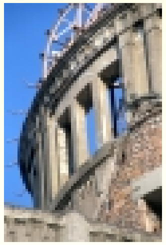
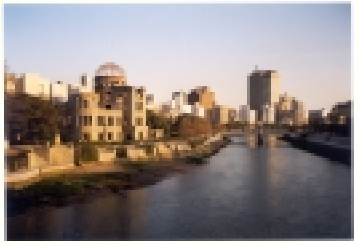
The Cohort of the Atomic Bomb Survivors - Major Basis of Radiation Safety Regulations

Cern Accelerator School

30 May 2005

Zeegse





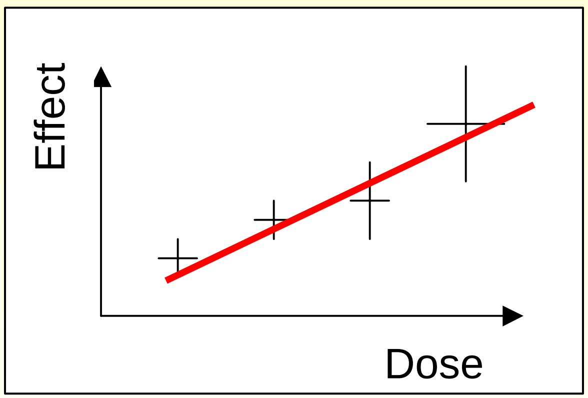
Werner Rühm

Institute for Radiation Protection

GSF - National Research Center for Environment and Health

Study of Radiation-induced *Late* Effects in Cohorts Exposed to Ionising Radiation

Principle (simplified)



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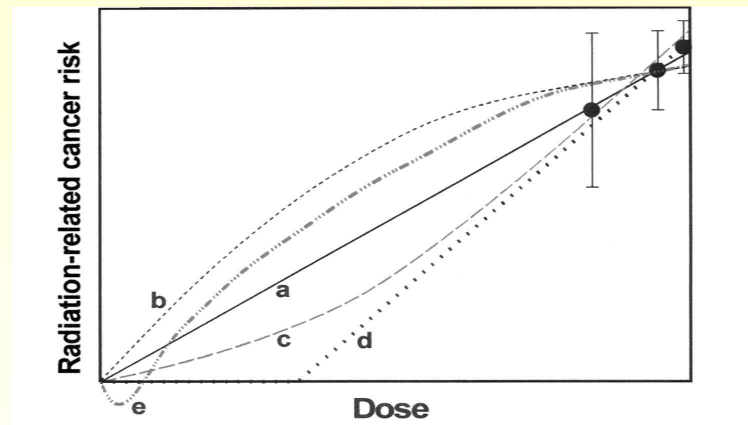


> effect per dose
> „risk estimate“

> extrapolation to low doses relevant for radiation protection

Recommendations of the International Commission on Radiological Protection (ICRP)

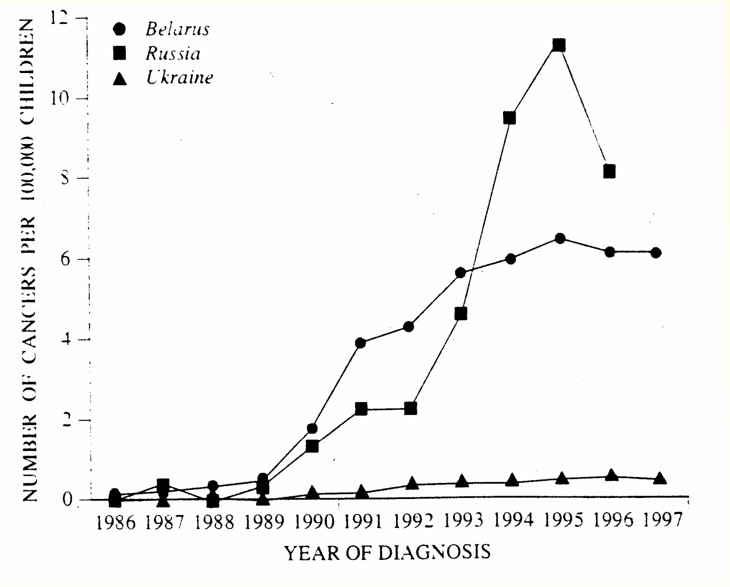
Examples of investigated cohorts

- **Dial painters in the US**

Incorporation of $^{226,228}Ra$

> excess of bone sarcomas

- **Children after Chernobyl**



Incorporation of ^{131}I

> excess of thyroid cancers

Other cohorts

- **Uranium miners**

  Inhalation of ^{222}Rn ... > excess of lung cancers

- **TBC Massachusetts cohort**

  TBC therapy > excess of breast cancers

- **Mayak workers**

  Incorporation of $^{239,240}Pu$ > excess of lung cancers

- **Oxford in-utero study**

  X-ray exposure > excess of leukemia and solid tumors

⋮

Why is the A-bomb survivor cohort unique?

- about 100.000 survivors investigated
- > 50 years follow-up
- exposure of representative population
  (males and females - children and adults)
- whole-body exposure
  (instead of partial-body exposure, as in many medical cohorts)
- dose-range from mSv to Sv
  (i.e. from natural levels to lethal doses)
- internal control group

Limitation of the study

- Acute exposure
  (i.e. not continuous as at many work places)

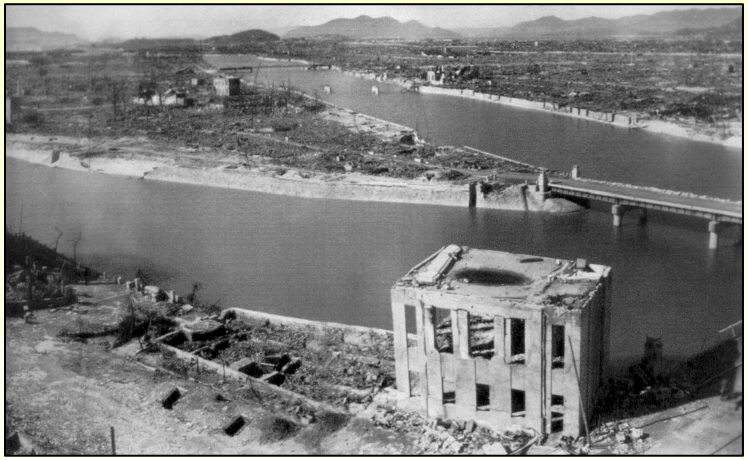
- mainly external exposure
  (i.e. consequences of internal exposures cannot be investigated)

- mixed radiation field
  (i.e. low-LET gamma radiation and high-LET neutron radiation)

- results obtained for Japanese population
  (i.e. difficult to transfer results e.g. to western populations)

The A-bomb Explosions

Hiroshima



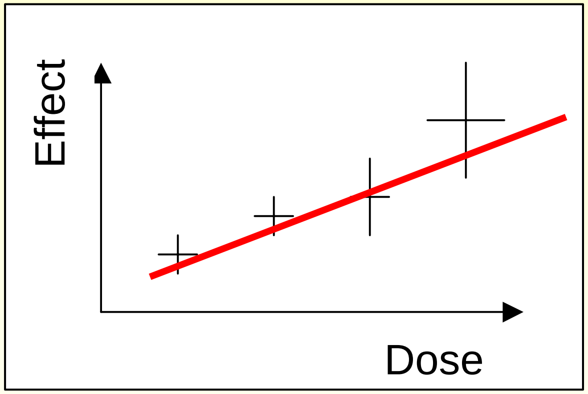
- August 6th, 1945, 8:15 a.m.
- inhabitants: 350.000
- casualties (end of 1945): 140.000

Nagasaki

- August 9th, 1945, 11:02 a.m.
- inhabitants: 270.000
- casualties (end of 1945): 70.000

Study of Radiation-induced *Late* Effects among the A-bomb Survivors

Principle (simplified)



> effect per dose
> „risk estimate“

y-axis: **Life Span Study** (LSS)

x-axis: **Dosimetry System 1986** (DS86)

Y-Axis: The Life Span Study Cohort

- Master cohort including 120.000 survivors established by
- Atomic Bomb Casualty Commission (ABCC): 1947 - 1975
- Radiation Effects Research Foundation (RERF): 1975 -

since 1950 biennial health examinations on about 24.000 survivors (**AHS**)

Children of atomic bomb survivors (**F1**) study on 77.000 individuals

since 1950 follow-up of about 86.000 survivors (**LSS**)

in-utero study on 3.300 individuals

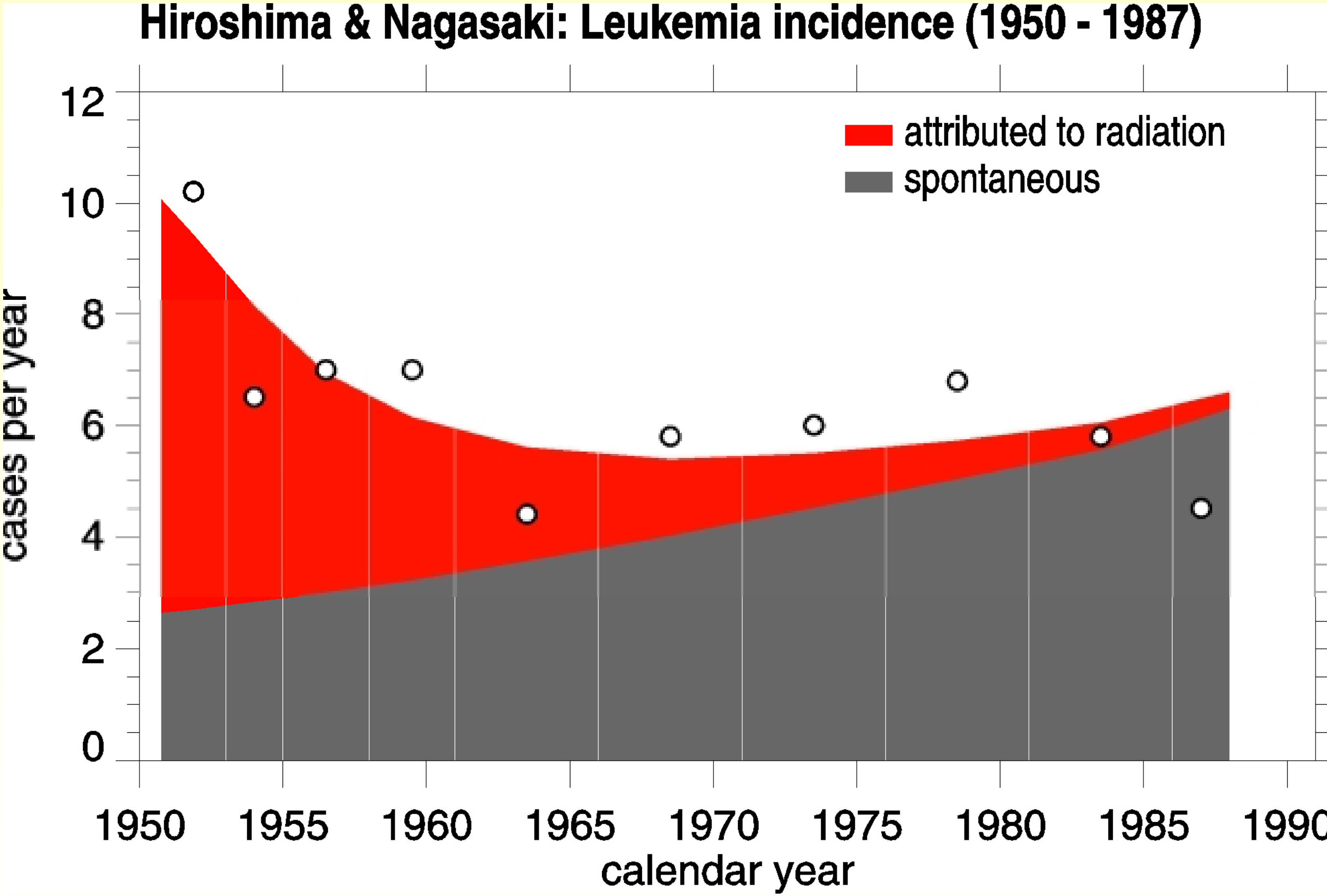
LSS cohort

Age at exposure	number	alive (1998)
0 – 9	17824	91 %
10 – 19	17558	80 %
20 – 29	10883	66 %
30 – 39	12266	31 %
40 – 49	13491	4 %
50+	14550	0 %
total	**86572**	**48 %**

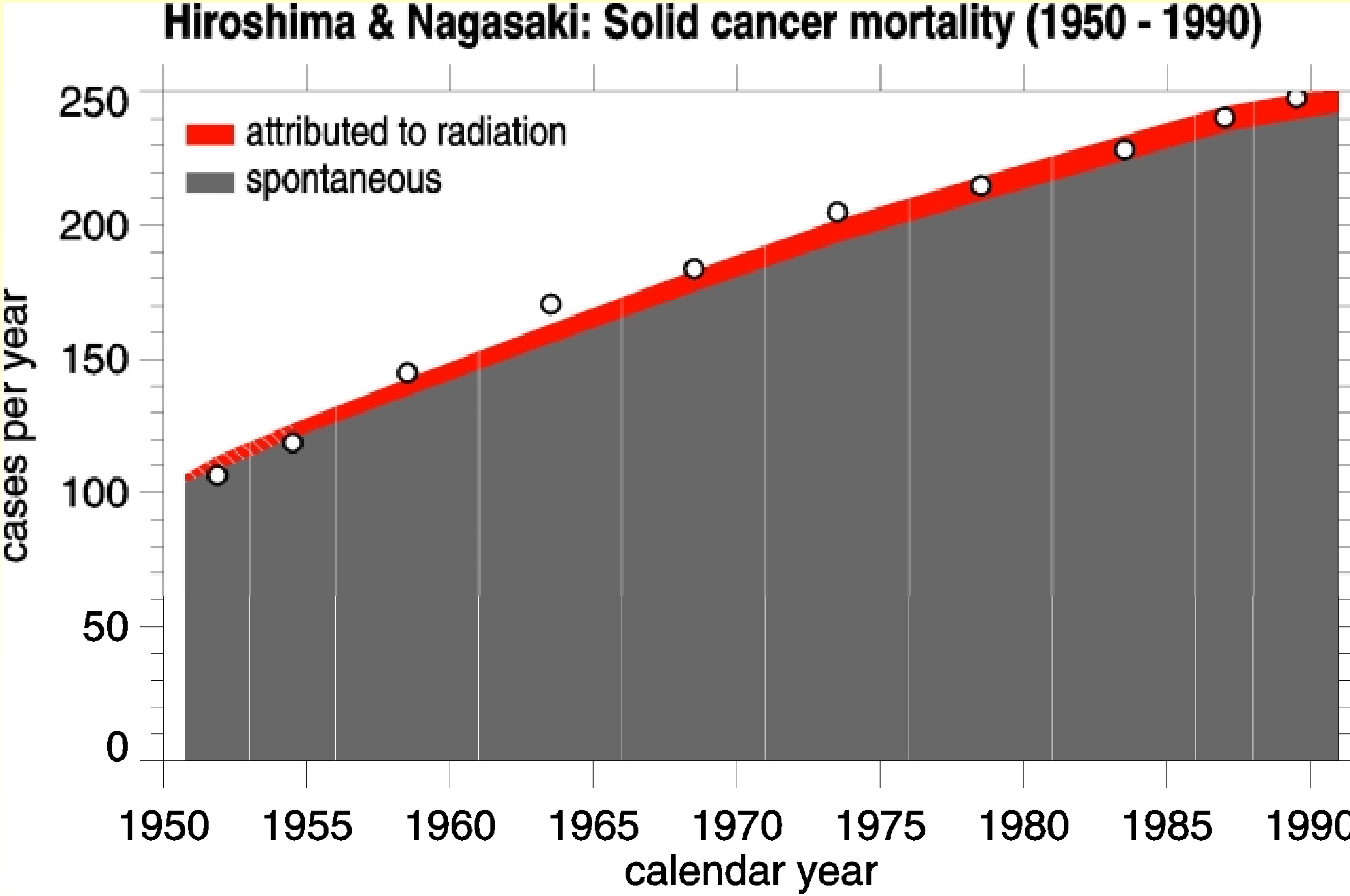
Example: solid tumours and leukemia

1950 - 1990	Hiroshima	Nagasaki	total	1950 – 2000 total
Survivors	58459	28113	**86572**	**86611**
Deaths	26495	11175	37670	47685
Solid tumors	5436	2142	7578	10127
Radiation-induced	247	87	**334**	**479**
Leukemia	196	53	249	296
Radiation-induced	70	17	**87**	**93**

Pierce et al. 1996, Preston et al. 2004



(Kellerer AM, www.nupecc.org/ iai2001/ risk estimation)



(Kellerer AM, www.nupecc.org/ iai2001/ risk estimation)

Noncancer Diseases (1968-1997)

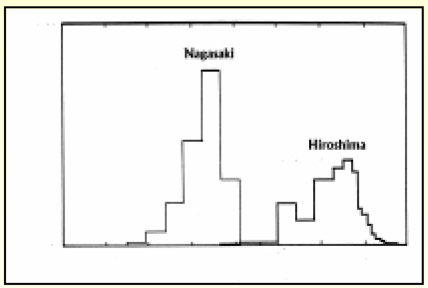
Follow-up 1968 - 1997
distance to hypocenter < 3.000 m

1968 - 1997	Deaths	Excess	ERR / Sv
Heart disease	4477	101	0.17 (+0.09; -0.09)
Stroke	3954	64	0.12 (+0.10; -0.10)
Respiratory disease	2266	57	0.18 (+0.14; -0.12)
Digestive disease	1292	27	0.15 (+0.17; -0.15)
Infectious disease	307	-1	-0.02 (+0.27; -0.22)
Other diseases	2073	24	0.08 (+0.15; -0.12)
total	**14459**	**273**	**0.14 (+0.06; -0.06)**

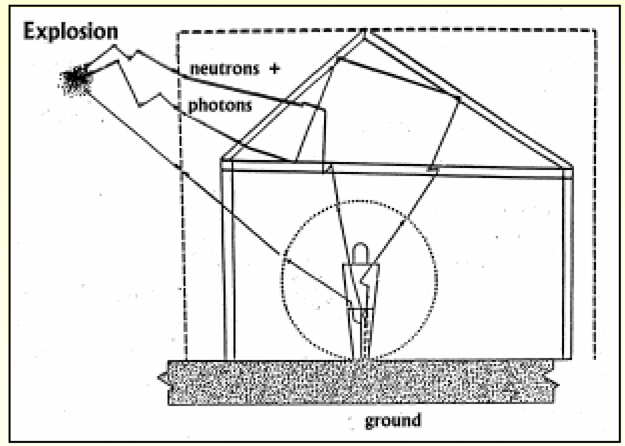
(Preston et al. 2003)

X-Axis: The Dosimetry Systems DS86 / DS02

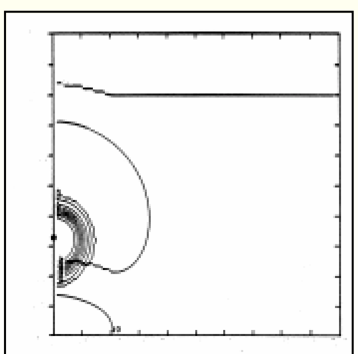
Principle: Coupled neutron-gamma transport calculations from epicentre to target organ (RERF 1987)



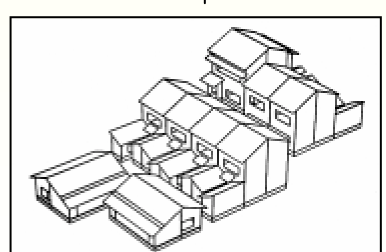
Neutron source terms



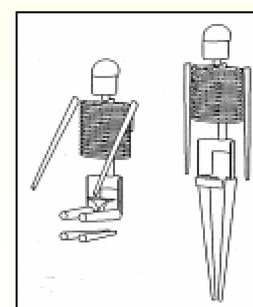
Individual location



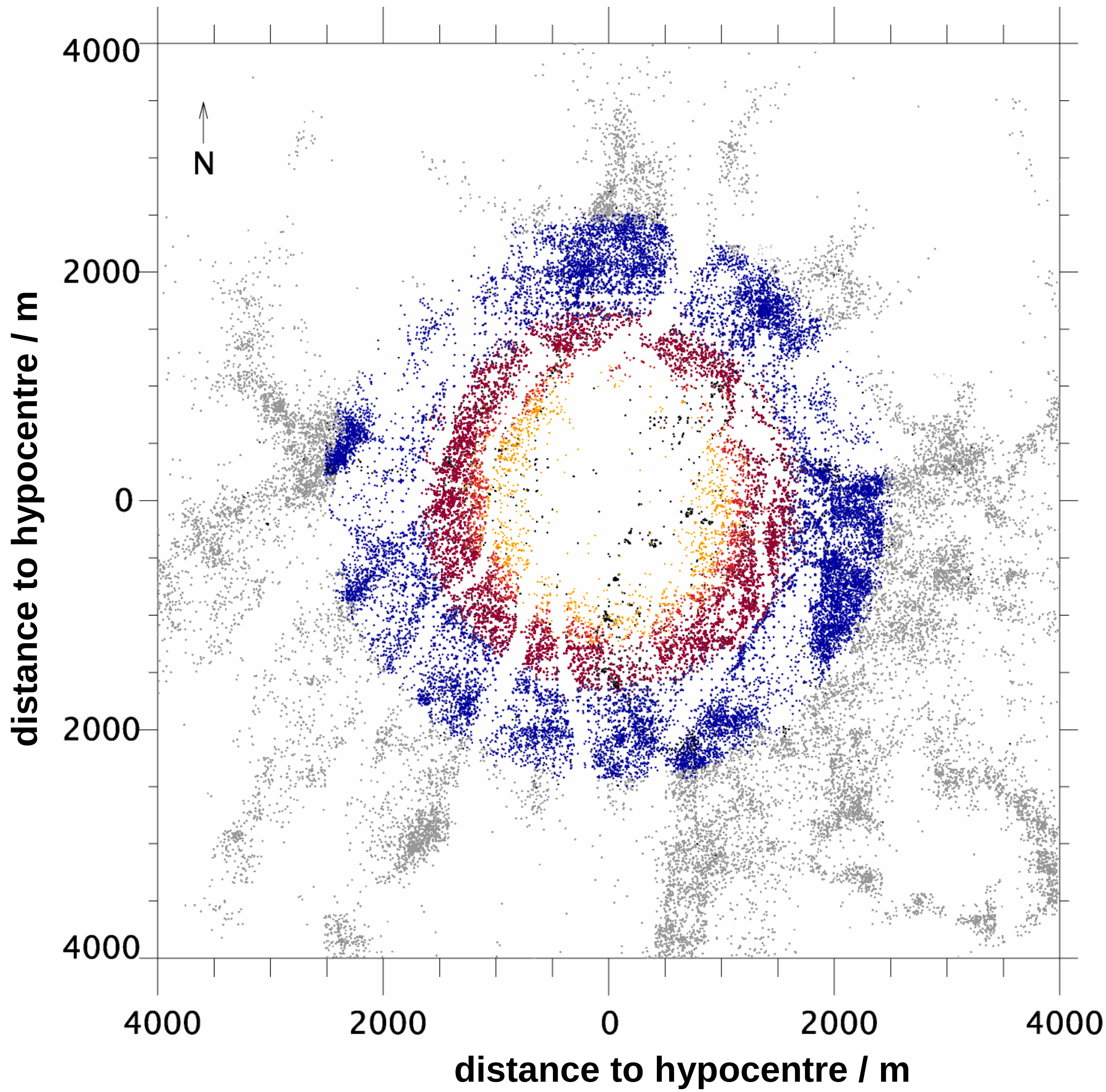
Iso-contours of air density



House cluster



Human phantoms



D < 5 mSv
5 mSv < D < 0,1 Sv
0,1 Sv < D < 0,5 Sv
0,5 Sv < D < 1,0 Sv
D > 1 Sv
unknown dose

Experimental Verification of DS86/DS02 Methodology

Use of measurements done at Nevada Test Site

- Test explosions (Nagasaki-type devices)
- tower (465 m high) with neutron and ^{60}Co source
- shielding of Japanese houses

Investigation of Environmental Samples from Hiroshima and Nagasaki

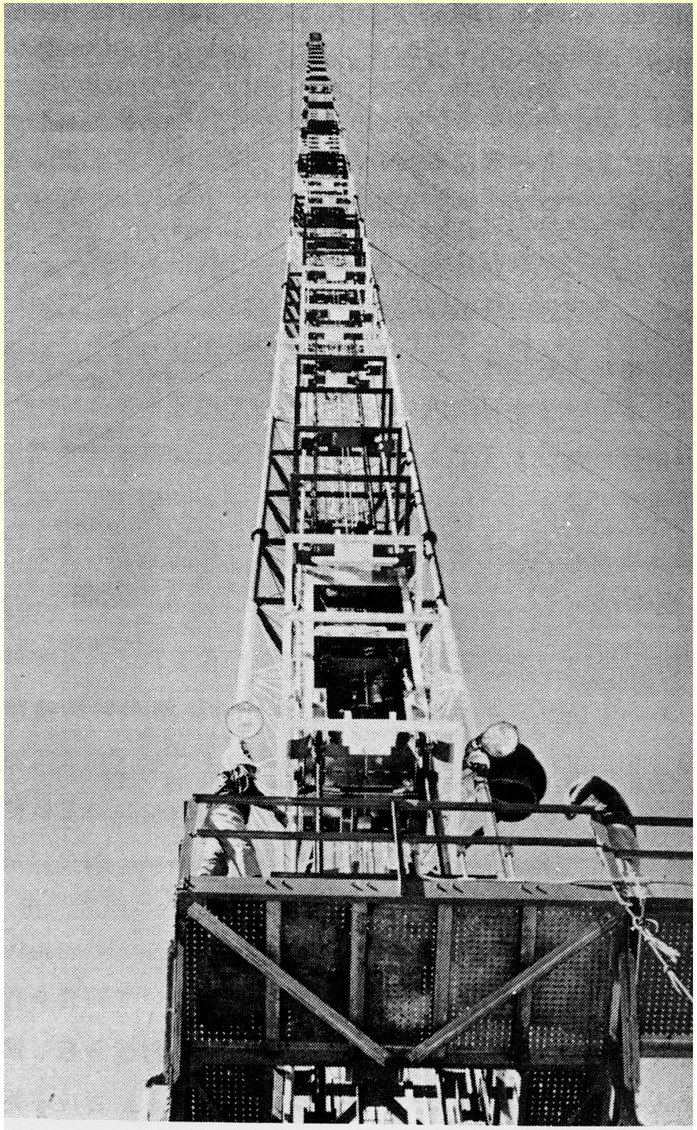
Gammas

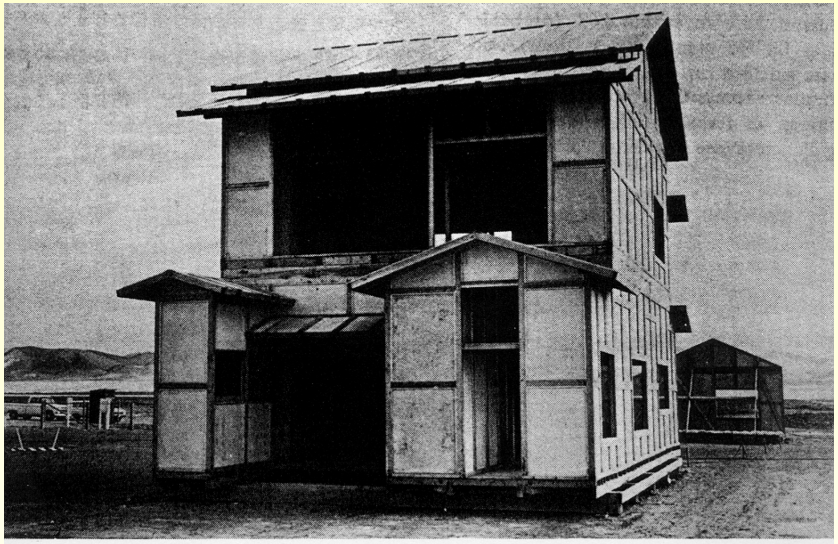
- method: thermoluminescence
- material: quartz
- samples: e.g. roof tiles

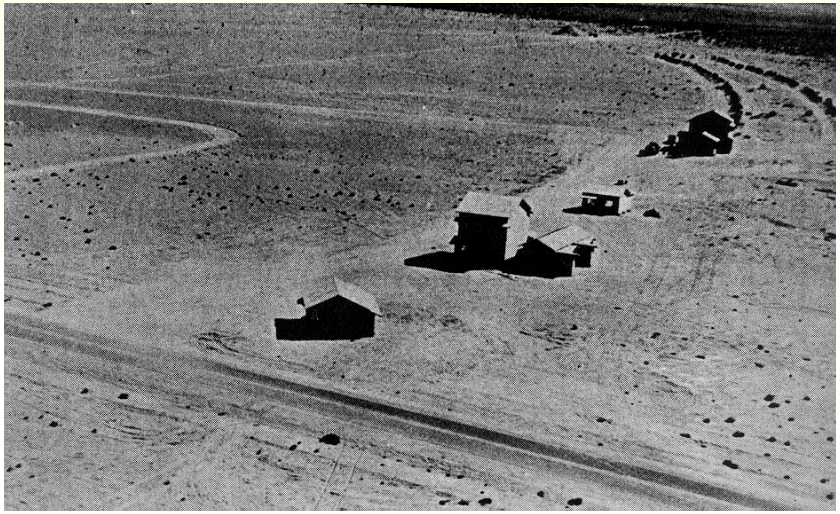
Neutrons

- detection of activation products
- by activity and AMS measurements
- samples: e.g. mineral samples

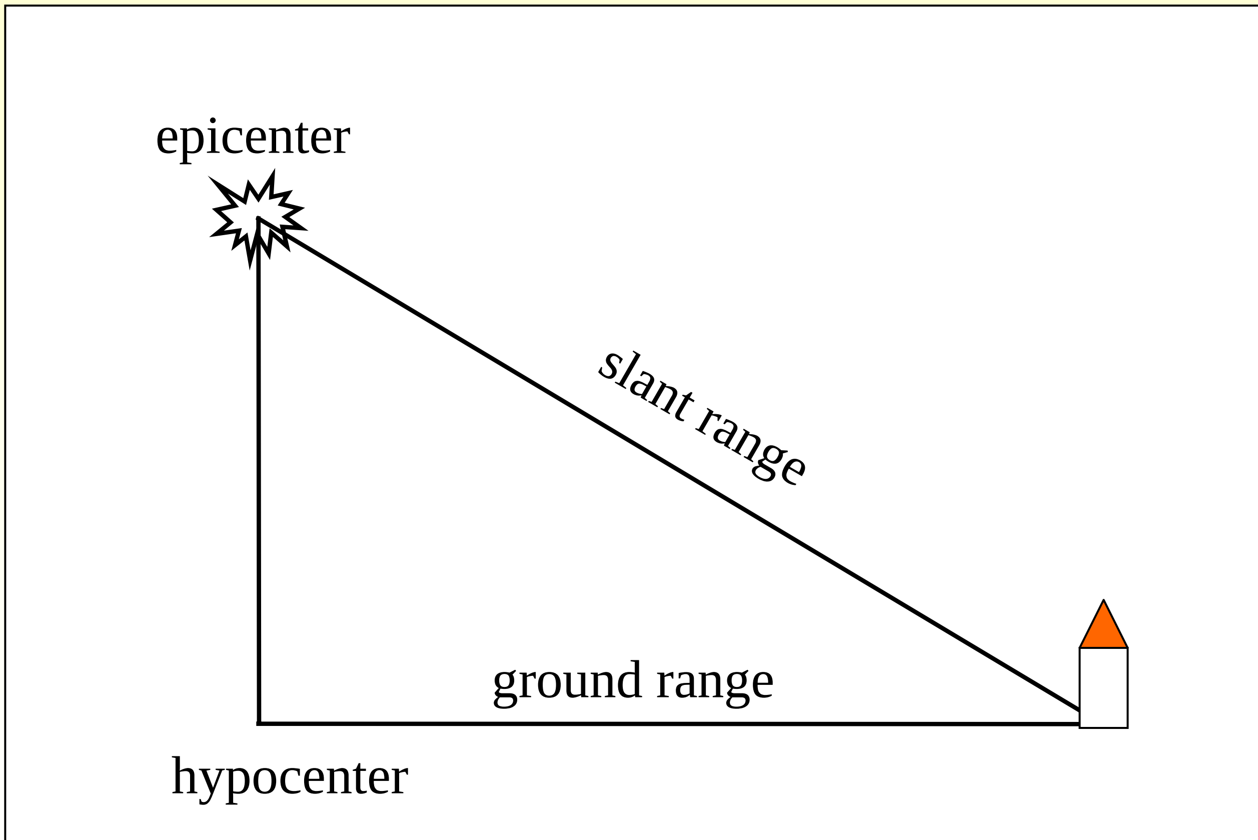
Nevada Test Site





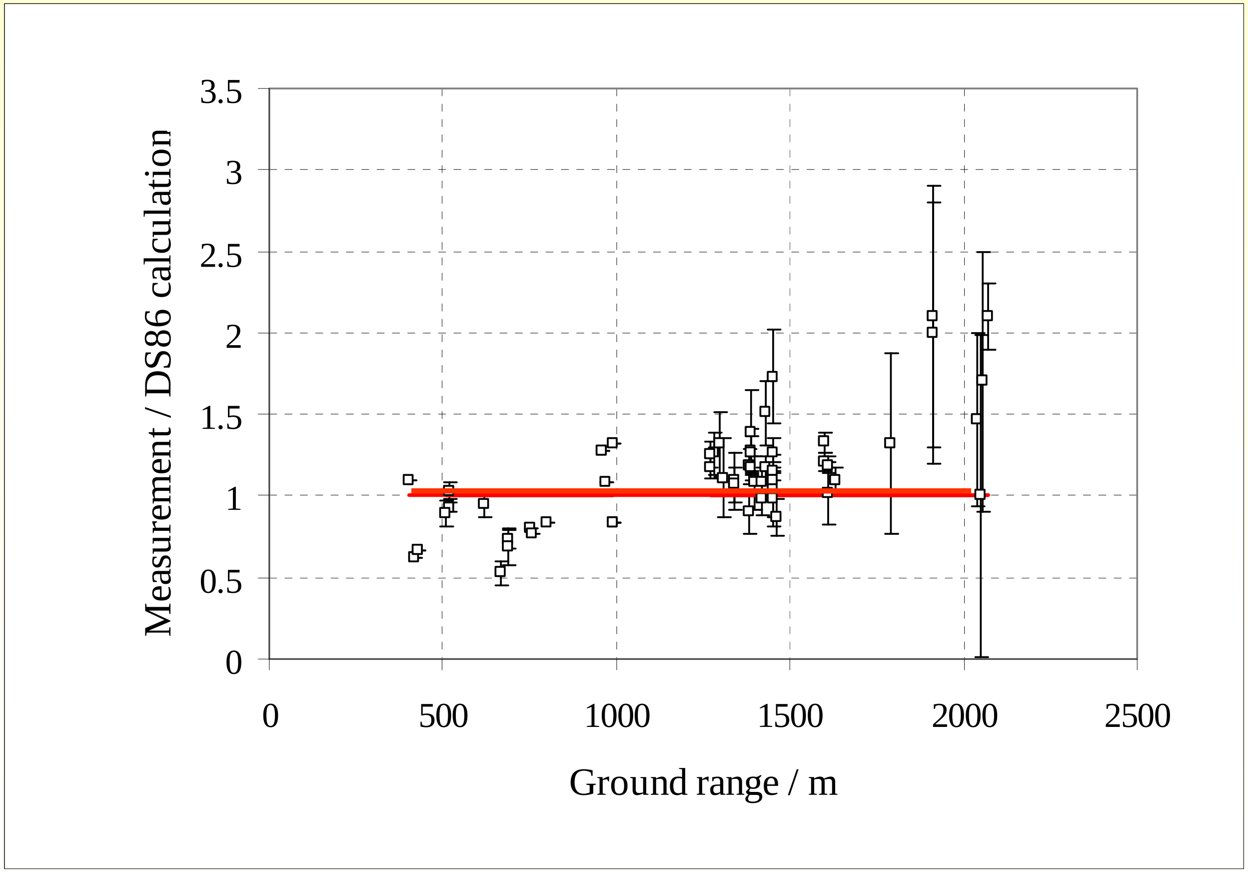


Definitions



Retrospective Assessment of Gamma-radiation, Hiroshima

Thermoluminescence measurements on roof tiles, ...

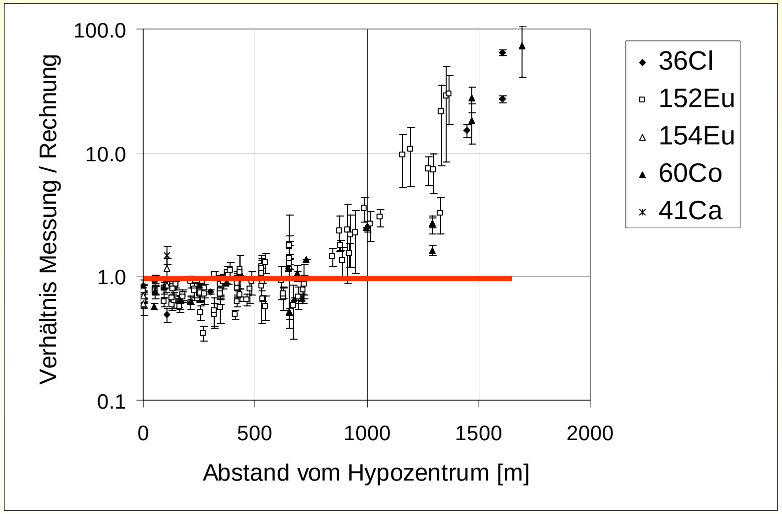


literature (1966 - 1995)

Retrospective Assessment of Neutrons, Hiroshima

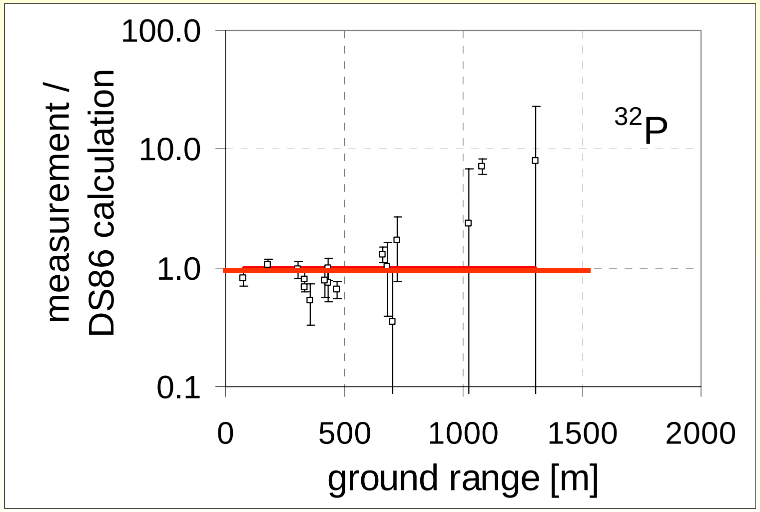
Nuclide	$T_{½}$	Reaction	Samples	Method	Reference
^{32}P	14.3 d	$^{32}S(n_f,p)^{32}P$	insulators	β	Yamasaki & Sugimoto 1953, Arakatsu 1953
^{60}Co	5.27 y	$^{59}Co(n_{th},\gamma)^{60}Co$	reinforcing steel bars, granite ...	γ	Saito 1961, Hashizume et al. 1967
^{152}Eu	13.3 y	$^{151}Eu(n_{th},\gamma)^{152}Eu$	rock, concrete	γ	Nakanishi et al. 1983
^{154}Eu	8.8 y	$^{153}Eu(n_{th},\gamma)^{154}Eu$	rock, concrete	γ	Nakanishi et al. 1983
^{36}Cl	$3{\cdot}10^5$ y	$^{35}Cl(n_{th},\gamma)^{36}Cl$	granite, concrete	AMS	Haberstock et al. 1986, Straume et al. 1992
^{41}Ca	$1{\cdot}10^5$ y	$^{40}Ca(n_{th},\gamma)^{41}Ca$	granite	AMS	Korschinek et al. 1987, Rühm et al. 1992
^{63}Ni	100 y	$^{62}Ni(n_{th},\gamma)^{63}Ni$	steel	β	Shibata et al. 1997

Results - **thermal** neutrons



literature, 1967 - 1998

Results - **fast** neutrons



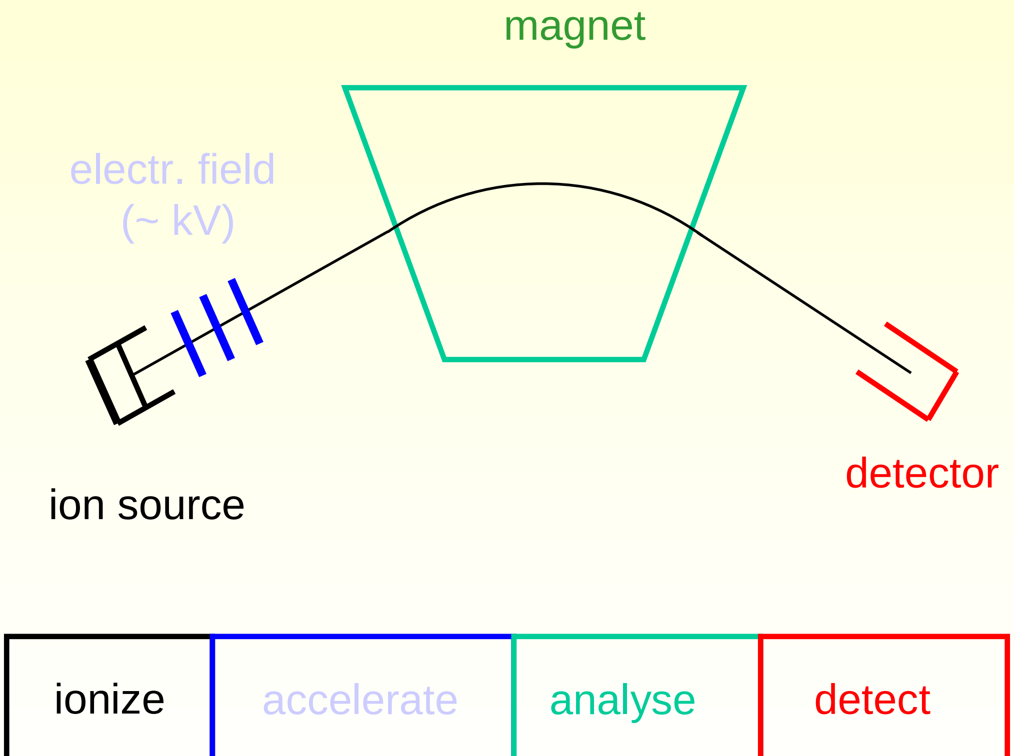
Yamasaki & Sugimoto 1953, Arakatsu 1953

„Hiroshima neutron discrepancy“

Retrospective Assessment of Fast Neutrons at Munich (Neutron Dose!)

- Detection of **^{63}Ni** in copper samples from Hiroshima
- produced by **fast** neutrons: $^{63}Cu(n_f,p)^{63}Ni$
- half-life: 100 years
- DS86, 1.500 m ground range: $^{63}Ni/^{63}Cu \approx 2 \times 10^{-18}$; $\approx 3 \times 10^{-6}$ Bq/gCu
- sample collection by RERF, University of Hiroshima
- dedicated chemistry at LLNL, University of Utah
- detection at Maier-Leibnitz-Laboratory, Garching, by means of **accelerator mass spectrometry**
- unique combination of 14 MP Tandem and gas-filled magnet

Conventional mass spectrometry - principle



Problem:

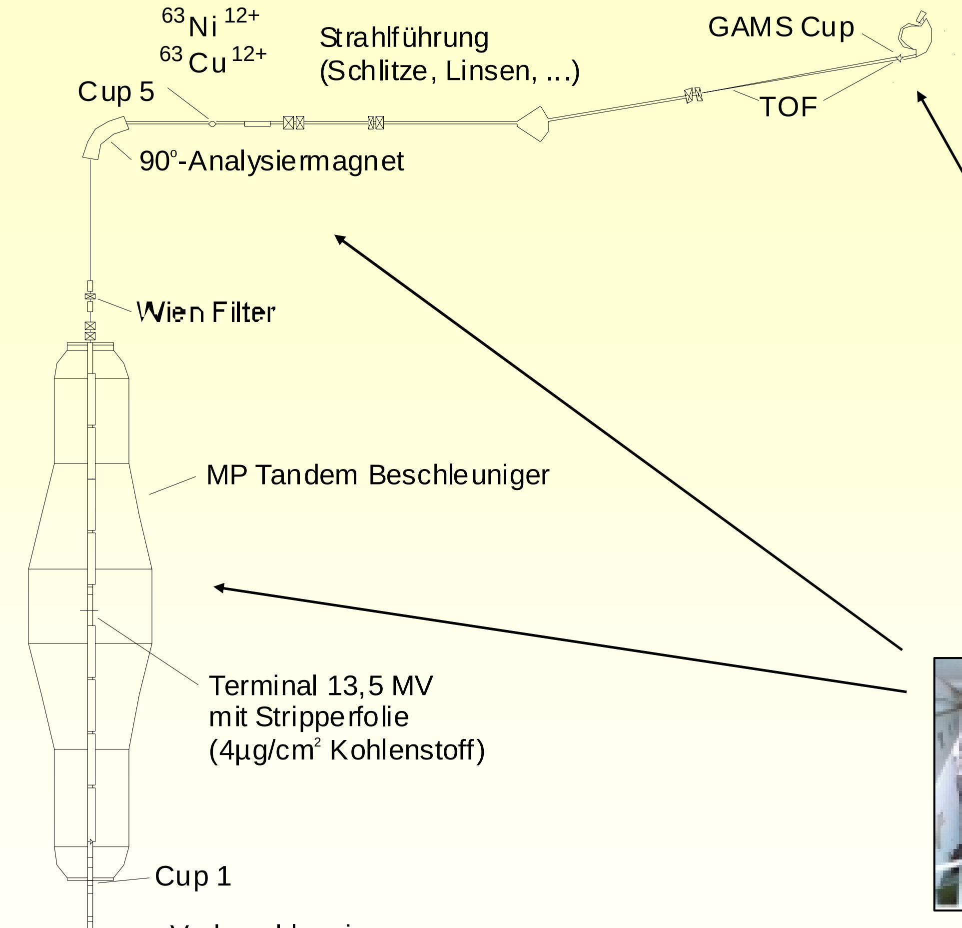
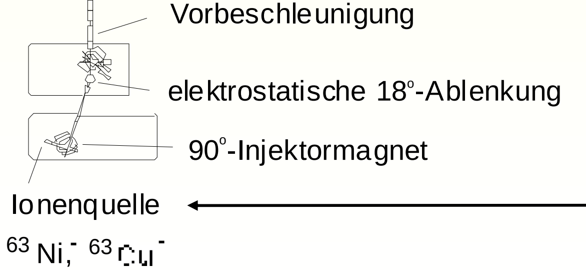
- molecules with same mass
  ➡ molecular background
- nuclei with same mass
  ➡ isobaric background

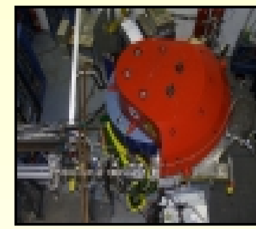
solution:

- high energies

  ➡ **accelerator mass spectrometry (AMS)**

AMS with ^{63}Ni at Munich Tandem Laboratory

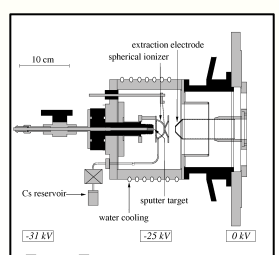





Detector

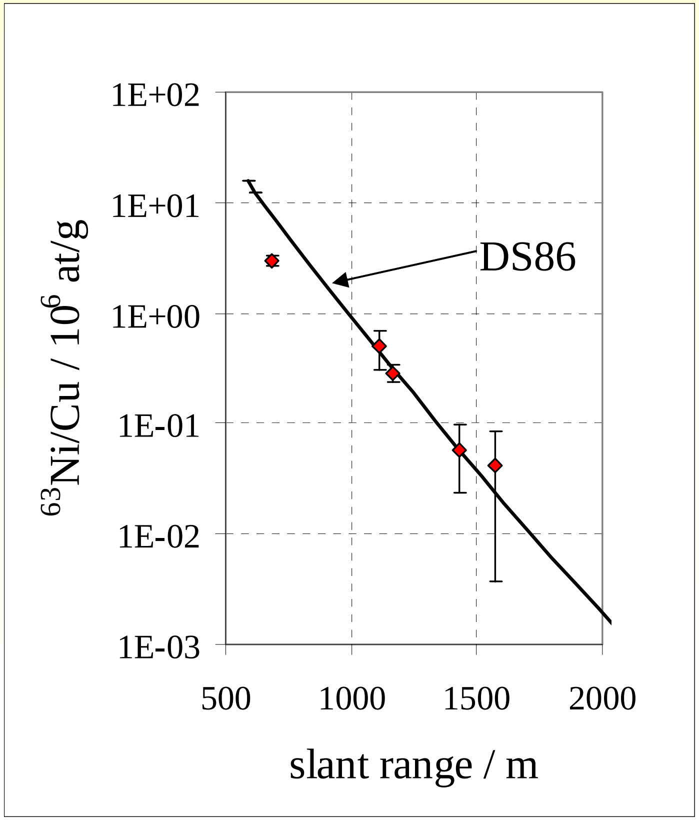
Analysing magnet

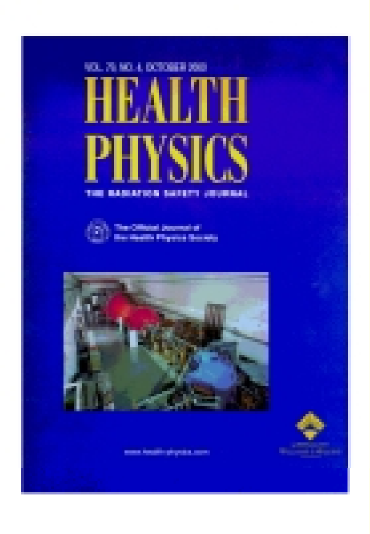
13.5 MV Tandem Accelerator



Copper free ion source

^{63}Ni - Results





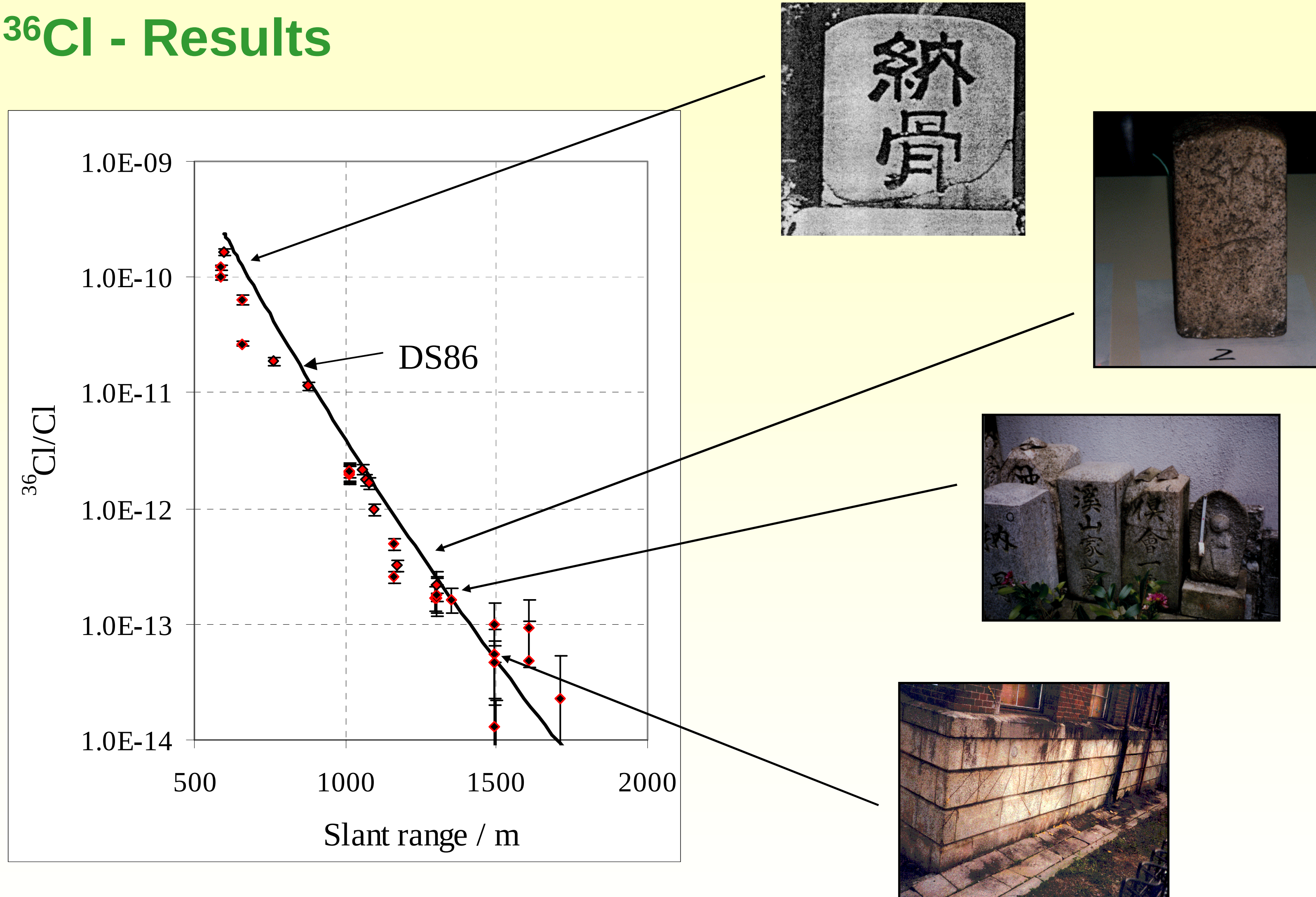
Rühm, Knie, Rugel, Marchetti, Faestermann, Wallner, McAninch, Straume, Korschinek. *Health Phys.* **79**, 358-364 (2000)

Straume, Rugel, Marchetti, Rühm, Korschinek, McAninch, Carroll, Egbert, Faestermann, Knie, Martinelli, Wallner, Wallner. *Nature* **424**, 539-542 (2003)

Retrospective Assessment of Thermal Neutrons at Munich

- Detection of **^{36}Cl** in granite samples from Hiroshima
- produced by **thermal** neutrons: $^{35}Cl(n_{th},\gamma)^{36}Cl$
- half-life: 300.000 years
- DS86, 1.500 m ground range: $^{36}Cl/Cl \approx 10^{-14}$
- sample collection: Hiroshima Pref. College of Health Science
- sample preparation at Munich
- detection at Maier-Leibnitz-Laboratory, Garching, by means of **accelerator mass spectrometry**

^{36}Cl - Results



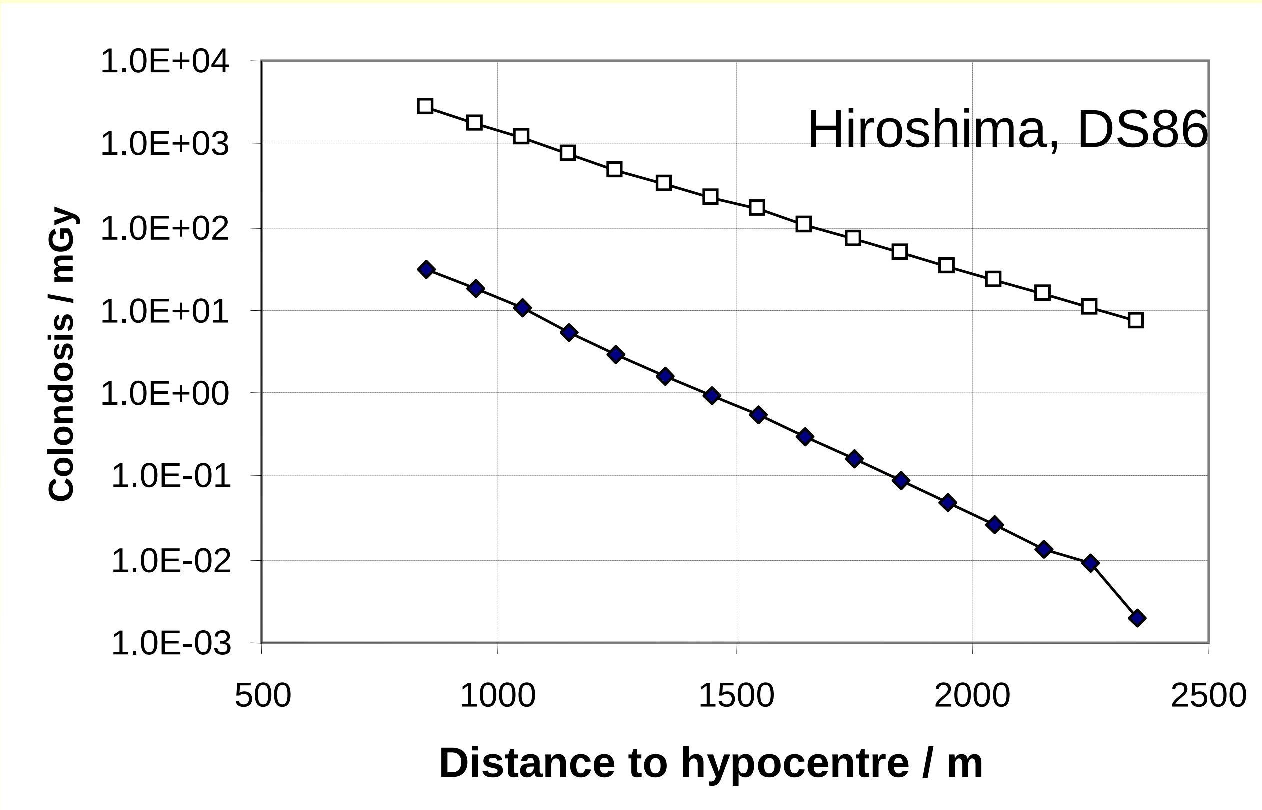
(Huber, Rühm, Kato, Nolte, 2005, submitted to Radiat Environ Biophys)

Major revision of DS86 now finished

- joint US-Japanese-German effort
- new source terms
- new coordinates of epicentre
- new calculations
- new cross sections
- new measurements
- reevaluation of old measurements
- systematic investigation of background issues

>> DS02

Resulting Risk Estimates - Examples



- only small contribution of neutrons to absorbed dose
- RBE=10 > contribution of neutrons to equivalent dose still small („RERF philosophy“)

(Preston et al., RERF Report 13, Rad Res 160, 2003)

Risk Assessment

O - number of events observed in an **exposed** population

E - number of events expected in an **unexposed** population

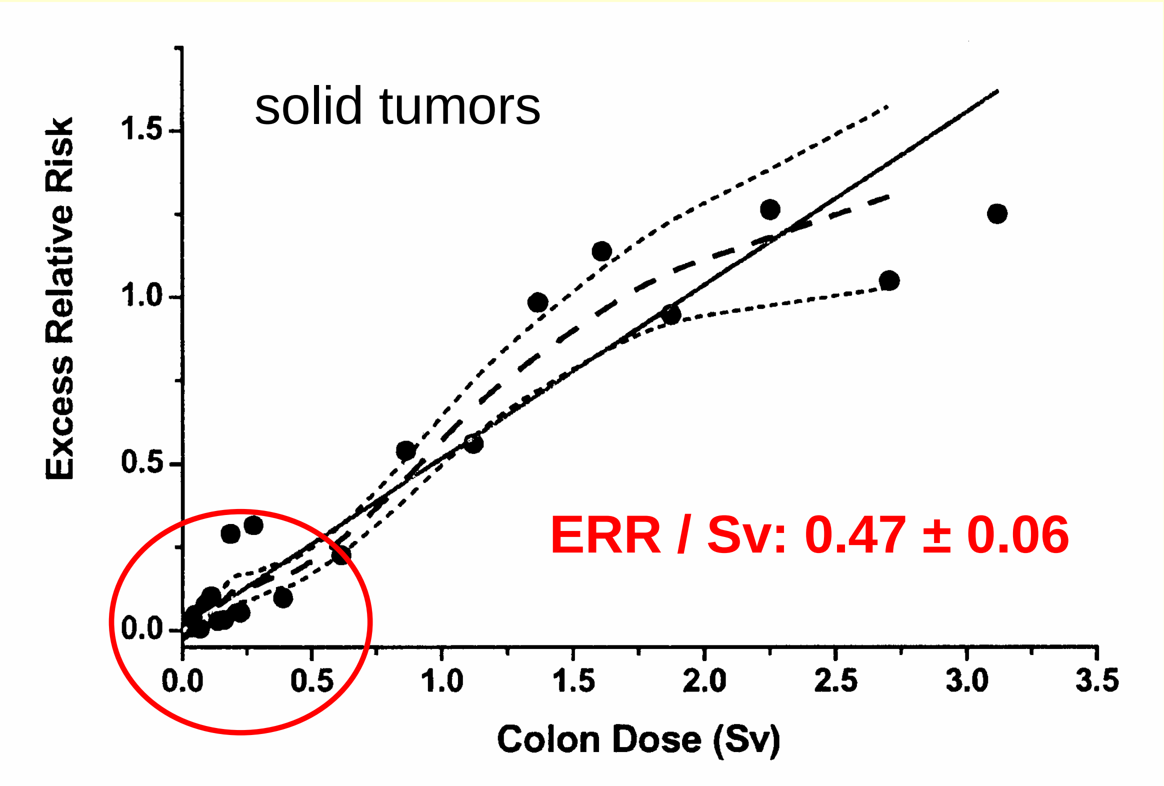
D - average dose recieved by an exposed population

Excess relative risk per unit dose (ERR/D) = (O-E) / E·D

Acute irradiation of 1 Sv increases the solid tumour rate by 50%

--------> ERR = 0.5 / Sv

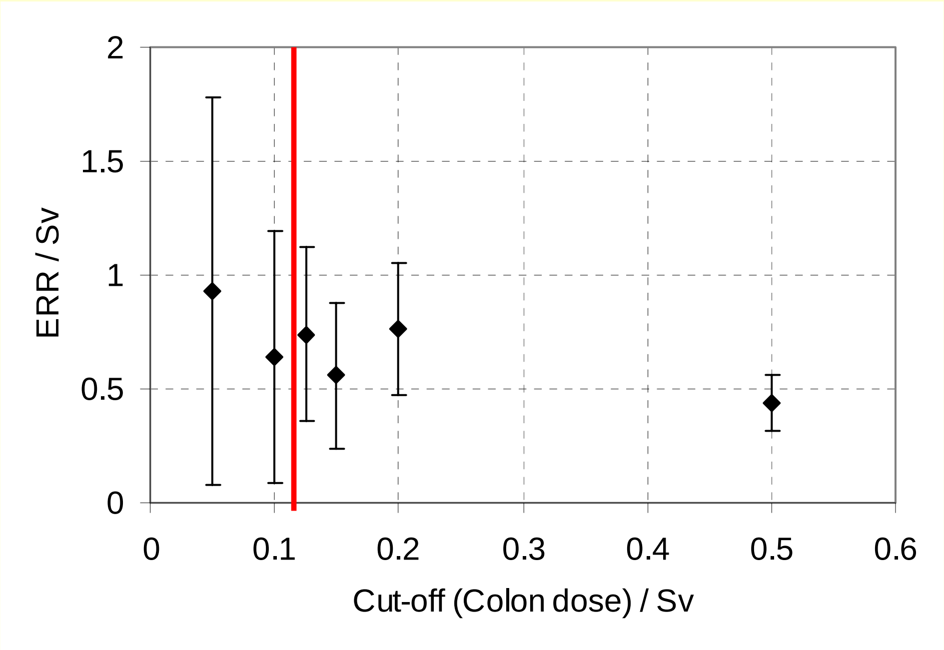
Follow-up 1950-1997



(age: 70 years,
age at exposure: 30 years,
gender averaged)

(Preston et al.,
RERF Report 13,
Rad Res 160, 2003)

„There is little evidence against a simple linear dose response, with the only apparent curvature being a flattening for those dose estimates above 2 Sv that is not statistically significant.“



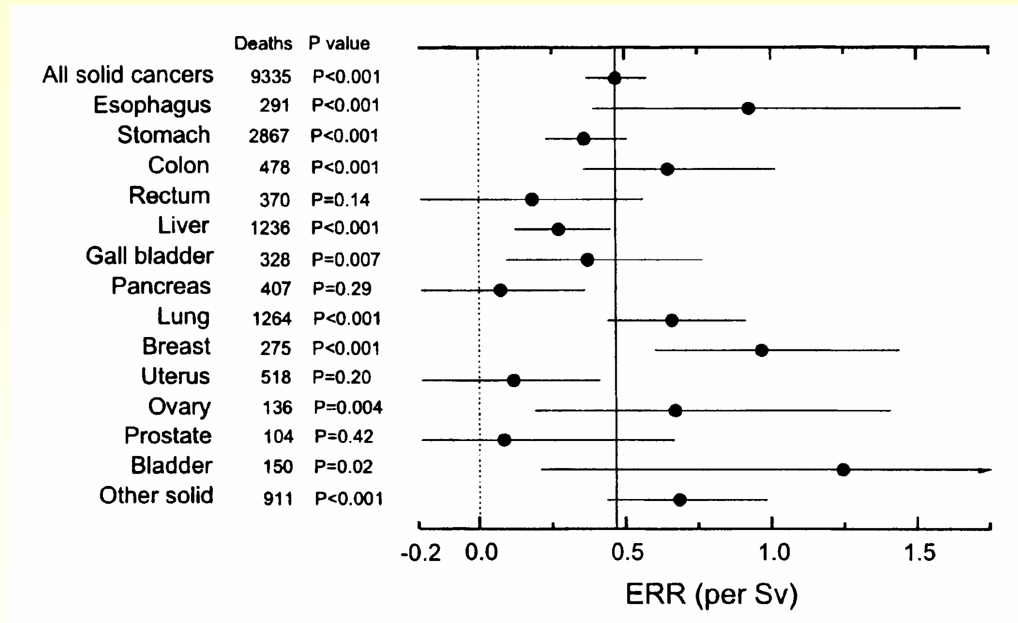
„... a statistically significant increase with dose when analysis is restricted to survivors with dose estimates less than about 0.12 Sv *(i.e. the cut-off dose from figure)***. The ERR per Sv estimate over this range is 0.74 (90% CI 0.1; 1.5).“**

(Preston et al., RERF Report 13, Rad Res 160, 2003)

1950 - 1997	total
survivors	86572
Solid tumors	9335
excess	**440**

1950 - 1997	excess
stomach	100
colon	30
liver	50
lung	100
breast	40
others	120

Organ-specific analysis



age: 70 years, age at exposure: 30 years;
relative to colon dose, partly gender averaged

(Preston et al., RERF Report 13, Rad Res 160, 2003)

Follow-up 1950-2000

- solid tumors: number of excess cases now 479 (instead of 440 til 1997)
- leukemia: number of excess cases now 93 (instead of 87 til 1990)
- new dosimetry DS02: ca. 10% higher γ-dose
  > new risk estimates about 8% lower
- no significant difference between Hiroshima and Nagasaki
- curvature in the dose response curve for solid tumors

„... But for solid cancers the additional 3 years of follow-up has some effect. In particular there is for the first time a statistically significant upward curvature for solid cancer on the restricted dose range 0 - 2 Sv.“

(Preston et al., RERF, Rad Res 162, 2004)

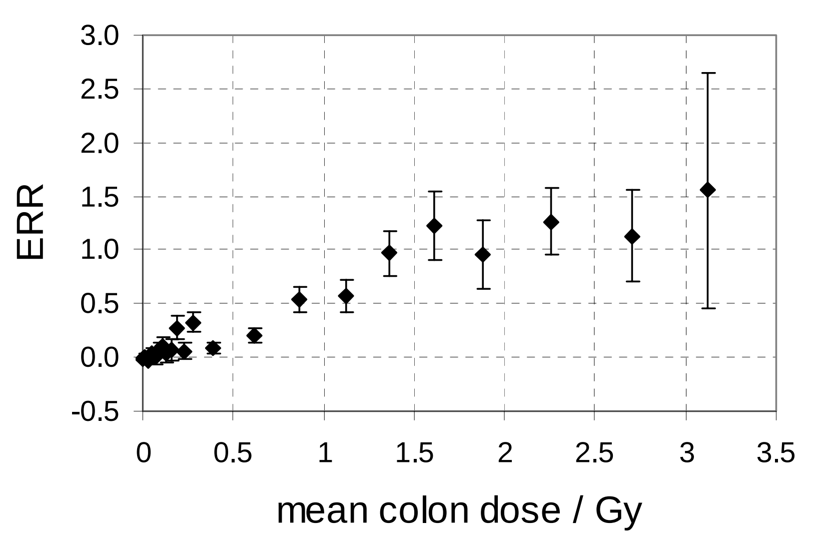
Independent analysis shows similar results

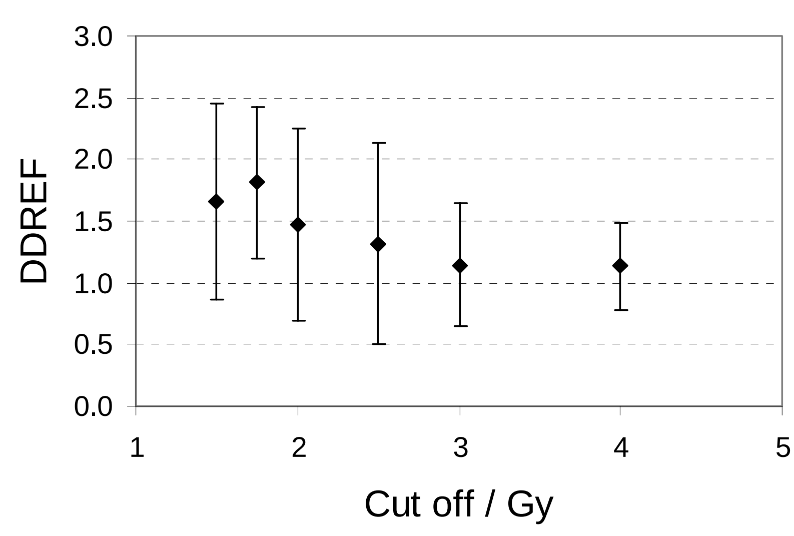
- solid tumours, follow-up 1950-1997
- organ-specific doses
- cut-off 2 Sv
- R = 35 for the neutrons, bei 1 Gy

(Walsh, Rühm, Kellerer, Rad Environ Biophys 43, 2004a))

- **ERR/GY = 0.47 (0.37-0.58) (age-at-exposure: 30 y)**
- **„A DDREF=2 is now much more in line with the data than before“**

DDREF = $\text{slope}_{\text{linear}}$ / $\text{slope}_{\text{low doses, linear-quadratic}}$



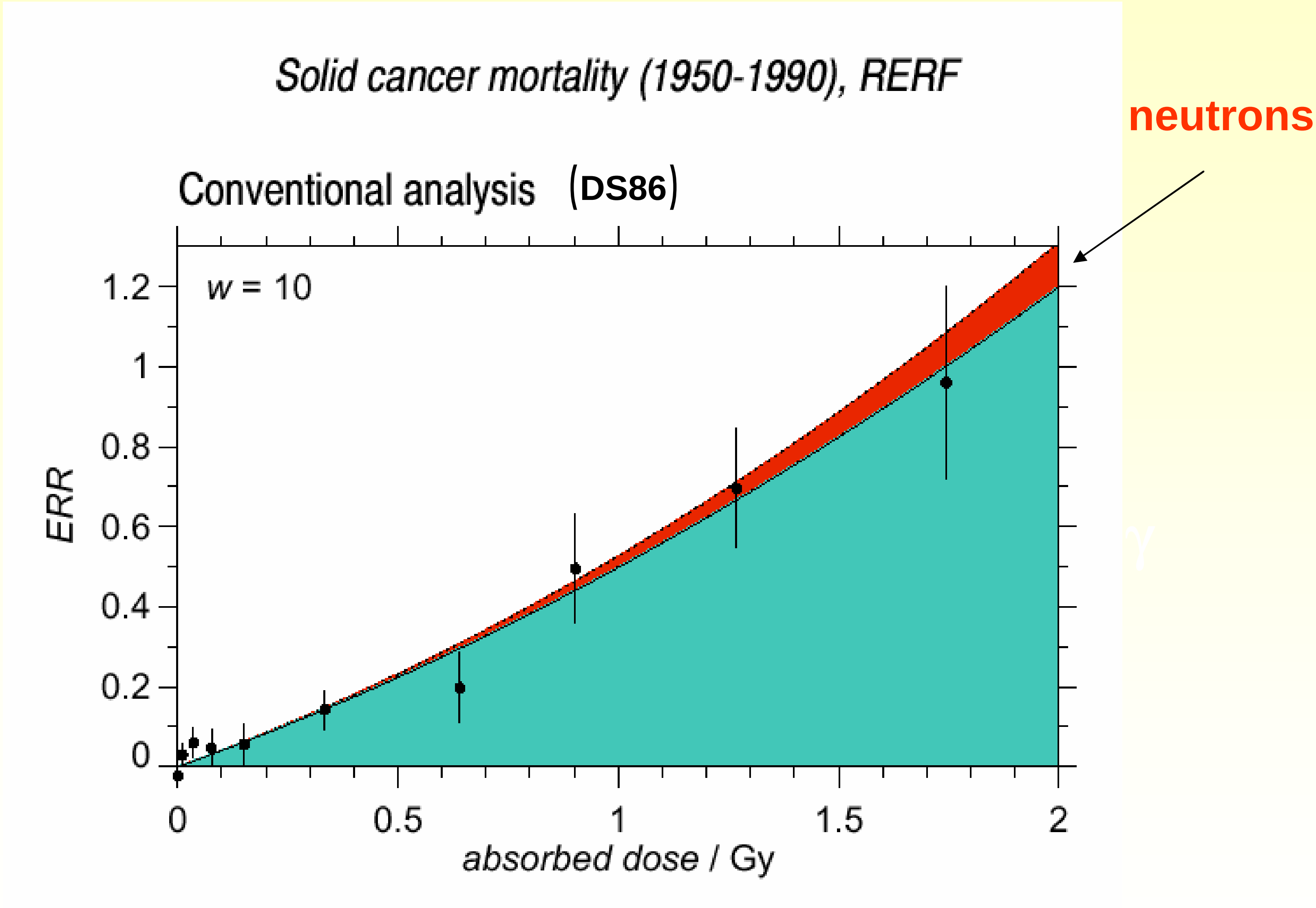


Problem: RBW=10 as used by RERF probably too low

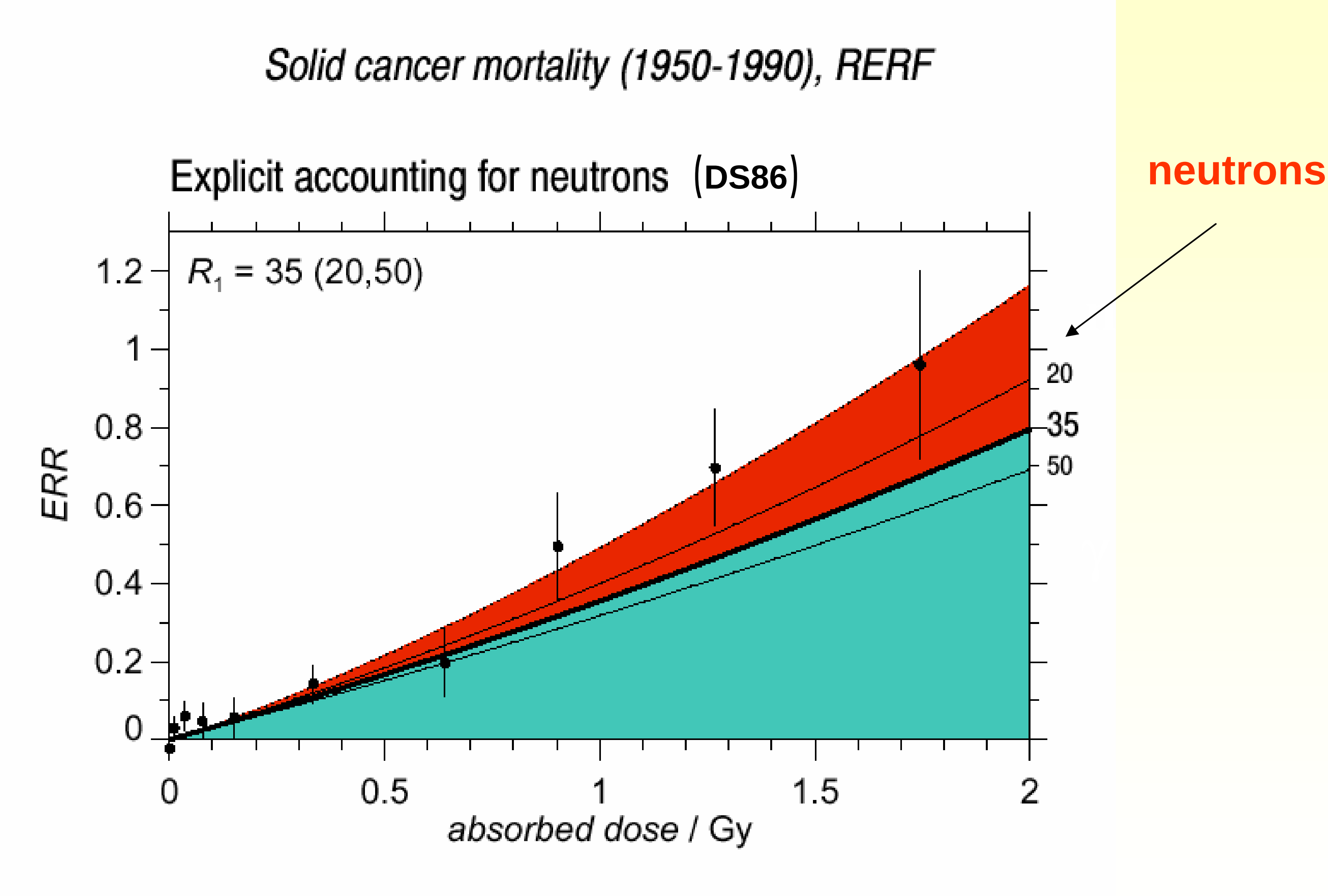
- Chromosome aberrations in vitro
  (Rühm, Walsh, Chomentowski, Radiat Environ Biophys, 2003)

- animal experiments
  (Wolf et al., Radiat Res 154 2000)

- ICRP neutron weighting factor



(Kellerer, Walsh, Nekolla, Radiat Environ Biophys 41, 113-123, 2002)



(Kellerer, Walsh Nekolla, Radiat Environ Biophys 41, 113-123, 2002)

Conclusions

- Cohort of A-bomb survivors essential for risk estimates
- follow-up began in 1950 and is still continuing
- reevaluation of dosimetry just finished
- contribution of the neutrons to the observed health effects presently under discussion
- higher neutron RBE would decrease risk estimates for gamma radiation