The biological effects of ionizing radiation

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CERN Academic Training Lectures

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The biological effects of ionizing radiation

First lecture

- - Ionizing radiations and radiations units
- - Exposure to natural background radiation
- - Exposures by medical usage of radiation
- - Biological effects (cellular damage, genomic instability, bystander effects and adaptive response, dose response as function of radiation quality, dose fractionation and dose rates effects).

Second lecture

- - Biological effects (some particular effects, tissue reactions: skin, intestine, blood, testis, ovary, fetus. Hereditary effects. Lethal doses. Stochastic effects)
- - Health effects of ionizing radiations on short and long terms, from high and low doses (Hiroshima and Nagasaki).

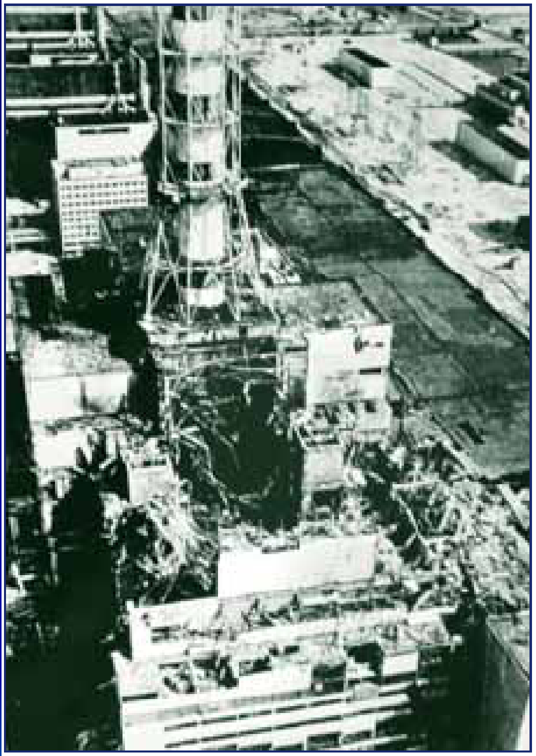
Third lecture

- - Health effects of ionizing radiations on short and long terms, from high and low doses (Chernobyl, radiologists, radon exposures, nuclear workers.)
- - Risk estimate from epidemiological data
- - Radiation limits and ICRP recommendation
- - Future research on radiation effects.

The Chernobyl Forum: 2003–2005

Second revised version

Major releases of radionuclides from unit 4 of the Chernobyl reactor continued for ten days following the April 26 explosion. These included radioactive gases, condensed aerosols and a large amount of fuel particles. The total release of radioactive substances was about 14 EBq[5], including 1.8 EBq of iodine-131, 0.085 EBq of ^{137}Cs, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium radioisotopes. The noble gases contributed about 50% of the total release.



More than 200 000 square kilometres of Europe received levels of ^{137}Cs above 37 kBq m^{-2}. Over 70 percent of this area was in the three most affected countries, Belarus, Russia and Ukraine. The deposition was extremely varied, as it was enhanced in areas where it was raining when the contaminated air masses passed. Most of the strontium and plutonium radioisotopes were deposited within 100 km of the destroyed reactor due to larger particle sizes.

Many of the most significant radionuclides had short physical half-lives. Thus, most of the radionuclides released by the accident have decayed away. The releases of radioactive iodines caused great concern immediately after the accident. For the decades to come ^{137}Cs will continue to be of greatest importance, with secondary attention to ^{90}Sr. Over the longer term (hundreds to thousands of years) the plutonium isotopes and americium-241 will remain, although at levels not significant radiologically.

1 EBq = 10^{18} Bq (Becquerel).

^{131}I

Physical half-life 8·0545±0·0063 days.

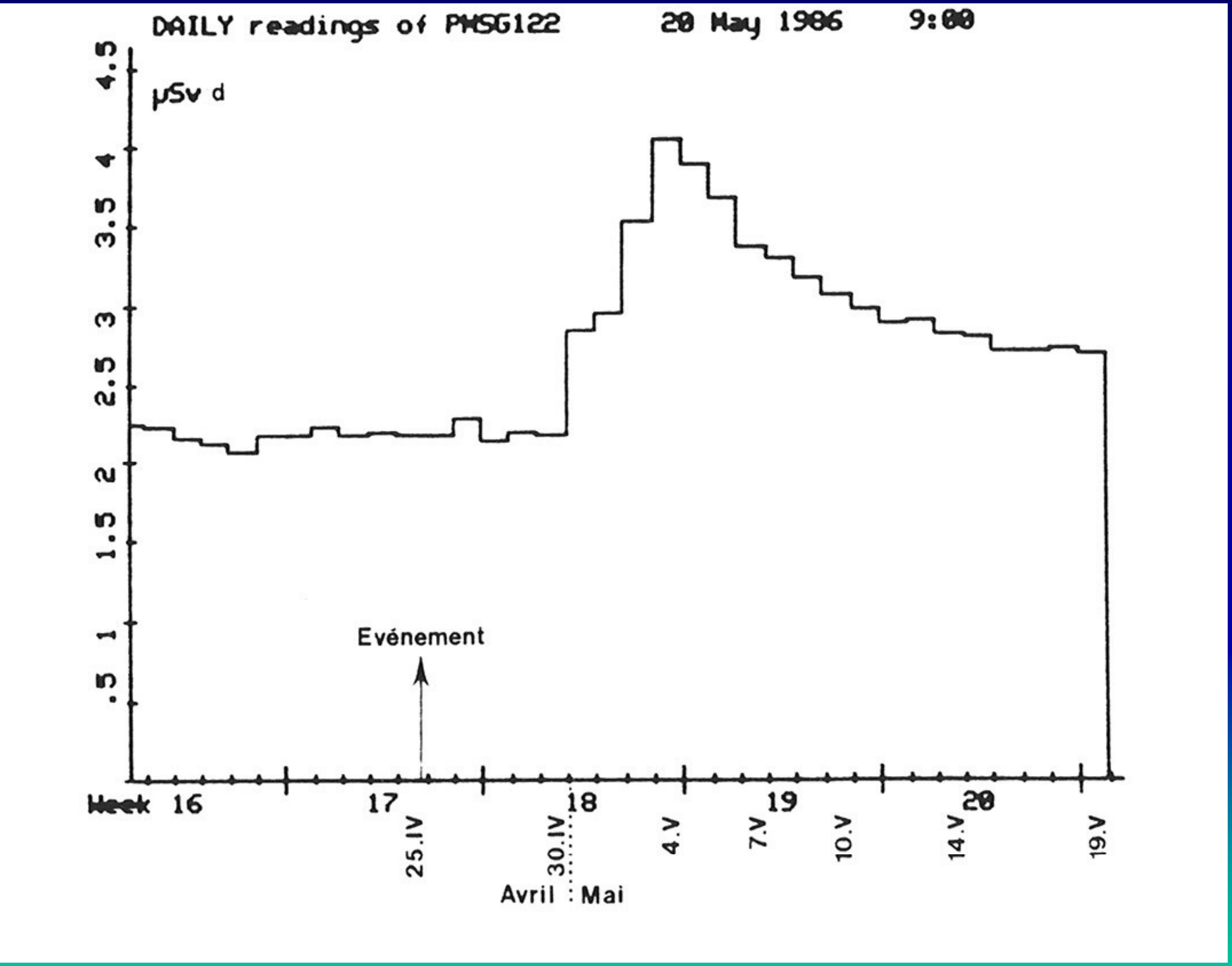
^{137} Cs

Physical half-life 30.1 years

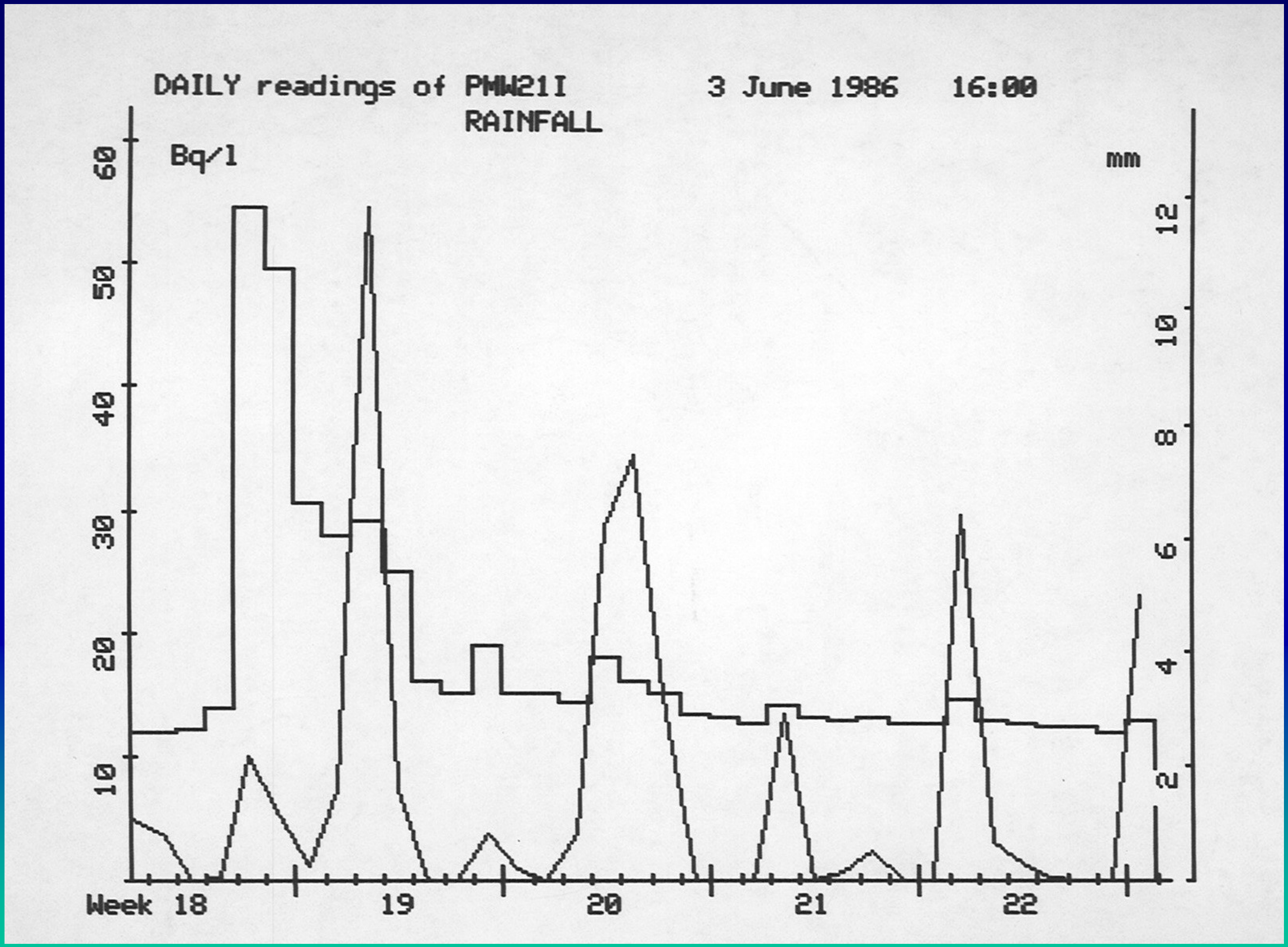
^{90} Sr

Physical Half-life 28.1 Years

Chernobyl: Site monitor measurement at CERN



Chernobyl: Rainfall measurements at CERN



Mean effective doses from Chernobyl

Table 1. Estimates of mean effective doses (mSv) for population groups of interest (Cardis *et al* 1996, UNSCEAR 2000).

Population	Approximate size of population	Mean effective dose (mSv)
Liquidators (1986–1987, 30 km zone)	240000	100
Evacuees of 1986	116000	33
Persons living in contaminated areas:		
Deposition density of $^{137}Cs > 37\ kBq\ m^{-2}$	5200000[a]	10[b]
Deposition density of $^{137}Cs > 555\ kBq\ m^{-2}$ [c]	270000	50[b]

[a] Including approximately 1 900 000 persons from Belarus, 2 000 000 from Russia and 1 300 000 from Ukraine (UNSCEAR 2000).
[b] For the period 1986–2005.
[c] Strict control zones (included in the areas with deposition density $>37\ kBq\ m^{-2}$).

Doses to clean-up workers in Chernobyl

Table 2. Distribution of doses to clean-up workers as recorded in state Chernobyl registries (UN Chernobyl Forum 2006).

Country and period	Number of clean-up workers	Percentage for whom dose is available	External dose (mSv)			
			Mean	Median	75th (%)	95th (%)
Belarus						
1986–1987	31 000	28	39	20	67	111
1986–1989	63 000	14	43	24	67	119
Russian Federation						
1986	69 000	51	169	194	220	250
1987	53 000	71	92	92	100	208
1988	20 500	83	34	26	45	94
1989	6000	73	32	30	48	52
1986–1989	148 000	63	107	92	180	240
Ukraine						
1986	98 000	41	185	190	237	326
1987	43 000	72	112	105	142	236
1988	18 000	79	47	33	50	134
1989	11 000	86	35	28	42	107
1986–1989	170 000	56	126	112	192	293

From Cardis E. et al 2006

Estimated Thyroid doses from Chernobyl accident

Table 3. Estimates of thyroid doses (Goulko *et al* 1996, Likhtarov *et al* 2005, Minenko 2000, UNSCEAR 2000).

		Mean thyroid dose (Gy)		
Population	Size of population	0–7 years	Adults	Total
Evacuees of 1986, including	116 131	1.82	0.29	0.48
villages, Belarus	24 725	3.10	0.68	1.00
Pripyat town	49 360	0.97	0.07	0.17
villages, Ukraine	28 455	2.70	0.40	0.65
Belarus				
Entire country	10 000 000	0.15	0.04	0.05
Gomel region	1 680 000	0.61	0.15	0.22
Ukraine				
Entire country	55 000 000	—	—	0.01
Region around Chernobyl NPP	500 000	—	—	0.38
Kiev city	3 000 000	—	—	0.04
Russian Federation				
Entire country	150 000 000	—	—	0.002
Bryansk region	1 457 500	0.16	0.026	0.04
Kaluga, Orel, Tula regions	4 000 000	—	—	0.01

From Cardis E. et al 2006

Populations in Europe for which epidemiological studies have been made

Country	*Study region*	*Age group*	*Average absorbed dose (mGy)* [a]
Thyroid studies			
Croatia	Whole country	All ages	15 [b]
Greece	Whole country	20-60 years	5
Hungary	Whole country	All ages	3 [b]
Poland	Krakow, Nowy Sacz	All ages	4 [b]
Turkey	Five most affected areas on Black Sea coast and Edirne province	All ages	1.5 [b]
Leukaemia studies			
Bulgaria	Whole country	Adults	2
		Children 0-14 years	2
Finland	Whole country	Children 0-14 years	2
Germany	Bavaria	Children 0-14 years	4
Greece	Whole country	Children 0-14 years	1
Hungary	Six counties	All ages	0.7
Romania	Whole country	Children 0-14 years [c]	3
Sweden	Whole country	Children 0-14 years	4
Turkey	Five most affected areas on Black Sea coast and Edirne province	All ages	0.7

a To thyroid in thyroid studies and to bone marrow in leukaemia studies; assumes bone marrow dose is numerically equal to effective dose and dose in children is the same as in adults.
b Assumes population-weighted thyroid dose is three times that to adults.
c Age at death.

From UNSCEAR 2000

Acute radiation sickness (ARS) from Chernobyl

- **Death of 30 workers.**
- 237 initially suspected ARS persons,
  in 1989 only 134 confirmed ARS, all are under medical control.

internal exposure:
short-lived radioiodines and radiotelluriums,
long-lived radionuclides (Cesium)

external exposure:
gamma, beta to skin and eyes
(essentially in recovery operation workers)

Population (years exposed)	Number	Average total 20 years (mSv)
Liquidators (1986-1987) highly exposed	240000	> 100
Evacuees (1986)	116000	> 33
Residents (>555kBq/m^2)	270000	> 50
Residents low contamination (37 kBq/m^2)	5000000	10-20
Natural background	2.4 mSv/year (range 1-10, max > 20)	48

Thyroid cancers after Chernobyl accident

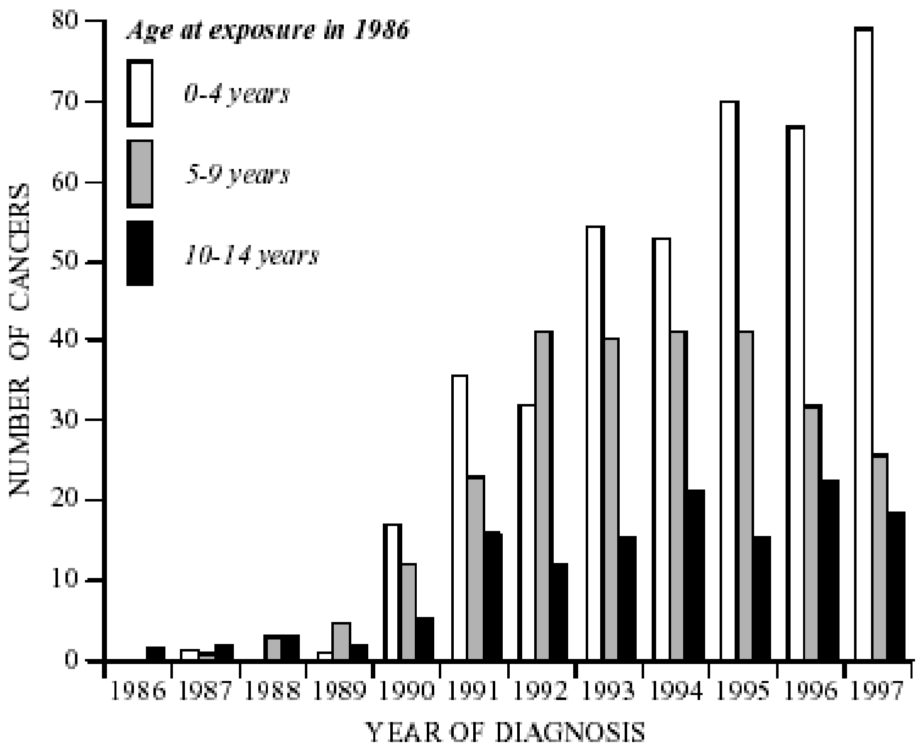
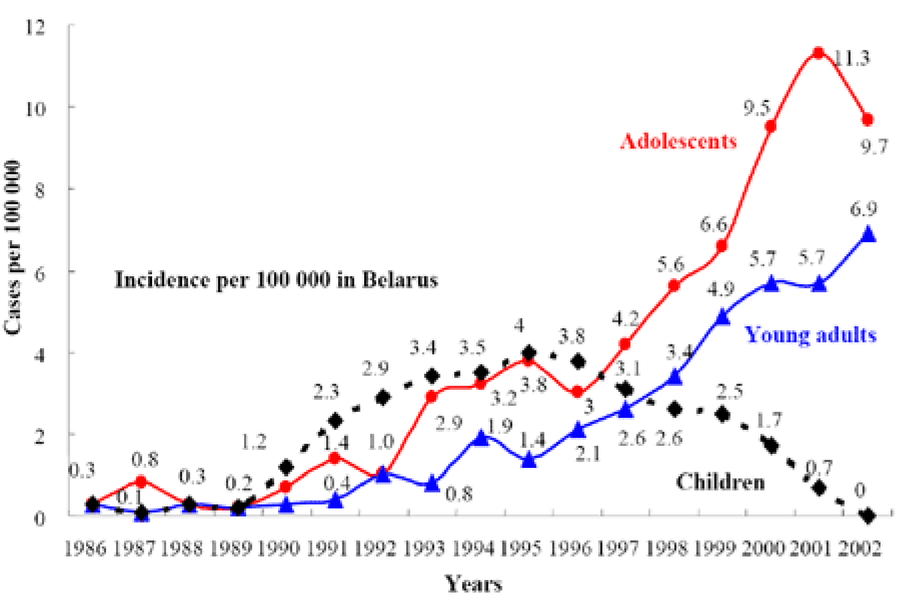


Figure XXVI. Number of diagnosed thyroid cancer cases in Belarus as a result of the Chernobyl accident [K41].

From UNSCEAR 2000

Incidence of thyroid cancers in Belarus 1986-2002



From Yamashita S. 2006
Demidchik E.P. 2006

Thyroid cancer in Chernobyl childrens

- 85% of children, 3 years old or irradiated in uterus.
- 60% of children between 4-15 years old and 50% of teenagers receiving 50-300 mGy
- >15000 children born (1979 – 1986)received more than 2 Gy.

Number of cases of thyroid cancer diagnosed between 1986 and 2002 by country and age at exposure

Age at exposure	Belarus (1)	Russian Federa-tion (2)	Ukraine (3)	Total
<15	1711	349	1762	3822
15-17	299	134	582	1015
Total	2010	483	2344	4837

1) Cancer registry Belarus 2006
2) Russian National Medical and dosimetric registry 2006
3) Cancer registry of Ukraine 2006

From Cardis E. et al 2006

http://www.chernobyltissuebank.com/

Cancers in Chernobyl adults

1. Improvement in diagnosis, reporting and registration may affect the results
2. Some of the studies reported have methodological limitations
3. For solid tumour latent period is long therefore too early for a full radiological impact evaluation

"There have been reports of an elevated incidence of all solid cancers combined as well as of specific cancers in Belarus, the Russian Federation and Ukraine, but much of the increase appears to be due to other factors, including improvements in registration, reporting and diagnosis….

In the coming years, careful studies of selected populations and health outcomes are needed in order to study the full effects of the accident and compare them to predictions"

from "Cancer consequences of the Chernobyl accident: 20 years on" Cardis E. et al. 2006

Cancers in Chernobyl adults

- 2 fold increase in breast cancer and 2-7 fold increase in thyroid cancer have been reported.
- 2 fold increase in non-CLL leukemia between 1986 and 1996 only in Russian liquidation workers exposed to >150 mGy external dose (Ivanov V.K. et al 2003c).

Leukemia in recovery operation workers

Table 65
Incidence of leukaemia and all cancer during 1993–1994 among recovery operation workers and residents of contaminated areas
[C2]

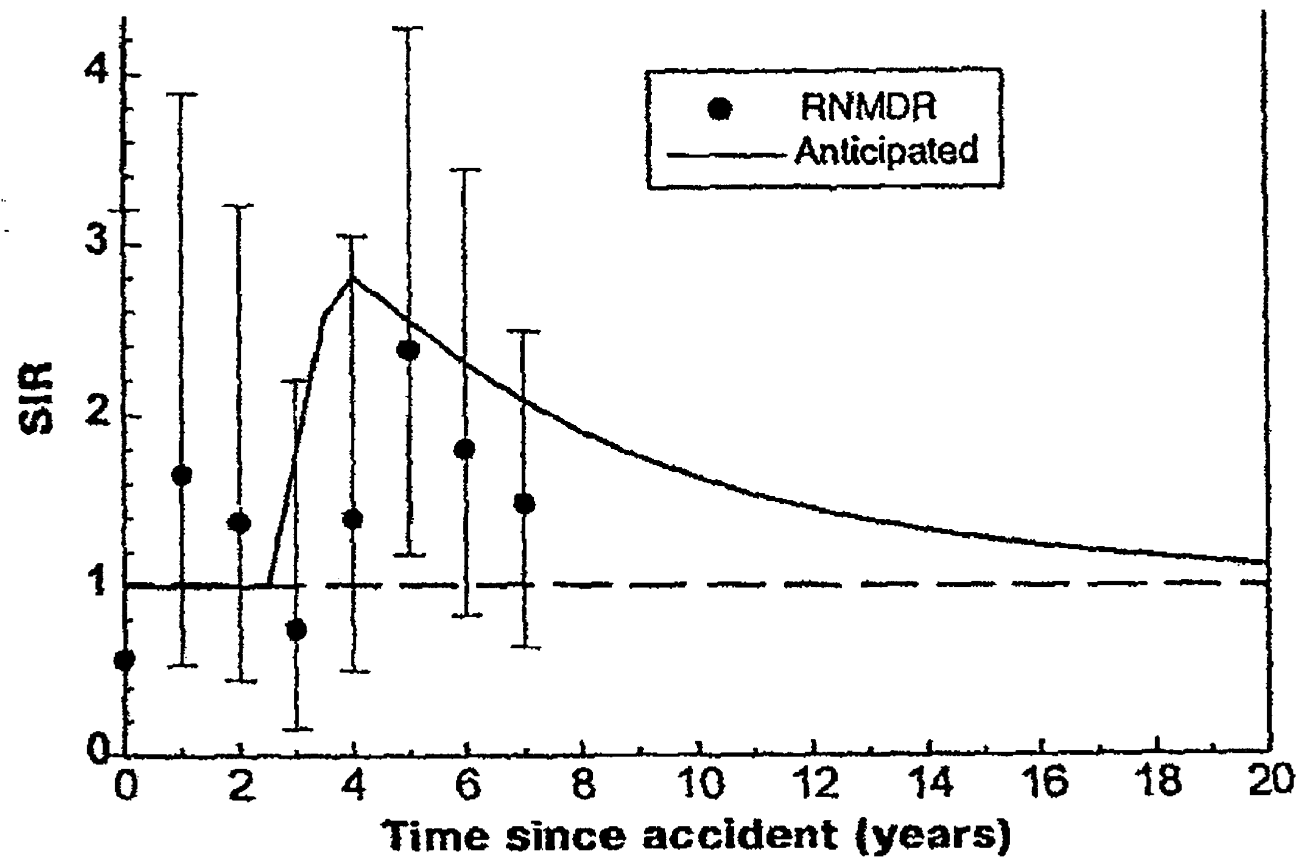
Country	Leukaemia cases [a]		All cancer cases [a]		Standardized incidence ratio (SIR)	
	Observed	Expected	Observed	Expected	Leukaemia	All cancer
Recovery operation workers [b]						
Belarus	9	4.5	102	136	200	75
Russian Federation	9	8.4	449	405	108	111
Ukraine	28	8	399	329	339	121
Residents of contaminated areas [c]						
Belarus	281	302	9 682	9 387	93	103
Russian Federation	340	328	17 260	16 800	104	103
Ukraine	592	562	22 063	22 245	105	99

a ICD9 codes: 204-208 (leukaemia) and 140-208 (all cancer); expected cases are for age- and sex-matched members of the general population.
b Males who worked in the 30-km zone during 1986 and 1987.
c Areas with ^{137}Cs deposition density > 185 kBq m^{-2}.

From UNSCEAR 2000

Leukaemia in Chernobyl clean-up workers

Figure 4.3 Anticipated and Observed Standardised Incidence Ratios of Leukaemia in Russian Clean-up Workers (bars give 95% confidence intervals)



source: reproduced from Ivanov *et al* (1997d)

Recent article on leukemia

- "Empirical studies in affected populations are summarized, and it is concluded that, possibly apart from Russian cleanup workers, no meaningful evidence of any statistical association between exposure and leukemia risk as yet exists."

From *Howe G. R. 2007* "**LEUKEMIA FOLLOWING THE CHERNOBYL ACCIDENT**" Health Physics. 93(5):512-515.

Chernobyl B-cell chronic lymphocytic leukemia

- IGHV3-21 gene expression was found in 11 cases (5.8%) - (frequency intermediate between Scandinavian (11.7%) and Mediterranean CLL (2.9%) cohorts)
- Negative prognostic significance of IGHV3-21 gene expression.
- IGHV3-21 expression was associated with development of secondary solid tumors.

From Abramenko I. et al. 2007

Reproductive effects from Chernobyl

Table 68
Comparison of reproductive effects in population groups in the Russian Federation during 1980-1993
[B19, L27, L28, L29]

Parameter / effect	*Ratio of effect before and after accident* [a]							
	Bryansk region			*Tula region*			*Ryazan region*	
	<37 kBq m⁻²	*37-185 kBq m⁻²*	*185-555 kBq m⁻²*	*<37 kBq m⁻²*	*37-185 kBq m⁻²*	*185-555 kBq m⁻²*	*<37 kBq m⁻²*	*37-185 kBq m⁻²*
Birth rate	0.81	0.83	0.75	0.87	0.73	0.69	1.0	0.90
Spontaneous abortions	1.27	1.34	1.34	0.90	1.03	1.18	1.22	0.91
Congenital anomalies	0.66	1.41	1.67	1.32	1.28	0.91	1.43	0.91
Stillbirths	0.66	1.39	1.29	1.50	0.93	1.41	0.90	0.97
Perinatal mortality	1.18	1.13	0.91	0.77	1.57	1.21	1.13	1.00
Premature births	1.07	0.95	1.39	0.88	0.86	0.71	0.83	1.23
Overall diseases in newborns	1.02	1.03	1.42	1.06	1.32	1.29	1.00	1.38
Overall unfavourable pregnancy outcome	1.07	1.16	1.35	0.95	0.97	0.92	1.07	1.00

a Number of women examined before and after accident: Byransk region: 3,500-4,100 in each area; Tula region, 2,400 (<37 kBq m^{-2}), 2,100 (37-185 kBq m^{-2}) and 810-860 (185-555 kBq m^{-2}); Ryazan region, 1,600-1 ,00 (<37 kBq m^{-2}) and 1,200-1,400 (37-185 kBq m^{-2}).

From UNSCEAR 2000

Immune response Chernobyl

1) radiation emergency workers exposed to low-dose irradiation during 1986–1989 and
2) nuclear industry workers exposed under professional limits

irradiation dose limits of 250 and 100 mSv

Comparison group 42000 persons

Early response:

Immunological deficiency with T-cell subset changes

Lymphocyte membrane changes and increased lipid peroxidation

Reconstitution period:

Inhibition of the immune function associated with lymphocyte subset changes (decreased CD3+ and CD4+ cells counts and increased number of somatic mutations in TCR-locus).

Late response:

decreased CD8+ suppressor cell function that could lead to poor proliferation control

No dependency of dose–effect type were detected in nuclear industry workers

From Bazyka D. et al. 2003

Psychological impact

- Excess of suicides among the atomic bomb survivors exposed to low doses (0–90 mGy) (Kusumi et al., 1993).
- Direct dependence between the suicide rate and the residency distance from the Atomic Test Site (Alimkhanov, 1995).
- Suicides are the leading cause of death among Estonian clean-up workers (Rahu et al., 1997).

From Loganovsky K. 2007

Others non cancers effects from Chernobyl

- Cardiovascular and cerebro-vascular diseases
- Blood diseases

If you want to know more:

http://www.unscear.org/unscear/en/chernobyl.html

http://www.who.int/ionizing_radiation/chernobyl/en/

http://www.iaea.org/NewsCenter/Focus/Chernobyl/index.html

Results from some studies in Europe

- Finland: Monthly dose rate estimated= double the natural background. Transient decrease in birth rate not related to the fallout as it had already begun before 1986.Statistically significant small increase in spontaneous abortions in July-December 1986 with dose rate (attributable to unusual low rates in 87 and 88?).From Auvinen A. et al. 2001
- Greece: Leukemia cases since 1980. Infants exposed in utero had 2.6 times the incidence of leukemia compared to non exposed childrens. From Petridou et al. 1996
- Germany: Increase in trisomy 21 in Berlin 9 months after the accident. From Sperling K. et al. 1994.

  Greek findings not confirmed by German study. From Steiner et al. 1998

  No evidence of congenital malformation in Bavaria. From Irl C. et al. 1995
- Sweden: Indication of increase in Down syndrom and childhood leukemia that if no random could be related to exposure. From Ericson A. and Kallen B. 1994

  No increase in malformation seen. From De Wals P. and Dolk W. 1990

Data from Radiologists

Table I.

	British radiologists study [1][a]	US radiologists study [6,7]
Number of radiologists	2,629	6,510
Control physicians	Rates estimated from census data	23,215
Profession entry years	1920 - 1979	1920 -1969
Last year of follow up	1996	1974
No. of radiologists deceased	837 (35%)	1,871 (29%)
SMR for all cancer mortality[b]	1.04 (n.s.)	1.31 (s.s)
SMR for non-cancer mortality[b]	0.86 (s.s.)	1.18 (s.s.)
SMR for all cancer mortality[b] for most recent entry cohort	0.71 (n.s.) (profession entry 1955-1979)	1.15 (n.s.) (profession entry 1940-69)

n.s., not statistically significant ($p > 0.05$).
s.s., statistically significant ($p < 0.05$).
[a] Restricted to radiologists who entered the profession after 1920.
[b] SMRs relative to all physicians; this is the most appropriate comparison group as death rates in 25-74 year old British physicians are about half those of the general public [8]).

From
Brenner D. J. & Hall E. J. 2003

SMR=Standardized Mortality Ratio

US survey include radiologist from 1960.
British survey include radiologists that entered the field from 1970 (lower doses and shorter follow-up)

Early radiologist estimated annual doses is about 1 Gy/yr (Braestrup C.B. 1957)

The British cohort ,1955-1970, show decrease of mortality compared to control Group (Cameron L.S. 2002 and Daunt S. 2002)

Impact of new technologies in cancer induction

- 10% of patients presenting at major Cancer Centers have a second cancer (lifestile, genetic, RT)
- 10-year survival rate for patients treated for breast or prostate cancer
- ***younger patients*** *are treated, and with* ***longer life expectancy****, RT-induced second malignancies will assume increasingly greater importance due to Intensity Modulated Radiation Therapy (IMRT) treatments*

Increase on CT scan in USA and attributable risk

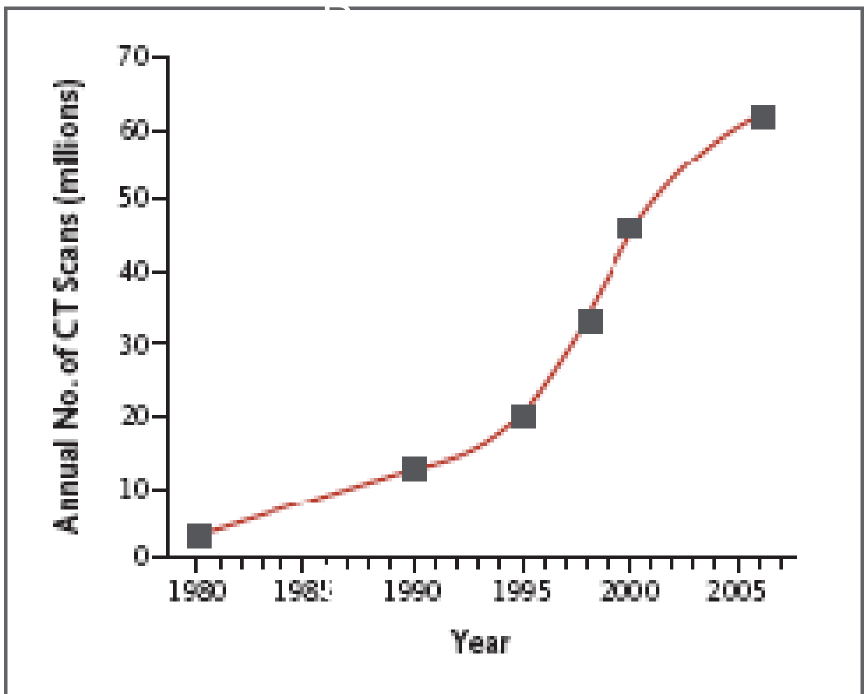
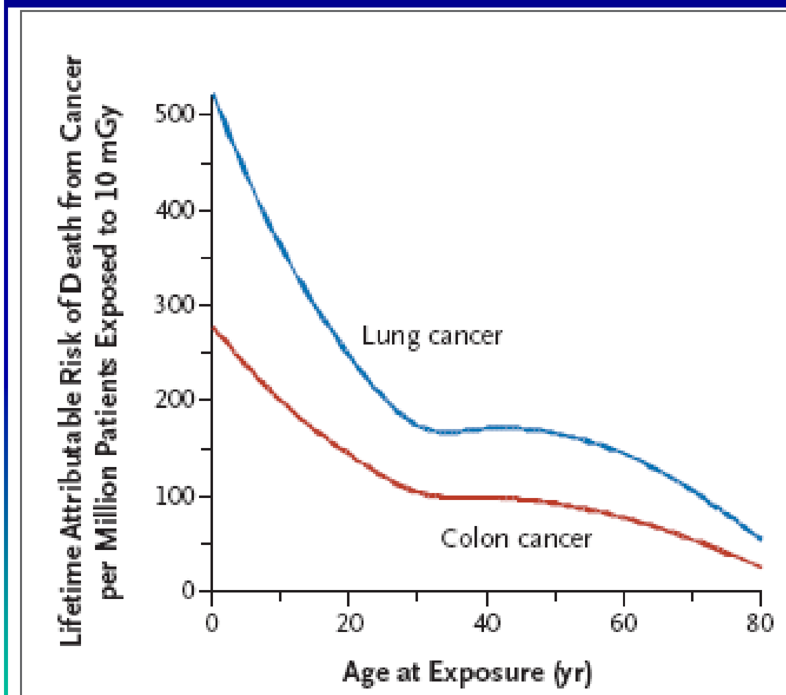
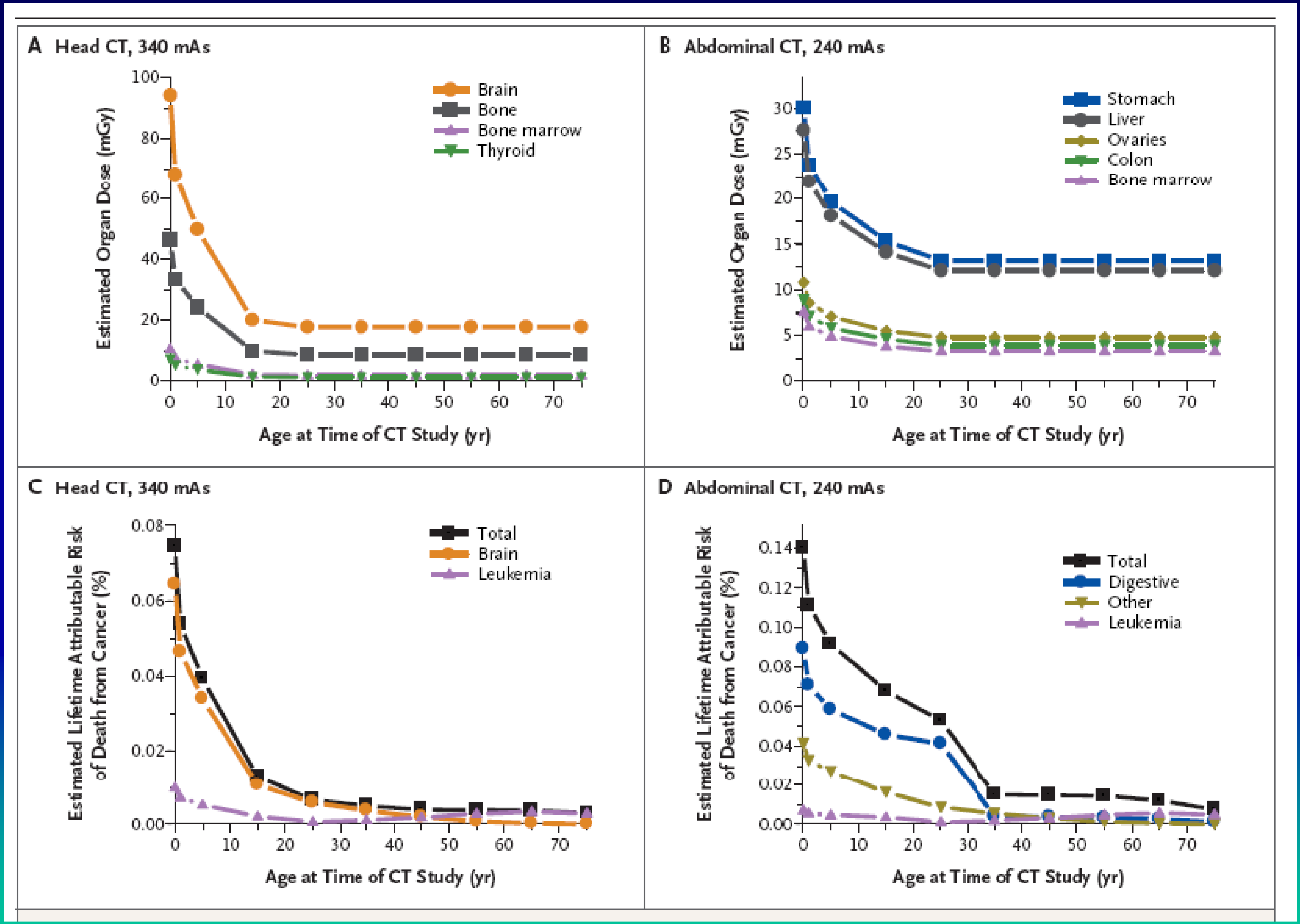


Figure 2. **Estimated Number of CT Scans Performed Annually in the United States.**
The most recent estimate of 62 million CT scans in 2006 is from an IMV CT Market Summary Report.[3]

From:
Brenner D. J. & Hall E. J. 2007



Estimated risk from CT scan



from BRENNER D.J. and HALL E.J. 2007

Radon and lung cancer

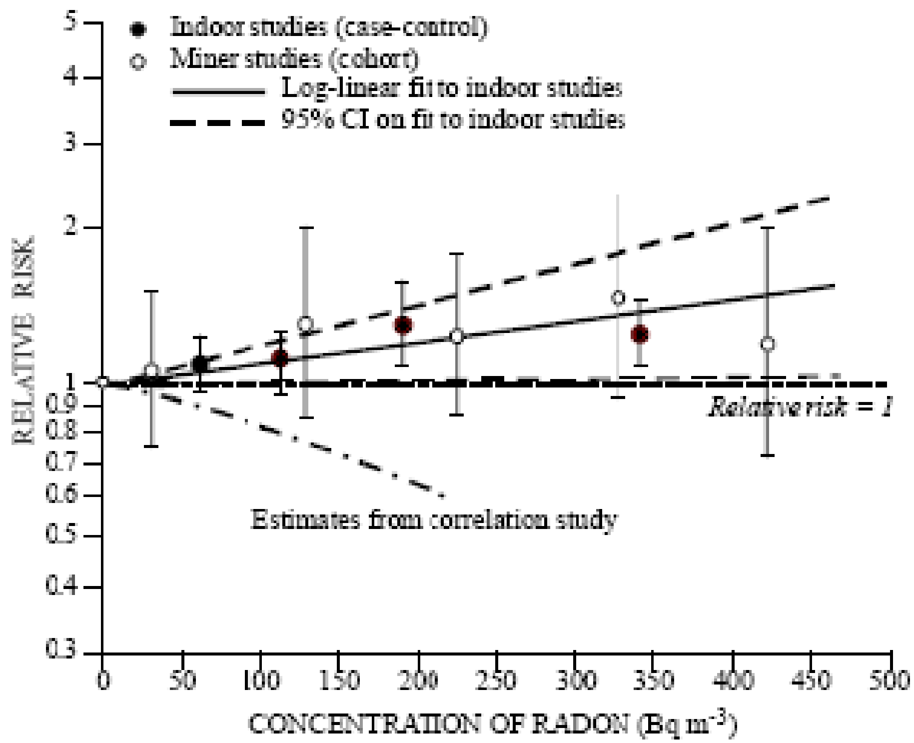


Figure II. Risk estimates of lung cancer from exposure to radon (based on [L21]).
Shown are the summary relative risks from meta-analysis of eight indoor radon studies and from the pooled analysis of underground miner studies, restricted to exposures under 50 WLM [L22] and the estimated linear relative risk from the correlation study of Cohen [C18].

15-country nuclear workers study

(Australia, Belgium, Canada, Finland, France, Hungary, Japan, Korea, Lithuania, Slovakia, Spain, Sweden, Switzerland, UK, USA)

407 391 workers individually monitored for external radiation with a total follow-up equivalent to 5.2 million person years.

- Excess relative risk for all cancers excluding leukemia: 0.97 Sv^{-1} (95% CI 0.14, 1.97), for all solid cancers 0.87 Sv^{-1} (95% CI 0.03, 1.88). These estimates are somewhat higher but statistically compatible with current Radiation Protection recommendations.
- Lymphocytic leukemia 1.93 Sv^{-1} (95% CI <0, 8.47) close to what previously observed in previous nuclear workers studies

From Cardis E. et al. 2005, Cardis et al. 2007 and Vrijheid M et al 2007

- In occupationally exposed person in general is common to observe the so called « healty worker effect ». Overall mortality rate is about 15% lower than in general population. This effect has been also reported for radiation workers.
- Conclusions from BEIR VII
  -Health benefit exceeding detrimental effects from low doses radiations is unwarranted-

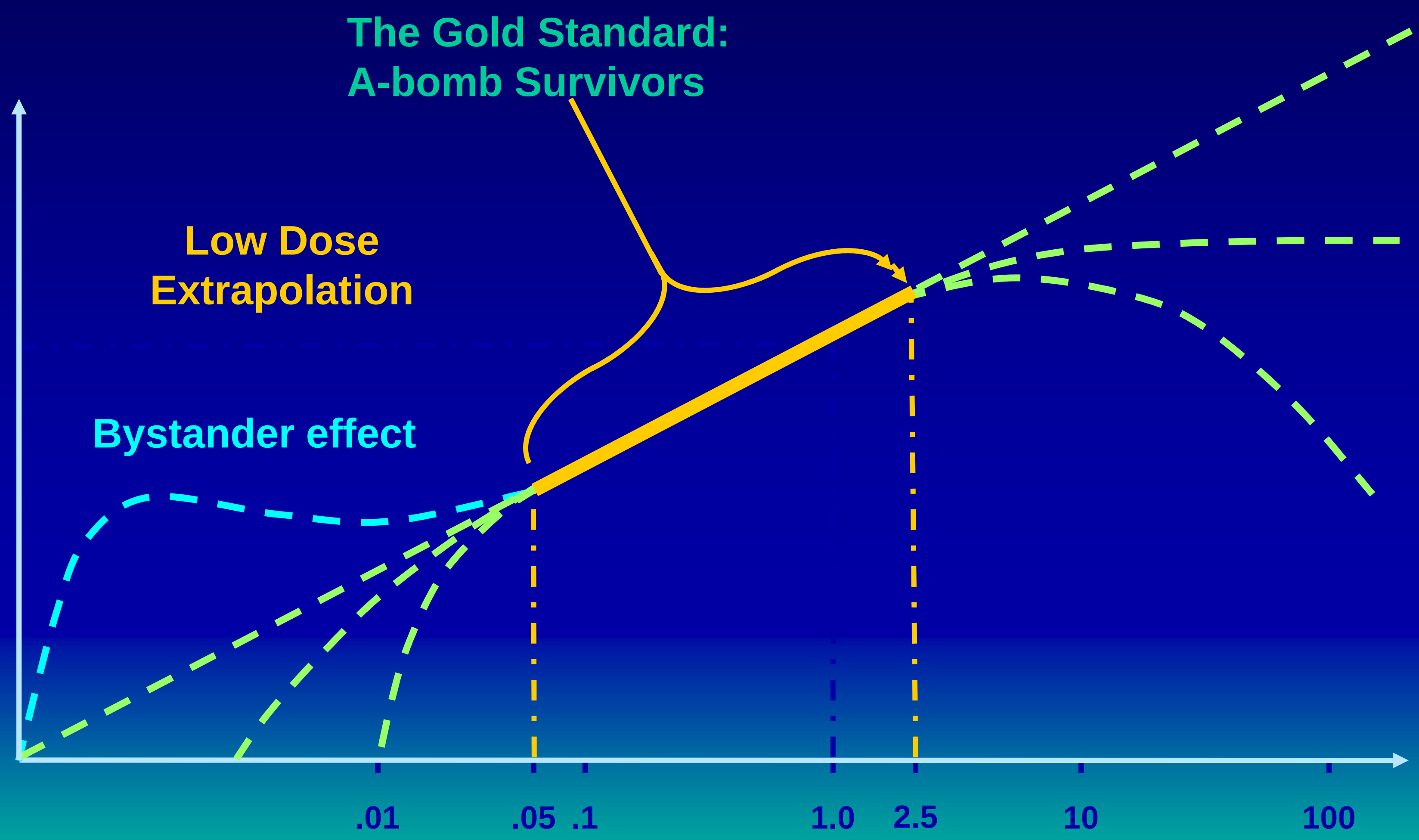
HBNRs

- People residing at high altitude level have less health problems.
- Considering the population living in Guodong, China population receiving 3-4 mGy have been compared with near population receiving 1 mGy/year, no difference was obtained. Excess cancer are expected to be only 1-2% above cancers occurring from all causes during lifetime. How to detect it even if cofounders would be taken into account ??????

Are low doses beneficial?

- Adaptive response (< effect D_1+D_2 =< D_1+D_2)
- Additivity (effects adds up $D_1+D_2 = D_1+D_2$)
- Synergistic effects (> effect D_1+D_2 => D_1+D_2)

Limitations



From E. Hall 2007

Assumptions

- Induction of gene and chromosomal mutations are important for the cancer process
- For low LET radiation (doses of a few mGy and below) linearity of response for targeted events in cells (inherent DNA error-prone repair process for the DNA double-strand lesions as complex clustered DNA lesions are difficult to repair correctly)

Are linear-no threshold (LNT) model good enough for projecting cancer risk to low doses and low dose rates?

PRAGMATIC APPROACH USED

by ICRP 103 and BEIR VII

AS NO BETTER EVIDENCE BASED JUDGMENT IS TODAY AVAILABLE

Contested by French Academy of Science

as too conservative

The dose and dose rate effectiveness factor (DDREF)

- A factor (DDREF) to take into account human exposures at low doses (dose ~ 100 mSv) and low dose rates
- Derived from animal data excluding ovarian and thymic lymphoma induction (highly curvilinear threshold-like response)
- A factor of **2** at doses < 2 Gy is used by ICRP (ICRP 103) whereas BEIR VII takes as value a factor of **1.5**.

Cancer risk estimates from epidemiological data

- Average sex and age at exposure time
- Lifetime risk estimates are computed using risk estimates specific to various cancer sites.
- ICRP system, estimates are derived for males and females combined whereas BEIR VII make a distinction between male and female
- The nominal risks are computed for each site of interest and summed to give the population total nominal risk
- The overall site-specific and total nominal risks are computed by averaging the population-specific average risks.
- Risk estimate are averaged across Asian and Euro-American populations
- Excess relative risk (ERR) or excess absolute risk (EAR) both take into account sex, attained age, age at exposure
- Risk and detriments are calculated for **whole population** and **working age population (18-64 years)**

0.1 Gy radiation cancer estimates in 100000 people

	All solid cancer		Leukemia	
	Males	Females	Males	Females
Excess cases (including non-fatal cases) from exposure to 100 mSv	800 (400–1600)	1300 (690–2500)	100 (30–300)	70 (20–250)
Number of cases in the absence of exposure	45,500	36,900	830	590
Excess deaths from exposure to 100 mSv	410 (200–830)	610 (300–1200)	70 (20–220)	50 (10–190)
Number of deaths in the absence of exposure	22,100	17,500	710	530

(from: BEIR VII)

( ) 95% Confidence Limits
Solid cancer estimate based on Linear model and Reduced Dose and Dose-Rate
Dose and Dose Rate Effectiveness Factor (DDREF) = 1.5

New ICRP recommendations – Biological aspects

1. Tissue reactions (dose modifying factors 1.1 to 2)
2. Cataracts and cardiovascular disease need more accurate risk evaluation
3. w_R and w_T for stochastic effects have been revised
4. LNT model (and DDREF of 2) retained as prudent practice
5. Heritable effects/multifactorial diseases have been considered in more detail

Genetic Risks

- They are low probably as the genetic changes compatible with embryonic development and viability. Essentially multigene deletions
- Considered for 2 generations only
- Most chronic diseases have genetic component, but are multifactorial

Doubling dose=amount of radiation required to produce as many mutations as accounting in one generation

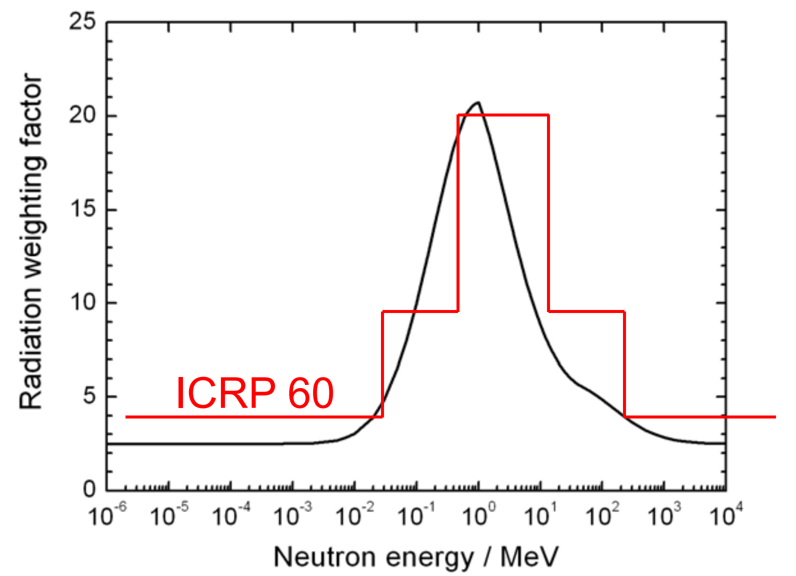
- Spontaneous 3 mutations/million people/generation

20 cases per 10,000 people / Sv

Previously in ICRP 60 (100 cases / 10,000 / Sv)

Recommended radiation weighting factors w_R for stochastic effects (ICRP 103 2008)

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (see Fig. 1 and Eqn. 4.3)



$$w_R = \begin{cases} 2.5 + 18.2\,e^{-[\ln(E_n)]^2/6}, & E_n < 1\,\text{MeV} \\ 5.0 + 17.0\,e^{-[\ln(2E_n)]^2/6}, & 1\,\text{MeV} \le E_n \le 50\,\text{MeV} \\ 2.5 + 3.25\,e^{-[\ln(0.04E_n)]^2/6}, & E_n > 50\,\text{MeV} \end{cases} \quad (4.3)$$

- Cancer risks and tissue weighting factors have been calculated for 12 tissues and organs (oesophagus, stomach, colon, liver, lung, bone, skin, breast, ovary, bladder, thyroid, and red bone marrow). The remaining tissues and organs have been grouped into ‘remainder’

Recommended tissue weighting factors w_T for stochastic effects (ICRP 103 2008)

Tissue	w_T	Σw_T
Bone-marrow (red), Colon, Lung, Stomach, Breast (was 0.05) Remainder tissues* (was 0.05)	0.12	0.72
Gonads (was 0.20)	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04

Total 1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (M), Small intestine, Spleen, Thymus, Uterus/cervix (F).

ICRP 103 Recommendations (2008)

- LNT model and DDREF of 2 retained, as previously said
- The possibility that there might be a threshold dose, below which there would be no radiation-related cancer risk, has been not upheld
- Adaptive responses to radiation – the animal studies **do not provide sufficient evidence of reduced adverse health effects** to be taken into account for radiological protection
- Epigenetic phenomena - **not sufficient proof of their influence on cancer risk** (differential contribution to risk?)
- Heritable effects and multi-factorial diseases to be considered more in detail
- Genetic risks expressed to 2nd generation, 0.2% per Sv

Cataracts, cardiovascular diseases

- Lens: 150 mSv/year occupational, 15 mSv public

  Cataract threshold dose 1.5 Gy (ICRP 60)
  New evidence suggests threshold <100 mGy (haemangioma treatment in childrens (Hall E.J. et al. 1999), A-bomb survivors (Minamoto A. et al. 2004), Chernobyl)

- Heart: Not yet included for threshold doses, but could be around 1 Gy.
- From A-bombs and Chernobyl non-cancer diseases becoming more recognised as important.

Nominal risk coefficients/100/Sv
at low dose-rate (ICRP 103 and previous ICRP 60)

Exposed population	Cancer		Heritable effects		Total	
	Present[1]	*Publ. 60*	Present[1]	*Publ. 60*	Present[1]	*Publ. 60*
Whole	5.5	6.0	0.2	1.3	5.7	7.3
Adult	4.1	4.8	0.1	0.8	4.2	5.6

Limits (in agreement with current ICRP recommendations)

Type of limit	Occupational (CERN)	Public (CERN)
Effective dose	20 mSv / year	1 mSv / year
Annual equivalent dose		
lens of the eye	150 mSv	15 mSv
skin	500 mSv	50 mSv
hands and feet	500 mSv	-

In your interest, remember

- Pregnancy has to be announced to medical service as soon as known.
  - Person taken away from working in controlled radiation areas.
  - Max dose allowed during pregnancy equally dose to the public (1 mSv)

- Children are forbidden to stay in radiation controlled areas

- Accidents or near misses to be announced immediately to RP or Medical Service

Assessment of dose

after an accident or a suspected accident

- Physical dosimetry (personal dosimeter, area monitors, dose reconstruction and reconstruction of accident)
- Medical examination
- Blood analysis (including chromosomal aberrations for biological dosimetry)
- In case of possible contamination risk: whole body counting (at HUG, Geneva)

Others possible bioassay or dosimetry to reconstruct doses but not of standard use

- Tooth enamel (Electron Paramagnetic Resonance dosimetry)
- Hairs

More research is needed

- Molecular biomarkers to quantify low level of DNA damage
- DNA repair fidelity at low level of radiation damage and mechanisms of error-prone repair of radio-induced lesions
- Damage in stem cell spermatogonia and oocytes as well as in various tissue stem cells
- Dose-dependence of post-irradiation cellular signalling, its implications for estimating DNA damage and cancer risk at low doses
- Genomic instability and bystanders effects at very low dose-rate and after fractionated exposures
- Roles of DNA repair processes in the origin of deletion in germ cells
- Identification of regions prone to radiation deletion
- Do hormetic effects exist for radiation induced carcinogenesis?
- Role of radiation in multi-stage radiation tumour-genesis
- Genetic factors in radiation cancer risk
- Future studies on medical exposures (i.e. epidemiological studies in children exposed to CT exams, follow-up of radiotherapy patients for secondary tumour induction)
- Environmental studies (accidents)
- Continuation of follow-up on occupationally exposed people