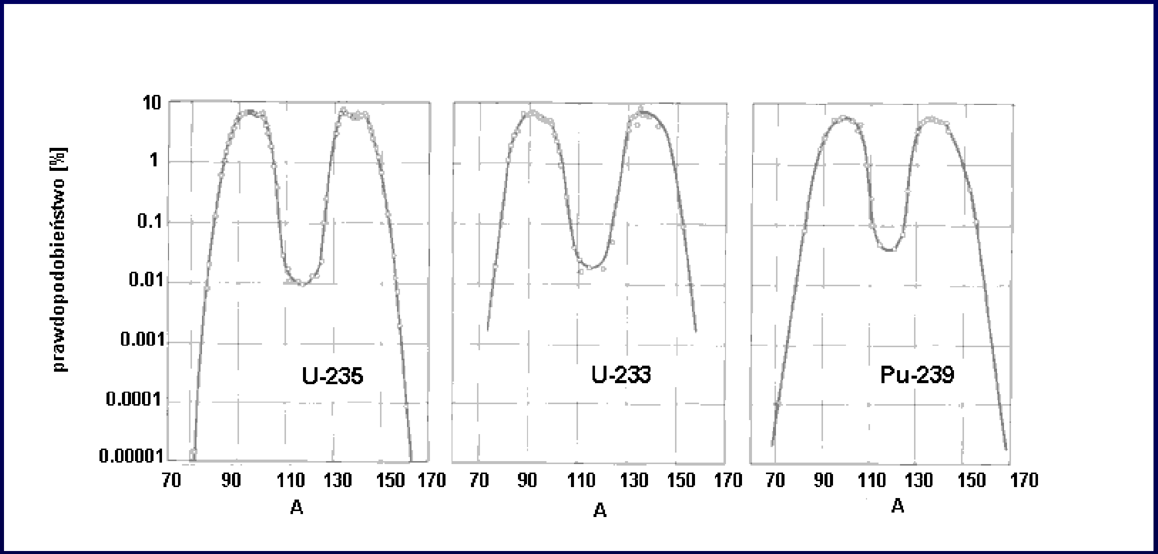
- **Whole cycle of nuclear fuel production and reprocessing – including accidents**
- **Nuclear weapons – production and use**

SECONDARY

- Nuclear medicine
- Industry
- Laboratories

Physical processes in which radionuclides are produced

1. Nuclear fission (NPP, bomb A): >100 isot.: ^{137}Cs, ^{90}Sr,...



2. Activation (by **neutrons**, protons, other) ^{60}Co, ^{63}Ni, ^{134}Cs...
3. Nuclear fusion (thermonuclear explosion) ^{14}C, ^{3}H

Man-made radionulides

long-lived (years):

^{85}Kr, ^{137}Cs, ^{134}Cs, ^{99}Tc, $^{238,239,240,241}Pu$, ^{241}Am, ^{90}Sr....(+many others)

Intermediate: (weeks): ^{103}Ru, ^{95}Nb, ^{95}Zr, ^{89}Sr,...

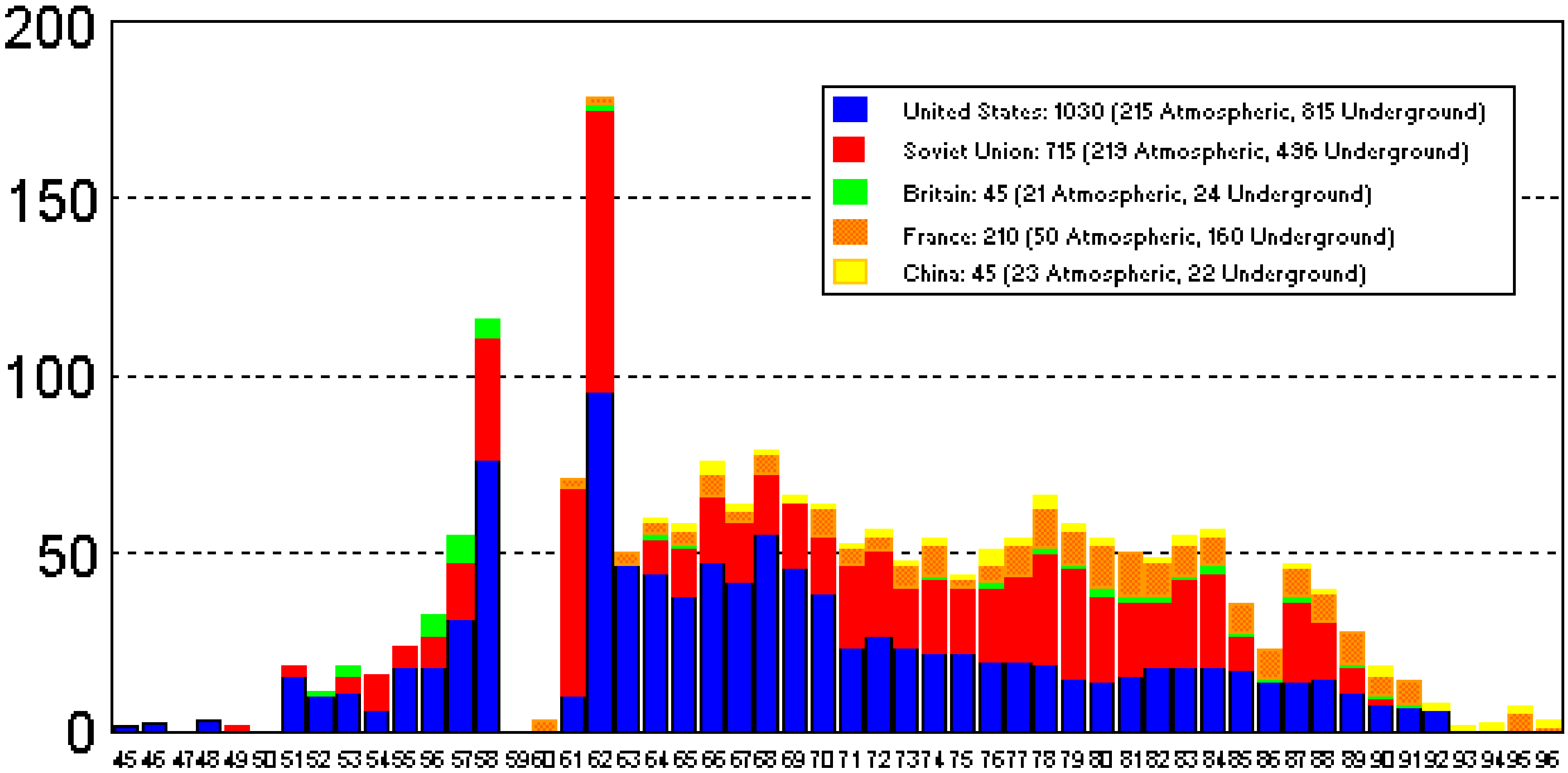
Short lived (days): ^{131}I, ^{132}I, ...

Main events (Poland)

- Global fallout (1945...-1957- 1963-...1980)
- Chernobyl (1986)

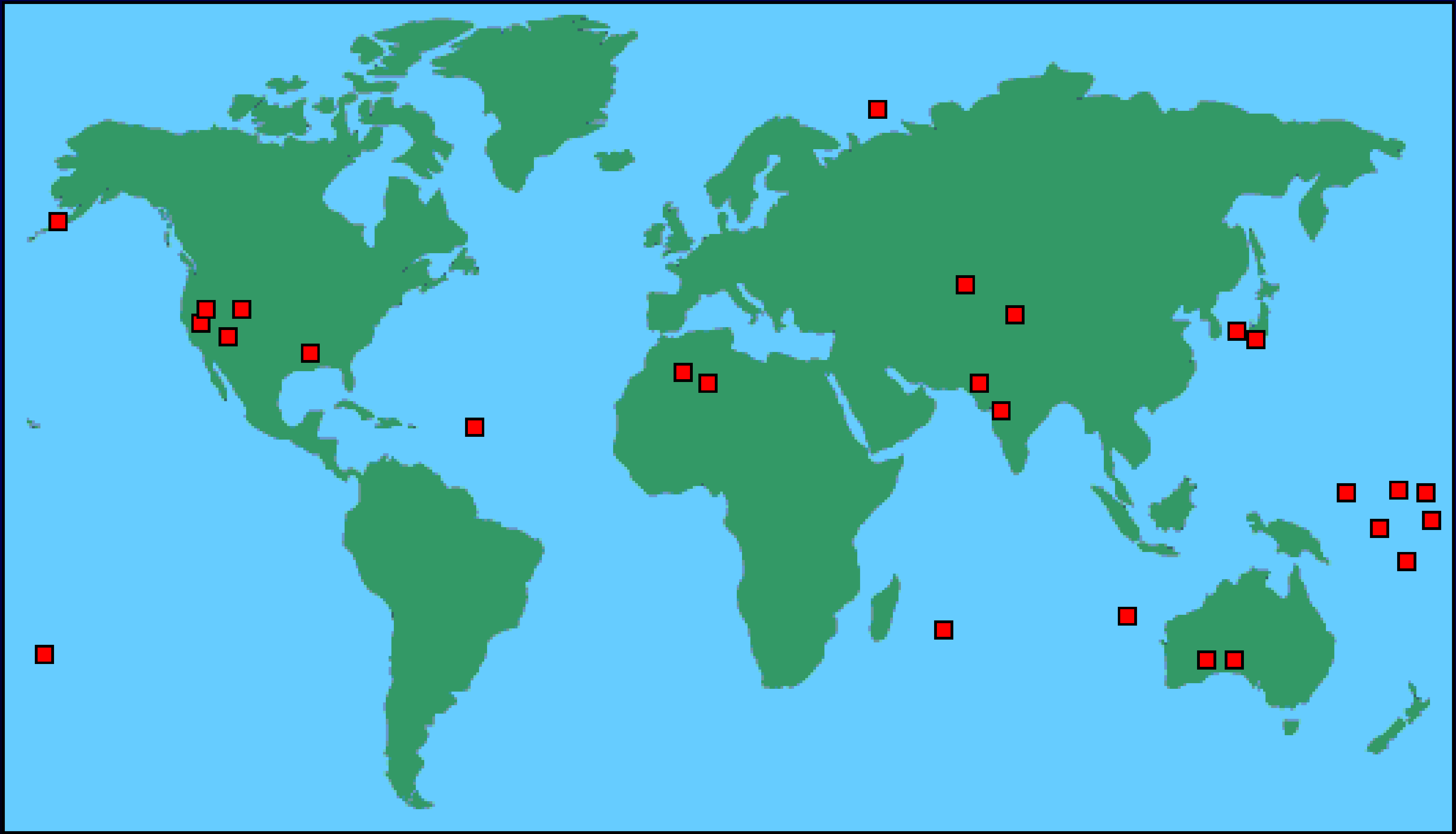
Global Nuclear Weapons Tests

1945-1996



U.S. total does not include the two atomic bombs dropped on Hiroshima and Nagasaki in August 1945.
The U.S. and the Soviet Union conducted 27 and 124 "Peaceful Nuclear Explosions," respectively, which are included in the above totals.
India conducted an underground nuclear test in 1974.
Sources: U.S. Department of Energy; Natural Resources Defense Council, Nuclear Weapons Databook Project

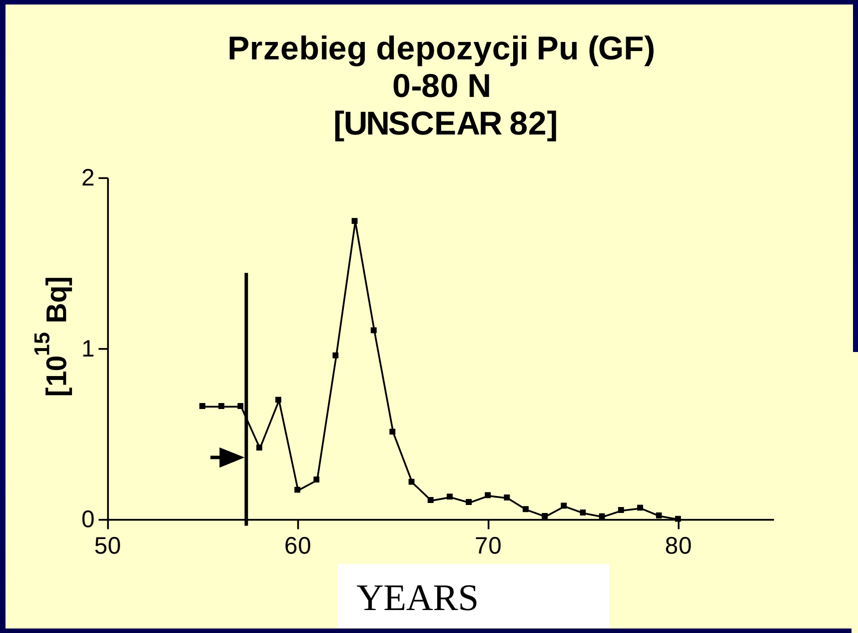
Atmospheric nuclear explosions

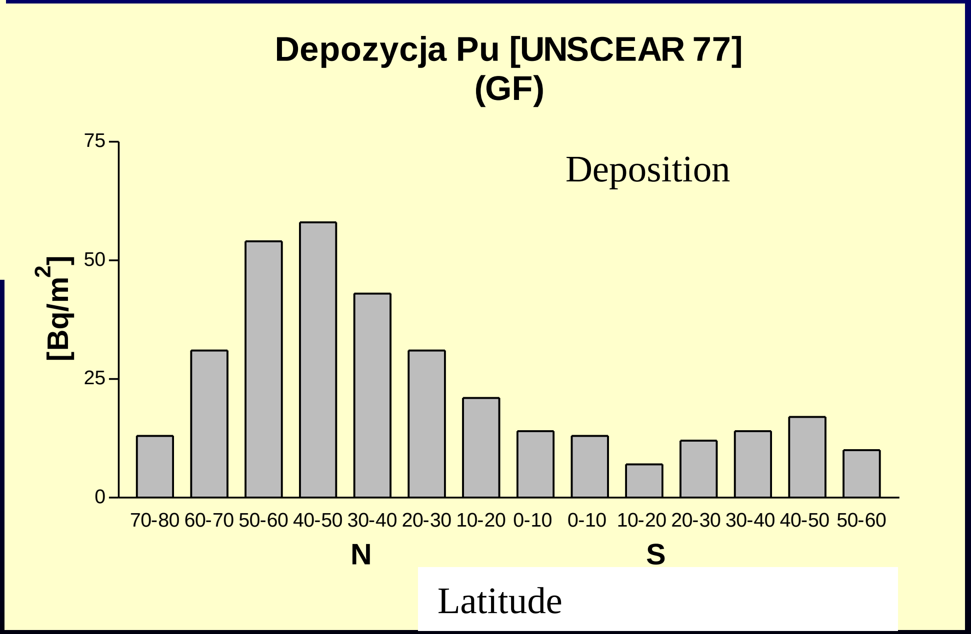


Releases and cummulated deposition - decay corrected

Radionuclid	$T_{1/2}$	Releases PBq	Deposition till 1963 Bq/m^2	Deposition till 1999 Bq/m^2
^{89}Sr	50.5 d	117000	604	0
^{90}Sr	28.78 a	622	1040	825
^{95}Zr	64 d	148000	1770	0
^{106}Ru	373.6 d	12200	4780	0.0004
^{125}Sb	2.76 a	741	602	0.46
^{131}I	8.02 d	675000	9.11	0
^{137}Cs	30.07 a	948	1560	1300
^{144}Ce	284.9 d	30700	9290	0
^{239}Pu	24110 a	6.52	24.5 (NH)	24.5 (NH)
^{240}Pu	6563 a	4.35	16.3 (NH)	16.3 (NH)
^{241}Pu	14.35a	142	549 (NH)	88 (NH)

Example –
global fallout of $^{239+240}$Pu





SNAP 9A (USA)

(Navigation satellite Transit 5-BN-1)

- 1 kg ^{238}Pu – 0.629 PBq

Launched: 28.9.1963,

Re-entry: 24.04.1964 over Indian Ocean near Madagascar, burned at ~50 km (stratosphere!)

Cosmos 954 (USSR)

Accidental re-entry and burn of nuclear reactor (January 1978)

Northwest Territory of Canada

^{131}I –181 TBq

^{90}Sr – 3 TBq

^{137}Cs - 3 TBq

Global fallout for Central Europe

Deposition (kBq/m^2)

Cs-137: 5

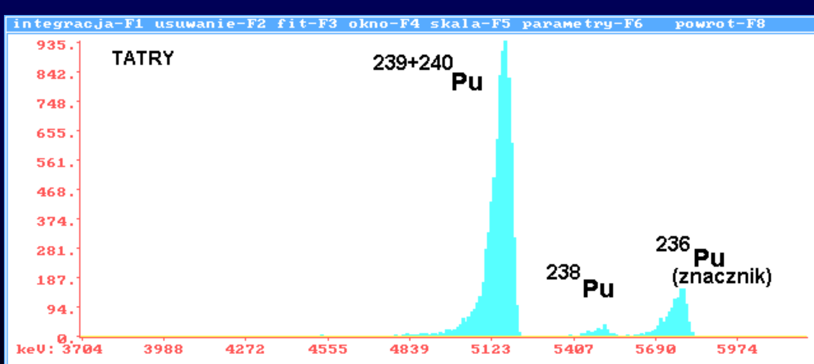
Sr-90: 3

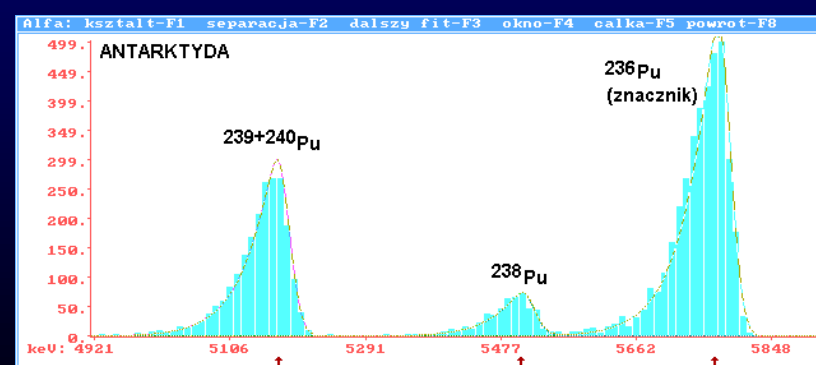
(activities for 1963) Pu-239 i 240: 0.06

....

<u>Satellite SNAP 9A, ’64 (1 kg ^{238}Pu)</u>

Pu-238: 0.002

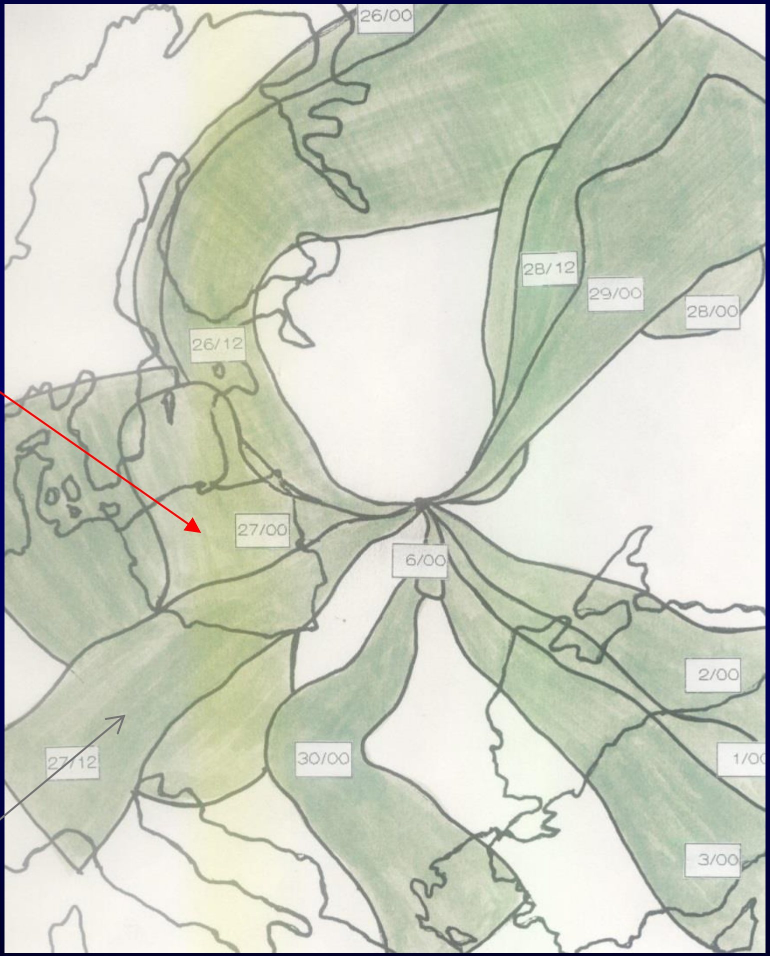




Chernobyl fallout

POLAND

26 April 1986
~24hour emission moved over Poland toward Europe
Total 10 day of release
~7 EBq

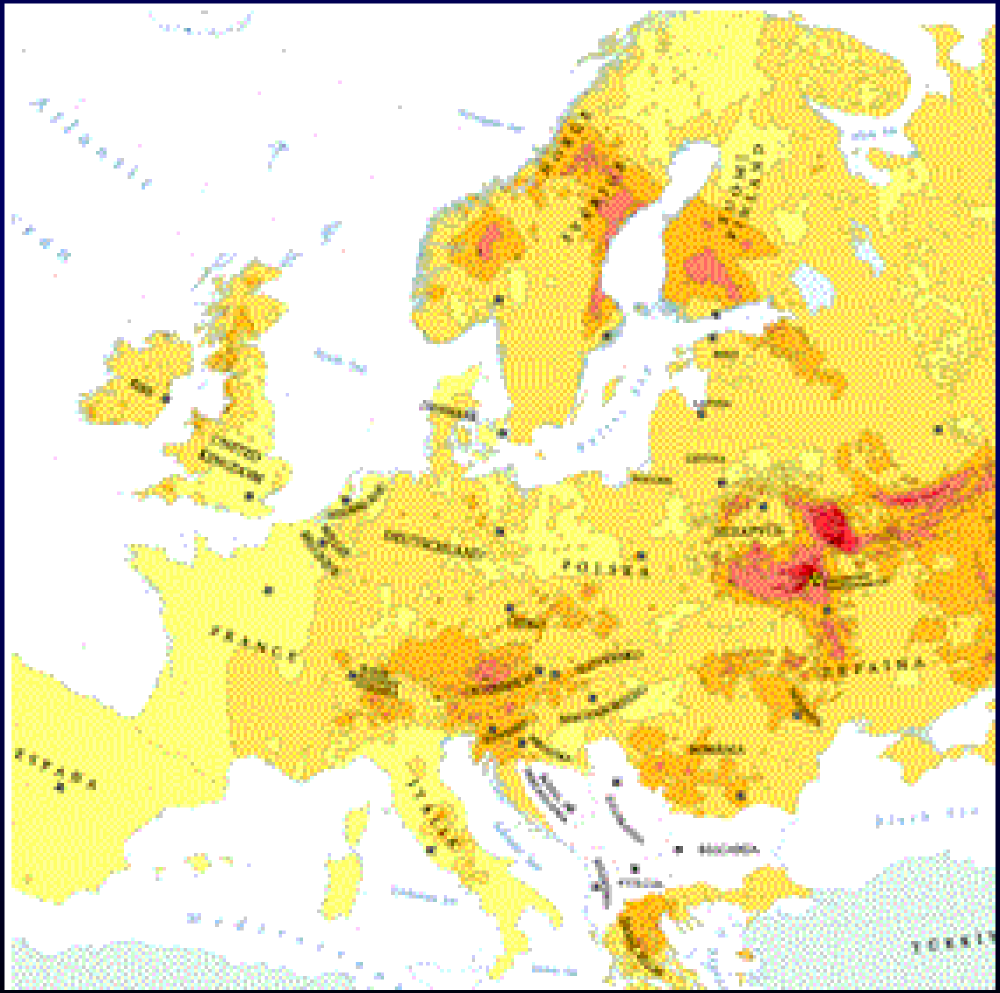


Radioactive plum
(for release in date given in box)

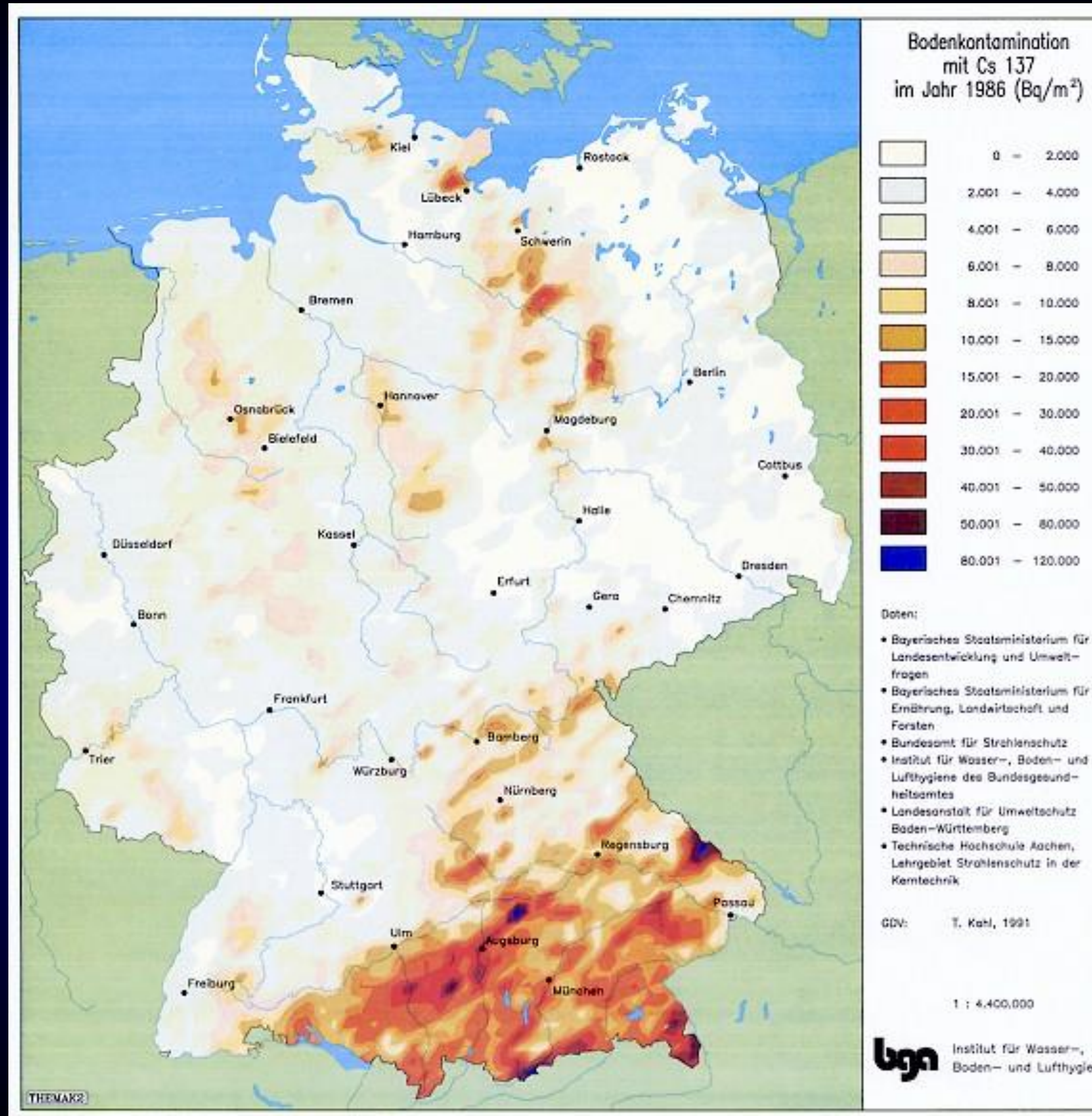
Cs-137 nearby NPP (IAEA 1991)

Figure 32
Radiation Hotspots Resulting From the Chornobyl' Nuclear Power Plant Accident, April 1986

Cs-137 contamination of Europe



Cs-137 contamination of Germany



Chernobyl fallout

„continuous fraction” (~1μm), (kBq/m^2):

Long lived isotopes:

Cs-137 - mean 5 (max. ~100)

Sr-90 - 1/50 x Cs-137

$^{239+240}$Pu 10^{-6} x Cs-137

+several short or intermediate T1/2 (I, Te, Ru, Ba, La, Ce, Sb, Ag...)

For comparison Global Fallout (UNSCEAR data for Polish latitude):

1963, kBq/m2: Cs-137 5

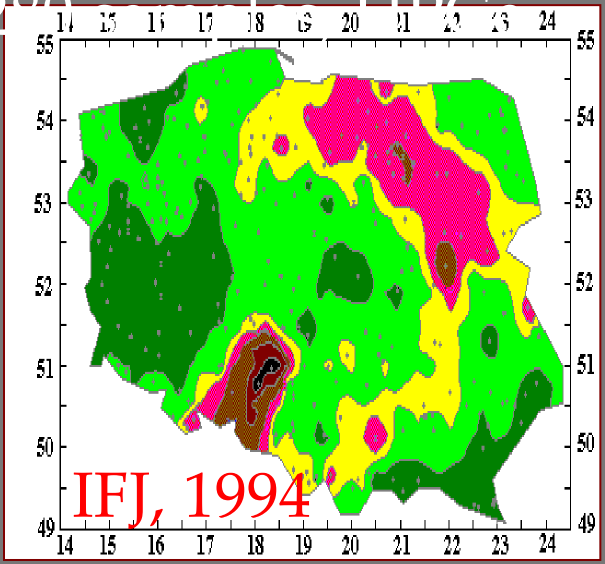
Sr-90

Chernobyl fallout

Approximate maps for ^{137}Cs in Poland

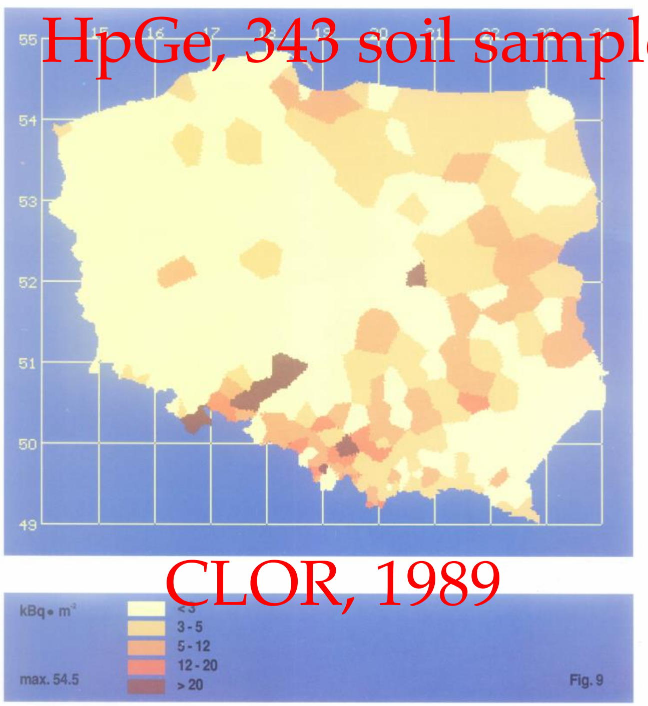
MUSHROOM Xerocomus badius

280 samples, HPGe



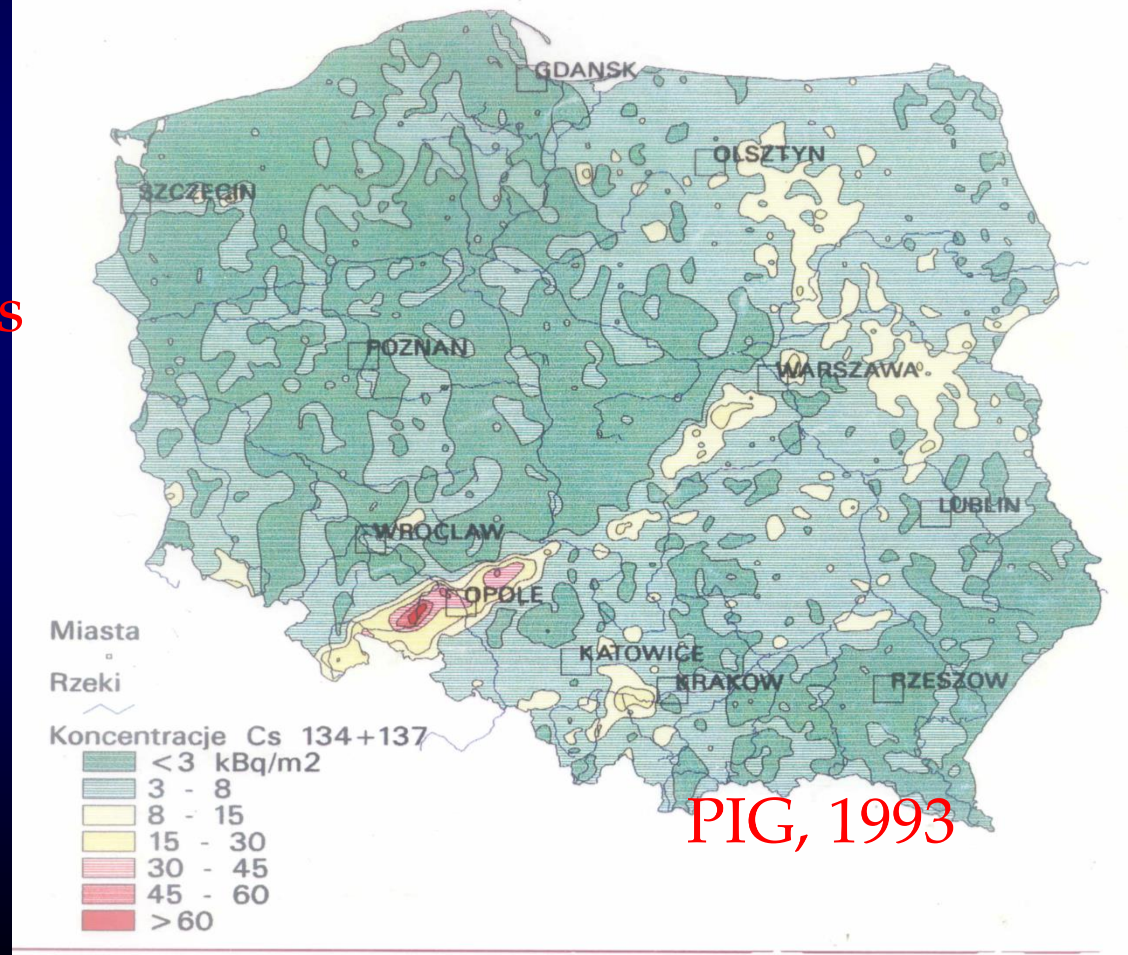
IFJ, 1994

HpGe, 343 soil samples



CLOR, 1989

In situ NaI spect



PIG, 1993

„Hot particles” (in Poland- 5-10 μm)

- „Fuel-like” UO_2 or U_3O_8 matrix

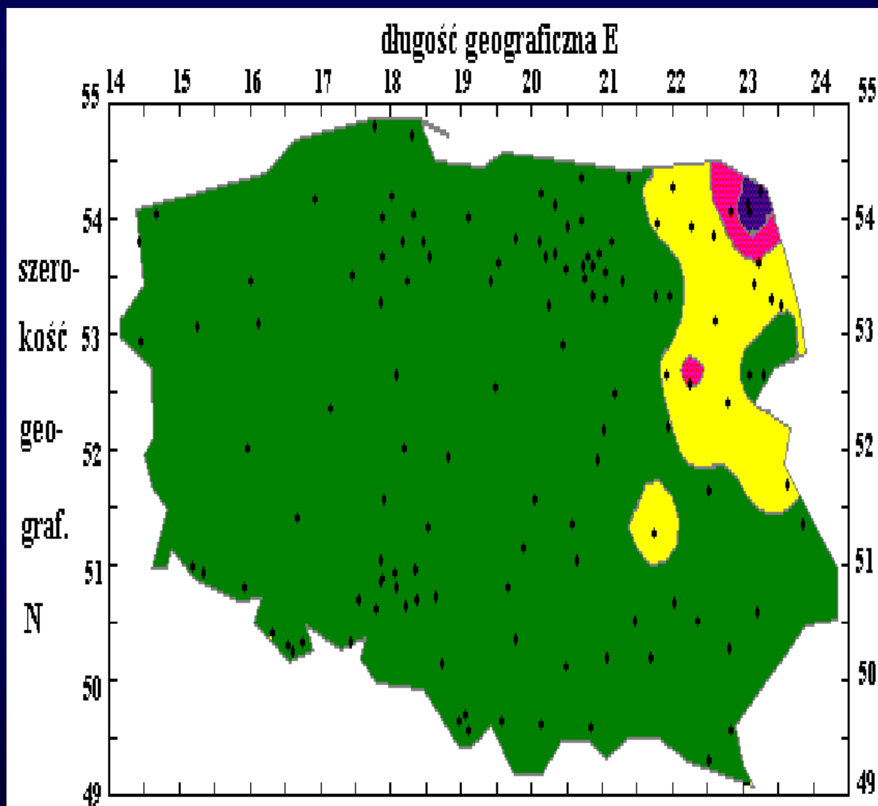
$^{238,239,240,241}Pu$, ^{241}Am, $^{243,244}Cm$, ^{90}Sr, ^{154}Eu, ($^{141,144}Ce$, ^{95}Zr, ^{95}Nb, ^{155}Eu, ^{89}Sr, ^{242}Cm...)

- „condensation” or „monoelemental”) - condensation of vapours or „white inclusions”? –

Matrix of Ru, Mo, ...Fe, Ni...: ($^{103,106}Ru$...) **^{63}Ni,** ^{60}Co **^{99}Tc**?

Approximate geographical distribiution of HP in Poland

Mietelski, IFJ, 1994

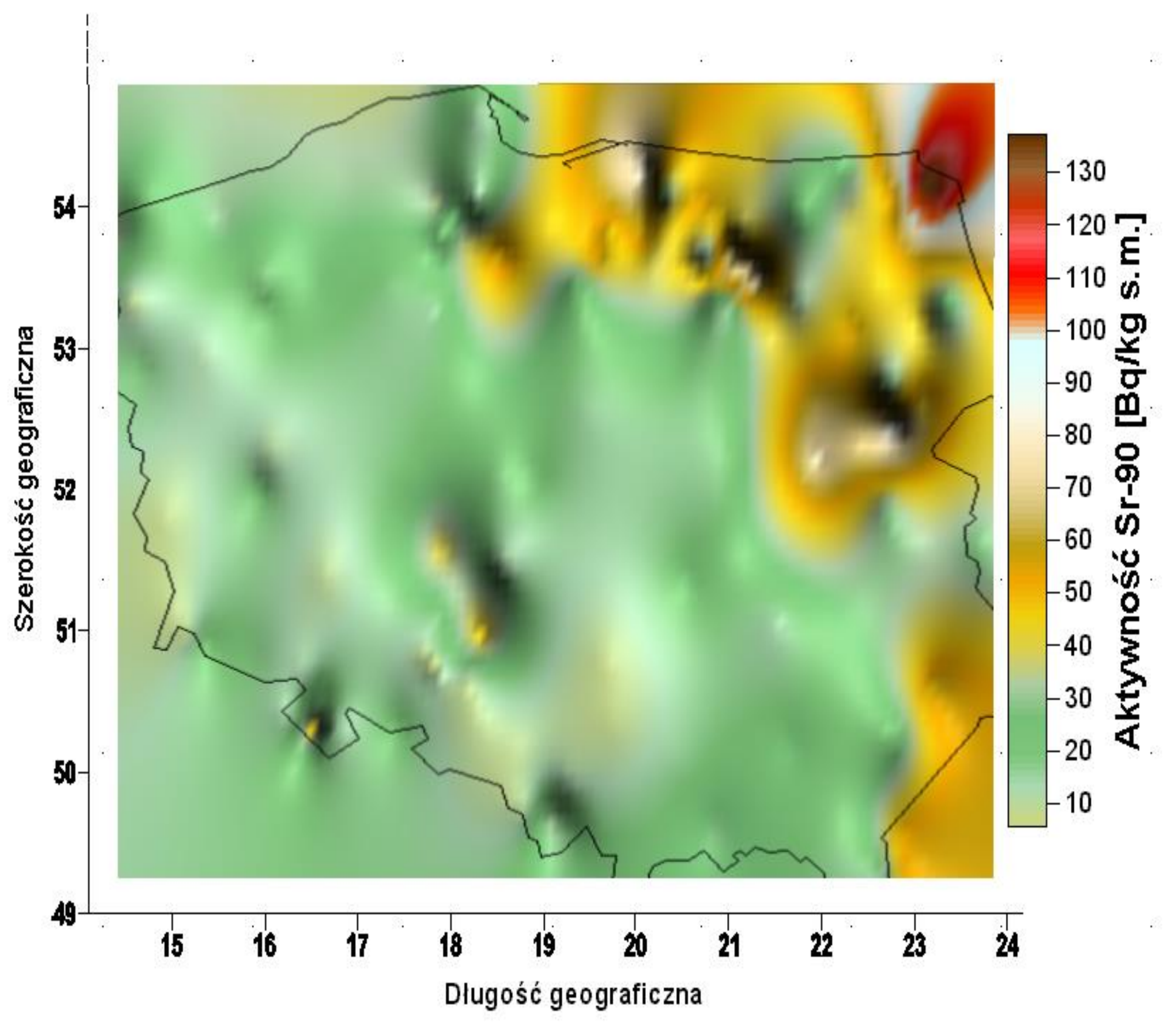


Activity for 1 st Sep. 1991

(Ce-144 x 110 for 1986)

^{90}Sr (bilberry leaf)
(P.Gaca PhD, IFJ-UG , 2004)

~ 2 kBq/m2 in NE



Conclusions

- Natural and artificial radionuclides are present all over globe
- Large variety can be observed
- Local background should be recognized