FUKUSHIMA DAIICHI NUCLEAR EVENT (PART 2)
RADIATION HEALTH EFFECTS AND IMPLICATIONS

Osher Lifelong Learning Institute

George Mason University

November 12, 2014

Keith Welch

Outline

- Brief review of the Fukushima Daiichi event
- Overview of ionizing radiation definitions and units
- Exposure pathways from environmental releases
- Magnitude of radioactivity released from Fukushima
- Summary of radiation doses since 3/11/11
- Health implications for the various categories of people, including occupational workers, emergency workers, and general public
- Current and future actions taken as a result of the Fukushima event

Data presented come primarily from the 2013 report of the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)


Reactors 1, 2 and 3 operating
Reactors 4, 5 and 6 shutdown for maintenance, inspection, refueling
Fukushima - Daiichi

What are Radiation and Radioactivity?

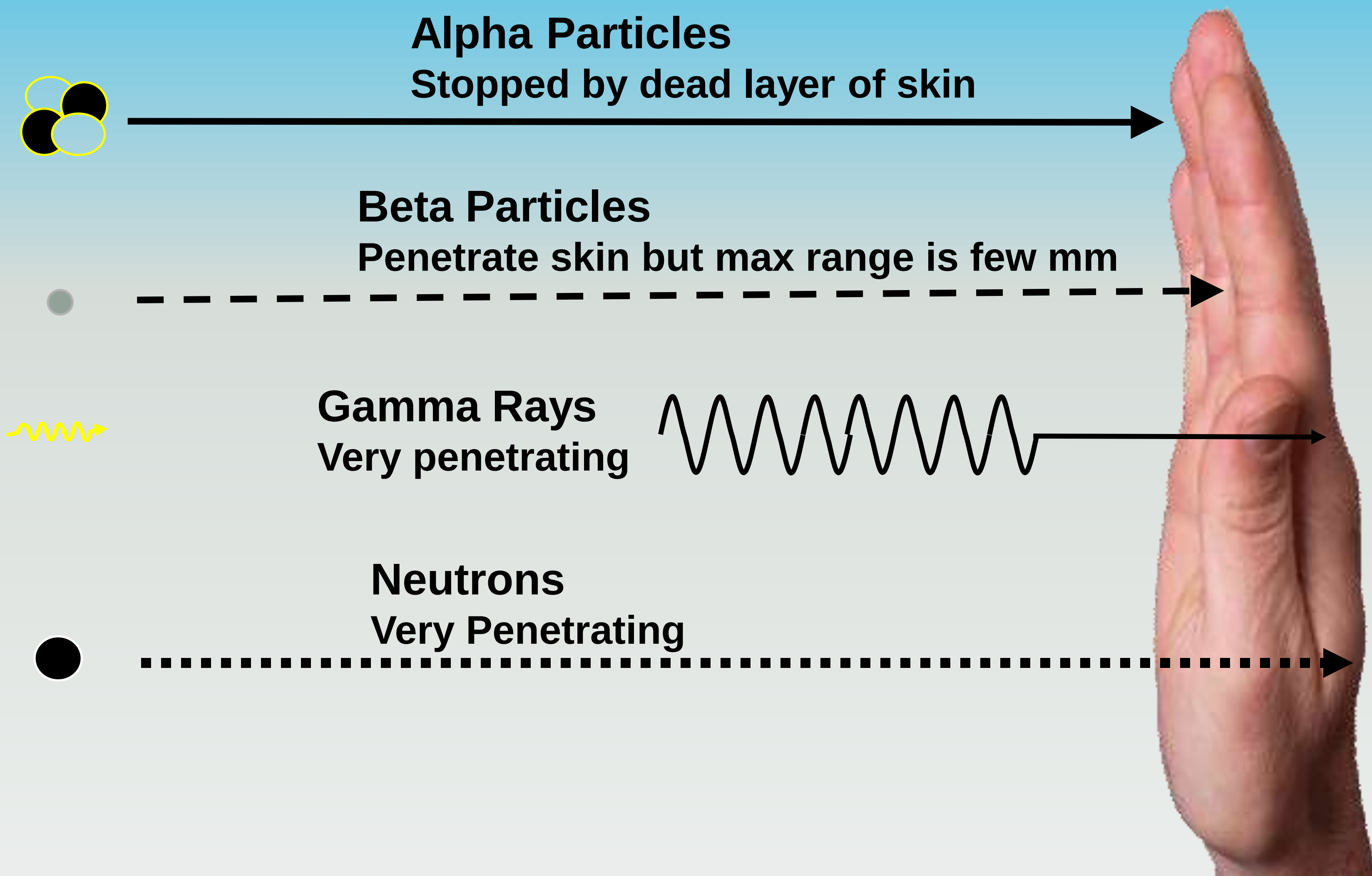
- **Ionizing radiation** consists of energetic waves or particles with sufficient energy to produce *energetic ions* in ordinary matter

…"dose" is caused by the absorption of the kinetic energy of these charged particles

- **Types of ionizing radiation…**

Alpha and Beta particles, Gamma- & X-rays, Neutrons

Penetration of Radiation in Tissue



What are Radiation and Radioactivity?

Radioactivity: The spontaneous transformation ("decay") of unstable nuclei, resulting in a more stable "daughter", *accompanied by emission of ionizing radiation.*

Radioactive Material: A substance that contains unstable (radioactive) atoms, and therefore emits ionizing radiation.

Radioisotope (radionuclide): A radioactive isotope of an element. Well over 2000 radioisotopes have been identified.

Examples: carbon-14 (C-14), cesium-137 (Cs-137)

Radioactivity is quantified using the **becquerel** (Bq)

1 Bq = 1 disintegration per second

A typical smoke detector has about 37,000 Bq of activity

A typical person has about 8000 Bq in their body

What is Radiation Dose and How is it Measured?

- **Absorbed Dose (D):** Absorbed dose is the amount of energy absorbed per unit mass in any material by ionizing radiation. The unit of absorbed dose used in the U.S. is the rad. *The S.I. unit is the gray (Gy).* One gray equals 100 rad.

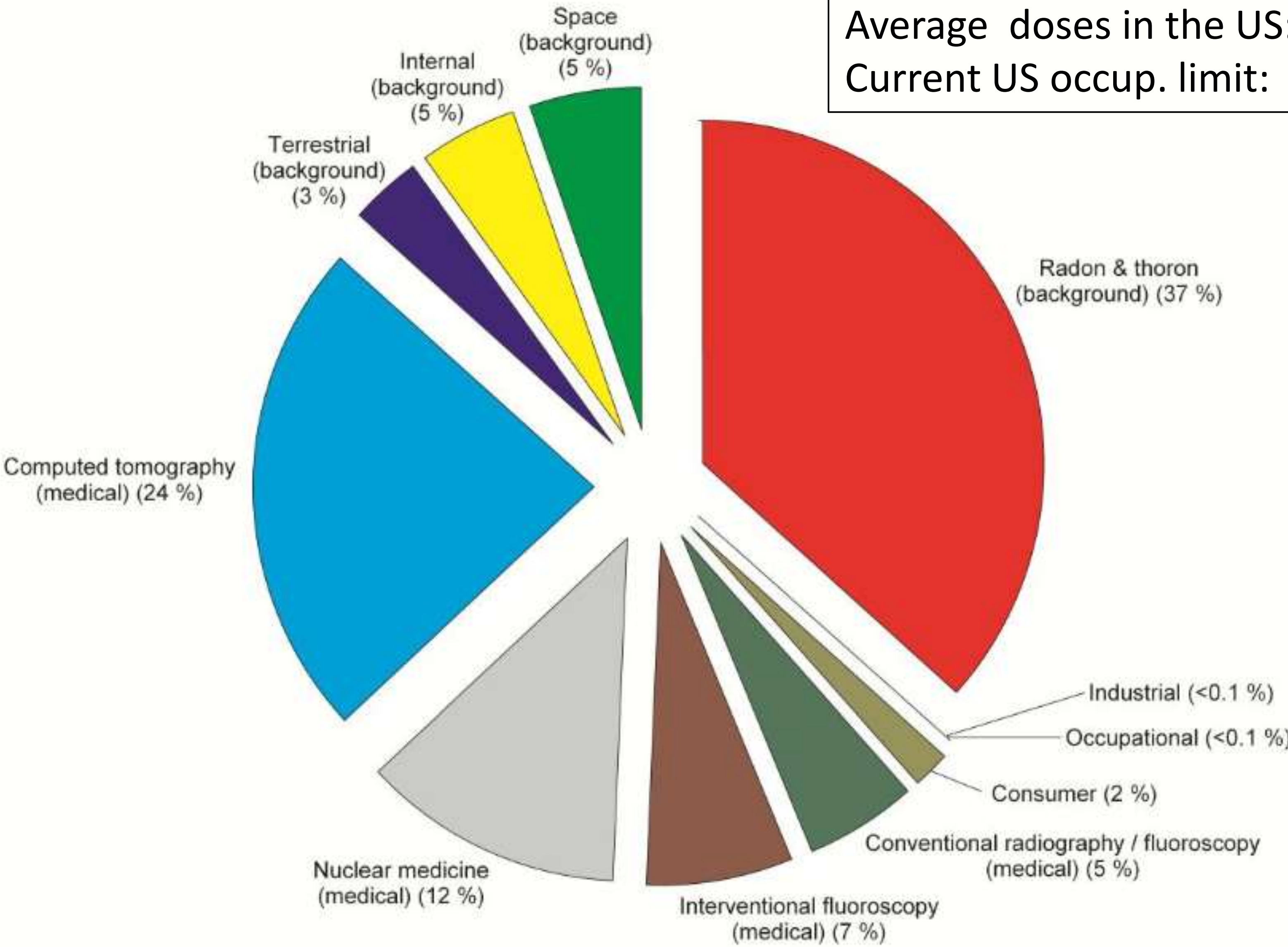
- The radiation weighting factor (W_R) is used to convert the absorbed dose received by a person from radiations of differing quality into a unit that expresses the exposure normalized to risk – *equivalent dose*.

- **Equivalent Dose (H):** Equivalent dose is a special concept relating absorbed dose to biological detriment. In the U.S. the unit is the rem. *The S.I. unit is the sievert (Sv)*. One sievert equals 100 rem.

Sources of Radiation

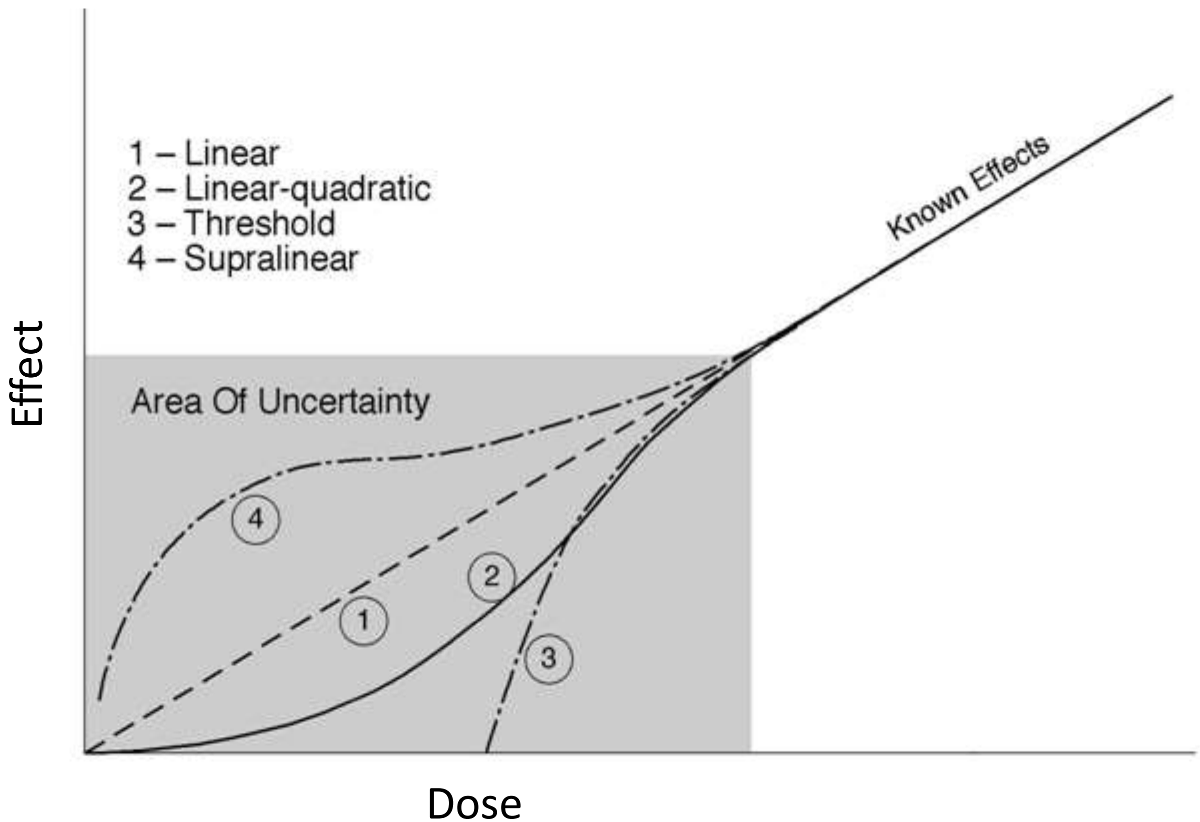
How Much Dose do We Receive?

Average doses in the US: ~ 6 mSv/y
Current US occup. limit: 50 mSv/y



Dose and Risk

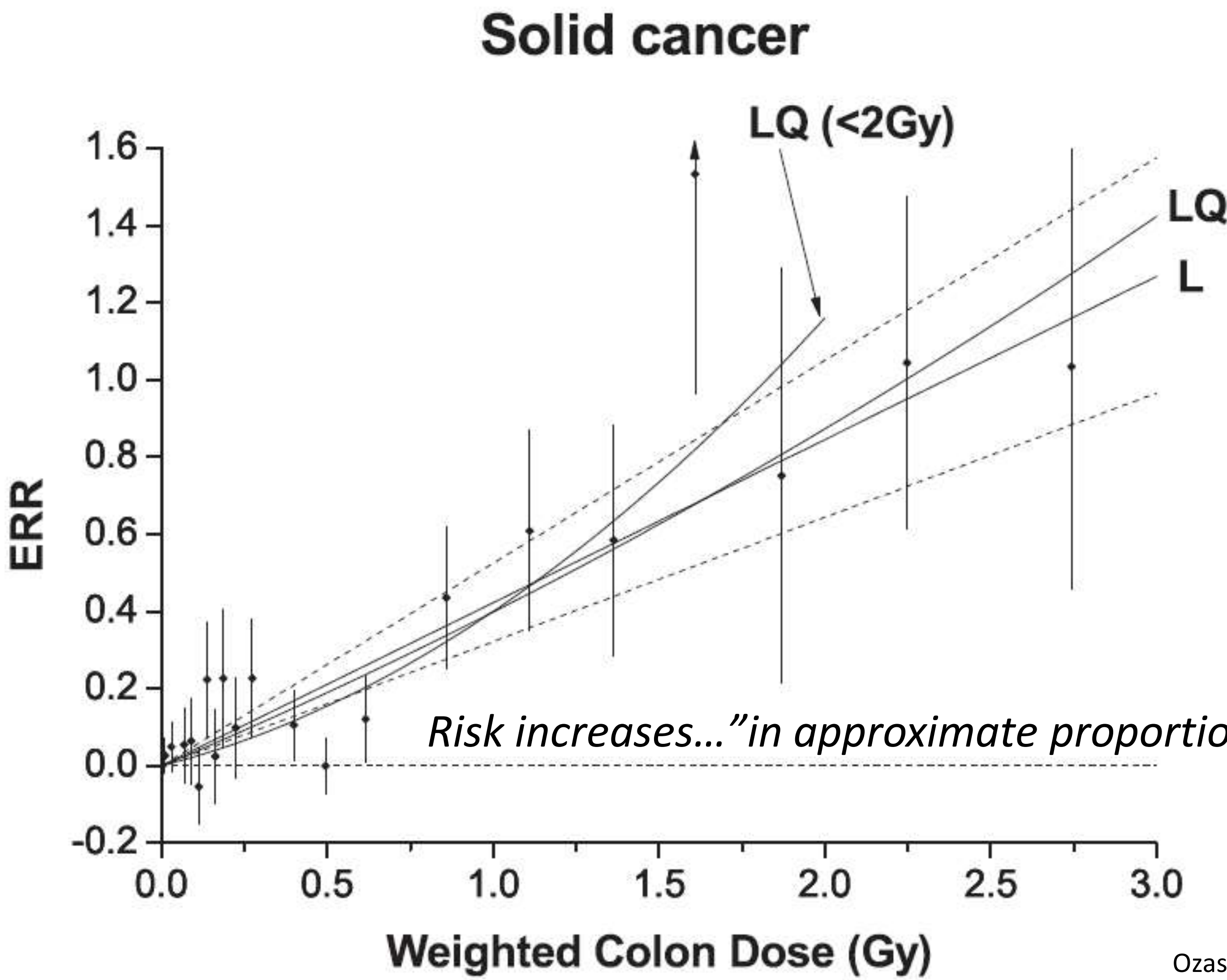
Possible Radiation Dose Response Curves



1. LNT: An increase in dose results in a proportional increase in risk without threshold
2. At low doses there is only a slight increase in risk that becomes proportional to dose at higher doses
3. There is a threshold for dose response at which lower doses do not result in increased risk
4. At low doses there is a higher risk that becomes proportional to dose at higher doses
5. Hormesis model (not shown): Low doses of radiation have a positive effect and decrease risk

Quantifying Cancer Risk

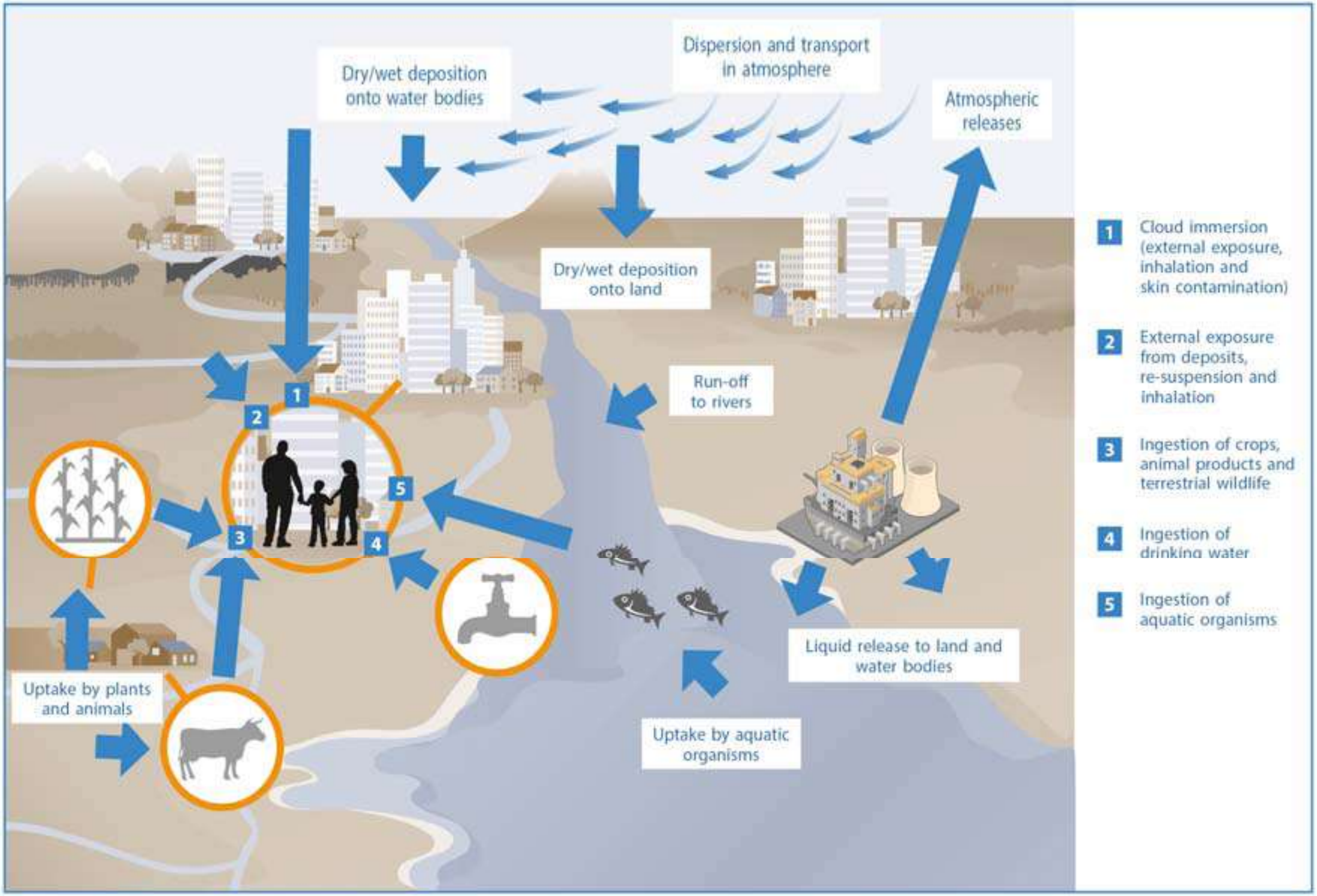
Epidemiology – Atomic bomb survivors



Risk increases…"in approximate proportion to radiation dose"

Ozasa et al., *Rad Res* 177; 2012

Exposure Pathways – Releases to Environment



Fukushima Radiation Dose Pathways

- *Primary Radionuclides as Dose Contributors*
  - *I-131/133*
  - *Cs-134/137*
- *Release to atmosphere – airborne*
- *Release to marine environment – ocean, fish, aquatic biota*
- *Release to groundwater*
- *Release to terrestrial environment – food crops, vegetation*

Total Radioactivity Released to Atmosphere

Radionuclides	*Total release to atmosphere (Bq)*	*Percentage of the inventory at reactor shutdown released (%)*
^{132}Te	2.85×10^{16}	0.33
^{131}I	1.24×10^{17}	2.1
^{132}I[a]	2.85×10^{16}	0.32
^{133}I	9.56×10^{15}	0.07
^{133}Xe	7.32×10^{18}	61
^{134}Cs	9.01×10^{15}	1.3
^{136}Cs	1.77×10^{15}	0.81
^{137}Cs	8.83×10^{15}	1.3

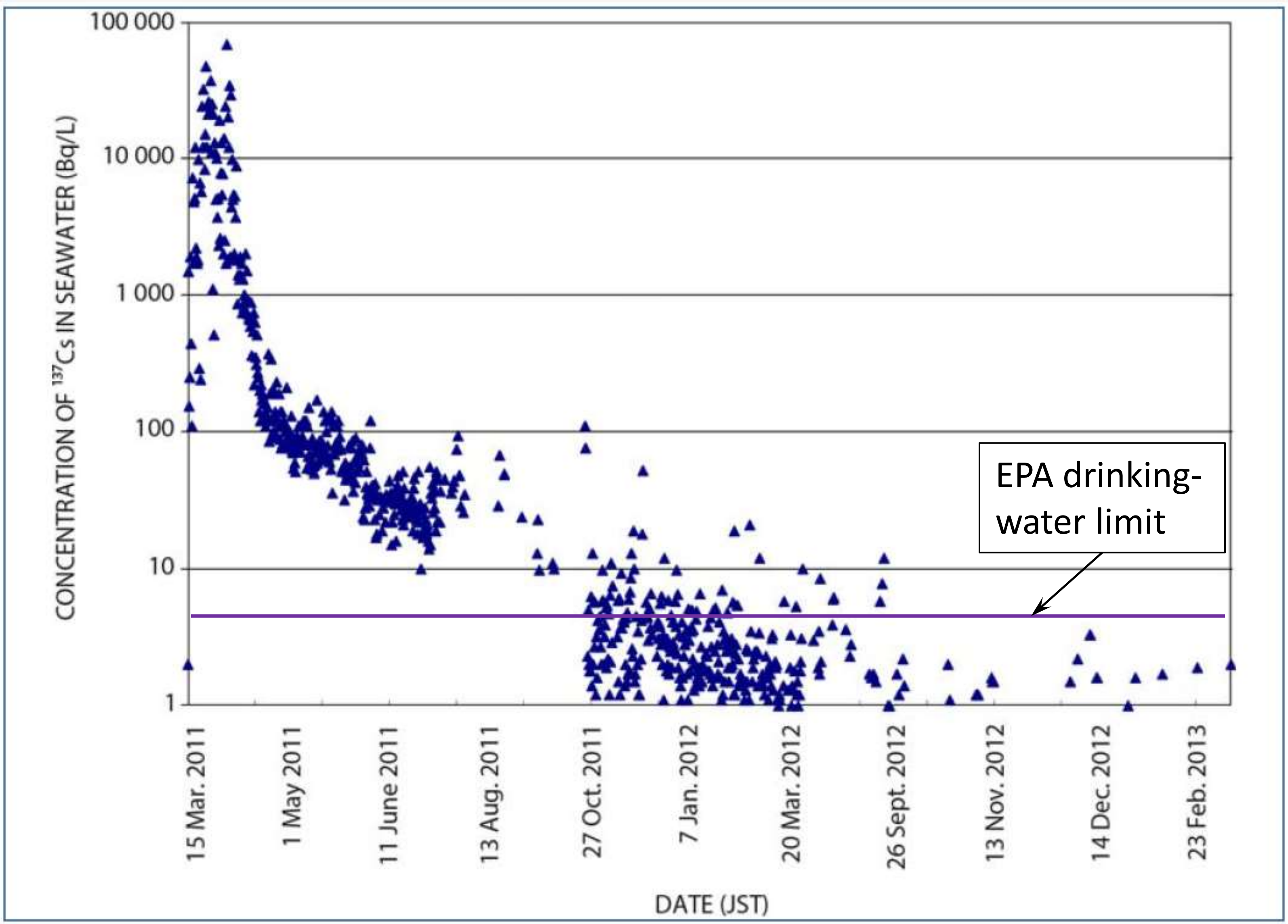
[a] *Direct release of ^{132}I was small compared to the ingrowth from radioactive decay of released ^{132}Te.*

Total Radioactivity Released to Ocean

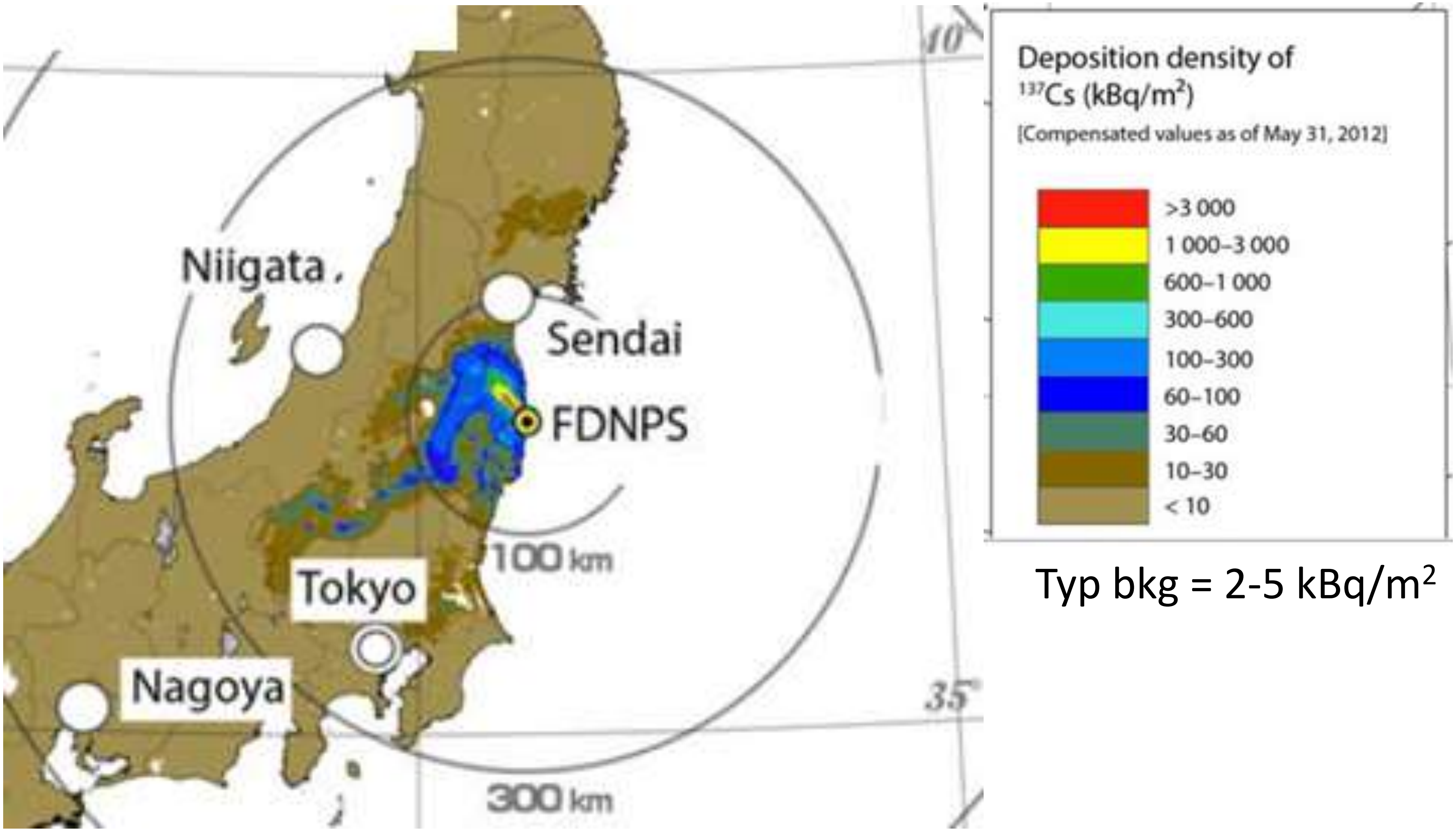
Source of estimate (Period considered in 2011)	*Direct release to the ocean (PBq)*		*Deposition on ocean surface from the atmosphere (PBq)*	
	^{131}I	^{137}Cs	^{131}I	^{137}Cs
TEPCO [T15] (26 March–30 September)	11	3.6		
Kawamura et al. [K3] (12 March–30 April)	11[a]	4[a]	57	5
Tsumune et al. [T24] (26 March–31 May)		3.5 ± 0.7		
Bailly du Bois et al. [B2] (26 March–18 July)		27 ± 15		
Estournel et al. [E4]		0.81[b] 4.1–4.5[c] 5.5 (upper bound)		5.7–5.9 (northern Pacific Ocean)
Charette et al. [C4]		11–16		
Kobayashi et al. [K18] (12 March–1 May)	11	3.5[d]	99	7.6

[a] 21 March–30 April. [b] 1–6 April. [c] 12 March–30 June. [d] 26 March–30 June.

Radioactivity in Seawater Near FDNPS



Surface Deposition of Cs-137



Typ bkg = 2-5 kBq/m^2

Radiation Dose Assessments

- *Conservative models used with copious measurements of external dose rates, activity concentrations in air, water, soil*
- *Environmental data analyzed extensively in assuring the quality and appropriateness of the data was used for dose calculations*
- *Doses for special categories of general public included nursing infants, mothers, embryo/fetus, occupational workers (shipboard personnel, aircrews and personnel visiting Fukushima Daiichi area, general public at large in surrounding villages*
- *Effective dose and Thyroid doses for children and adults based on primary dose contributors, Cs-134/137 and I-131/133*

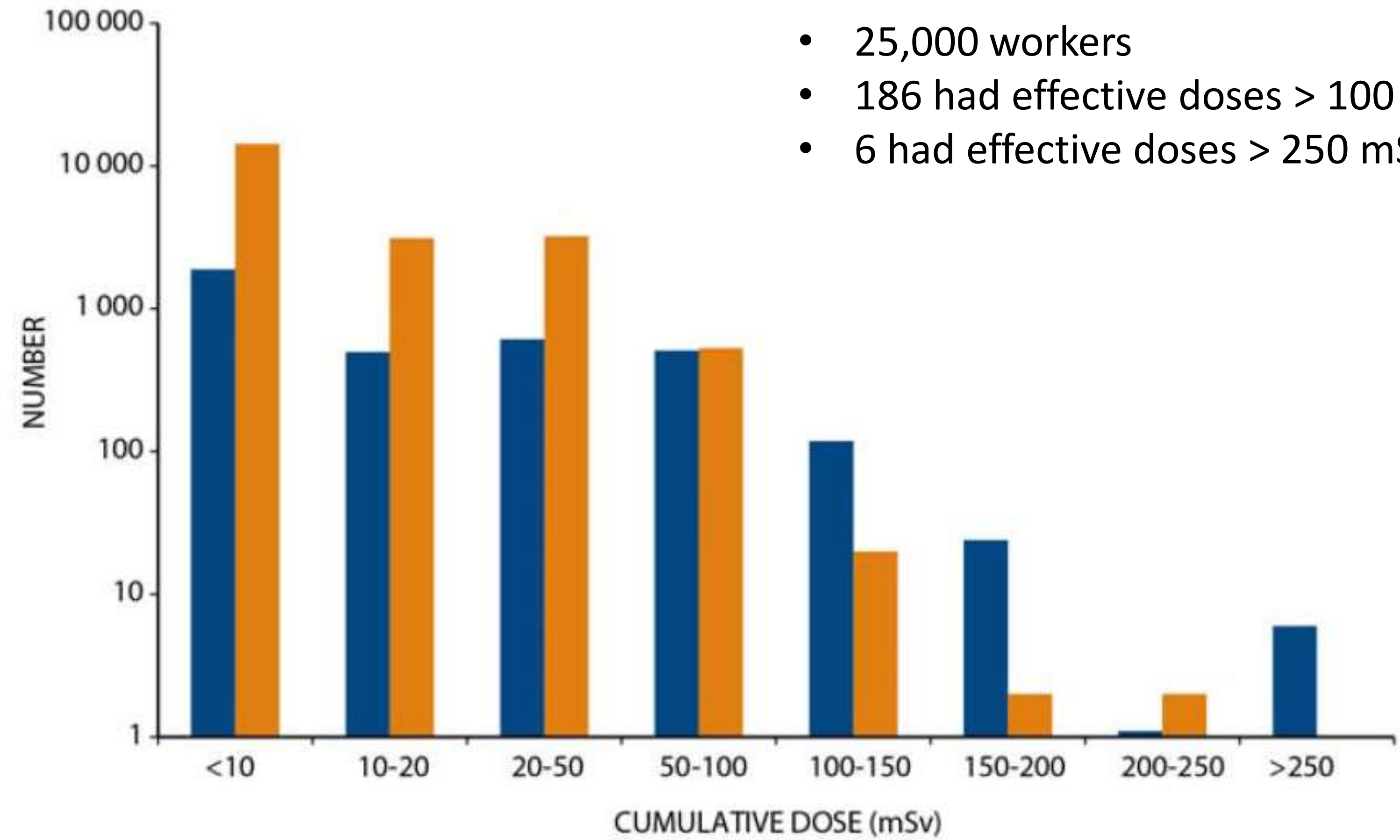
Doses to Workers and Public

- Most important dose pathway for the workers with the highest doses was from internal exposure (predominantly from inhalation of I-131)
- Primary dose pathway for members of the public is external exposure from surface deposition of Cs-134/137
- Other dose pathways are much less important (consumption of contaminated food/water, etc.)

Doses to Workers

Worker Doses for Period March 2011 – October 2012

- 25,000 workers
- 186 had effective doses > 100 mSv
- 6 had effective doses > 250 mSv



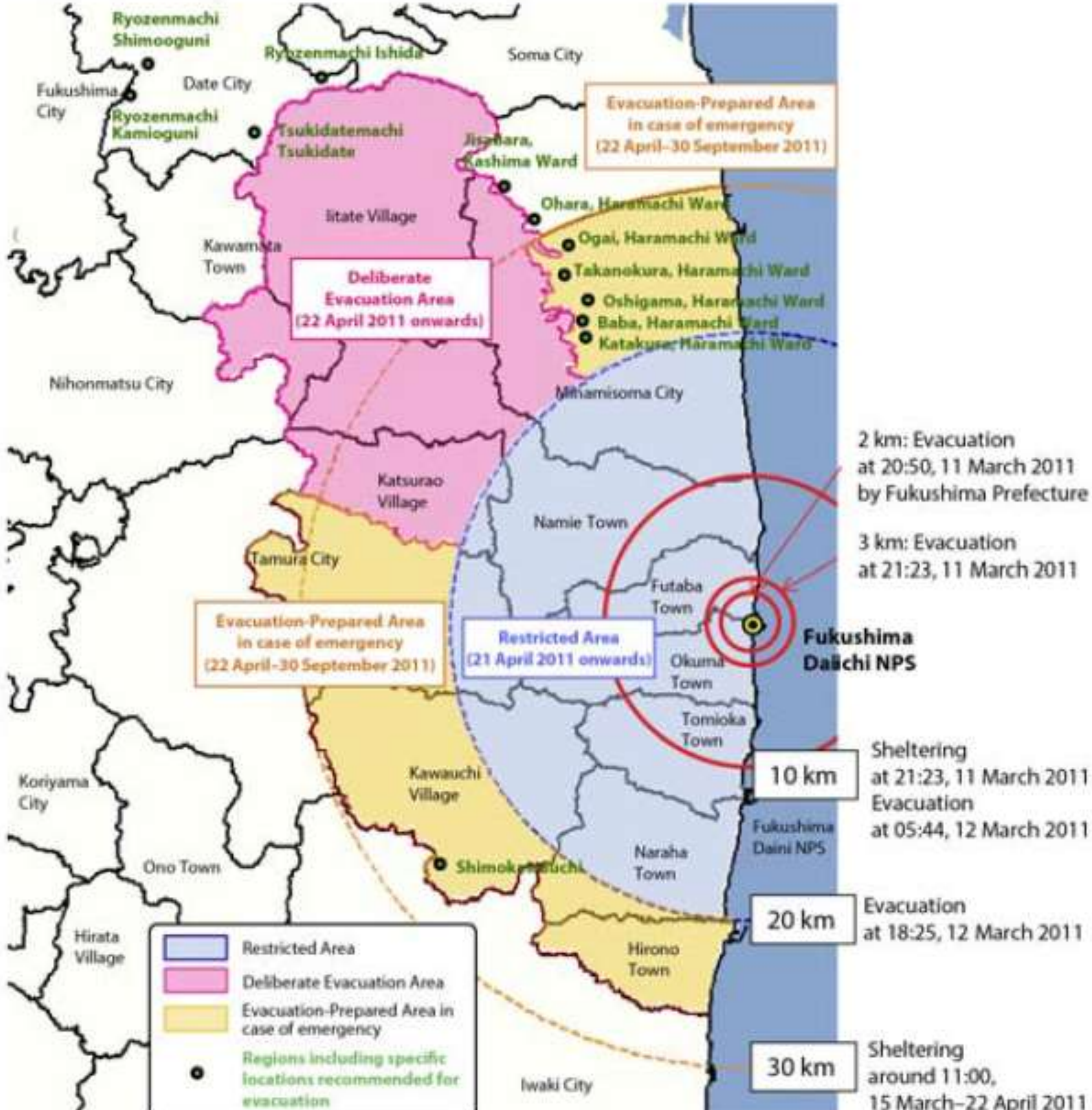
	TEPCO workers	Contractors	All
Average dose (mSv)	25	10	12
Maximum dose (mSv)	679	238	679

Doses to Public

- Evacuation zones

~ 85,000 people in the 20 km zone evacuated as precaution between 11 and 15 March

Another 10,000 evacuated outside 20 km zone between March and June based on environmental measurements



Doses to Public

Dose to Evacuated Populations

Age group	*Precautionary evacuated settlements*[a]			*Deliberately evacuated settlements*[b]		
	Before and during evacuation	*At the evacuation destination*	*First year total*	*Before and during evacuation*	*At the evacuation destination*	*First year total*
	EFFECTIVE DOSE (mSv)					
Adults	0–2.2	0.2–4.3	1.1–5.7	2.7–8.5	0.8–3.3	4.8–9.3
Child, 10-year old	0–1.8	0.3–5.9	1.3–7.3	3.4–9.1	1.1–4.5	5.4–10
Infant, 1-year old	0–3.3	0.3–7.5	1.6–9.3	4.2–12	1.1–5.6	7.1–13
	ABSORBED DOSE TO THE THYROID (mGy)					
Adults	0–23	0.8–16	7.2–34	15–28	1–8	16–35
Child, 10-year old	0–37	1.5–29	12–58	25–45	1.1–14	27–58
Infant, 1-year old	0–46	3–49	15–82[c]	45–63	2–27	47–83[c]

Context: Effective dose limit for pubic = 1 mSv, for workers = 50 mSv

Doses to Public

First-Year Doses in Non-Evacuated Areas

Residential area	*Effective dose (mSv)*			*Absorbed dose to the thyroid (mGy)*		
	Adults	*10-year old*	*1-year old*	*Adults*	*10-year old*	*1-year old*
Group 2[a] - Fukushima Prefecture	1.0–4.3	1.2–5.9	2.0–7.5	7.8–17	15–31	33–52
Group 3 prefectures[b]	0.2–1.4	0.2–2.0	0.3–2.5	0.6–5.1	1.3–9.1	2.7–15
Group 4[c] - rest of Japan	0.1–0.3	0.1–0.4	0.2–0.5	0.5–0.9	1.2–1.8	2.6–3.3

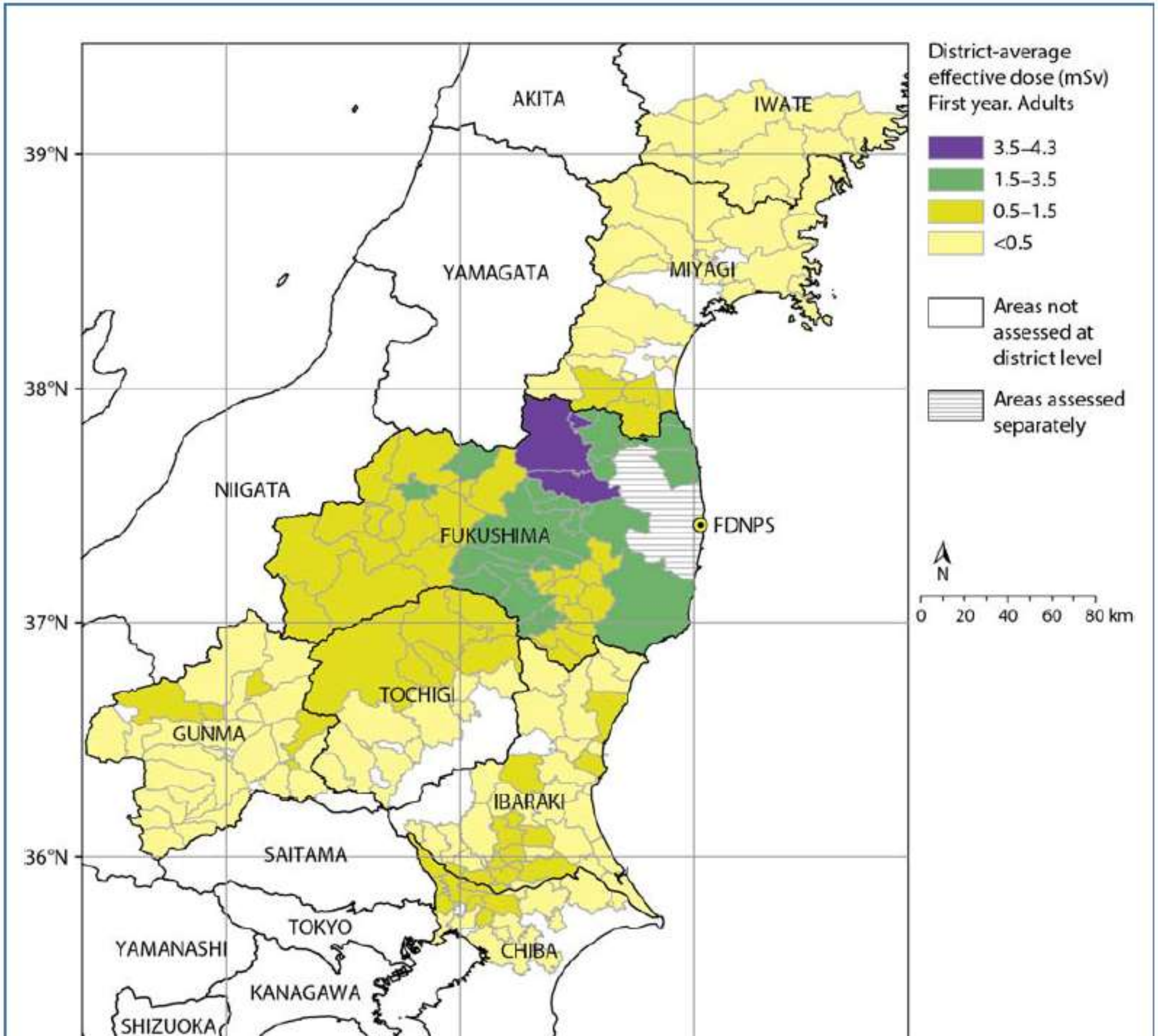
[a] *Group 2 - Members of the public living in the non-evacuated districts of Fukushima Prefecture.*

[b] *Group 3 - Members of the public living in the prefectures of Miyagi, Gunma, Tochigi, Ibaraki, Chiba and Iwate.*

[c] *Group 4 - Members of the public living in the remaining prefectures of Japan.*

Doses to Public

First Year Average Doses in Non-Evacuated Areas



Health Implications

- Public Health Impacts
  - "…any overall increase in disease incidence in the general population due to radiation exposure from the accident would be too small to be observed…"
  - "The most important health effects observed so far among the general public and among workers were considered to be on mental health and social well-being, relating to the enormous impact of the earthquake and tsunami…"
- Worker Health Impacts
  - "Low risk" for disease due to radiation exposure
  - "…it is not expected that any potential increase in leukemia incidence would be discernible"

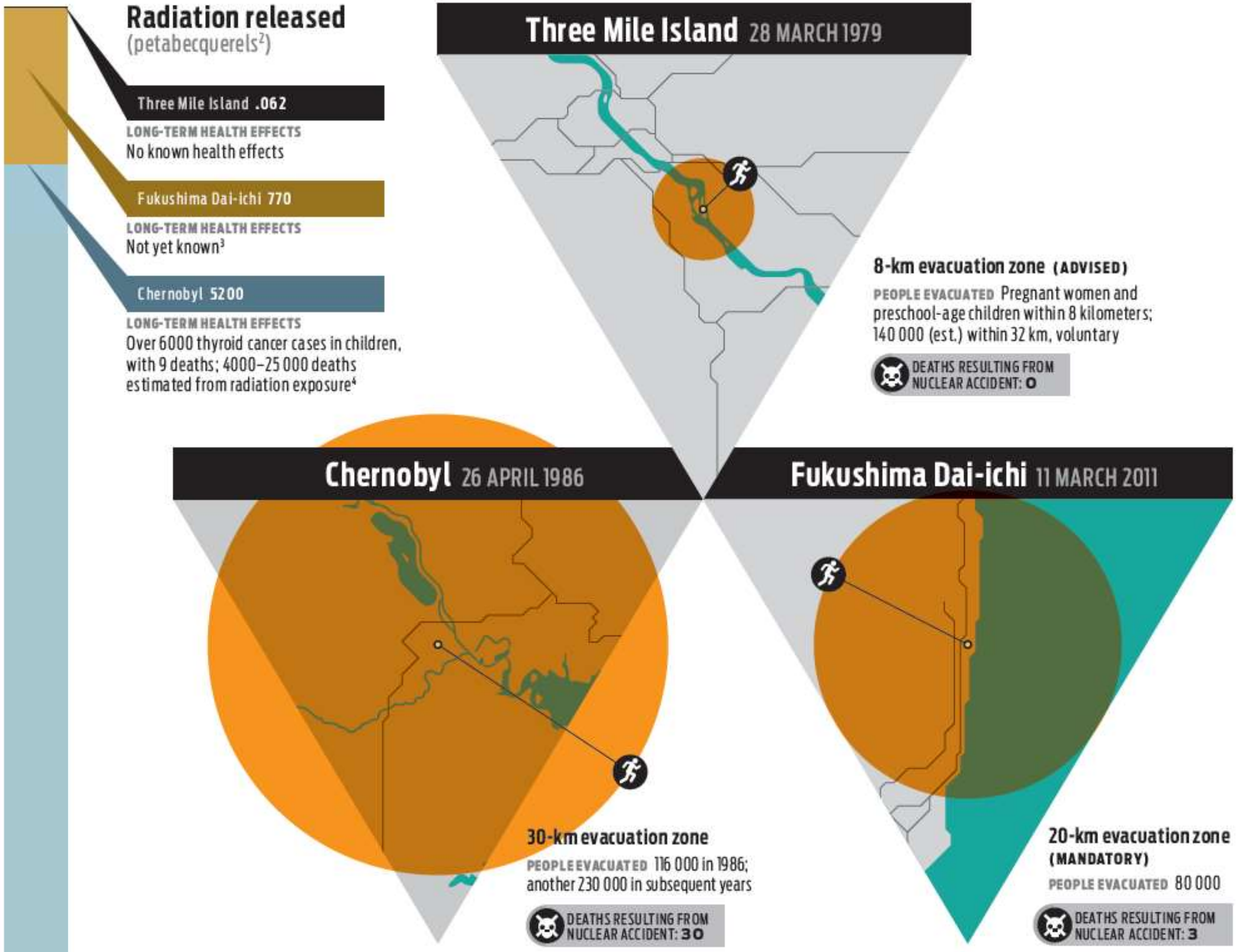
Scientific Approach to Health Risk

- Health Physics Society:

  …the Society has concluded that estimates of risk should be limited to individuals receiving a dose of 50 mSv in one year or a lifetime dose of 100 mSv in addition to natural background…Below these doses…expressions of risk should only be qualitative, that is, a range based on the uncertainties in estimating risk…emphasizing the inability to detect any increased health detriment (that is, zero health effects is a probable outcome).

HPS Position Paper PS010-2, 2010

- *Only 0.7% of the workforce has exceeded a dose of 100 mSv thus far*
- *Doses to the public were much lower than worker doses*



TMI/Chernobyl/Fukushima comparison *Source: IEEE*

Remediation in Japan

- Site area mitigation, decontamination
- Cleanup of surface soils, building decontamination
- Phytoremediation
- Containment of contaminated water
- Groundwater freezing
- Over 50,000 people in the general public now being monitored with personal dosimetry

US Nuclear Industry Response

- *Short Term Actions*
  - *US NPPs verification assessment of capabilities to manage major challenges, including aircraft impacts, loss of large areas of plant due to natural events, fires, explosions*
  - *US NPPs verification assessment of capacity to manage loss of off-site power*
  - *US NPPs verification assessment of capacity to mitigate flooding and impact of floods on systems internal and external to the plant*
  - *Performance of comprehensive walk-downs/inspections of all vital equipment needed to respond to extreme events*

US Nuclear Industry Response

- *Long Term (Srategic) Actions*
  - *Beyond Design Basis (BDB) Program Developed and Deployed*
    - *Installation of equipment to deal with extreme events (local and regional)*
    - *Fukushima Design Basis includes earthquake and tsunami simultaneous events*
    - *US NPPs review/perform gap analysis of all design bases*
    - *Identify and implement appropriate corrective measures to address potential hazards outside design bases*
    - *Identify all critical safety functions*
    - *Implement necessary mods./upgrades*

Risks in Perspective

- Risk of cancer increases in a generally proportional way with radiation dose. The exact relationship of dose to risk is not known for low doses.
  - About 55% of US citizens *get* cancer (normal incidence).
  - About 25% of US citizens *die* from cancer (normal mortality).
  - The approximate excess relative risk for radiation is about 40%/Sv.
  - *Extrapolating* to the lowest level for which quantitative estimates should be considered, gives the following:

❖ In a population of 100,000 people, all exposed to 100 mSv*, we would predict about 1000 excess cancer deaths

❖ Studies of people with doses in this range do not show a clearly measurable risk in such populations

❖ There will be about 25,000 non-radiation cancer deaths in this population

*100 mSv is almost 100 times the normal annual background from cosmic, terrestrial, and internal radiation sources combined.

For More Information on Radiation Protection

Health Physics Society

WEBSITE: **http://hps.org**

National Council on Radiation Protection and Measurements

WEBSITE: **http://www.ncrponline.org/**

International Committee on Radiation Protection

WEBSITE: **http://www.icrp.org/**

United Nations Scientific Committee on the Effects of Atomic Radiation

WEBSITE: **http://www.unscear.org/**

Keith Welch, M.S. RRPT

Thomas Jefferson National Accelerator Facility

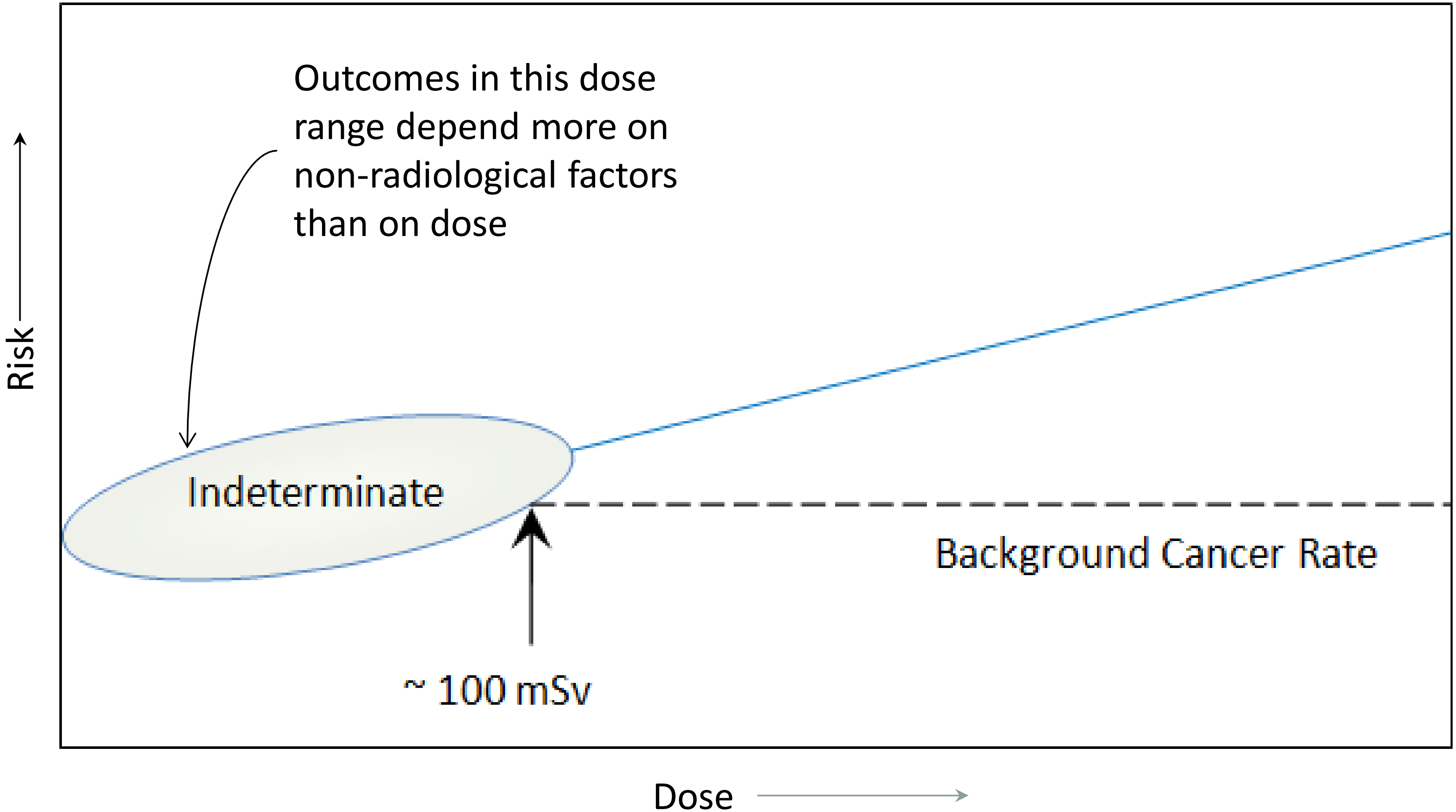
E-MAIL: **welch@jlab.org**

I would like to acknowledge the assistance and enthusiasm of Carl Tarantino in the preparation of this talk. Unfortunately Carl was unable to attend this session.

Extra slides

A Reasonable Interpretation?

Another way to depict the idea of a variable low-dose outcome becoming definitive at high dose



Conclusions

- Given all the uncertainties, what can we say with any reasonable level of confidence about low-dose radiation?
  - ICRP conclusions:

    ... the adoption of the LNT model combined with a judged value of a dose and dose rate effectiveness factor (DDREF) provides a prudent basis for the practical purposes of radiological protection, i.e., the management of risks from low-dose radiation exposure.

    (ICRP Pub. 103, 2007)

Conclusions

- UNSCEAR:

  In general, increases in the incidence of health effects in populations cannot be attributed reliably to chronic exposure to radiation at levels that are typical of the global average background levels of radiation... Therefore, the Scientific Committee does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels;

  UNSCEAR Sup. 46, 2012

Conclusions

- Health Physics Society:

  …the Society has concluded that estimates of risk should be limited to individuals receiving a dose of 50 mSv in one year or a lifetime dose of 100 mSv in addition to natural background…Below these doses…expressions of risk should only be qualitative, that is, a range based on the uncertainties in estimating risk…emphasizing the inability to detect any increased health detriment (that is, zero health effects is a probable outcome).

HPS Position Paper PS010-2, 2010

Conclusions

- Practical inferences
  - LNT can be used to help estimate radiation risks
  - The LNT model probably doesn’t under-estimate the risks, and may over-estimate them
  - LNT is useful for “radiation protection”
    - When applied with care, can be used to quantitatively estimate risks for persons with non-trivial doses
    - Useful in making ALARA comparisons and decisions
  - Should not be used for quantitative risk assessments when doses are < 100 mSv
  - Should not be applied to collective doses of low-dose populations (within the range of normal background dose)

Conclusions

“The dose makes the poison.”

Paracelsus, circa 1520

“All models are wrong, some models are useful.”

George Box, industrial statistician, 1979