OSNOVE VARSTVA PRED IONIZIRAJOČIM SEVANJEM

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Institut Jožef Stefan

VSEBINA

1. **Zgodovinski utrinki**

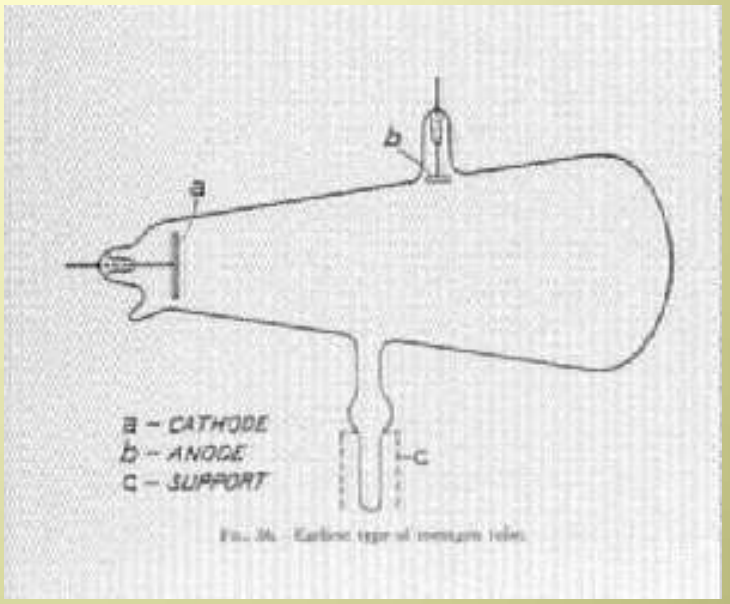
2. **Načela varstva pred IS**

3. **Izpostavitve sevanju**

   - **naravno sevanje**
   - **medicinska diagnostika (RTG, nuklearna medicina)**
   - **poklicne izpostavitve**
   - **letalski poleti**
   - **jedrski objekti**

   - ***poskusne jedrske eksplozije***
   - ***Černobil***

Wilhelm Conrad Röntgen
Žarki X (1895)



Pionirske RTG preiskave in terapije (okoli 1900)

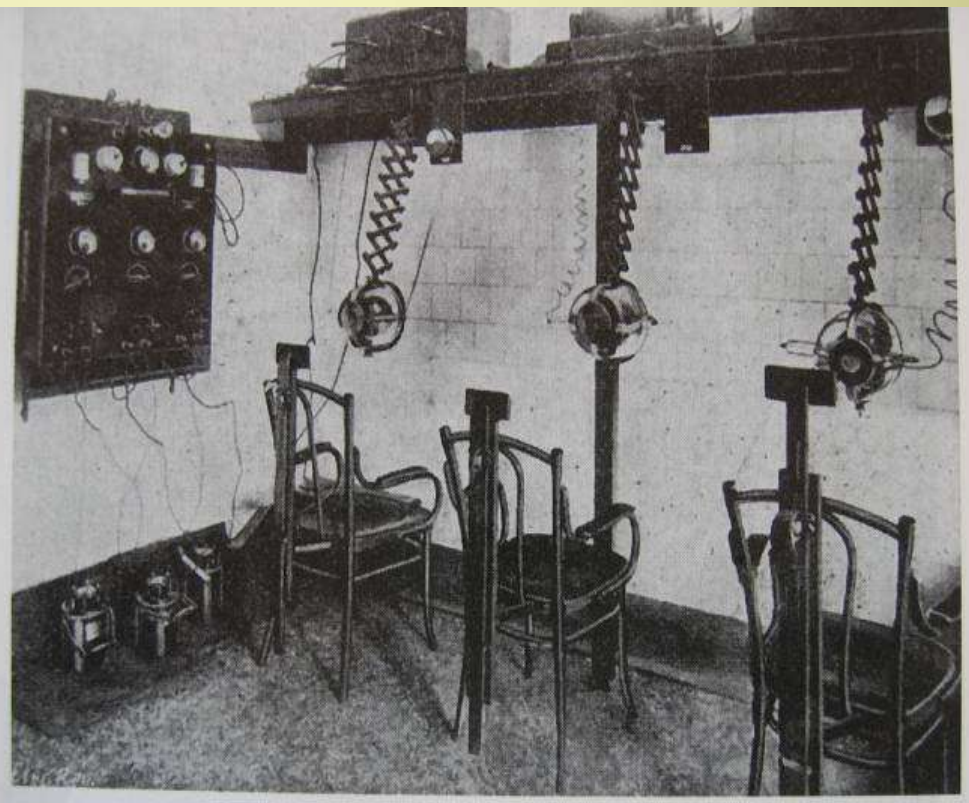
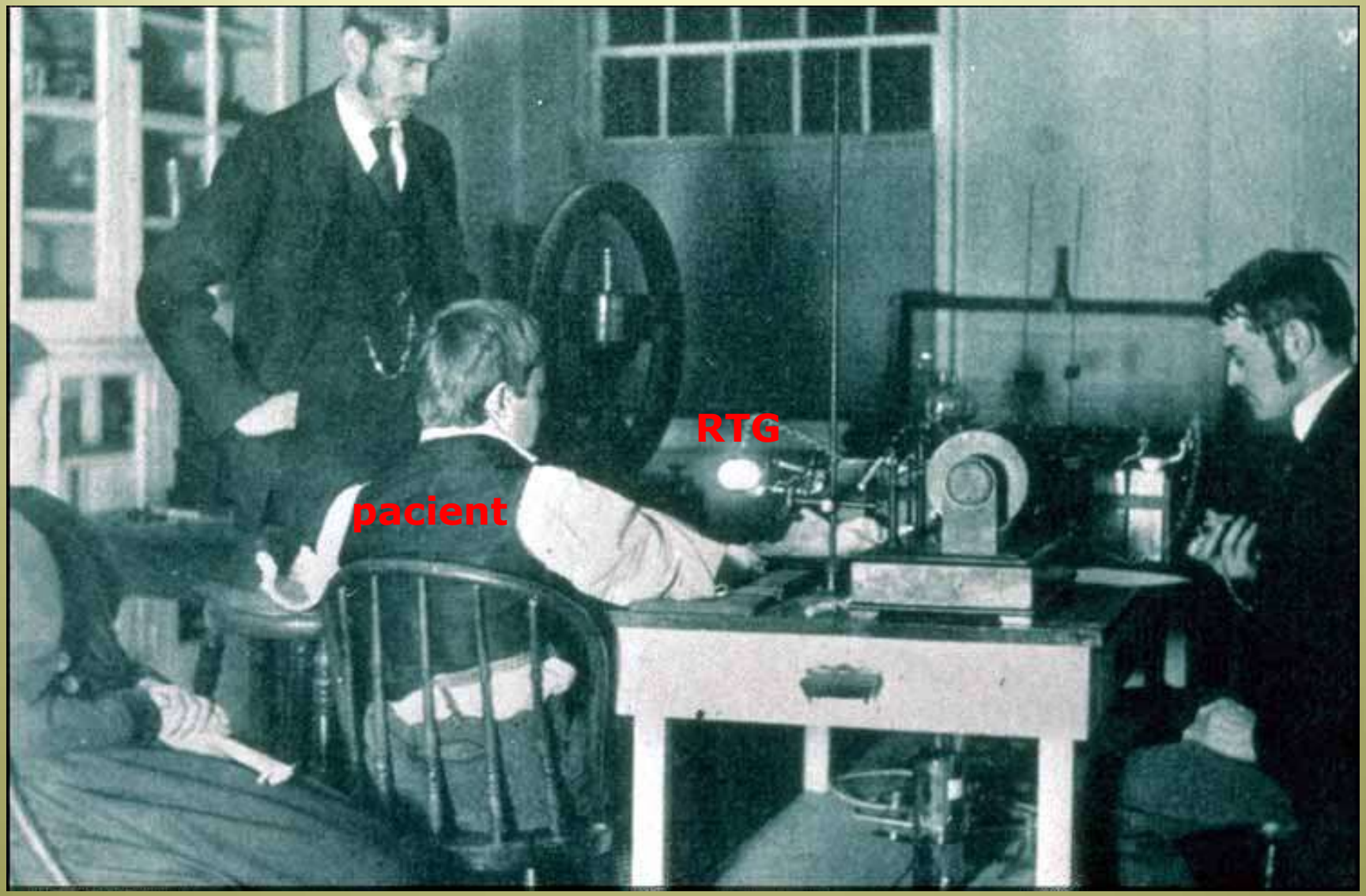


Fig. 6. The Roentgen Therapy room at the London Hospital in about 1905. Note that the x-ray tubes are unshielded and several patients could be treated simultaneously. Reproduced from Sequeira and Morton (1905; with permission).

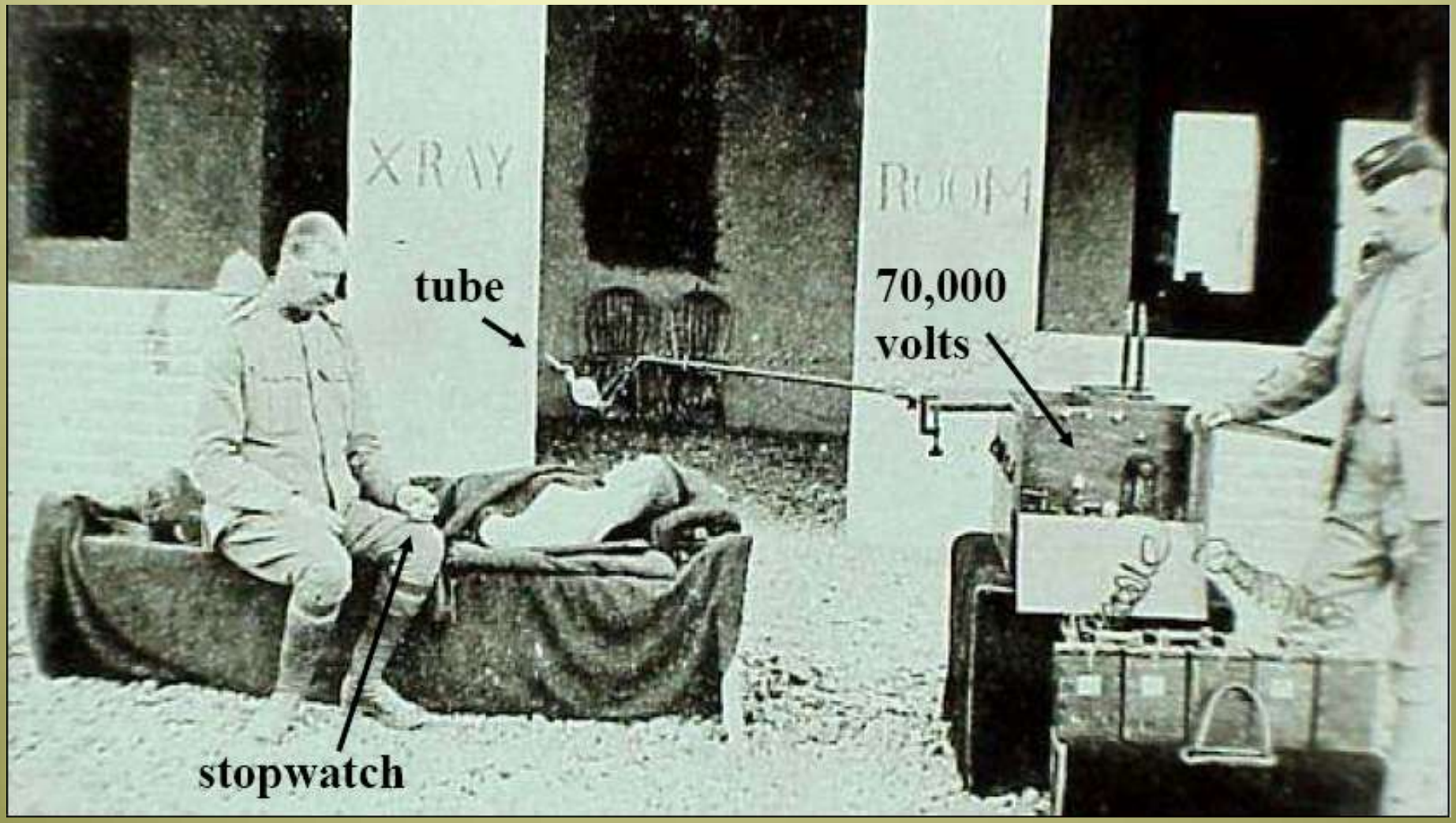
"Anti ALARA" uporaba RTG



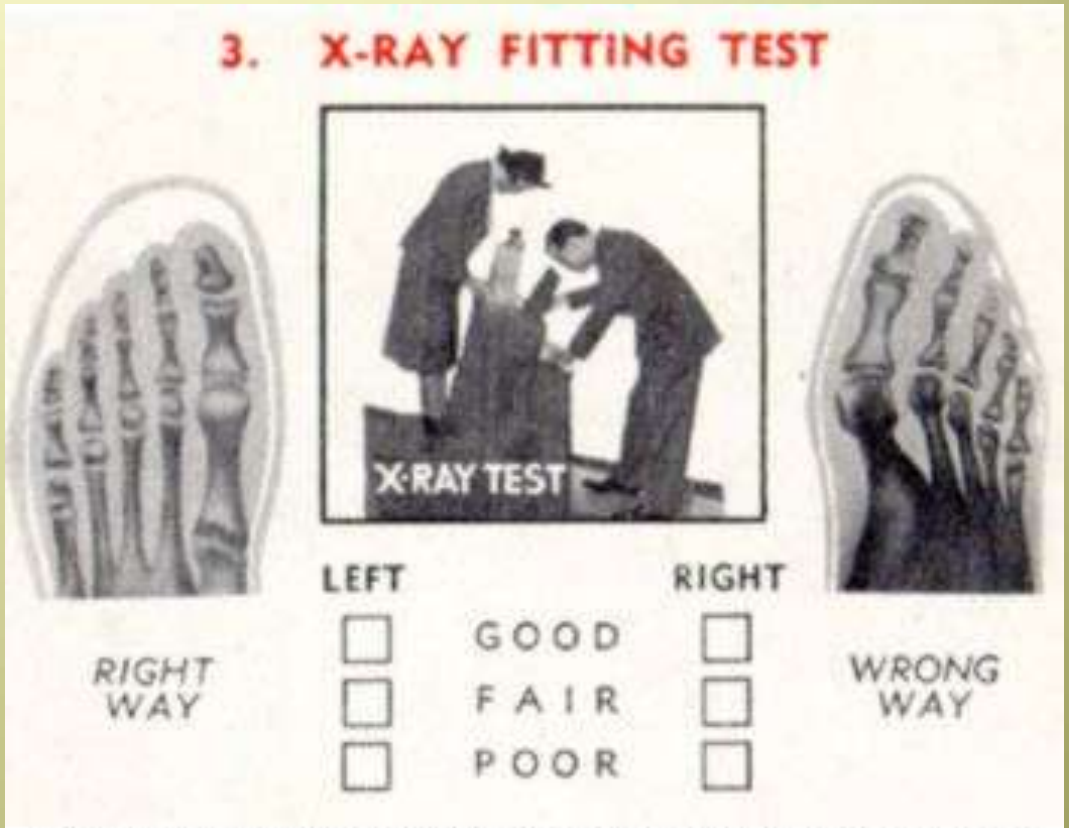
RTG v 1. svetovni vojni

WHAT'S THIS?

Terenske RTG preiskave med 1. svetovno vojno



RTG pregled ustreznosti obuval



Detail from shoecard possibly distributed by salesmen to their clients, showing both X-ray images of feet in shoes and a fluourscope in use. (Image courtesy of Oak Ridge Associated Universities)

Mihran Kassabian (1870-1910)

- izpostavitve RTG žarkom v letu 1900
- umrl za rakom 1910

Mihran K. Kassabian

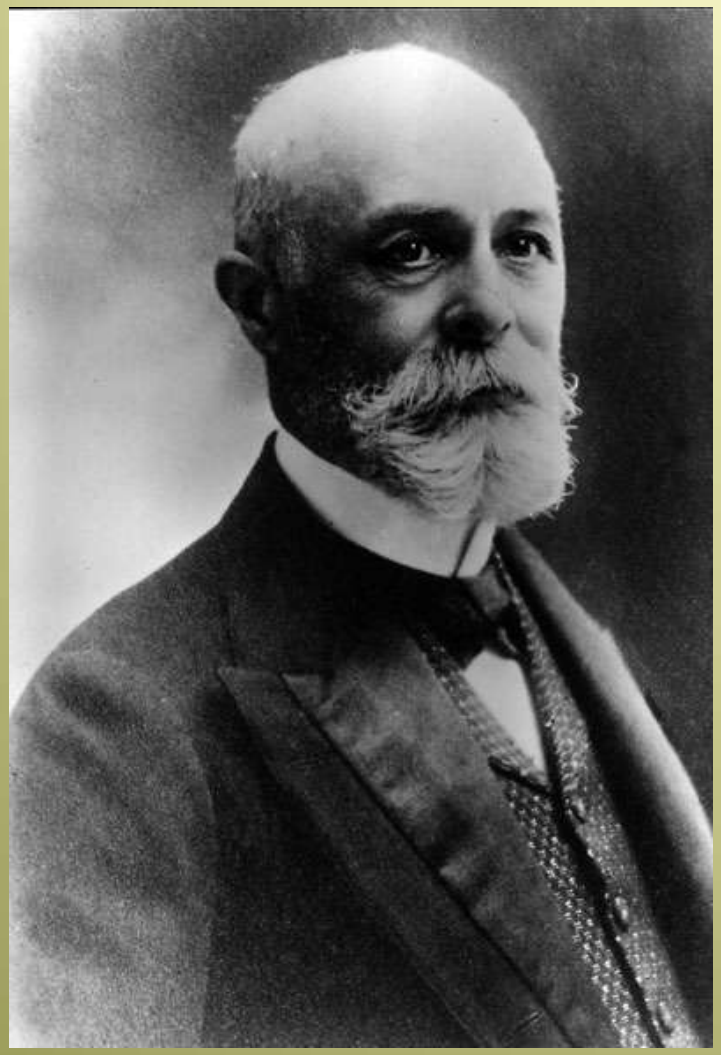
a. 1903

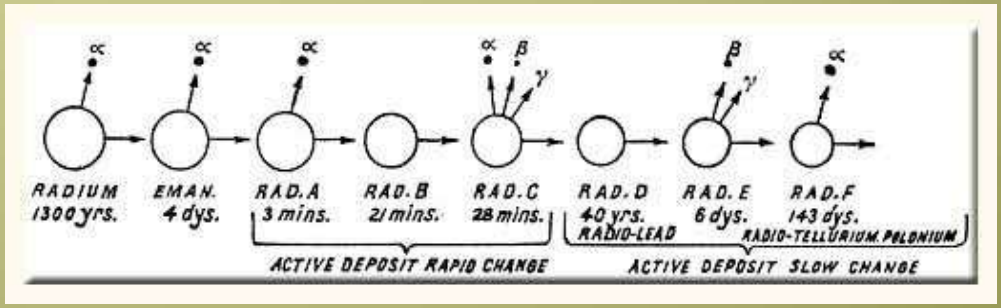
b. 1908 January

c. 1908 month unknown

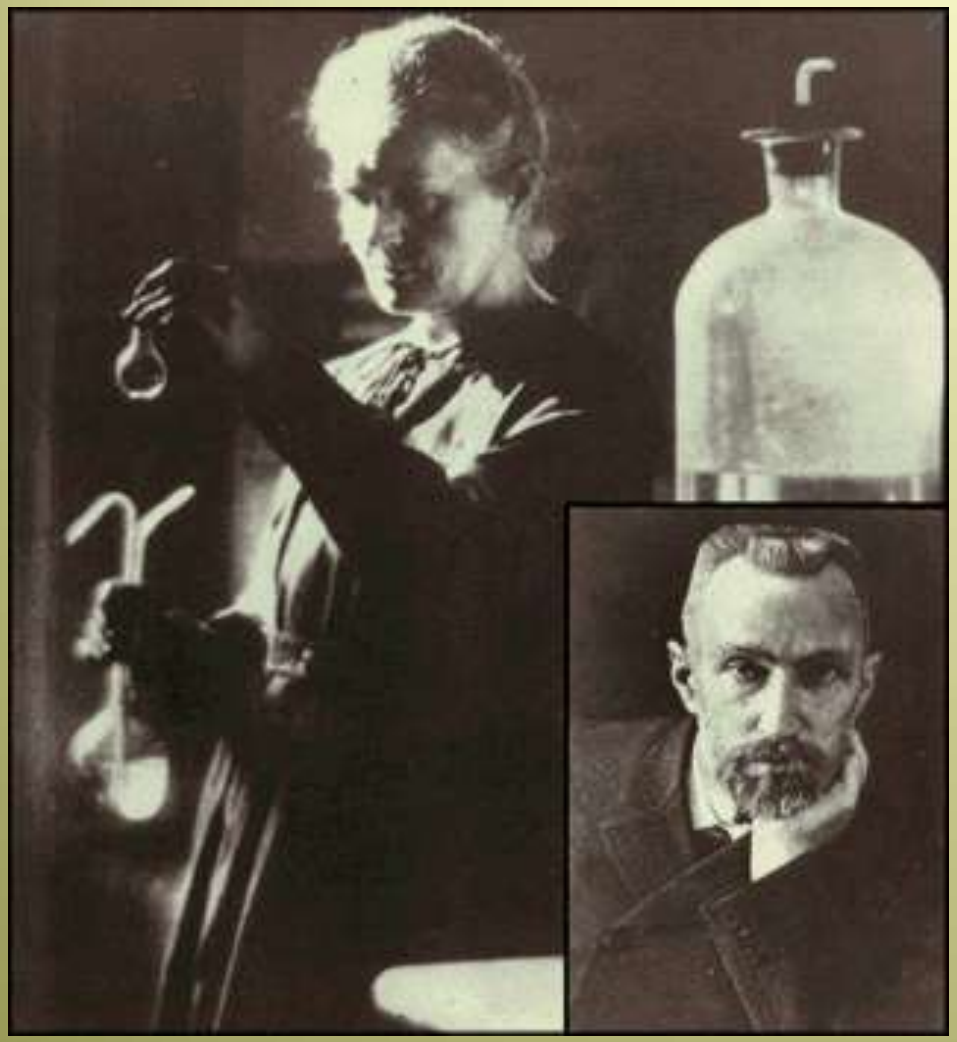
d. 1909

Henri Becquerel
Naravna radioaktivnost (1896)





Marie Curie Skłodowska
(1898: Po-210, Ra-226)



For that Healthy Glow, Drink Radiation!

Ra-226

A = 30 MBq, HD = 70 μSv/h

Danes: meja izvzetja = 10 kBq


PURE-RADIUM-WATER
REMEDY FOR
RHEUMATISM-ECZEMA-STOMACH TROUBLES
FROM
HOTEL SEQUOYAH-BATHS
O. L. JAMES, PROP.
CLAREMORE, OKLA.

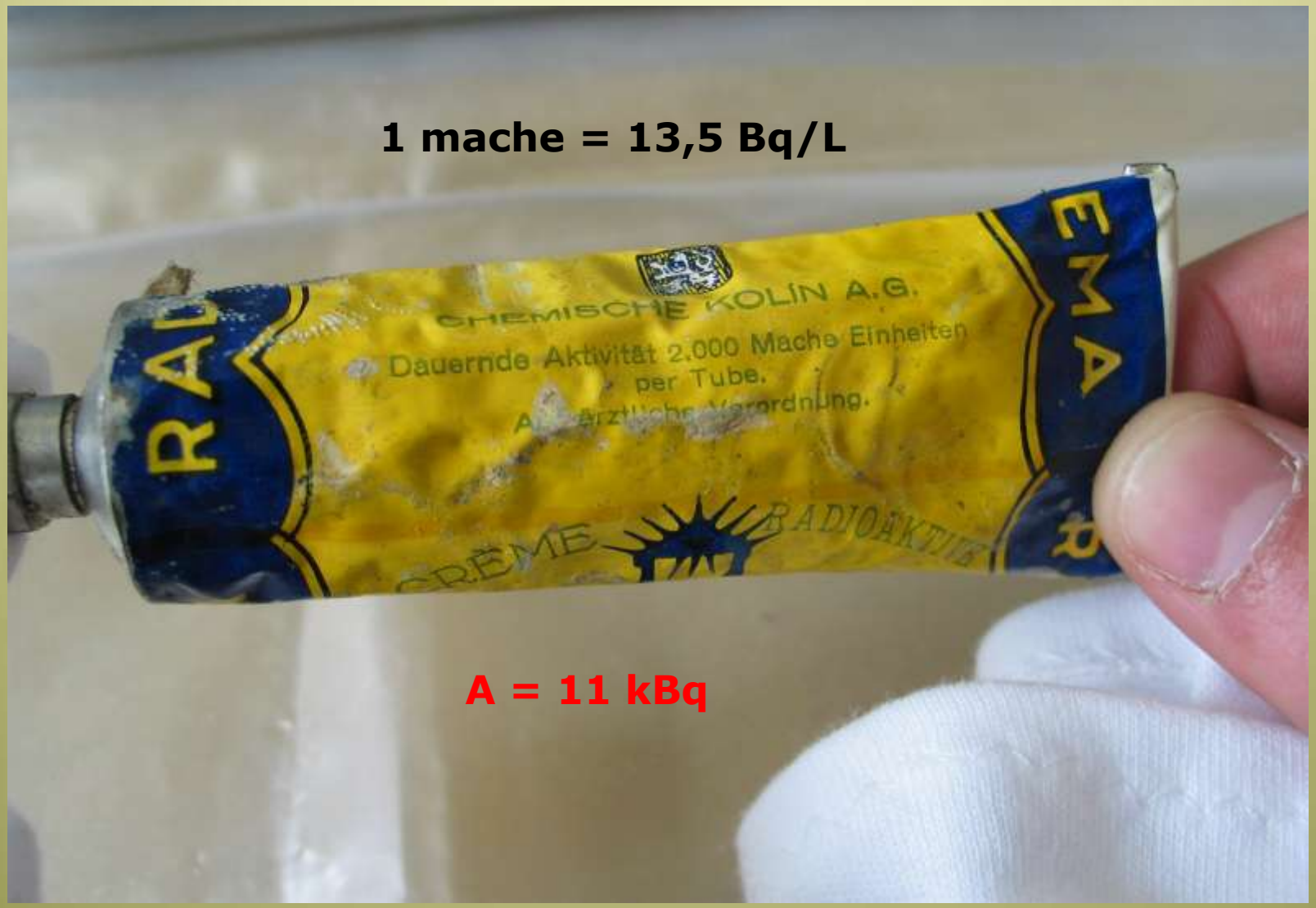

RADIUM
LIQUID WAX
POLISH
Radium Specialty Co.


Radium Hand Cleaner
CLEANSING
RADIUM
COMPOUND


LUPUS
SCROFULA
RADIUM SALVE
THE CARDINAL MFG. Co., Ltd.
Finsbury, London,
England


RADITHOR
CERTIFIED
RADITHOR
CERTIFIED

Ra krema (meritev IJS 2010)



Ra tablete – zdravljenje revmatizma

"Take two tablets with glass of water before or after each meal"

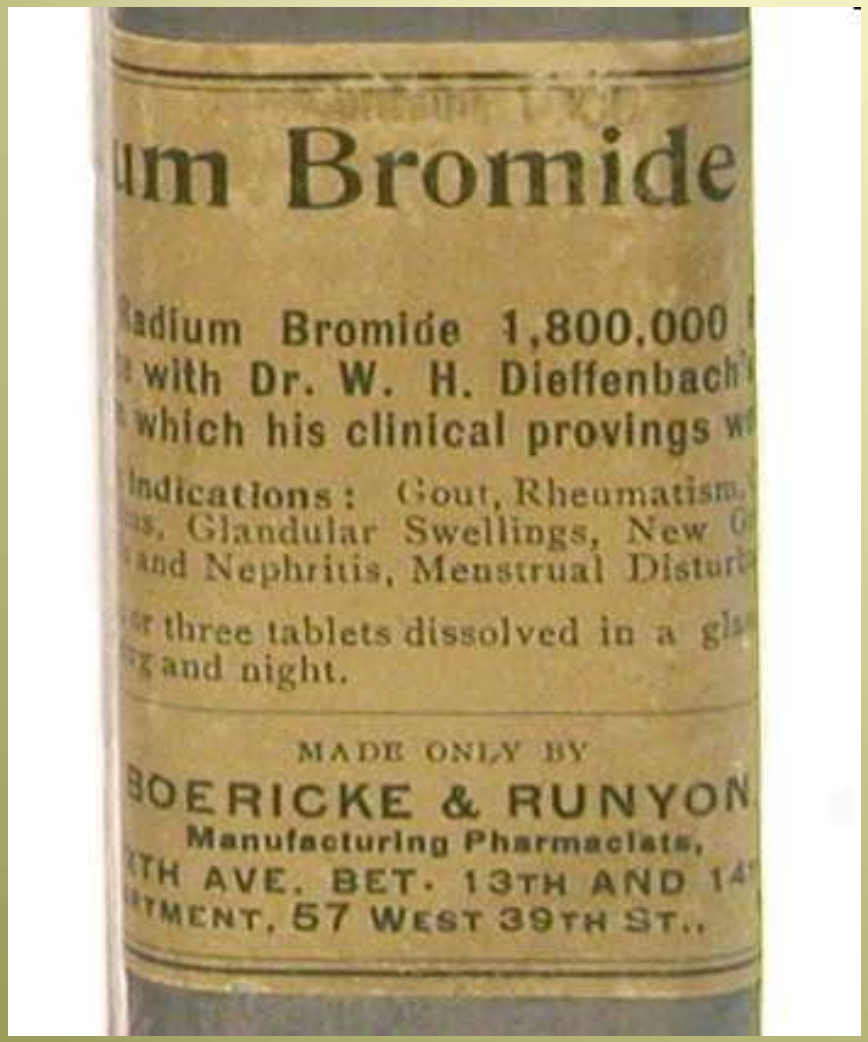
$5,000 reward if they fail!

Ra kruh / U NICO CLEAN

Ra water from Joachimstal

Enhance your cigarette smoking
lowering tar and nicotine

"Vsemogočni učinki!"



Bizarne uporabe

Dr. Alfred Curie – krema za obraz

RADIUM MAKES THINGS GROW

Take a high class fertilizer and add to it Radium Element in just the right proportion and you have the ideal plant food —Radium Brand Fertilizer (R. A. F.). Apply it according to directions and your flowers will bloom more beautifully, your vegetables give greater yield, your lawn will thrive, your shrubbery will increase its foliage and bloom. Put up in handy packages for small users. One lb. will fertilize 50 square feet surface, or a plot 10 feet by 5 feet.

RADIUM BRAND Fertilizer (R A F)

has been thoroughly tested on 130 acre farm, in conservatories, gardens, etc. In fact, scientists in Europe and America have been testing effect of radium upon plant life for ten years. In addition to its wonderful beneficial effects, it has been discovered that where Radium Brand Fertilizer (R. A. F.) was used, plants suffered less from soil parasites, especially cut worms. Dr. H. H. Rusby, Columbia University, in speaking of his experiments with Radium Brand Fertilizer (R. A. F.) says: "Perhaps the most important effect of the radium was that of improving the edible properties of the products."

This Free Book tells how Radium makes things grow.

Sample Can, Prepaid, 25c

Radium Brand Fertilizer (R. A. F.) is sold by florists, grocers, druggists and seed and hardware dealers. If your dealer cannot supply you, send us his name and 25 cents for can (12 oz. net R. A. F.) prepaid. Also, sold as follows, prepaid, where dealers can not supply you:

2 lb. can . . . 50c 10 lb. can . . . $1.75
5 lb. can . . . $1.00 25 lb. can . . . $3.75

In writing always be sure to give us your dealer's name, so we can arrange for your future supply.

RADIUM FERTILIZER COMPANY
207 Vanadium Building Pittsburgh, Pa.

Vžigalne svečke za avto

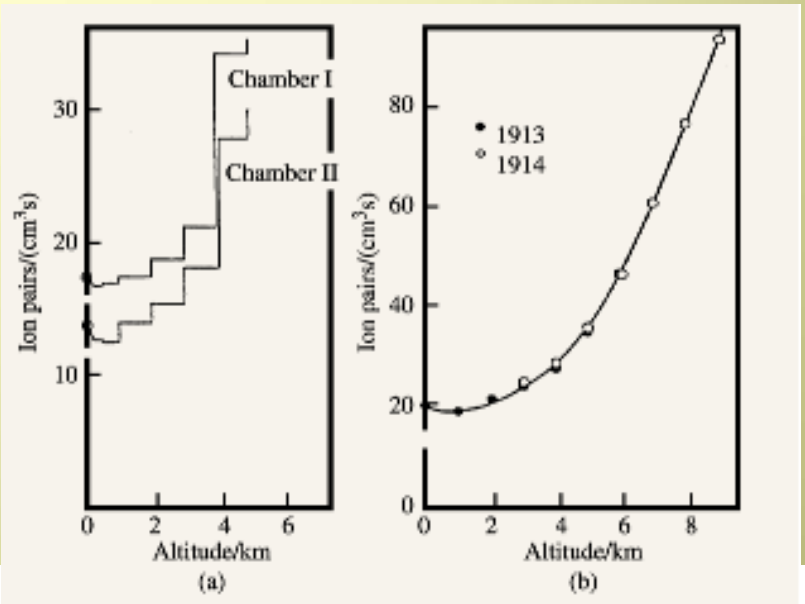
Patent 1929, komercialno 1940 (Po-210)

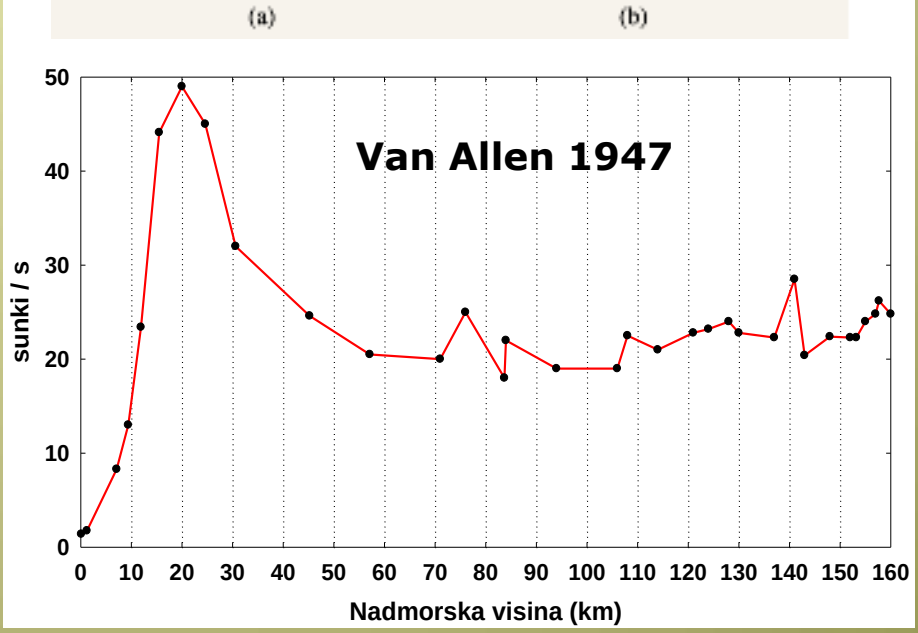
Rn emanatorij

"Radijeva" dekleta (1917+)

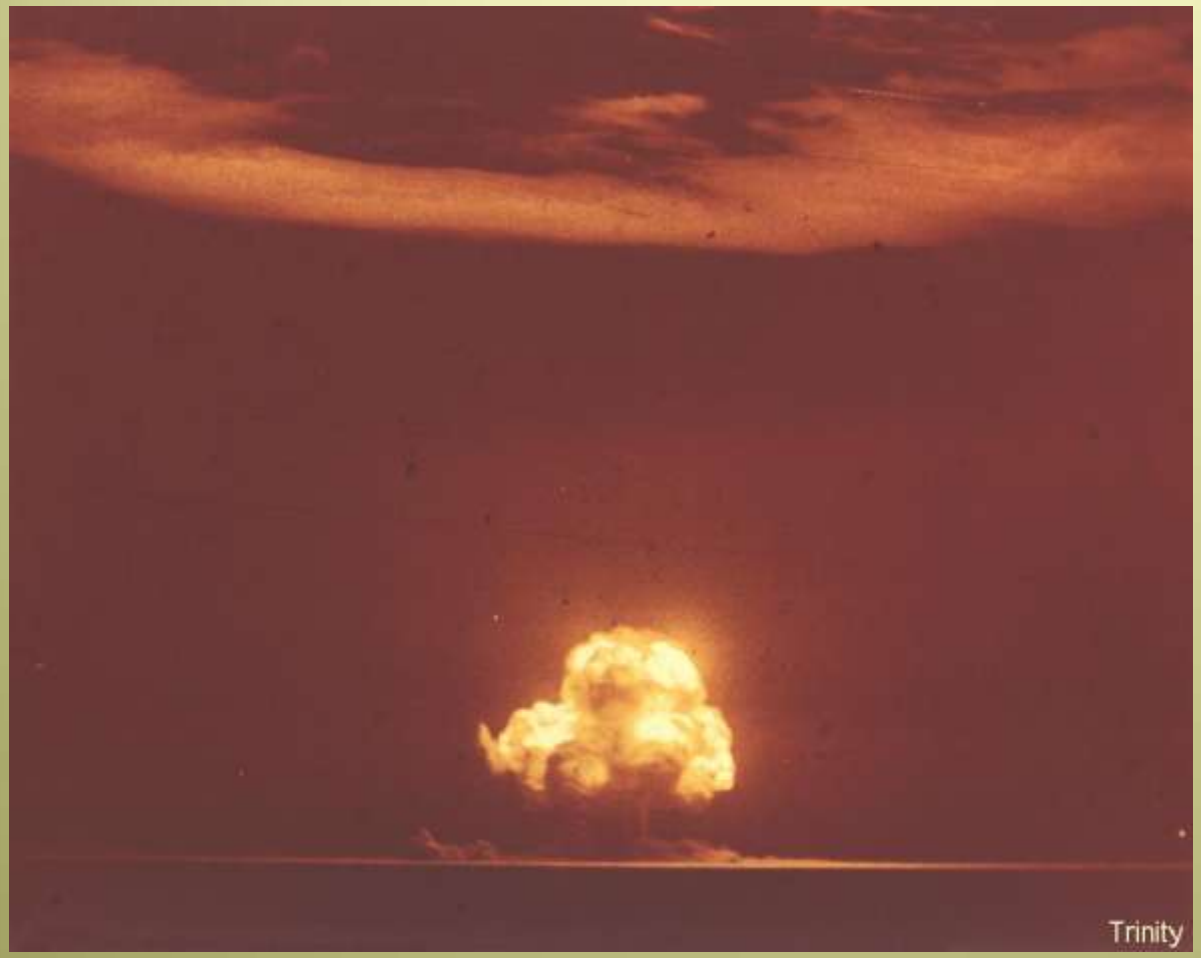
Victor Hess
Kozmično sevanje (1912)

Victor Hess before his 1912 balloon flight in Austria, during which he discovered cosmic rays



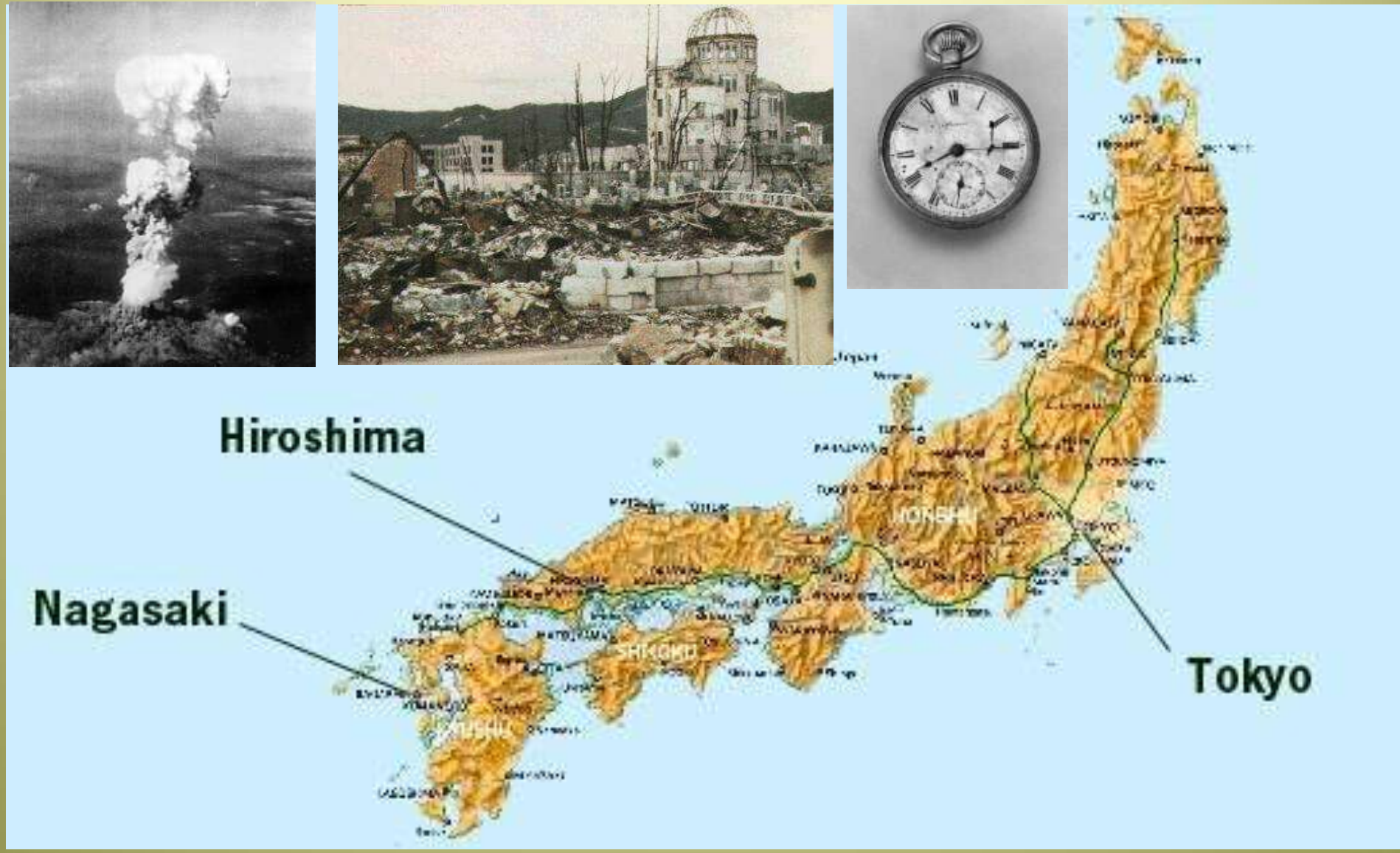


Projekt "Manhattan" – Trinity 16. julij 1945



"I am become Death, the Destroyer of Worlds"

dr. J. Robert Oppenheimer, Director of Los Alamos


Hiroshima
Nagasaki
Tokyo
HONSHU
SHIKOKU
KYUSHU

Hirošima, 6. avgust 1945

Epidemiologija 86.000 preživelih

7000 smrti zaradi raka (do 1995)

6600 pričakovanih


ЧОРНОБИЛЬ
26. April 1986

Mednarodna vodila

- **Recommendations ICRP 60 (1990)**
  (International Commission on Radiological Protection)

- **Basic Safety Standards BSS 115 (1996)**
  (FAO, IAEA, ILO, OECD/NEA, PAHO, WHO)

- **Council Directive 96/29/EURATOM**
  (European Union 13 May 1996)

Recommendations ICRP 2007!

Biološke posledice sevanja

Deterministični učinki

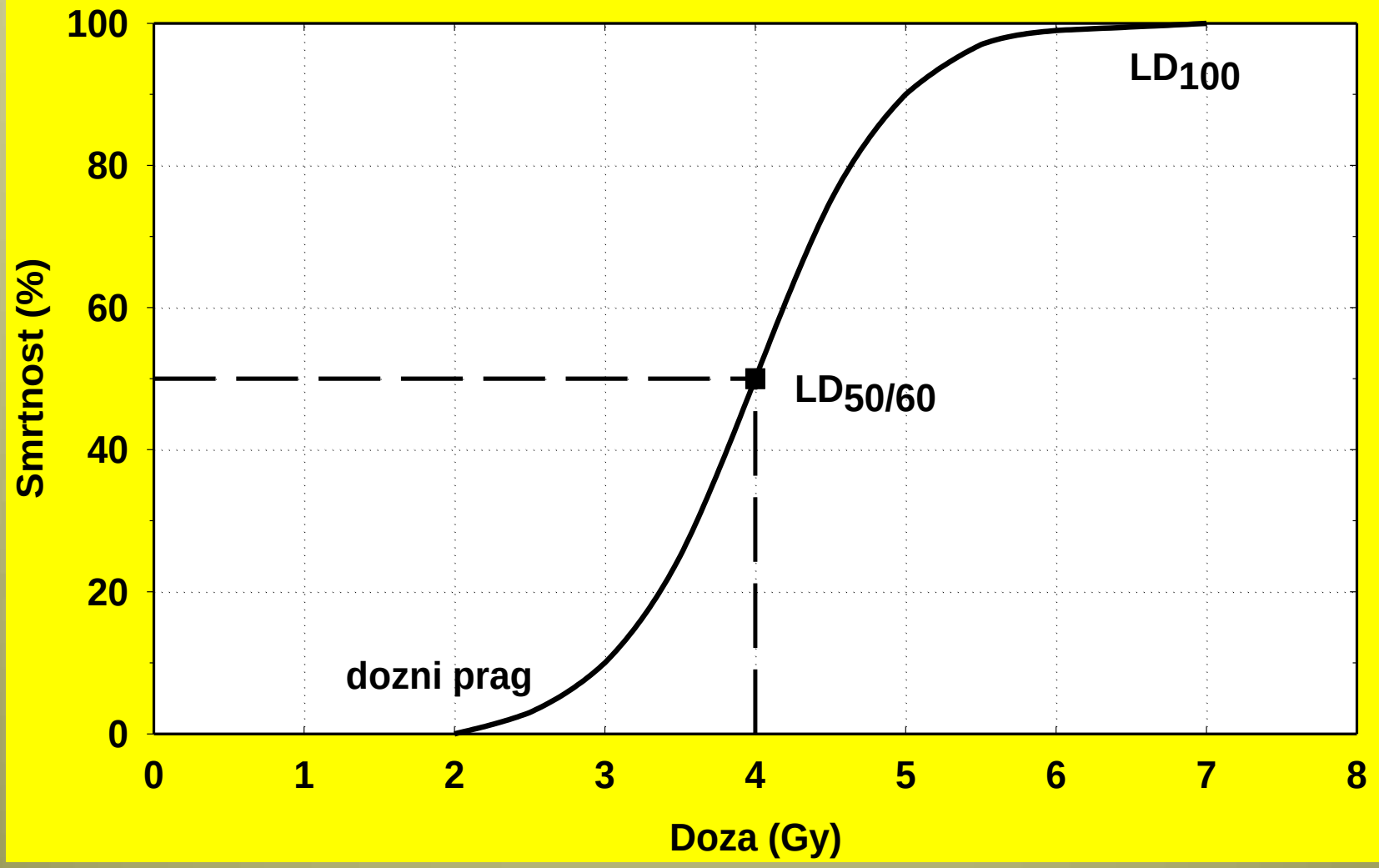
- **akutni: lahko smrtno nevarni**

Stohastični učinki

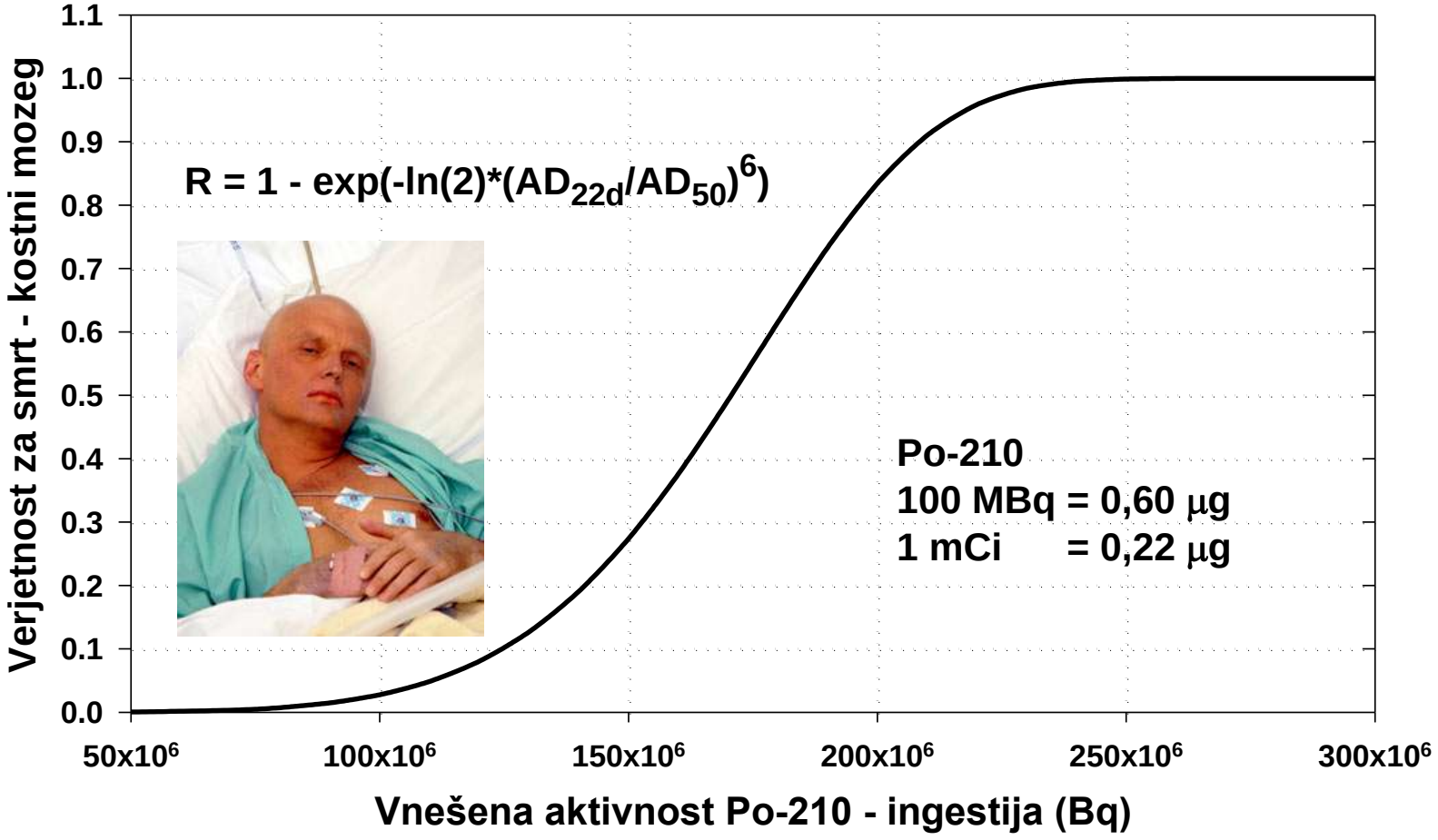
- **zakasneli: rak, levkemija (latentna doba)**
- **dedne posledice pri potomcih**

DETERMINISTICNE POSLEDICE SEVANJA

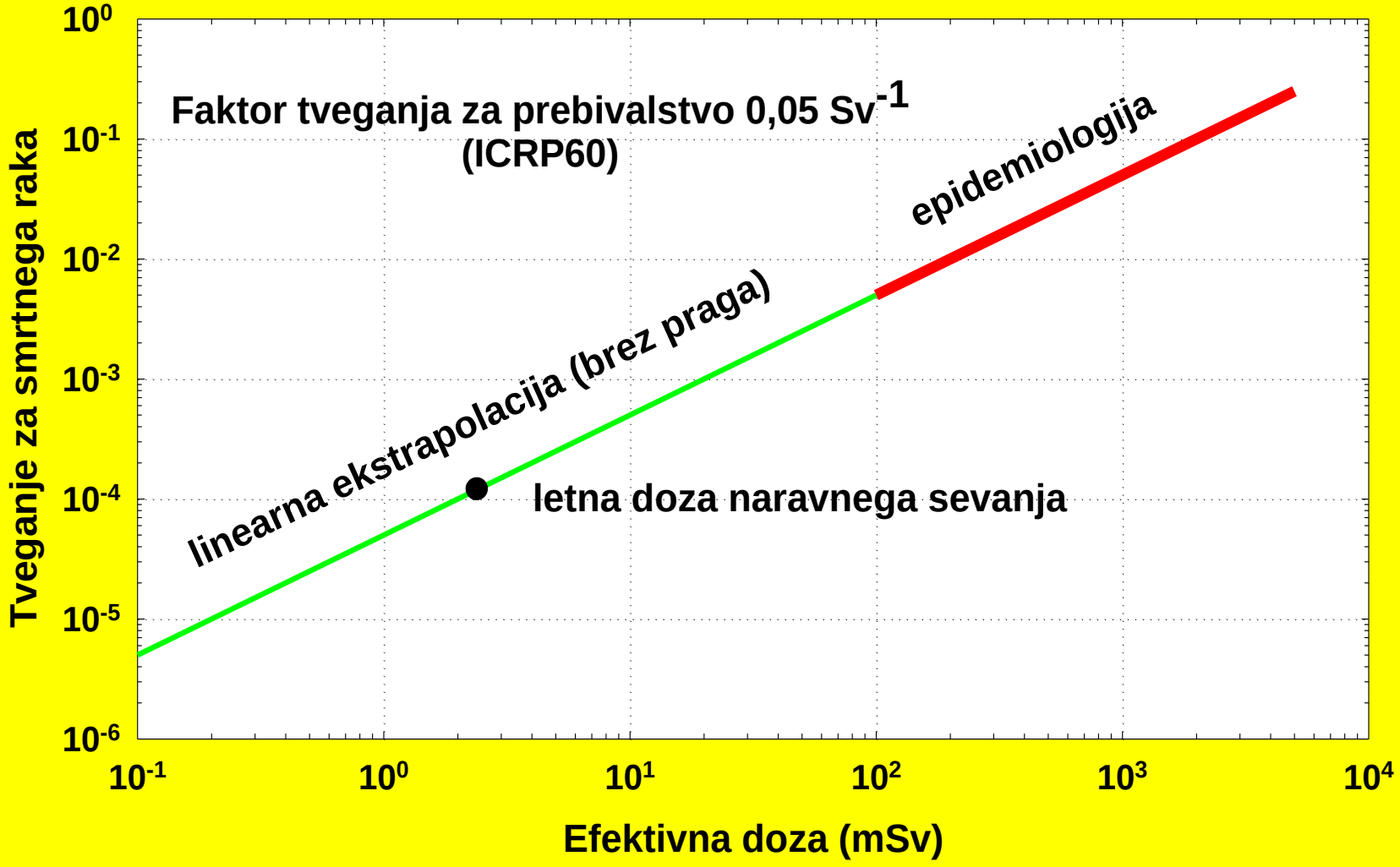
Akutni radiacijski sindrom ARS



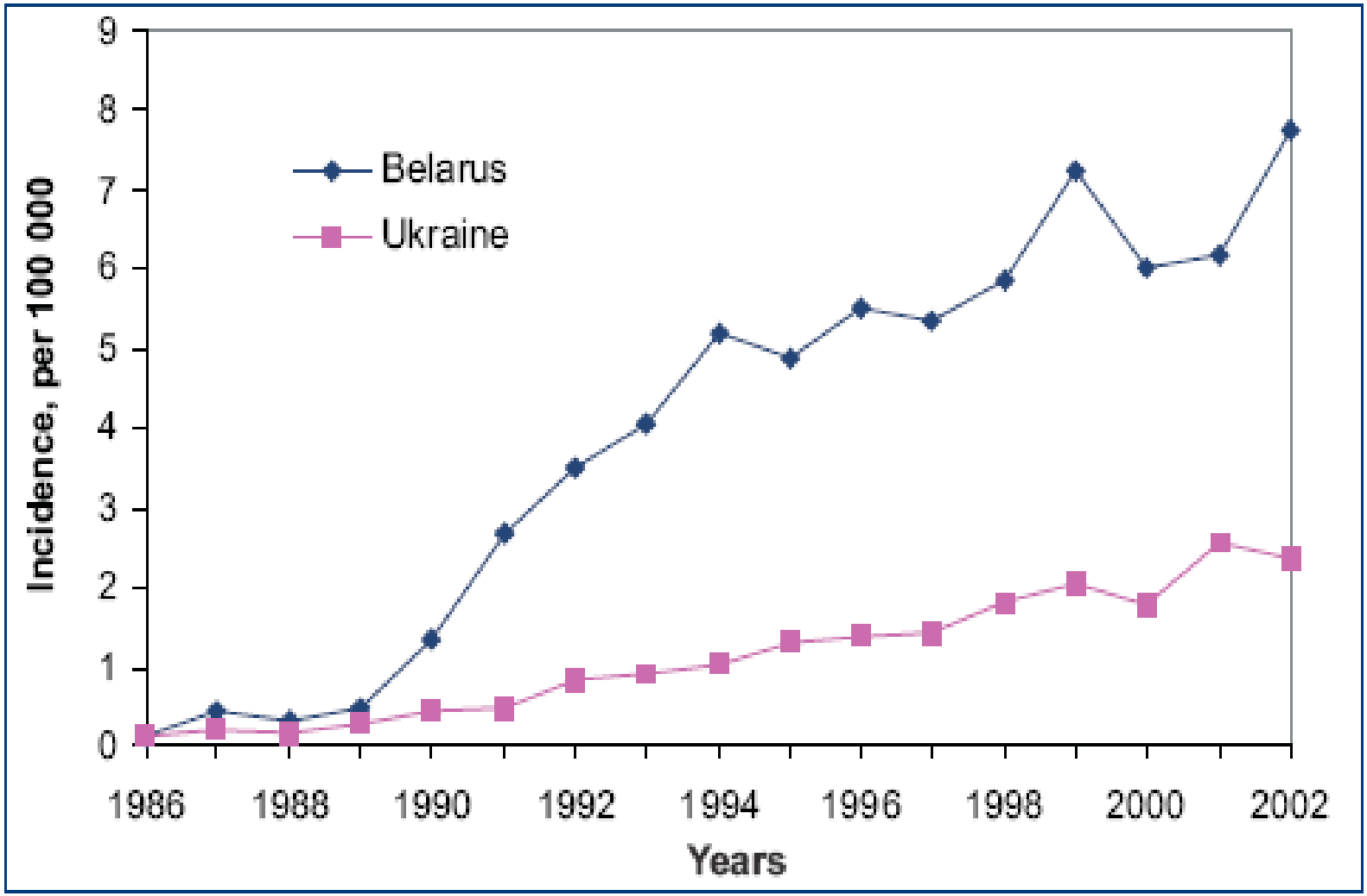
Funkcija tveganja zaradi ingestije Po-210



Stohasticne posledice sevanja



Pogostost raka ščitnice pri otrokih (Černobil)



Značilnosti stohastičnih učinkov

- **rak, levkemija; dedne posledice**
- **latentna doba (nekaj let, desetletje)**
- **verjetnost narašča z dozo (LNT)**

Absorbirana doza

Biološke posledice so sorazmerne absorbirani energiji

Absorbirana doza D

$$D = E/m = J/kg$$

1 gray = 1 J/kg = 1 Gy

Ekvivalentna doza

Odvisnost od vrste sevanja

Ekvivalentna doza H_T

$$H_T = w_R D_R$$

utežni faktor sevanja w_R

1 sievert = 1 J/kg = 1 Sv

Utežni faktorji sevanja w_R

Sevanje	w_R
X, γ, β	1
α	20
p	5 (2)
n	5 - 20

Efektivna doza

Odvisnost od občutljivosti tkiva (stohastični učinki)

Efektivna doza E

$$E = w_T H_T$$

utežni faktor tkiva w_T

1 sievert = 1 J/kg = 1 Sv

Utežni faktorji tkiva w_T
(stohastični učinki)

Tkivo / organ	w_T
gonade	0,20
rdeči kostni mozeg, debelo črevo, pljuča, želodec	0,12
mehur, prsa, jetra, požiralnik, ščitnica	0,05
koža, kostne površine	0,01
ostalo	0,05

$$\Sigma w_T = 1$$

Kategorije izpostavljenih

- **poklicni delavci z viri IS**
- **medicina (pacient)**
- **prebivalstvo**

1. Poklicno delo z viri IS

Umetni viri

- **naprave (RTG, reaktor, LINAC itd.)**
- **radioizotopi (medicina, industrija, raziskave)**

Naravni viri (povečana raven)

- **radon (rudniki urana, Postojnska jama)**
- **tehnološko koncentrirani naravni izotopi**
- **kozmično sevanje (letalski poleti)**

2. Medicina - pacient

Diagnostika

- RTG
- nuklearna medicina (izotopi)

  E ~ mSv

Terapija

- teleterapija
- brahiterapija
- ciljana radionuklidna terapija (I-131)

  H_T > 100 Gy

3. Prebivalci

Naravno sevanje

- naravni radionuklidi: K-40, Th-232+, U-238+, H-3
- kozmično sevanje

Umetni viri

- nadzorovani
  (medicina, industrija, raziskave, transport)
- nenadzorovani
  (atomske eksplozije, Černobil)

Sistem radiološke zaščite - 1

NAMEN

- **preprečiti deterministične posledice**

- **zmanjšati verjetnosti za stohastične posledice na "sprejemljivo" vrednost**
  (tveganje = 0,05 Sv^{-1})

Sistem radiološke zaščite - 2

NAČELA

- **Upravičitev dejavnosti** (justification)

- **Optimizacija – ALARA**
  As Low As Reasonably Achievable

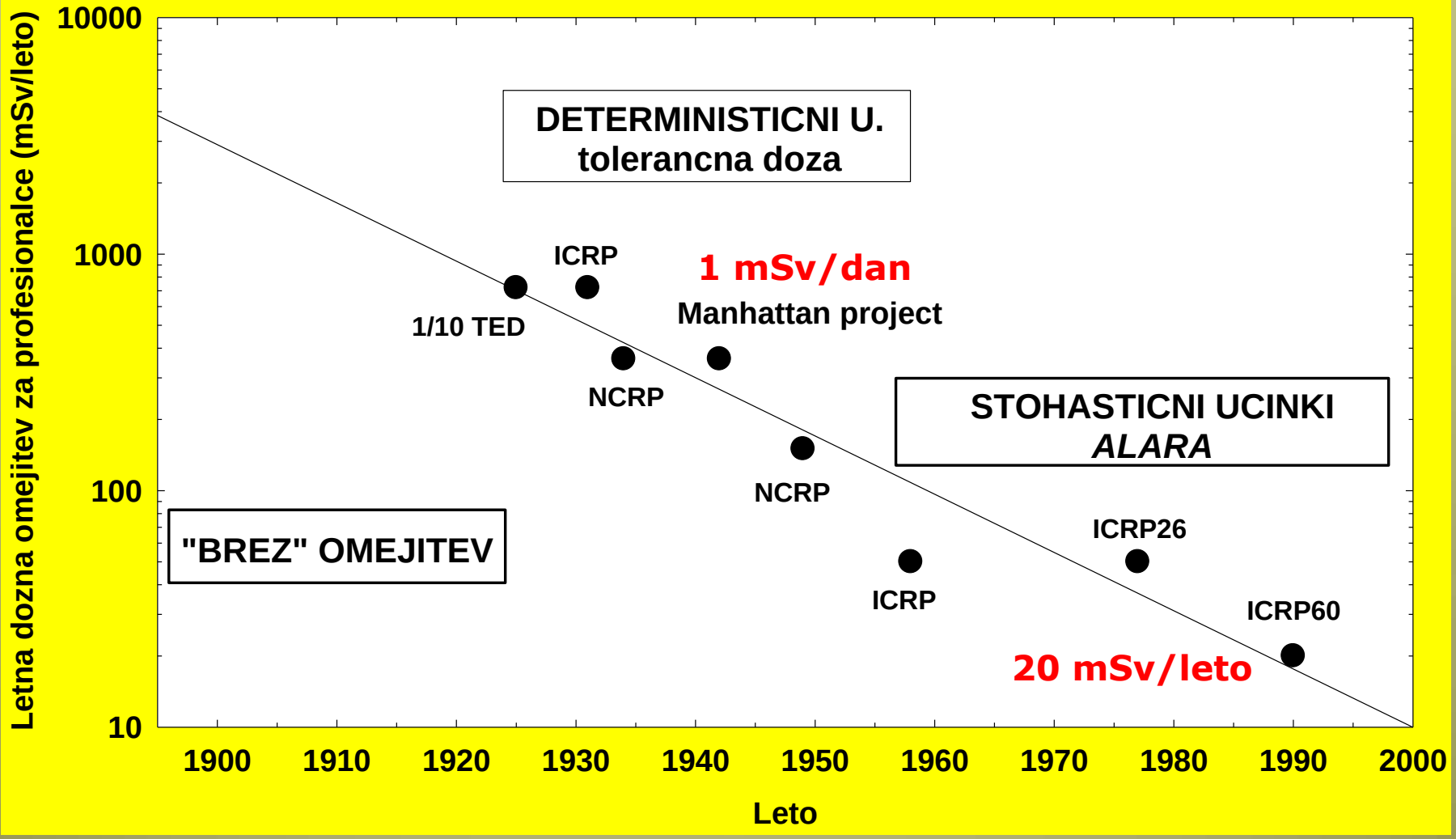
- **Dozne omejitve** (dose limits)

Dozne omejitve

Dozna količina	Profesionalci	Prebivalci
efektivna doza (stohastični učinki)	20 mSv/leto	1 mSv/leto
ekvivalentna doza (deterministični učinki) • očesne leče • koža • roke, noge	 • 150 mSv/leto • 500 mSv/leto • 500 mSv/leto	 • 15 mSv/leto • 50 mSv/leto

Naravno sevanje in medicinske izpostavitve niso vključeni!

Iz zgodovine: Dozne omejitve za poklicno delo



Značilne izpostavitve sevanju

- naravno sevanje
- poklicne izpostavitve
- medicina (pacient)
- jedrski objekti
- letalski poleti
- poskusne jedrske eksplozije
- Černobil

Načini izpostavitve

<u>Zunanje obsevanje</u> (prodorni viri v okolici)

- **radioaktivni izotopi (sevanje gama!)**
- **kozmično sevanje**
- **naprave (RTG, reaktor, linak)**

<u>Notranje obsevanje</u> (vnos v organizem)

- **inhalacija**
- **ingestija (hrana, pijača)**
- **koža, rane**

NARAVNO SEVANJE

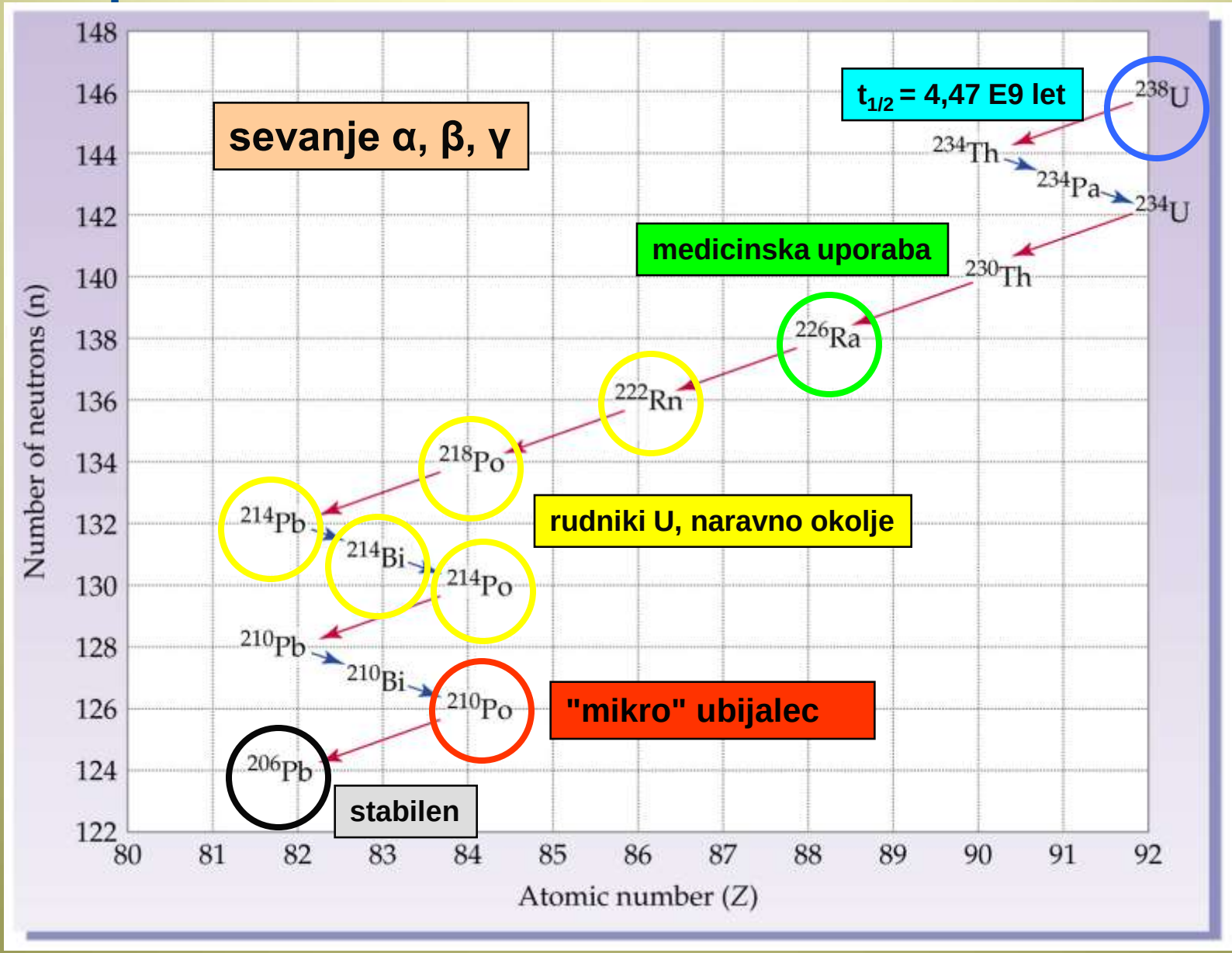
Naravni radioaktivni izotopi

- zemeljski (K-40, Th-232+, U-238+)
- kozmogeni (H-3, C-14)

Kozmično sevanje

- primarno – nad atmosfero (protoni)
- sekundarno – v atmosferi (nevtroni, mioni)

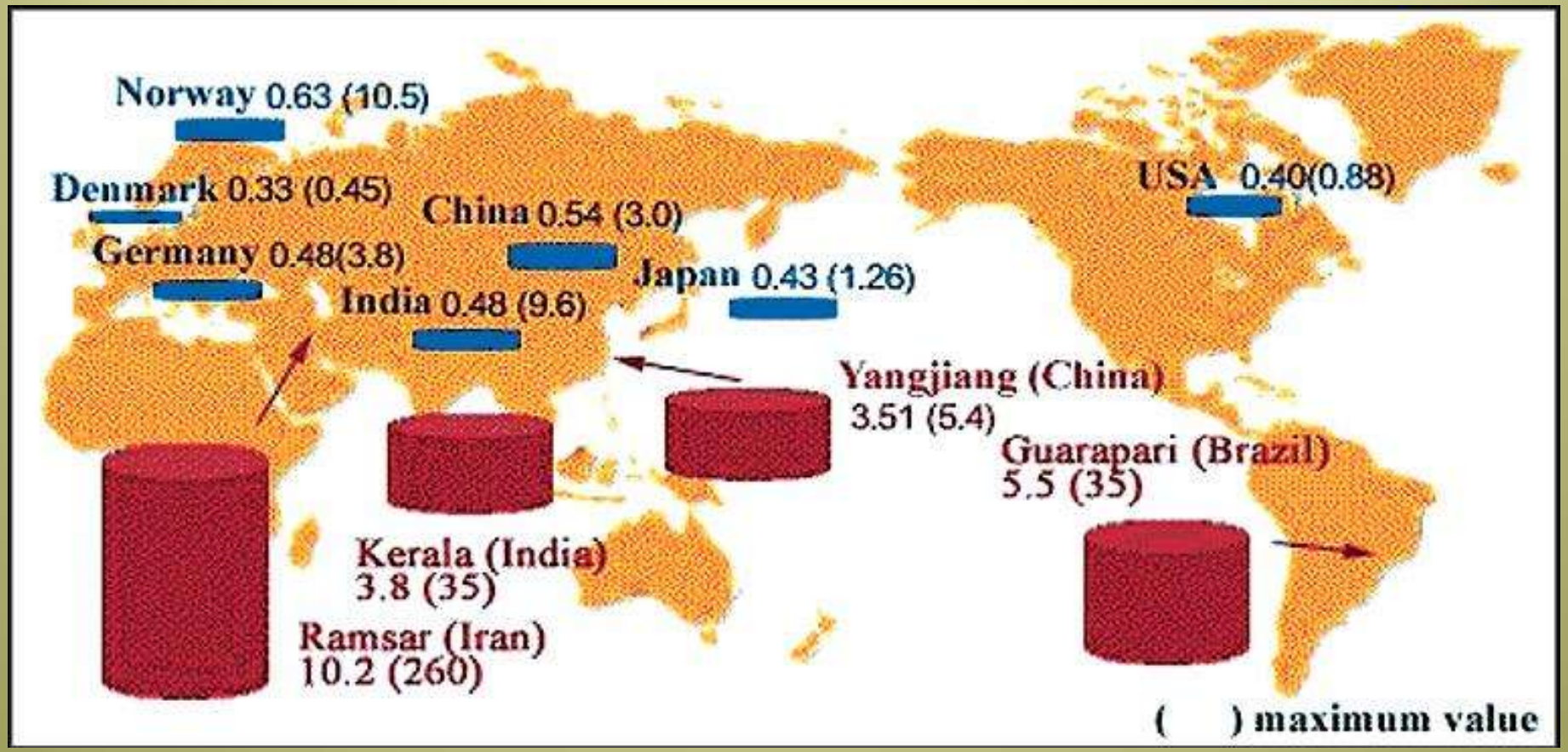
Razpadna vrsta U-238



Izpostavitve naravnemu sevanju (UNSCEAR 2000)

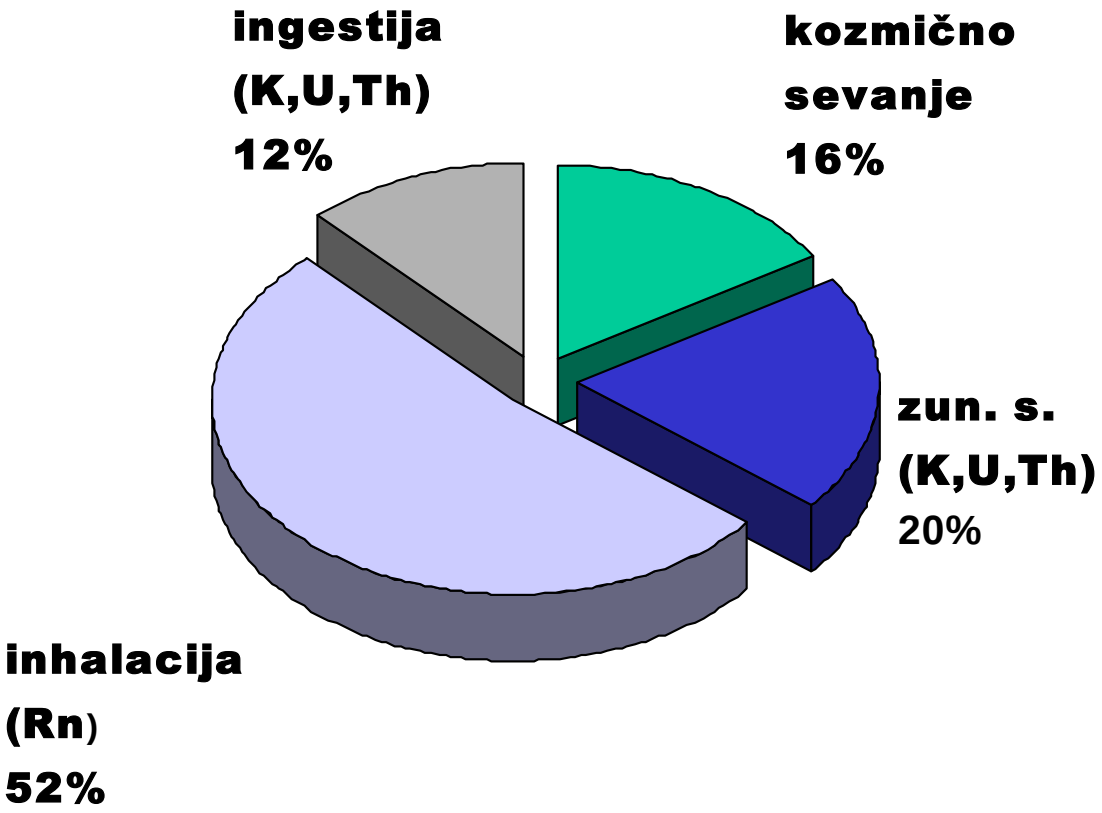
Vir	Svetovno povprečje (mSv/leto)	Razpon (mSv/leto)
Zunanje obsevanje • žarki gama • kozmično sevanje	• 0,5 • 0,4	• 0,3 – 0,6 • 0,3 – 1,0
Notranje obsevanje • inhalacija (Rn+) • ingestija	• 1,2 • 0,3	• 0,2 – 10 • 0,2 – 0,8
Skupaj	**2,4**	**?**

Področja z znatno povečanim naravnim zunanjim sevanjem (mSv/leto - povprečna in maksimalna vrednost)

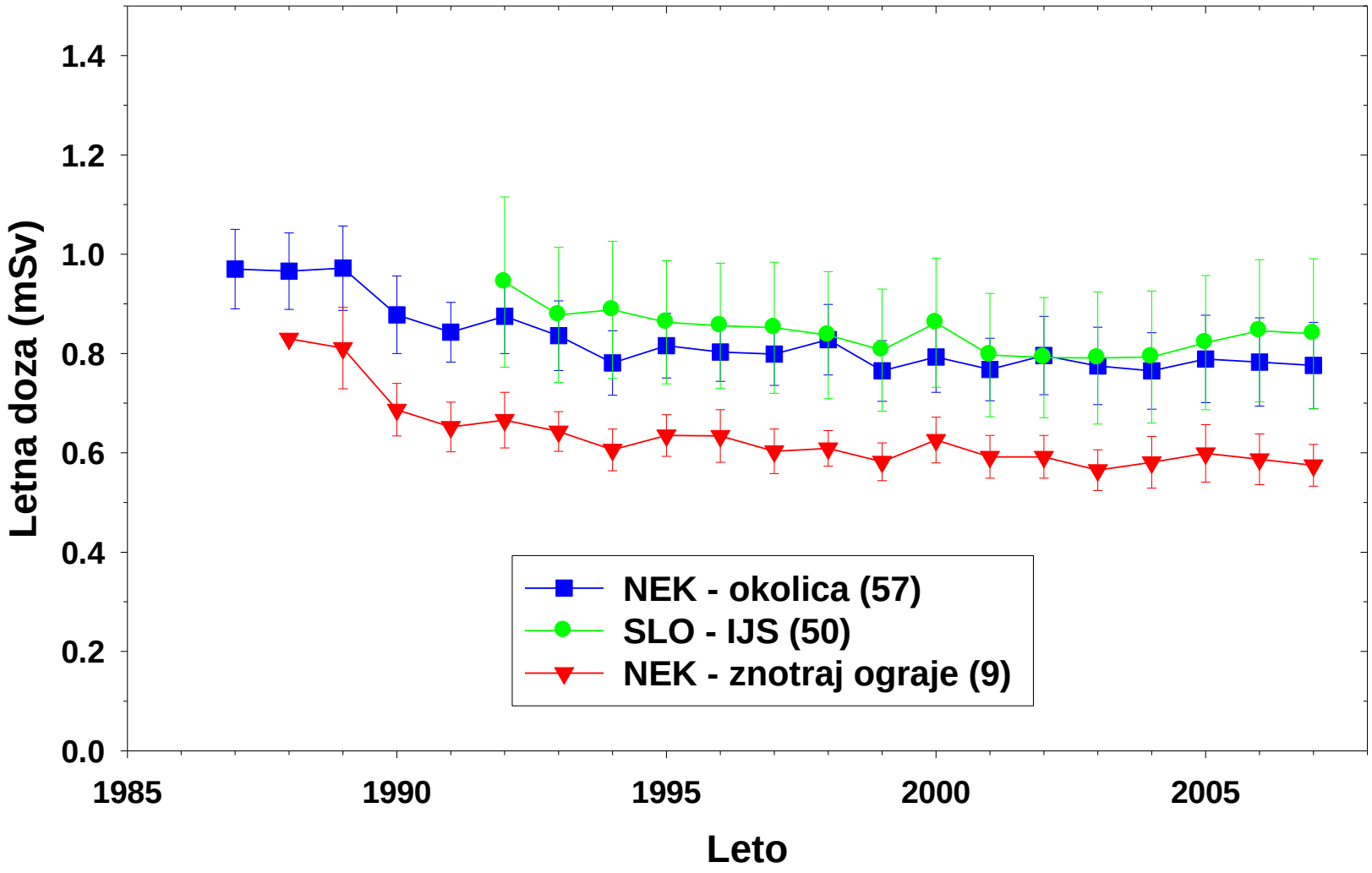


Slovenija: povprečje 0,85 mSv/leto (maksimum 1,4 mSv/leto?) (maksimum od 50 TLD)

Dozni kolač (UNSCEAR 2000)

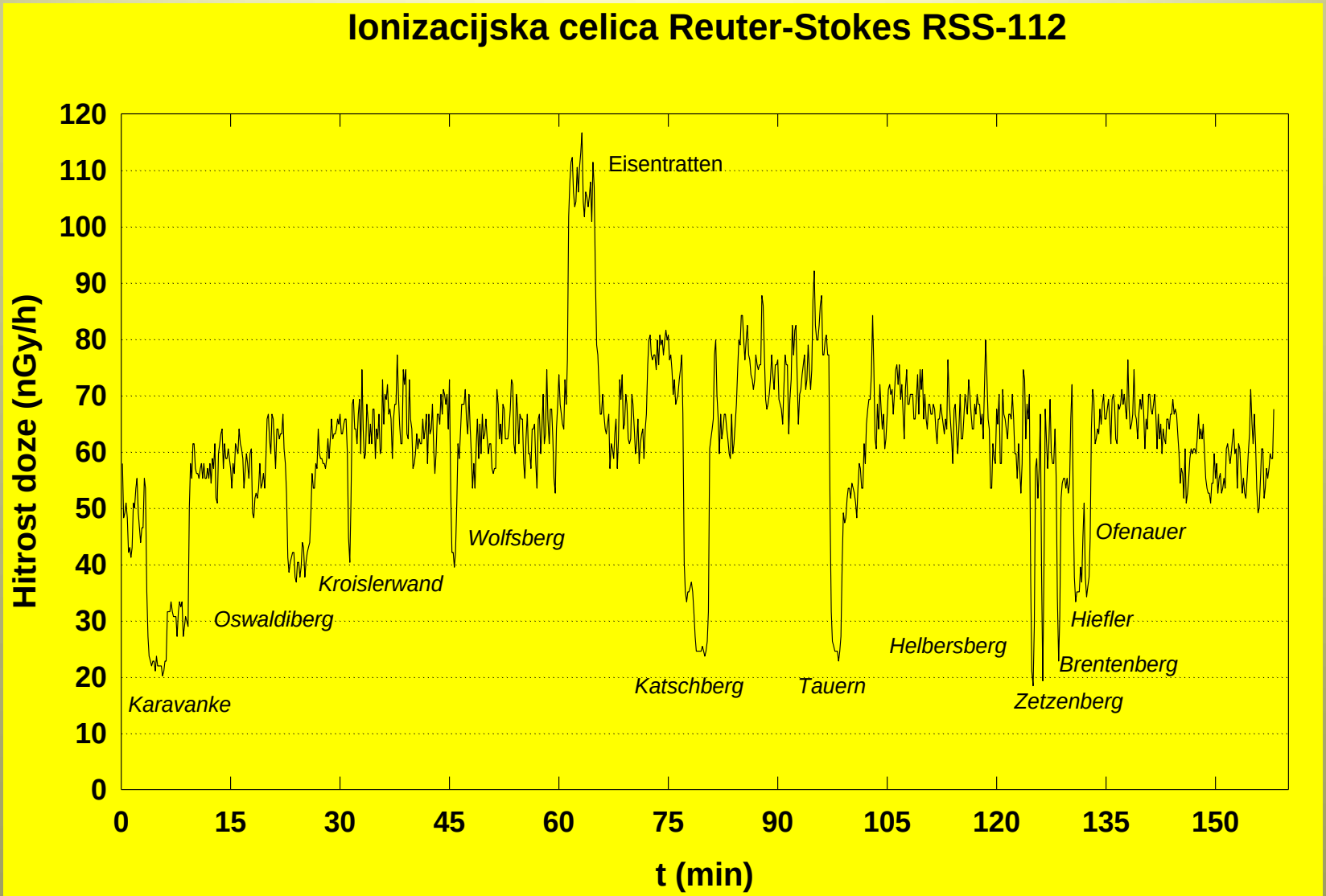


Letna doza = 2,4 mSv/leto

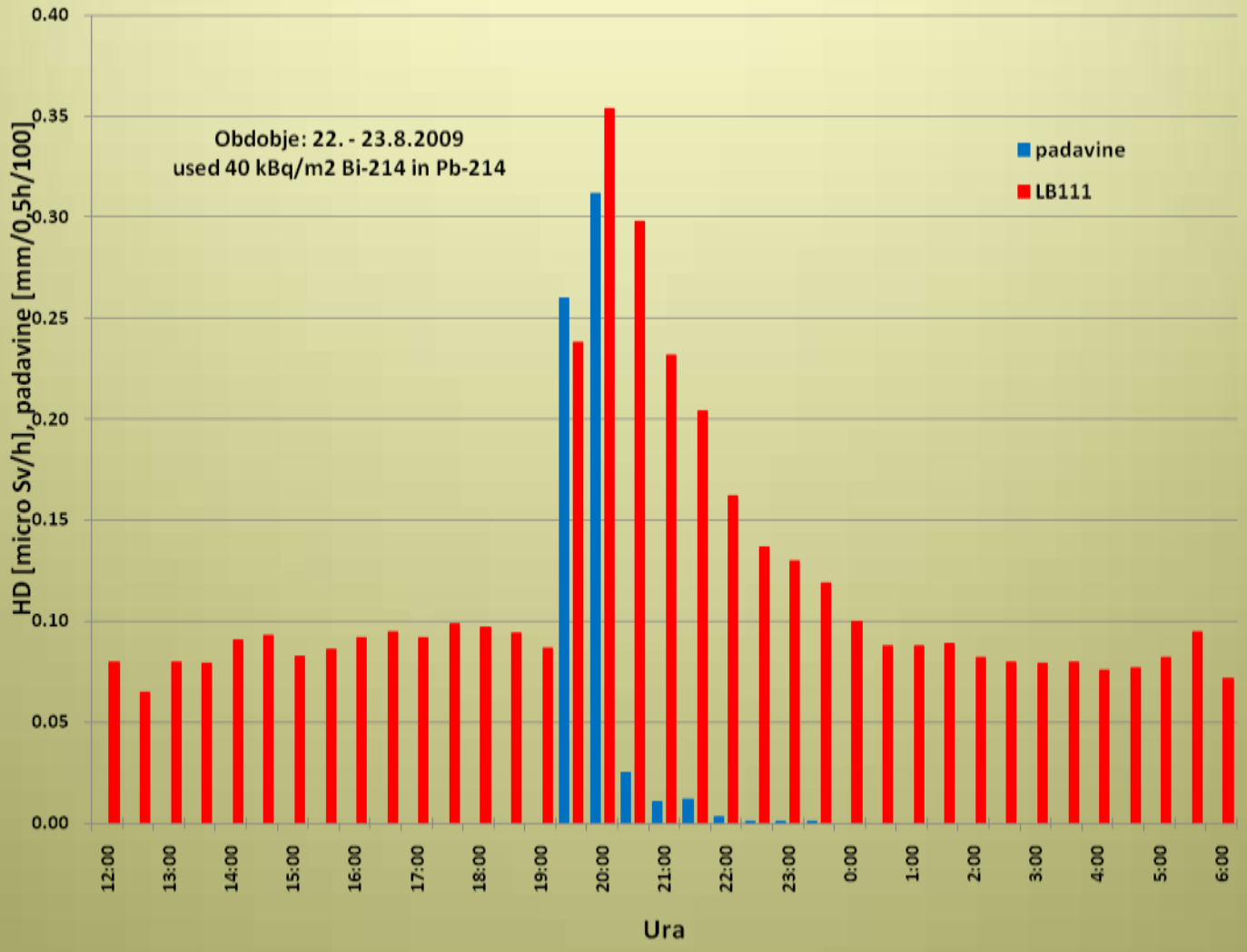

1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Letna doza (mSv)
1985
1990
1995
2000
2005
Leto
NEK - okolica (57)
SLO - IJS (50)
NEK - znotraj ograje (9)

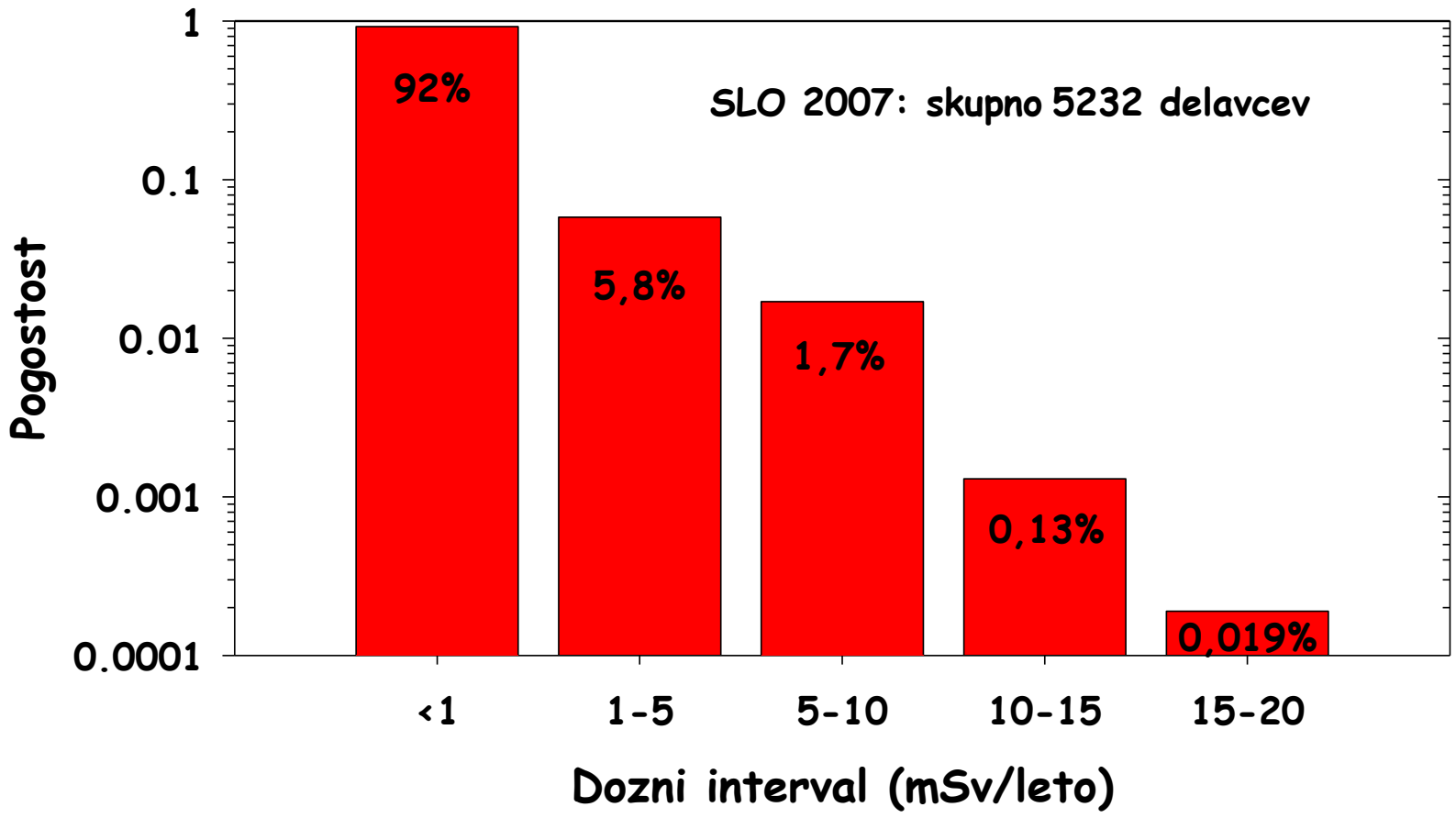
Meritve sevanja na poti (Route monitoring)

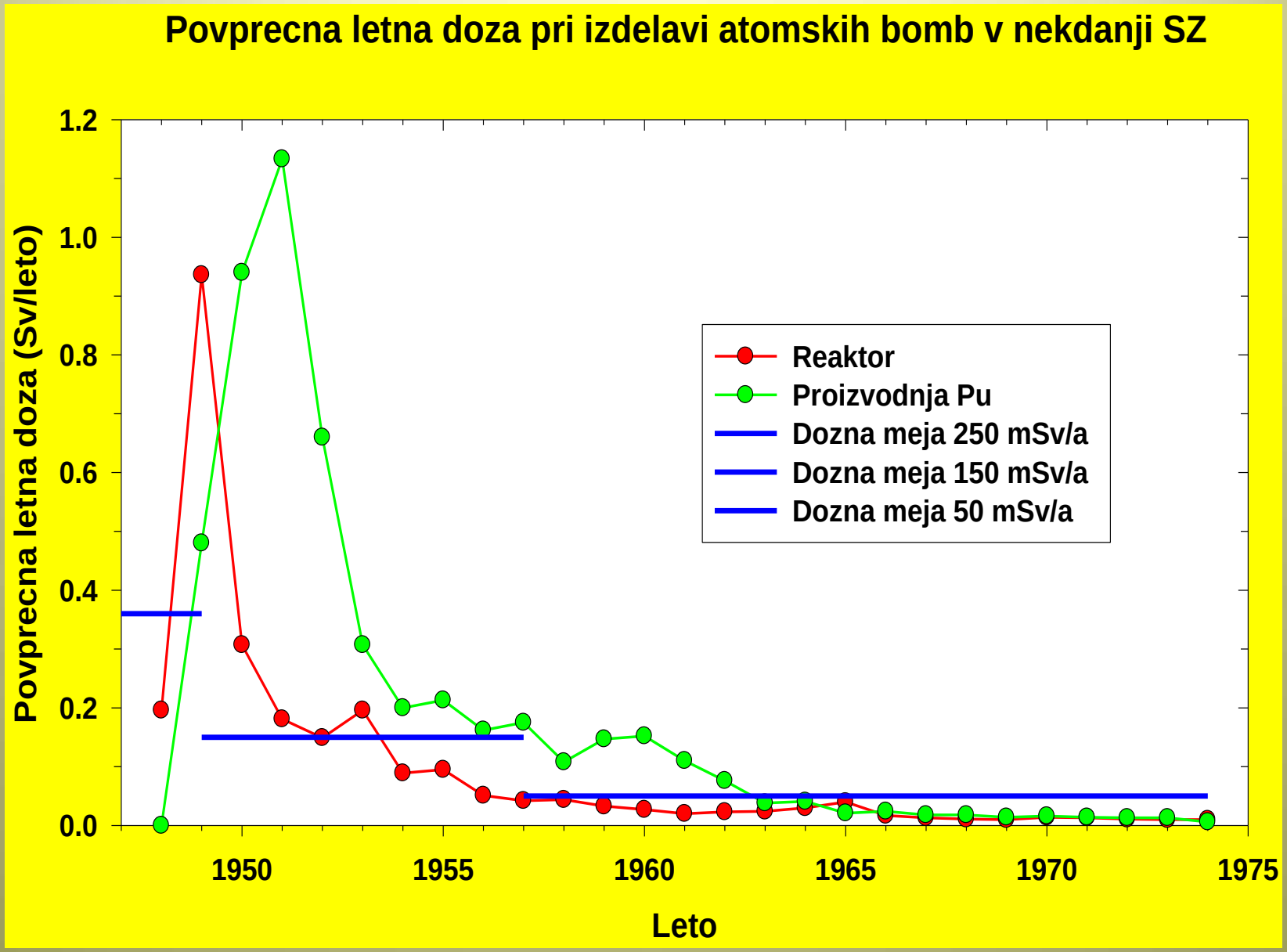
ionizacijska celica + GPS + notesnik


Ionizacijska celica Reuter-Stokes RSS-112
Hitrost doze (nGy/h)
t (min)
0
10
20
30
40
50
60
70
80
90
100
110
120
0
15
30
45
60
75
90
105
120
135
150
Karavanke
Oswaldiberg
Kroislerwand
Wolfsberg
Eisentratten
Katschberg
Tauern
Helbersberg
Zetzenberg
Brentenberg
Hiefler
Ofenauer

Used kratkoživih potomcev Rn




SLO 2007: skupno 5232 delavcev
92%
5,8%
1,7%
0,13%
0,019%
1
0.1
0.01
0.001
0.0001
Pogostost
<1
1-5
5-10
10-15
15-20
Dozni interval (mSv/leto)


Povprecna letna doza pri izdelavi atomskih bomb v nekdanji SZ
Povprecna letna doza (Sv/leto)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1950
1955
1960
1965
1970
1975
Leto
Reaktor
Proizvodnja Pu
Dozna meja 250 mSv/a
Dozna meja 150 mSv/a
Dozna meja 50 mSv/a

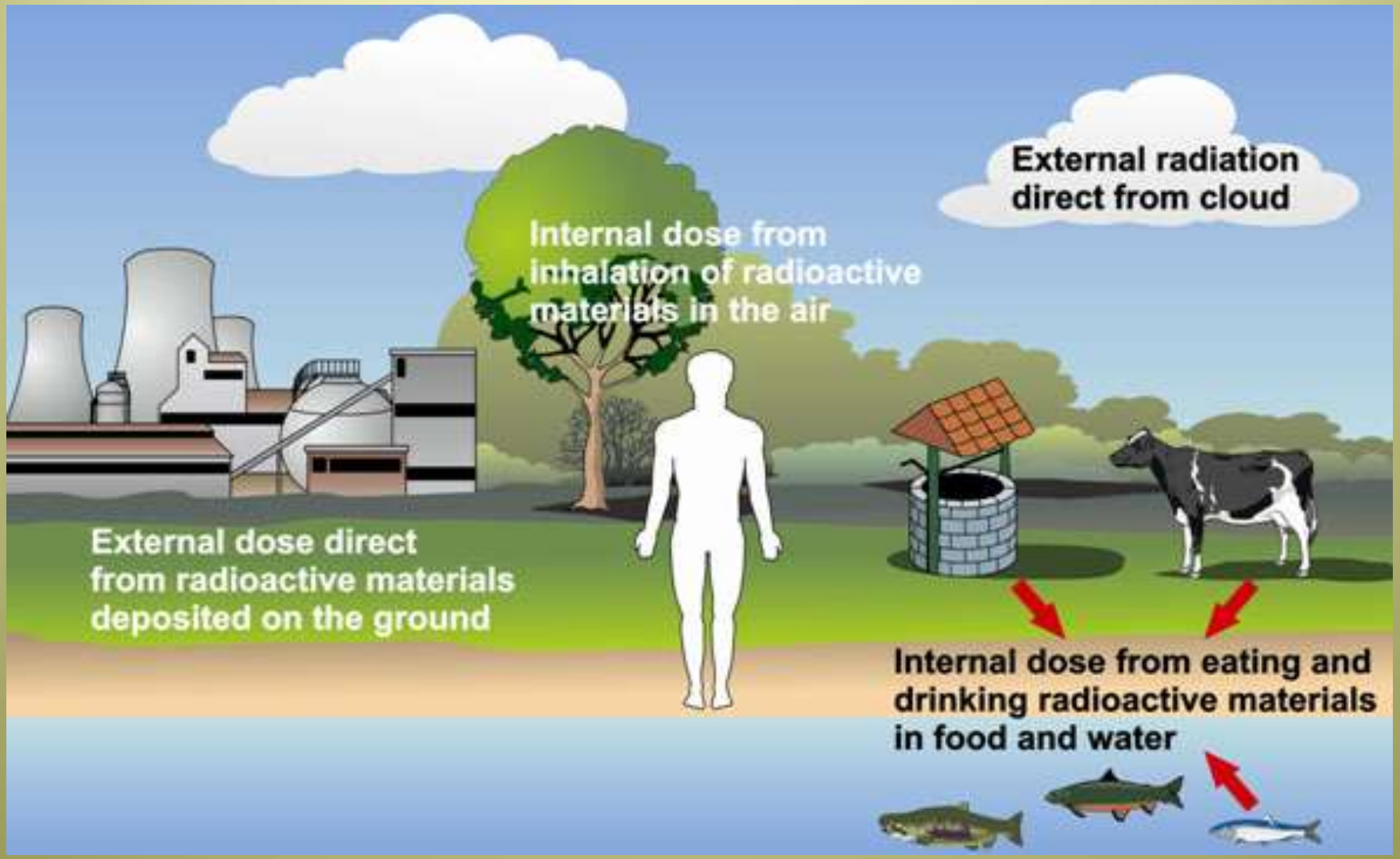
VSAKDANJE ŽIVLJENJE – medicinska diagnostika

Medicina – pacient

RTG	Efektivna doza (μSv)
• roka, noga	<10
• zobje	20
• prsni koš	40
• kolk	300
• abdomen	1400
• CT abdomen	7300
• barijev kontrast	8700

Nuklearna elektrarna Krško

Poti izpostavitve sevanju



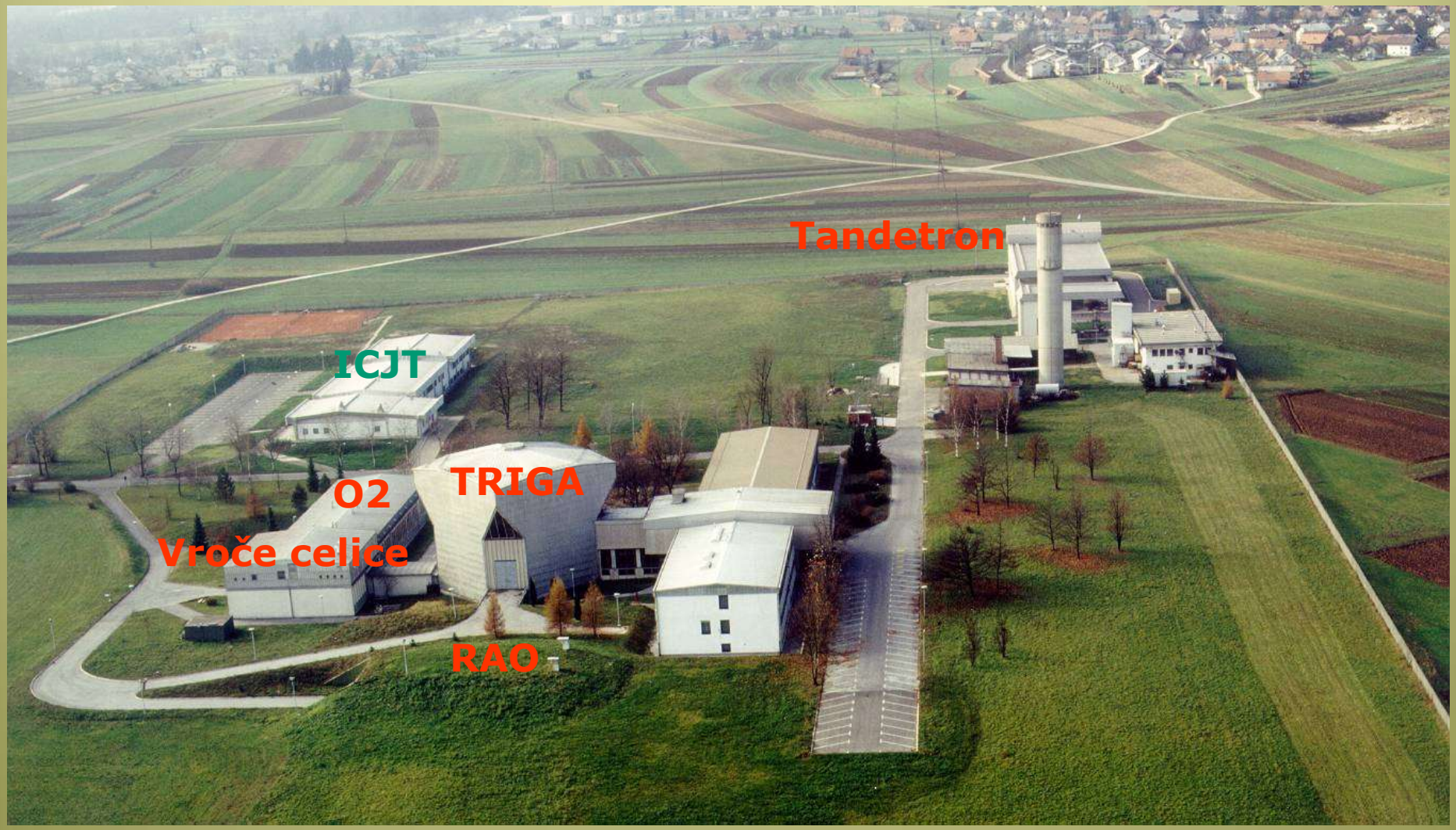
Sevalni vpliv NEK na prebivalstvo

Atmosferski izpusti
<1 μSv na leto

Izpusti v Savo
<0,1 μSv na leto

Naravno sevanje: 2,4 mSv na leto

Reaktorski center Podgorica (TRIGA 250 kW)



Vpliv RC na okolje

- **<u>Atmosferski izpusti</u> (reaktor)**
  - **Ar-40 + n → Ar-41**
  - **žlahtni plin – zunanja izpostavitev**
  - **letna doza: < 1μSv/leto**

- **<u>Tekočinski izpusti</u> (O2 reka Sava)**
  - **< MBq/leto**
  - **pitje savske vode!?**
  - **letna doza: 1E-4 Sv/leto**

Letna doza naravnega sevanja: 2,4 mSv

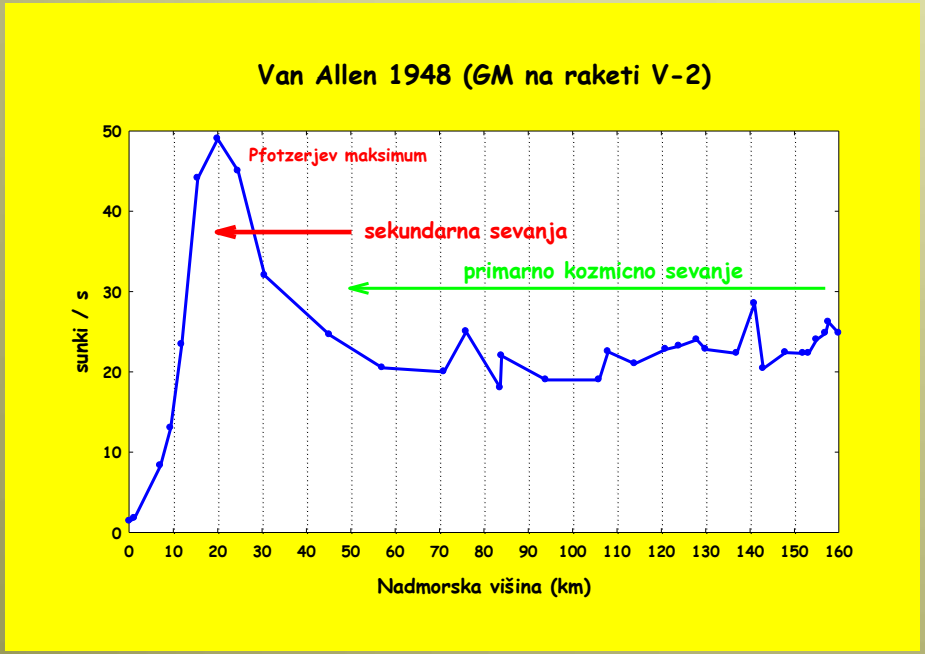
Zunanja izpostavitev zaradi atmosferskih izpustov Ar-41

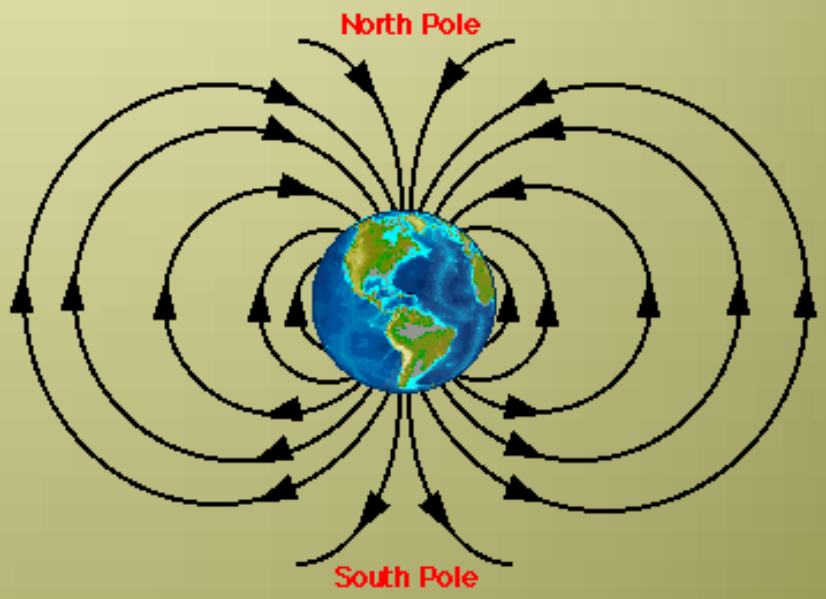
Letalski poleti

- nadmorska višina
- ekvator < pol

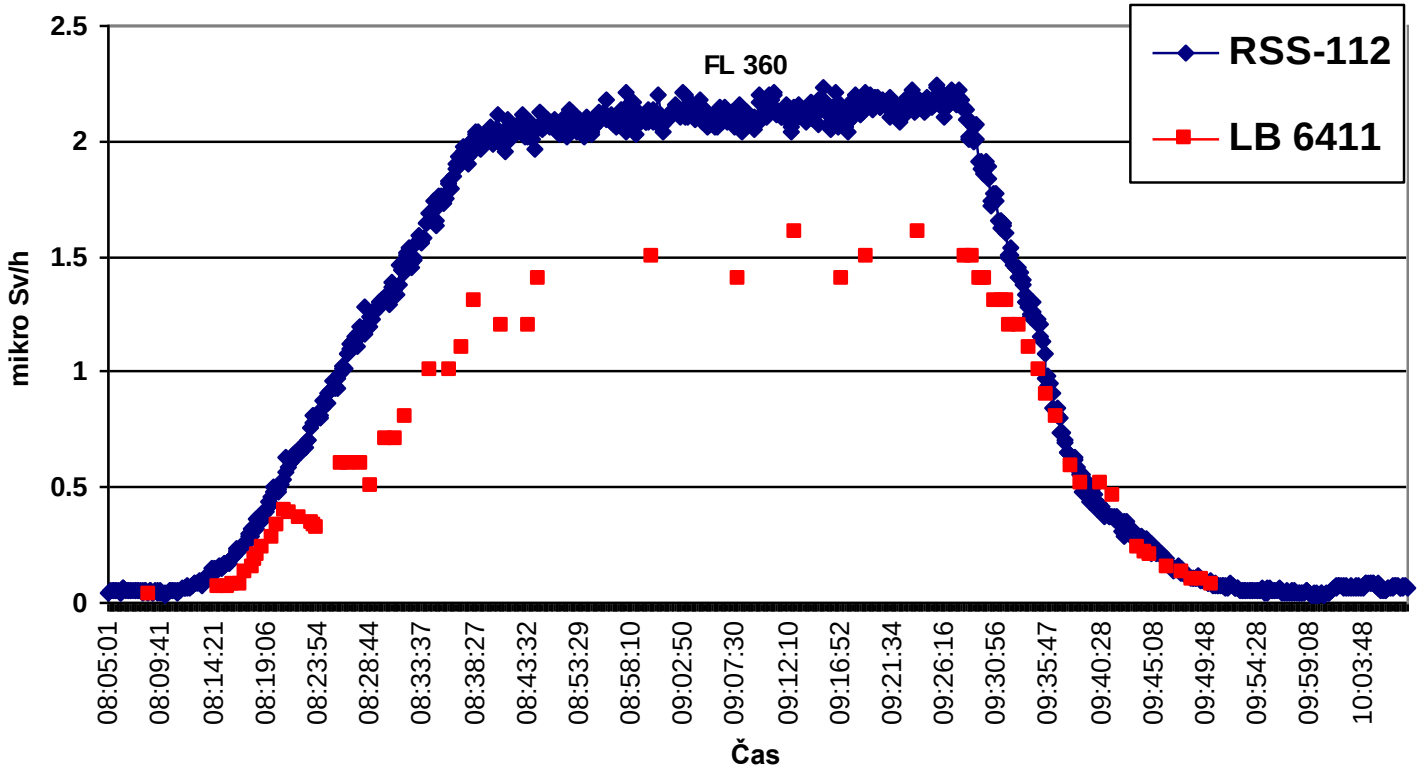
Evropa – ZDA -Evropa

~ 0,1 mSv





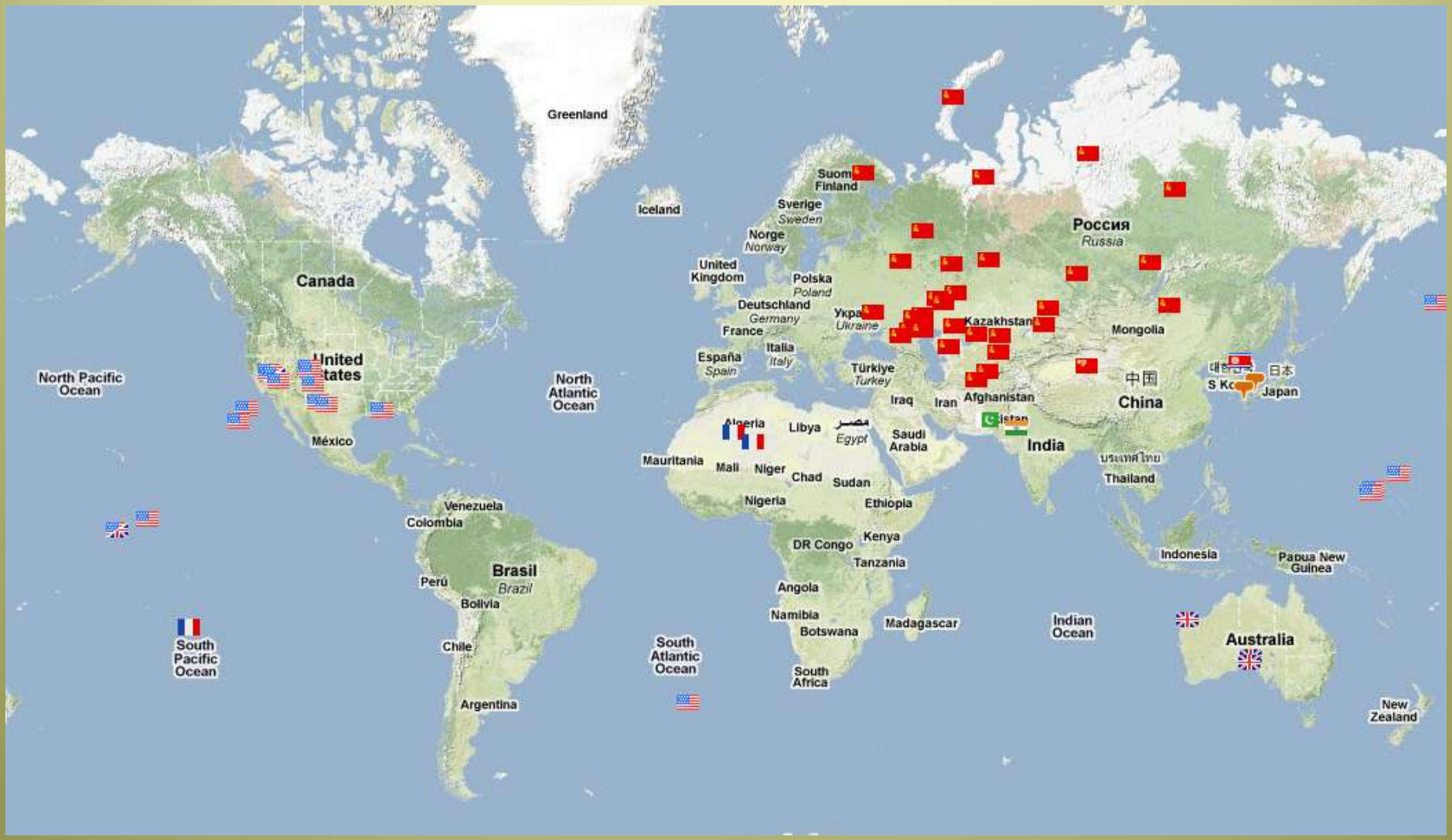
Sevanje na letu Ljubljana - Kopenhagen



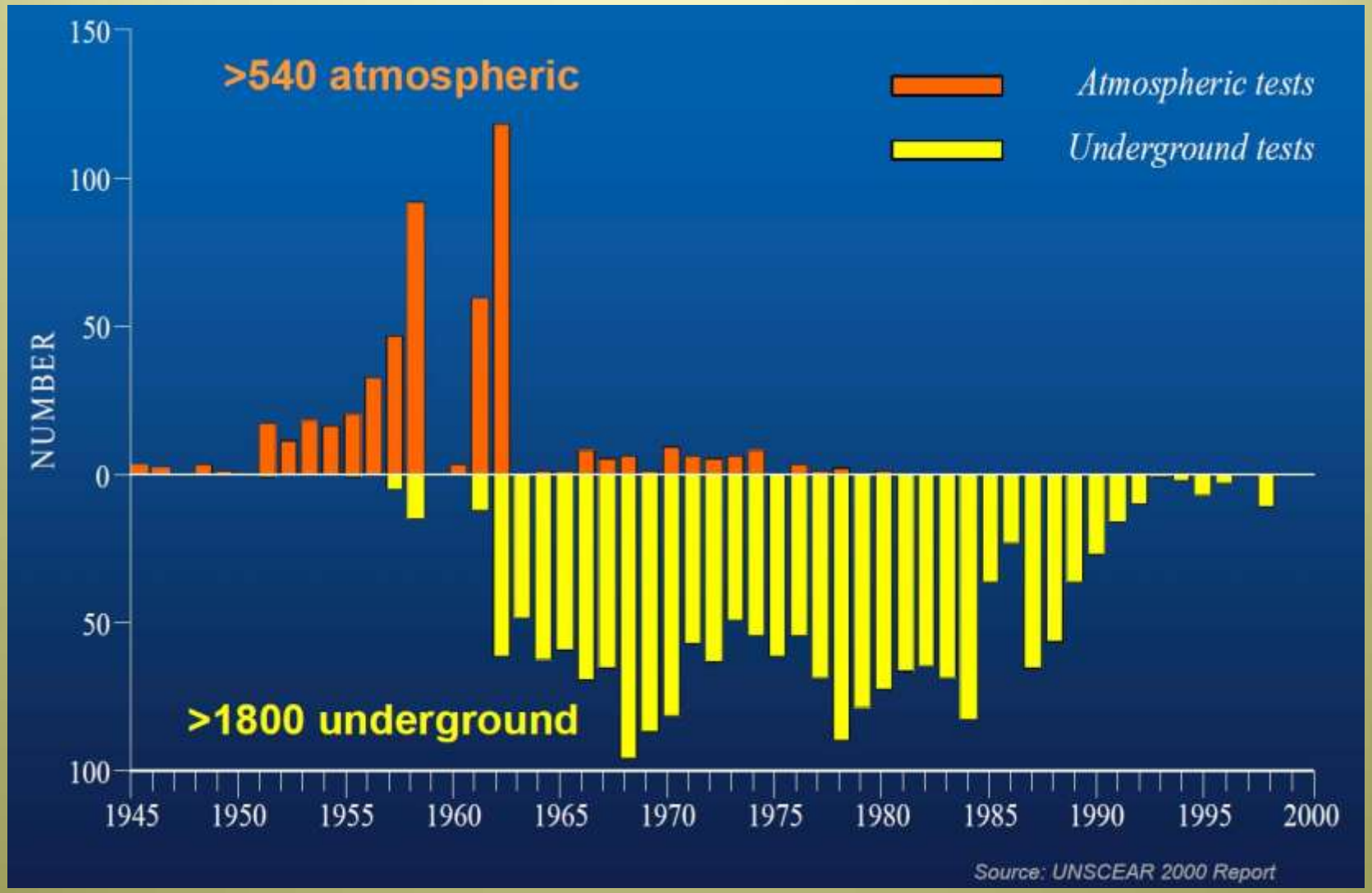
Izpostavitve sevanju pri letalskih poletih

AA (regionalni poleti)	piloti	CRJ200 A320	1 mSv/leto 3 mSv/leto
	kabinsko osebje	CRJ200 + A320	2 mSv/leto
medcelinski poleti	piloti, kabinsko osebje		do 6 mSv/leto

Lokacije jedrskih eksplozij



Poskusne jedrske eksplozije



Operacija "Crossroads", Bikini 1946

Podvodna eksplozija "Baker" (23 kt, -30 m)

Dekontaminacija ladje "Prinz Eugen"

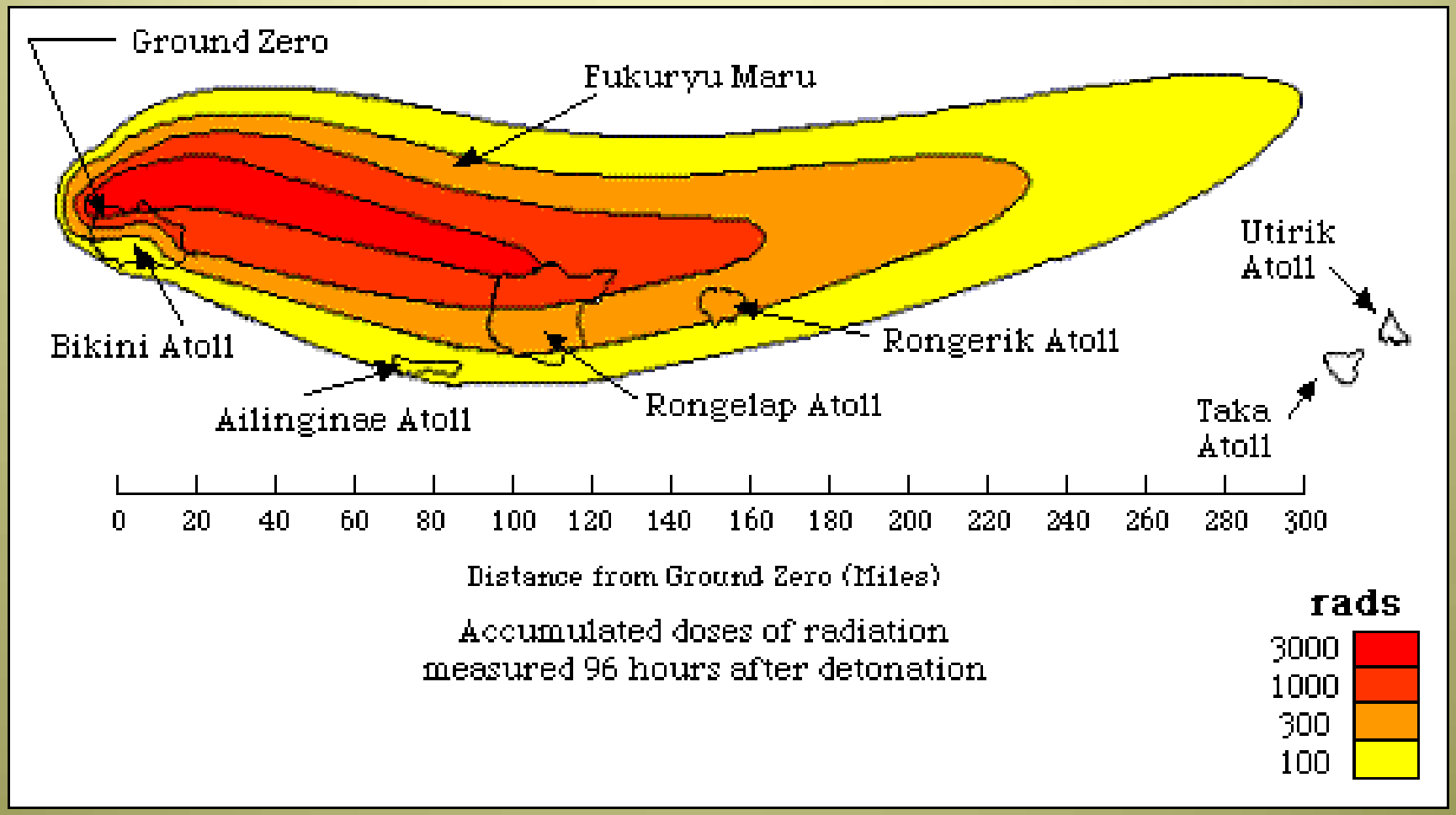
The tried and true Navy method: scrubbing the deck of the *Prinz Eugen* to reduce radiation levels. Radsafe monitors on the target ships were fully clothed at all times, including rubber gloves and boots, but enlisted men were not. "I had on a pair of shorts and my tennis shoes and my . . . little t-shirt with a sailor hat," recalled one sailor. "And that's all the clothing that I had on me." (U.S. Naval Institute Research Library)

Goats tethered to the deck of the target ship *Niagara* munch hay peacefully as they await the Able shot. Thousands of letters were sent to Washington protesting the use of more than 5,000 animals in the tests. (National Archives)

Dozna omejitev: 1mSv/dan (danes 20 mSv/leto)

IJS 2005 - dekontaminacija "vročih" celic

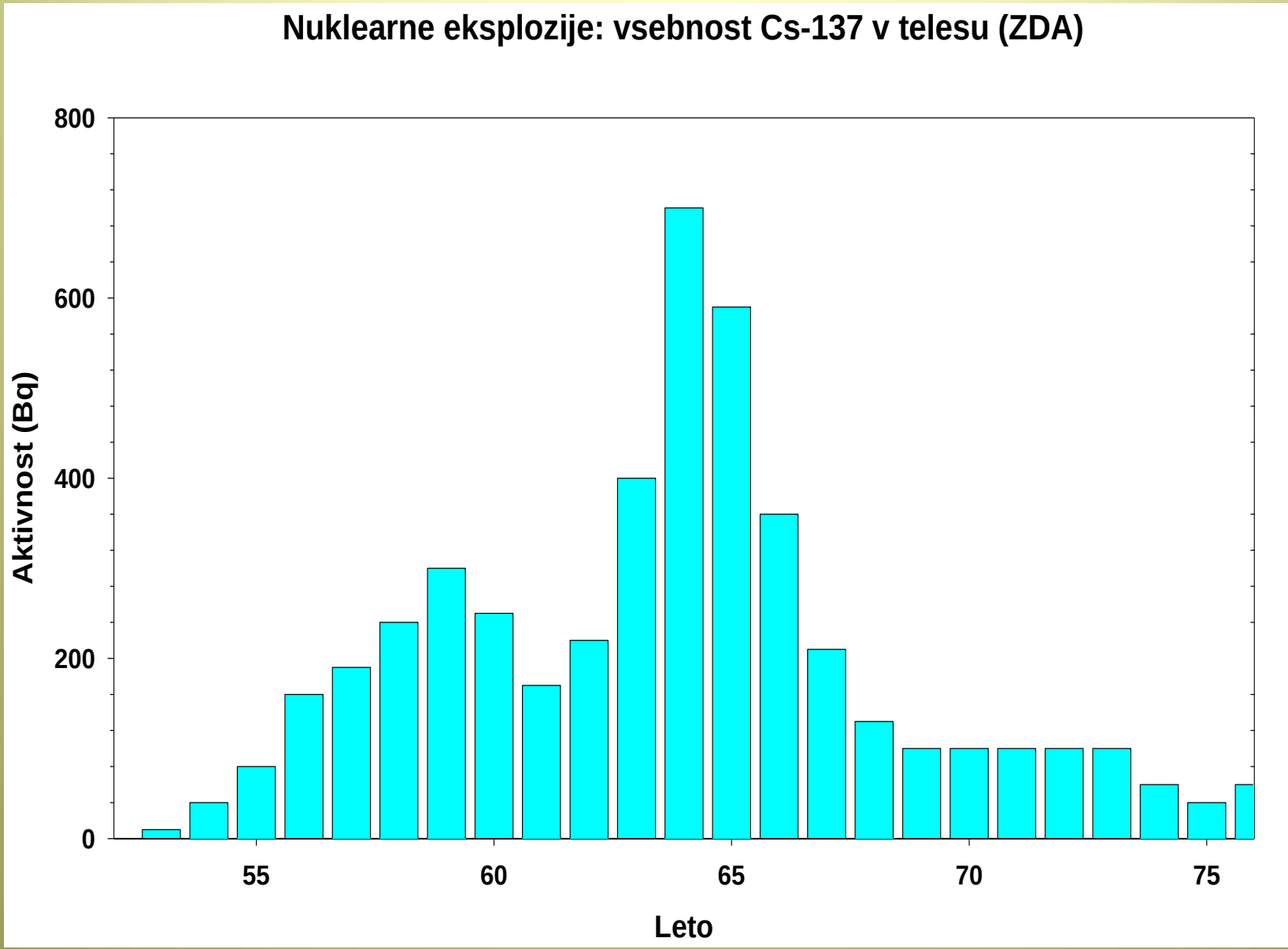
Test BRAVO (1.marec 1954 - 15 Mt TNT)
Doze v 4 dneh zaradi useda



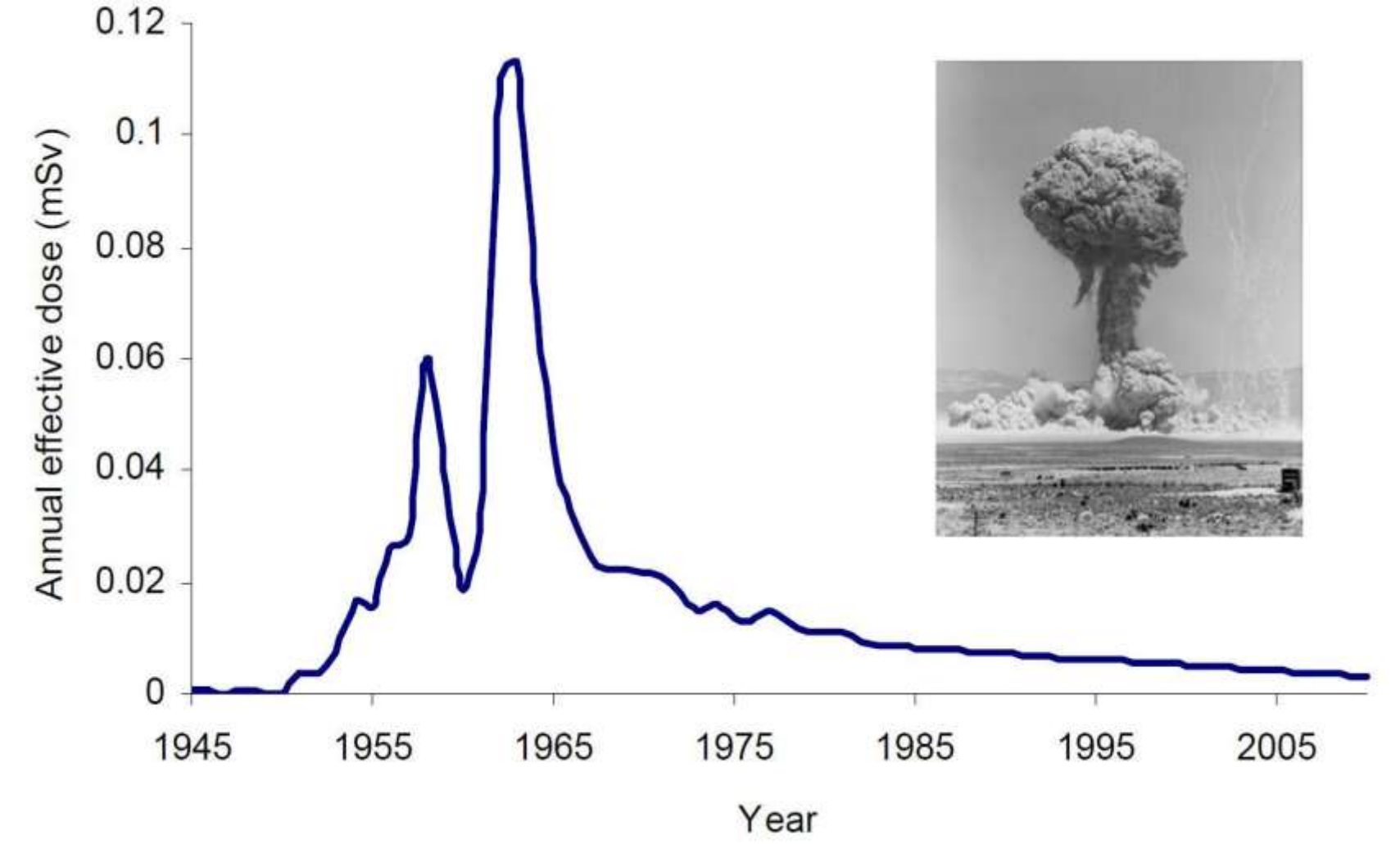
Tune z japonske ribiške ladje *Fukuryu Maru*

Municipal officials at Tokyo's Tsukiji fish market measure the level of radiation in a tuna that had been unloaded from the Fukuryu Maru No. 5, in a file photo from March 1954.

The Japan Times: Feb. 27, 2004


Nuklearne eksplozije: vsebnost Cs-137 v telesu (ZDA)
Aktivnost (Bq)
800
600
400
200
0
55
60
65
70
75
Leto

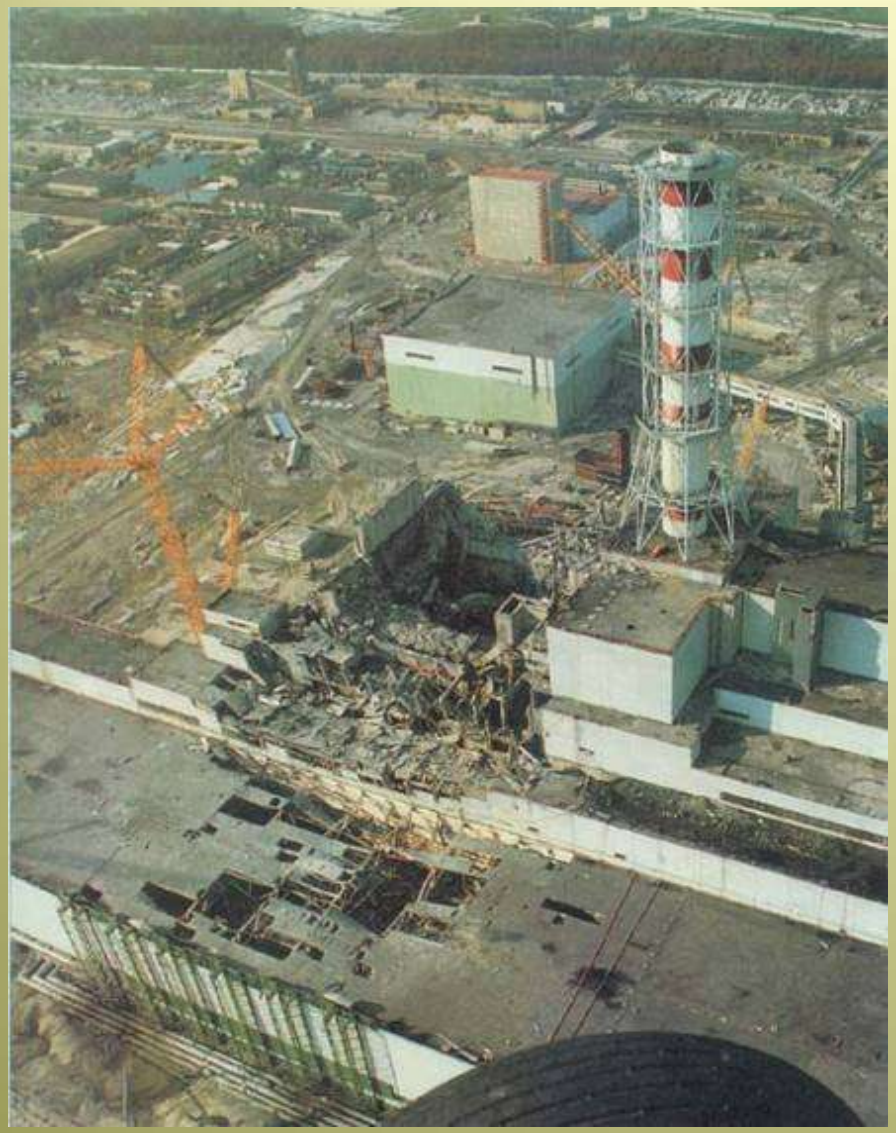
Izpostavitve sevanju zaradi jedrskih poskusov

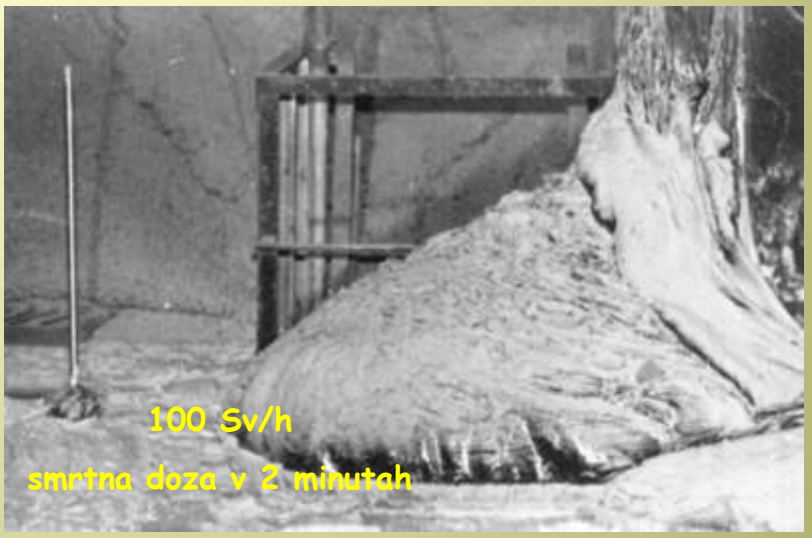


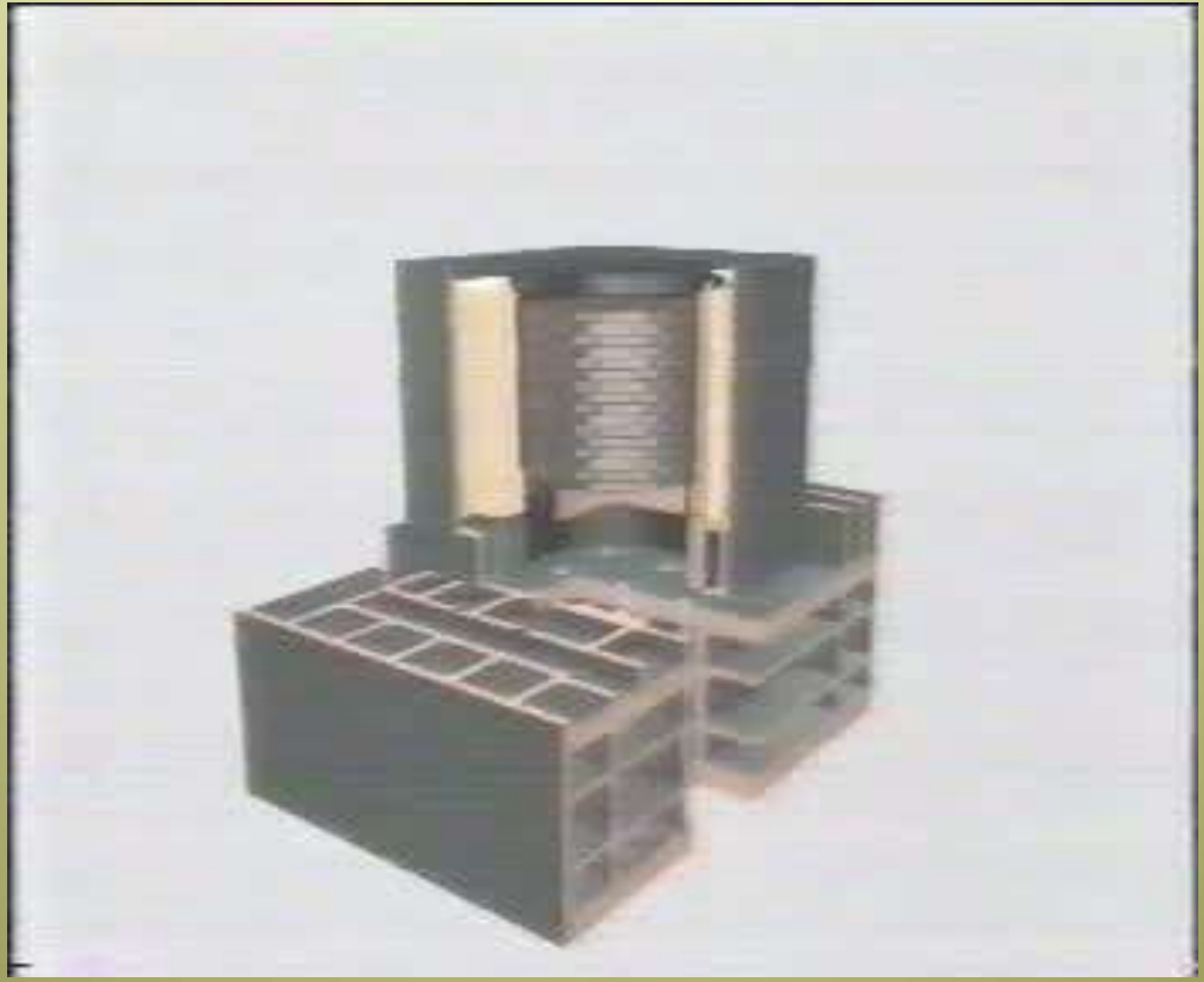
Černobil, 26. 04. 1986

Nekdanji černobilski reaktorji

Černobil, 26. april 1986

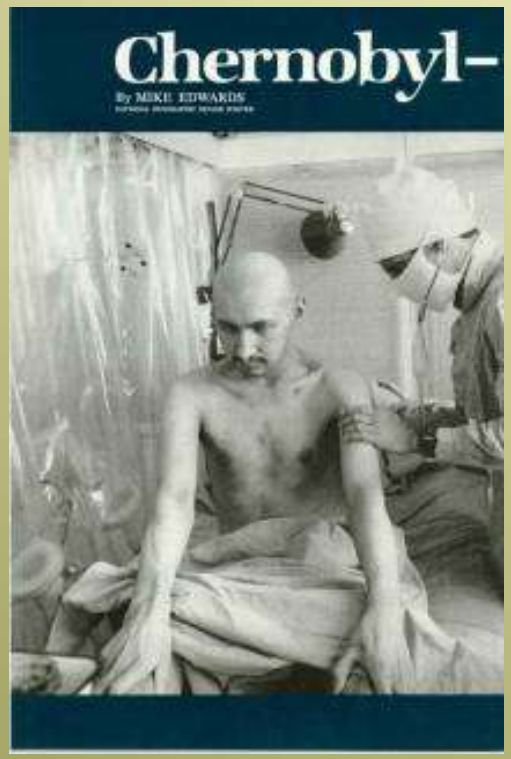






Akutni radiacijski sindrom (ARS)

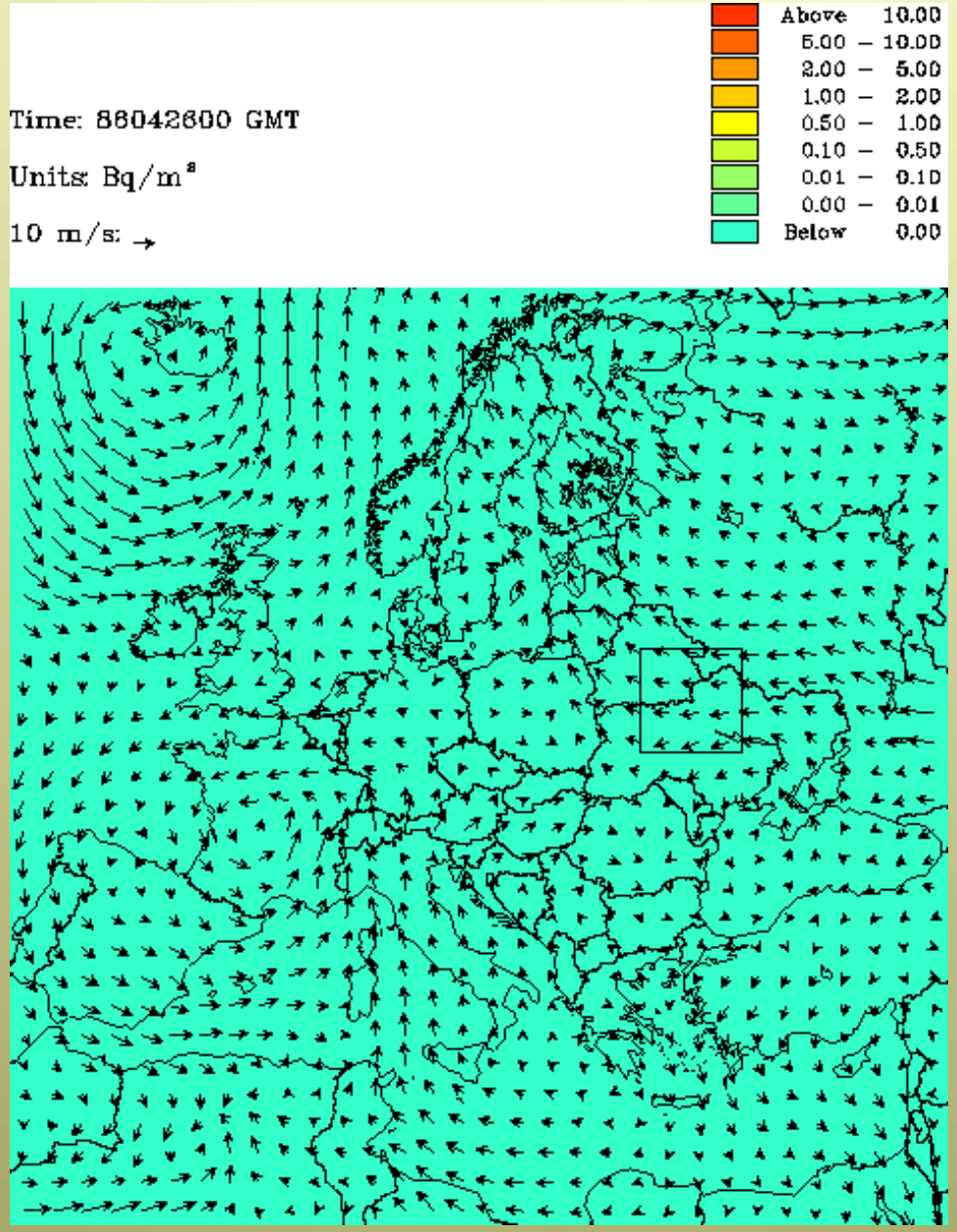
1000 delavcev izpostavljenih v prvi fazi
ARS diagnosticiran pri 134 delavcih
28 smrti v letu 1986
19 smrti v obdobju 1987-2004

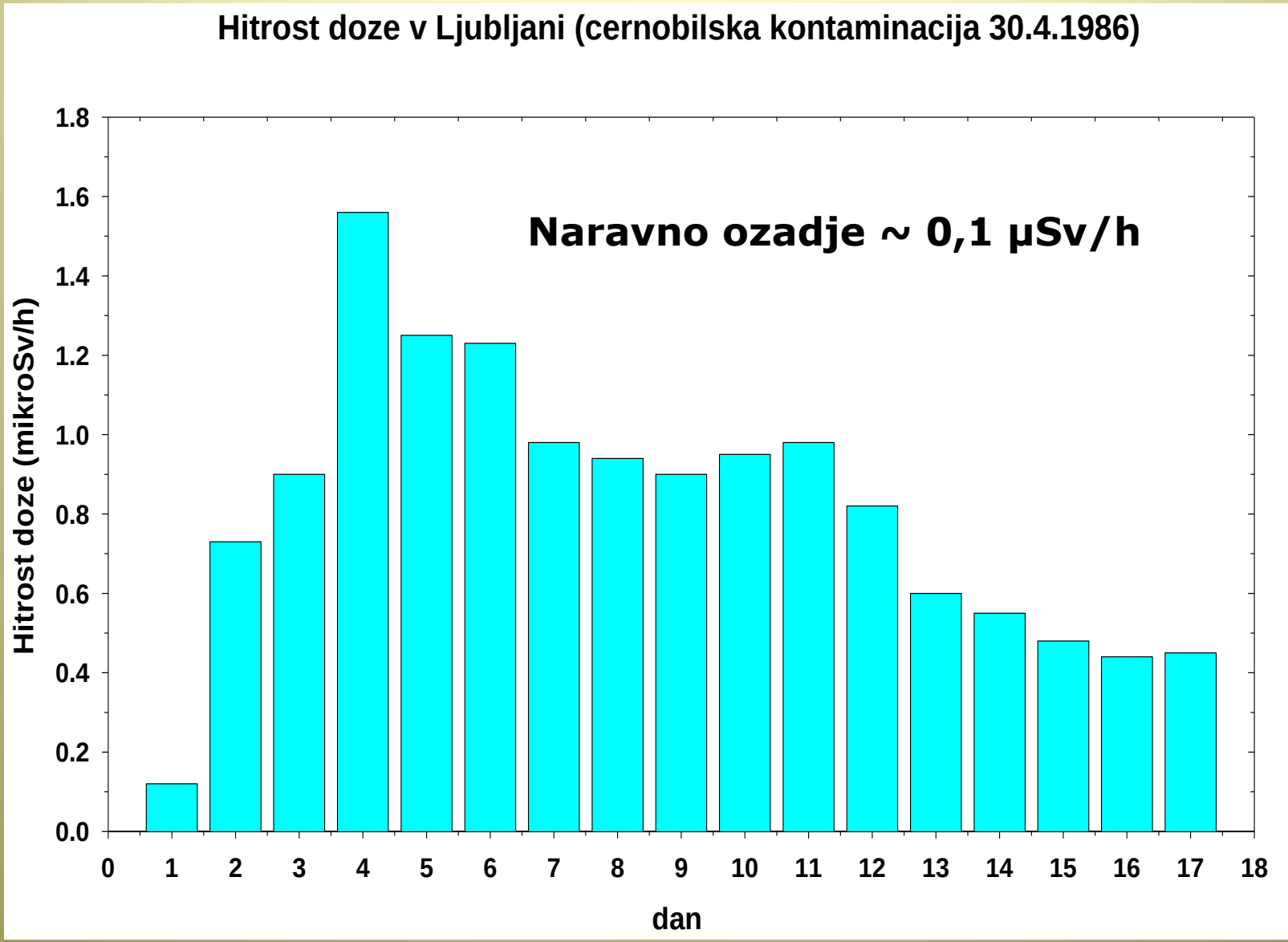


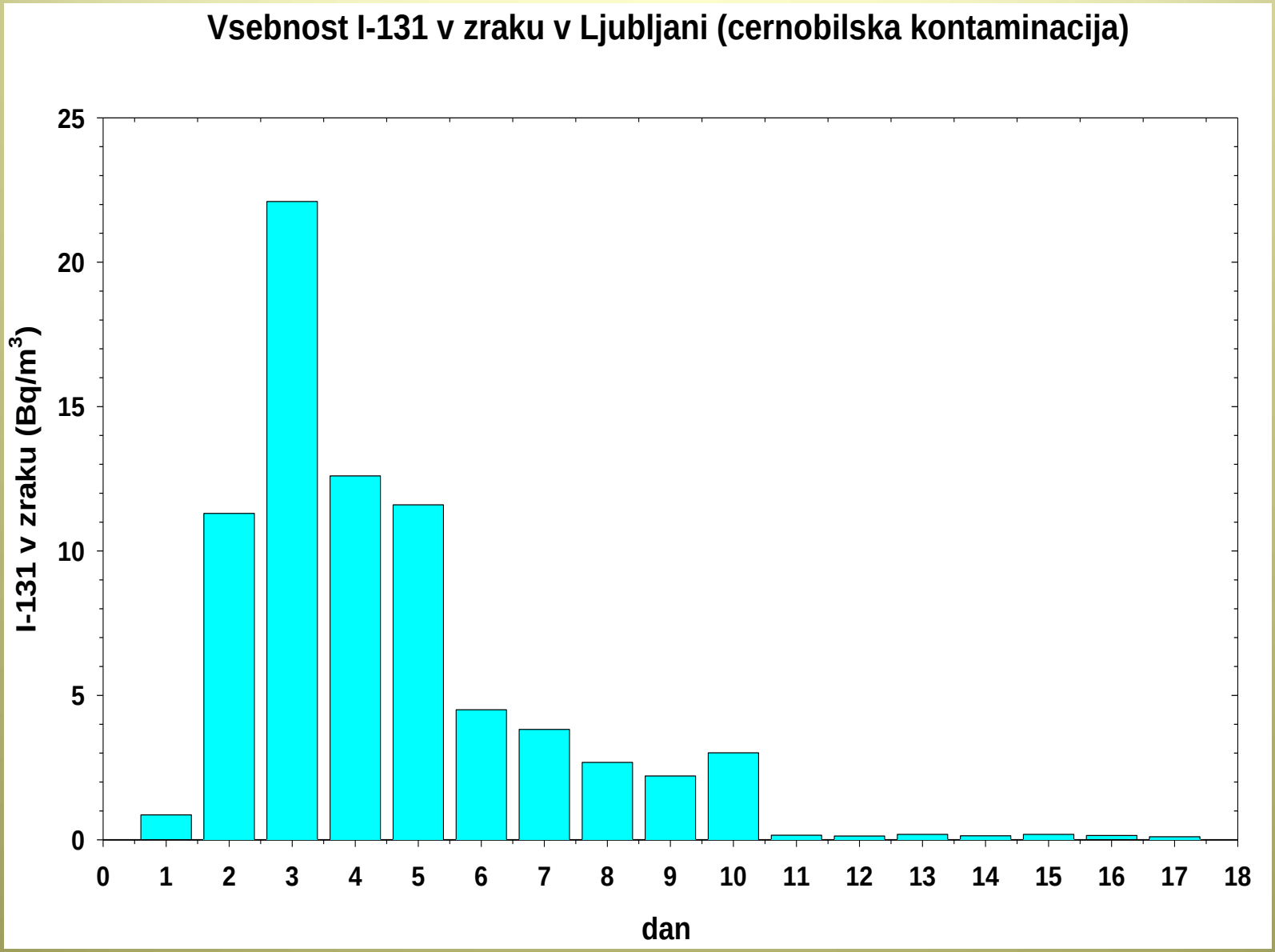
"Rdeči" gozd

Zaprto območje (Exclusion zone)

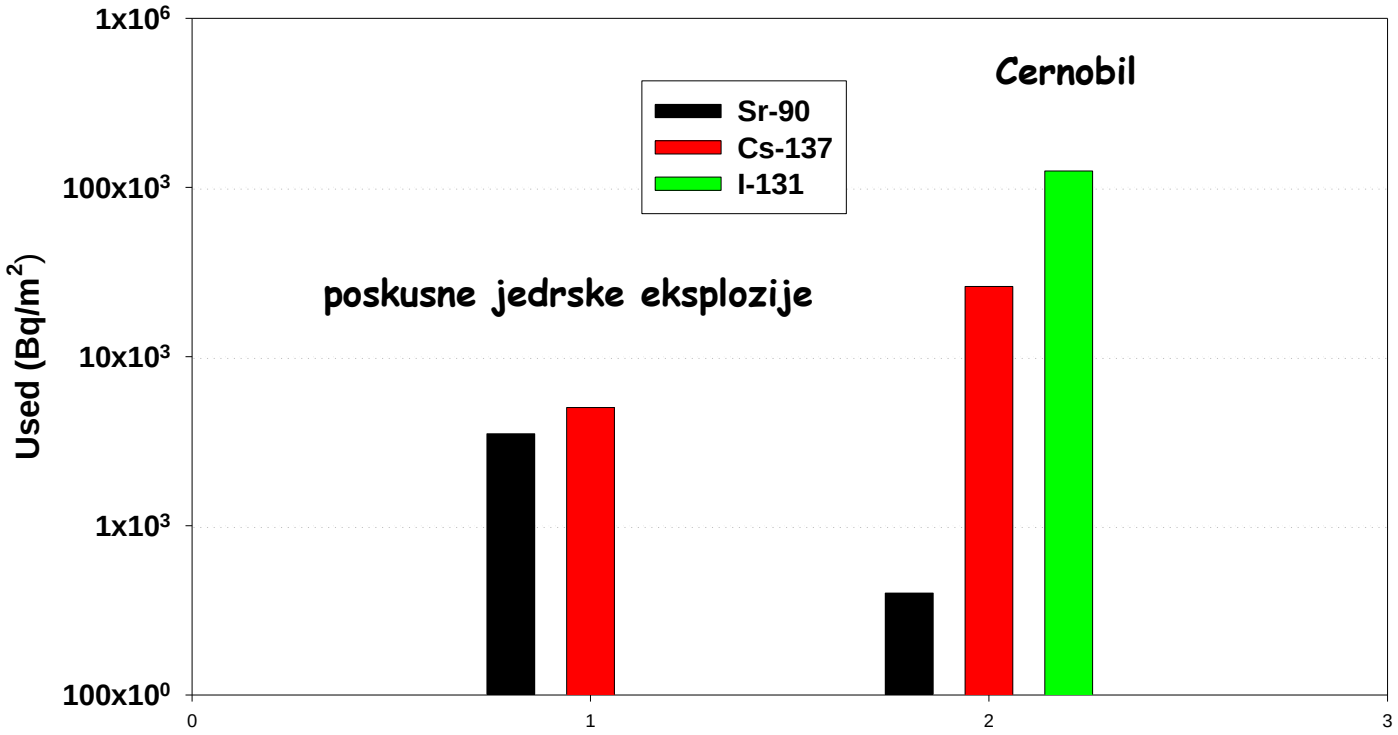
(National Geographic, April 2006)


Time: 86042600 GMT
Units: Bq/m³
10 m/s:
Above 10.00
5.00 – 10.00
2.00 – 5.00
1.00 – 2.00
0.50 – 1.00
0.10 – 0.50
0.01 – 0.10
0.00 – 0.01
Below 0.00


Hitrost doze v Ljubljani (cernobilska kontaminacija 30.4.1986)
Naravno ozadje ~ 0,1 μSv/h
Hitrost doze (mikroSv/h)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
dan


Vsebnost I-131 v zraku v Ljubljani (cernobilska kontaminacija)
I-131 v zraku (Bq/m3)
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
dan

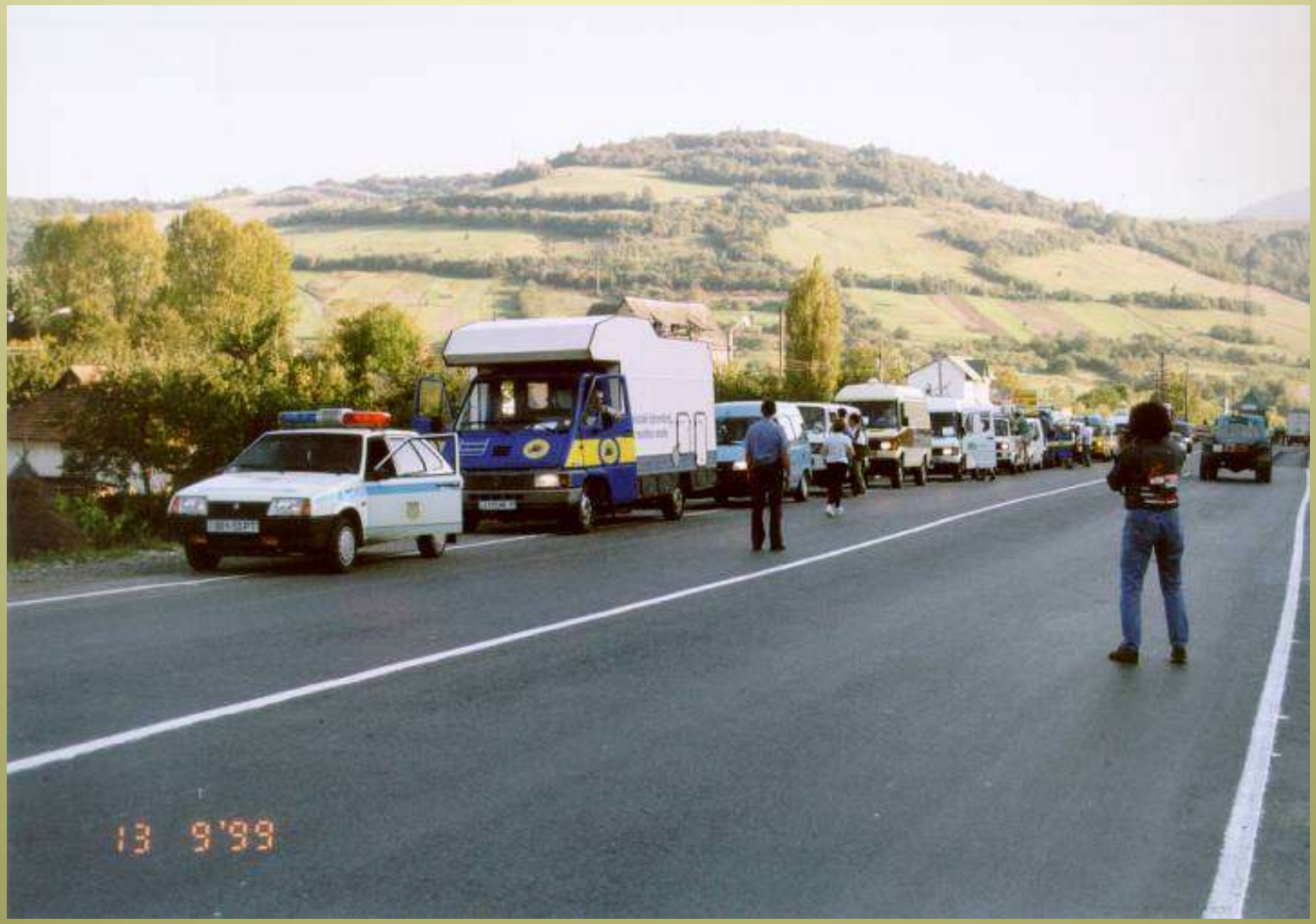
Used radionuklidov v Ljubljani

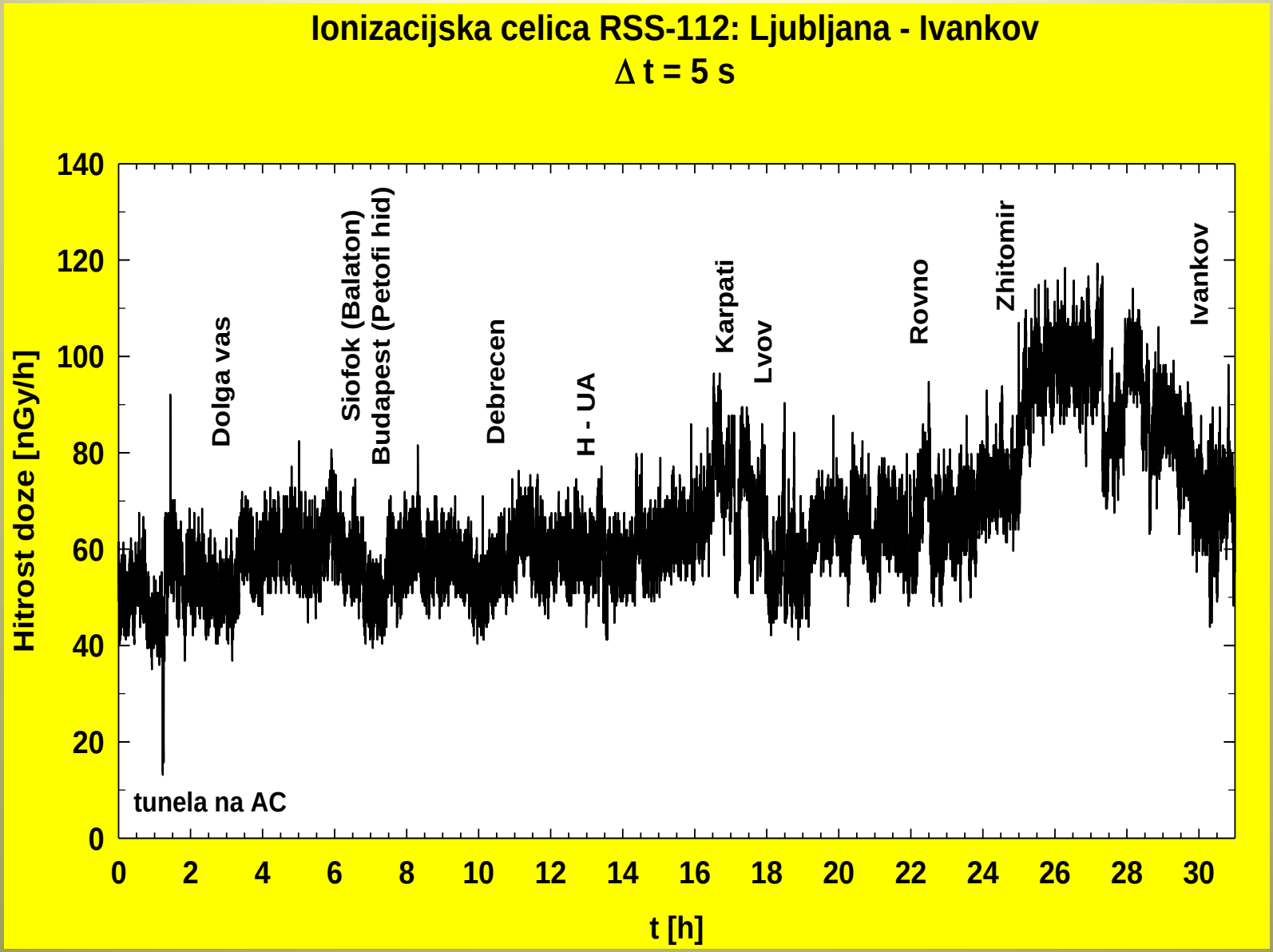


Sr-90 kosti / Cs-137 celo telo / I-131 ščitnica

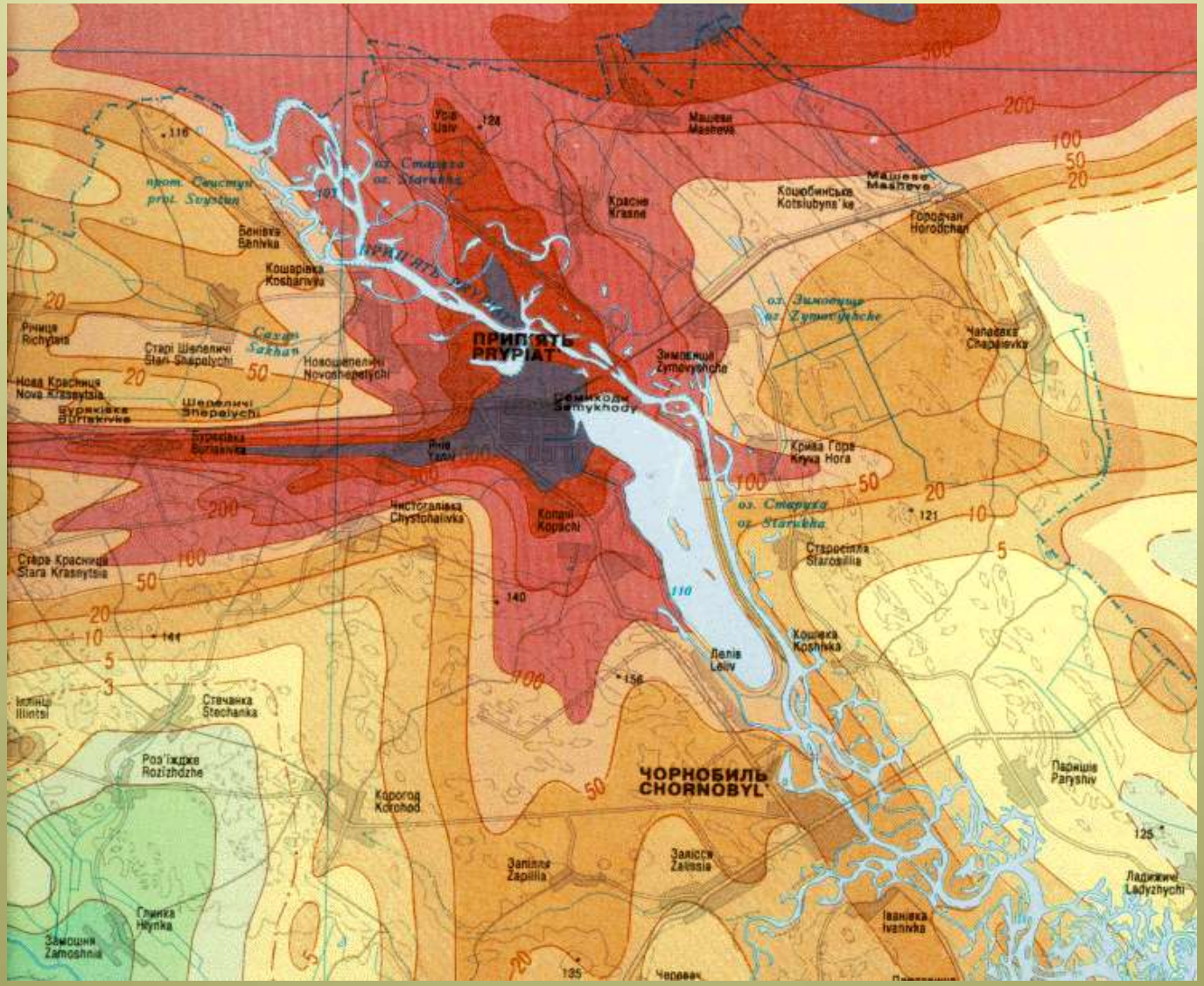
Vaja "MORAL 12"

Interkomparacijske meritve mobilnih enot v Černobilu (september 1999)

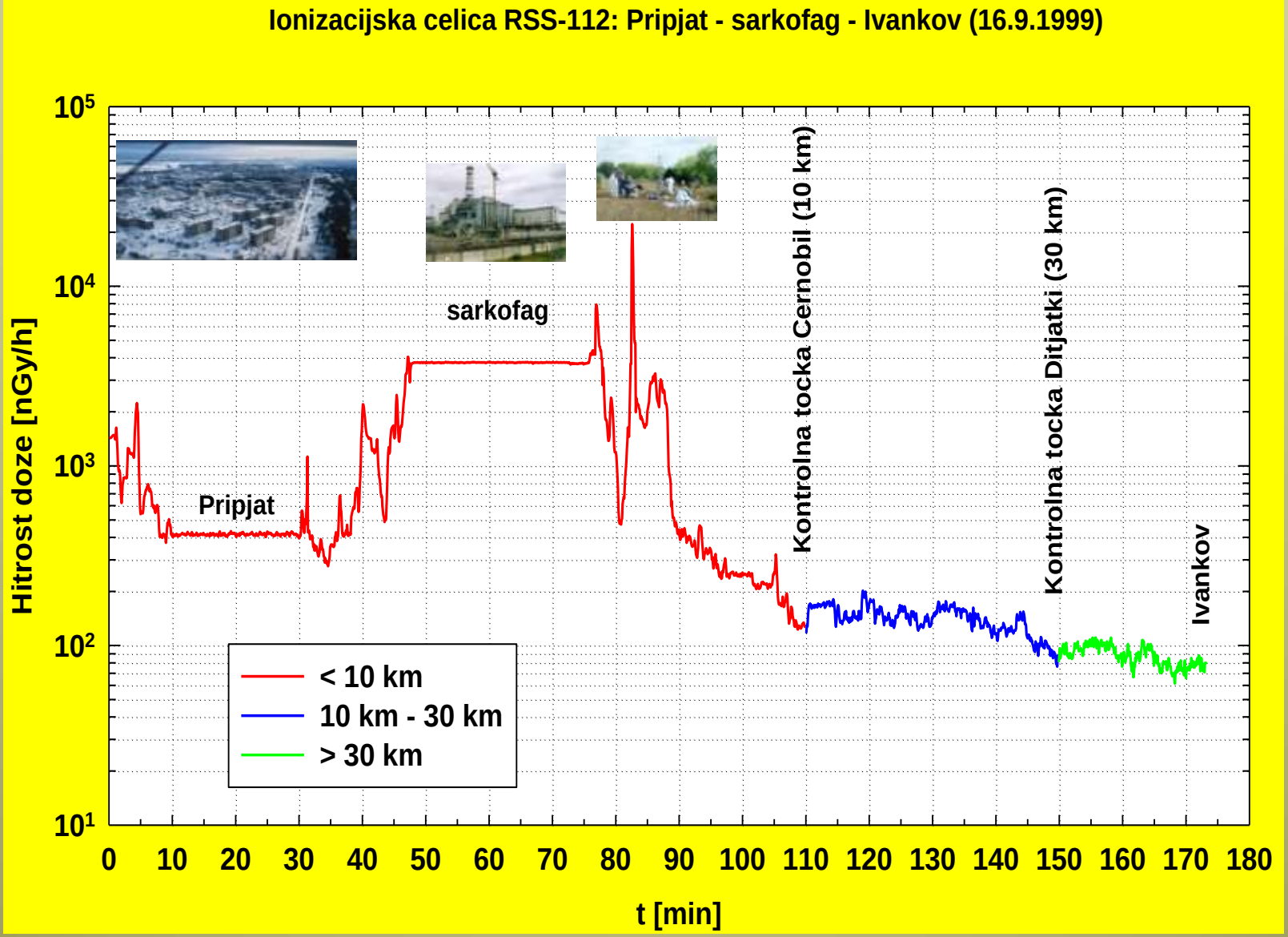



Ionizacijska celica RSS-112: Ljubljana - Ivankov
Δ t = 5 s
Hitrost doze [nGy/h]
t [h]
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
tunela na AC
Dolga vas
Siofok (Balaton)
Budapest (Petofi hid)
Debrecen
H - UA
Karpati
Lvov
Rovno
Zhitomir
Ivankov

Zemljevid kontaminacije



Kontrolna točka Ditjatki (30 km jug)


Ionizacijska celica RSS-112: Pripjat - sarkofag - Ivankov (16.9.1999)
Hitrost doze [nGy/h]
t [min]
Pripjat
sarkofag
Kontrolna tocka Cernobil (10 km)
Kontrolna tocka Ditjatki (30 km)
Ivankov
< 10 km
10 km - 30 km
> 30 km

Živalske kosti Sr-90 ("bone seeker")

Osebna zaščitna oprema – pestrost!

Spektrometrija gama in-situ (HD = 400 mikroSv/h)

Pripjat (50.000 prebivalcev – evakuacija 36 ur po nesreči)

Otroci se tu niso nikoli igrali!

Pripjat - zob časa

Zaključki

	Doza
naravno sevanje	2,4 mSv/leto
• letna mejna doza za poklicno delo • letna mejna doza za prebivalca	20 mSv/leto 1 mSv/leto
RTG pregled	~ mSv
pregled na nuklearni medicini	~ mSv
jedrski objekt	< 0,001 mSv/leto
černobilski gasilci	1000 – 15.000 mGy
$LD_{50/60}$ (celo telo)	~ 4000 mGy