Cancer Epidemiology (EPI 213 C)
(35th)

Radiation Epidemiology and Reflections on Fukushima

John D Boice Jr
National Council on Radiation Protection and Measurements
Vanderbilt University Medical Center
john.boice@vanderbilt.edu
February 7, 2012

Outline – Radiation Epidemiology

- Overview
- Atomic Bomb Survivors
- Medical Exposures
- Nuclear Workers
- Radon (Miners, Home)
- Environmental: Chernobyl
- Fukushima

"And it was so typically brilliant of you to have invited an epidemiologist."

The New Yorker, Nov 26, 2001, Wm Hamilton

Airport "Backscatter" X-ray Scanner

A Reflection on You

The technology of X-rays for whole-body scanning in airports involves tiny doses of radiation and technology to record how it bounces off the skin. Here's how it differs from medical X-rays.

Transmission X-rays, such as

Backscatter X-rays, such as

Transmission

TYPICAL DOSE 4 millirems

Backscatter

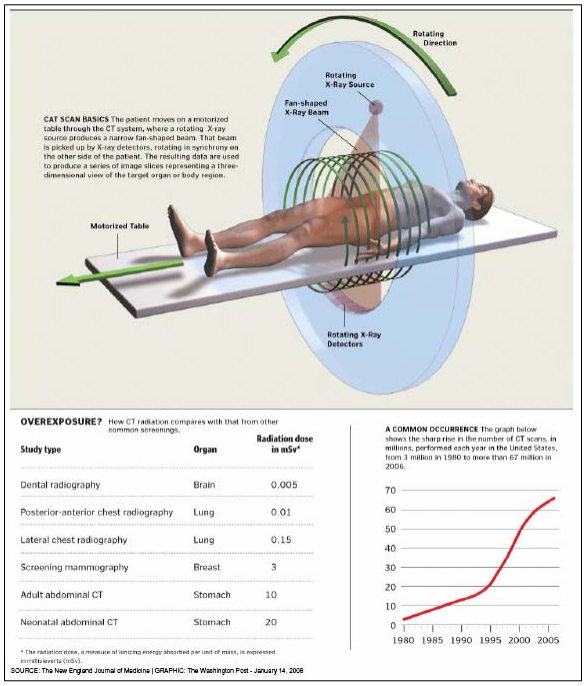
TYPICAL DOSE: .005 millirem

Sources: Health Physics Society; American Science and Engineering Inc.

NCRP
National Council on Radiation Protection & Measurements

NCRP Commentary 16 (2003)

Screening of Humans for Security Purposes Using Ionizing Radiation Scanning Systems



CT use on the rise.

Also PET scans

Weekend Edition
June 10 - 12, 2011

A 35% Spike in Infant Mortality in Northwest Cities Since Meltdown

Is the Dramatic Increase in Baby Deaths in the US a Result of Fukushima Fallout?

By JANETTE D. SHERMAN, MD
and JOSEPH MANGANO

U.S. babies are dying at an increased rate. While the United States spends billions on medical care, as of 2006, the US ranked 28th in the world in infant mortality, more than twice that of the lowest ranked countries. (DHHS, CDC, National Center for Health Statistics. Health United States 2010, Table 20, p. 131, February 2011.)

SCIENTIFIC AMERICAN™

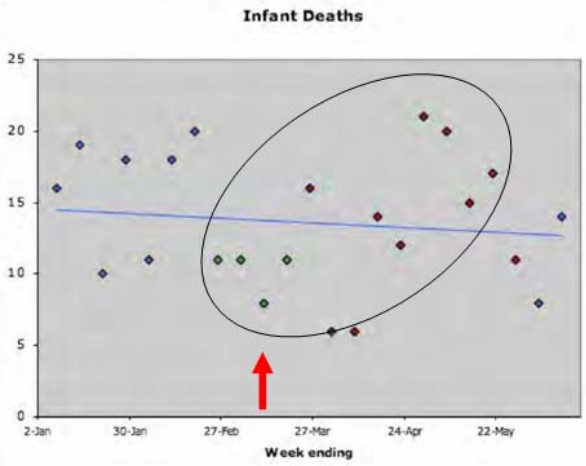
Permanent Address: http://www.scientificamerican.com/blog/post.cfm?id=are-babies-dying-in-the-pacific-nor-2011-06-21

Are Babies Dying in the Pacific Northwest Due to Fukushima? A Look at the Numbers

By Michael Moyer | Tuesday, June 21, 2011 | 34 comments

A recent article on the A
certain U.S. Northwest c
Fukushima Daiichi nucl
and epidemiologist Jose
infant mortality in north
well be the result of fall
Radioactive fallout from
imperil the lives of child

Bad "science" scares people



Radiation Units

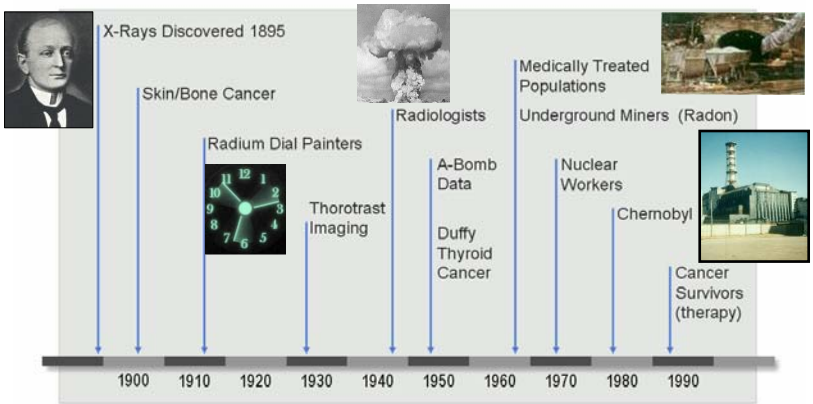
- 1 mSv - background from terrestrial gamma rays/per year
- 10 mSv - from "typical" CT scan
- 150-200 mSv - detectable by epidemiologic methods
- 3,500 mGy - LD50/30 - death of 50% in 30 days (3.5 Gy)
- 40,000 mGy - treat cancer (40 Gy)
- 0.04 mSv - chest x-ray (4 mrem)
- 0.000005 mSv - backscatter x-ray scan (0.005 mrem)

10 mSv = ~ 10 mGy = 1 cGy = 1 rad = ~1 rem

NCRP
National Council on Radiation Protection & Measurements

Epidemiology is the study of the distribution and causes of disease in humans.

Radiation Epidemiology Dates Back 100 Years



Epidemiologic Studies of Exposed Human Populations

JAPANESE ATOMIC BOMB SURVIVORS

RADIOTHERAPY - CANCER
- Cervical
- Endometrial
- Childhood
- Breast
- Hodgkin Lymphoma

RADIOTHERAPY - NON-MALIGNANT
- Spondylitis
- Thymus
- Tonsils
- Menstrual Disorders
- Scalp Ringworm
- Mastitis
- Infertility
- Otitis Media
- Ulcer
- Hemangioma

DIAGNOSTIC
- TB - Fluoroscopy
- Pelvimetry
- Scoliosis
- General

RADIONUCLIDES
- Thorotrast
- I - 131
- Uranium
- P - 32
- Ra - 224
- Plutonium

OCCUPATION
- Ra Dial Painters
- Miners (Radon)
- Radiologists
- Technologists
- Nuclear Workers
- Atomic Veterans

ENVIRONMENT
- Chernobyl
- Weapons Fallout
- Natl Background
- Techa River

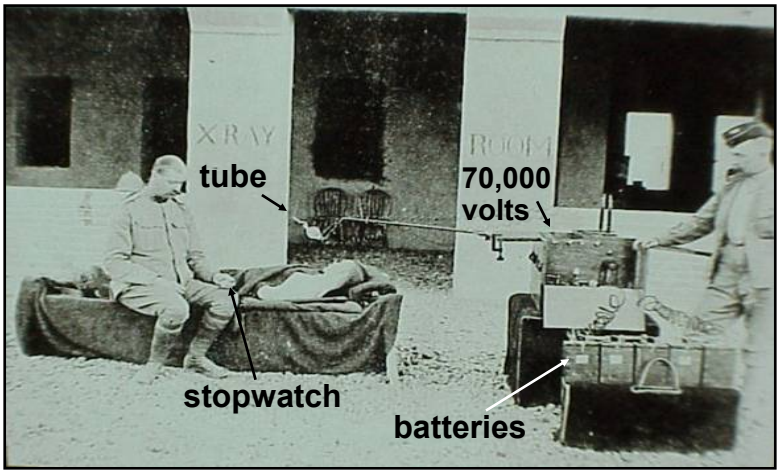
Epidemiology has shifted the focus from genetic effects in future generations to somatic effects on the individuals exposed.

Radiation epidemiology (UNSCEAR 2008) tells us that:

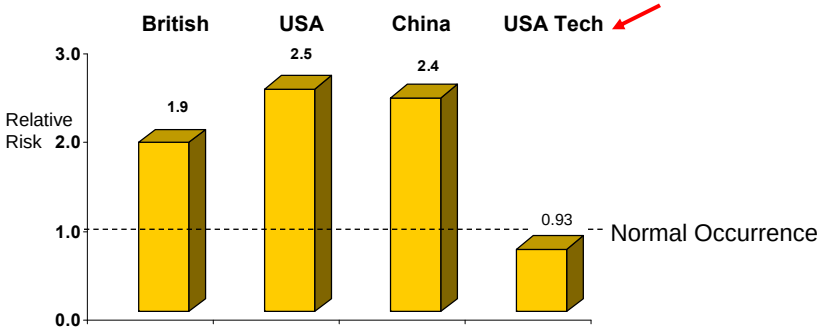
- a single exposure can increase your cancer risk for life
- the young are more susceptible than the old
- *in utero* susceptibility is no greater than early childhood
- females are more susceptible than males.
- risks differ by organ or tissue and
- some sites have not been convincingly increased after exposure.

Radiation epidemiology is highly uncertain about low dose and low dose rate risks

Early Radiologists and Technicians 1898 - Sudan



Leukemia Among Early Radiologists / Technologists

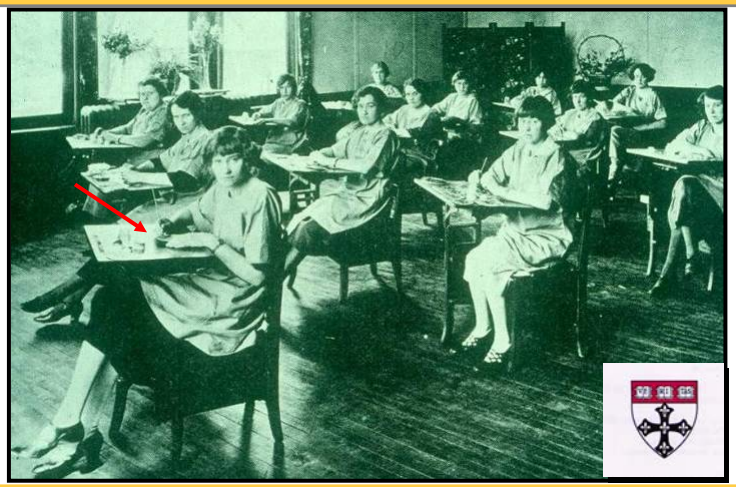


	British	USA	China	USA Tech
Years	1897-1979	1915-1954	1926-1985	1926-1980
No. cases	9	17	34	158

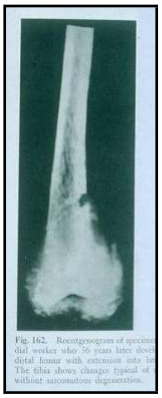
Berrington, *Br J Radiol* 74:507, 2001
Seltzer, *Am J Epidemiol* 81:2, 1965
Wang, *Int J Cancer* 45:889, 1990
Mohan, *Int J Cancer*, 2003

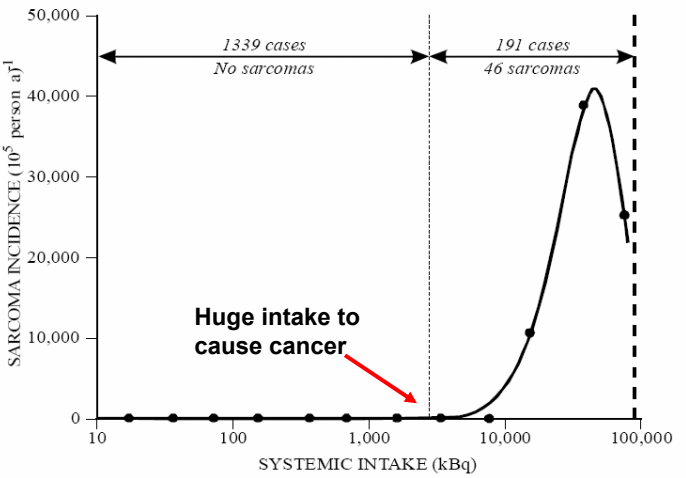
Early radiation workers

Radium Dial Painters



Bone Cancer in Radium Dial Painters (UNSCEAR 2000)



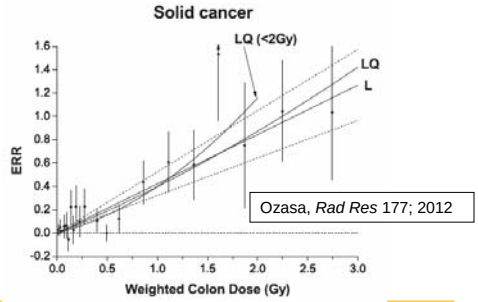


10 Gy suggested as a "practical threshold" for bone cancer

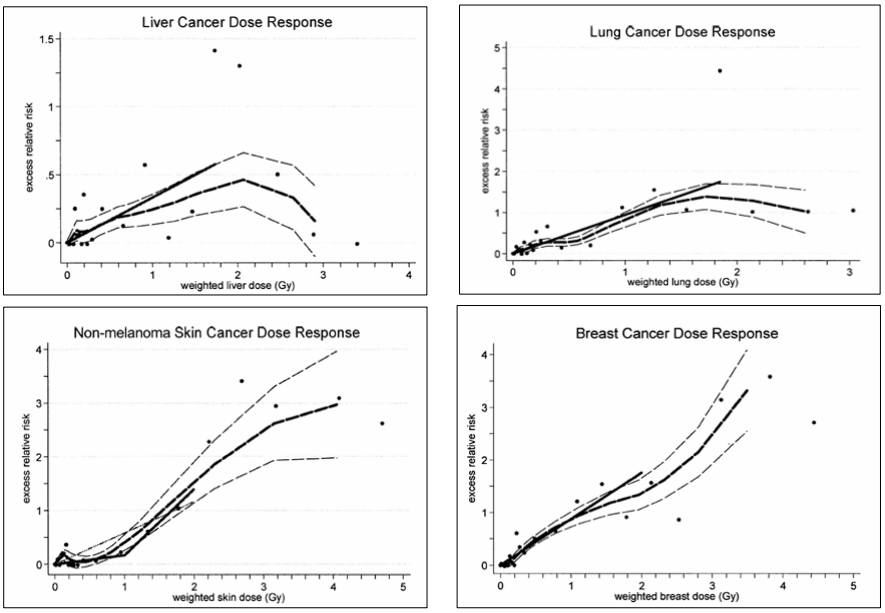
Bone Cancer, not leukemia

Epidemiologic Studies are the Basis for Cancer Risk Estimates.

"Radiation risk estimates are derived for incidence data for specific tumour sites when adequate dose response data are available from the Japanese Life Span Study (LSS), pooled analyses of multiple studies, or other sources." **ICRP Publ 103, 2007**



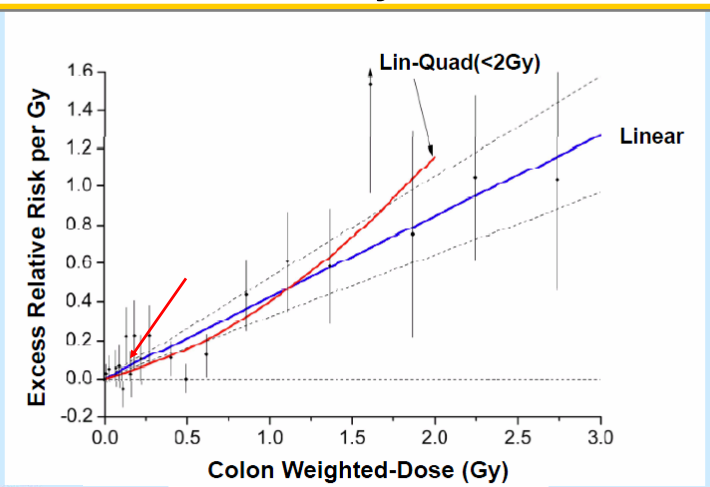
Ozasa, *Rad Res* 177; 2012



The "solid cancer" dose response combines non-linear age-adjusted specific sites.

Preston et al, *Rad Res* 168:1, 2007

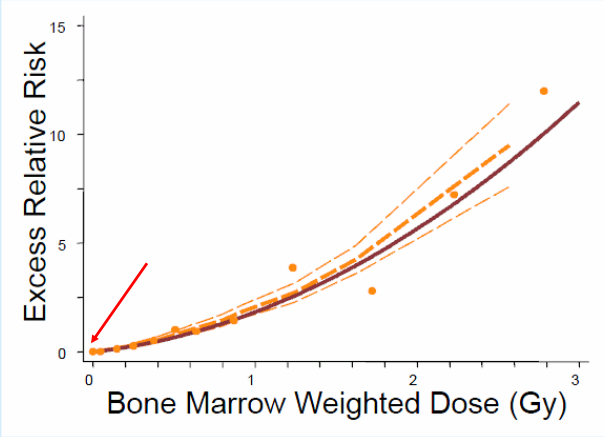
LSS Dose Response for Solid Cancer Mortality, 1950-2003



Beebe Symposium
National Academy of Sciences
December 1, 2010
Roy Shore,

Ozasa et al, *Rad Res* 177; 2012

LSS Leukemia Dose Response



Linear-quadratic fits better than Linear model.

Dose-threshold estimate: 80 mGy (95% CI: 30, 190 mGy)

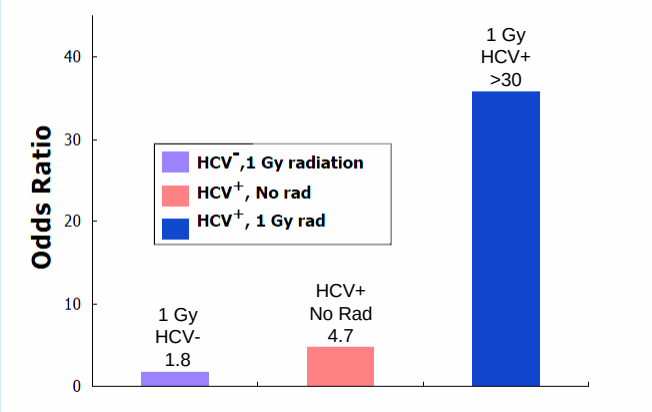
(Hsu et al, Unpublished, 2010)

Beebe Symposium
National Academy of Sciences
December 1, 2010
Roy Shore,

Leukemia has much higher risk coefficient than solid cancer. Excess occurs early.

Other Factors

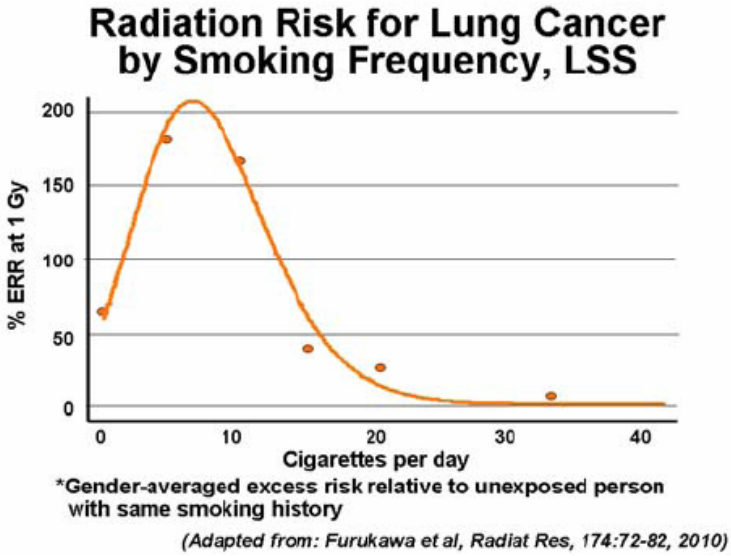
Liver Cancer Risk From Hepatitis C Virus (HCV+) and Radiation



(Sharp et al, *Int J Cancer*, 103:531-37, 2003)

Beebe Symposium
National Academy of Sciences
December 1, 2010
Roy Shore,

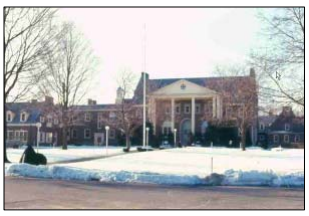
The "solid cancer" dose response combines cancers altered by other factors .

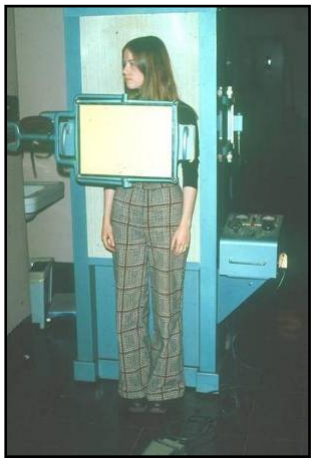


Courtesy of K Kodama, RERF 2011

Studies of Low-Dose Exposures Accumulating to High Dose

Lung collapse therapy for tuberculosis and associated multiple chest fluoroscopic x-rays (1930-1954)





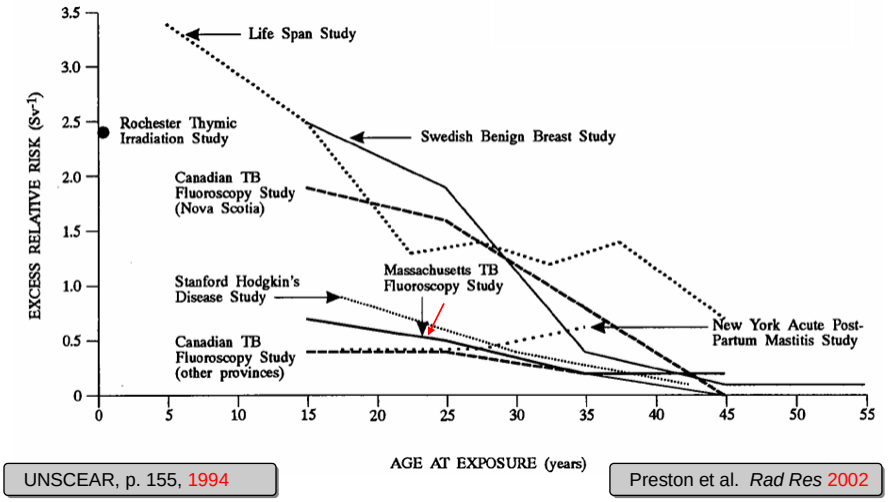
Breast Cancer
TB - Fluoroscopy, Massachusetts

	Exposed	Nonexposed
No. of women	2,573	2,367
No. chest fluoroscopies (ave)	**88**	--
Dose (ave) [*Dale Trout*]	790 mGy	--
Breast cancers		
Observed (O)	147	87
Expected (E)	114	101
O/E	**1.29**	0.86

29% Excess

Boice et al, *Radiat Res* 126:214, 1991
Boice & Monson, *J Natl Cancer Inst* 59:823 1977

Age at Exposure
Radiation-Induced Breast Cancer Studies



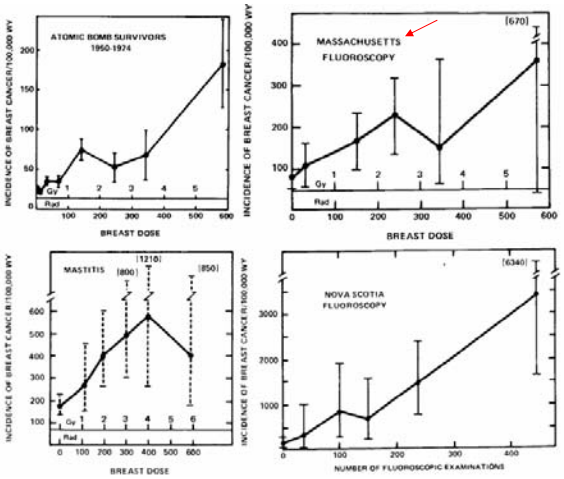
UNSCEAR, p. 155, 1994

Preston et al. *Rad Res* 2002

Dose Response – Pooled Analysis of Breast Cancer Studies

Breast Cancer

Consistent with linearity



Boice, *Radiology* 131:589, 1979

Lung and Leukemia TB - Fluoroscopy, Massachusetts

	Lung	Leukemia
No. exposed	6,285	6,285
No. unexposed	7,100	7,100
No. chest fluoroscopies (ave)	77	77
Dose to lung or marrow	840 mGy	90 mGy
Observed (O)	69	17
Expected (E)	86	19
RR (95% CI)	**0.8** (0.6-1.0)	**0.9** (0.5-1.8)

No excess lung or leukemia

Not all tissues respond similarly to fractionation.

Davis et al, *Cancer Res* 49:6130, 1989

Lung
TB - Fluoroscopy, Canada
Compared with Japanese LSS

	Multiple Fluoroscopy		Atomic Bomb	
Lung Dose (mGy)	# Lung Ca	RR (95% CI:)	# Lung Ca	RR (95% CI:)
< 10	723	1.0	248	1.0
10 -	180	0.87 (0.7-1.0)	290	1.26 (1.1-1.5)
500 -	92	0.82 (0.7-1.0)	38	1.45 (1.0-2.1)
1000 -	114	0.94 (0.8-1.2)	30	1.93 (1.3-2.9)
2000 -	41	1.09 (0.8-1.5)	10	2.65 (1.5-4.7)
3000+	28	1.04 (0.7-1.5)	3	--

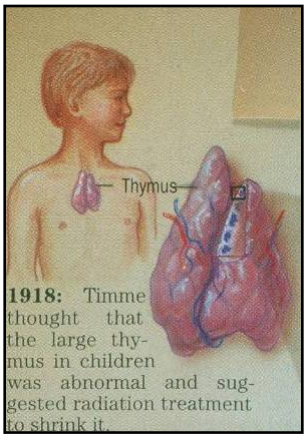
ERR/Gy (95% CI)	0.00 (-0.06–0.07)	0.60 (0.27–0.99)

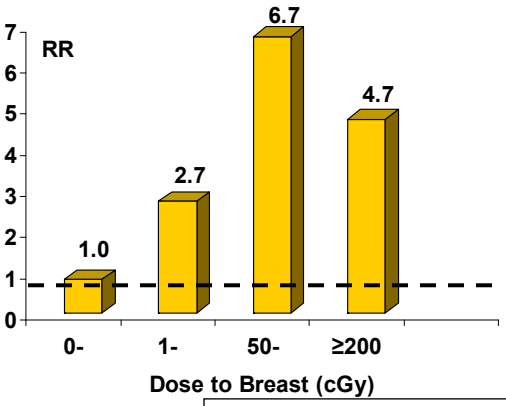
Howe G, *Radiat. Res.* 1995; 142:295

Summary
TB Fluoroscopy

- Low-dose fractions increase breast cancer
- Age at exposure modifies effect
- Linearity fits the breast cancer data
- Low-dose fractions NOT found to increase
  - Lung cancer
  - Leukemia
  - Heart disease
- Be cautious when generalizing

Breast Cancer Thymus Irradiation



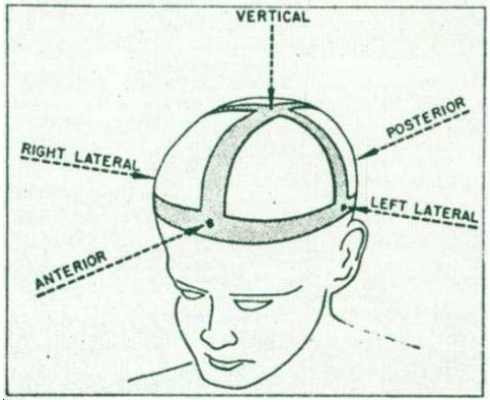


Hildreth et al, *NEJM* 321:1281, 1989

Immature breast tissue at risk but risk manifests many years later.

Radiotherapy for Ringworm
5 treatments, 3-12 minutes each

Fig 1.—Five Treatment fields used in the Adamson-Kienbock treatment were positioned with the aid of a "cap" made from steel bands.



Thyroid
Tinea Capitis - Israel

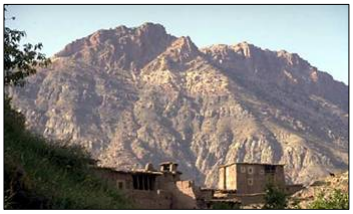
Number Exposed:	10,834
Number Nonexposed:	16,226
Thyroid Dose (mean):	90 mGy
Observed Thyroid Cancers:	43
Expected:	10.7
RR (95% CI):	4.0 (2.3 - 7.9)

Ron et al, *Radiat Res* 120:516, 1989

Wiggle, Morocco, genetic

Some Uncertainties of Epidemiology…

- Effect primarily among immigrants, mainly from **Morocco**, not Israeli born (Ron, *Rad Res*, 1989)
- "Irradiation for tinea capitis was given to many Jews in **Morocco** prior to immigration…"(Modan, *JNCI* , 1980)
- **Genetic susceptibility** & family clustering (4 sisters thyroid disease)
- **Wiggle** could increase dose x 3
- Immigrants from Morocco came from Atlas Mt region, and **diets** deficient in stable iodine

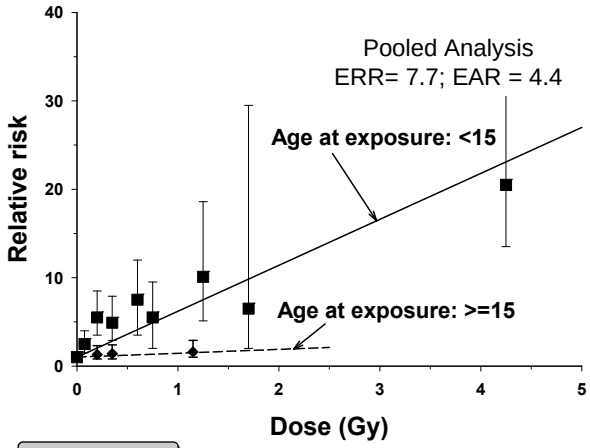


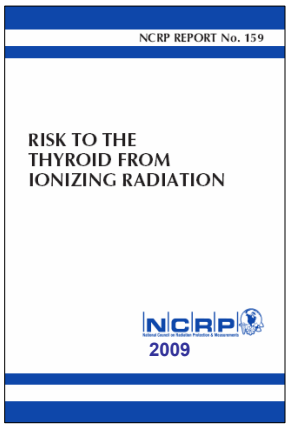
Thyroid Cancer after Exposure to External Radiation: A Pooled Analysis of Seven Studies

Ron et al, 1995

Art Schneider, E Ron Symposium 2011

Thyroid Cancer & External Radiation Risk Dose Response by Age at Exposure

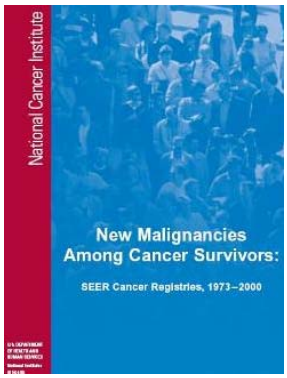




Ron et al, 1995

Radiation Treatments
Multiple Primary Cancers

Warren and Gates, 1932, Definitions

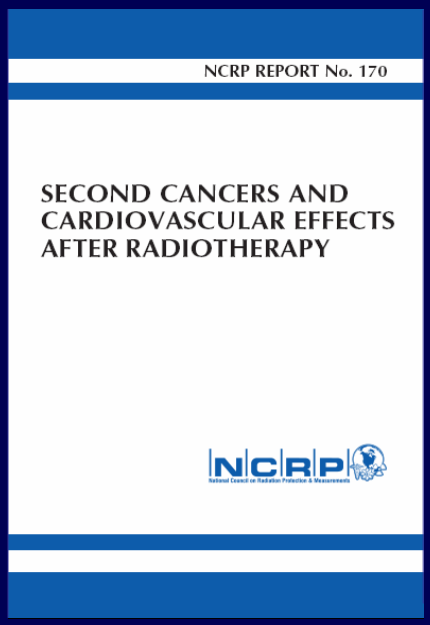


Risk Quantification

2006: http://seer.cancer.gov/publications/mpmono/

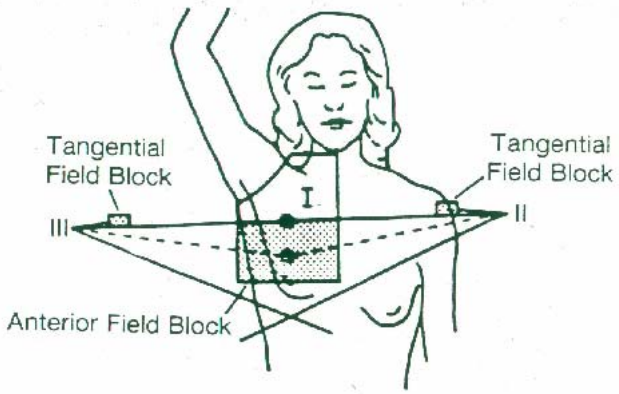
NCRP Report
In Press 2012

- 420 pages
- 12 Committee members
- Work: 2006-2011
- http://www.NCRPonline.org

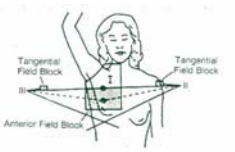


[1] Travis LB, Ng AK, Allan JM, …Boice JD Jr. NCRP SC-17: Second Cancers and CVD after radiotherapy, Report 170. In Press, 2012.

Travis et al JNCI 2012;104:1-14



RADIOTHERAPY DOSE TO CONTRALATERAL BREAST



Radiotherapy for Breast Cancer
Breast Cancers in Connecticut (1935-82)
Second Breast Cancer

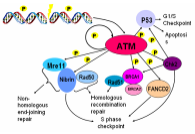
200 cGy (ave)

	RR	95% CI
All Subjects*	**1.19**	0.9-1.5
Time After Exposure (Yr)		
5-9	0.99	0.7-1.4
≥10	**1.33**	1.0-1.8
Age at Exposure (Yr)		
<35	**2.26**	0.9-5.7
35 -	1.46	0.9-2.3
≥45	1.01	0.8-1.4

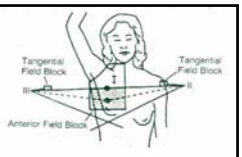
*655 Cases, 1,189 Controls

Boice et al, *NEJM* 326:781, 1992

Risk after 10 years among young.
Example of age modification.



Genetic Susceptibility? Second Breast Cancer



WECARE, 2nd breast (n=~600) to study Interaction Between Radiation and Genes*

	Exposure	RR	95% CI
Genes	*BRCA1* mutation	4.5	2.8-7.1
	BRCA2 mutation	3.4	2.0-5.8
	ATM (common variants)	0.8	0.7-1.0
Radiation	1 Gy (age <40 y)	**1.6**	1.1-2.5
	1 Gy (age ≥45 y)	1.0	0.9-1.3

**BRCAs, ATM, CHEK2*1100delC*

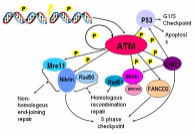
Stovall, *IJROBP* 72, 2008
Begg et al, *JAMA* 2008

Bernstein J. **Abstract S303**, Rad Res 2009
Concannon et al. *Cancer Res* 68, 2008

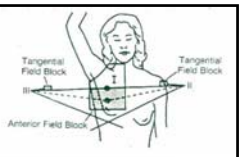
Risk of Second Primary Breast Cancer by *ATM* Variant and Radiation Dose

ATM	Dose	Case	Control	RR	95% CI
Variants Broadly Classified					
Wild type	**No**	**112**	**72**	**1.0**	
	0<1.0Gy	**57**	**177**	**1.0**	**0.7-1.6**
	≥1.0Gy	**54**	**169**	**1.1**	**0.7-1.7**
Missense	**No**	**26**	**30**	**1.0**	
	<1.0Gy	**21**	**45**	**2.7**	**1.2-6.4**
	≥1.0Gy	**21**	**38**	**3.3**	**1.4-8.0**
SIFT Classified					
Tolerated	**No**	**12**	**16**	**1.0**	
	<1.0Gy	**9**	**29**	**1.4**	**0.4-4.7**
	≥1.0Gy	**10**	**20**	**2.1**	**0.6-7.1**
Deleterious	**No**	**14**	**14**	**1.0**	
	<1.0Gy	**12**	**17**	**5.3**	**1.6-17.3**
	≥1.0Gy	**11**	**15**	**5.8**	**1.8-19.0**

Bernstein et al JNCI 2010



Conclusions

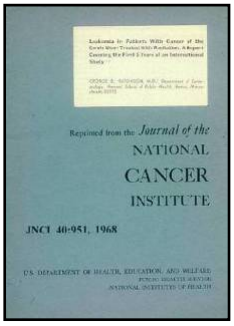


Women who carry rare deleterious ATM missense variants and who are treated with radiation may have an elevated risk of developing contralateral breast cancer.

However, the rarity of these deleterious missense variants in human populations implies that ATM mutations could account for only a small portion of second primary breast cancers.

Bernstein et al. J Natl Cancer Inst 2010;102:475–483

Cervical Cancer and Leukemia
Blood Studies and Clinical Follow-up
30 Radiotherapy Centers in 9 Countries



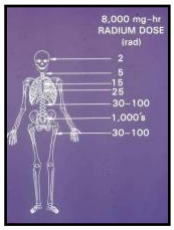
Number	30,000 women
Dose	5-15 Gy (marrow)
Leukemia	
Observed	13
Expected	15.5
Risk	**No excess**

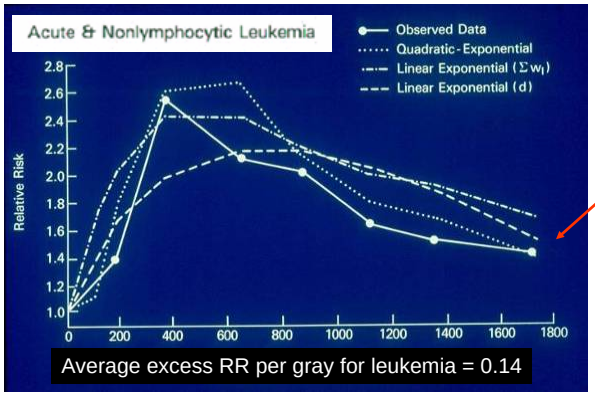
Boice & Hutchison, *JNCI* 65:115, 1980

Huge dose, but no risk

Bone Marrow Dosimetry Downturn at High Doses

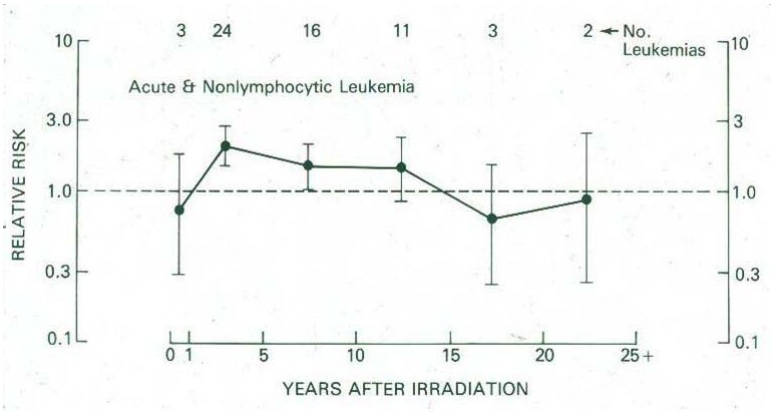
Boice et al, *JNCI* 79, 1987





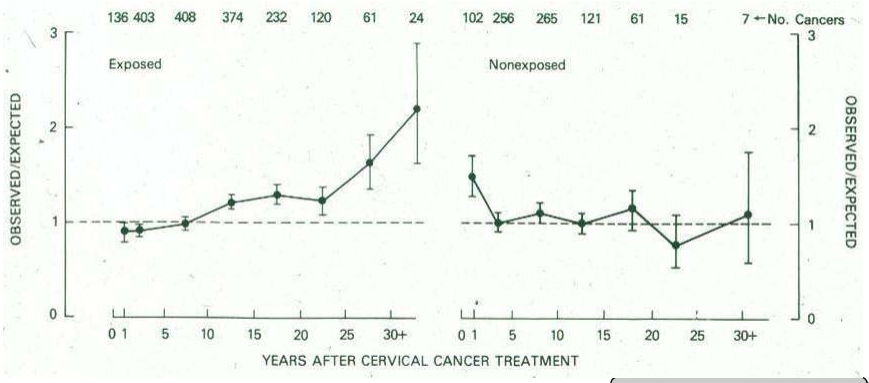
International Cervical Cancer Study Expansion – 16 Radiotherapy Centers and 17 Cancer Registries in 14 Countries

Characteristic wave-like pattern over time



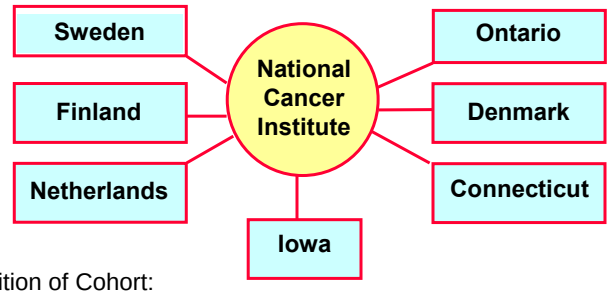
Boice et al, *JNCI* 74:955, 1985

Long Minimum Latency - Solid Cancers



Boice, *JNCI* 74:955, 1985

Lung Cancer Following Hodgkin Lymphoma International Case - Control Study (2002)



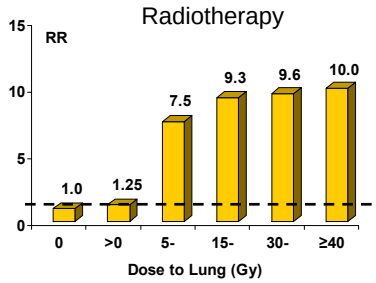
Definition of Cohort:

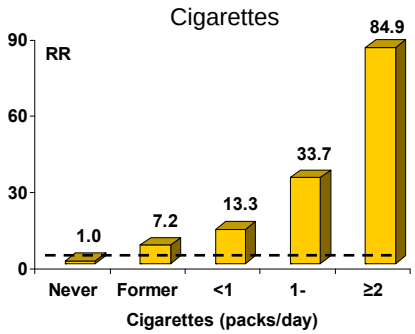
- Diagnosis of Hodgkin lymphoma: 1965-1994
- Survival of 1 or more years

Final Cohort: 22,977 (222 cases, 444 controls)

Travis et al. *JNCI* 94:182, 2002

Lung Cancer After Hodgkin Lymphoma Radiotherapy and Environmental Factor Effects

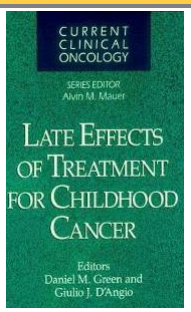


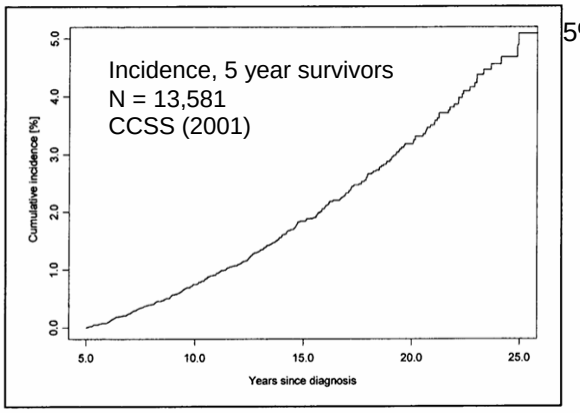


<1 pack/day has greater risk than ≥40 Gy

Gilbert et al, *Rad Res* 159:161, 2003
Travis et al, *JNCI* 94:182, 2002

2nd Cancers After Childhood Cancer (CCSS)

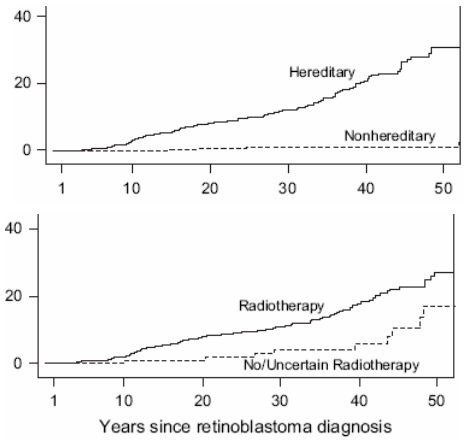




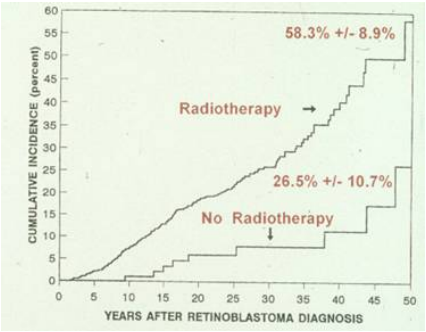
5%

Neglia, *JNCI* 93:618, 2001

Second Cancer after Retinoblastoma



Possible high dose interaction with genetic susceptibility

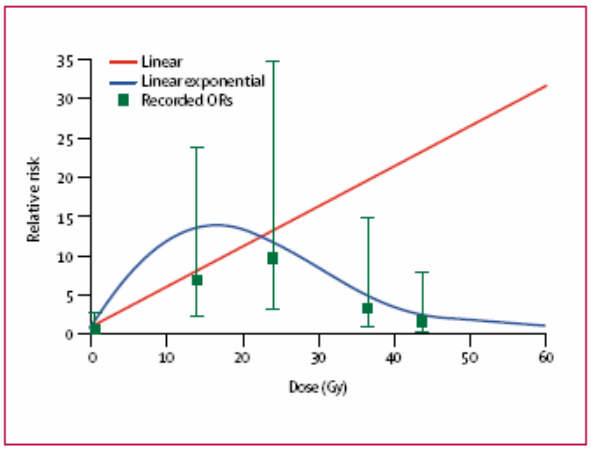


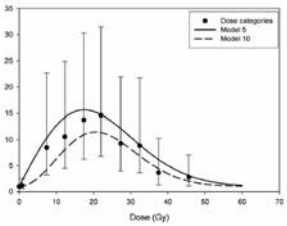
Updated. Yu et al. *JNCI 101:581,* **2009**

Updated. Kleinerman et al. *JCO 23:2272,* **2005**

Wong et al. *JAMA 278:1262,* **1997**

Thyroid Cancers After Childhood Cancer (CCSS) Cell Killing





Sigurdson, *Lancet* 365:2014, 2005
Tucker, *Cancer Res* 51:2885, 1991
Meadows, *JCO* 27, 2009
Bhatti, Rad Res 174, 2010

Radiation Dose and Breast Cancer Risk in the Childhood Cancer Survivor Study

Peter D. Inskip, Leslie L. Robison, Marilyn Stovall, Susan A. Smith, Sue Hammond, Ann C. Mertens, John A. Whitton, Lisa Diller, Lisa Kenney, Sarah S. Donaldson, Anna T. Meadows, and Joseph P. Neglia

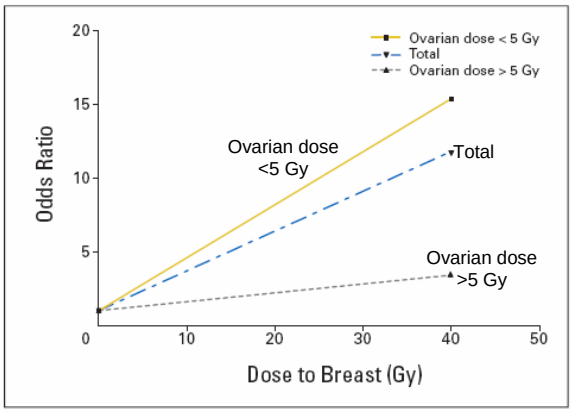


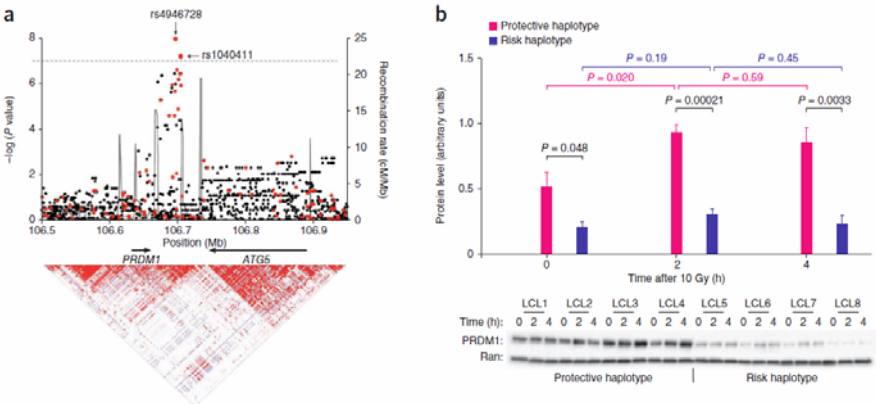
Fig 2. Fitted breast cancer risk by radiation dose to the breast and ovary.

Competing effect of ovarian dose and radiation induced early menopause --

Host factor influence

Inskip, *JCO* 27, 2009

Variants at 6q21 are associated with both radiation therapy–induced SMNs and PRDM1 protein abundance before and after radiation exposure.



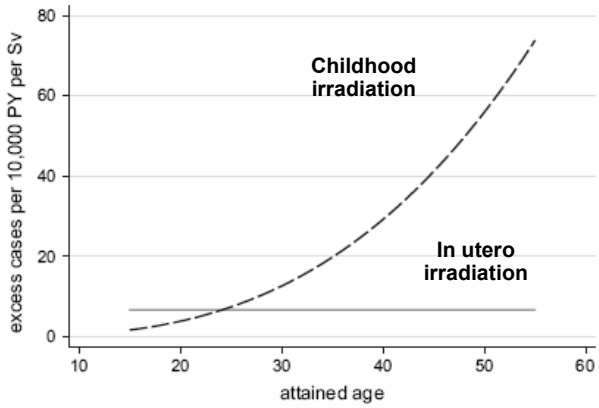
Survivors of pediatric Hodgkin's lymphoma are at risk for radiation therapy–induced second malignant neoplasms (SMNs). Two variants at chromosome 6q21 were associated with SMNs in survivors treated with radiation therapy as children but not as adults. The variants comprise a risk locus associated with decreased basal expression of PRDM1 and impaired induction of the PRDM1 protein after radiation exposure.

These data suggest a new gene-exposure interaction that may implicate PRDM1 in the etiology of radiation therapy-induced SMNs. Best et al. Nature Med 2011

Pregnancy and A-Bomb Radiation

Atomic Bomb Survivors In Utero and Post-Natal Cancer Risk

Risk of Cancer

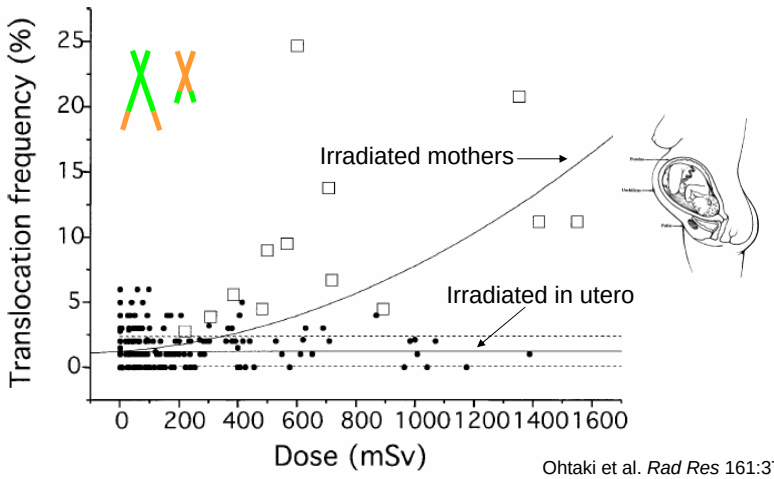


No apparent increased sensitivity

No childhood leukemia

Preston et al. *JNCI* 100:428, 2008

No Dose-Response for Chromosome Aberrations after *In Utero* Exposure, RERF



Ohtaki et al. *Rad Res* 161:373, 2004

Oxford Prenatal X-ray Survey

Is the low-dose association causal?

Childhood cancer	Cases	% X-ray	RR
Leukemia			
Lymphatic	2,007	14	1.5
Myeloid	866	14	1.5
Lymphoma	719	13	1.4
All leukemia/lymphoma	4,771	14	1.47
Wilms	590	15	1.6
CNS	1,332	13	1.4
Neuroblastoma	720	14	1.5
Bone	244	11	1.1
Other solid	856	15	1.6
All solid	3,742	14	1.47

Bithell, Stewart, *Br J Cancer* 31:271, 1975

Biologically plausible to have same RR?

ICRP Publication 90 (2003) Biological Effects after Prenatal Irradiation (Embryo and Fetus)

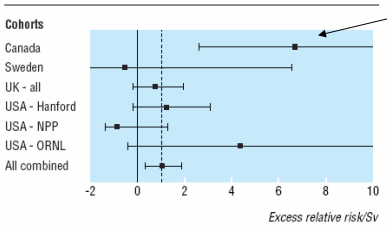
" Although the arguments fall short of being definitive because of the combination of biological and statistical uncertainties involved, they raise a serious question of whether the great consistency in elevated RRs, including embryonal tumours and lymphomas, may be due to biases in the OSCC study rather than a causal association. "

Christian Streffer, Chairman

Low Dose Studies are More Susceptible to – Bias and Confounding and Chance

81. … there are a number of studies of occupationally exposed persons, who generally receive low doses of ionizing radiation at low dose rates. For example, in the IARC 15-country study, average cumulative doses were 19.4 mSv, and fewer than 5% of workers received cumulative doses exceeding 100 mSv.

Canada

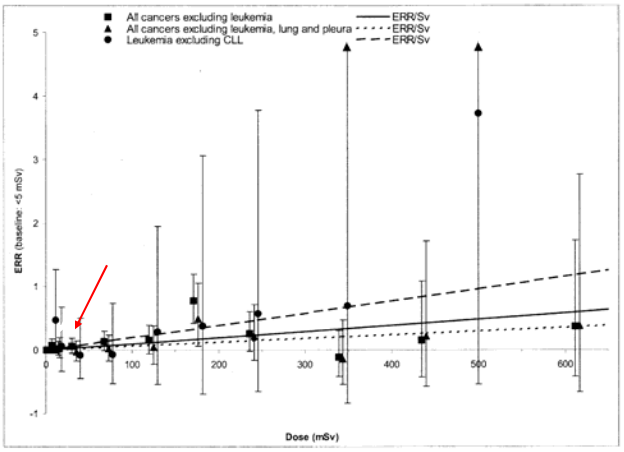


Boice JRP 2011

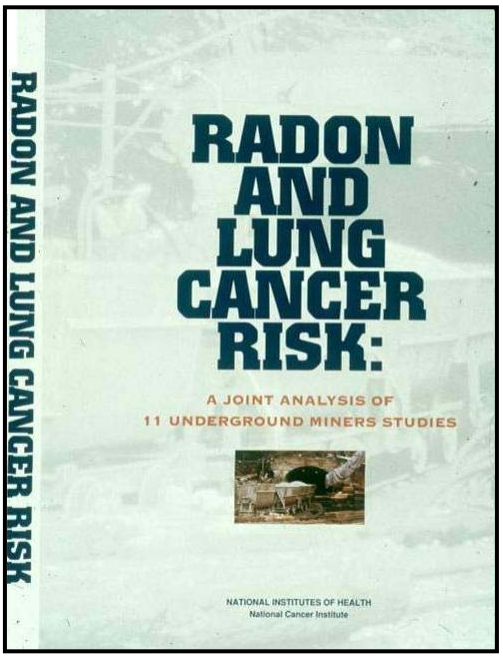
Fig 2 Excess relative risks per Sv for all cancer excluding leukaemia in cohorts with more than 100 deaths (NPP=nuclear power plants, ORNL=Oak Ridge National Laboratory)

Cardis et al. BMJ 2005

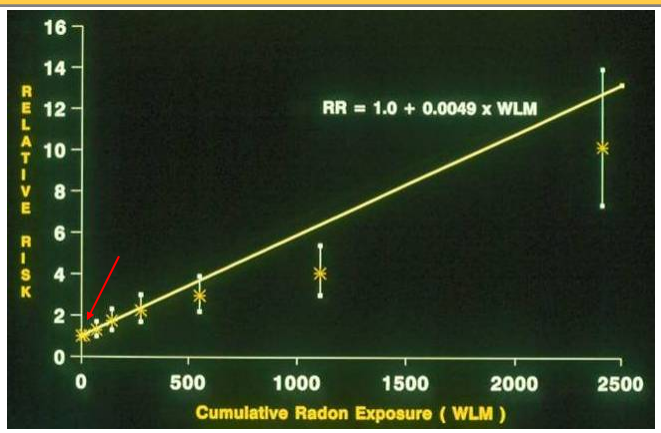
Leukemia and Cancer Dose Response
IARC - 15-Country Study - 2007



Cardis et al. Radiat Res 2007



11 Underground Miner Studies
68,000 Miners – 2,700 Lung Cancers

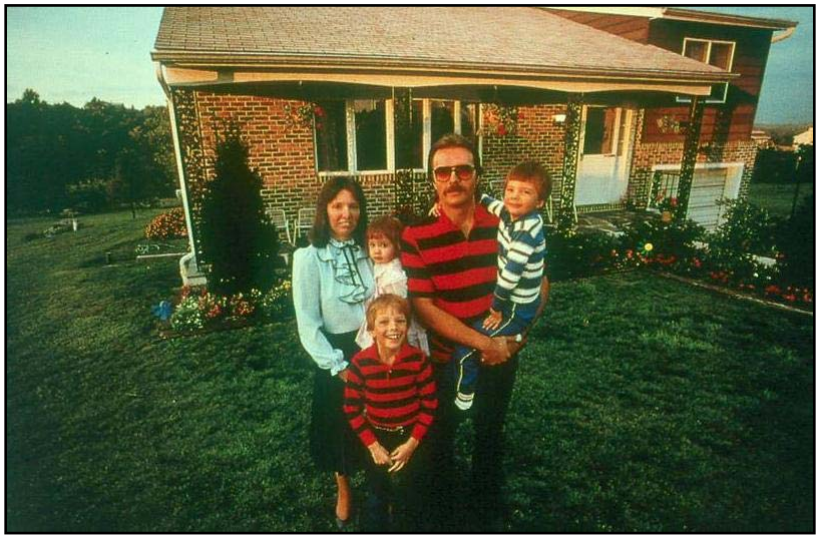


Lubin et al, 1993

1 pCi/l ~ 0.2 WLM / yr.

Washington Post, February 6, 1986

New Meaning to "The Nuclear Family"



Radon Studies in Homes (Case-Control)

United States
- √ New Jersey
- √ Missouri
- Iowa
- Connecticut
- Utah/Idaho

Canada
- Winnipeg

Europe
- Southwest England
- Western Germany
- Czech (cohort)

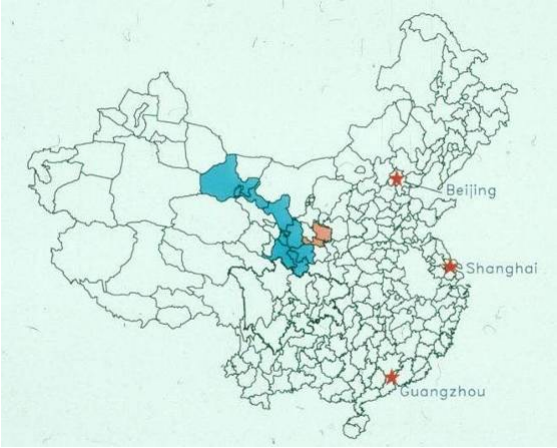
Nordic Countries
- √ Sweden
- Finland

China
- √ Shenyang
- √ Gansu

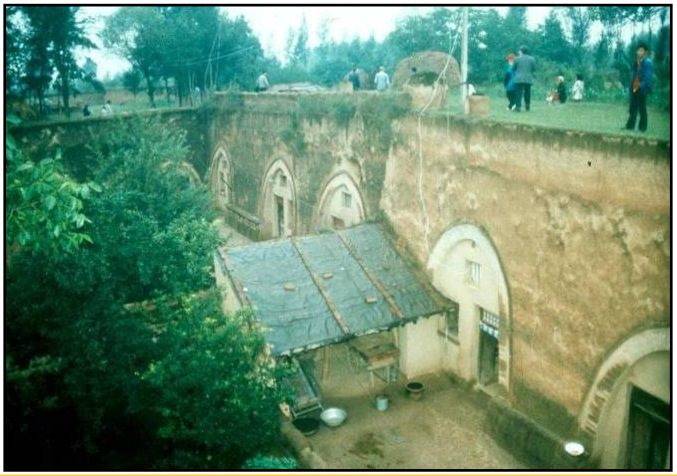
Pooled
- √ Lubin (1997, 1999)
- North America (Krewski, 2005)
- Europe (Darby, 2005)
- √ China (Lubin, 2004)
- World (Darby, in progress)

BEIR VI, 1999; Field, *Rev Envir Health* 16, 2001

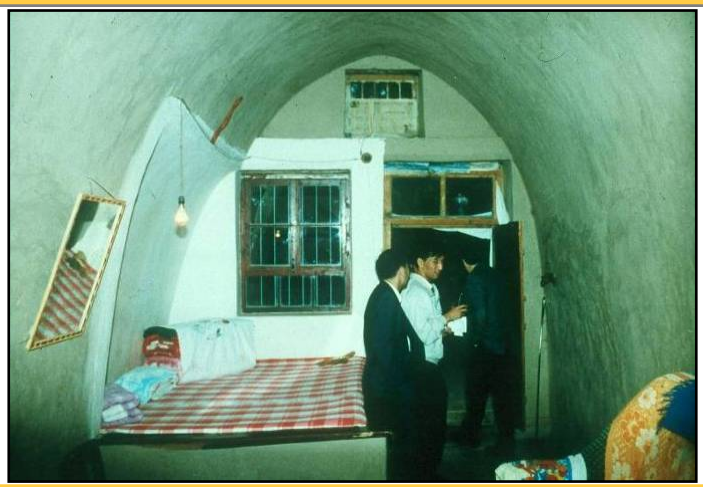
People's Republic of China
Gansu Province



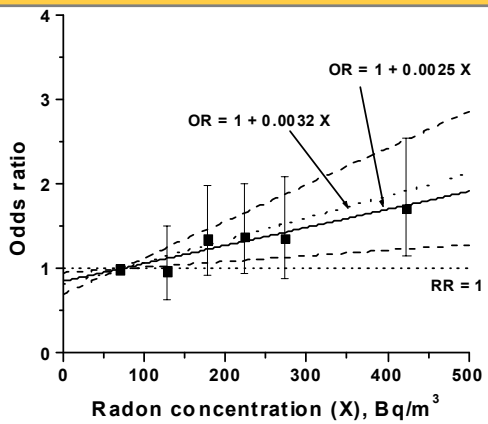
Gansu Province
Underground Dwellings



Gansu Province
Underground Dwelling



Gansu China - Radon Study



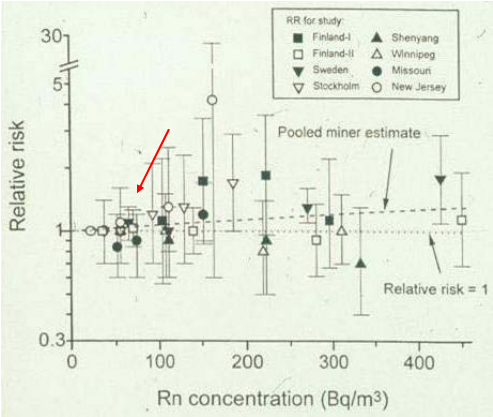
Consistent with linearity

4 pCi/l = 150 Bq/m^3

Wang et al. *Am J Epidemiol* 155:554 2002

Lubin et al. *Int J Cancer* 109:132, 2004

Indoor Radon Meta-Analysis
Lung Cancer



Difficult to detect low-dose risks, yet significant trend when studies combined

Lubin & Boice, *JNCI*, 89:49, 1997

4 pCi/l = 150 Bq/m^3

Radon Interacts with Smoking
to Enhance Risk

A nearly multiplicative interaction

NRC, BEIR, 1999

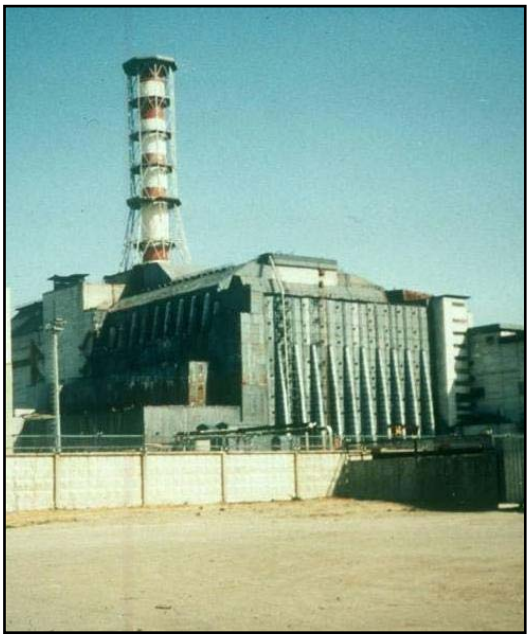
Smoking
Compared with Radiation/Radon

RR	Cigarettes Per Day	A-Bomb Dose, 1000 mSv	Miners WLM	Radon Indoor Bq/m^3
1.0	0	0	0	< 40
4.6	**1-9**	**3.4**	735	**4,500***

*140 pCi/L

Boice, *Radiat Res*, 146:356, 1996

Smoking <10 cig/day equivalent to being high dose A-bomb survivor



Thyroid Cancers in Children in Belarus

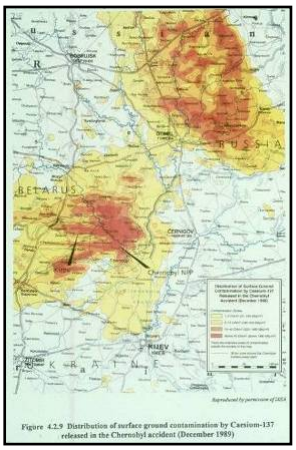
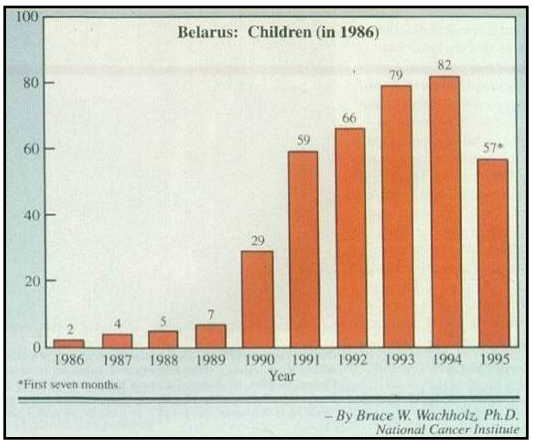
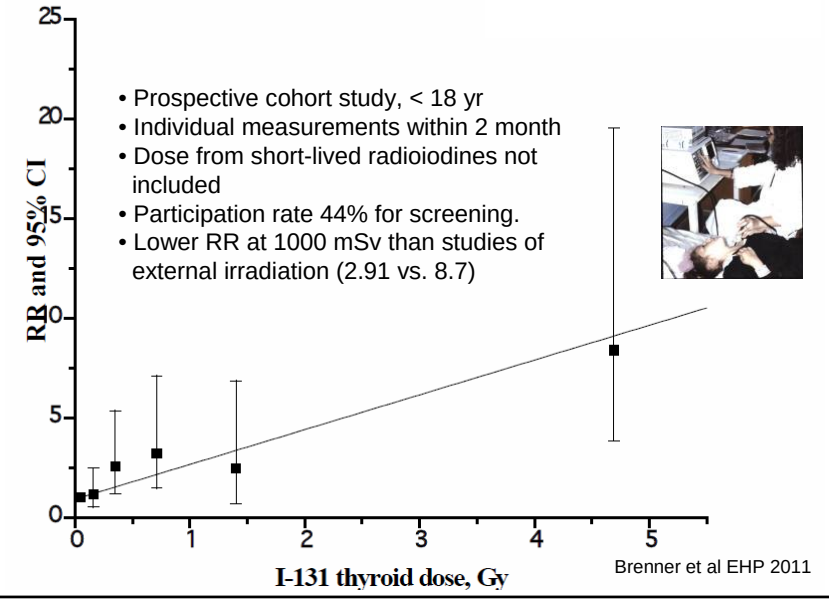


Figure 4.2.9 Distribution of surface ground contamination by Caesium-137 released in the Chernobyl accident (December 1989)



Belarus Milk
Japanese children - Fukushima
Washington State

Ukrainian – American Thyroid Study



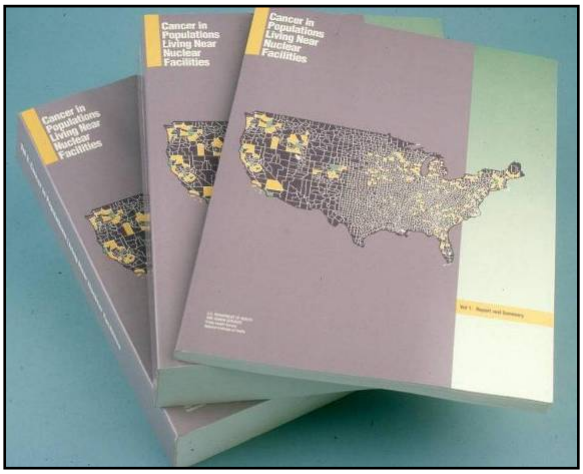
- Prospective cohort study, < 18 yr
- Individual measurements within 2 month
- Dose from short-lived radioiodines not included
- Participation rate 44% for screening.
- Lower RR at 1000 mSv than studies of external irradiation (2.91 vs. 8.7)

Brenner et al EHP 2011

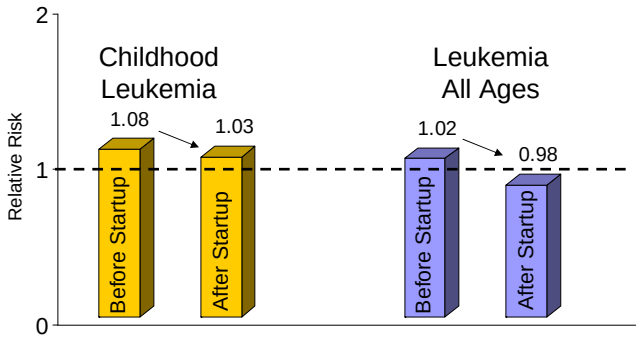
Descriptive Studies
Nuclear Facilities (Sellafield, U.K.)

Cancer in Populations
Living Near Nuclear Facilities

JAMA 256: 1991



Overall Relative Risk of Leukemia Before and After Nuclear Facility Startup



Risk higher before than after facilities began operating

Jablon et al, *JAMA* 265:1403-1408, 1991

What is the major unanswered question in radiation epidemiology?

- What is the level of risk when exposure received gradually over time and not briefly
- Being considered in U.S. by studying One Million Radiation Workers and Veterans

Barcellos-Hoff MH, Brenner DJ, Brooks AL, Formenti S, Hlatky L, Locke PA, Shore R, Tenforde T, Travis EL, Williams J. Low-dose radiation knowledge worth the cost. Science. 2011 Apr 15;332:305-6. https://www.orau.gov/lowdose2011/abstracts/boice_john.pdf

When Exposure is Spread Over Time

One Million U.S. Radiation Workers and Veterans

- Manhattan Project
- Atomic veterans
- Nuclear utility workers
- Medical and other occupational
- Nuclear navy workers

The 8th Series - Trinity

- First weapons test, Alamagordo, NM, 16 July 1945
- Longer follow-up than Japanese atomic bomb survivor study
- Historical figures:
  Robert Oppenheimer
  General Leslie Groves
  Enrico Fermi, Hans Bethe
  Theodore Hall

Risk Perception and Communication

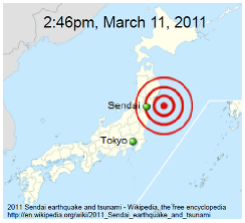
- Before your flight to Tokyo, you're sitting in a freshly dry-walled house, drinking coffee from a Styrofoam cup, talking on a cell phone while fish from Japan is cooking on the grill – Which of these is most likely to be a cancer risk? (AP July 15, 2011)
- Carcinogens are things that can cause cancer, but that label doesn't mean that they will or that they pose a meaningful risk.
- Better communication and understanding of radiation health effects needed. (Vano et al. JRP, 2011)

Cancer and the danger of risk perception. Scientific American, June 1, 2011

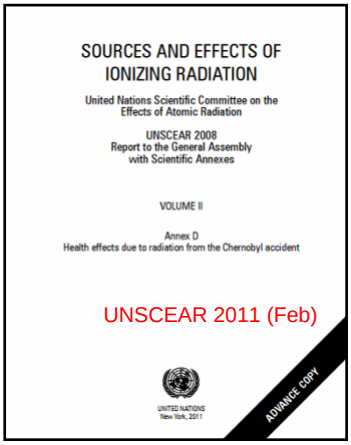
A Perspective on Fukushima

Summary

- Fukushima is not Chernobyl – doses to people much lower
- Japanese acted quickly – to reduce population dose
- “It is the dose that makes the poison” (Paracelsus)
- “… know which way the wind blows” (Dylan)
- “… and miles to go...” (Frost) – the immediate crisis over Dec 2011 but cleanup and societal problems are not
- Health surveys being conducted



Fukushima is not Chernobyl


SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2008
Report to the General Assembly with Scientific Annexes

VOLUME II

Annex D
Health effects due to radiation from the Chernobyl accident

UNSCEAR 2011 (Feb)

UNITED NATIONS
New York, 2011

ADVANCE COPY

“Fukushima is not Chernobyl”
CNN 3-21-11

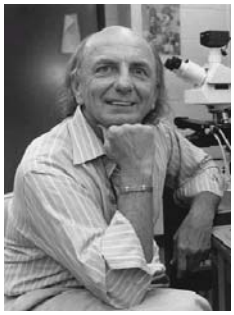
http://www.youtube.com/watch?v=5XbitM9LiYk&list=SL

134 workers had Acute Radiation Sickness with doses > 2000 mGy, some > 10,000 mG, highest 16,000 mG. 28 died in a few months.

Chernobyl firemen

Thanks - Fred Mettler

530,000 Recovery Workers (liquidators) were used in the cleanup over 3 years – mean dose 100 mSv



Worgul, Basil et al. **Cataracts** among Chernobyl Clean-up Workers: Implications Regarding Permissible Eye Exposures. Rad Res 2007

Radioactive iodines in the environment caused epidemic of thyroid cancer.

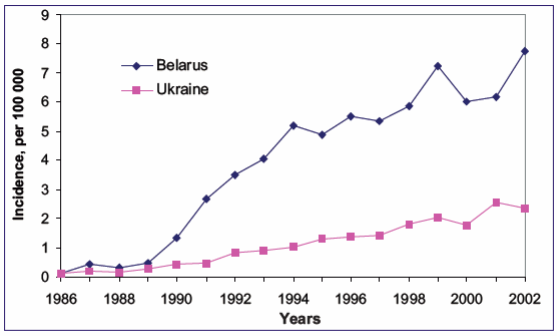
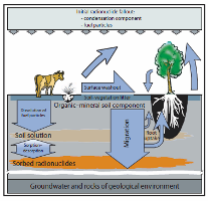


FIG. 3. Incidence rate of thyroid cancer in children and adolescents exposed to ^{131}I as a result of the Chernobyl accident (after Jacob et al., 2005).

Figure III. The main transfer pathways of radionuclides in the terrestrial environment [B13]

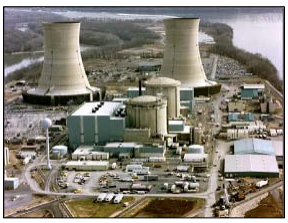


Iodine-131 Releases

(8 day half-life)

- Three Mile Island 0.005 PBq
- Fukushima 160 PBq
- Chernobyl 1760 PBq
- Atmospheric testing 675,000 PBq

Iodine-131, Cesium-137, other releases mainly seaward and lower than Chernobyl



PBq= Peta Bq = 1 x 10^{15} Bq 1 PBq = 27kCi

Radiation was released at Fukushima but ...

- "the poison is in the dose" (Paracelsus)
- And population exposure appears low (at the moment)

Population Exposure

- 1,080 children examined for thyroid dose – lower than the screening level.

Quick action taken to minimize adverse health consequences

- Evacuation
- Recommend to stay indoors
- Food restrictions
- Monitoring, masks
- Extensive population screening (200,000)

Worker Exposure

- Number of workers (23 May) 7,800
- Average exposure dose 8 mSv
- Number between 100-250 mSv (external) 30
- Number > 250 mSv (external + internal) at least 2
- Lifetime risk of developing cancer may be 1-2% for those > 100 mSv

Above 50 mSv (external + internal) 405

Internal Exposure and External Exposure in Highly Exposed Plant Workers

WORKER	Total (mSv)	External (mSv)	Internal (mSv)
A	678	88 (13%)	590 (87%)
B	643	103 (16%)	540 (84%)

Operation TomoDachi

U.S. Military Exposure

Internal Monitoring Preliminary

- Number monitored (2 Aug) 7,740 of 61,000
- Number > MDA 183 (2.4%)
- Average internal dose .04 mSv
- Highest internal dose 0.25 mSv

Stars and Stripes, July 20, 2011

What about food?

Regulated values of radioactive materials in food (Bq/kg)

Item	I-131	Cs	U	Pu, Am, Cm
Drinking water	300 †	200	20	1
Milk	300	200	20	1
Vegetables, etc	2000	500	100	10

† Belarus 32,000 Bq/L 3 days after Chernobyl

Population exposures appear low -- but

- To show compassion and provide assurance, health surveys are planned
- Provide medical care
- Mental health problems most likely consequence

Health Survey – Fukushima Residents

BASIC STUDY

- 2 Million Residents sent 10 Page Questionnaire
- To learn location, intake of food, baseline data
- 30 year follow-up planned, first year to cost 96 Billion Yen
- Purposed stated to alleviate anxiety

KOSHU EISEI JOHO (Public Health Information) 41(6):18-21, Sep 2011
Normile D. Newsmaker interview: Seiji Yasumura. Science 333:685, 2011

Health Survey – Fukushima Residents

DETAILED STUDIES

- (1) Thyroid study of 360,000 <18y, 2 ½ y started Oct 2011
- (2) Health exam, including blood samples of ~ 80,000 in . the evacuation zone
- (3) Mental health, counseling of those in evacuation zone
- (4) Pregnant women and nursing mothers

KOSHU EISEI JOHO (Public Health Information) 41(6):18-21, Sep 2011
Normile D. Newsmaker interview: Seiji Yasumura. Science 333:684-5, 2011

Fukushima Diaichi NPP
Sept 13, 2011

Bibliography - 1

Amundson S, et al. Low-dose radiation risk assessment. Report of an International Workshop on Low Dose Radiation Effects held at Columbia University Medical Center, New York, April 3-4, 2006. *Radiat Res* 166:561-565, 2006.

Boice JD Jr. Ionizing radiation. In: *Cancer Epidemiology and Prevention, 3rd Edition*. (Schottenfeld D, Fraumeni JF Jr, eds). New York, Oxford University Press, 2006.

Boice JD Jr. Lauriston S. Taylor lecture: Radiation epidemiology: the golden age and future challenges. Health Phys 100:59-76, 2011.

Boice JD, Hendry J, Nakamura N, Niwa O, Nakamura S, Yoshida K. Meeting report: low dose rate epidemiology of high background radiation areas. Radiat Res 173:849-854, 2010.

Cardis E, et al. The 15-Country collaborative study of cancer risk among radiation workers in the nuclear Industry: estimates of radiation-related cancer risk. *Radiat Res* 167:396, 2007.

Darby S, et al. Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. *BMJ* 330:223, 2005.

Fry RJM, Boice JD Jr. Radiation carcinogenesis. In: Oxford Textbook of Oncology, Second Edition (Souhami RL, Tannock I, Hohenberger P, Horiot J-C, eds). New York: Oxford Press, pp 167-184, 2002.

Bibliography - 2

Hall EJ, Metting N, Puskin J, Ron E. Low dose radiation epidemiology: what can it tell us? *Radiat Res* 172:134-138, 2009.

International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Vol 75. Ionizing Radiation, Part 1: X- and Gamma (γ) – Radiation, and Neutrons. Lyon, France: IARC, 2000.

International Agency for Research on Cancer. IARC monographs on the evaluation of carcinogenic risks to humans. Vol 78. Ionizing Radiation, Part 2: Some Internally Deposited Radionuclides. Lyon, France: IARC, 2001.

Nair RR, Rajan B, Akiba S, Jayalekshmi P, Nair MK, Gangadharan P, Koga T, Morishima H, Nakamura S, Sugahara T. Background radiation and cancer incidence in Kerala, India-Karanagappally cohort study. *Health Phys* 96:55-66, 2009.

National Academy of Sciences. Committee on Health Risks of Exposure to Radon. (BEIR VI). Washington, DC: National Academies Press, 1999.

National Research Council. Committee on the Biological Effects of Ionizing Radiation. (BEIR VII). Washington, DC: National Academies Press, 2006.

National Council on Radiation Protection and Measurements. Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation. NCRP Report No. 136. Bethesda, MD: NCRP, 2001.

Bibliography - 3

Ozasa K, et al. Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950–2003: An Overview of Cancer and Noncancer Diseases. *Radiat Res* 2012;177 [Epub ahead of print].

Preston DL, et al. Effect of recent changes in atomic bomb survivor dosimetry on cancer mortality risk estimates. *Radiat Res* 162:377, 2004.

Preston DL et al. Solid cancer incidence in atomic bomb survivors: 1958-1998. *Radiat Res* 168:1, 2007.

Tao Z, Akiba S, Zha Y, Sun Q, Zou J, Li J, Liu Y, Yuan Y, Tokonami S, Morishoma H, Koga T, Nakamura S, Sugahara T, Wei L. Cancer and non-cancer mortality among Inhabitants in the High Background Radiation Area of Yangjiang, China (1979-1998). *Health Phys*. 2012 Feb;102(2):173-181.

Tubiana M, et al. Dose-effect relationships and the estimation of carcinogenic effects of low doses of ionizing radiation. Joint Report No. 2, Academie Nationale de Medecine, Institut de France-Academie des Sciences, Paris, 2005.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). UNSCEAR 2006 Report to the General Assembly with Scientific Annexes, Effects of Ionizing Radiation. Vol 1: Report and Annexes A and B. New York: United Nations, 2008; Vol 2: Annexes C, D and E, 2009.

Bibliography Fukushima - 1

Barcellos-Hoff MH, Brenner DJ, Brooks AL, Formenti S, Hlatky L, Locke PA, Shore R, Tenforde T, Travis EL, Williams J. Low-dose radiation knowledge worth the cost. Science 332:305-306, 2011.

Boice JD Jr. Testimony before the House Committee on Science, Space and Technology, Subcommittees on Energy & Environment and on Investigations & Oversight, Hearing on Nuclear Energy Risk Management, May 13, 2001. [http://science.house.gov/sites/republicans.science.house.gov/files/documents/hearings/051311_Boice%20Testimony.pdf]

Boice JD Jr. Uncertainties in studies of low statistical power (Editorial). J Radiol Prot 30:115-120, 2010.

Boice JD Jr. Radiation epidemiology: a perspective on Fukushima. J Radiol Prot 2012 in press.

Bromet EJ, Havenaar JM. Psychological and perceived health effects of the Chernobyl disaster: a 20-year review. Health Phys 93:516-521, 2007.

CNN – State of the Union. Boice JD Jr. It's not Chernobyl. 3-21-11 http://www.cnn.com/video/data/2.0/video/world/2011/03/23/sotu.boice.0320.cnn.cnn.html

Bibliography Fukushima - 2

Dauer LT, Zanzonico P , Tuttle RM, Quinn DM, Strauss HW. The Japanese Tsunami and resulting nuclear emergency at the Fukushima Daiichi Power Facility: technical, radiologic, and response perspectives. J Nucl Med, 28 July 2011 [Epub ahead of print].

Douple EB, Mabuchi K, Cullings HM, Preston DL, Kodama K, Shimizu Y, Fujiwara S, Shore RE. Long-term radiation-related health effects in a unique human population: lessons learned from the atomic bomb survivors of Hiroshima and Nagasaki. Disaster Med Public Health Prep 5(Suppl 1):S122-133, 2011.

IAEA. Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety - The Accident at TEPCO's Fukushima Nuclear Power Stations - Nuclear Emergency Response Headquarters Government of Japan, June 2011. Available at http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html (accessed June 2011).

ICRP. Application of the Commission's recommendations to the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency. International Commission on Radiological Protection. Publication 111. Annals of the ICRP, Vol. 39, Elsevier, Amsterdam, 2009.

Bibliography Fukushima – 3

IRSN (2011). Institut de Radioprotection et de Surete Nucleare. Assessment on the 66th Day of Projected External Doses for Populations Living in the North-West Fallout Zone of the Fukushima Nuclear Accient – Outcome of Population Evacution Measures - Report DRPH/2011-10. Directorate of Radiological Protection and Human Health. Available at http://www.irsn.fr/EN/news/Documents/IRSN-Fukushima-Report-DRPH-23052011.pdf (Accessed June 24, 2011).

Kaiser J. Radiation risks outlined by bombs, weapons work, and accidents. Science 331: 1504-1505, 2011.

Kusumi S. The 2011 off the pacific coast of Tohoku earthquake and tsunami. The 58th session of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 23rd May, 2011.

Land CE. Estimating cancer risks from low doses of ionizing radiation. Science 109:1197-1203, 1980.

MSNBC. Boice JD Jr. Radiation in US Milk. 4-2-11 http://www.youtube.com/watch?v=IiB48G8E-cE

Normile D. Newsmaker interview: Seiji Yasumura. Fukushima Begins 30-Year Odyssey in Radiation Health. Science 333:684-5, 2011.

Bibliography Fukushima – 4

Normile D. Fukushima revises the low-dose debate. Science 332: 908-910, 2011.

Ohnishi T. The disaster at Japan's Fukushima-Daiichi nuclear power plant after the March 11, 2011 earthquake and tsunami, and the resulting spread of radioisotope contamination. Radiat Res. 2012 Jan;177(1):1-14. Epub 2011 Nov 7

Smith J. A long shadow over Fukushima. Nature 472:7, 2011.

Stone R. Fukushima cleanup will be drawn out and costly. Science 331:1507, 2011

UNSCEAR (2011). United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report, Volume II, Scientific Annex D, Health effects due to radiation from the Chernobyl accident. United Nations, New York, 2011.

Vano E, Ohno K, Cousins C, Niwa O, Boice J. Radiation risks and radiation protection training for healthcare professionals. ICRP and the Fukushima experience (Editorial). J Radiol Prot 31:285-285, 2011.

Wakeford R. And now, Fukushima. J Radiol Prot 31:167-176, 2011.

Yonekura Y. Exposures from the events at the NPPs in Fukushima following the Great East japan earthquake and Tsunami. The 58th session of United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 23rd May, 2011.