Implication of the LNT Hypothesis for Evacuees from the Fukushima NPP Disaster

August 30, 2012

(Revised: September 8. 2012)

Genn Saji

An Awareness of Issues

- Among the evacuees* from the Fukushima NPP disaster, many "disaster-related deaths (DODs)" have been reported. It is necessary to critically examine whether the evacuation orders, based on the LNT hypothesis, are justified in comparison with the averted radiological risk.
- ANS President's Special Session: Low Level Radiation and Its Implications For Fukushima Recovery (June 25, 2012)
- ML Group Pre-Conference Meeting:
  "Extreme discrepancies among specialists, on health effects of low level radiation, were main causes of confusion"
  http://jein.jp/pre-nbp2012.html (*in Japanese*)

* The term "evacuation" was originally defined to avoid the acute radiation sickness during the active phase of severe accidents, typically for the first two weeks. After that, it is indispensable to redefine safety criteria for "relocation" and "resettlement" for the evacuees. At Fukushima, the prolonged evacuation was enforced by the governments, in consideration of wide spread radiation phobia.

Disaster-Related Death*
- Final Report of Recovery Agency (2012.8.21) –

http://www.reconstruction.go.jp/topics 240821_higashinihondaishinsainiokerushinsaikanrenshinikansuruhoukoku.pdf

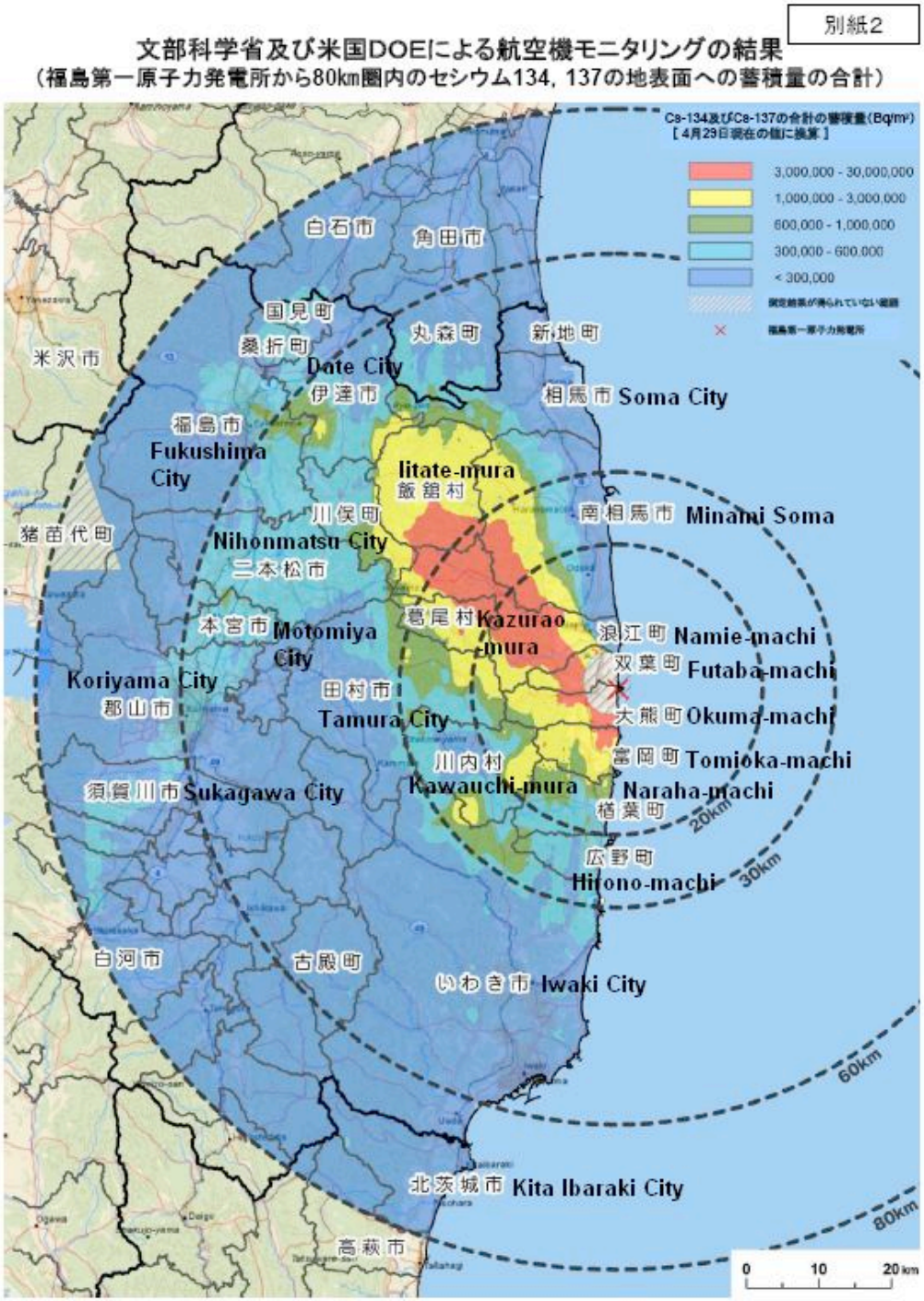
- Objectives: Investigation of causes of DRDs in those areas with high rates of DRDs. It also includes evacuees from towns and villages where residents were instructed to evacuate because of the nuclear disaster. In total, it consists of 1,263 (as of March 31, 2012).
- Methods: Review and analysis of basic data provided from the municipal districts such as death certificates and background information used by the "evaluation committees on the stipulation of condolence money".
- 761 in Fukushima Prefecture, 636 in Miyagi Prefecture. Approximately 90% were above 60 y.o. and half of them died in the first month.
- Approximately even tolls among males and females. Approximately 60% of them had anamneses, 10% of them without, 30% of them unknown. For age of death, approximately 60% in 80th, 90% above 70th. Approximately 80% within one month, 80% within 3 months.

* "Disaster-Related Death (DRD)" is a word-by-word translation of "shinsai kanren shi". No official translation is available. It is defined as "those who passed away due to worsening of wounds or other effects of the Great Eastern Japan Disaster and were included as grantees provided with the "disaster condolence money" by the Law.

Area Coverage

1. Iwate Prefecture: Oofunawatari, Kamaishi and Ootsuchi
2. Miyagi Prefecture: Ishinomaki , Sendai, Kesen-numa
3. Fukushima Pref.: Minami-Souma, Namie-Machi, Iwaki City, Tomioka-machi, Ookuma-machi, Futaba-machi, Iitaate-mura, Naraha-machi, Kawauchi-mura, Hirono-machi, Kuzuo-mura, Tamura-shi

Note:
All of the Fukushima towns and villages included in this investigation are from former “Vigilance” Zone (< 30km) or “Scheduled- and Planned Evacuation” Zones (the highly contaminated NW collider stretching from the Fukushima Dai-ichi).



Basic Statistics of DRD (1/3)

Time of Deaths

	< 1 w	1 w ~ 1 m	1 ~ 3 m	3 ~ 6 m	6 m ~ 1y	> 1 y	Total
Iwate and Miyagi	144	196	134	40	15		529
Fukushima	86	182	244	174	48		734
Total	230	378	378	214	63		1263
Accumulation In Fukushima	86 (12%)	268 (37%)	512 (70%)	686 (93%)	734		

Age Distribution of Deaths

	0 - 9	10 ~	20 ~	30 ~	40 ~	50 ~	60 ~	70 ~	80 ~	90 ~	100 ~	NA	Total
Iwate and Miyagi	1			3	8	20	53	102	239	96	7		529
Fukushima			2	2	7	13	59	136	310	188	16	1	734
Total	1		2	5	15	33	112	238	549	284	23	1	1263

Suicides

Iwate and Miyagi	4
Fukushima	9
Total	13

Basic Statistics of DRD (2/3)

Cause	1-1	1-2	1-3	2	3	4-1	4-2	5-1	5-2	6-1	6-2	Total
Iwate and Miyagi	39	97	13	21	205	112	1	1		110	65	664
Fukushima	51	186	4	380	433	38	33			105	56	1286
Total	90	283	17	401	638	150	34	1		215	121	1950

Cause:

1-1 Delay in first aid due to collapse of hospital infrastructure

1-2 Worsening of anamneses due to collapse of medical infrastructure (including at transferred hospitals)

1-3 Delay of first care due to traffic jam

2 Physical and psychological fatigue due to travelling to refuges

3 Physical and psychological fatigue in refuges, etc.

4-1 Physical and psychological fatigue due to earthquake and tsunami.

4-2 Physical and psychological fatigue due to nuclear accident

5-1 Over loading of rescue and supporting activities

5-2 Inhalation of soot and ash

6-1 Others

Basic Statistics of DRD (3/3)

Dwelings at the time of Deaths

Dwelling	1	2	3-1	3-2	3-3	3-4	3-5 Same as before the earthquake			4 Other locations			
							3-5-1	3-5-2	3-5-3	4-1	4-2	4-3	Total
Iwate and Miyagi	15	3	66	4	5	40	125	57	45	81	32	56	529
Fukushima	2	9	28	3	18	27	47	30	9	150	81	330	734
Total	17	12	94	7	23	67	172	87	54	231	113	386	1263

1 At or near the place hit by the earthquake
2 Moving to refuges
3-1 Refuges
3-2 Temporary housings for refugees
3-3 Government rent housings for refugees
3-4 Relatives' and friends'
3-5 Same place as before the earthquake
3-5-1 Home residence
3-5-2 Hospitals
3-5-3 Care houses
4 Other locations
4-1 Hospitals
4-2 Care houses
4-3 Others, unknown

ANS

President's Special Session: Low Level Radiation and Its Implications for Fukushima Recovery (June 25, 2012)

The pessimism that now makes much noise in the global public about nuclear radiation can, in our time, be shown to be wrong. The information collected and discussed in this Special Session has, we are hopeful, opened the door to a change in our attitudes with the foundation of scientific evidence about radiation. It is dedicated to the residents surrounding the Fukushima site who are still unable to return to their homes due to the overreaction toward low-level radiation.

Eric P. Loewen, Ph.D.
ANS President
June 25, 2012

Points of ANS Report

Dr. J.A Cuttler's Points (1/2)

- Public exposure in Fukushima Dai-ichi disaster
  <91μSv/h × 8766 h/y = 798 mSv/y is in
  a level of the high radiation zones in the world

- In 1920th, the agreed "tolerable" occupational dose limit was 640 mSv/y

- A DNA damage rate induced by 1mSv/y radiation exposure is negligible, since it is equivalent to 1/600,000,000 of natural DNA damages, induced by activated oxygen produced in mitochondria.

Mortality of 1338 British Radiologists

Tolerance dose limit at dermis 600R/m × safety factor 1/100≈2mSv/d

TABLE 1. Observed and expected numbers of deaths from cancer and all other causes among radiologists who entered the study prior to 1921 or after 1920.

Cause of death	Observed (O) and expected (E) numbers of deaths					
	Entry prior to 1921			Entry after 1920		
	O	E	O/E	O	E	O/E
All causes	319	(1) 334.42	0.95	411	541.77	0.76***
		(2) 308.03	1.04		461.14	0.89*
		(3) 327.97	0.97		469.97	0.87**
All neoplasms	62	(1) 49.11	1.26*	72	114.93	0.63***
		(2) 43.07	1.44**		91.07	0.79*
		(3) 35.39	1.75***		68.65	1.05
Other causes	257†	(1) 285.31	0.90*	339†	426.84	0.79***
		(2) 264.96	0.97		370.07	0.92
		(3) 292.58	0.88*		401.32	0.84**

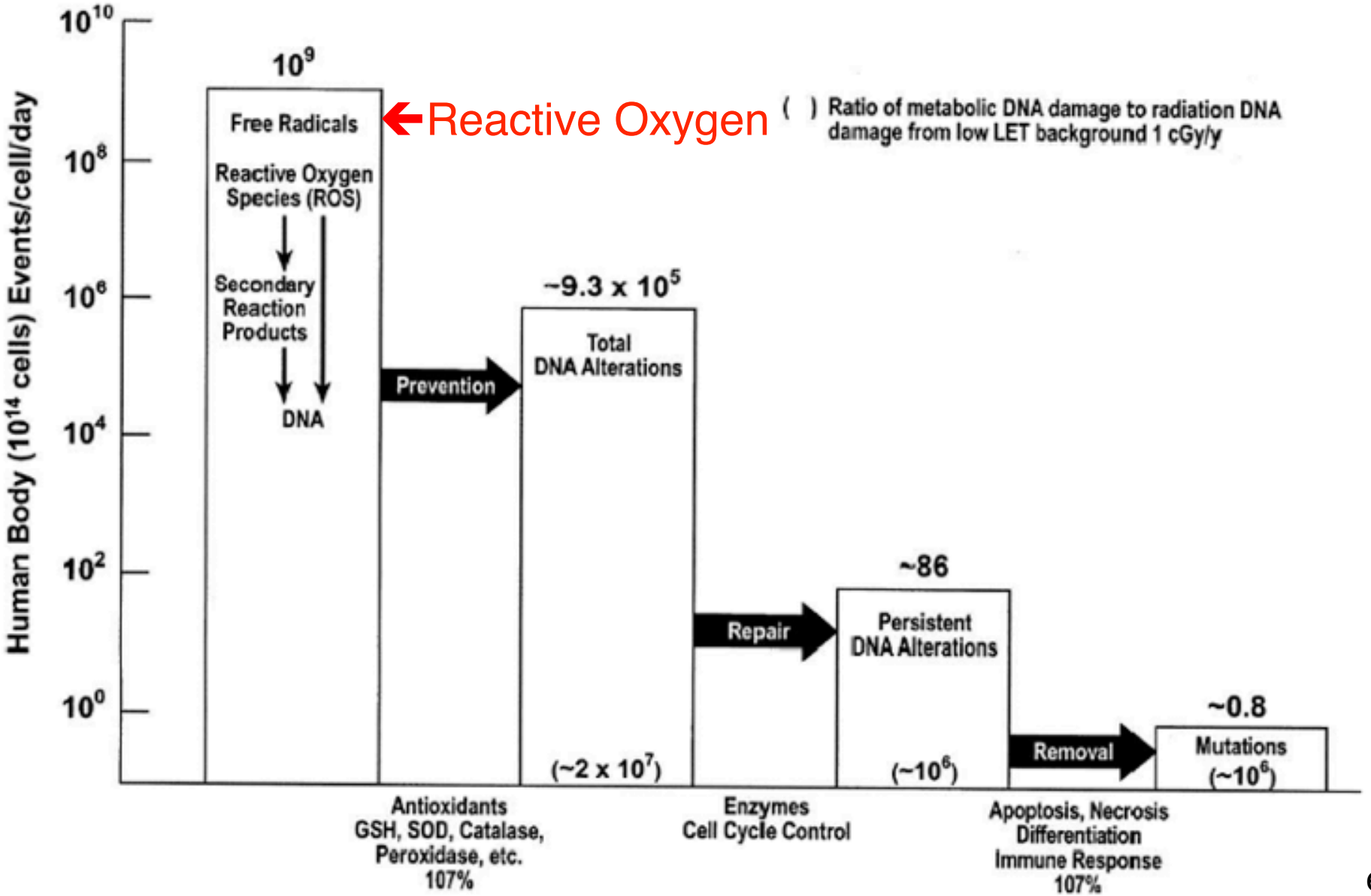
(1) Based on rates for all men in England and Wales.
(2) Based on rates for social class 1.
(3) Based on rates for medical practitioners.
† includes one death with unknown cause.

*P < 0.05
**P < 0.01
***P < 0.001
} One sided in direction of difference.

E.J. Calabrese, 2009. The road to linearity: why linearity at low doses became the basis for carcinogen risk assessment Arch Toxicol (2009) 83:203–225

In a DNA, alteration/recovery/removal processes are always taking place

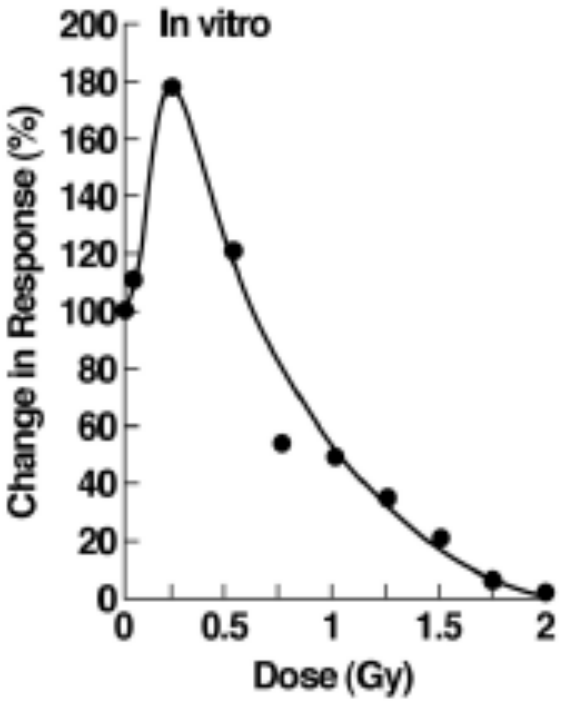
1mSv/y radiation alteration frequency is 6 orders of magnitude lower than the spontaneous alteration of DNA

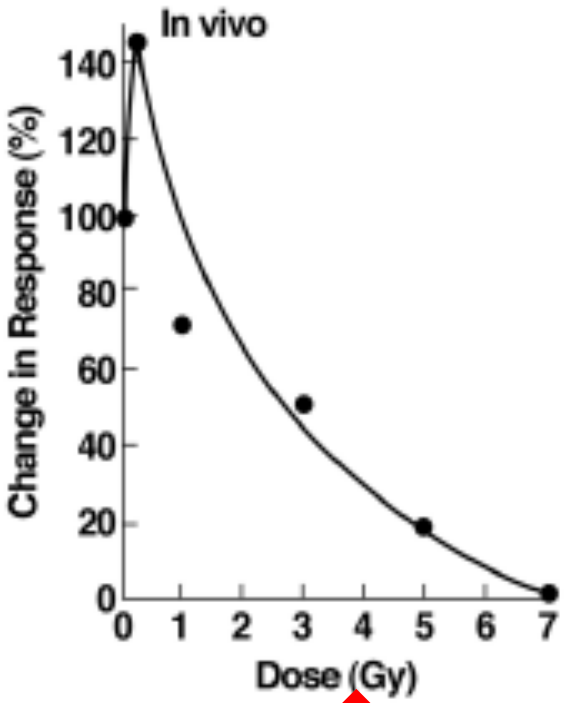


D. Billeı ersy
in Radiation Protection. Radiat. Res. 124, 242-245 (1990).

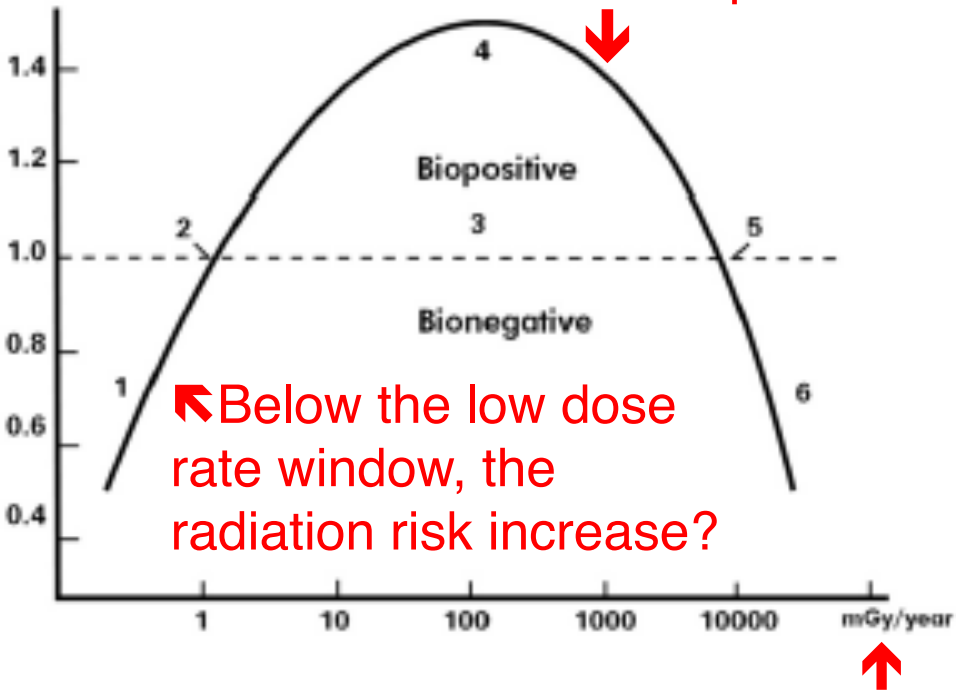
Dr. J.A Cuttler's Points (2/2)

- "Radiation Hormesis" -





Hormesis may not work in low dose rate exposure?



Below the low dose rate window, the radiation risk increase?

Dose (Gy).（Should not extrapolate to）. **Dose Rate（mGy/y)**

- Organisms are stressed: physical, chemical, biological, radiation
- Organisms adapt to stress
- Radiation modulates organism's defenses

The illustration on R.H.S. needs verification for Fukushima!

Low radiation dose/dose-rate reduces cancer incidence because it stimulates:

- prevention of DNA damage
- repair of DNA damage
- removal of damaged cells and removal of cancer cells

High radiation dose/level has opposite effects

Early Re-settlement of Evacuees of Fukushima Disaster

Is it possible to substantiate the non-LNT hypothesis as deployed in the ANS report ?[note]

Note Unfortunately, anti-nuke people would not try to listen to this kind of discussion in Japan, by rejecting it out of hand, although their words and deeds are actually shortening the life of Fukushima evacuees.

An independent verification by scientists are indispensable now.

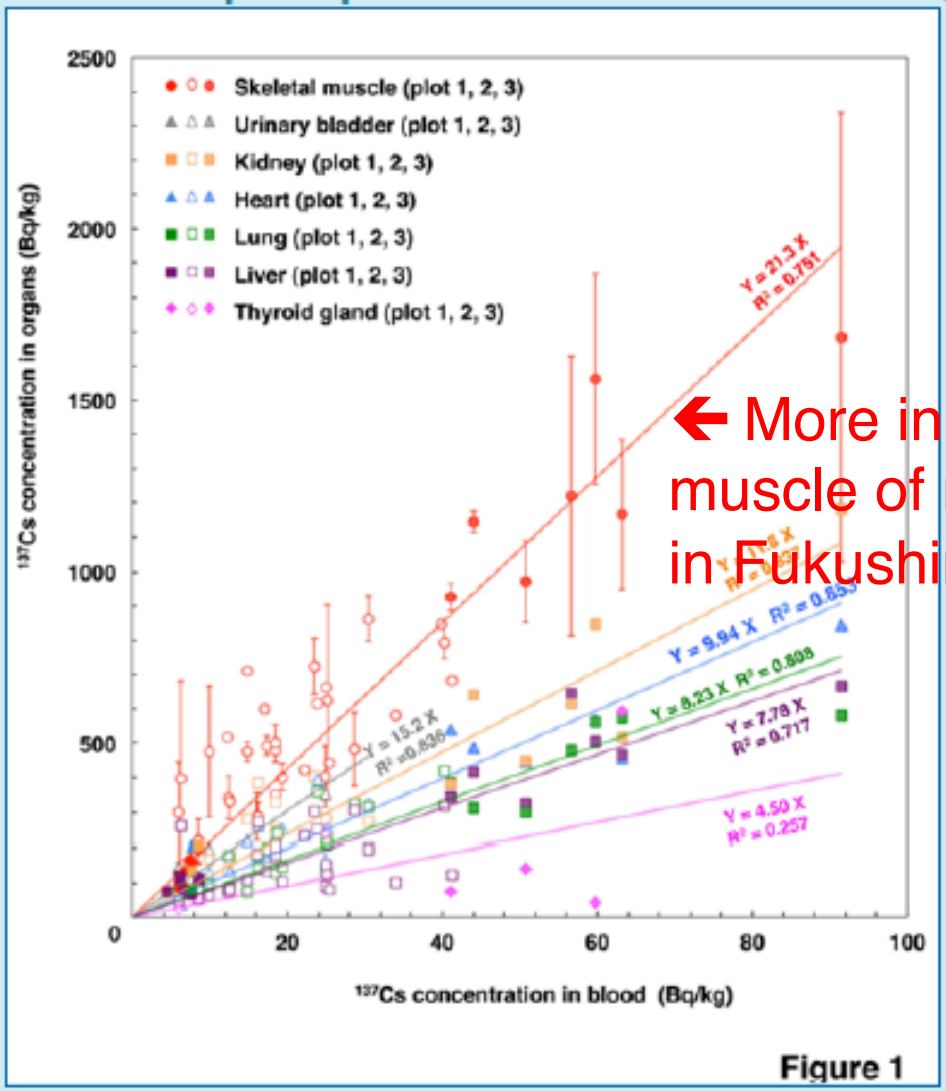
Implication of Health Effects of Low Level Radiation
for Early Re-settlement of Evacuees of Fukushima Disaster

- The most concerned issue is internal radioactive iodine exposure through inhaled radioactive plume during evacuation. This exposure pathway is nothing to do with early re-settlement for evacuees (too late).
- Need to evaluate effects of the low-level chronic external exposure due to $^{134+137}$Cs through at the heavily contaminated areas.
- Not necessary to worry about internal exposure of $^{134+137}$Cs.

Internal Exposure of Radioactive Cs

- It does not accumulate in a particular organ -

Correlation of ^{137}Cs radioactivity between peripheral blood and organs



← More in skeletal muscle of released cattle in Fukushima

Manabu Fukumoto
2012

Figure 1

Issues in the Hormesis hypothesis (1/2)

Is it applicable for early re-settlement of Fukushima evacuees?

1. It is not scientific to convert the dose (Sv) effects to dose rates (Sv/y) for radiation protection. However
2. Some epidemiological data are valuable, such as the data of the high dose rate districts in the world as well as accidental exposure of residents in Taiwan due to a ^{60}Co orphan source, inadvertently mixed in structural steels of apartments. However, there is a limitation in interpretation of confounding factors as well as limited sizes of cohorts. (For example, those with higher sensitivity to radiation, such as vulnerable babies and children, may not be included in the cohorts due to early deaths.)
3. Data are limited in “life span studies” of experimental animals, performed in the low dose-rate and chronic exposure conditions. (In general, research people tend to refrain from experiments where dose/dose-rate effects are not “visible.”

Issues in the Hormesis hypothesis (2/2)

Is it applicable for early re-settlement of Fukushima evacuees?

4. Biological effects are diversified and complex in general
   ➔ Overly simplified ?
   - Mutation effects (sensitivity, genetic diseases), target organs, sex etc.
   - Dose and dose rate
   - Time of exposure in life: impregnation, embryo, fetus, infant, baby, adolescent, adult
   - Radiation-induced anomalies in focus
5. Dose-Response curve is a conceptual diagram
   - Bio-positive effects are reported among residents of high dose rates in the several places in the world as well as in the epidemiological report in Co-60 exposed cohort in Taiwan. However, different interpretation are possible….
   - No life extension effects observed in healthy animals under chronic low dose-rate exposure?
   - Various effects are reported in experiments targeted on specific disease models, with a “ping point” exposure at impregnation/embryo with high dose-rate and low level exposure. Very complex to apply for human being.
6. To what extent we should include the weaks when not sufficient data are available.
   - Fetus, infants, babies, pregnant women, anamneses
   - Genetic diseases, physically weak children

Health Effects of ^{60}Co Exposure in Taiwan

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2477708/

- **^{60}Co accidentally contaminated steels in** 1982-1984
- Residents were exposed for several years in approximately 1770 apartments, 180 buildings
- Doses and exposed individuals

TABLE 1: Annual and accumulated doses

Cohort	Number of people	Mean annual dose in first year 1983 (mSv)	1983 to 2003 individual dose (mSv)	1983 to 2003 "collective dose" (person-Sv)
High	1,100	525	4000	2,660*
Medium	900	60	420	378
Low	8,000	18	120	960
Averaged	10,000	74	600	6,000
Adjusted	10,000	49	400	4,000

*From July 1996, 50% of residents relocated.

Cancer Rates

- Significantly lower than an average Taiwan -

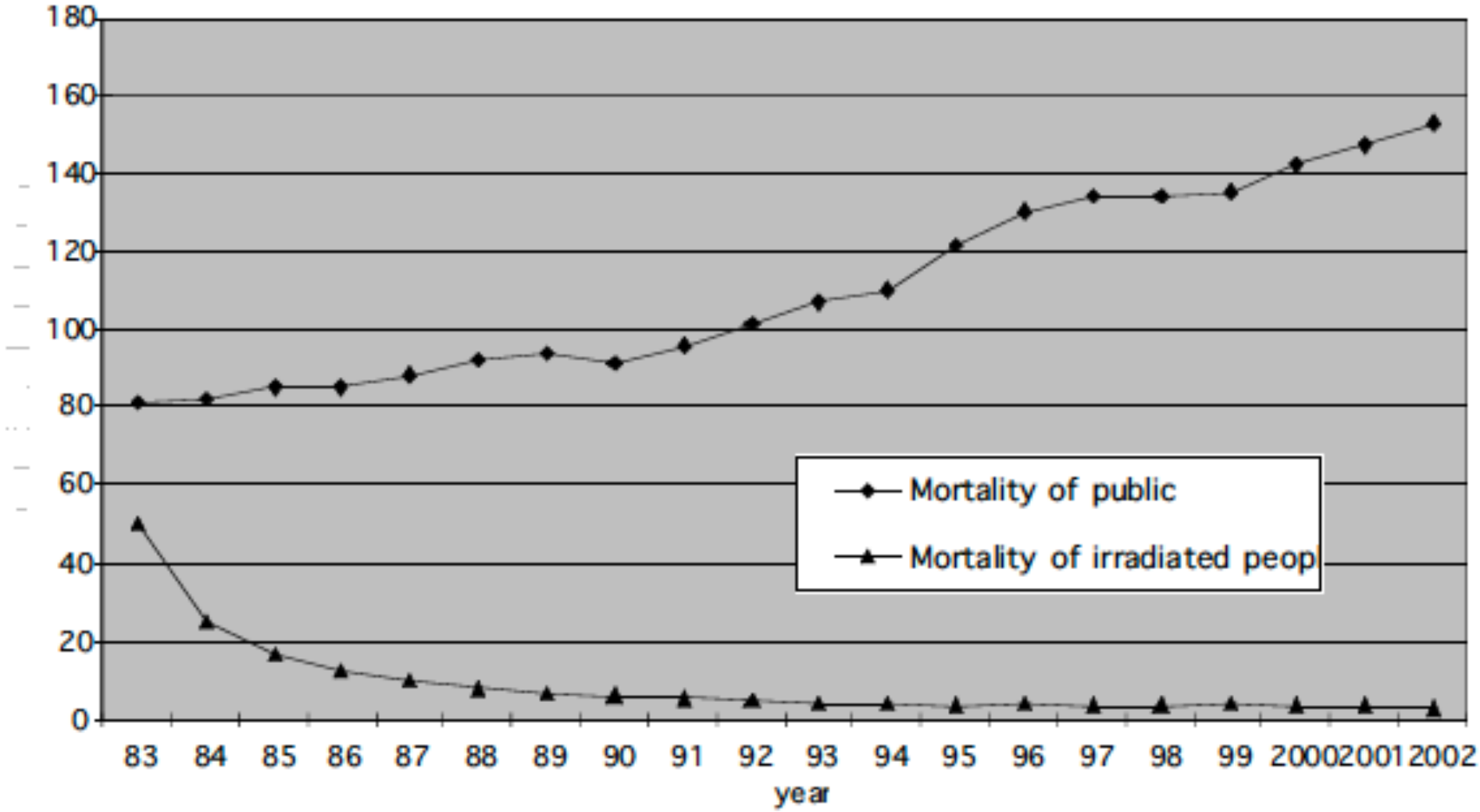
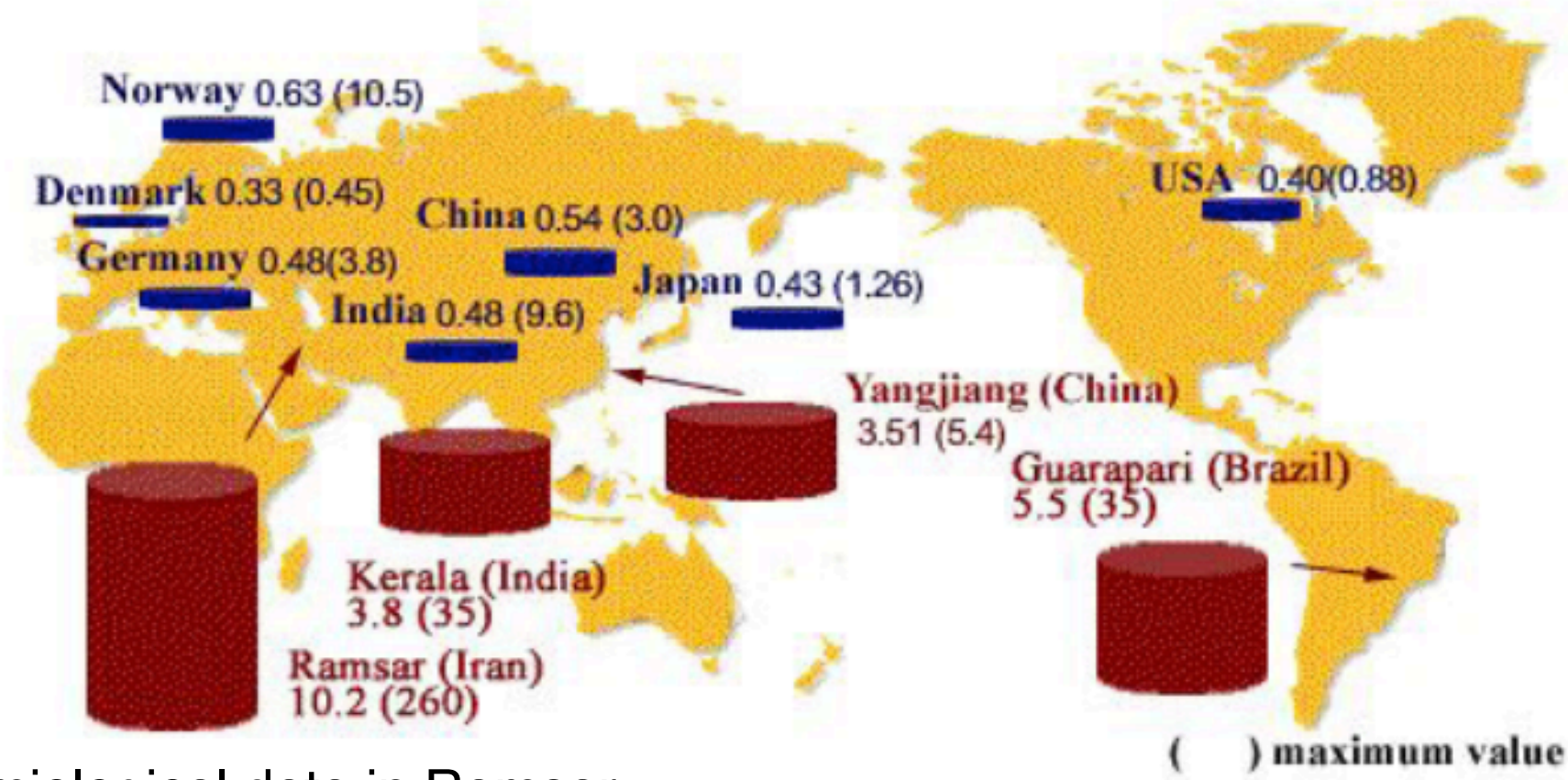


FIGURE 1. Cancer mortality of the general public and of the irradiated people

W.L. Chen et al., 2007. EFFECTS OF COBALT-60 EXPOSURE ON HEALTH OF TAIWAN RESIDENTS SUGGEST NEW APPROACH NEEDED IN RADIATION PROTECTION. Dose-Response, 5:63–75, 2007

High Background Dose Areas

http://www.ecolo.org/documents/documents_in_english/ramsar-natural-



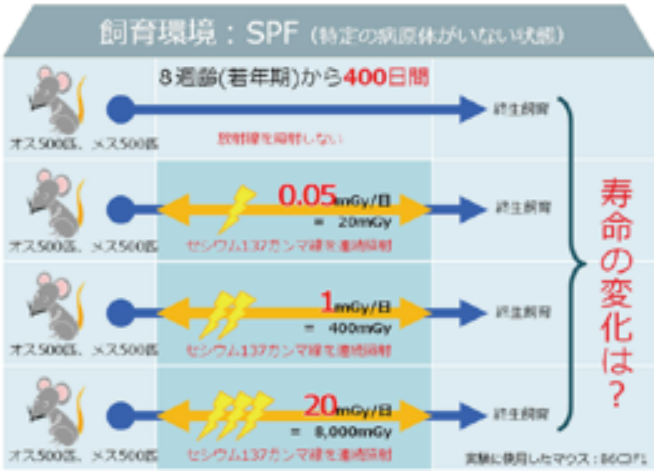
Epidemiological data in Ramsar (Iran) are highly waited for.

Figure 1. High Background Radiation Areas Around the World. Numbers given are in mSv/year.

Ref. M. Ghiassi-nejad et al., 2002. VERY HIGH BACKGROUND RADIATION AREAS OF RAMSAR, IRAN: PRELIMINARY BIOLOGICAL STUDIES. Health Phys. 82(1):87–93; 2002

Life Span Test of Mice under Chronic Exposure

http://www.aomori-hb.jp/ahb2_03_01bio01_seika.html

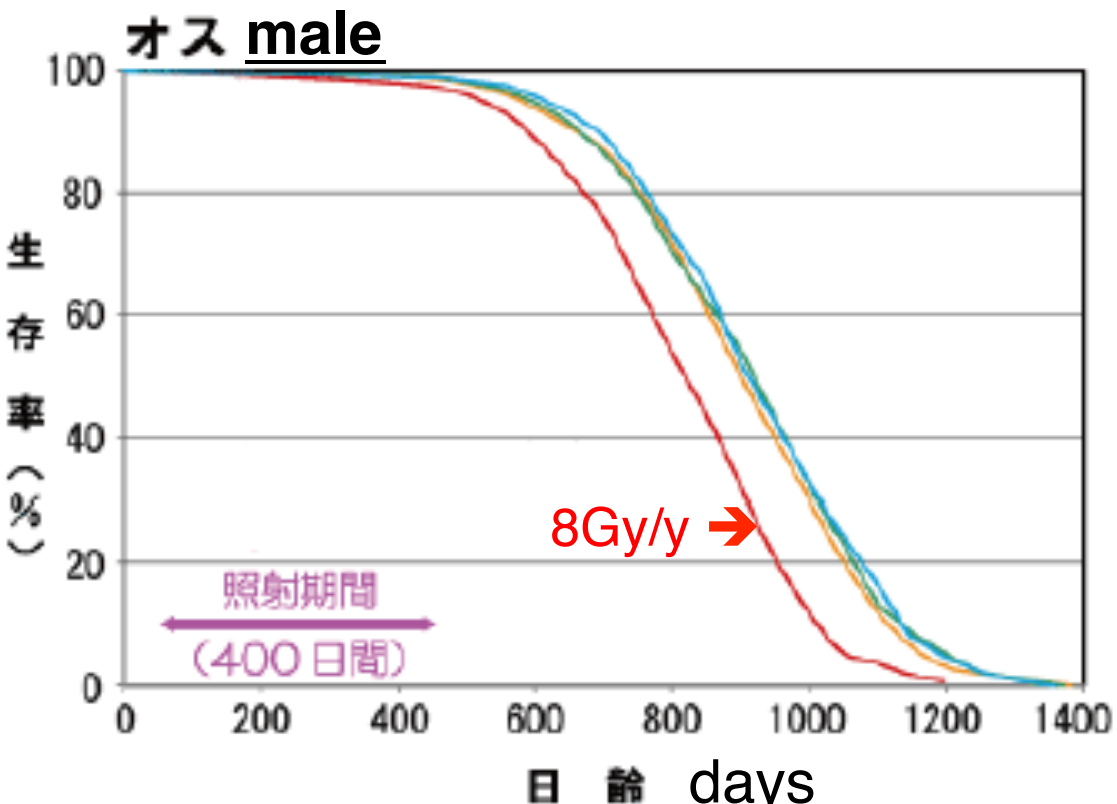


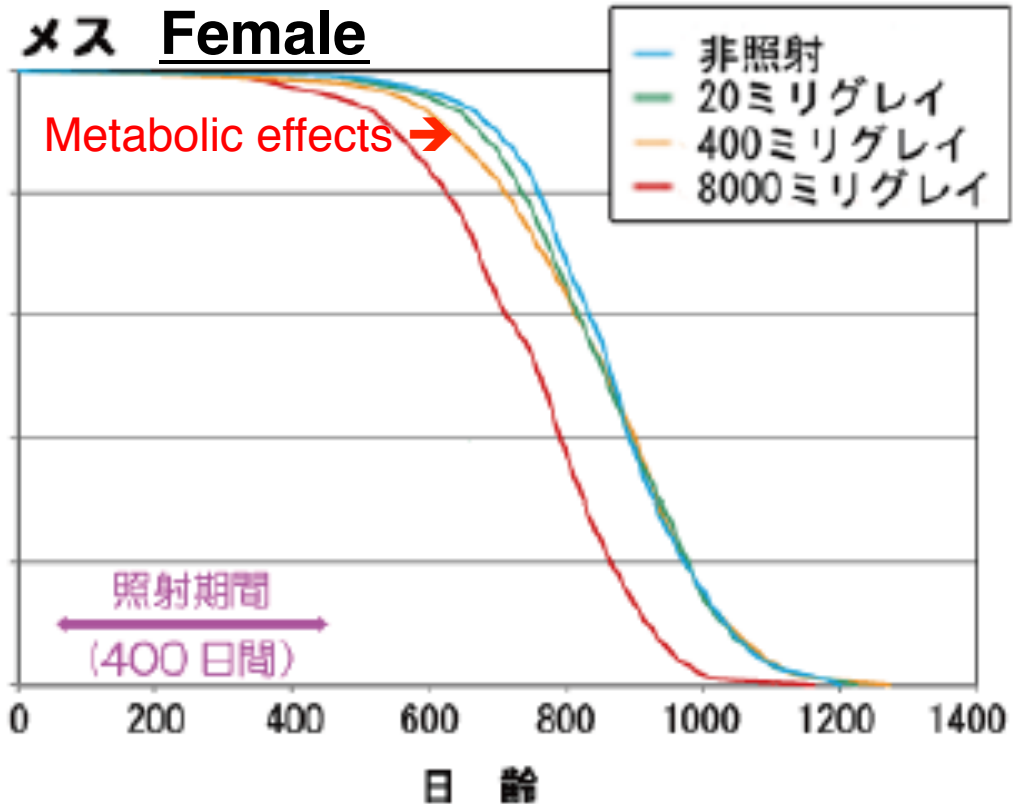
B6C3F1マウス

線量率 (mGy/日)	総線量 (mGy)	線量・線量率の意味
非照射		照射したマウスと比較するための集団
0.05	20	自然放射線の約20倍＝職業人の年平均線量限度に相当
1	400	原爆被爆者の平均被ばく線量の範囲に相当
20	8,000	発がん等影響が確実に現れると予測される線量

mGy ： ミリグレイ （参照：放射線の単位）

400日間連続照射、ただしマウス飼育管理（2時間）のため1日あたり22時間の照射とする。





Life Span Test of Mice under Chronic Exposure CBA/H Mice Test by Dr. Mitchel

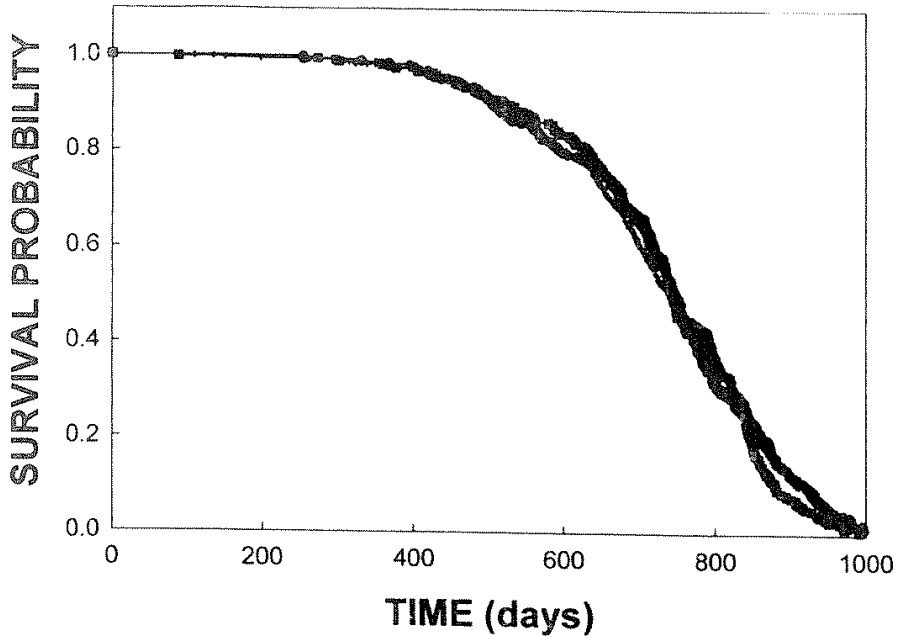


FIG. 1. Survival of mice that did not develop AML after a 1.0-Gy irradiation at either 0.5 Gy/h (●) or 0.004 Gy/h (■) compared to unirradiated control animals that did not develop AML (+).

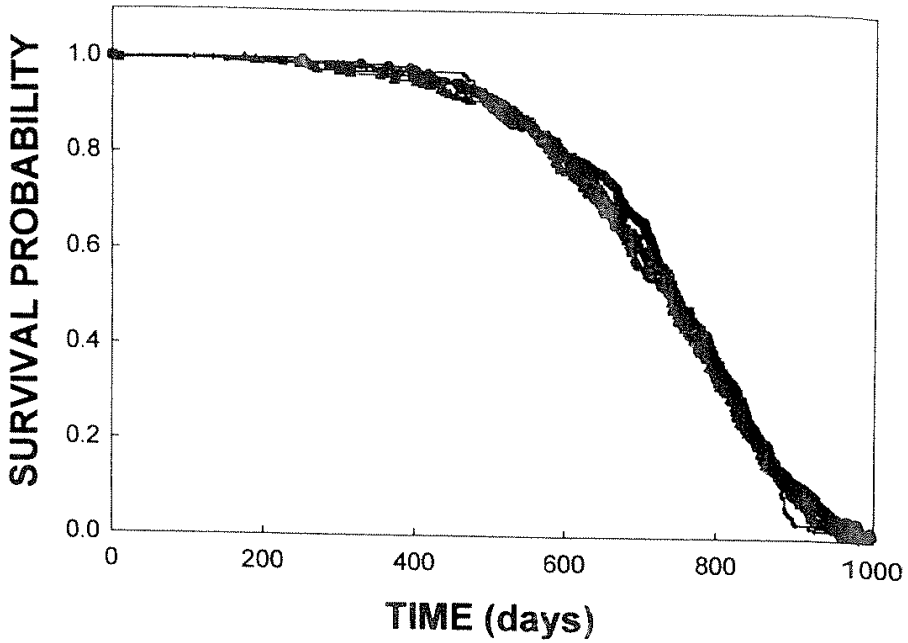


FIG. 2. Survival of animals that did not develop AML after a chronic 1.0-Gy (0.5 Gy/h) irradiation with (■) or without (●) a prior 0.1-Gy (0.5 Gy/h) irradiation, hyperthermia treatment (▲) or injection of IL1 (▼) compared to unirradiated control animals that did not develop AML (+).

Frequency of Myeloid Leukemia

Test group	Frequency (%)	AML-positive euthanized/ found dead	AML-negative euthanized/ found dead	*n*
Control	0.7	2/2	449/119	572
1.0 Gy at 0.5 Gy/h	3.2	3/5	190/52	250
1.0 Gy at 0.004 Gy/h	3.2	5/5	239/61	310

R. Mitchel, 1999. The Adaptive Response Modifies Latency for Radiation-Induced Myeroid Leukemia in CBA/H Mice. Radiation Research 152, 273-279 (1999) .

With mutation anomaly (Trp53+/-) Radiation exposure promotes generation and retention of tumors

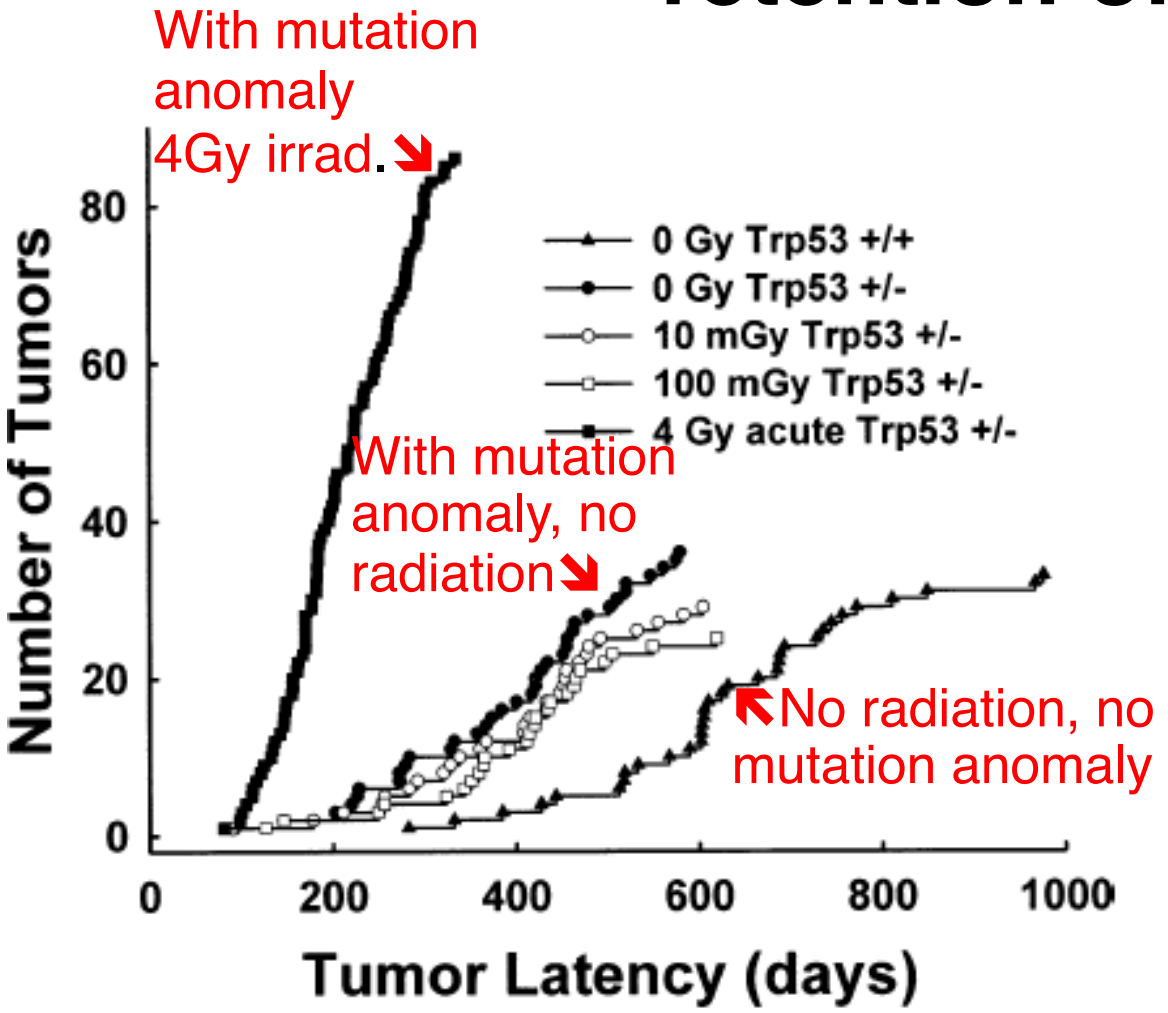


FIG. 4. Latency of lymphomas appearing in unexposed *Trp53* normal mice and in *Trp53* heterozygous mice exposed to various doses of radiation.

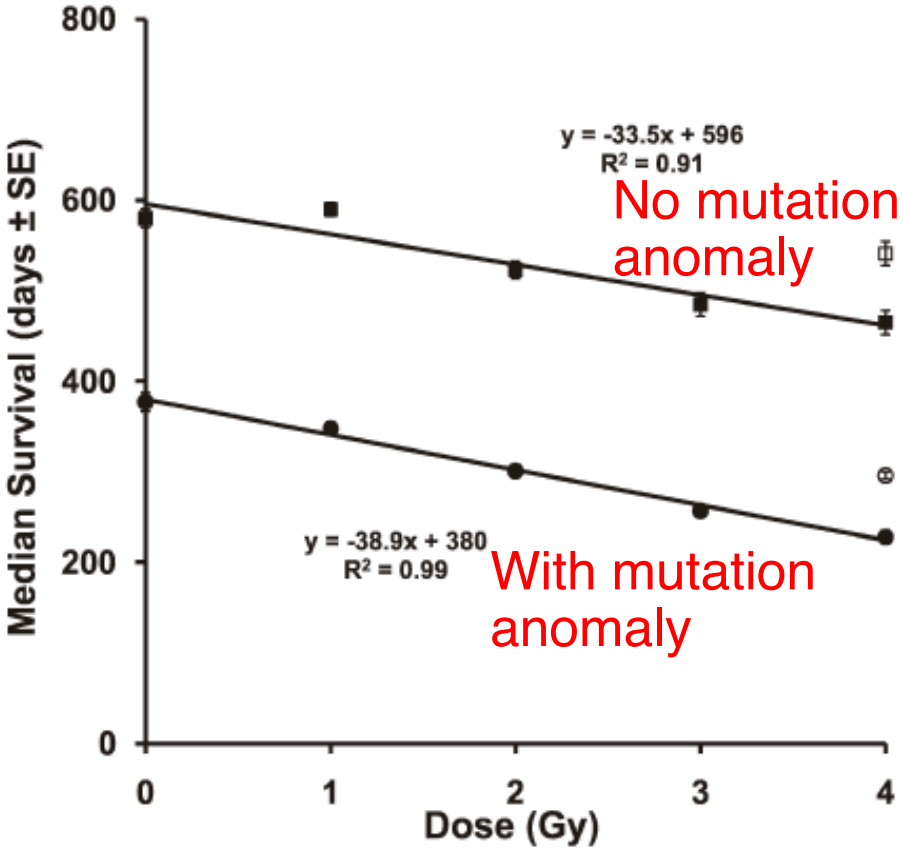


FIG. 1. Changes in the median survival times of groups of mice exposed to large radiation doses. The figure shows the median survival (days at risk after exposure ± SE) of mice in the groups of *Trp53* normal (squares) and *Trp53* heterozygous mice (circles) exposed to various dose of ^{60}Co γ radiation at high (solid symbols) or low (open symbols) dose rates. The lines through the data points represent linear regression analyses of the data for the groups exposed at high dose rate only. The equation and the correlation coefficient for each regression line are given.

S.M. Carlisle et al. (2010), Cancer and Non-cancer Risks in Normal and Cancer-Prone Trp53 Heterogeneous Mice Exposed to High-Dose Radiation. Radiation Research 173.

With mutation anomaly (Ptch1+/-)

Early deaths of off-spring mice when exposed with high-dose rate/low level dose at generation

- Irradiated on the first day
- >0.1 Gy-total @0.65 Gy/min or <0.1 Gy-total @0.10 Gy/min

↑

High dose rates

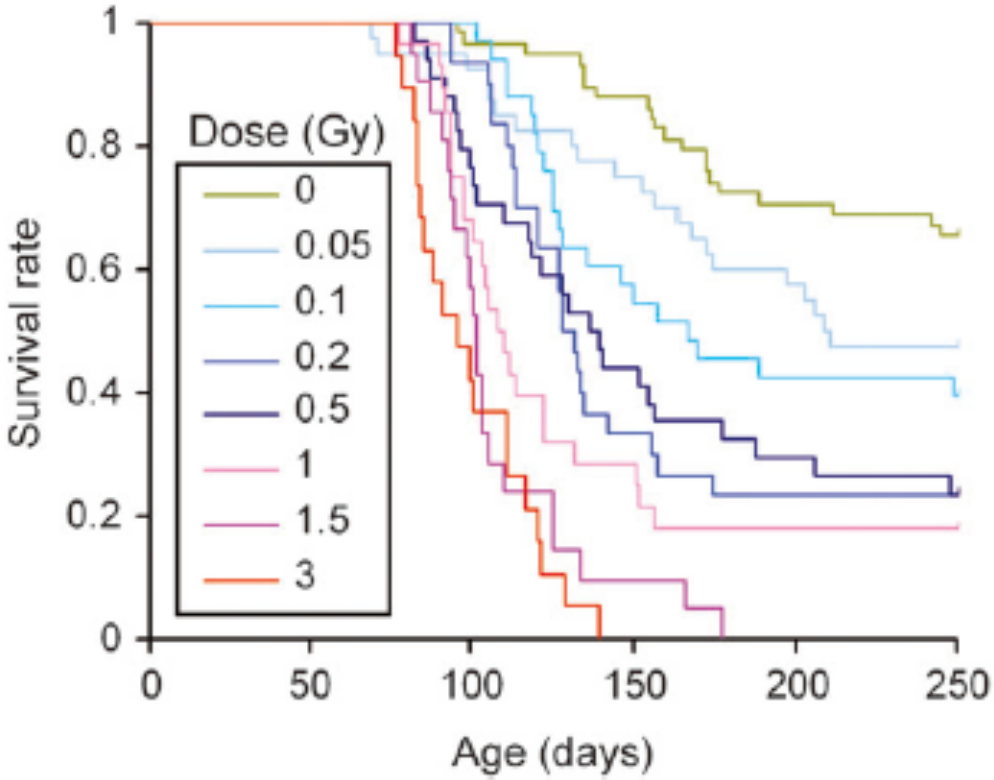


Fig. 1. Survival curves showing dose-dependent effects of radiation in *Ptch1* heterozygous mice. Irradiation was carried out at PN1. *Ptch1*$^{+/-}$ mice were monitored for 250 days. The life span of mice irradiated with doses ≥0.1 Gy was significantly shorter compared with non-irradiated control mice ($P < 0.05$).

Y. Ishida, 2010. Genomic and gene expression signatures of radiation in medulloblastomas after low-dose irradiation in Ptch1 heterozygous mice. Carcinogenesis vol.31 no.9 pp.1694–1701, 2010

Dose-response Effects are Reported Visible in a Drosophila Experiment

- Drosophila 20 male and female each
- Dose rate: 22.4 mSv/h
- Irradiation 4-8d after laying eggs
  - 500μGy
  - 0.1Gy
  - 1 Gy
  - 5 Gy
  - 10 Gy
- Sex-linked recessive lethal mutation assay by mating the irradiated males with un-irradiated females and obtained J-shaped dose-response curve.

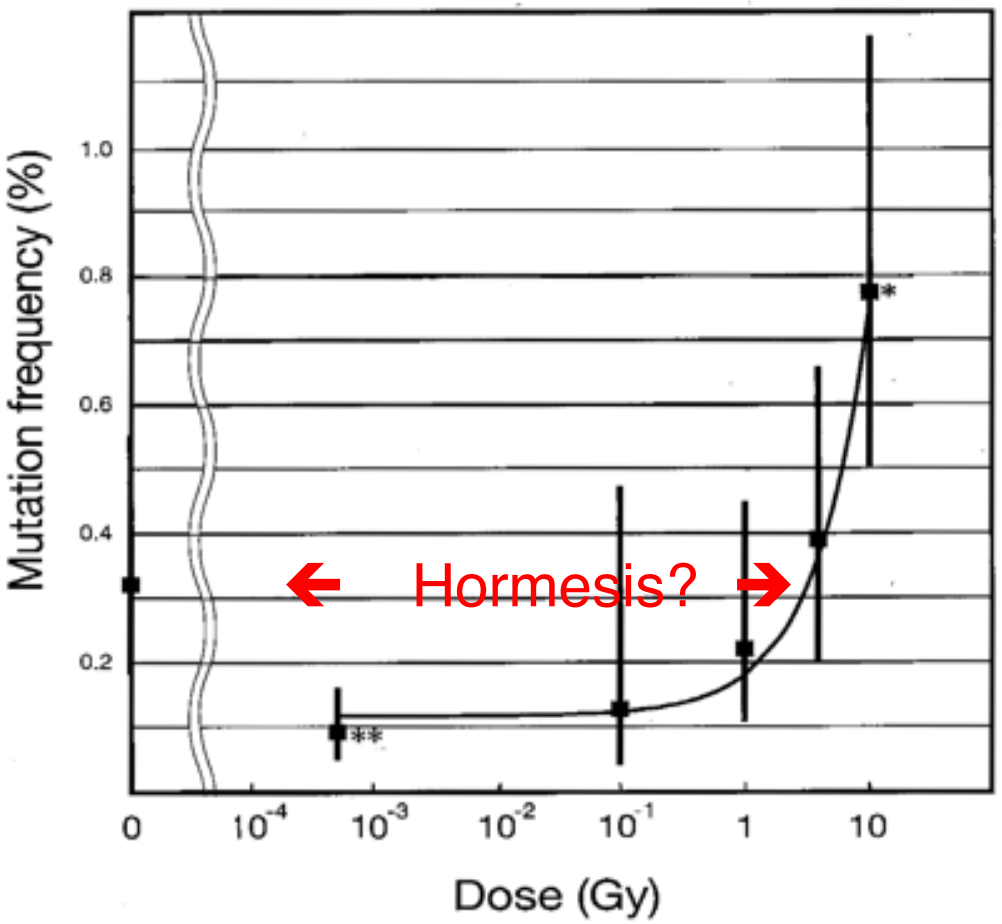
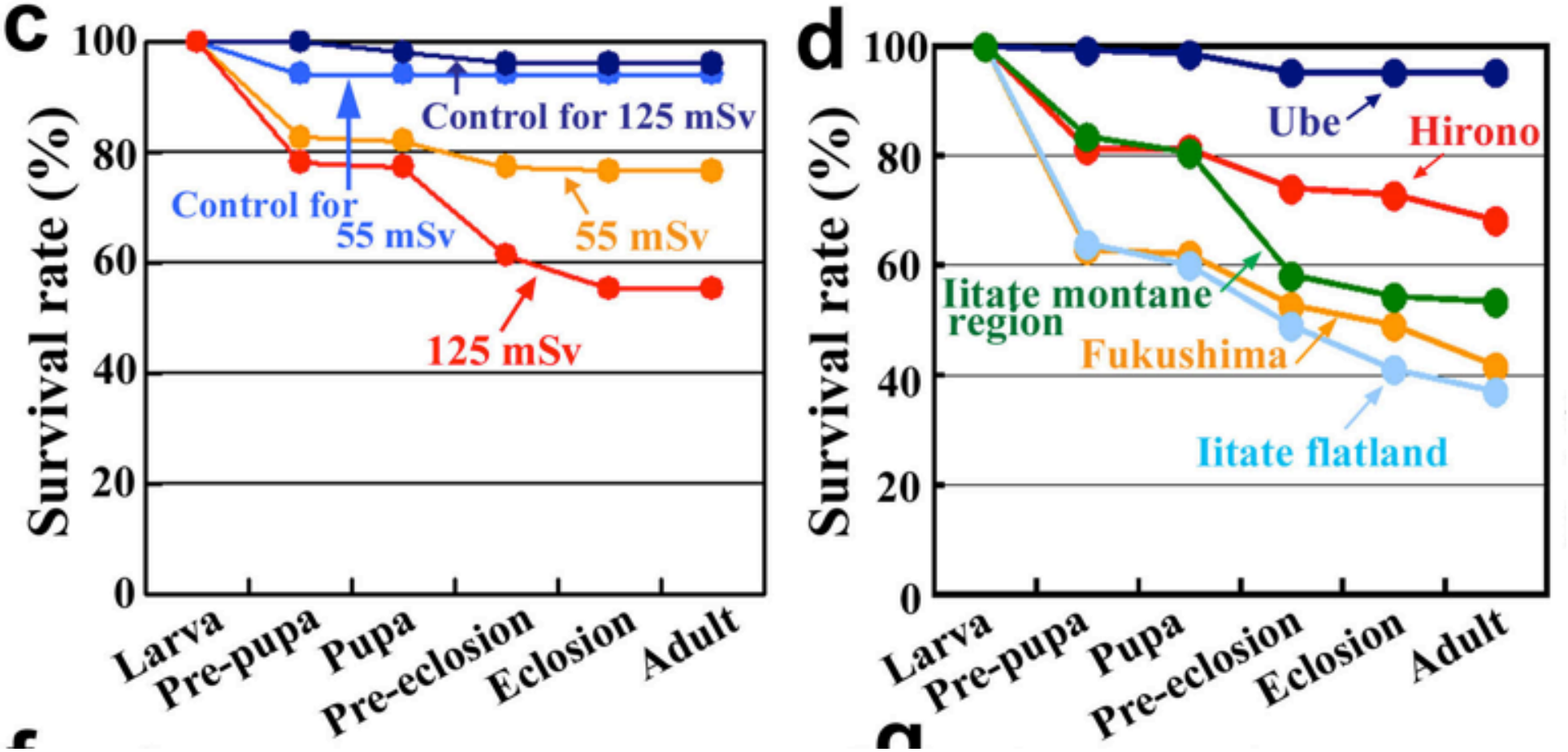


FIG. 2. Frequency of sex-linked recessive lethals as a function of γ-ray dose to immature male germ cells at 22.4 mGy/h. Means (closed boxes) and 95% confidence intervals (bars) are shown. The numbers of chromosomes tested were 3484, 10,500, 1507, 2662, 2055 and 2730 for 0, 0.0005, 0.1, 1, 5 and 10 Gy, respectively. Asterisks indicate the points where mutation frequency is significantly different from control ($*P < 0.05$, $**P < 0.01$). A linear regression curve is shown as a thin line (abscissa is in logarithmic scale).

K. Ogura et al., 2009. Reduction of Mutation Frequency by Low-Dose Gamma Irradiation of Drosophila *melanogaster* Germ Cells. Radiation Research 171,1-8 (2009).

A completely different effect is reported in pale grass blue butterfly in larva/pupa stage.

A. Hiyama1 et al., 2012. The biological impacts of the Fukushima nuclear accident on the pale grass blue butterfly. Sci. Rep. 2, 570; DOI:10.1038/srep00570 (2012)



- ^{137}Cs 14.4 MBq radiation source
- Accumulated doses 3-55 mSv （irradiated for 177-387 h）and 57-125 mSv irradiated for 37-125 h）
- 150 larva irradiated. Fifty un-irradiated control

No statistically significant effects observed among the children of survivors of the Hiroshima-Nagasaki atomic bombings

Table 6

Note: fetus > fifth lunar month of pregnancy

Summary of Regression of Various Indicators on Parental Radiation Exposure and of Impact of Spontaneous Mutation on Indicator

Trait	Regression/Combined Parental Sv	Contribution of Spontaneous Mutation
UPO . . Untoward pregnancy outcome	+.00264	
F_1 mortality	+.00076	.0033–.0053
Protein mutations	−.00001	
Sex-chromosome aneuploids	+.00044	.0030
F_1 cancer	−.00008	.00002–.00005
	.00375	.00632–.00835

- The most probable doubling dose is between 1.7 and 2.2 Sv.
- The appropriate figure for chronic radiation would be between 3.4 and 4.5 Sv/y.
- This is higher than the previous estimations, based on the acute exposures employed in mice, of 1 Sy/y by UNSCEAR-1986 or 0.5-2.5 Sv/y by BEIR-1980.

J. V. Neel et al., The Children of Parents Exposed to Atomic Bombs: Estimates of the Genetic Doubling Dose of Radiation for Humans. Am. J. Hum. Genet. 46:1053-1072, 1990

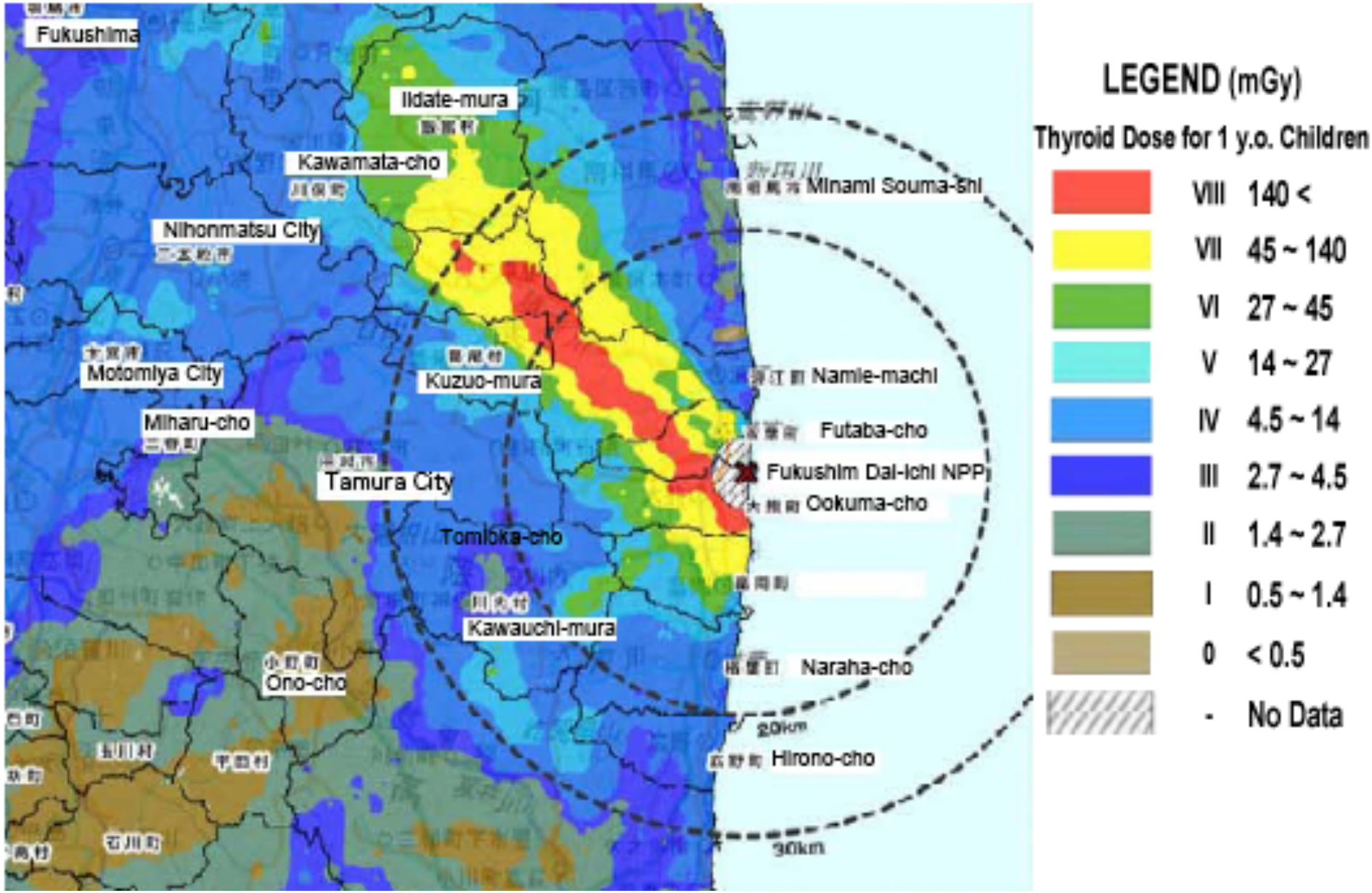
Points at Issue and Conclusions
- for early re-settlement of Fukushima evacuees -

- **The toll of approximately 700 Disaster Related Deaths among evacuees of Fukushima NPP disaster is likely induced by negative effects of the stringent radiation protection based on ALARA/LNT hypothesis. There are no one who died of immediate radiation effects. It is necessary to verify whether the evacuation was justified in comparison with the actual radiation risk.**
- **It is urgent to let the healthy adolescents and adults resettle even into the contaminated regions with a dose rate as high as 100 mSv/y, in order to recover their healthy life.**
- **Although there are no sufficient data as to the health effects of radiation for the period of impregnation, fetus, infant and baby, it is likely that the 100mSv/y may not induce effects, based on the epidemiological studies of Hiroshima-Nagasaki atomic bomb survivors.**
- **The highly proclaimed hormesis effects are not likely in the case of chronic low dose-rate exposure, by activating not only immune systems but also induces latent tumors, although further malignancy is prevented.**
- **It is necessary to continue health monitoring on the effects of iodine exposure likely received during the active phase of the accident. However, prolonged inactive life of evacuees are inducing bio-negative influence.**
- **The Health Monitoring by Fukushima Prefecture are being performed periodically, using ultrasonic thyroid examination, for those who were at the age of 0-18 y.o. Among the approximately 40 thousands people, 36% of them were found with nodules and cysts. (Asahi Shinbun, August 26). A control group、consisting with a matched cohort, out of Fukushima is being organized by Japan Association of Breast and Thyroid Sonology (http://www.jabts.net/english.html)**
- **To what extent the weaker people should be considered is an issue of ethics for radiological medicine.**

Supplemental Materials

Thyroid Dose for 1 y.o. Children

G. Saji, 2012. Estimation of thyroid doses from land contamination maps for the Fukushima disaster. ICONE20POWER2012-55048, Proceedings of the 20th international Conference on Nuclear Engineering ICONE20, July 30-August 3, 2012, Anaheim, California, USA



Age specific thyroid doses

for individuals stayed outside of housing at the time of plume passage (mGy)

Zone Cs-137	0 <10K	I 10K-30K	II 30K-60K	III 60K-100K	IV 100K-300K	V 300K-600K	VI 600k-1000K	VII 1000K-3000k
3 m.o.	0 - 0.3	0.3 - 0.8	0.8 - 1.5	1.5 -2.5	2.5 - 7.5	7.5 - 15	15 - 25	25 - 75
1y	0 - 0.5	0.5 - 1.4	1.4 - 2.7	2.7 - 4.5	4.5 - 14	14 - 27	27 - 45	45 - 140
5y	0 - 0.4	0.4 - 1.2	1.2 - 2.4	2.4 - 4.0	4.0 - 12	12 - 24	24 - 40	40 - 120
10y	0 - 0.4	0.4 - 1.1	1.1 - 2.1	2.1 - 3.6	3.6 - 11	11 - 21	21 - 36	36 - 110
15y	0 - 0.3	0.3 - 0.8	0.8 - 1.7	1.7 - 2.8	2.8 - 8.3	8.3 - 17	17 - 28	28 - 83
adult	0 - 0.2	0.2 - 0.6	0.6 - 1.3	2.8 - 2.1	2.1 - 6.3	6.3 - 13	13 - 21	21 - 63

Note-1: Vd (deposition velocity)=0.04 (IAEA Safety Series 57, 1982
Note-2: Age dependent ventilation parameters as well as dose conversion factorw were taken from ICRP Pub.71, 1995
Note 3: The rate of absorption of radioactive iodine following deposition in a chemical form of CsI, was assumed "Type M"

- The Cs-137 contamination map were converted into I-131 as well as I-133 map at the time of hydrogen explosion in 1F1 and calculated age specific thyroid doses.
- Compared with the Chernobyl accident, the inhalation doses for Fukushima are approximately ¼ of the Chernobyl. ←difference in assumed aerosol composition
- Babies are not protruding without contaminated milk.

Estimated integrated concentration and intake of iodine for Chernobyl (Method-1)

G. Saji, 2005. A Scoping Study on the Environmental Releases from the Chernobyl Accident (Part II): Iodine. International Topical Meeting on Probabilistic Safety Analysis, PSA'05 11-15 September 2005, San Francisco, California, USA

Land contamination Zones	II	III	IV	V	VI
Land contamination densities of I-131 (kBq/m^2)	**185 - 370**	**370 - 1850**	**1850 - 5550**	**5550-11100 (note c)**	**11100-18500 (note c)**
Time-Integrated densities during the plume passage (MBq/m^3) note a	16 - 33	33- 160	160 – 490	490 – 920	920 – 1600
Thyroid dose note b (mGy), 1y old, inhalation note c	**2.4 - 4.7**	**4.7 - 24**	**24 - 71**	**71 - 140**	**140 - 240**
Thyroid dose note c (Gy), 7-12 months old, ingestion d	**1.2 - 2.4**	**2.4 - 12**	**12 – 36**	**36 - 72**	**72 - 120**

[a] $\chi(x, y, 0)\cdot t$ in MBq/m3, assuming an average deposition velocity of 0.01136 m/sec. The composition was taken from the integrated iodine composition measured in Munich (e.g. 23%, 27%, 50%, for particulate, elemental/gaseous, and an organic iodine compound, respectively).

[b] Using a dose conversion factor as provided by ICRP-71. For the absorption type of particulate, 'a Type F' was assumed.

[c] These high land contamination densities only occurred with precipitation or within several kilometers of the Chernobyl reactor.

[d] Using the ingestion-to-inhalation dose ratio and milk consumption data for the regions of Brest and Mogilev, as well as for the entire BSSR (data from Institute of Biophysics, Moscow, 1990), and applying ICRP-56 and 71. The factors do not apply for milk products such as 'baby formula.'

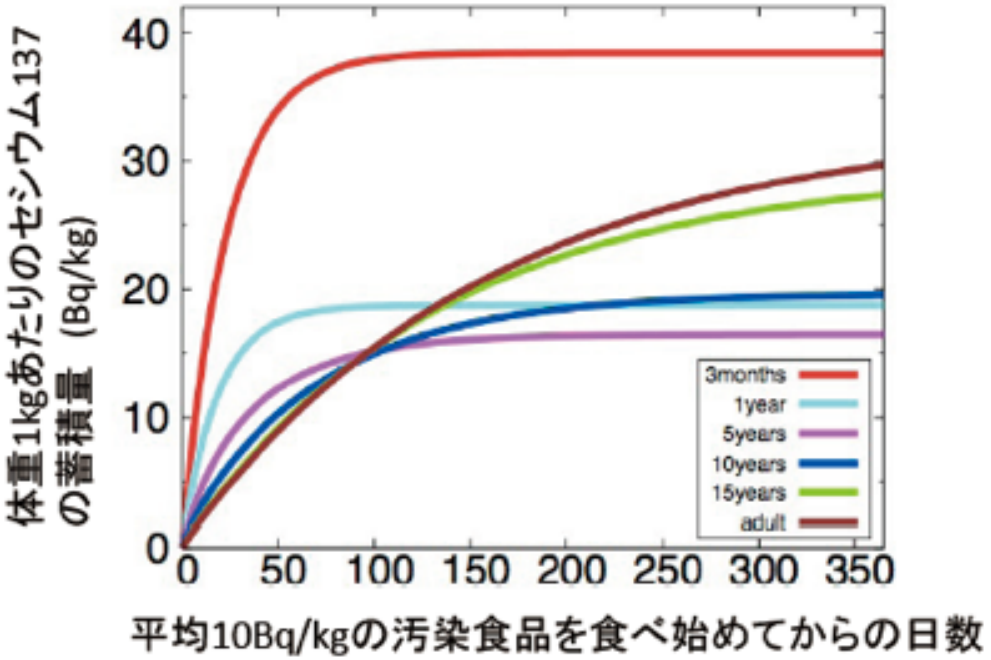
Above 60 Gy, the predominance of cellular destruction over cell transformation is likely.

P. Hall et al. Radiation Research 145, 86-92 (1996), Thyroid Cancer after Diagnostic Admin. of I-131.

Retention of ^{137}Cs in Organs

http://www.nirs.go.jp/db/anzendb/RPD/JPDF/gy/jgyCs137WB.pdf

- Figure on RHS illustrate a time change of retention rates in a whole body after a single ingestion of radioactive cesium.
- With a intake of a constant amount P, an equilibrium concentration（P/μ) will be reached in several months.
- μ=0.693/(biological half life). Approximately 70 days for adults and 20 davs for chilren.



S. Nakagawa http://yakkaihousyasen.web.fc2.com/cs_accumlation.pdf