April 12, 2011

The Lesson learned from the Chernobyl Accident and the Data from Atomic Bomb Survivors

— For Understanding the Fukushima Daiichi Accident and the Robustness of the Human Body to Ionizing Radiation —

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1. The Accident of Chernobyl Unit 4 of 1,000 MWe Graphite-Moderated Boiling Water Pressure Tube Reactor in 1986

1. **The worst nuclear power excursion (supercriticality) ,** which led **a large-scale reactor (pressure tubes) explosion,** was caused.
2. A hydrogen explosion was involved due to water reaction with overheated fuel-rod claddings (zirconium metal claddings).
3. The large amount of energy release caused the ignition of a large amount of graphite moderators, **resulting in a large-scale fire.**

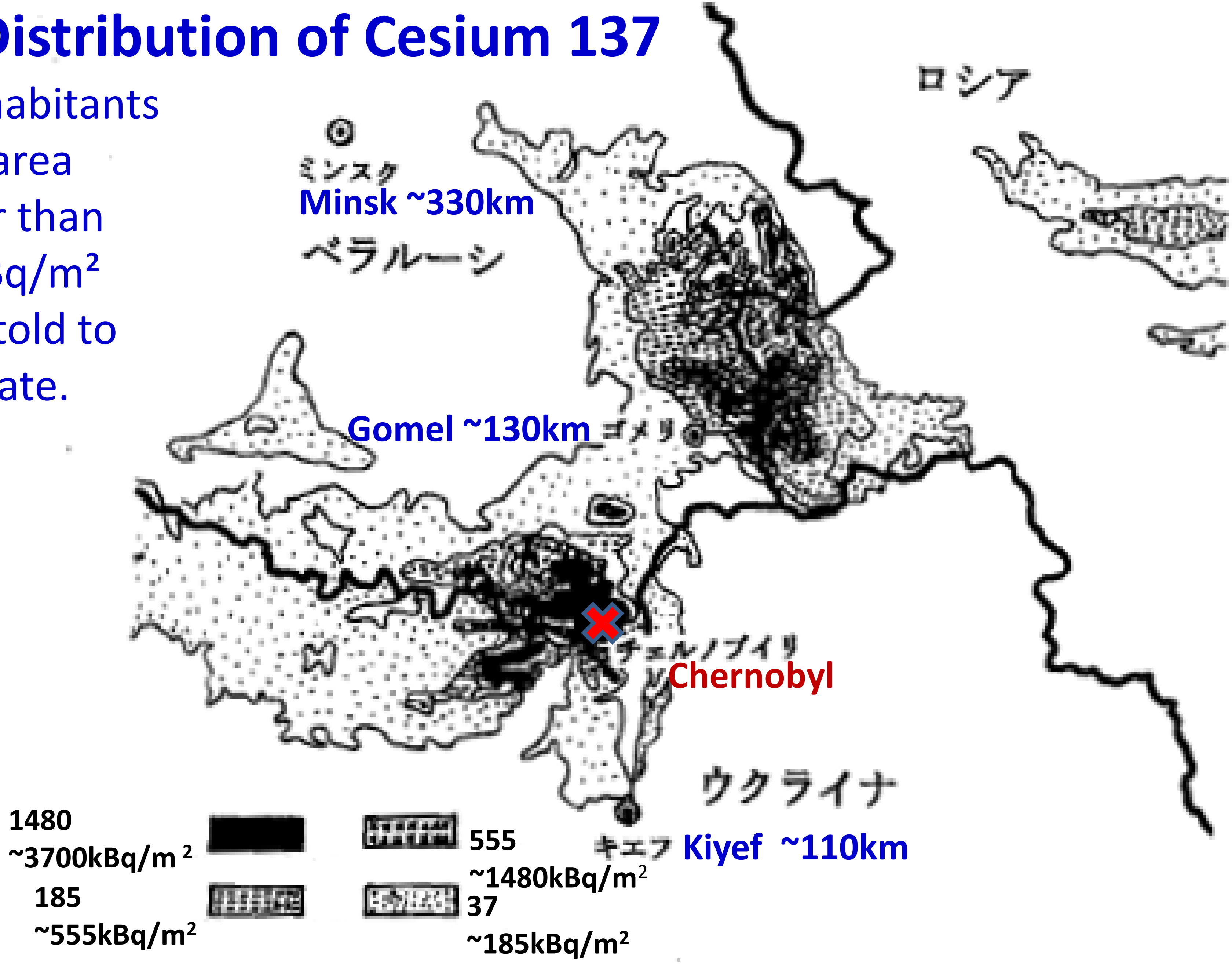
The Chernobyl accident as **a type of uncontrolled nuclear power excursion** was caused **by many violations of no educated and no trained operators** in the former Soviet Union. All radioactive fission products and core materials were exposed to the atmosphere and caused the fire. The fission products were carried not only to a large area in the former Soviet Union but also to northern European countries and to Scandinavian countries by prevailing wind.

The Chernobyl reactor was completely exposed to the atmosphere shortly after the accident.

100% of Krypton and Xenon,
~50% of Iodine,
~30% of Cesium, and
3~4% of the fuel was released into the atmosphere .

The Distribution of Cesium 137

All inhabitants in an area larger than 555kBq/m^2 were told to evacuate.



図IV・13 チェルノブイリ事故で放出された^{137}Csの地上分布[20]

Effects of Radiation from the Chernobyl Disaster

1. When the accident happened, two workers died immediately, one from the explosion, and one by a coronary heart attack.
2. **134 workers received acute doses ranging from 0.8 to 16 Grays** and suffered radiation sickness, resulting in emergency hospitalization.
3. **Of the 134, 27 workers received 4.2 to 16 Grays of and 1 worker exposed to 2.2 to 4.1 Grays died** in the next few months. **The 106 workers including 90 workers receiving less than 4.1 Grays recovered**.
4. There had been about **1,800 cases of thyroid cancer in children** according to UNSCEAR 2000 report. Thyroid cancer can be treated surgically.
5. **There is no scientific evidence of increases in overall cancer incidence or mortality or non-malignant disorders** to radiation exposure 14 years after such an accident.
6. Owing to its short latency time, **the risk of leukemia,** which was a major concern **did not appear** even among the 106 recovery workers.

Fukushima Daiichi Power Station

Hydrogen Explosion in Units 1 to 4

Water-Zirconium Reaction and Fuel Bundle Melt

Degraded Reactors

Small or Medium Scale Hydrogen Explosion in Units 1 to 3

Degraded Containments

Hydrogen Explosion in Unit 2

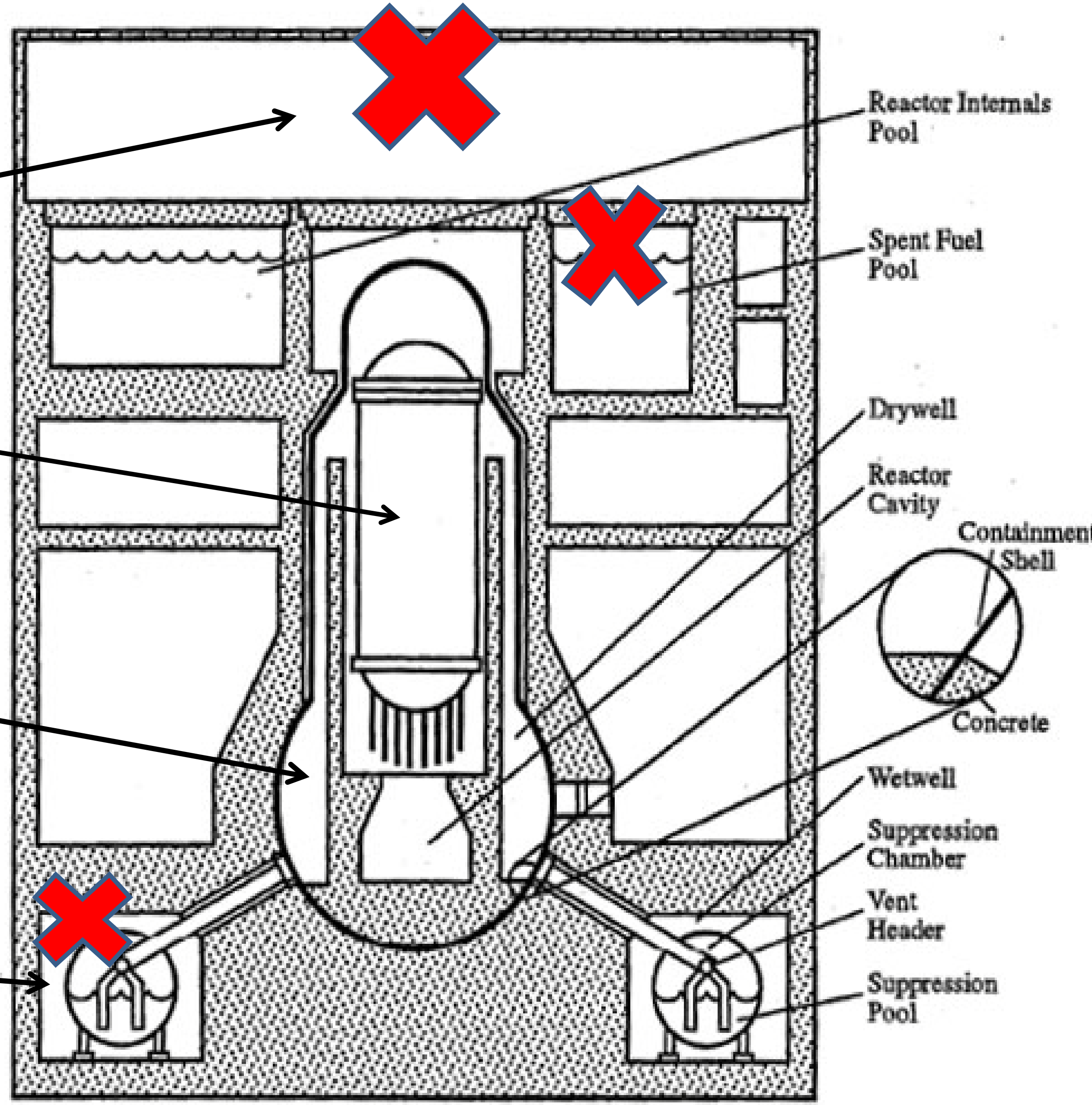


Figure 8-1. BWR MK-I Containment (courtesy of General Electric Co.).

2. Data from the Atomic Bomb Survivors:

Instantaneous Exposure to High Radiation Doses

1. The bombs dropped on Hiroshima and Nagasaki took a horrendous **death toll of 200,000**.
2. **86,572 survivors have been monitored**. About half of them were within 2.5km from the epicenter of the atomic bomb blasts, and **about 8,500, or 10% suffered radiation doses from 1 to 6 Sieverts.**
3. Up to the end of 1997, it is estimated that only 450 cancer deaths occurred as a result of radiation exposure from the bombs.
4. The projection for when all survivors have died is that **about 800, or 0.9% will have died as a result of cancer from radiation of the bombs**.

The life-span data of survivors clearly show a robustness of human body. The joint Japanese/US study shows **no significant differences among groups from 0 to 0.8 Gray at the median age of life span. No genetic effects were caused by radiation in the children born to the survivors.**

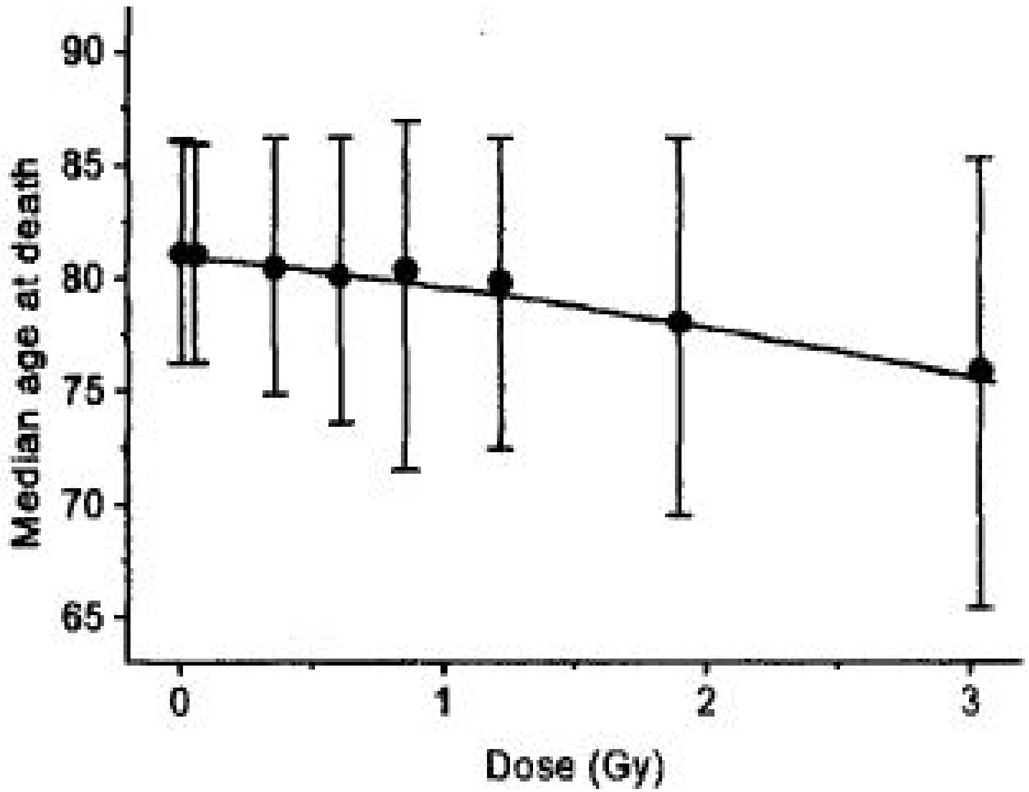


Fig. 1.14.1 Japanese atom bomb survivors, life expectancy with dose

Data of 120,000 Radiation Workers in the UK :
Long-Term Exposure to Low Radiation Dosage

There is **no significant additional risk** from radiation received.

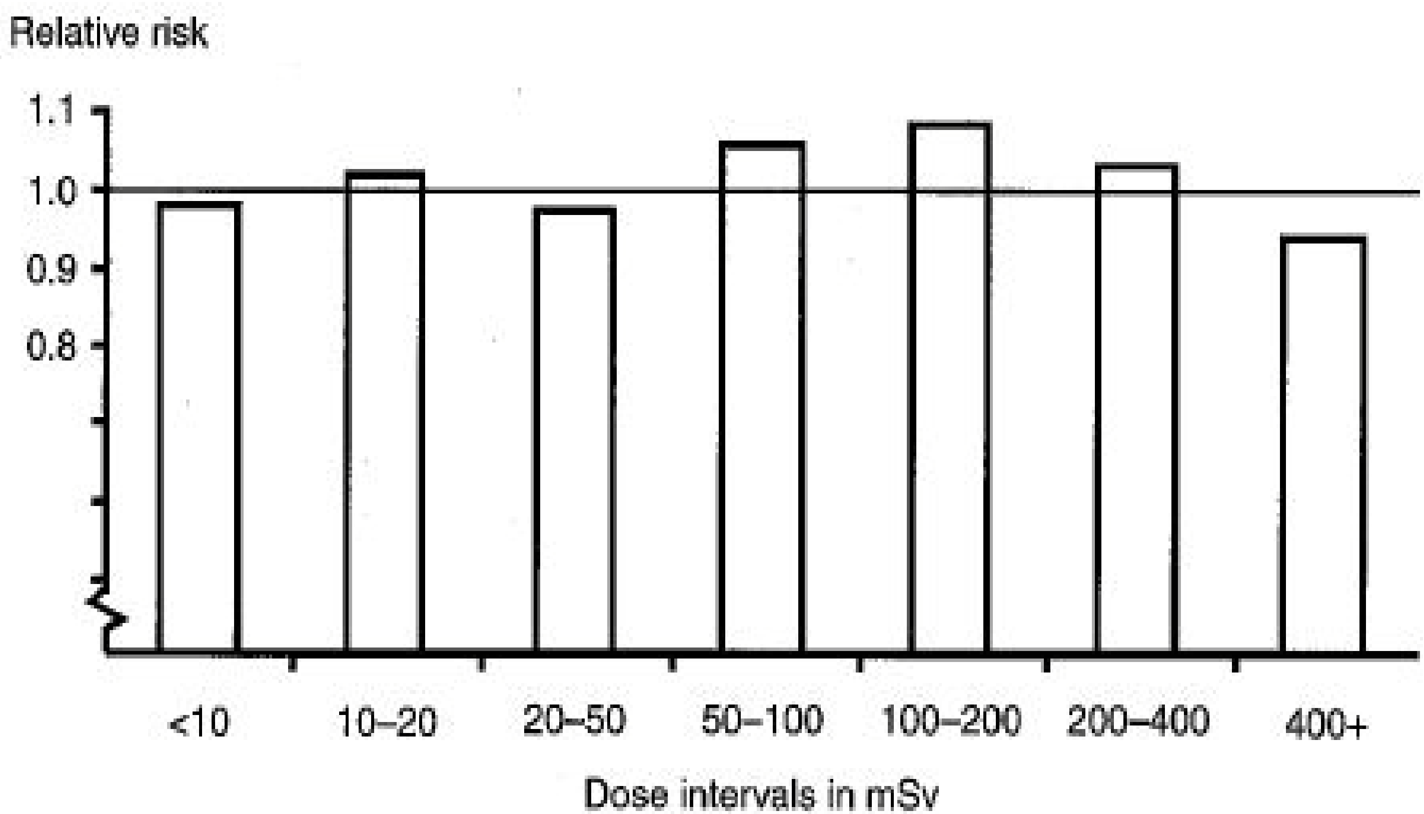


Fig. 1.14.3 Relative risk for UK radiation workers

DNA Repair Mechanism to Low Radiation Doses

DNA damage occurs naturally from a variety of processes other than radiation. **The repair mechanism repairs 99.99 percent of single-stranded breaks and 90 percent of double-strand breaks. Severe DNA damage and error-prone repair disappear through apoptosis.**

The accumulation of mutated cells with aging gradually impairs DNA repair processes and leads to the increased probability of cancer with age.

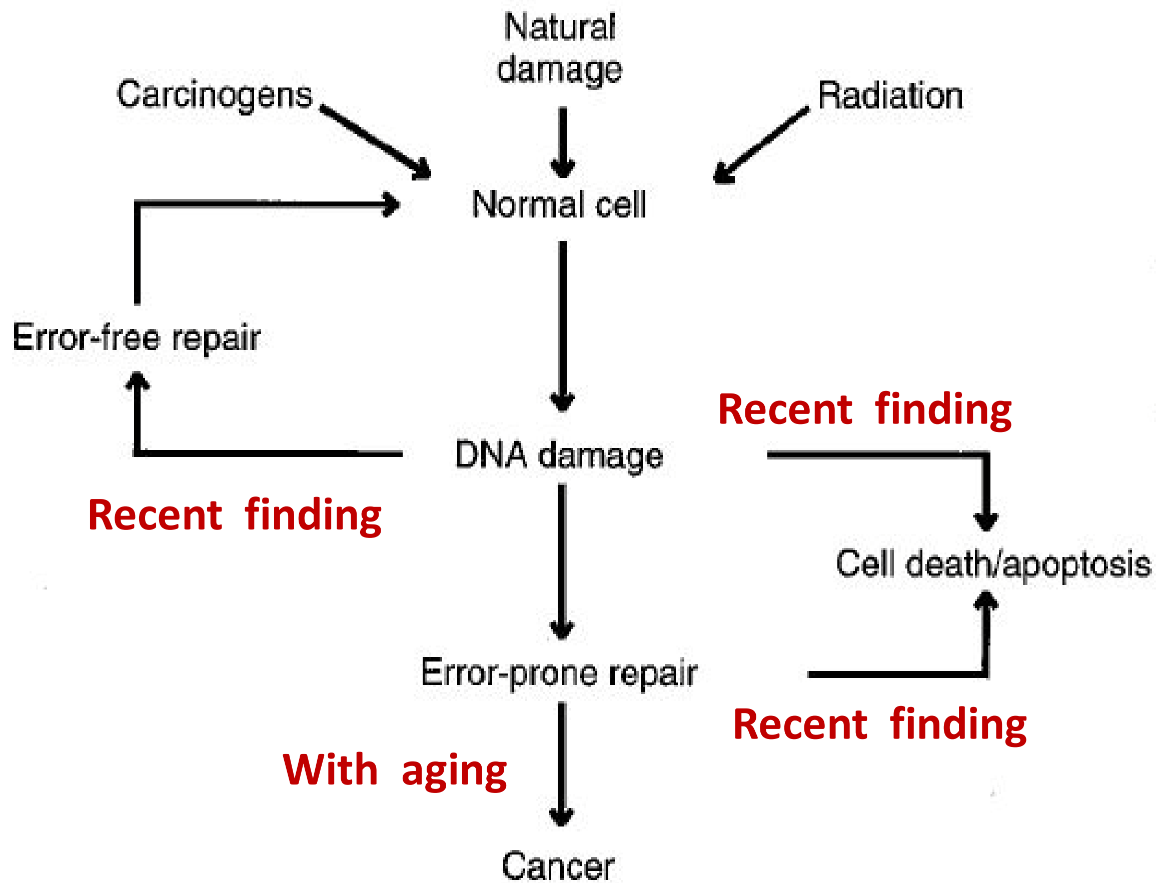


Fig. 1.14.4 DNA and cancer model

3. Recommendation on Ionizing Radiation Effects to Human Body from International Organizations

5 00 m Sv : Safe limits of workers in emergency recommended by the International Commission on Radiological Protection (ICRP)

250 m Sv : Present safe limits of workers in emergency at Japan

100 m Sv : Safe limits on indoor stay of general public living near nuclear plants in emergency recommended by the International Commission on Radiological Protection (ICRP)

50 m Sv : Safe limits for foods as established by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO)

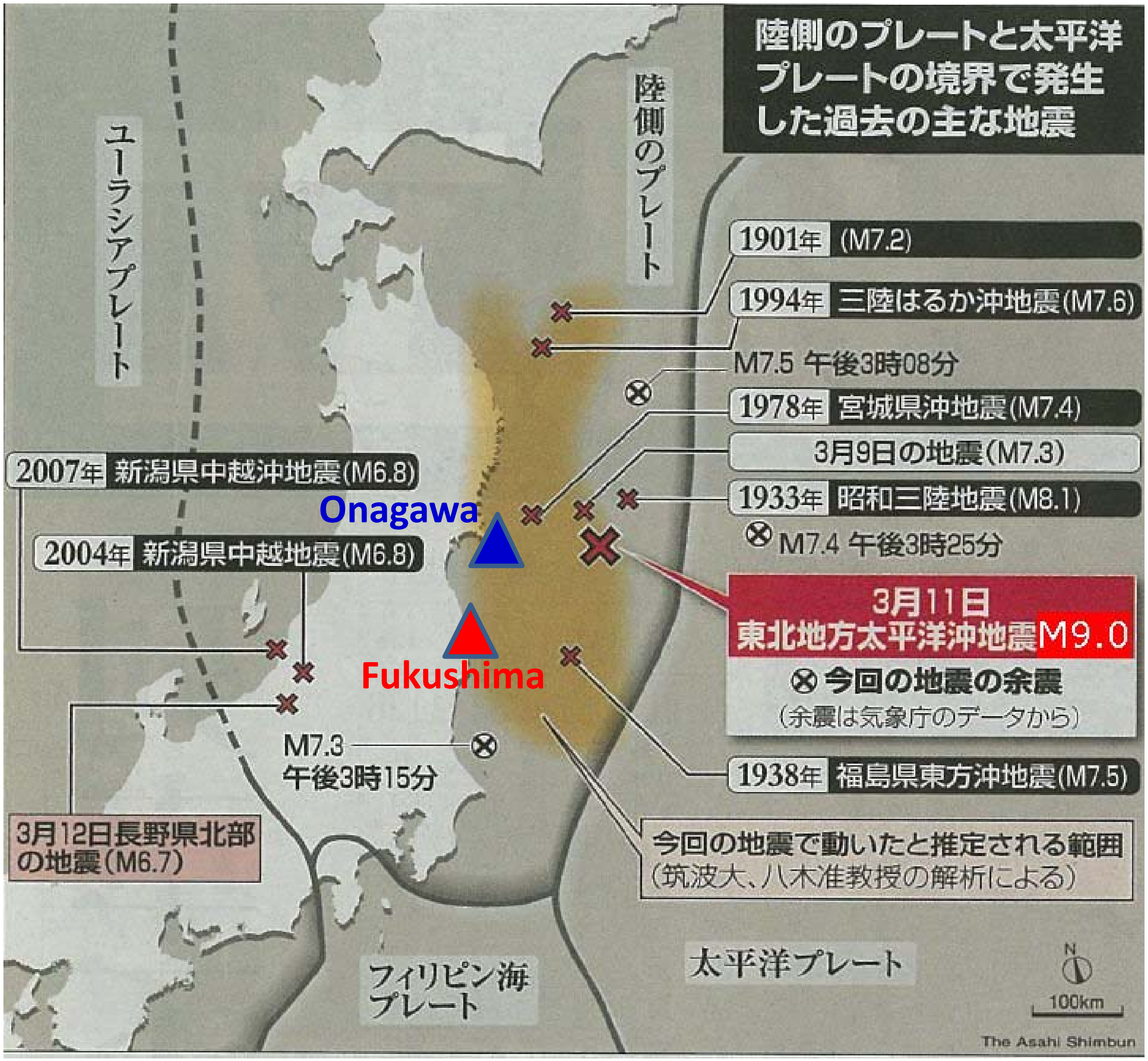
20 m Sv : The current safe limit for indoors of general public living in the nuclear power plant zone.

5 m Sv : Present safety limit on foods in Japan

Safety Limits on Foods between IAEA and Japan for Adults

		Japan	IAEA
Radioactive Iodine	milk	300Bq/kg	3,000Bq/kg
	vegetables	2,000Bq/kg	3,000Bq/kg
	Meat, fish, dairy products	2,000Bq/kg	30,000Bq/kg
Radioactive Cesium	milk	200Bq/kg	3,000Bq/kg
	vegetables	500Bq/kg	3,000Bq/kg
	meat, fish, egg	500Bq/kg	30,000Bq/kg (meat and dairy products)

4. Onagawa BWR Power Station Unit No.1 to No.3



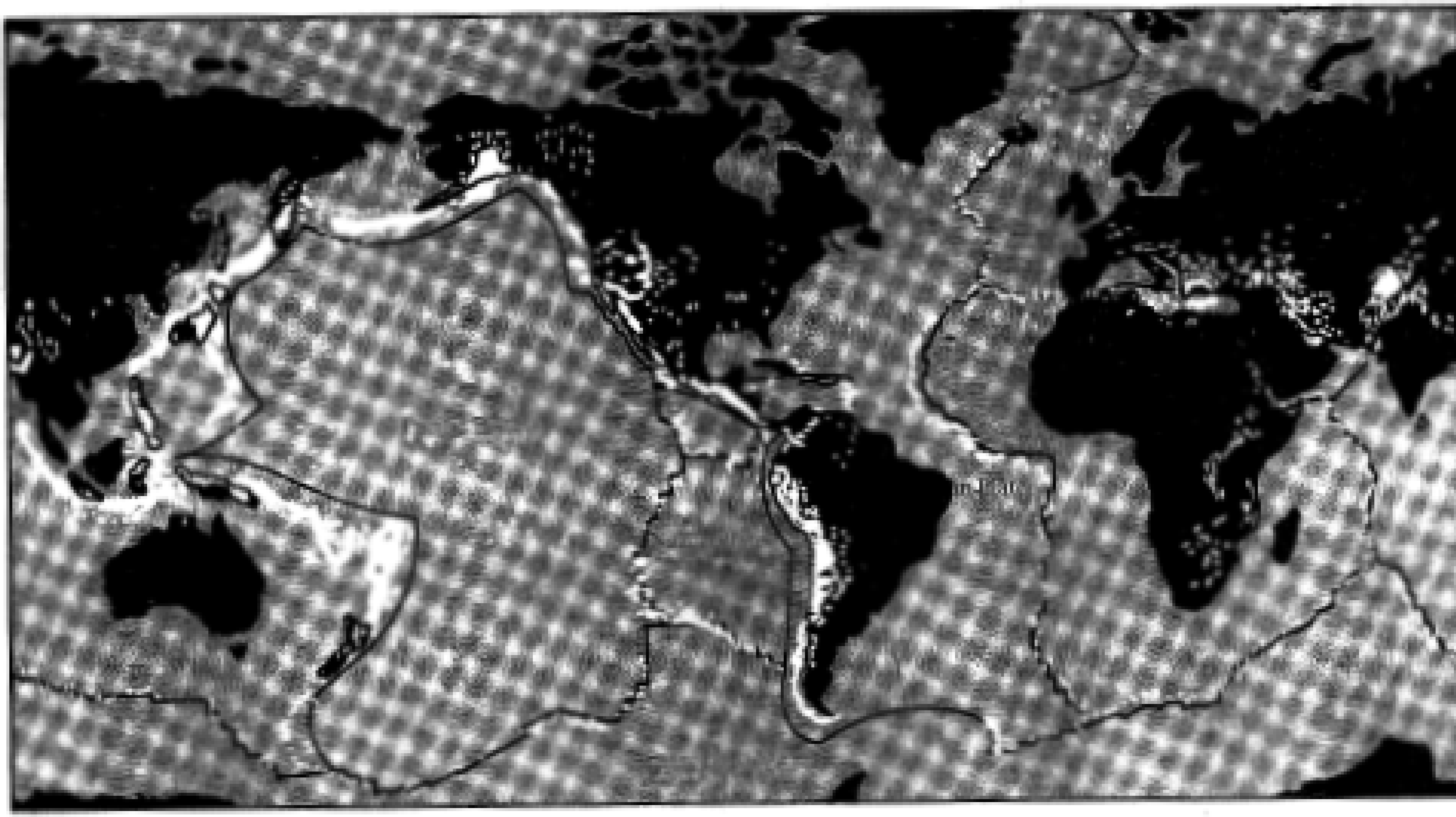
The Nearest Nuclear Facility to the Earthquake Center

The Earthquake and Tsunami presented no problem because **it is situated 15 meters above sea level.**

5. The Lesson Learned from the Tsunami Caused by M9 Earthquake

1. Provided power station has a good base rock layer and a high location, catastrophic damage from these kinds of natural disasters will be dramatically decreased.
2. A passive air-cooling system not using electric power is required for preventing fuel rod damage.
3. An Ignition system should be standard to prevent hydrogen explosions in fuel rod-damaged reactors.
4. A passive filtered-venting system that doesn’t use electric power should be standard to release volatile fission products from severely core-damaged reactors.

The white dots show the centers of 42,000 earthquakes occurred between 1961 and 1969 from C.Kissinger



The Relation between Energy and Magnitude

The energy E in ergs is related to the magnitude M by the following empirical formula :

$$\log_{10} E = 11.4 + 1.5M .$$

The energy E increases logarithmically with M :

$$\frac{E_{M+1}}{E_M} = 10^{1.5} = 31.6$$

What scale of Earthquake Occurred in Fukushima and Onagawa Nuclear Power Stations

Modified Mercalli Intensity Scale, I		Ground Acceleration, a ($\frac{cm}{sec^2}$)	$\frac{a}{g}$
VII	Everybody runs outdoors; damage to buildings varies, depending on quality of construction; noticed by drivers of autos.	80, 100	.1g
VIII	Panel walls thrown out of frames; fall of walls, monuments, chimneys; sand and mud ejected; drivers of autos disturbed.	200	
IX	Buildings shifted off foundations, cracked, thrown out of plumb; ground cracked; underground pipes broken.	400, 600	.5g
X	Most masonry and frame structures destroyed; ground cracked; rails bent; landslides.	800, 1000	1g
XI	New structures remain standing; bridges destroyed; fissures in ground; pipes broken; landslides; rails bent.	2000	
XII	Damage total; waves seen on ground surface; lines of sight and level distorted; objects thrown up into air.	4000, 6000	5g

Definition of Becquerel, Gray and Sievert

Becquerel (symbol : Bq)

One Bq is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.

The unit of Bq is [s^{-1}].

Gray (symbol : Gy)

The Ggray is the SI unit of absorbed radiation dose of ionizing radiation (for example, X-rays), and is defined as the absorption of one joule of ionizing radiation by one kilogram of matter (usually human tissue).

The unit of Gy is [J/kg].

Sievert (Sv)

The Sievert (symbol : Sv) is the SI derived unit of dose equivalent radiation. It attempts to quantitatively evaluate the biological effects of ionizing radiation as opposed to the physical aspects, which are characterized by the absorbed dose, measured in gray.

The unit of Sv is [J/kg].

Conversion from Gray to Sievert

- **α-ray**

  Z [Sv] = 20 × Y [Gy]

- **β-ray, γ-ray, X-ray**

  Y [Sv] = 1 × Y [Gy]

- **Neutron**

  Z [Sv] = (5 ~ 20) × Y [Gy]

Recommendation and Estimation on Ionizing Radiation Effects to Human Body from International Organizations(cont'd)

50 m Sv : Safe limits for foods as established by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO)

20 m Sv : The current safe limit for indoors of general public living in the nuclear power plant zone.

5 m Sv : Present safety limit on foods in Japan

2.4m Sv : Average worldwide annual radiation dose **from cosmic rays, soil and produce**, with a typical range in different parts of the world from 1 mSv to 10 mSv

3. Recommendation and Estimation on Ionizing Radiation Effects to Human Body from International Organizations

~10,000 m Sv : 100% mortality estimated from Japanese atom bomb survivors by the UN Scientific Committee on the Effects of Atomic Radiation **(UNSCEAR estimates 11 excess deaths per 100person Sv at high and medium doses)**

5 00 m Sv : Safe limits of workers in emergency recommended by the International Commission on Radiological Protection (ICRP)

250 m Sv : Present safe limits of workers in emergency at Japan

100 m Sv : Safe limits on indoor stay of general public living near nuclear plants in emergency recommended by the International Commission on Radiological Protection (ICRP)