Effects on Human Body

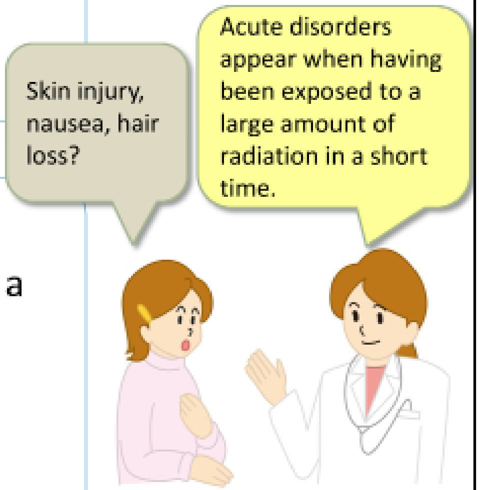
## Exposure Modes and Effects

**High-dose exposure**
(Exposed to a large amount of radiation)

**Low-dose exposure**
(Exposed to a small amount of radiation)

**Acute exposure**
(Radiation exposure on one occasion or in a short time)

**Chronic exposure**
(Radiation exposure over a long period of time)




Physical effects of radiation depend on the amount of exposure, not on whether a person is ever exposed to radiation.

Whether any significant effects appear in the human body due to having been exposed to radiation depends on whether it is internal exposure or external exposure, whole-body exposure or local exposure, or which part was exposed in the case of local exposure, the amount of radiation, or the duration of exposure.

Types and levels of radiation effects on the human body can be ascertained more accurately when there is more information available.

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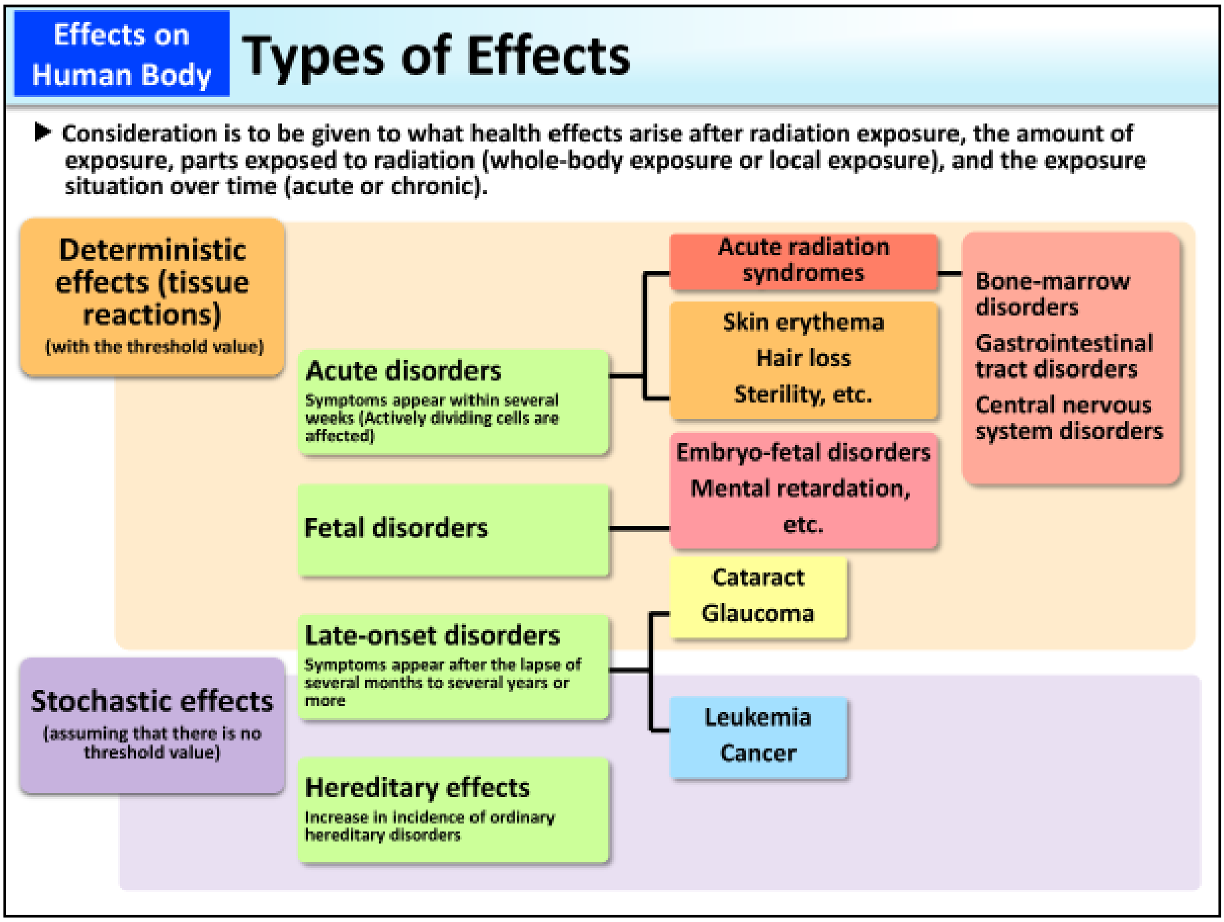


When considering health effects of radiation on human body, one method is to separately consider stochastic effects and deterministic effects (tissue reactions). The above figure compiles these two effects.

Deterministic effects (tissue reactions) do not appear unless having been exposed to radiation exceeding a certain level. Most of the deterministic effects are categorized into acute disorders whose symptoms appear within several weeks after exposure.

Stochastic effects are effects whose incidence cannot be completely denied even with low-dose exposure. Exposure doses are managed on the safe side in general under the assumption that there is no threshold value.

However, it has not been confirmed that hereditary disorders due to radiation exposure appear among human beings at the same frequencies as estimated from the results of tests on laboratory animals.

(Related to p.85 of Vol. 1, “Classification of Radiation Effects,” and p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

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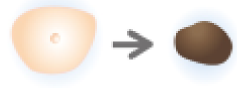
Updated on March 31, 2021

Effects on Human Body

# Classification of Radiation Effects

| Categories of effects | | Incubation period | e.g. | Mechanism of how radiation effects appear |
|---|---|---|---|---|
| | Physical effects | Within several weeks = Acute effects (early effects) | Acute radiation syndromes*1<br>Acute skin disease | Deterministic effects (tissue reactions) caused by cell deaths or cell degeneration*2<br> |
| | | After the lapse of several months = Late effects | Abnormal fetal development (malformation) | |
| | | | Opacity of the lens | |
| | | | Cancer and leukemia | Stochastic effects due to mutation<br> |
| | Heritable effects | | Hereditary disorders | |

*1: Major symptoms are vomiting within several hours after exposure, diarrhea continuing for several days to several weeks, decrease of the number of blood cells, bleeding, hair loss, transient male sterility, etc.

*2: Deterministic effects do not appear unless having been exposed to radiation exceeding a certain dose level.

Radiation effects are classified into physical effects appearing in a person exposed to radiation and heritable effects appearing in his/her children or grandchildren.

Radiation effects may also be classified depending on the length of time until any symptom appears after exposure. That is, there are acute effects (early effects) that appear relatively early after exposure and late effects that appear after the lapse of several months.

Another classification is based on the difference in mechanisms of how radiation effects appear, i.e., deterministic effects (tissue reactions) and stochastic effects.

Deterministic effects (tissue reactions) are symptoms caused by deaths or degeneration of a number of cells constituting organs and tissues. For example, after exposure to a relatively large amount of radiation, a skin injury or a decrease of the number of blood cells due to deterioration of hemopoietic capacity may occur within several weeks (acute radiation syndrome). Exposure to a large amount of radiation during pregnancy may cause some effects on the fetus and radiation exposure to the eyes may induce cataracts after a while.

On the other hand, stochastic effects are caused by mutation of cell genes, such as cancer and heritable effects. Radiation may damage DNA, which may result in genetic mutation (p.88 of Vol. 1, “Damage and Repair of DNA”). Each mutation is unlikely to lead to diseases, but theoretically, the possibility of causing cancer or heritable effects cannot be completely denied. Therefore, in relation to cancer or heritable effects, exposure doses are managed on the safe side under the assumption that there is no threshold dose.

(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects,” and p.108 of Vol. 1, “Risks of Heritable Effects for Human Beings”)

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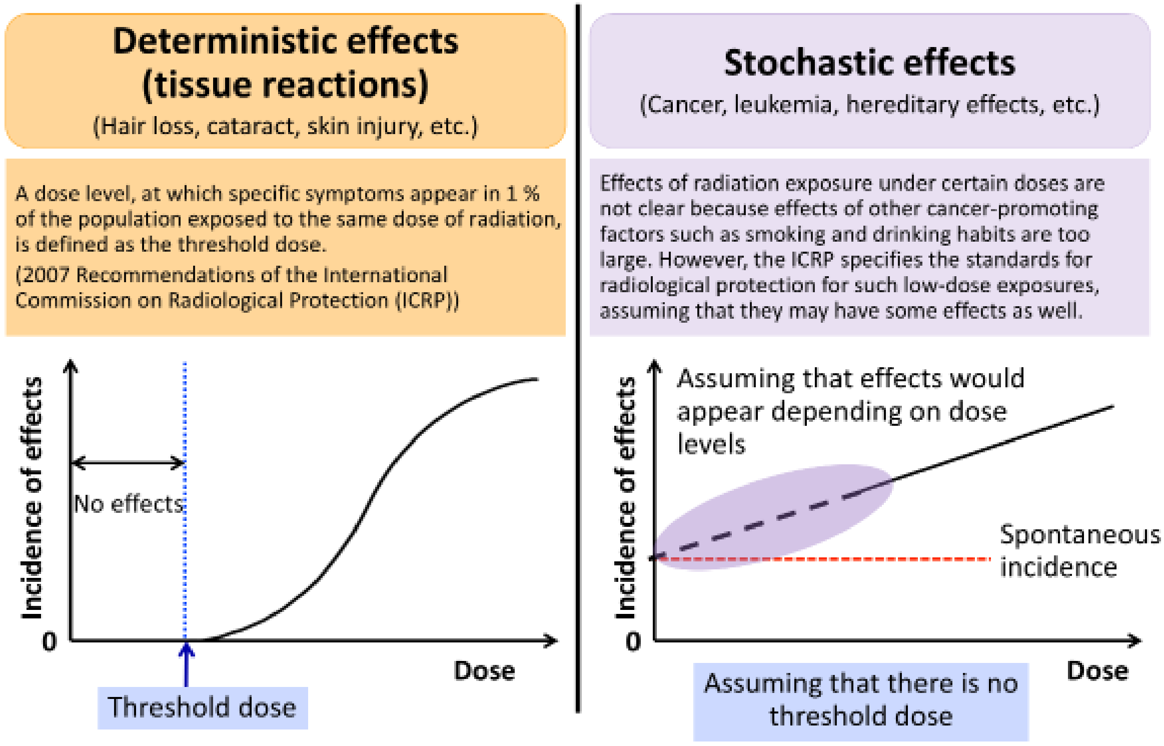
Effects on Human Body

# Deterministic Effects (Tissue Reactions) and Stochastic Effects




One of the characteristics of the deterministic effects (tissue reactions) is the existence of the threshold dose, which means that exposure to radiation under this level causes no effects but exposure to radiation above this level causes effects. Radiation exposure above the threshold dose causes deaths or degeneration of a large number of cells at one time and the incidence rate increases sharply.

On the other hand, in radiological protection, it is assumed that there is no threshold dose for stochastic effects. Under this assumption, the possibility that radiation exposure even at extremely low doses may exert some effects can never be eliminated. It is difficult to epidemiologically detect stochastic effects due to radiation exposure at low doses below the range of 100 to 200 mSv, but the ICRP specifies the standards for radiological protection for low-dose exposures, assuming that effects would appear depending on dose levels (linear dose-response relationship) (p.165 of Vol. 1, “Biological Aspect”).

When assessing cancer risks due to low-dose exposures, results of the epidemiological studies of atomic bomb survivors in Hiroshima and Nagasaki have mainly been used. It is known that cancer risks increase almost linearly as exposure doses increase above approx. 100 mSv (p.117 of Vol. 1, “Relationship between Solid Cancer Deaths and Doses”). However, it is not clear whether risks also increase linearly in the case of radiation exposure at doses below 100 mSv (p.166 of Vol. 1, “Disputes over the LNT Model”). Additionally, it is shown that risks increase quadratically in tandem with doses above approximately 1,000 mSv (p.118 of Vol. 1, “Dose-response Relationship of Radiation-induced Leukemia”). The WHO and UNSCEAR assess risks by applying the linear-quadratic dose response model.

Furthermore, experiments using animals or cultured cells have revealed that comparing high-dose exposures in a short time as experienced by atomic bomb survivors and low-dose exposures over a long period of time, the latter poses lower risks even when the total exposure doses are the same (p.116 of Vol. 1, “Cancer-promoting Effects of Low-dose Exposures”).

(Related to p.91 of Vol. 1, “Cell Deaths and Deterministic Effects (Tissue Reactions)”)

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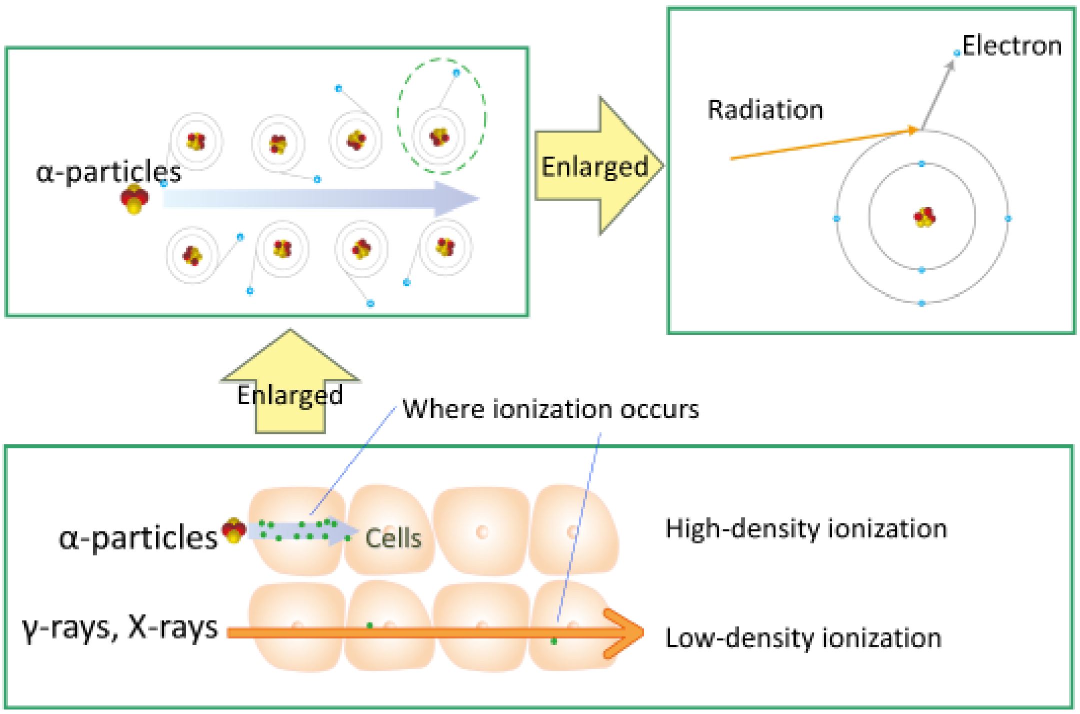
Mechanism of Causing Effects on Human Body

# Ionization due to Radiation




Radiation provides energy to substances along its pathway. Electrons of substances along the pathway are ejected with the given energy. This is ionization.

The density of energy provided by radiation differs by the type of radiation. Compared with β (beta)-particles and γ-rays, α (alpha)-particles provide energy more intensively to substances in an extremely small area. Due to such difference in the ionization density, damage to cells differs even with the same absorbed dose.

(Related to p.18 of Vol. 1, "Ionization of Radiation - Property of Ionizing Radiation")

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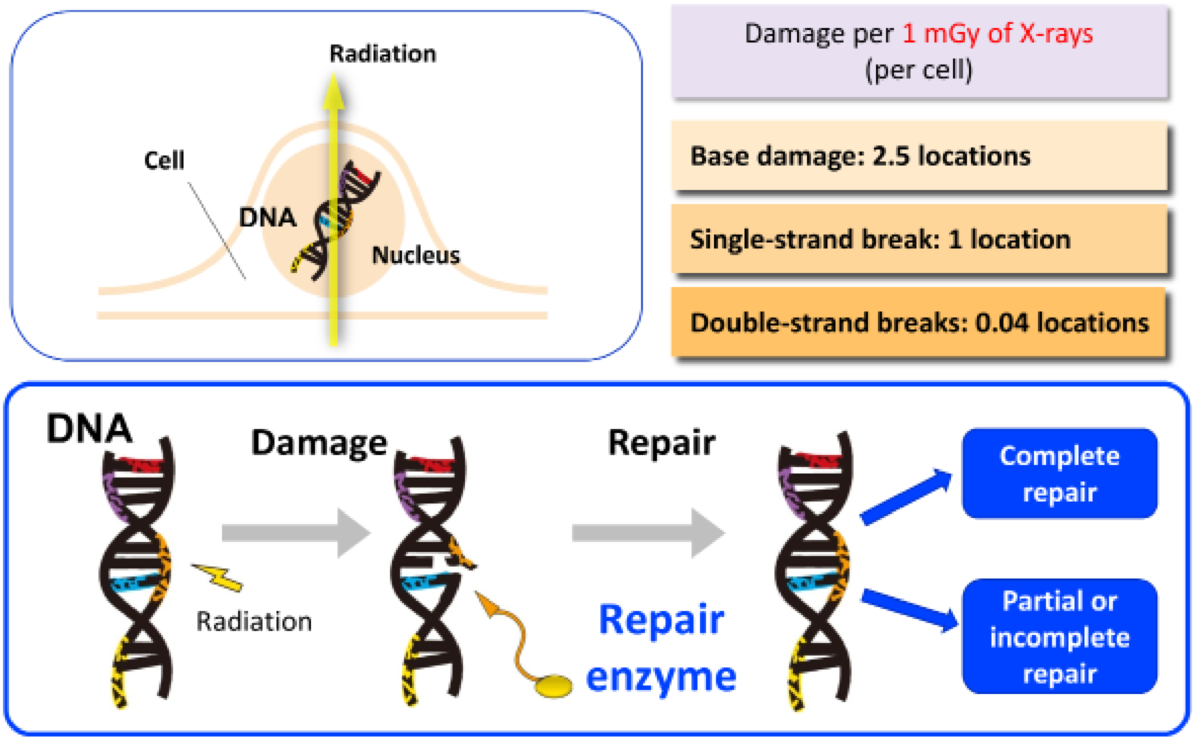
Mechanism of Causing Effects on Human Body

# Damage and Repair of DNA




Source: Morgan, Annual Meeting of the National Committee on Radiation Protection and Measurements (NCRP) (44th, 2008)

Cells have DNA, the blueprint of life. DNA consists of two chains of sugar, phosphate and four different bases. As the genetic information is incorporated in the arrangement of these bases, bases are combined firmly to mutually act as a template in order to maintain the arrangement. When DNA is irradiated, it may be partially damaged depending on the amount of radiation.

1 mGy of X-rays is thought to cause a single-strand break at one location per cell on average. A double-strand break occurs less at 0.04 locations. Therefore, when 100 cells are evenly exposed to 1 mGy of X-rays, double-strand breaks occur in four cells.

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and reactive oxygen, etc. It is said that DNA is damaged at 10,000 to 1,000,000 locations per cell every day.

Cells have functions to repair damaged DNA. Damaged DNA is repaired by the action of repair enzymes. There are cases where DNA is completely repaired and partially or incompletely repaired (p.89 of Vol. 1, “DNA→Cells→Human Body”).

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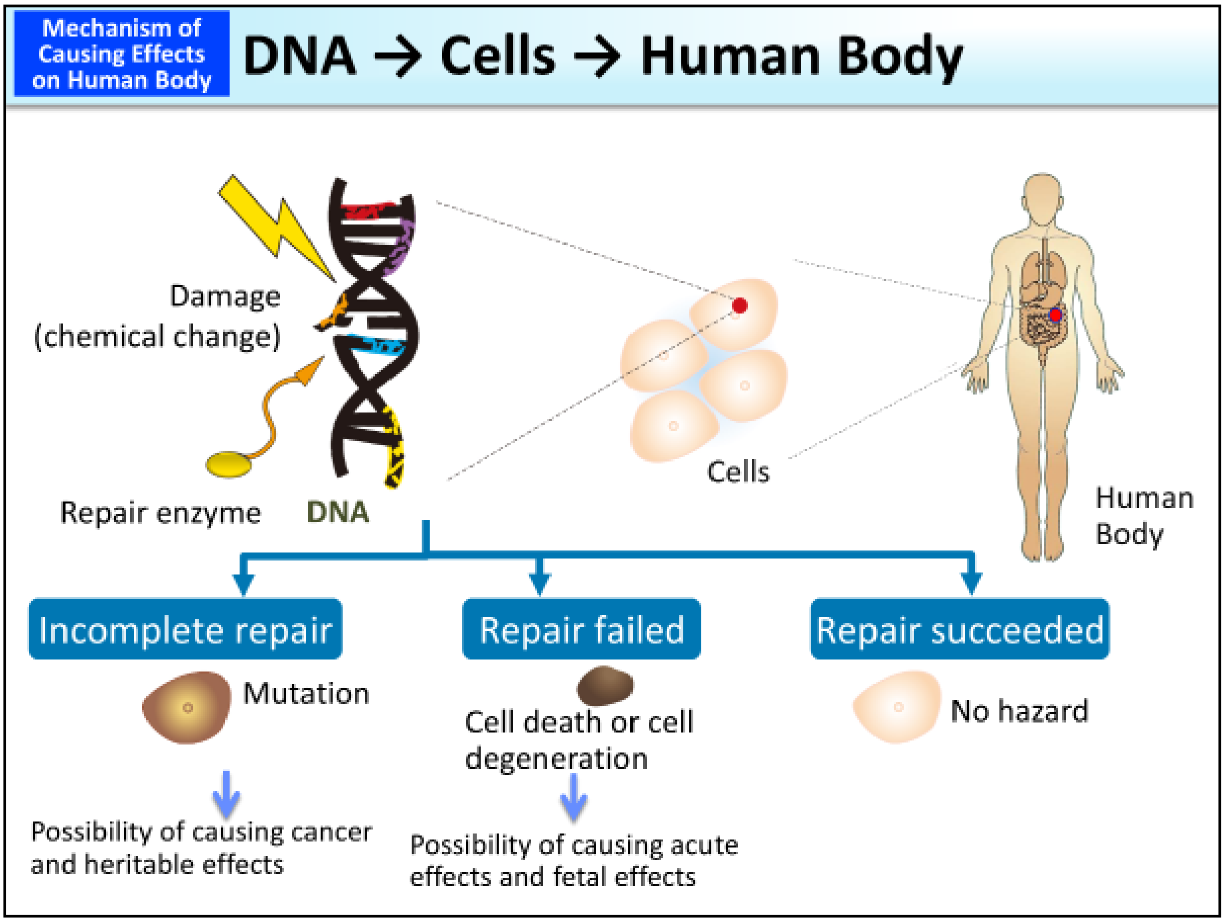


Looking closely into the irradiated portion, radiation may directly or indirectly damage the DNA sequences of a gene. These damaged DNA sequences are repaired by a pre-existing system in the body.

Minor damage is successfully repaired and restored. However, when many parts are damaged, they cannot be fully repaired and cells themselves die. Even when some cells die, if other cells can replace them, dysfunction does not occur in organs and tissues. However, when a large number of cells die or degenerate, there is the possibility that deterministic effects (tissue reactions) will appear, such as hair loss, cataract, skin injury or other acute disorders, as well as fetal disorders (p.90 of Vol. 1, “Lapse of Time after Exposure and Effects,” and p.91 of Vol. 1, “Cell Deaths and Deterministic Effects (Tissue Reactions)”).

When a cell in which DNA was not completely repaired survives, the cell gene may mutate and cause a stochastic effect such as cancer or heritable effect.

DNA is damaged not only by radiation but also by carcinogens in foods, tobacco, chemical substances in the environment and reactive oxygen, etc. It is said that DNA is damaged at 10,000 to 1,000,000 locations per cell every day. Damage due to low-dose exposures is significantly rare compared with metabolic DNA damage. However, radiation provides energy locally and causes complicated damage affecting multiple parts in DNA strands. Approx. 85% of radiation effects are caused by reactive oxygen, etc. created by radiation and approx. 15% is direct damage by radiation.

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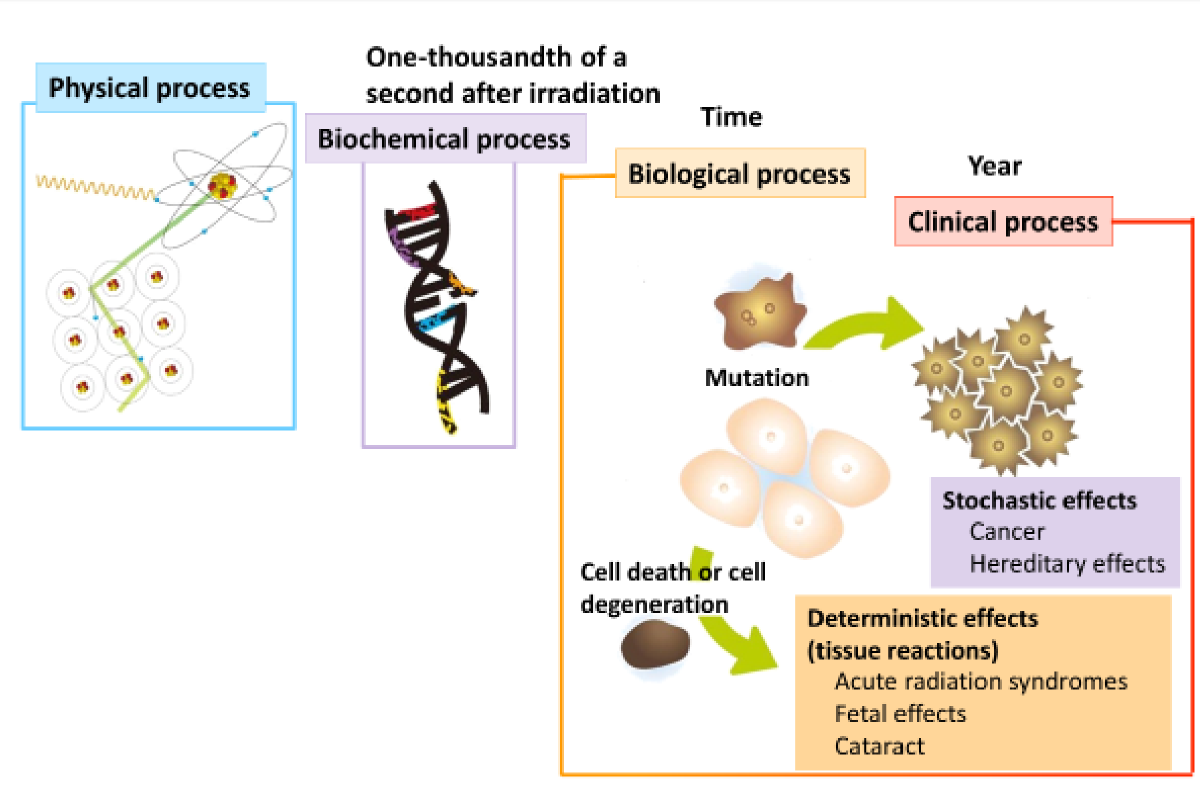
Mechanism of Causing Effects on Human Body

# Lapse of Time after Exposure and Effects




In as short a time as one-thousandth of a second after irradiation, DNA breaks and base damage occur. In a second after irradiation, DNA repair starts, and if repair fails, cell deaths and mutation occur within an hour to one day. It takes some time until such reaction at the cell level develops into clinical symptoms at an individual level. This period is called the incubation period.

Effects due to which symptoms appear within several weeks are called acute (early) effects, while effects that develop symptoms after a relatively long period of time are called late effects. In particular, it takes several years to decades until a person develops cancer. (Related to p.113 of Vol. 1, “Mechanism of Carcinogenesis”)

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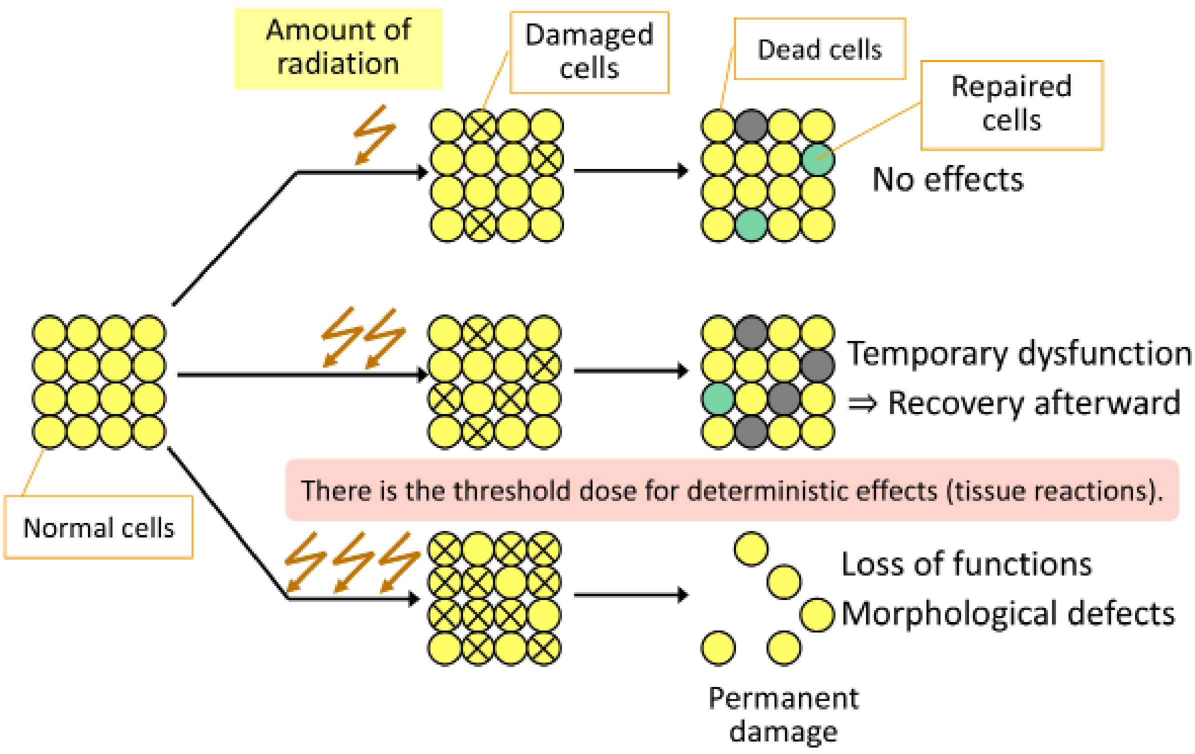
# Cell Deaths and Deterministic Effects (Tissue Reactions)




Even if some cells die due to exposure to a small amount of radiation, if tissues and organs can fully function with the remaining cells, clinical symptoms do not appear.

When the amount of radiation increases and a larger number of cells die, relevant tissues and organs suffer temporary dysfunction and some clinical symptoms may appear. However, such symptoms improve when normal cells proliferate and increase in number.

When cells in tissues or organs are damaged severely due to a large amount of radiation, this may lead to permanent cell damage or morphological defects.

In this manner, for deterministic effects (tissue reactions) due to cell deaths, there is a certain exposure dose above which symptoms appear and under which no symptoms appear. Such dose is called the threshold dose (p.97 of Vol. 1, “Threshold Values for Various Effects”).

(Related to p.86 of Vol. 1, “Deterministic Effects (Tissue Reactions) and Stochastic Effects”)

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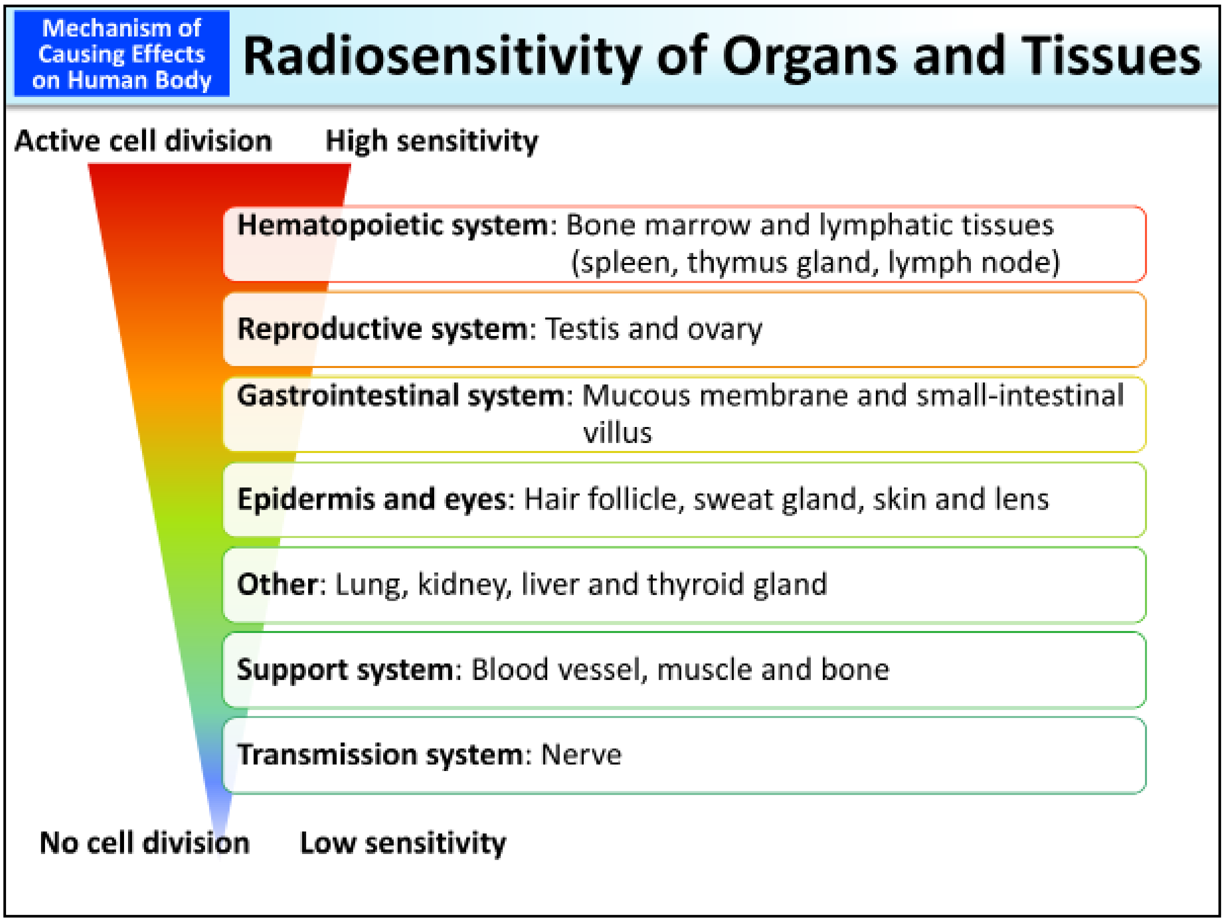


Actively dividing cells that are less differentiated tend to show higher radiosensitivity. For example, hematopoietic stem cells in bone marrow are differentiated into various blood cells, while dividing actively. Immature (undifferentiated) hematopoietic cells that have divided (proliferated) from stem cells are highly sensitive to radiation and die due to a small amount of radiation more easily than differentiated cells.

As a result, the supply of blood cells is suspended and the number of various types of cells in blood decreases. In addition, the epithelium of the digestive tract is constantly metabolized and is also highly sensitive to radiation.

On the other hand, nerve tissues and muscle tissues, which no longer undergo cell division at the adult stage, are known to be resistant to radiation.

(Related to p.94 of Vol. 1, “Whole-body Exposure and Local Exposure,” and p.97 of Vol. 1, “Threshold Values for Various Effects”)

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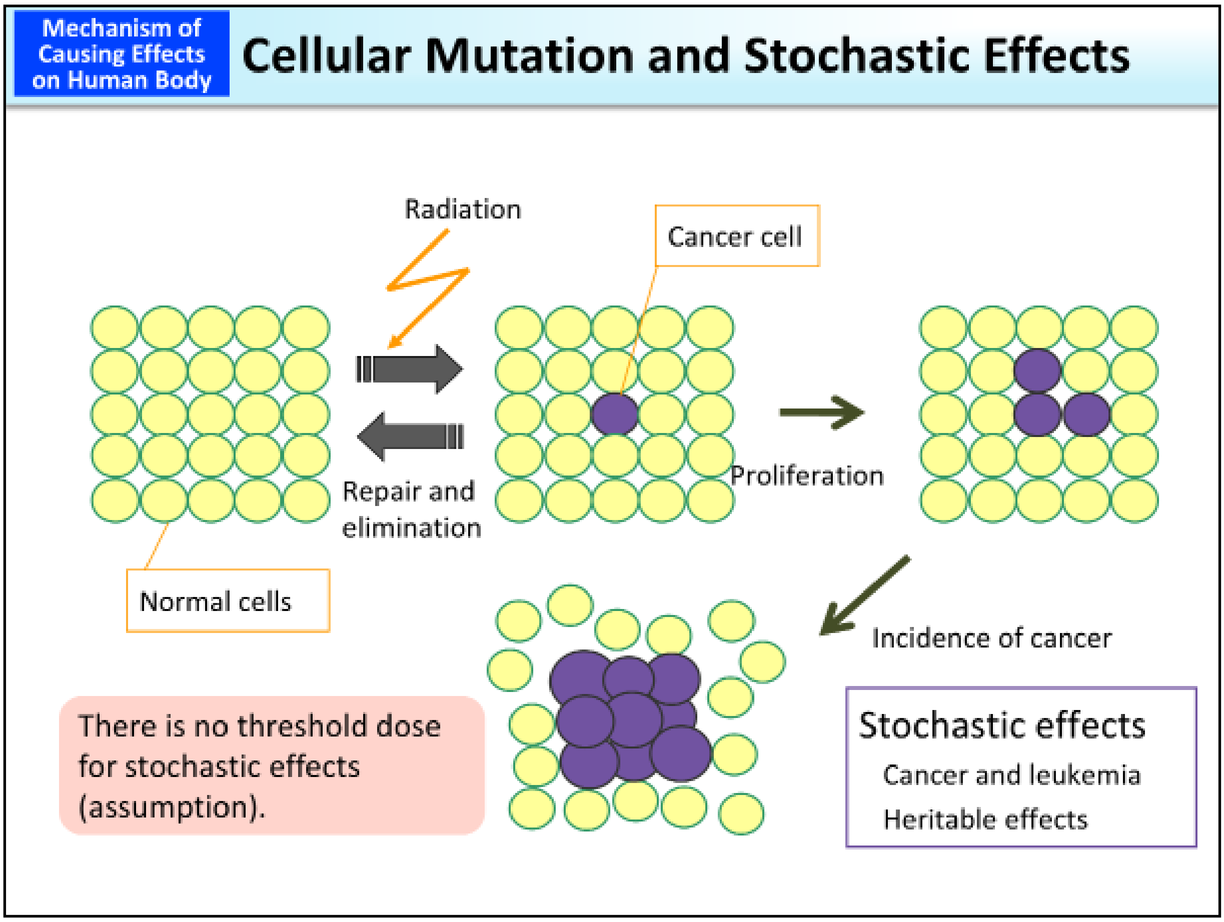


Risks of effects of cellular mutation are considered to increase even if mutation occurs in a single cell.

Mutated cells are mostly repaired or eliminated but some survive and if their descendant cells are additionally mutated or the level of gene expression changes, the possibility of developing cancer cells increases. Proliferation of cancer cells leads to clinically diagnosed cancer (diagnosed by a doctor based on physical symptoms). Cells become cancerous as multiple mutated genes have accumulated without being repaired. Therefore, when assessing cancer-promoting effects, all doses that a person has received so far need to be taken into account.

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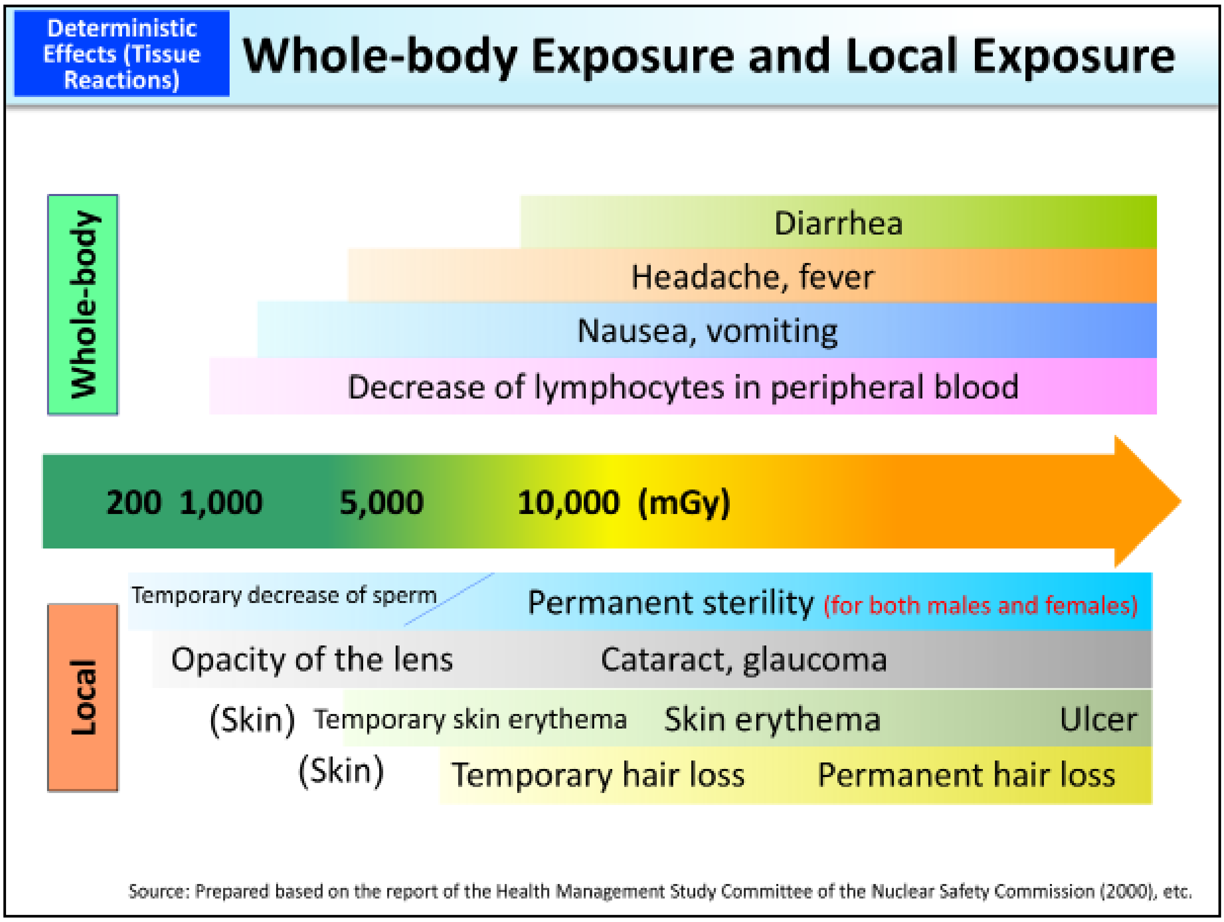


Radiation exposure at levels exceeding 100 mGy at one time may cause effects on the human body due to cell deaths. Organs highly sensitive to radiation are more likely to be affected with a small amount of radiation.

As the testes in which cells are dividing actively are highly sensitive to radiation, even low doses of radiation at the levels of 100 to 150 mGy temporarily decrease the number of sperm and cause transient sterility. Bone marrow is also highly sensitive to radiation and lymphocytes in blood may decrease due to exposure to radiation even less than 1,000 mGy (= 1 Gy). However, these effects are naturally subdued.

On the other hand, clinical symptoms may appear that require clinical care after exposure to radiation of more than 2,000 mGy at one time.

In the case of local exposure, disorders appear in the exposed organs.

(Related to p.88 of Vol. 1, “Damage and Repair of DNA”)

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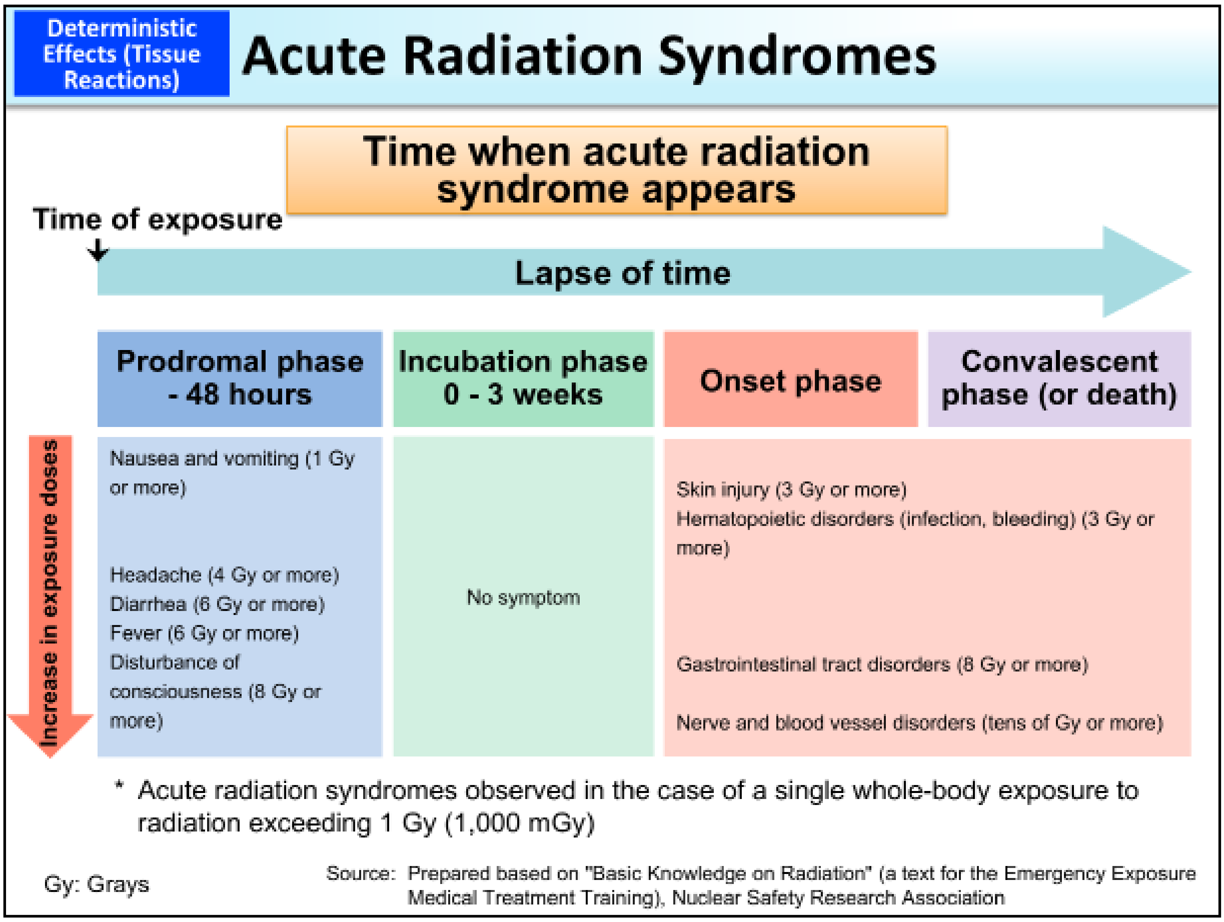


A single whole-body exposure to radiation exceeding 1 Gy (1,000 mGy) causes disorders in various organs and tissues, leading to complicated clinical developments. This series of disorders in organs is called acute radiation syndrome, which typically follows a course from the prodromal phase to the incubation phase, the onset phase, and finally to the convalescent phase or to death in the worst case.

From prodromal symptoms that appear within 48 hours after the exposure, exposure doses can roughly be estimated (p.96 of Vol. 1, “Prodromal Phase of Acute Radiation Syndrome and Exposure Doses”).

In the onset phase after the incubation phase, disorders appear in the order of hematopoietic organ, gastrointestinal tract, skin, and nerves and blood vessels, as doses increase. Disorders mainly appear in organs and tissues highly sensitive to radiation. In general, the larger the exposure dose, the shorter the incubation phase.

Skin covers a large area of 1.3 to 1.8 $m^2$ of the whole body of adults. Epidermis, which is the result of gradual differentiation of basal cells that are created at the basal stratum, finally becomes a stratum corneum and is separated from the body surface as scurf.

It is said to take approx. 20 to 40 days until basal cells move from the basal stratum to the skin surface, which means[1] that two to more than four weeks is required for exposed subcutaneous cells existing in the stratum corneum to the basal stratum to come up to the skin surface. Therefore, skin erythema may appear immediately after exposure depending on radiation intensity, but skin injury generally appears after the lapse of a few weeks or more (p.25 of Vol. 1, “External Exposure and Skin”).

1. Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1988 “Radiation Sources, Effects and Risks,” translated by the National Institute for Radiological Sciences (Jitsugyo-koho Co., Ltd.; March 1990)

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Deterministic Effects (Tissue Reactions)

# Prodromal Phase of Acute Radiation Syndrome and Exposure Doses

## Prodromal phase and exposure dose

| Symptom | Mild (1-2 Gy) | Moderate (2-4 Gy) | Severe (4-6 Gy) | Very severe (6-8 Gy) | Lethal (> 8 Gy) |
|---|---|---|---|---|---|
| Vomiting | 2 hours or later after exposure (Rate of incidence) Up to 50% | 1 to 2 hours 70 to 90% | Within 1 hour 100% | Within 30 minutes 100% | Within 10 minutes 100% |
| Diarrhea | None | None | Moderate | Severe | Severe |
| Headache | Very mild | Mild | Moderate | Severe | Severe |
| Consciousness | Unaffected | Unaffected | Unaffected | Affected | Loss of consciousness |
| Body temperature | Normal | Slight fever | Fever | High fever | High fever |

Gy: Grays

Source: Prepared based on IAEA Safety Reports Series No.2 "Diagnosis and Treatment of Radiation Injuries" (1998)

From prodromal symptoms that appear within 48 hours after the exposure, exposure doses can roughly be estimated in the case of acute exposure. Exposure to radiation of 1 to 2 Gy may cause loss of appetite, nausea and vomiting. In addition, very mild headache appears. Exposure to radiation of 2 to 4 Gy may cause vomiting, mild headache or slight fever (1 to 3 hours, 10 to 80% incidence). Exposure of 4 to 6 Gy causes 100% incidence of vomiting within one hour after exposure and also causes moderate diarrhea and headache as well as 80 to 100% incidence of fever. Exposure of 6 to 8 Gy causes 100% incidence of vomiting within 30 minutes and also causes severe diarrhea/headache as well as 100% incidence of high fever. Furthermore, disturbance of consciousness may appear. Exposure to radiation exceeding 8 Gy causes 100% incidence of vomiting within 10 minutes and causes symptoms such as severe diarrhea/headache, high fever and loss of consciousness.

Included in this reference material on March 31, 2021

Deterministic Effects (Tissue Reactions)

# Threshold Values for Various Effects

## Threshold acute absorbed doses of γ-rays

| Disorders | Organs/Tissues | Incubation period | Threshold value (Gy)* |
|---|---|---|---|
| Temporary sterility | Testis | 3 to 9 weeks | Approx. 0.1 |
| Permanent sterility | Testis | 3 weeks | Approx. 6 |
| | Ovary | Within 1 week | Approx. 3 |
| Deterioration of hemopoietic capacity | Bone marrow | 3 to 7 days | Approx. 0.5 |
| Skin rubor | Skin (large area) | 1 to 4 weeks | 3 to 6 or lower |
| Skin burn | Skin (large area) | 2 to 3 weeks | 5 to 10 |
| Temporary hair loss | Skin | 2 to 3 weeks | Approx. 4 |
| Cataract (failing vision) | Eyes | 20 years or longer | Approx. 0.5 |

* Threshold doses for symptoms with clear clinical abnormalities (doses causing effects on 1% of people)

Source: Prepared based on the 2007 Recommendations of the International Commission on Radiological Protection (ICRP), and ICRP Report 118 (2012)

Sensitivity to radiation differs by organ (p.92 of Vol. 1, "Radiosensitivity of Organs and Tissues").

The most sensitive organs include the testes. When the testes are exposed to γ-rays or other types of radiation exceeding 0.1 Gy (100 mGy) at one time, this may cause temporary sterility with a temporary decrease in the number of sperm, which is due to radiation damage to cells in the testes that create sperm.

Also if bone marrow is irradiated by more than 0.5 Gy (500 mGy) at one time, the hematopoietic function is impaired and a total number of blood cells may decrease.

Some deterministic effects (tissue reactions), such as cataract, take several years to appear.

The threshold dose for cataract had been set at 1.5 Gy, but the ICRP revised this value downward to approx. 0.5 Gy and set a new equivalent dose limit for the eye lens for occupational exposures.

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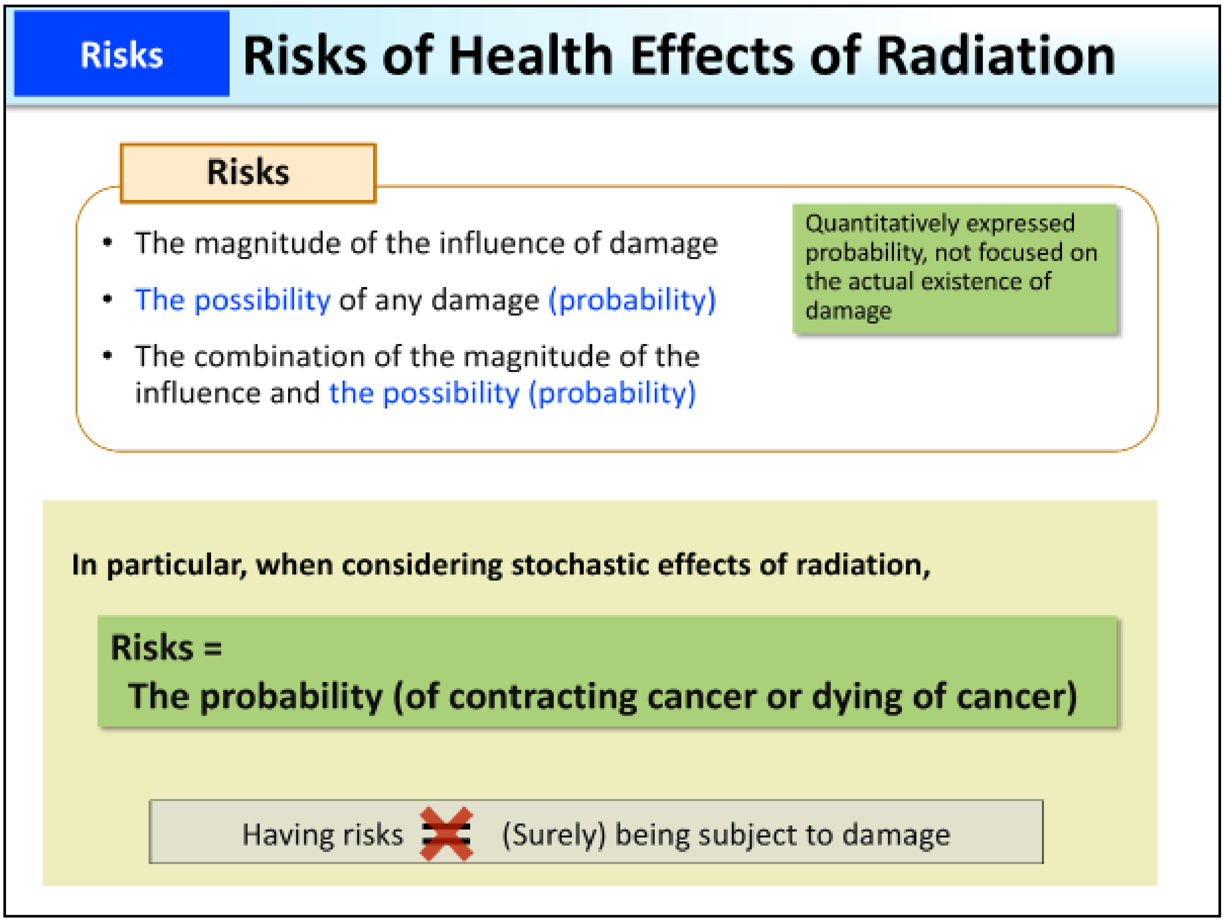


The term "risk" generally means "dangerousness" or "degree of hazard." However, more strictly, the term is used to refer to "the magnitude of the influence of damage," "the possibility of any damage (probability)," or "the combination of the magnitude of the influence and the possibility (probability)." The focus is not on "whether or not there are any risks" but on "to what extent or by how many times risks increase."

On the other hand, what causes damage is called "hazard." It is important to clearly distinguish hazard information on the existence or non-existence of hazards and risk information on the degree and probability of damage, and properly communicate and utilize these two types of information.

When considering health effects of radiation, in particular, stochastic effects of radiation, it is common to use the term "risk" in the sense of "the probability (of contracting cancer or dying of cancer)."

In this case, it should be noted that "having risks" is not equal to "(surely) being subject to damage."

Included in this reference material on February 28, 2018

# Risks: Relative Risks and Attributable Risks

| Factors | Incidence: Yes | Incidence: No | Total |
|---|---|---|---|
| Exposed group | A | B | A+B |
| Non-exposed group | C | D | C+D |

**How many times factor exposure would increase the incidence of an individual:**

$$\text{Relative risk} = \frac{\text{Incidence risk among an exposed group}}{\text{Incidence risk among a non-exposed group}} = \frac{\frac{A}{A+B}}{\frac{C}{C+D}}$$

Relative risk larger than 1 represents that risks have increased due to factor exposure.

The value obtained by subtracting 1 from the relative risk is an excess relative risk, showing an increased amount of risks.

**How many times factor exposure would increase the incidence rate of a group:**

$$\text{Attributable risk} = \text{Incidence risk among an exposed group} - \text{Incidence risk among a non-exposed group}$$

$$= \frac{A}{A+B} - \frac{C}{C+D}$$

A relative risk represents how many times a certain factor increases the risk of an individual exposed thereto. In epidemiology, the term “risk” normally refers to a relative risk. The value obtained by subtracting 1 from the relative risk is an excess relative risk and shows an increased amount of risks compared with a group free from risk factors. There is also an attributable risk that represents how much a certain factor increases the incidence or mortality rate of a group.

Suppose a group is exposed to some risk factor while another group is not, and there are 2 patients of a certain disease among one million people in the non-exposed group, while there are 3 patients among one million people in the exposed group.

Then, an increase in the number of patients from 2 to 3 is construed to mean that the relative risk has increased by 1.5 times from the perspective of how much more an individual is likely to develop a disease.

On the other hand, as an attributable risk focuses on increases in the number of patients in a group, the increase is construed as one in a million, that is, an increase of $10^{-6}$ in risk.

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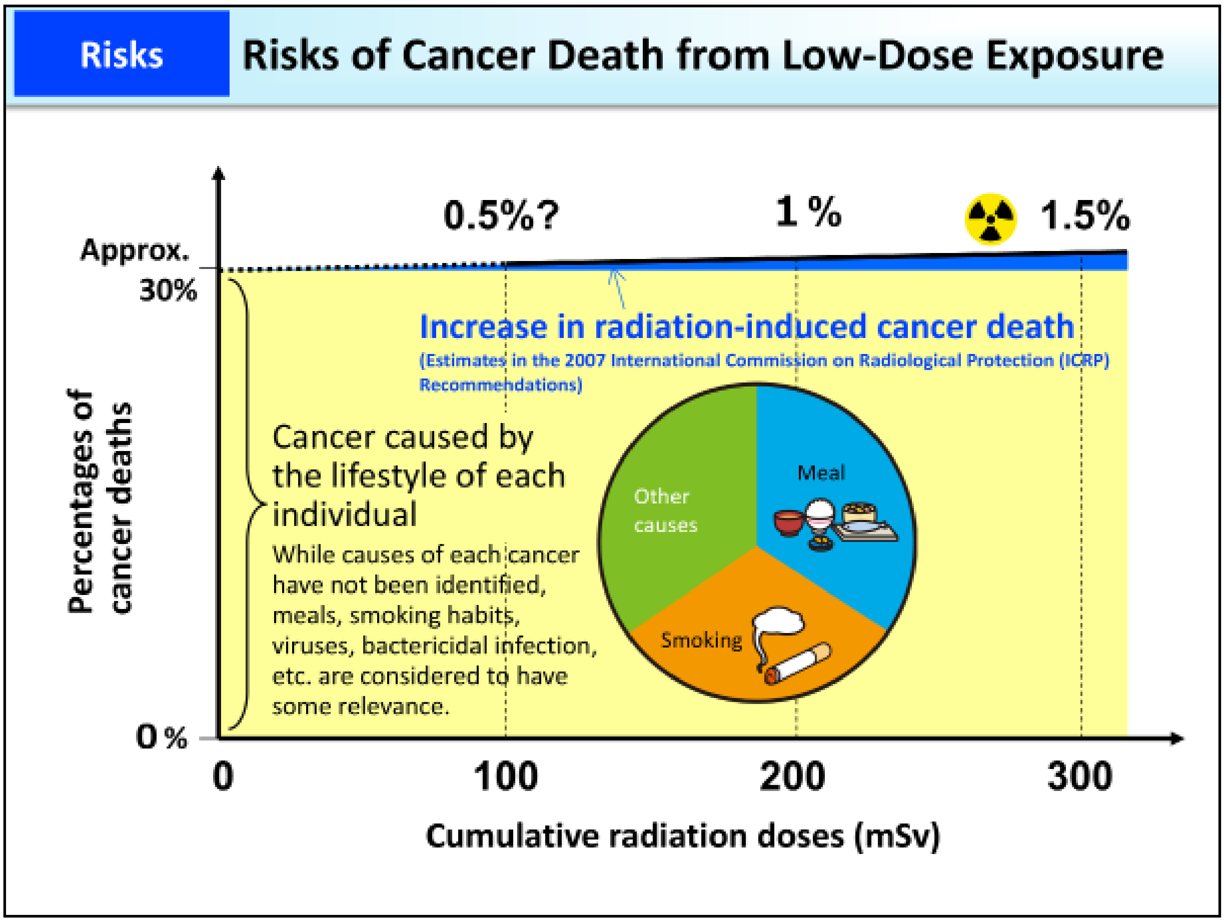
## Risks of Cancer Death from Low-Dose Exposure




The International Commission on Radiological Protection (ICRP) considers radiological protection based on the idea that in a group of people including both adults and children, the probability of cancer death increases by 0.5% per 100-mSv exposure. This value shows estimated risk of low-dose exposure based on data obtained from atomic bomb survivors (p.117 of Vol. 1, “Relationship between Solid Cancer Deaths and Doses”).

Currently, the leading cause of deaths among Japanese people is cancer, with around 30% of the entire population dying of cancer.

That is, 300 people in a group of 1,000 will die of cancer. If the probability of death from radiation-induced cancer is added, it can be estimated that if all people in such group of 1,000 people are exposed to 100 mSv, 305 will die of cancer in their lifetime.

However, in actuality, the value of 300 out of 1,000 people could vary from year to year and from region to region,[1] and no methods have been established yet to confirm if cancer is really attributable to radiation exposure. It is thus considered very difficult to actually detect an increase in cancer deaths among people exposed to not higher than 100 mSv, i.e., an increase of up to 5 people in a group of 1,000.

1. Comparison of age-adjusted mortality rates among prefectures in Japan in FY2010 shows that the mortality against 100,000 people varies from 248.8 people (Nagano) to 304.3 people (Aomori) for females and from 477.3 people (Nagano) to 662.4 people (Aomori) for males. The mortality rate from cancer also varies from 29.0% (Okinawa) to 35.8% (Nara) for males and from 29.9% (Yamanashi) to 36.1% (Kyoto) for females.

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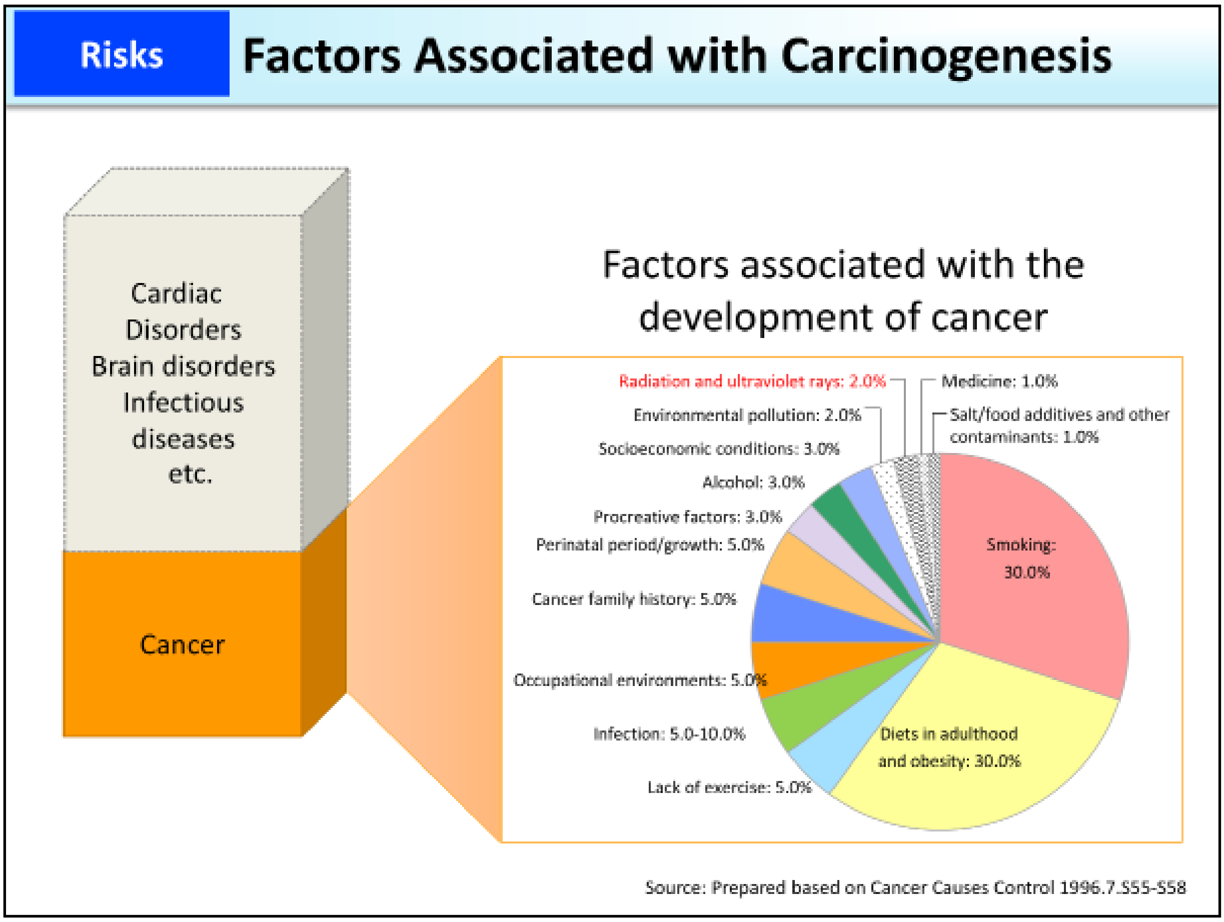


We are surrounded by various risk factors for cancer in our lives. The pie chart above provides U.S. data, which gives an idea that meals and smoking habits are closely associated with the development of cancer. If having been exposed to radiation, risks due to radiation are to be added to these factors. Accordingly, it is best to avoid radiation exposure from the viewpoint of reducing risks of cancer.

It may be possible to refuse X-ray examinations or avoid taking flights, but that would make early detection of diseases impossible and make life inconvenient, and such efforts would not dramatically reduce the risks of developing cancer due to the existence of various cancer-causing factors other than radiation in our lives.

(Related to p.102 of Vol. 1, “Risks of Cancer (Radiation),” and p.103 of Vol. 1, “Risks of Cancer (Life Habits)”)

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Updated on March 31, 2019

Risks

## Risks of Cancer (Radiation)

| Radiation doses (mSv) | Relative risks of cancer* |
|---|---|
| 1,000 ~ 2,000 | 1.8 [estimated to be 1.5 times per 1,000 mSv] |
| 500 ~ 1,000 | 1.4 |
| 200 ~ 500 | 1.19 |
| 100 ~ 200 | 1.08 |
| Less than 100 | Difficult to detect |

Source: Prepared based on the information available on the website of the National Cancer Center Japan

* Risks of developing radiation-induced cancer are based on the data (solid cancers only) obtained from the analysis of instantaneous exposure due to the atomic bombing in Hiroshima and Nagasaki, and are not based on the observation of long-term exposure effects.
* Relative risks indicate how many times larger the cancer risks are among people subject to certain causes (radiation exposure here).

The table above shows the effects of radiation exposure doses on the relative risks of cancer released by the National Cancer Center Japan.

It is estimated that the relative risk increases by 1.8 times due to radiation exposure doses of 1,000 to 2,000 mSv, by 1.4 times due to doses of 500 to 1,000 mSv and by 1.19 times due to doses of 200 to 500 mSv.

In the case of radiation exposure below 100 mSv, it is considered to be extremely difficult to detect the risk of developing cancer.

(Related to p.103 of Vol. 1, “Risks of Cancer (Life Habits)”)

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Updated on March 31, 2019

# Risks — Risks of Cancer (Life Habits)

| Lifestyle factors | Relative risks of cancer *1 |
|---|---|
| Smokers | 1.6 |
| Heavy drinking (450 g or more/week)*2 | 1.6 |
| Heavy drinking (300 to 449 g or more/week)*2 | 1.4 |
| Obese (BMI≧30) | 1.22 |
| Underweight (BMI<19) | 1.29 |
| Lack of exercise | 1.15 ～ 1.19 |
| High-salt foods | 1.11 ～ 1.15 |
| Lack of vegetable intake | 1.06 |
| Passive smoking (nonsmoking females) | 1.02 ～ 1.03 |

Source: Prepared based on the information available on the Website of the National Cancer Center Japan

*1 Relative risks indicate how many times larger the cancer risks are among people subject to certain causes (life habits here).
*2 Alcohol consumption is in ethanol equivalent.

The table above shows relative risks of cancer due to respective life habits as released by the National Cancer Center Japan.

It is estimated that the relative risk of cancer for people who smoke or drink a lot is 1.6 times higher than that for people who do not. It is also estimated that factors, such as obesity, lack of exercise, and lack of vegetable intake, will make the relative risks of cancer higher by 1.22 times, 1.15 to 1.19 times and 1.06 times, respectively.

(Related to p.101 of Vol. 1, “Factors Associated with Carcinogenesis,” and p.102 of Vol. 1, “Risks of Cancer (Radiation)”)

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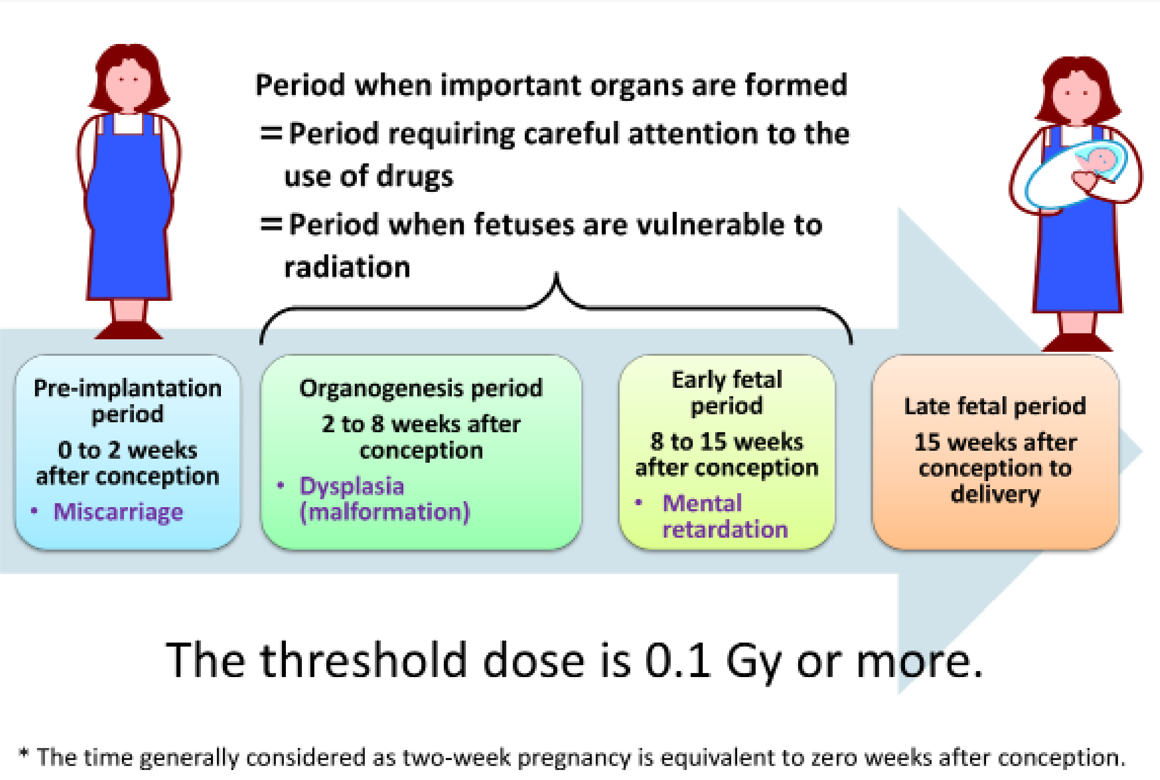
Updated on March 31, 2019

## Effects on Fetuses — Deterministic Effects (Tissue Reactions) and Time Specificity




Deterministic effects (tissue reactions) include fetal effects for which the threshold dose is especially low. When a pregnant woman is exposed to radiation and radiation passes through her womb or radioactive materials migrate into her womb, her unborn baby may also be exposed to radiation.

It is known that fetuses are highly sensitive to radiation and incidence of effects has time specificity. Radiation exposure exceeding 0.1 Gy at an early stage of pregnancy (pre-implantation period) may lead to miscarriage.

After this period, the possibility of miscarriage decreases, but radiation exposure exceeding 0.1 Gy during the period when important organs are formed (organogenesis period) may cause dysplasia (malformation). Radiation exposure exceeding 0.3 Gy during the period when the cerebrum is actively growing (early fetal period) poses risks of mental retardation (p.105 of Vol. 1, “Mental Retardation”).

The period when fetuses are highly sensitive to radiation coincides with the period during which pregnant women are advised not to take drugs carelessly. During this period before the stable period, fetuses are vulnerable to both drugs and radiation. Fetal effects are caused by radiation exposure exceeding 0.1 Gy. Therefore, the International Commission on Radiological Protection (ICRP) states in its 2007 Recommendations that a fetal absorbed dose less than 0.1 Gy should not be considered as a ground for abortion. Exposure to 0.1 Gy of radiation is equivalent to exposure to 100 mSv of γ-rays or X-rays at one time. Incidentally, fetuses’ exposure doses are not always the same as their mothers’ exposure doses. Risks of stochastic effects such as cancer or heritable effects also increase depending on exposure dose levels.

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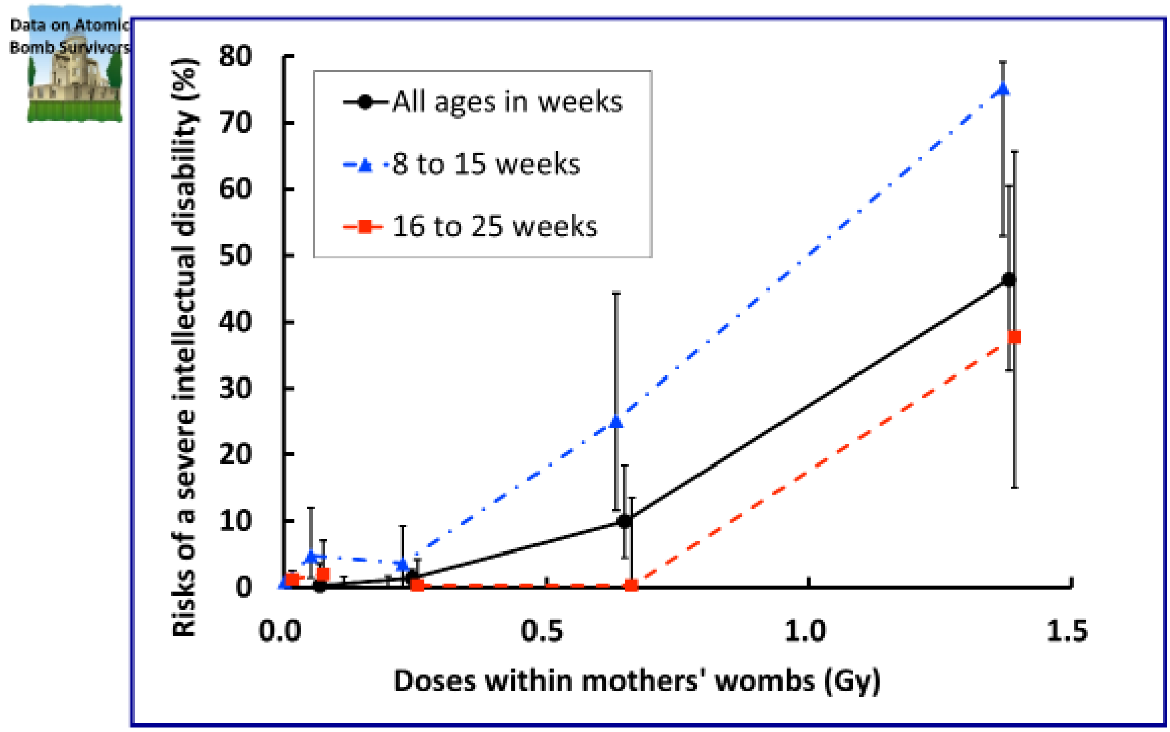
# Mental Retardation




Source: Prepared based on "Physical and Mental Development of Children Exposed to Radiation in Their Mothers' Wombs" on the website of the Radiation Effects Research Foundation (https://www.rerf.or.jp/programs/roadmap/health_effects/uteroexp/physment/)

Time specificity in fetal effects was made clear through health surveys on a group of people who were exposed to radiation in their mothers' wombs due to the atomic bombing.

This figure shows the relationship between ages in weeks at the time of the atomic bombing and its effects on fetuses' mental development.

Those aged 8 to 15 weeks show high radiosensitivity and the threshold value for exposure doses in mothers' wombs seems to be between 0.1 Gy and 0.2 Gy. In the range above this level, the incidence rate of a severe intellectual disability increases as doses increase, as observed in the figure.

On the other hand, a severe intellectual disability is not observed among those who were aged 16 to 25 weeks and were exposed to radiation at doses around 0.5 Gy, but radiation exposure exceeding 1 Gy caused mental disorders at a significant frequency.

In other words, the incidence rates of disorders differ depending on whether radiation exposure occurred at the age of 8 to 15 weeks or at the age of 16 to 25 weeks, even if the total exposure doses were the same.

(Related to p.104 of Vol. 1, "Deterministic Effects (Tissue Reactions) and Time Specificity")

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Effects on Fetuses

## Effects on Children - Chornobyl NPS Accident -

**Survey on children born from mothers who were pregnant at the time of the Chornobyl NPS Accident**

**Survey targets**

**(i) 138 children who were exposed to radiation in the womb and their parents**(a group of children exposed to radiation in the womb: exposed group)

**(ii) 122 children in non-contaminated regions in Belarus and their parents**(control group: non-exposed group)

| Children's mental development | When aged 6 to 7 | | When aged 10 to 11 | |
|---|---|---|---|---|
| | (i) Exposed group | (ii) Control group | (i) Exposed group | (ii) Control group |
| Difficulty in speech | 18.1% | 8.2% | 10.1% | 3.3% |
| Disorder of emotion | 20.3% | 7.4% | 18.1% | 7.4% |
| IQ=70～79 | 15.9% | 5.7% | 10.1% | 3.3% |

○ A significant difference in mental development was observed between the exposed group and the control group, but there was no correlation between exposed doses and intelligence quotients. Therefore, the difference was considered to be attributable to social factors associated with forced evacuation.

○ There was correlation between parents' extreme anxiety and their children's emotional disorders.

**It is considered that radiation exposure during pregnancy does not directly affect intelligence quotients of fetuses and children after growth.**

Source: Prepared based on Kolominsky Y et al., J Child Psychol Psychiatry, 40 (2): 299-305, 1999

Researchers in Belarus conducted surveys targeting 138 children born from mothers who were pregnant and were residing near the nuclear power plant at the time of the Chornobyl NPS Accident and 122 children born from mothers who were pregnant at the time of the accident but were exposed to little radiation. The surveys were conducted twice when survey targets were aged 6 to 7 and when they were aged 10 to 11 in order to study effects of radiation exposure in the womb on their mental development.

In both surveys, incidences of difficulty in speech and disorder of emotion were larger among the exposed group than among non-exposed group with statistically significant differences.

Regarding intelligence quotient, fewer children in the exposed group were above the average compared with the non-exposed group and children on the borderline between normal levels and mental retardation were clearly larger in number.

However, no correlation has been found between estimated absorbed doses to the thyroid in fetal life and intelligence quotient and possibilities of other factors are suggested such as social-psychological and sociocultural factors (school education and guardians' academic levels, etc.) associated with forced evacuation from contaminated regions. The possibility that radiation exposure during pregnancy has directly affected the intelligence quotients of fetuses and children after growth is considered to be low.

A survey targeting parents using a stress evaluation index revealed clear correlation between parents' anxiety and children's emotional disorders.

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**Effects on Fetuses**

## Knowledge on Malformation Induction
### - Chornobyl NPS Accident -

**Has the Chornobyl NPS Accident increased malformation?**

Comparison of European congenital malformation/twin registry database between before and after the Chornobyl NPS Accident

**European Surveillance of Congenital Anomalies (EUROCAT): 18 regions in 9 countries:**

No change in incidence of malformations before and after the accident

**Finland, Norway, Sweden:**

No change in incidence of malformations before and after the accident

**Belarus:**

Increase in registration of malformations of aborted fetuses regardless of whether from the contaminated areas or not

Possibility of reporter bias*1

**Ukraine:** participated in EUROCAT in this century

Increase in neural tube defects in an isolated Polish community in the Rivne province

It is necessary to evaluate the influences of folate depravation, alcoholism, consanguineous marriage, etc., in addition to radiation.*2

Source: *1: Stem Cells 15 (supple 1): 255, 1997, *2: Pediatrics 125:e836, 2010

There have been various reports on the incidence of congenital anomalies before and after the Chornobyl NPS Accident. Comparison of databases of the European Surveillance of Congenital Anomalies (EUROCAT), and of Finland, Norway, and Sweden showed no change in incidence of malformations before and after the accident.

In the northern part of the Rivne province of Ukraine, there are people who live a self-sufficient life in a contaminated area. There is a report that neural tube defects have been increasing among them, and analysis is underway to determine whether it has been caused by radiation.

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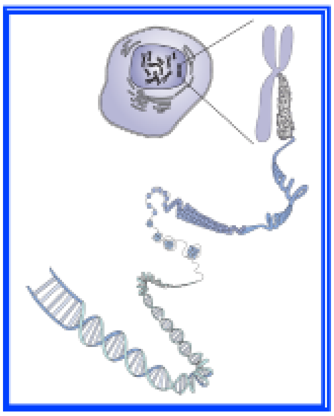
Heritable Effects

## Risks of Heritable Effects for Human Beings



- **Radiation effects on gonads (reproductive cells)**
  - ◎ Gene mutations
    Changes in genetic information in DNA (point mutation)
  - ◎ Chromosome aberrations
    Structural chromosomal aberrations
    * Increases in hereditary diseases in the offspring have not been proved among human beings.

- **Risks of heritable effects (up to children and grandchildren)**
  = Approx. 0.2%/Gy (Two out of 1,000 people per gray)
  (2007 Recommendations of the International Commission on Radiological Protection (ICRP))

  This value is indirectly estimated using the following data:
  - Spontaneous incidences of hereditary diseases among a group of human beings
  - Average spontaneous gene mutation rate (human beings) and average radiation-induced mutation rate (laboratory mice)
  - Correction factor for extrapolating potential risks of induced hereditary diseases among human beings based on radiation-induced mutation rate among laboratory mice

- **Tissue weighting factor for gonads** (ICRP Recommendations)
  0.25 (1977) → 0.20 (1990) → 0.08 (2007)

In animal testing, when parents are exposed to high-dose radiation, congenital disorders and chromosomal aberrations are sometimes found in their offspring. However, there has been no evidence to prove that parents' radiation exposure increases hereditary diseases in their offspring in the case of human beings. The ICRP estimates risks of heritable effects as 0.2% per gray. This is even less than one-twentieth of the risk of death by cancer. Furthermore, the ICRP assumes that the exposure dose that doubles the spontaneous gene mutation rate (doubling dose) is the same at 1 Gy for human beings and laboratory mice. However, heritable effects have not been confirmed for human beings and there is the possibility that this ICRP estimate is overrated.

Targeting children of atomic bomb survivors, life-span surveys, health effects checks, and surveys on various molecular levels have been conducted. Results of these surveys have made it clear that risks of heritable effects had been overestimated. Accordingly, the tissue weighting factor for gonads was reduced in the ICRP Recommendations released in 1990 and further in the ICRP Recommendations released in 2007.

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Heritable Effects

## Chromosomal Aberrations among Children of Atomic Bomb Survivors

Data on Atomic Bomb Survivors

### Stable chromosome aberrations among children of atomic bomb survivors

| Sources of aberrations | Number of children with chromosome aberrations (percentage) | |
|---|---|---|
| | Control group (7,976 children) | Exposed group (8,322 children) Average exposure dose: 0.6 Gy |
| Derived from either of the parents | 15 (0.19%) | 10 (0.12%) |
| Newly developed cases | 1 (0.01%) | 1 (0.01%) |
| Unknown (Examination of parents was not possible.) | 9 (0.11%) | 7 (0.08%) |
| **Total** | 25 (0.31%) | 18 (0.22%) |

Source: Prepared based on "Chromosomal Aberrations among Children of Atomic Bomb Survivors (1967 - 1985 surveys)" on the website of the Radiation Effects Research Foundation (https://www.rerf.or.jp/programs/roadmap/health_effects/geneefx/chromeab/)

Surveys of health effects on children of atomic bomb survivors examine incidence rates of serious congenital disorders, gene mutations, chromosome aberrations and cancer, as well as mortality rates from cancer or other diseases. However, no significant differences were found between the survey targets and the control group regarding any of these.

Stable chromosome aberrations do not disappear through cell divisions and are passed on from parents to their offspring. As a result of a survey targeting 8,322 children (exposed group), either or both of whose parents were exposed to radiation within 2,000 m from the center of the explosion (estimated exposure doses: 0.01 Gy or more), stable chromosome aberrations were found in 18 children. On the other hand, among 7,976 children (control group), both of whose parents were exposed to radiation at locations 2,500 m or farther from the center of the explosion (estimated exposure doses: less than 0.005 Gy) or were outside the city at the time of the atomic bombing, stable chromosome aberrations were found in 25 children.

However, a later examination of their parents and siblings revealed that most of the detected chromosome aberrations were not those newly developed but those that had already existed in either of their parents and were passed on to them. Given these, it was made clear that radiation effects, such that stable chromosome aberrations newly developed in parents' reproductive cells due to radiation exposure were passed on to the offspring, have not been found among atomic bomb survivors.
(Related to p.89 of Vol. 1, "DNA→Cells→Human Body")

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Heritable Effects

## Survey of Children of Childhood Cancer Survivors

- An epidemiological survey to compare children of childhood cancer survivors in the United States and Canada (average gonadal dose is 1.26 Gy for females and 0.46 Gy for males) and children of those survivors' siblings does not show any increases in chromosome aberrations and Mendelian disorders expected from the average gonadal doses.*

Source: Green DM et al: J Clin Oncol Vol.27, 2009: 2374-2381

* Based on a study on hereditary influences using mice, the ICRP estimated the doubling dose** for genetic diseases due to radiation as 1 Gy.

** The doubling dose here means the gonadal dose that increases the incidence rate of genetic diseases twofold.



According to the results of the survey of children of childhood cancer survivors in the United States and Canada, as in the case of the surveys targeting children of atomic bomb survivors, excess incidence of chromosome aberrations, Mendelian disorders and malformation was not observed. Based on the study on heritable effects among laboratory mice, the International Commission on Radiological Protection (ICRP) estimates the doubling dose for hereditary disorders to be 1 Gy. However, these survey results do not show any increases in chromosome aberrations and Mendelian disorders expected from the average gonadal doses.

Source

• D.M. Green et al.: J. Clin. Oncol. 27: 2374-2381, 2009.

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**Heritable Effects**

## Abnormalities at Birth among Children of Atomic Bomb Survivors (Malformations, Stillbirths, Deaths within Two Weeks)

| | | Father's dose (Gy) | | | |
|---|---|---|---|---|---|
| | | <0.01 | 0.01-0.49 | 0.5-0.99 | >=1 |
| Mother's dose (Gy) | <0.01 | 2,257/45,234 (5.0%) | 81/1,614 (5.0%) | 12/238 (5.0%) | 17/268 (6.3%) |
| | 0.01-0.49 | 260/5,445 (4.8%) | 54/1,171 (4.6%) | 4/68 (5.9%) | 2/65 (3.1%) |
| | 0.5-0.99 | 44/651 (6.8%) | 1/43 (2.3%) | 4/47 (8.5%) | 1/17 (5.9%) |
| | >=1 | 19/388 (4.9%) | 2/30 (6.7%) | 1/9 (11.1%) | 1/15 (6.7%) |

Source: M. Ohtake et al.: Radiat. Res. 122: 1-11, 1990.

Surveys targeting newborns of atomic bomb survivors were conducted between 1948 and 1954 in order to examine the possibility that genetic mutations in the genome of germ-line cells induced by radiation exposure due to the atomic bombing may impair growth of fertilized embryos, fetuses or newborn babies. However, radiation effects were not observed.[1]

Furthermore, in the United States and Canada[2,3] and in Denmark,[4,5] abnormalities at birth among children of childhood cancer survivors were epidemiologically surveyed (p.110 of Vol. 1, "Survey of Children of Childhood Cancer Survivors"). These surveys also do not show any risks of congenital anomalies or stillbirths caused by fathers' radiation exposure. On the other hand, it was found that mothers' exposure to radiation exceeding 10 Gy in the ovary or womb increased premature births and stillbirths caused by deterioration of uterine function.[3]


1. M. Ohtake et al.: Radiat. Res. 122: 1-11, 1990.
2. L.B. Signorello et al.: J. Clin. Oncol. 30: 239-45, 2012.
3. L.B. Signorello et al.: Lancet 376(9741): 624-30, 2010.
4. J.F. Winther et al.: J. Clin. Oncol. 30: 27-33, 2012.
5. J.F. Winther et al.: Clin. Genet. 75: 50-6, 2009.



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Heritable Effects

## Other Epidemiological Surveys of Children of Atomic Bomb Survivors

- **Deaths from malignant tumors, etc. developed by the age of 20**

  The follow-up survey of 41,066 subjects revealed no correlation between parents' gonadal doses (0.435 Sv on average) and their children's deaths.

  (Source: prepared based on Y. Yoshimoto et al.: *Am J Hum Genet* 46: 1041-1052, 1990.)

- **Incidence rate of cancer (1958 - 1997)**

  As a result of the follow-up survey of 40,487 subjects, development of solid tumors and blood tumors was found in 575 cases and 68 cases, respectively, but no correlation with parents' doses was observed (the survey is still underway).

  (Source : prepared based on S. Izumi et al.: *Br J Cancer* 89: 1709-13, 2003.)

- **Deaths from cancer**

  As a result of the follow-up survey of 75,327 subjects conducted from 1946 to 2009, there were 1,246 deaths from cancer, but no correlation with parents' doses was observed.

  (Source : prepared based on E. Grant et al.: *Lancet Oncol* 16: 1316-23, 2015.)

- **Prevalence rates of lifestyle-related diseases (2002 - 2006)**

  The clinical cross-sectional survey of approx. 12,000 subjects revealed no correlation between parents' doses and their children's prevalence rates of lifestyle-related diseases (the survey is still underway).

  (Source : prepared based on S. Fujiwara et al.: *Radiat Res* 170: 451-7, 2008.)

The Radiation Effects Research Foundation has been conducting follow-up surveys to ascertain whether parents' radiation exposure increases their children's incidence or prevalence rates of lifestyle-related diseases, which are multifactorial disorders. The Foundation has so far conducted a survey of development of malignant tumors by the age of 20,[1] a survey of cancer,[2,3] and a survey of lifestyle-related diseases,[4] but none of them revealed specific radiation effects.

1. Y. Yoshimoto et al.: Am J Hum Genet 46: 1041-1052, 1990.
2. S. Izumi et al.: Br J Cancer 89: 1709-13, 2003.
3. E. Grant et al.: Lancet Oncol 16: 1316-23, 2015.
4. S Fujiwara et al.: Radiat Res 170: 451-7, 2008.

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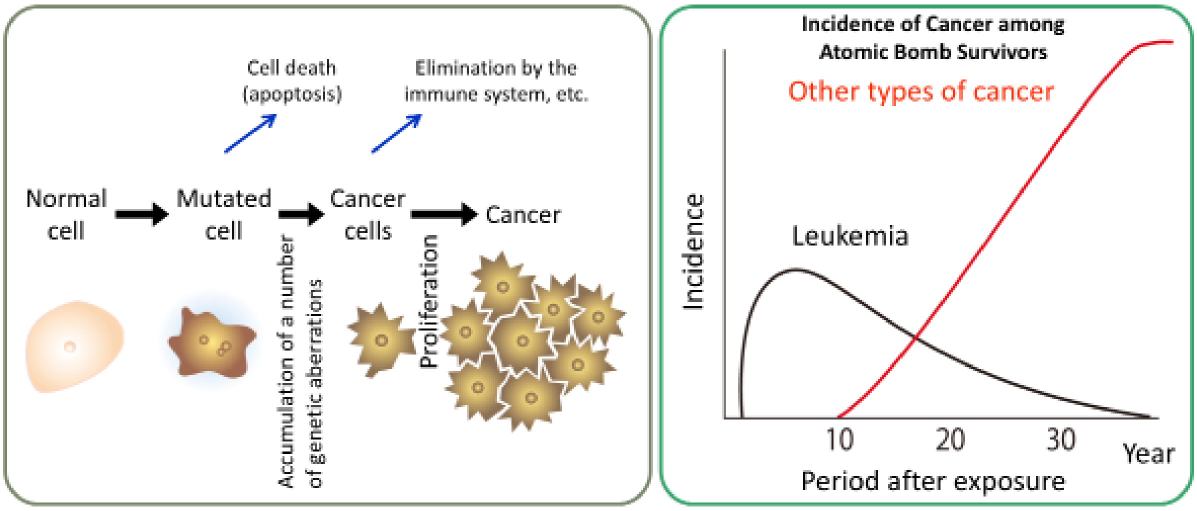
Cancer and Leukemia

# Mechanism of Carcinogenesis




- Radiation is only one of various factors that induce cancer.
- Mutated cells follow multiple processes until developing into cancer cells.
  → It takes several years to decades.

Not only radiation but also various chemical substances and ultraviolet rays, etc. damage DNA. However, cells have a mechanism to repair damaged DNA and DNA damage is mostly repaired. Even if repair was not successful, the human body has a function to eliminate cells wherein DNA damage has not been completely repaired (p.88 of Vol. 1, “Damage and Repair of DNA”).

Nevertheless, cells with incompletely repaired DNA survive as mutated cells in very rare cases. Genetic aberrations may be accumulated in cells that happen to survive and these cells may develop into cancer cells. However, this process requires a long period of time. Among atomic bomb survivors, leukemia increased in around two years, but the incidence decreased thereafter. On the other hand, cases of solid cancer started to increase after an incubation period of around 10 years.

(Related to p.90 of Vol. 1, “Lapse of Time after Exposure and Effects”)

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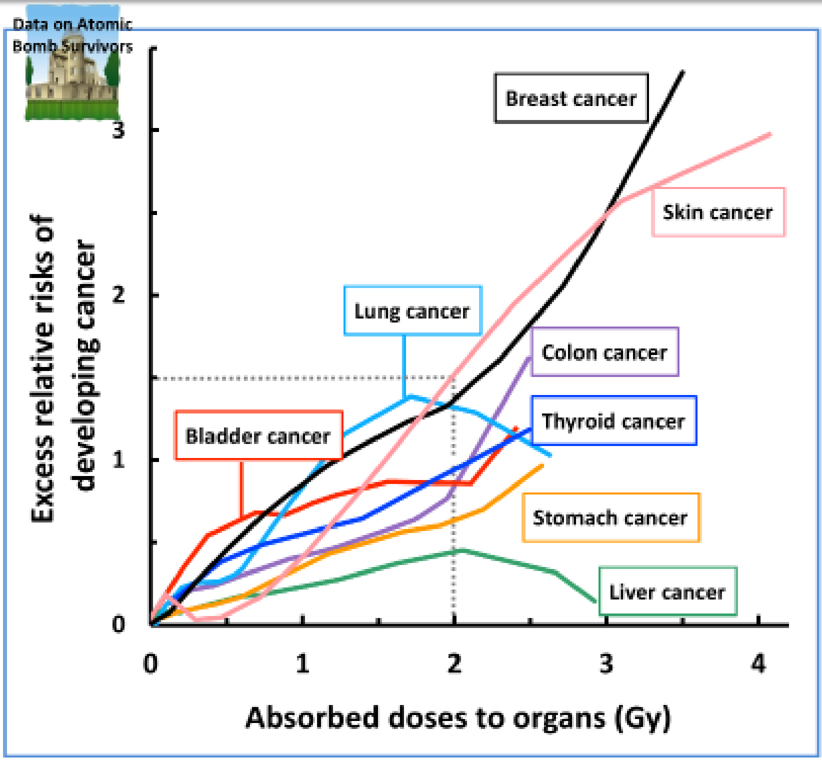
Cancer and Leukemia

## Tissues and Organs Highly Sensitive to Radiation




| Tissue | Tissue weighting factor $w_T$* |
|---|---|
| Red bone marrow, stomach, lungs, colon, breasts | 0.12 |
| Gonad | 0.08 |
| Bladder, esophagus, liver, thyroid | 0.04 |
| Bone surface, brain, salivary gland, skin | 0.01 |
| Total of the remaining tissues | 0.12 |

Source: 2007 Recommendations of the International Commission on Radiological Protection (ICRP)

* The tissue weighting factor is larger for organs and tissues for which risks of radiation effects are higher.

Source: Prepared based on Preston et al., Radiat Res., 168, 1, 2007

This figure shows how cancer risks have increased for each organ depending on exposure doses, targeting atomic bomb survivors. The horizontal axis indicates the absorbed doses to organs through a single high-dose exposure at the time of the atomic bombing, while the vertical axis indicates excess relative risks, which show how cancer risks have increased among the exposed group compared with the non-exposed group.

For example, when the absorbed dose to organs is 2 Gy, the excess relative risk for skin cancer is 1.5, meaning that the risk increased in excess of 1.5 times compared with the non-exposed group (in other words, among the group of people exposed to 2 Gy of radiation, the relative risk of developing skin cancer is 2.5 times higher (1 + 1.5) than among the non-exposed group).

As a result of these epidemiological studies, it was found that the mammary gland, skin, and colon, etc. are tissues and organs that are easily affected by radiation and develop cancer. The 2007 Recommendations of the ICRP specify tissue weighting factors while taking into account the radiosensitivity of each organ and tissue and the lethality of each type of cancer.
(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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Cancer and Leukemia

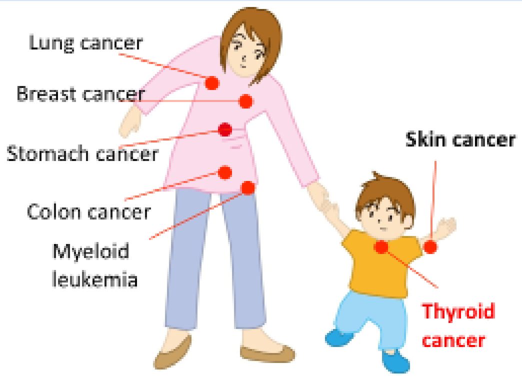
# Difference in Radiosensitivity by Age

## Children are not small adults.

| | Committed effective dose coefficients for I-131[*1] (μSv/Bq) | Committed effective doses when having taken in 100 Bq of I-131 (μSv) | Equivalent doses to the thyroid when having taken in 100 Bq of I-131[*2] (μSv) |
|---|---|---|---|
| **3 month-old infants** | **0.18** | **18** | **450** |
| **1 year-old children** | **0.18** | **18** | **450** |
| **5 year-old children** | **0.10** | **10** | **250** |
| **Adults** | **0.022** | **2.2** | **55** |

*1: Committed effective dose coefficients are larger for children due to difference in metabolism and physical constitution.
*2: Calculated using the tissue weighting factor of 0.04 for the thyroid

Source: Prepared based on International Commission on Radiological Protection (ICRP), ICRP Publication 119, Compendium of Dose Coefficients based on ICRP Publication 60, 2012




**Risks of thyroid cancer and skin cancer are higher for children than for adults.**

μSv/Bq: microsieverts/becquerel

In the case of adults, bone marrow, colon, mammary gland, lungs and stomach easily develop cancer due to radiation exposure, while it has become clear that risks of developing thyroid cancer and skin cancer are also high in the case of children.

In particular, children's thyroids are more sensitive to radiation and committed effective doses per unit intake (Bq) are much larger than adults (p.127 of Vol. 1, "Thyroid"). Therefore, the exposure dose to the thyroids of 1-year-old children is taken into account as the standard when considering radiological protection measures in an emergency. Additionally, much larger values are adopted as children's committed effective dose coefficients per unit intake (Bq) than those for adults.

(Related to p.120 of Vol. 1, "Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks")

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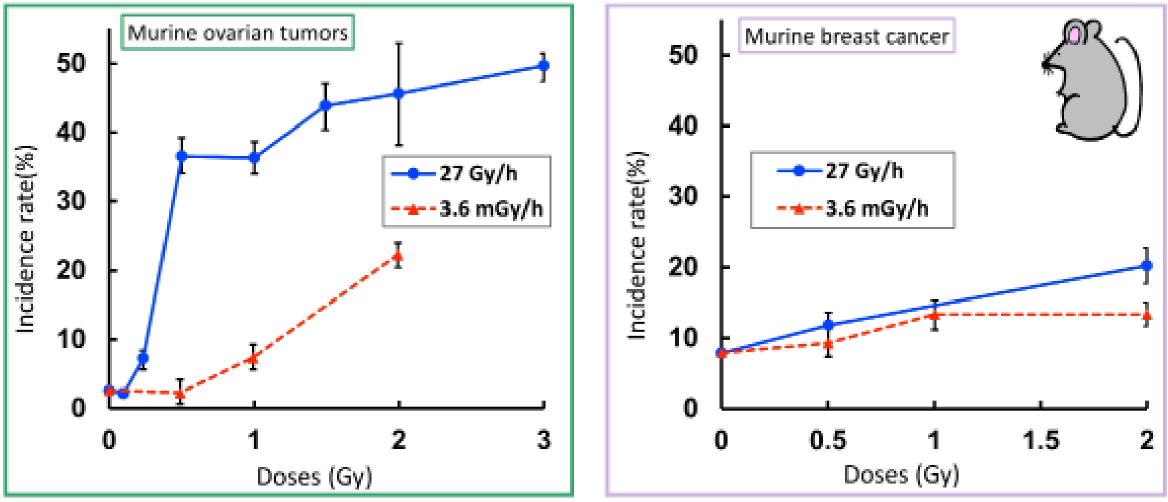
Cancer and Leukemia

## Cancer-promoting Effects of Low-dose Exposures




Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1993

Risks of low-dose and low-dose-rate exposures

$$= \frac{\text{Risks of high-dose and high-dose-rate exposures}}{\text{Dose and dose-rate effectiveness factor}}$$

| Organizations | Dose and dose-rate effectiveness factors |
|---|---|
| UNSCEAR 1993 | Less than 3 (1 to 10) |
| National Academy of Sciences (NAS) 2005 | 1.5 |
| International Commission on Radiological Protection (ICRP) 1990 and 2007 | 2 |

Surveys targeting atomic bomb survivors have examined effects of large-amount radiation exposure at one time, while occupational exposures and exposures caused by environmental contamination due to a nuclear accident are mostly chronic low-dose exposures.

Therefore, animal testing using mice has been conducted to ascertain differences in oncogenic risks between a single large-amount radiation exposure and low-dose exposures over time. Although test results vary by type of cancer, it has become clear that radiation effects are generally smaller for low-dose exposures over a long period of time.

Dose and dose-rate effectiveness factors are correction values used in the case of estimating risks of low-dose exposures, for which no concrete data is available, on the basis of risks of high-dose exposures (exposure doses and incidence rates), or estimating risks of chronic exposures or repeated exposures based on risks of acute exposures. Researchers have various opinions on specific values to be used for considering radiological protection, but the ICRP uses 2 as the dose and dose-rate effectiveness factor in its Recommendations and concludes that long-term low-dose exposure would cause half the effects as those caused by exposure at one time, if the total exposure dose is the same.

(Related to p.124 of Vol. 1, “Effects of Long-Term Low-Dose Exposure”)

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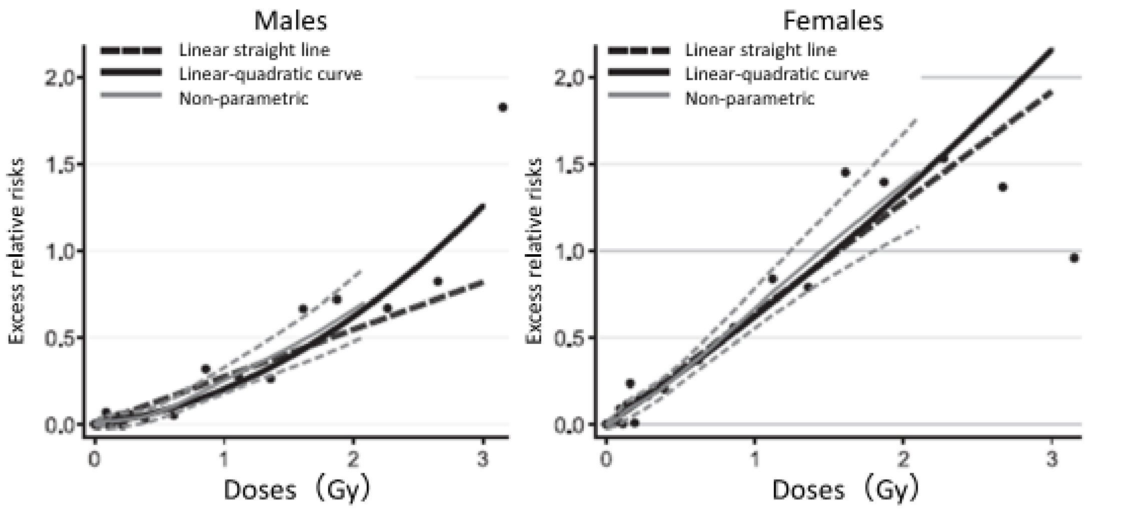
Cancer due to Acute External Exposure

# Relationship between Solid Cancer Deaths and Doses


## Deaths from solid cancer (results among atomic bomb survivors)




Source: Prepared based on Grant *et al.*, Radiat Res, 187, 513-537, 2017

Excess relative risks: How cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people

Health effects surveys targeting atomic bomb survivors have revealed that cancer risks increase as exposure doses increase. The latest epidemiological survey on solid cancer risks shows proportionate relationships between doses and risks, i.e., between exposure doses exceeding 100 mSv and the risk of solid cancer incidence[1] and between exposure doses exceeding 200 mSv and the risk of death from solid cancer.[2]

However, there is no consensus among researchers concerning a relationship between cancer risks and exposure doses below 100 to 200 mSv. It is expected to be clarified in future studies whether a proportionate relationship can be found between cancer risks and all levels of exposure doses, whether there is any substantial threshold value, or whether any other correlations are found.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks,” and p.166 of Vol. 1, “Disputes over the LNT Model”)

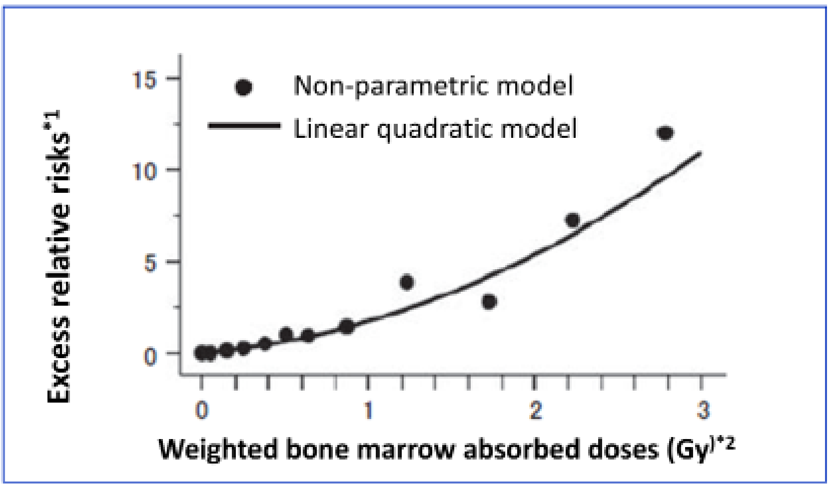
1. E. J. Grant et. al., “Solid Cancer Incidence among the Life Span Study of Atomic Bomb Survivors: 1958-2009” RADIATION RESEARCH 187, 513-537 (2017)
2. K. Ozasa et. al., “Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950-2003: An Overview of Cancer and Noncancer Diseases” RADIATION RESEARCH 177, 229-243 (2012)

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Cancer due to Acute External Exposure

# Dose-response Relationship of Radiation-induced Leukemia


**Dose-response relationship of radiation-induced leukemia among atomic bomb survivors in Hiroshima and Nagasaki**




*1: An indicator to show increments in the mortality rate (or incidence rate) in the case of having been exposed to radiation against the mortality rate (or incidence rate) in the case of having been free from radiation exposure; showing how many times increase was caused by radiation exposure

*2: In the case of leukemia, weighted bone marrow doses (sum of 10 times the neutron doses and total amount of γ-rays) are used.

Source: Prepared based on Wan-Ling Hsu et al. The Incidence of Leukemia, Lymphoma and Multiple Myeloma among Atomic Bomb Survivors: 1950–2001, Radiation Research 179, 361–382 (2013)

Surveys targeting atomic bomb survivors made it clear that the dose-response relationship of leukemia, excluding chronic lymphocytic leukemia and adult T-cell leukemia, is quadric, and the higher an exposure dose is, the more sharply risks increase, showing a concave dose-response relationship (the linear quadratic curve in the figure). On the other hand, risks posed by low-dose exposure are considered to be lower than estimated based on a simple linear dose-response model.

In the figure above, black dots show excess relative risks depending on levels of bone marrow absorbed doses and the black line shows excess relative risks based on a linear quadratic model.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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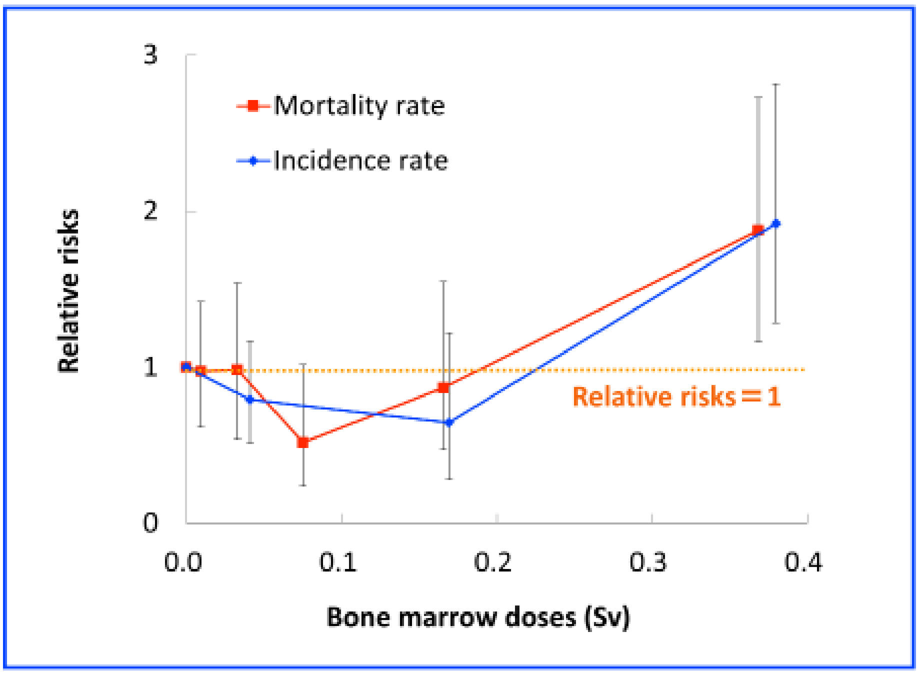
Cancer due to Acute External Exposure

# Risks of Developing Leukemia


## Risks of developing leukemia among atomic bomb survivors whose bone marrow doses are 0.4 Sv or lower




Source: Prepared based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2006 Report

Relative risks of developing leukemia (values indicating how many times larger the risks are among people exposed to radiation when assuming the risks among non-exposed people as 1) among atomic bomb survivors do not increase notably among those whose bone marrow doses are below 0.2 Sv but increase significantly among those whose bone marrow doses are around 0.4 Sv.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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**Cancer due to Acute External Exposure**

# Relationship between Ages at the Time of Radiation Exposure and Oncogenic Risks


## Atomic bomb survivors' lifetime risks by age at the time of radiation exposure

| Age | Gender | Lifetime risks of death from cancer per 100-mSv exposure (%) | Lifetime risks of death from cancer when having been free from acute exposure (%) | Lifetime risks of death from leukemia per 100-mSv exposure (%) | Lifetime risks of death from leukemia when having been free from acute exposure (%) |
|---|---|---|---|---|---|
| 10 | Males | 2.1 | 30 | 0.06 | 1.0 |
| | Females | 2.2 | 20 | 0.04 | 0.3 |
| 30 | Males | 0.9 | 25 | 0.07 | 0.8 |
| | Females | 1.1 | 19 | 0.04 | 0.4 |
| 50 | Males | 0.3 | 20 | 0.04 | 0.4 |
| | Females | 0.4 | 16 | 0.03 | 0.3 |

Source:
- Preston DL et al., Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiat Res., 2003 Oct; 160(4):381-407
- Pierce DA et al., Studies of the mortality of atomic bomb survivors. Report 12, Part I. Cancer: 1950-1990 Radiat Res., 1996 Jul; 146 (1): 1-27

This table shows lifetime risks of death from cancer due to radiation exposure based on data obtained through epidemiological surveys targeting atomic bomb survivors. Specifically, comparisons are made between lifetime risks of deaths from cancer and leukemia per 100-mSv acute exposure and respective death risks when having been free from acute exposure, i.e., background death risks due to naturally developing cancer and leukemia.

The table suggests that a 10-year-old boy, for example, is likely to die of cancer in the future with a probability of 30% (the background risk of death from cancer for 10-year-old boys is 30% as shown in the table), but if the boy is acutely exposed to radiation at the level of 100 mSv, the risk of death from cancer increases by 2.1% to 32.1% in total.

The table shows the tendency that in the case of acute exposure to 100 mSv, lifetime risks of death from cancer are higher for those who are younger at the time of the exposure.

The reasons therefor include the facts that younger people have a larger number of stem cells that may develop into cancer cells in the future and cell divisions are more active and frequent compared with aged people.

(Related to p.115 of Vol. 1, “Difference in Radiosensitivity by Age”)

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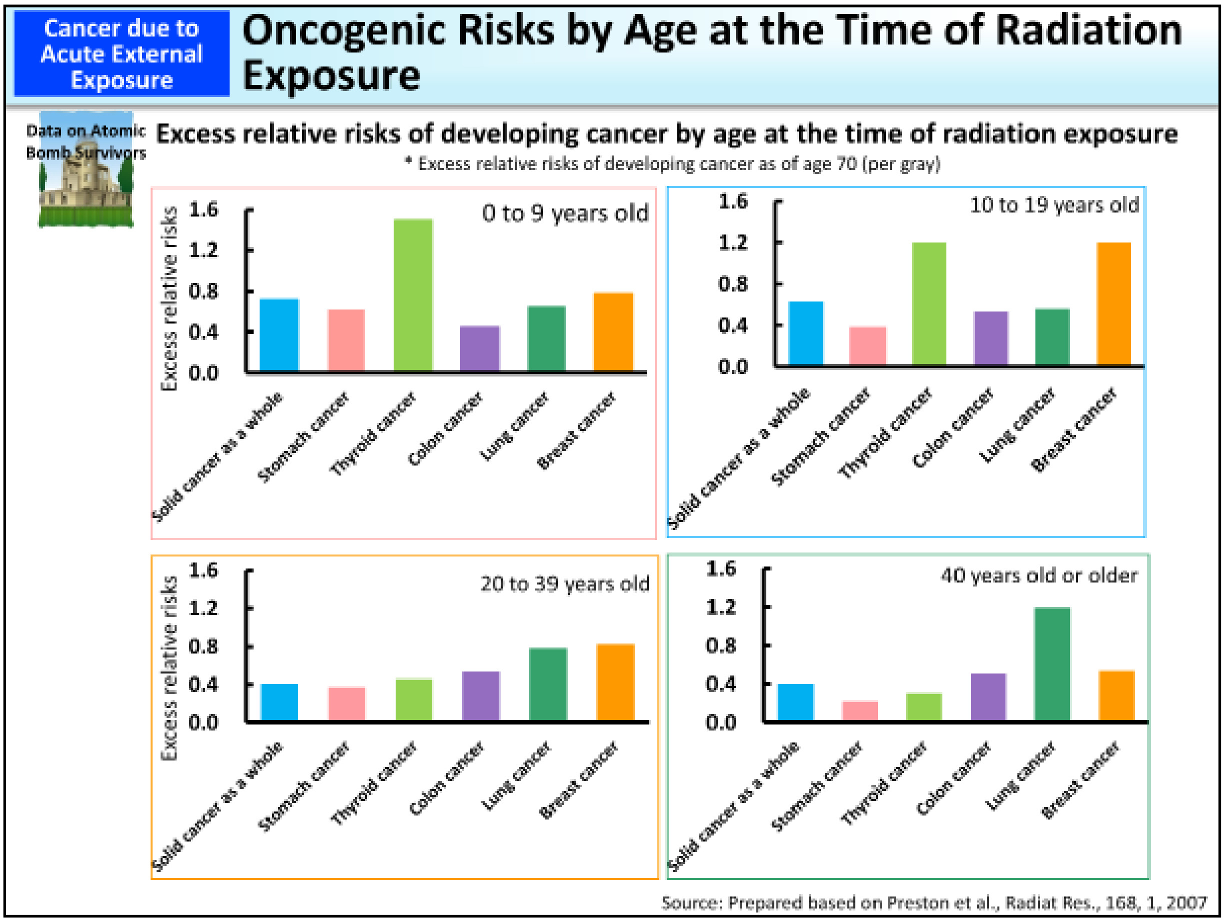


These figures show excess relative risks of developing cancer (values indicating how much cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people) per gray as of age 70, using the results of the surveys targeting atomic bomb survivors.

It can be observed that types of cancer with higher risks differ by age at the time of radiation exposure.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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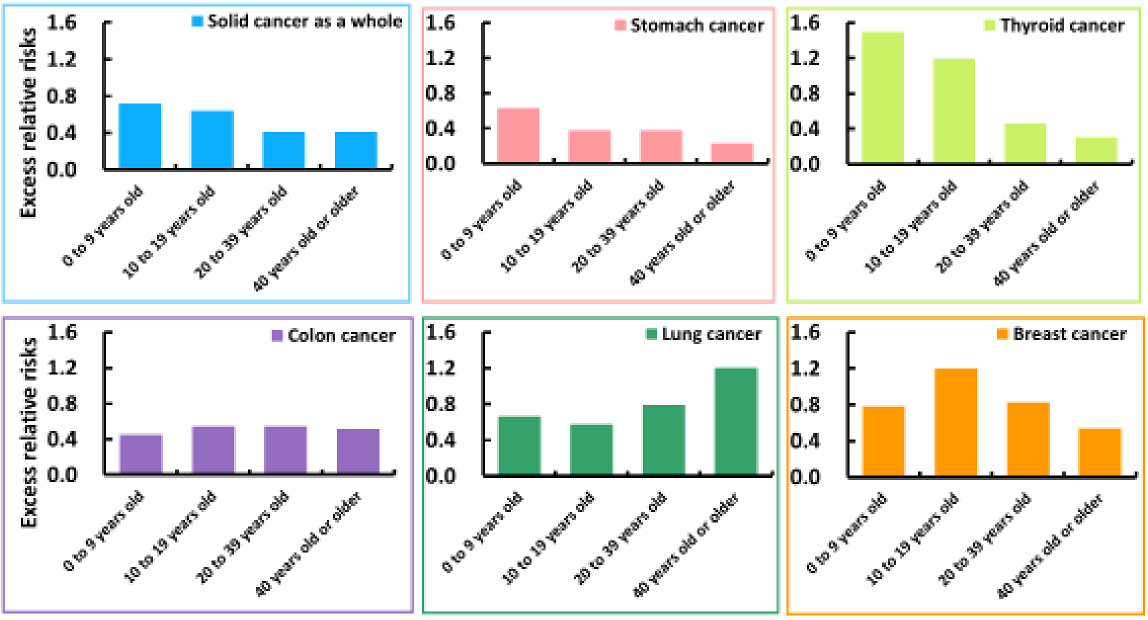
Cancer due to Acute External Exposure

# Ages at the Time of Radiation Exposure and Risks by Type of Cancer


## Excess relative risks of developing cancer by age for each type of cancer

* Excess relative risks of developing cancer as of age 70 (per gray)




Source: Prepared based on Preston et al., Radiat Res., 168, 1, 2007

These figures show excess relative risks of developing cancer (values indicating how cancer risks have increased among a group of people exposed to radiation compared with a group of non-exposed people) per gray as of age 70, using the results of the surveys targeting atomic bomb survivors.

For example, the excess relative risk of developing solid cancer as a whole for the age group of 0 to 9 years old is approx. 0.7, which means that the excess relative risk increases by 0.7 among a group of people exposed to 1 Gy compared with a group of non-exposed people. In other words, supposing the risk for a group of non-exposed people is 1, the risk for a group of people aged 0 to 9 who were exposed to 1 Gy increases by 1.7 times. The excess relative risk of developing solid cancer as a whole for people aged 20 or older is approx. 0.4 and the risk for a group of people exposed to 1 Gy will be 1.4 times larger than the risk for a group of non-exposed people.

As shown in the figures above, risks differ by age at the time of radiation exposure and type of cancer.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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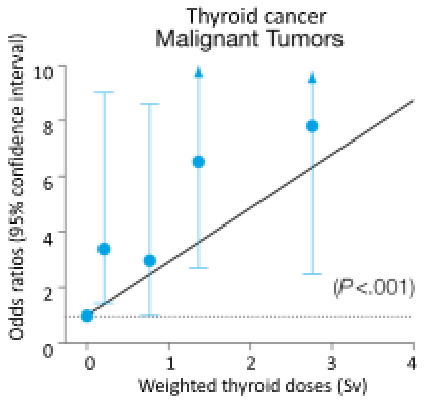
Cancer due to Acute External Exposure

# Incidence of Thyroid Cancer among Atomic Bomb Survivors


Source: Radiation Effects Research Foundation; JAMA 2006; 295(9): 1011-1022

**Analysis of micro papillary cancer**

mGy: milligrays

| Weighted thyroid doses | Average doses (mGy) | Targets (people) | Cancer detected in (people) | Odds ratios (95% confidence interval) |
|---|---|---|---|---|
| <5mGy | — | 755 | 33 | 1 |
| 5～100mGy | 32 | 936 | 36 | 0.85 (0.52～1.39) |
| 100～500mGy | 241 | 445 | 22 | 1.12 (0.64～1.95) |
| 500mGy< | 1237 | 236 | 15 | 1.44 (0.75～2.67) |

Source: Hayashi et al., Cancer, 116, 1646, 2010

* Odds ratio: A statistical scale for comparing the probability of a certain incident between two groups
Odds ratios larger than 1 suggest that the probability is larger. When the probability that a certain incident occurs is p (Group 1) and q (Group 2), respectively, the odds ratio is obtained by the following formula.
Odds of p / Odds of q = p / (1-p) ÷ q / (1-q)
When the 95% confidence interval does not include 1, the difference in the probability is statistically significant.

Odds ratios (statistical scales for comparing the probability of a certain incident between two groups) regarding incidence of thyroid cancer among atomic bomb survivors show that risks of thyroid cancer increase as doses increase.

A survey only targeting micro papillary thyroid cancer shows that the odds ratio remains low until the weighted thyroid dose exceeds 100 mGy, and that the ratio slightly exceeds 1 when the weighted thyroid dose becomes 100 mGy or larger, but no significant difference was found.[1,2] (When the odds ratio is larger than 1, the relevant incident is more highly likely to occur. However, in this data, as the 95% confidence interval includes 1, there is no statistically significant difference in the probability.)

1. M. Imaizumi, et.al., “Radiation Dose-Response Relationships for Thyroid Nodules and Autoimmune Thyroid Diseases in Hiroshima and Nagasaki Atomic Bomb Survivors 55-58 Years After Radiation Exposure” JAMA 2006;295(9):1011-1022
2. Y. Hayashi, et.al., “Papillary Microcarcinoma of the Thyroid Among Atomic Bomb Survivors Tumor Characteristics and Radiation Risk” Cancer April 1, 2010, 1646-1655

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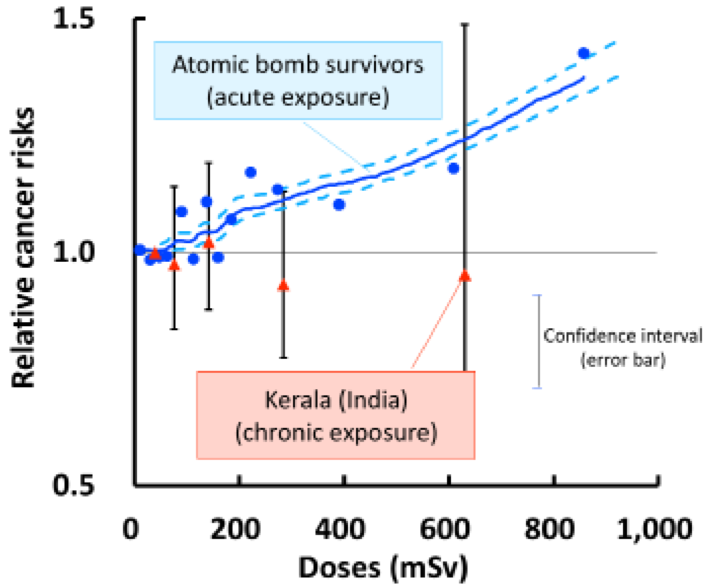
Carcinogenesis due to Chronic Exposure

# Effects of Long-Term Low-Dose Exposure

## Carcinogenesis among residents in high natural radiation area in India

**Kerala (India)**
Outdoor average dose:
4 mSv/year or more
Up to 70 mSv/year in some areas




mSv: millisieverts

Source: Prepared based on Nair et al., Health Phys 96, 55, 2009; Preston et al., Radiat Res. 168, 1, 2007

It is considered that effects appear in different manners depending on whether it is a low-dose-rate radiation exposure or a high-dose-rate radiation exposure.

The figure on the right compares the data on atomic bomb survivors and risks for residents in high natural radiation areas such as Kerala in India. No increase is observed in relative risks for cancer (values indicating how many times cancer risks increase among exposed people when supposing the risk for non-exposed people as 1) among residents in Kerala even if their accumulated doses reach several hundred mSv. This suggests that risks are smaller in the case of chronic exposure than in the case of acute exposure, although further examination is required as the range of the confidence interval (the error bar on the figure) is very large (p.116 of Vol. 1, “Cancer-promoting Effects of Low-dose Exposures”).
(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

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Carcinogenesis due to Chronic Exposure

# Radiation Effects Health Examinations

## – Chornobyl NPS Accident –

| Country | Number of leukemia cases | | Number of all types of cancer cases | | Standardized incidence ratio (SIR) | |
|---|---|---|---|---|---|---|
| | Number of samples | Expected number | Number of samples | Expected number | Leukemia | All types of cancer |
| Residents in contaminated regions | | | | | | |
| **Belarus** | 281 | 302 | 9,682 | 9,387 | 93 | 103 |
| **Russia** | 340 | 328 | 17,260 | 16,800 | 104 | 103 |
| **Ukraine** | 592 | 562 | 22,063 | 22,245 | 105 | 99 |

Source: Prepared based on the UNSCEAR 2000 Report

After the Chornobyl NPS Accident, an epidemiological study on effects of radiation on health was conducted with regard to various diseases. However, no causal relationship with the accident has been confirmed regarding leukemia.

The table shows the results of the examinations analyzing cancer cases found in 1993 and 1994 among residents of regions contaminated due to the Chornobyl NPS Accident from 1986 to 1987. In the three affected countries, no significant increase in cancer cases was observed. Contaminated regions are regions where the deposition density of Cs-137 is 185 kBq/$m^2$ or larger. The UNSCEAR 2000 Report states that no increase was found in risks of radiation-related leukemia either for workers dealing with the accident or residents in the contaminated regions.

Thereafter, there were research reports stating that an increase in relative risks of leukemia was observed, although the increase was not statistically significant, and that the incidence rate of leukemia was approximately twice for workers who were employed in 1986 compared with workers who were employed in 1987, when radiation doses became lower. Despite these reports, the UNSCEAR 2008 Report evaluates them to be far from conclusive to explain any significant increases.

With regard to the general public, the report concludes that no persuasive evidence has been found to suggest any measurable increases in risks of leukemia among people who were exposed to radiation in utero or during childhood.

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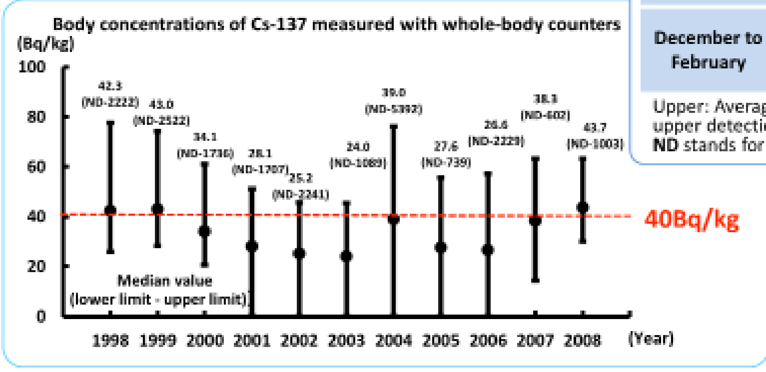
Basic Information on Thyroid Thyroid Exposure

# Internal Exposure due to Cesium
## - Chornobyl NPS Accident -


Seasonal changes in body concentrations of Cs-137 (Bq/kg) and number of examinees

| | 1998 to 2001 | 2002 to 2005 | 2006 to 2008 |
|---|---|---|---|
| March to May | 34.6<br>(ND-2154.9)<br>10,993 | 27.3<br>(ND-5392.2)<br>18,722 | 32.0<br>(ND-1757.1)<br>9,284 |
| June to August | 71.5<br>(ND-399.0)<br>265 | 32.2<br>(ND-393.0)<br>268 | 21.2<br>(ND-271.1)<br>451 |
| September to November | 40.9<br>(ND-2521.7)<br>9,590 | 33.5<br>(ND-1089.3)<br>8,999 | 44.2<br>(ND-2229.3)<br>4,080 |
| December to February | 33.5<br>(ND-1735.8)<br>8,971 | 20.6<br>(ND-607.0)<br>6,603 | 39.8<br>(ND-1454.3)<br>6,404 |

Upper: Average (Bq/kg); Middle: Lower detection limit to upper detection limit; Lower: Number of examinees (people); **ND** stands for below the detection limit.




The annual internal exposure of 40 Bq/kg was detected in the Bryansk State from 1998 to 2008.

Bq/kg: Becquerels per kilogram

Source: Prepared based on Sekitani et al., Radiat Prot Dosimetry, 141, 1, 2010

Due to the Chornobyl Nuclear Power Station (NPS) Accident in 1986, much larger amounts of radioactive materials were released compared with those released by the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. At first, the government of the former Soviet Union did not publicize the accident nor did it take any evacuation measures for residents around the nuclear facilities. In late April, when the accident occurred, pasturing had already started in the southern part of the former Soviet Union and cow milk was also contaminated with radionuclides.

As a result of the whole-body counter measurements of body concentrations of Cs-137, which were conducted for residents in the Bryansk State from 1998 to 2008, it was found that the median value of body concentrations of Cs-137 had decreased within a range of 20 to 50 Bq/kg until 2003 but has been on a rise since 2004. This is considered to be because residents in especially highly contaminated districts came to be included in the measurement targets in 2004 onward and because the contraction of off-limits areas has made it easier for residents to enter contaminated forests. At any rate, this suggests that exposure to Cs-137 due to the Chornobyl NPS Accident has been continuing over years.

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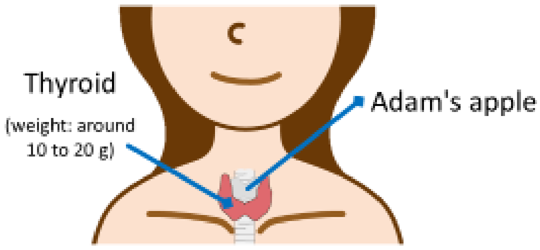
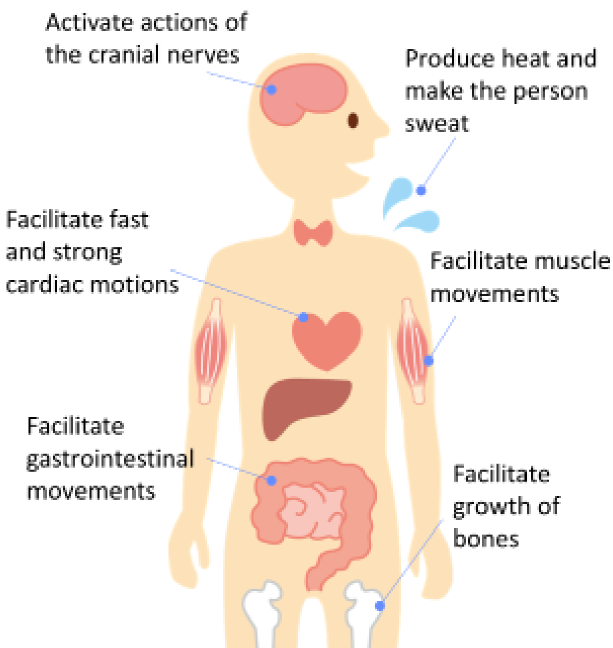
Basic Information on Thyroid

# Thyroid




- **The thyroid is located in the lower center of the neck (below the Adam's apple).**
- **The thyroid takes in iodine in foods, etc., produces thyroid hormones, and secretes them into the blood.**

## Actions of thyroid hormones




The thyroid is a small organ weighing around 10 to 20 g and shaped like a butterfly with its wings extended. It is located in the lower center of the neck (below the Adam's apple) as if surrounding the windpipe. The thyroid actively takes in iodine in the blood to produce thyroid hormones therefrom. Produced thyroid hormones are secreted into the blood and are transported to the whole body to act in various manners.

Thyroid hormones play roles of promoting metabolism to facilitate protein synthesis in the body and maintenance of energy metabolism and also roles of promoting growth and development of children's body and brains.

Included in this reference material on March 31, 2017

Basic Information on Thyroid

# Iodine

- **Iodine = Raw material of thyroid hormones**

| Intake at one meal | Amount of iodine |
|---|---|
| Kelp boiled in soy sauce (5 to 10 g) | 10～20mg |
| Boiled kelp roll (3 to 10 g) | 6～20mg |
| Hijiki seaweed (5 to 7 g) | 1.5～2mg |
| Wakame seaweed soup (1 to 2 g) | 0.08～0.15mg |
| Half sheet of dried laver seaweed (1 g) | 0.06mg |
| Stock made from kelp (0.5 to 1 g) | 1～3mg |
| Agar (1 g) | 0.18mg |

**Iodine intake**
**Dietary Reference Intakes 2015**

**Estimated average requirement: 0.095 mg**
**Recommended intake: 0.13 mg**

**Japanese people's iodine intake is estimated to be approx. 1 to 3 mg/d.**

Source: Zava TT, Zava DT, Thyroid Res 2011; 4: 14; Report of the "Development Committee for the Dietary Reference Intakes for Japanese 2015," Ministry of Health, Labour and Welfare; "Super Graphic Illustration: Thyroid Diseases," Houken Corp.

Iodine, which is a raw material of thyroid hormones, is contained in large quantities in seaweed, fish and seafood that are familiar to Japanese people.

The "Dietary Reference Intakes for Japanese" released by the Ministry of Health, Labour and Welfare states that the estimated average iodine requirement is 0.095 mg per day and recommended intake is 0.13 mg per day. Japanese people consume a lot of seaweed, fish and seafood on a daily basis and are considered to take in a sufficient amount of iodine (estimated to be approx. 1 to 3 mg/d).

When a person habitually consumes iodine, the thyroid constantly retains a sufficient amount of iodine. It is known that once the thyroid retains a sufficient amount of iodine, any iodine newly ingested is only partially taken into the thyroid and most of it is excreted in the urine.

Accordingly, even in the case where radioactive iodine is released due to such reasons as an accident at a nuclear power plant, accumulation of the released radioactive iodine in the thyroid can be subdued among a group of people who take in iodine on a daily basis.

In preparation for any emergency exposure such as due to a nuclear accident, efforts are being made to deliver stable iodine tablets, non-radioactive iodine tablets formulated for oral administration, in advance or in an emergency.

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Basic Information on Thyroid

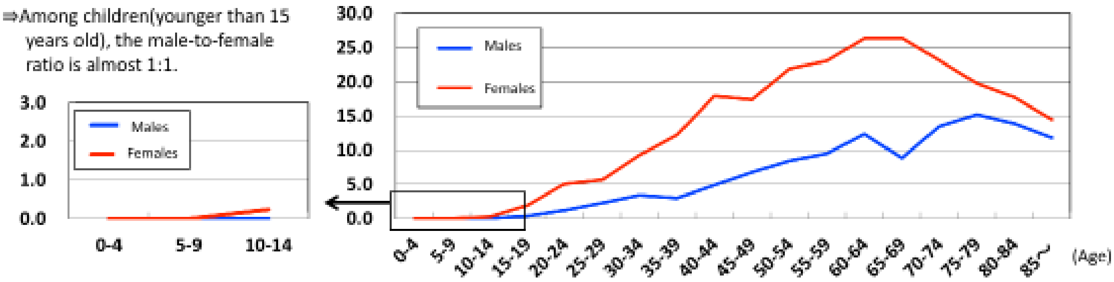
# Characteristics of Thyroid Cancer

- **The incidence rate of thyroid cancer is higher for females** (estimated age-adjusted incidence rate (nationwide) (against 100,000 people), 2010).

  **⇒Females: 11.5 (people); Males: 4.5 (people)**

- **Thyroid cancer is found in all age groups from younger people to aged people (estimated incidence rate by age group** (nationwide) (against 100,000 people), 2010).

⇒Among children(younger than 15 years old), the male-to-female ratio is almost 1:1.




- **In many cases, prognosis after surgery is good** (crude cancer mortality rate by organ/tissue (against 100,000 people), 2010).

| | Thyroid | Stomach | Liver | Lungs | Leukemia |
|---|---|---|---|---|---|
| Male | **0.9** | 53.5 | 34.9 | 81.8 | 7.9 |
| Female | **1.7** | 26.5 | 17.4 | 30.0 | 5.0 |

- **There is also occult thyroid cancer that does not exert any effects on people's health throughout their lifetime.**

Source: Prepared based on "Cancer Registration and Statistics," Cancer Information Service, National Cancer Center Japan

Thyroid cancer has some unique characteristics compared with other types of cancer.

The first is the higher incidence rate for females (11.5 females and 4.5 males against 100,000 people (national age-adjusted incidence rate)), but the male-to-female ratio is almost 1:1 among children younger than 15 years old.

It is known that breast cancer is most frequently detected in females in their 40s and 50s and the incidence rate of stomach cancer is higher among both males and females over 60 years old. On the other hand, thyroid cancer is characteristically found broadly in all age groups from teenagers to people in their 80s. Thyroid cancer is mostly a differentiated cancer, and the crude cancer mortality rate (national mortality rate by age group (against 100,000 people), all age groups, 2010) is lower for thyroid cancer than other cancers and better prognosis after surgery is also one of the characteristics of thyroid cancer. Nevertheless, some thyroid cancer may cause invasion into other organs or distant metastases or may affect vital prognosis. Therefore, careful evaluation is required.

Furthermore, thyroid cancer has long been known as a type of cancer, some of which are occult (latent) cancers without exerting any effects on people's health throughout their lifetime (p.130 of Vol. 1, "Occult (Latent) Thyroid Cancer").

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Basic Information on Thyroid

# Occult (Latent) Thyroid Cancer

**Some thyroid cancer is occult (latent) and presents no symptoms over a lifetime.**

*** Occult (latent) cancer**
A cancer that is slow-growing with no symptoms and is found only through postmortem autopsy

## Occult (latent) thyroid cancer

- Thyroid cancer is mostly a differentiated cancer and no symptoms appear over a lifetime in some cases as cancerous cell growth is slow.
- Autopsy studies conducted in the past reported that occult (latent) thyroid cancer was found in 10.5% to 30% and that around 95% of occult (latent) cancer was smaller than 1cm in diameter.

[Reference] Probabilities of developing thyroid cancer during lifetime for Japanese people*
Female: 0.78%; Male: 0.23%

* Probabilities that the Japanese people develop thyroid cancer at least once during their lifetime, which were calculated based on data on the number of cancer patients from 1975 to 1999 in Japan (Kamo, et al., Journal of Health and Welfare Statistics, Vol. 52, No. 6, June 2005)

Source: Prepared based on Kamo et al., (2008) Jpan. J. Clin Oncol 38(8) 571-576; Fukunaga et al., (1975) Cancer 36:1095-1099, etc.

Some types of cancer present no symptoms and exert no effects on people's health throughout their lifetime and are not clinically detected but are later found through histopathology diagnosis (including postmortem autopsy). Such cancer is called occult (latent) cancer.

One of the criteria for expressing the property of cancer cells is the degree of differentiation. This shows to what extent the relevant tumor resembles the normal tissue from which it originated, and the lower the degree is, the more malignant the tumor is and the easier the cancer grows.

Thyroid cancer is roughly categorized into differentiated cancer such as papillary cancer and follicular cancer, most of which are cancers with an especially high degree of differentiation, poorly differentiated cancer, undifferentiated cancer, and others. Out of these, in differentiated cancer, which accounts for the majority of thyroid cancer, cancer cells are mature and grow slowly and no symptoms appear over a lifetime in some cases. Such differentiated thyroid cancer is sometimes found as an occult (latent) cancer only through an autopsy conducted after a person's death due to other causes.

Based on an analysis using the cancer registry, probabilities that a Japanese person will develop thyroid cancer during his/her lifetime are 0.78% for females and 0.23% for males.[1] The results of the five autopsy studies targeting Japanese and Japanese Hawaiians[2-6] show that occult (latent) cancer was found with high frequency at 10.5% to 27.1% among males and 12.4% to 30.2% among females. In around 95% of the 525 cases found in the autopsy studies in Hiroshima and Nagasaki[2] and the 139 cases found in the autopsy studies in Sendai and Honolulu,[3] the sizes of tumors were smaller than 1cm.

These results also show that in many cases, thyroid cancer presents as an occult (latent) cancer without displaying symptoms throughout an individual's lifetime.

1. Kamo K et al., "Lifetime and Age-Conditional Probabilities of Developing or Dying of Cancer in Japan" Jpn. J. Clin. Oncol. 38(8) 571-576, 2008.
2. Sampson et al., "Thyroid carcinoma in Hiroshima and Nagasaki. I. Prevalence of thyroid carcinoma at autopsy" JAMA 209:65-70, 1969.
3. Fukunaga FH, Yatani R., "Geographic pathology of occult thyroid carcinomas" Cancer 36:1095-1099, 1975.
4. Seta K, Takahashi S., "Thyroid carcinoma" Int Surg 61:541-4, 1976.
5. Yatani R, et al., "PREVALENCE OF CARCINOMA IN THYROID GLANDS REMOVED IN 1102 CONSECUTIVE AUTOPSY CASES" Mie Medical Journal XXX:273-7, 1981.
6. Yamamoto Y, et al., "Occult papillary carcinoma of the thyroid ~ A study of 408 autopsy cases~" Cancer 65:1173-9, 1990.

Source
• International Classification of Diseases for Oncology, Third Edition. First Revision, ICD-O, edited by the Director-General for Policy Planning and Evaluation (in charge of statistics and information policy) of the Ministry of Health, Labour and Welfare (printed by Toukei Insatsu Industries, 2018)
• General Rules for the Description of Thyroid Cancer (the 8the Edition) edited by the Japan Association of Endocrine Surgery and the Japanese Society of Thyroid Pathology (printed by Kanehara & Co., Ltd., Tokyo, 2019)

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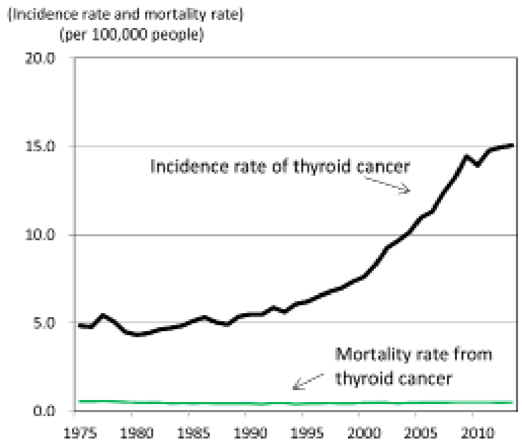
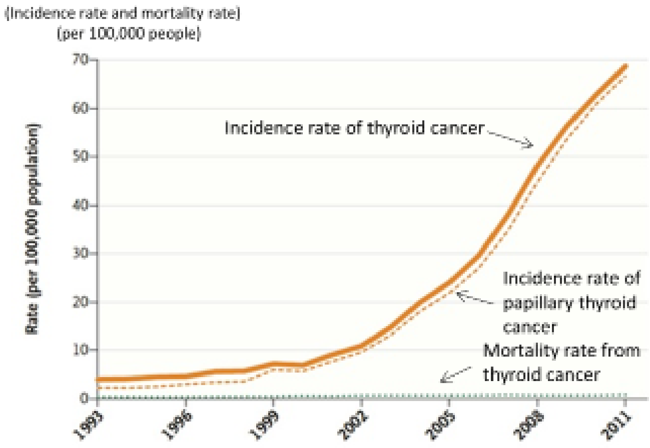
Basic Information on Thyroid

# Incidence Rates of Thyroid Cancer: Overseas

## Incidence rates and mortality rates (against 100,000 people) in America and South Korea




America*1




South Korea*2

Adapted with permission from [N Engl J Med., Ahn HS, Korea's thyroid-cancer "epidemic"--screening and overdiagnosis, 371(19), 1765-1767]. Copyright © 2014 Massachusetts Medical Society.

*1: Prepared based on NATIONAL CANCER INSTITUTE, Surveillance, Epidemiology, and End Results Program, SEER Cancer Statistics Review 1975-2013
*2: Prepared based on Ahn HS, N Engl J Med. 2014

In recent years, sharp increases in the incidence rate of thyroid cancer have been reported, which is said to be due to increases in the frequencies of medical surveys and use of healthcare services as well as the introduction of new diagnostic technologies, resulting in detection of many cases of micro thyroid cancer (micro papillary carcinoma).

As the mortality rate has remained almost unchanged despite sharp increases in the incidence rate, the possibility of overdiagnoses (detection of many cases of non-fatal micro papillary carcinoma that have no symptoms) is pointed out.[1]

Increases in the incidence rate of thyroid cancer are global trends observed in such countries as America, Australia, France and Italy, but are especially notable in South Korea. In South Korea, official assistance for thyroid cancer screening was commenced in 1999 to enable people to receive the most-advanced screening at low cost. This is considered to have prompted a larger number of people to receive screening, leading to significant increases in the incidence rate of thyroid cancer.

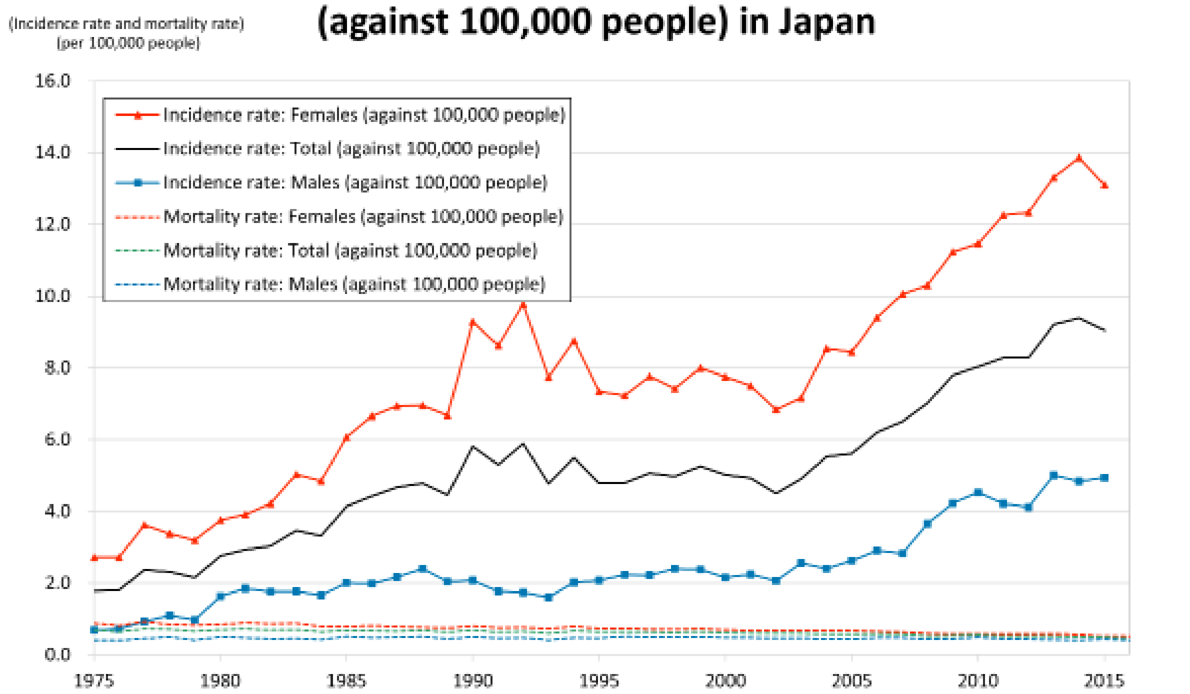
1. International Agency for Research on Cancer "Overdiagnosis is a major driver of the thyroid cancer epidemic: up to 50–90% of thyroid cancers in women in high-income countries estimated to be overdiagnoses" (August 18,2016)

Included in this reference material on March 31, 2017
Updated on March 31, 2019

Basic Information on Thyroid

# Incidence Rates of Thyroid Cancer: Japan

## Annual changes in age-adjusted incidence rates and mortality rates (against 100,000 people) in Japan




Source: Prepared based on the "Cancer Registration and Statistics," Cancer Information Service, National Cancer Center Japan

This figure shows annual changes in incidence rates (percentage of patients against the population during a certain period of time) and mortality rates concerning thyroid cancer in Japan.

The incidence rates of thyroid cancer have been on a rise both for males and females in Japan. The increasing trend is more notable among females and the incidence rate, which was around three per 100,000 people in 1975, exceeded 13 in 2014. In the meantime, the mortality rate from thyroid cancer has not shown any significant changes and has been slightly decreasing both for males and females. The total incidence rate of thyroid cancer including both males and females per 100,000 people in 2010 was approx. 15 in America, approx. 60 in South Korea, and approx. 8 in Japan (p.131 of Vol. 1, “Incidence Rates of Thyroid Cancer: Overseas”).

In Japan, palpation by doctors has long been conducted broadly as thyroid screening, but ultrasound neck examination is increasingly being adopted in complete medical checkups and mass-screening. Furthermore, thanks to recent advancement of ultrasonic diagnostic equipment, diagnostic capacity has been improving and the detection rate of tumoral lesions, in particular, is said to be increasing.[1]

1. Hiroki Shimura, Journal of the Japan Thyroid Association, 1 (2), 109-113, 2010-10

Included in this reference material on March 31, 2017
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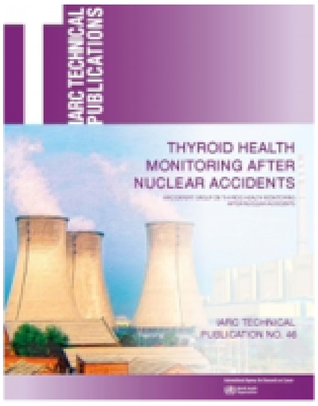
## Basic Information on Thyroid

# Recommendations by the IARC Expert Group

- In September 2018, an international Expert Group convened by the International Agency for Research on Cancer (IARC) published the Report on Thyroid Health Monitoring after Nuclear Accidents.
- In order to present the principles upon conducting a thyroid ultrasound examination in the event of a nuclear accident, the report compiles the latest knowledge on epidemiology and clinical practice concerning thyroid cancer and provides the following two recommendations. Incidentally, the report does not intend to remark on or evaluate thyroid ultrasound examinations conducted so far after nuclear accidents in the past.




**Recommendation 1**

The Expert Group recommends against population thyroid screening*1 after a nuclear accident.

*1 Actively recruiting all residents of a defined area, irrespective of any individual thyroid dose assessment, to participate in thyroid examinations followed by clinical management according to an established protocol

**Recommendation 2**

The Expert Group recommends that consideration be given to offering a long-term thyroid monitoring programme for higher-risk individuals*2 after a nuclear accident.

*2 Those who were exposed in utero or during childhood or adolescence (younger than 19 years old) with a thyroid dose of 100-500 mGy or more

Source: Prepared based on the "Thyroid Health Monitoring after Nuclear Accidents" by the IARC (2018) and "Long-term strategies for thyroid health monitoring after nuclear accidents - A summary of IARC Technical Publication No. 46" by the IARC (2018) (translated into Japanese: http://www.env.go.jp/chemi/rhm/post_132.html)

In April 2017, the International Agency for Research on Cancer (IARC), an external organization of the World Health Organization (WHO), established an international Expert Group on long-term strategies for thyroid health monitoring after nuclear accidents with the aim of providing scientific information and advice concerning effects of radiation exposure to policy making personnel and medical personnel of individual countries.

The Expert Group's Report on Thyroid Health Monitoring after Nuclear Accidents published in September 2018 compiles the latest knowledge on epidemiology and clinical practice concerning thyroid cancer and provides two recommendations concerning long-term strategies for thyroid health monitoring in the event of a nuclear accident, based on the currently available scientific evidence and on past experiences.

Firstly, the Expert Group recommends against population thyroid screening to actively recruiting all residents of a defined area to participate in thyroid ultrasound examinations.

Secondly, the Expert Group recommends that consideration be given to offering a long-term thyroid monitoring programme for higher-risk individuals who were exposed in utero or during childhood or adolescence with a thyroid dose of 100-500 mGy or more. A thyroid monitoring program here refers to one that is distinct from population screening and is defined as "including education to improve health literacy, registration of participants, centralized data collection from thyroid examinations, and clinical management." Targeted persons may choose how and whether to undergo thyroid examinations in an effort to benefit from early detection and treatment of less advanced disease. The Report also adds as follows: "Some individuals with lower risks may worry about thyroid cancer and may receive thyroid ultrasound examinations for peace of mind. If such individuals with lower risks seek to have an examination after receiving detailed explanations on potential advantages and disadvantages of thyroid ultrasound examinations, they should be provided with opportunities for thyroid ultrasound examinations under the framework of the developed thyroid monitoring programs."

Incidentally, this report does not remark on or evaluate thyroid ultrasound examinations conducted so far after nuclear accidents in the past.

Included in this reference material on March 31, 2020

Basic Information on Thyroid

## Risks of Thyroid Cancer among Japanese People

- The probability that Japanese people develop thyroid cancer during the lifetime without any influence of radiation exposure is*
  - 0.78% for females and 0.23% for males.

    (Kamo et al., (2008) Jpn. J. Clin. Oncol. 38(8) 571-576)

    * The probability that Japanese people develop cancer at least once during the lifetime, which was obtained based on the data on the number of cancer patients in Japan from 1975 to 1999

    (Kamo et al., Journal of Health and Welfare Statistics, Vol. 52, No. 6, June 2005)

- When the thyroid exposure dose is 1,000 mSv, the probability of developing thyroid cancer increases
  - by 0.58% to 1.39% for females and by 0.18% to 0.34% for males**.

    (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2006 Report, Annex A)

    ** There are multiple methods to calculate probability increases. Both for females and males, the lowest values are estimated using a method called the EAR model and the highest values are estimated using a method called the ERR model.

However, it is considered to be difficult to scientifically prove risk increases due to low-dose exposure of the thyroid, as effects of other factors are larger.

The probability that a Japanese person will develop thyroid cancer during their lifetime is 0.78% for females and 0.23% for males, which is the probability that they will develop thyroid cancer at least once during the lifetime, obtained based on the thyroid cancer incidence rate among the total cancer incidence data in Japan from 1975 to 1999. This is an index devised with the aim of explaining cancer risks to ordinary people in an easy-to-understand manner.

Exposure to 1,000 mSv in the thyroid increases the probability of developing thyroid cancer by 0.58% to 1.39% for females and by 0.18% to 0.34% for males.

However, if the thyroid exposure dose is low, it is considered to be difficult to scientifically prove risk increases due to the radiation exposure, as effects of other factors are larger.

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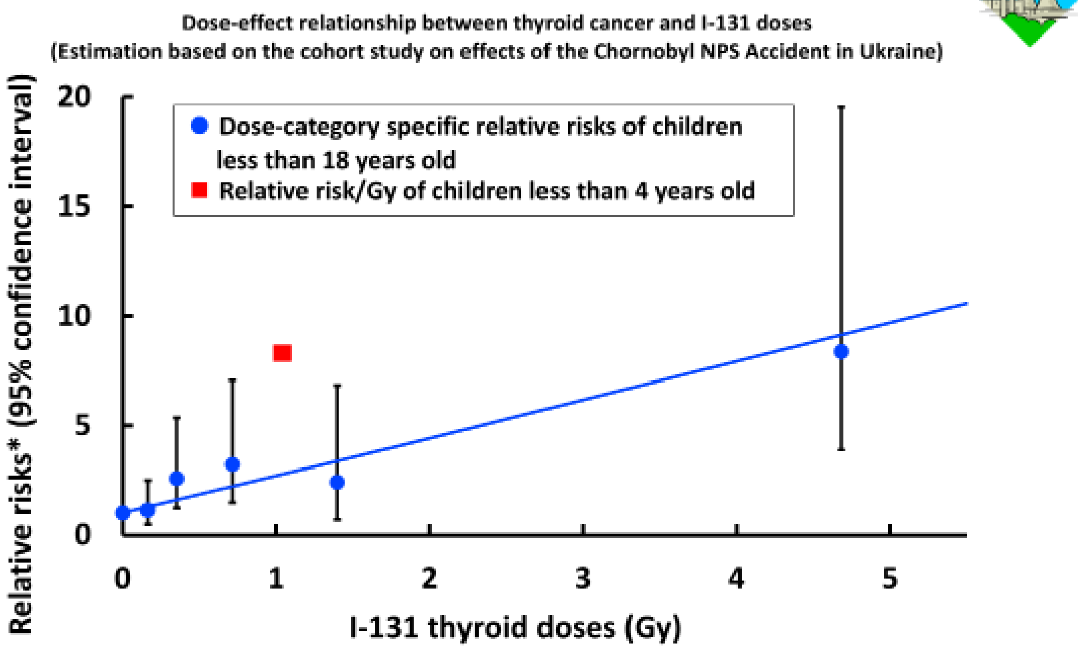
## Basic Information on Thyroid

# Relationship between Thyroid Cancer and Doses
## - Chornobyl NPS Accident -




Source: Prepared based on Brenner et al., Environ Health Perspect 119, 933, 2011

* Relative risks indicate how many times larger the cancer risks are among people exposed to radiation when assuming the risks among non-exposed people as 1.

The results of the study on the relationship between internal doses and risks of thyroid cancer among children affected by the Chornobyl NPS Accident are as shown in the figure above.

That is, exposure to 1 Gy in the thyroid increases the probability of developing thyroid cancer by 2.9. This study concludes that the 2.9-fold increase in risks is the average of children less than 18 years old, and for younger children less than 4 years old, the risk increase would be sharper (indicated with ■ in the figure).

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks”)

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Basic Information on Thyroid

## Thyroid Cancer and Iodine Intake
### - Chornobyl NPS Accident -

| Stable iodine tablets | Relative risks* of exposure to 1 Gy (95% confidence interval) | |
|---|---|---|
| | Areas where iodine concentration in soil is high | Areas where iodine concentration in soil is low |
| Administered | 2.5 (0.8-6.0) | 9.8 (4.6-19.8) |
| Unadministered | 0.1 (-0.3-2.6) | 2.3 (0.0-9.6) |

Source: Cardis et al., JNCI, 97, 724, 2005

* Relative risks indicate how many times larger the cancer risks are among people exposed to radiation when assuming the risks among non-exposed people as 1.

As shown in the table, there has been a report that the relative risk of thyroid cancer per gray increases in areas where iodine concentration in soil is low and iodine intake is insufficient. Areas around Chornobyl, where the relevant data was obtained, are located inland away from the sea and iodine concentration in soil is low, and people there do not habitually eat seaweed and salt-water fish that are rich in iodine.

Compared to areas around Chornobyl, iodine concentration in soil is higher in Japan as a whole and iodine intake is also higher than in other countries. Accordingly, such data as obtained in areas around Chornobyl is not necessarily applicable in Japan.

(Related to p.99 of Vol. 1, “Relative Risks and Attributable Risks,” and p.128 of Vol. 1, “Iodine”)

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Basic Information on Thyroid Thyroid Exposure

## Exposure of a Group of Evacuees
### - Chornobyl NPS Accident -

| Countries | Number of people (1,000 people) | Average effective dose (mSv) | | Average thyroid dose (mGy) |
|---|---|---|---|---|
| | | External exposure | Internal exposure (in organs other than the thyroid) | |
| Belarus | 25 | 30 | 6 | 1,100 |
| Russia | 0.19 | 25 | 10 | 440 |
| Ukraine | 90 | 20 | 10 | 330 |

mSv: millisieverts  mGy: milligrays

Source: United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2008 Report

Thyroid exposure doses are high for people who were forced to evacuate after the Chornobyl NPS Accident and the average is estimated to be approx. 490 mGy, which was far larger than the average thyroid exposure dose for people who resided outside evacuation areas in the former Soviet Union (approx. 20 mGy) and the average for people residing in other European countries (approx. 1 mGy).

The average thyroid exposure dose for children is estimated to be even higher. One of the major causes is that they drank milk contaminated with I-131 for two to three weeks after the accident.

The effective dose from internal exposure in organs other than the thyroid and from external exposure was approx. 31 mSv on average. The average effective dose was approx. 36 mSv in Belarus, approx. 35 mSv in Russia, and approx. 30 mSv in Ukraine. It is known that the average effective dose is larger in Belarus than in Ukraine and Russia as in the case of the average thyroid exposure dose.

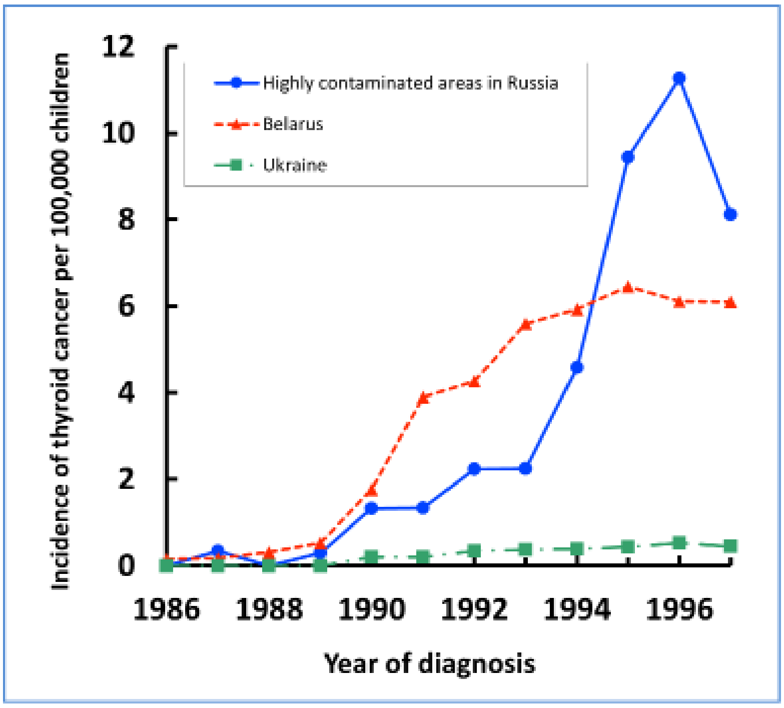
(Related to p.138 of Vol. 1, “Time of Developing Childhood Thyroid Cancer - Chornobyl NPS Accident -”)

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Basic Information on Thyroid Thyroid Exposure

# Time of Developing Childhood Thyroid Cancer - Chornobyl NPS Accident -

## Childhood thyroid cancer (Chornobyl NPS Accident)





Iodine is a raw material of thyroid hormones.

Childhood thyroid cancer cases started to appear four or five years after the accident, and showed a sharp increase by more than 10 times after the lapse of 10 years.

Source: Prepared based on the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report

At the time of the Chornobyl NPS Accident, a large amount of radioactive materials was released and broadly spread out due to the explosion. The major cause of the adverse effects of health is said to be radioactive iodine.

Some of the children who inhaled radioactive iodine that fell onto the ground or consumed the vegetables, milk, and meat contaminated through the food chain later developed childhood thyroid cancer. In particular, the major contributing factor is considered to be internal exposure to I-131 contained in milk.

In Belarus and Ukraine, childhood thyroid cancer cases started to appear four or five years after the accident. The incidence rate of thyroid cancer among children aged 14 or younger increased by 5 to 10 times from 1991 to 1994 than in the preceding five years from 1986 to 1990.

The incidence of childhood thyroid cancer for Belarus and Ukraine is the number per 100,000 children nationwide, while that for Russia is the number per 100,000 children only in specific areas heavily contaminated[1]. In addition, concerning the thyroid cancer cases observed with children and adolescents after the Chornobyl NPS Accident, the UNSCEAR calculated the attributable fraction (p.99 of Vol. 1, “Relative Risks and Attributable Risks”) based on the latest information provided by the three most affected countries (Russia, Ukraine, and Belarus) and estimated that among the thyroid cancer cases that appeared in the population of children or adolescents who were living in the most contaminated areas at the time of the accident, the thyroid cancer cases attributable to radiation exposure accounted for about 25%[2].

(Related to p.127 of Vol. 1, “Thyroid,” and p.137 of Vol. 1, “Exposure of a Group of Evacuees - Chornobyl NPS Accident -”)

1. UNSCEAR 2000 Report, Annex
2. UNSCEAR “Chornobyl 2018 White Paper”

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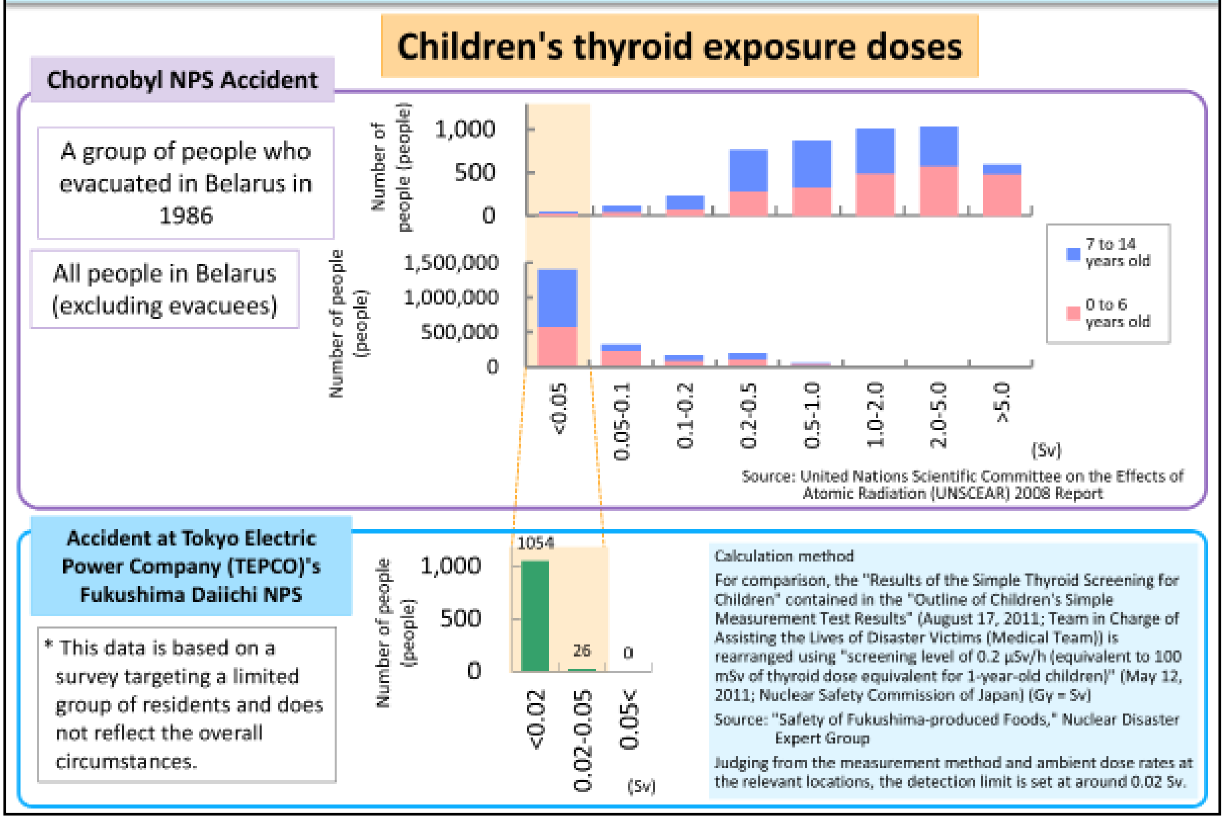
## Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Thyroid Doses)




It is very difficult to accurately assess the level of exposure of children's thyroids to radioactive iodine after the accident at TEPCO's Fukushima Daiichi NPS, but rough estimation is possible using the results of the thyroid screening conducted for children as of approx. two weeks after the accident.

This screening was conducted using survey meters for 1,080 children aged 15 or younger in Kawamata, Iwaki, and Iitate, where children's thyroid doses were suspected to be especially high.

As a result, thyroid doses exceeding the screening level set by the Nuclear Safety Commission of Japan (at that time) were not detected and measured thyroid doses were all below 50 mSv for those children who received the screening.

In the UNSCEAR's analysis of thyroid doses after the Chornobyl NPS Accident, the dose range below 50 mSv is considered to be the lowest dose range. Thyroid exposure doses for children in Belarus, where increased incidences of childhood thyroid cancer were later observed, were 0.2 to 5.0 Sv or over 5.0 Sv among a group of evacuees, showing two-digit larger values than the results of the screening in Fukushima Prefecture.
(Related to p.140 of Vol. 1, "Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Ages at the Time of Radiation Exposure)")

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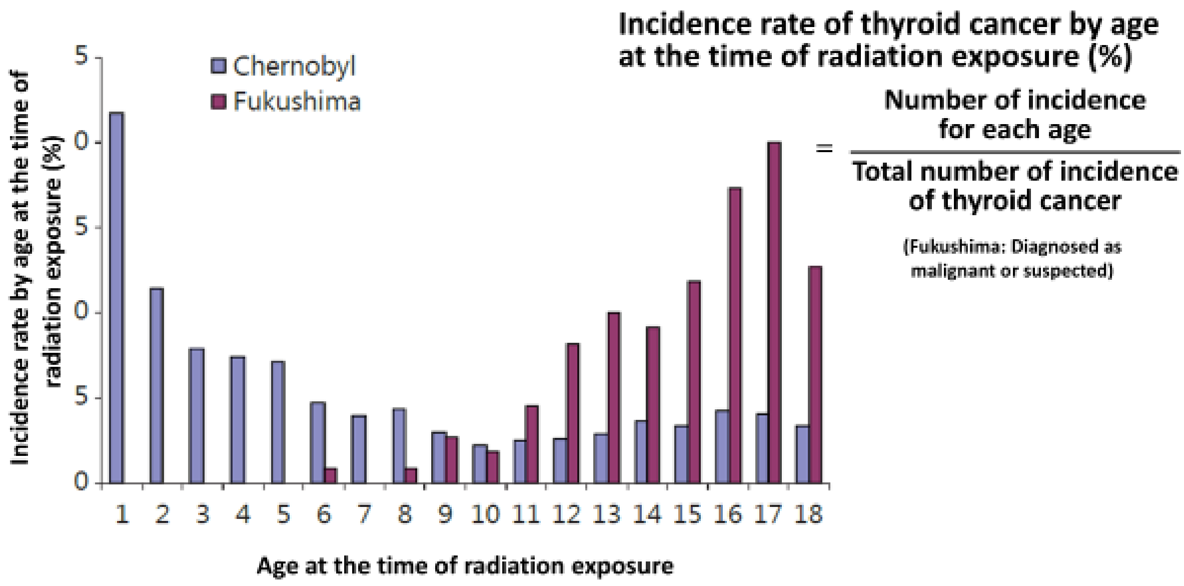
Basic Information on Thyroid Thyroid Exposure

## Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Ages at the Time of Radiation Exposure)

- **Distribution of age at the time of radiation exposure of childhood thyroid cancer patients observed in Chornobyl and Fukushima**

**(Among the total number of incidence in respective regions)**




Source: Prepared based on Williams D, Eur Thyroid J 2015; 4: 164–173

This figure shows the incidence rates of childhood thyroid cancer by age at the time of radiation exposure (aged 18 or younger), in comparison with those after the Chornobyl NPS Accident and those in three years after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS (the percentage in the figure shows the ratio by age, i.e., what percentage the incidence for each age accounts for against the total number of incidence of thyroid cancer in respective regions; the sum of all percentages comes to 100%). The figure shows clear difference in age distribution although an accurate comparison is difficult as thyroid cancer screening in Chornobyl has not been conducted in a uniform manner as in Fukushima and such information as the number of examinees and observation period is not clearly indicated.

Generally speaking, risks of radiation-induced thyroid cancer are higher at younger ages (especially 5 years old or younger) (p.121 of Vol. 1, “Oncogenic Risks by Age at the Time of Radiation Exposure”). In Chornobyl, it is observed that people exposed to radiation at younger ages have been more likely to develop thyroid cancer. On the other hand, in Fukushima, incidence rates of thyroid cancer among young children have not increased three years after the accident and incidence rates have only increased in tandem with examinees' ages. This tendency is the same as increases observed in incidence rates of ordinary thyroid cancer (p.129 of Vol. 1, “Characteristics of Thyroid Cancer”).

The document by Williams suggests that thyroid cancer detected three years after the accident at Fukushima Daiichi NPS is not attributable to the effects of the radiation exposure due to the accident in light of the facts that daily iodine intake from foods is larger in Japan than in areas around Chornobyl and that the maximum estimated thyroid exposure doses among children is much smaller in Japan (66 mGy in Fukushima and 5,000 mGy in Chornobyl).

(Related to p.139 of Vol. 1, “Comparison between the Chornobyl NPS Accident and the TEPCO's Fukushima Daiichi NPS Accident (Thyroid Doses)”)

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Basic Information on Thyroid Thyroid Exposure

## Evaluation of the Interim Report on Thyroid Cancer Compiled by the Expert Meeting on Health Management After the TEPCO's Fukushima Daiichi NPS Accident

The Expert Meeting* compiled the Interim Report (December 2014), wherein it considered the following points concerning the thyroid cancer cases found through the Preliminary Baseline Survey of Thyroid Ultrasound Examination conducted as part of the Fukushima Health Management Survey, and concluded that "no grounds positively suggesting that those cases are attributable to the nuclear accident are found at this moment."

* Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident

i. Thyroid exposure doses of residents after the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS are evaluated to be lower than those after the Chernobyl NPS Accident.

ii. In the case of the Chernobyl NPS Accident, increases in thyroid cancer cases were reported four or five years after the accident and this timing is different from when thyroid cancer cases were found in the Preliminary Baseline Survey in Fukushima.

iii. Increases in thyroid cancer cases after the Chernobyl NPS Accident were mainly observed among children who were infants at the time of the accident. On the other hand, the survey targets diagnosed to have or suspected to have thyroid cancer in the Preliminary Baseline Survey in Fukushima include no infants.

iv. The results of the Primary Examination did not significantly differ from those of the 3-prefecture examination (covering Nagasaki, Yamanashi and Aomori Prefectures), although the cohort was much smaller in the latter.

v. When conducting a thyroid ultrasound examination as screening targeting adults, thyroid cancer is generally found at a frequency 10 to 50 times the incidence rate.

Source: Interim Report (December 2014), Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident (http://www.env.go.jp/chemi/rhm/conf/tyuukanntorimatomeseigohyouhannei.pdf, in Japanese)

The Expert Meeting on Health Management After the Fukushima Daiichi Nuclear Accident examines various measures concerning dose evaluation, health management and medical services from an expert perspective.

It publicized the Interim Report in December 2014 and concluded that regarding the thyroid cancer cases found through the Preliminary Baseline Survey of Thyroid Ultrasound Examination conducted as part of the Fukushima Health Management Survey, “no grounds positively suggesting that those cases are attributable to the nuclear accident are found at this moment.”

The Expert Meeting points out the necessity to continue the Thyroid Ultrasound Examination as follows.

- The trend of the incidence of thyroid cancer, which is especially a matter of concern among the residents, needs to be carefully monitored under the recognition that radiation health management requires a mid- to long-term perspective in light of the uncertainties of estimated exposure doses.

(Related to p.150 of Vol. 2, “Thyroid Ultrasound Examination: Remarks on the Results of the Preliminary Baseline Survey”)

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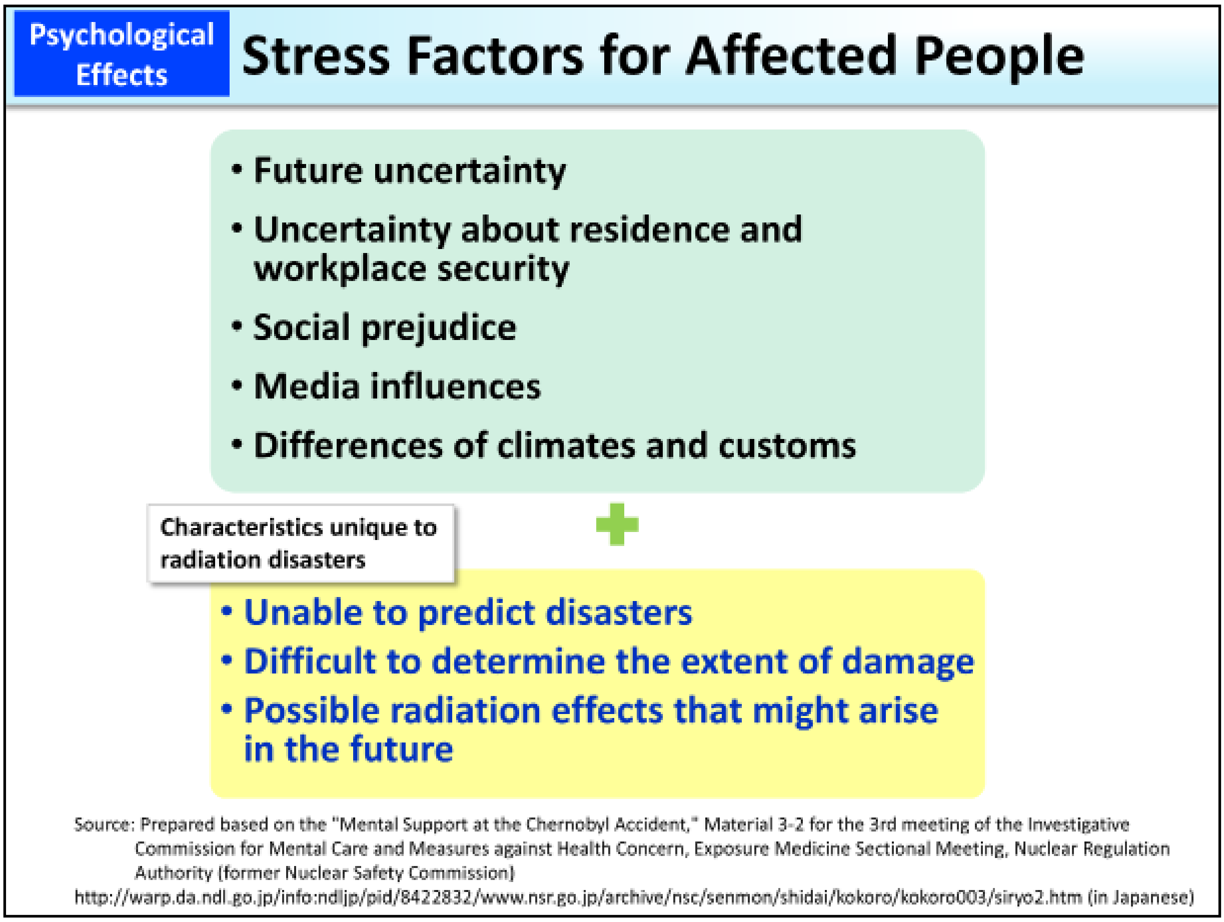




Generally, factors causing stress to the affected people include future uncertainty, uncertainty about residence and workplace security, social prejudices, media influences, differences of climates and customs, etc. For radiation disasters, there are other stress factors as well, such as being unable to predict disasters, difficulty in determining the extent of damage, and radiation effects that might arise in the future (p.143 of Vol. 1, “Radiation Accidents and Health Concerns”).

In particular, concerns over future radiation effects cause a huge stress as affected people have to be worried for a long time about the possibility that they might someday develop cancer.

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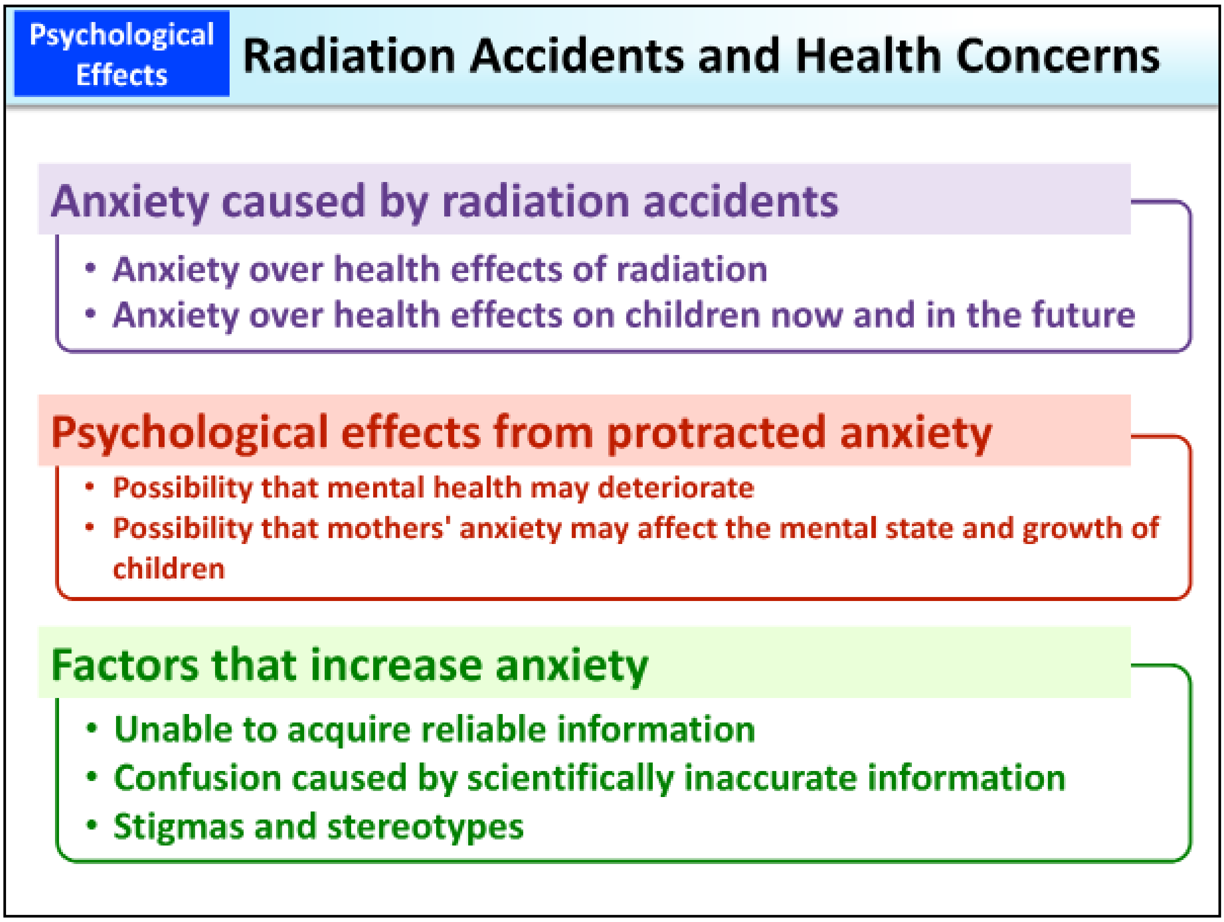


In the event of a radiation accident, people would be worried about the possibility of their exposure to radiation and about the extent of exposure and possible health effects if exposure occurred. Parents in particular would be concerned about the immediate and long-term health effects on their children.

People’s mental health would deteriorate as a result of protracted anxiety over possible future health effects. It has also been pointed out that the anxiety of mothers might affect the mental state and growth of their children (p.106 of Vol. 1, “Effects on Children - Chornobyl NPS Accident -”).

The anxiety could be heightened by being unable to acquire reliable and accurate information about radiation. It has also been reported that unreasonable public stigmas and discriminations (stereotypes) about people affected by contamination or exposure could exacerbate their mental health problems.[1,2]

1. Fukushima Psychological Care Manual, Fukushima Mental Health and Welfare Centre
2. Werner Burkart(Vienna) “Message to our friends affected by the nuclear component of the earthquake/tsunami event of March 2011 (August 26, 2013)”(Werner Burkart :Professor for Radiation Biology at the Faculty of Medicine of the Ludwig Maximilians University in Munich, Former Deputy Director General of the International Atomic Energy Agency (IAEA))
(http://japan.kantei.go.jp/incident/health_and_safety/burkart.html)

Included in this reference material on March 31, 2013
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Psychological Effects

## Psychiatric Effects on Children

**Possible psychological effects of radiation issues:**

- Parents' anxiety over radiation proves that they are dedicated parents.
- Parents' excessive concern over radiation could affect children mentally and physically.

**Regarding fetal exposure and neuropsychological disorders caused by the Chornobyl NPS Accident:**

- The results of studies on the neuropsychological disorders of children who were fetuses at the time of the accident are not coherent.
- Although there is a report that exposure affected the IQ of the fetuses, no correlation has been found between thyroid exposure doses and children's IQs.

Source: Prepared based on the Kolominsky Y et al., J Child Psychol Psychiatry, 40 (2): 299-305, 1999

In some of the studies targeting children who were fetuses at the time of the Chornobyl NPS Accident, investigations on neuropsychological effects were also conducted.

Although the results of the studies are not necessarily coherent, a report that attests to emotional disorders of the children caused by the accident also points out other effects such as parents' anxiety as factors affecting their mental state, rather than merely pointing out radiation exposure as a direct effect (p.106 of Vol. 1, "Effects on Children - Chornobyl NPS Accident -").

(For the results of the survey on children's mental health conducted by Fukushima Prefecture, see p.164 of Vol. 2, "Mental Health and Lifestyle Survey: What Has Become Clear (5/5).")

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Psychological Effects

# Response to the TEPCO's Fukushima Daiichi NPS Accident and Local Communities (1/2)

## Conclusion from dialogue with the local residents 1

(View of the International Commission on Radiological Protection (ICRP))

- Participants recognized the importance of developing radiation protection culture to allow inhabitants to understand and evaluate the information on the consequences of the accident and to take informed actions for reducing radiological exposure.
- They recognized the need for a more detailed characterization of the radiological situation to allow people to know where, when and how they are exposed.
- They underlined their concern about the future demographic pattern due to an acceleration in the younger generations leaving the prefecture and abandoning farming activities.
- They discussed with great emotion the issue of discrimination of people in the affected areas, especially for those of pre-marital age to marry and have children.
- The preservation of the traditional and popular activity of gathering wild vegetables (sansai) was identified as culturally important in maintaining the cohesion of the Fukushima community.

Source: Prepared based on Lochard, J (2012), the material for the 27th symposium of the Nuclear Safety Research Association

Providing useful information for helping affected people to solve or deal with real issues has been proven to be an effective means for offering psychological support.

In the event of a nuclear disaster, expert knowledge is required to understand the possible effects of radiation and to come up with measures for radiological protection.

After the Chornobyl NPS Accident, as well as after the Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS Accident, experts and local residents had dialogues. If affected people are able to solve radiation issues by themselves with experts' support, that is considered quite effective in reducing their psychological stress.

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Psychological Effects

## Response to the TEPCO's Fukushima Daiichi NPS Accident and Local Communities (2/2)

### Conclusion from dialogue with the local residents 2

(View of the International Commission on Radiological Protection (ICRP))

- Develop a mechanism to support projects proposed by local communities and residents to improve living conditions.
- Support community expectations that decisions on recovery actions reflect their priorities, be based on their knowledge of the local context, and support their current and future interests.
- Continue efforts to monitor individual internal and external exposures, and to provide information and tools in order to help people to make their own judgments.
- Create a forum for a permanent dialogue between all concerned parties (producers, distributers and consumers) on the issue of foodstuff.
- Promote the involvement of parents, grand-parents and teachers to develop radiation protection culture among children.
- Strengthen dialogue and cooperation with stakeholders elsewhere in Japan and abroad.

Source: Prepared based on Lochard, J (2012), the material for the 27th symposium of the Nuclear Safety Research Association

The ICRP provided some specific suggestions as a result of the dialogues between experts on radiological protection and the affected people of the accident at Tokyo Electric Power Company (TEPCO)'s Fukushima Daiichi NPS. The suggestions include the necessity to reflect the priorities of local communities, provide tools and information about radiation doses, create a permanent forum on foods, develop radiological protection culture, etc.

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Psychological Effects

## Overview of Health Effects - Chornobyl NPS Accident -

### Summary of effects on mental health

**World Health Organization (WHO) Report issued in 2006 upon the 20th anniversary of the Chornobyl NPS accident**

- **Anxieties and medically unexplained physical symptoms including depression and Post Traumatic Stress Disorders (PTSD) are increasing as stress-related disorders among the group of disaster victims, compared to a control group.**
- **The effects of the Chornobyl NPS Accident on mental health have been the biggest health issue for the residents.**

Source: World Health Organization: Mental, psychological and central nervous system effects. Health effects of the UN Chernobyl accident and special health care programmes: report of the UN Chernobyl forum expert group "Health" (eds. Bennett B., et al), 93-97, WHO, Geneva 2006

The effects of the Chornobyl NPS Accident are often cited as an example of psychological effects of nuclear disasters.

According to summaries by the International Atomic Energy Agency (IAEA) and WHO, psychological effects surpassed direct health effects of radiation.

After the Chornobyl NPS Accident, many complained about health problems because of mental stress. This was not caused solely by the effects of radiation but is considered to have resulted from a complex combination of multiple factors including social and economic instability brought about by the collapse of the USSR at the time, which caused a great deal of mental stress to people.

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Psychological Effects

## Summary by WHO - Chornobyl NPS Accident -

### Studies in the 2006 World Health Organization (WHO) Report

**(i) Stress-related symptoms**

**(ii) Concern over effects on brains in development (fetal effects)**

**(iii) Effects on decontamination workers**

- High suicide rate
- Some scholars point out concerns over functional brain disorders

Source: World Health Organization: Mental, psychological and central nervous system effects. Health effects of the UN Chernobyl accident and special health care programmes: report of the UN Chernobyl forum expert group "Health" (eds. Bennett B., et al), 93-97, WHO, Geneva 2006

The WHO Report summarizes psychiatric consequences of stress from the nuclear disaster, pointing out the following four points:

The first is about stress-related symptoms. The study reports that the percentage of those claiming unexplainable physical symptoms or health problems based on self-assessment in a group of exposed people was 3 to 4 times larger than that in a control group.

Secondly, it was found that mothers who were pregnant when the accident happened have been deeply concerned about radiation effects on the brain functions of their children. For example, to a questionnaire question such as “if they believe their children have problems with their memory,” 31% of mothers in mandatory evacuation areas answered yes, which is 4 times larger than the percentage (7%) of mothers in uncontaminated areas who answered yes.

The third and fourth points are radiation effects observed in decontamination workers.

A follow-up study on 4,742 Estonians who participated in decontamination operations found that 144 of them had been confirmed dead by 1993, with 19.4% of them dying by suicide, although no increases were seen in cancer incidence and mortality rates.

Additionally, there was a study report that functional brain disorders were found in decontamination workers with the highest exposure doses. However, such findings are criticized for a lack of scientific correctness as alleged by some researchers and are not confirmed individually.

Included in this reference material on March 31, 2013
Updated on March 31, 2024

Psychological Effects

## Views of Expert Groups - Chornobyl NPS Accident -

### Summary by Bromet et al. (2011)

(1) Among workers who participated in emergency work immediately after the accident and decontamination operations, a significant percentage is still suffering from depression and PTSD, even after the lapse of 20 years from the accident.

(2) Different studies show different results about psychiatric effects on children in the highly contaminated areas.

(3) Studies on general populations have found that the percentages of self-reported health problems, clinical or preclinical depression, anxiety and PTSD are high.

(4) Mothers remain in a psychiatric high-risk group as they have been concerned about family health at all times.

Source: Bromet EJ, JM Havenaar, LT Guey. A 25 year retrospective review of the psychological consequences of the Chernobyl accident, Clin Oncol 23, 297-305, 2011

In 2011, a research group specialized in psychiatry and preventive medicine published a paper detailing what psychiatric effects of the Chornobyl NPS Accident were observed.

It has been found that among a group of workers who worked at the site immediately after the accident and who were exposed to high levels of radiation, a significant percentage is still suffering from depression and PTSD, even after the lapse of 20 years from the accident. Different studies show different results concerning radiation effects on toddlers and fetuses who lived around the plant or in the highly contaminated areas at the time of the accident. For example, studies conducted in Kiev, Norway and Finland on children who were exposed to radiation in their mothers' wombs suggest that they had specific psychiatric and psychological disorders, but other studies do not observe such health problems. Studies on general populations have found that the percentages of self-reported health problems, clinical or preclinical depression, anxiety and PTSD are high. Mothers remain in a high-risk group from a psychiatric viewpoint as they have been concerned about family health at all times.

In the case of the Chornobyl NPS Accident, all such symptoms are not attributed solely to concern over radiation. Distrust of the government, inappropriate communications, the collapse of the USSR, economic issues, and other factors would also have had some relevance and some of them would have had a combined effect, rather than one factor being the sole culprit.

Included in this reference material on March 31, 2013
Updated on March 31, 2024

**Psychological Effects**

## View Different from the 2006 WHO Report
### - Chornobyl NPS Accident -

**2006 World Health Organization (WHO) Report：**

**Mental health such as anxiety is the biggest problem for regional healthcare.**

**Against this,**

**concerns have been raised over the decrease in international investigations since the 2006 WHO Report.**

**(i) It has been pointed out that the physical effects and damage from the Chornobyl NPS Accident might be greater than the estimate in the WHO Report, and that it would be necessary to continue international investigations.*1**

**(ii) There has been a criticism that the WHO's view would make people less wary of foods from the contaminated areas and could impede future investigations and research.*2**

*1: This view is based on the fact that in Rivne in Ukraine, the incidence of neural tube defects is 22.2 per 10,000 people, the highest throughout Europe. (Wertelecki, Pediatrics, 125, e836, 2010)

However, it has not been clear what is causing this.

*2: Holt, Lancet, 375, 1424 - 1425, 2010

There are also reports arguing that the WHO Report overestimates mental health aspects such as anxiety and underestimates physical effects.

These reports rely primarily on a report that people living as an isolated Polish community in the Rivne province of Ukraine, called “Polishchuks,” have a high incidence of neural tube defects. Because the effects of consanguineous marriage are also suspected and neural tube defects could be also caused by folate deprivation and maternal alcohol use, it is unclear whether the high incidence of neural tube defects in the Rivne province has been caused by radiation from the Chornobyl NPS Accident or other effects, or their combinations.

(Related to p.107 of Vol. 1, “Knowledge on Malformation Induction - Chornobyl NPS Accident -”)

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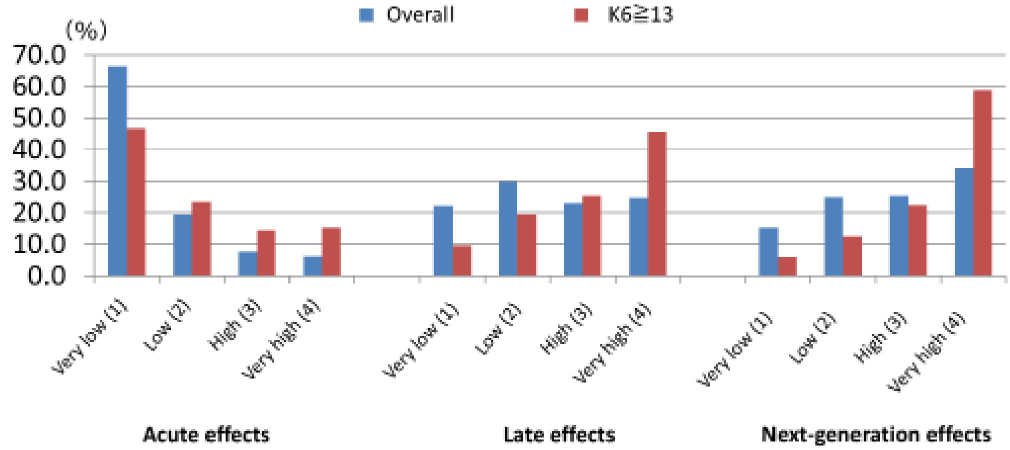
## Psychological Effects — Relationship between Mental Health and Perception of Risks Concerning Health Effects of Radiation

Results of the Mental Health and Lifestyle Survey of the FY2011 Fukushima Health Management Survey




*K6 is a self-recording scale to measure general levels of mental health. Scores exceeding 13 show strong depression and anxiety symptoms.

- **Overall trend**
  The majority answered that the possibility of acute effects is very low. Opinions vary with regard to late effects. The largest number of respondents chose the option "very high" for next-generation effects.
- **Among people with mental disorders**
  The percentages of respondents who chose the option "very high" were large for all three types of effects.

Source: Prepared based on Suzuki Y, et. al., Bull World Health Organ, 2015 (http://dx.doi.org/10.2471/BLT.14.146498)

As part of the Fukushima Health Management Survey, Fukushima Prefecture conducts the Mental Health and Lifestyle Survey targeting residents of evacuation areas, etc. every year (see Vol. 2, “10.5 Mental Health and Lifestyle” for details). The 2011 survey asked about the perception of (i) acute effects (hair loss and bleeding), (ii) late effects (thyroid cancer and leukemia), and (iii) any next-generation effects of radiation. As a result, the following were found.

- There are very few people worrying about acute exposure, but the majority have concerns over late effects and next-generation effects.
- Those worrying about radiation effects as indicated in their responses to all three questions clearly show worse mental health conditions and have depression and anxiety symptoms.

Given these, it can be said that people who are apt to have negative perception of risks are highly likely to have strong depression and anxiety symptoms as well.

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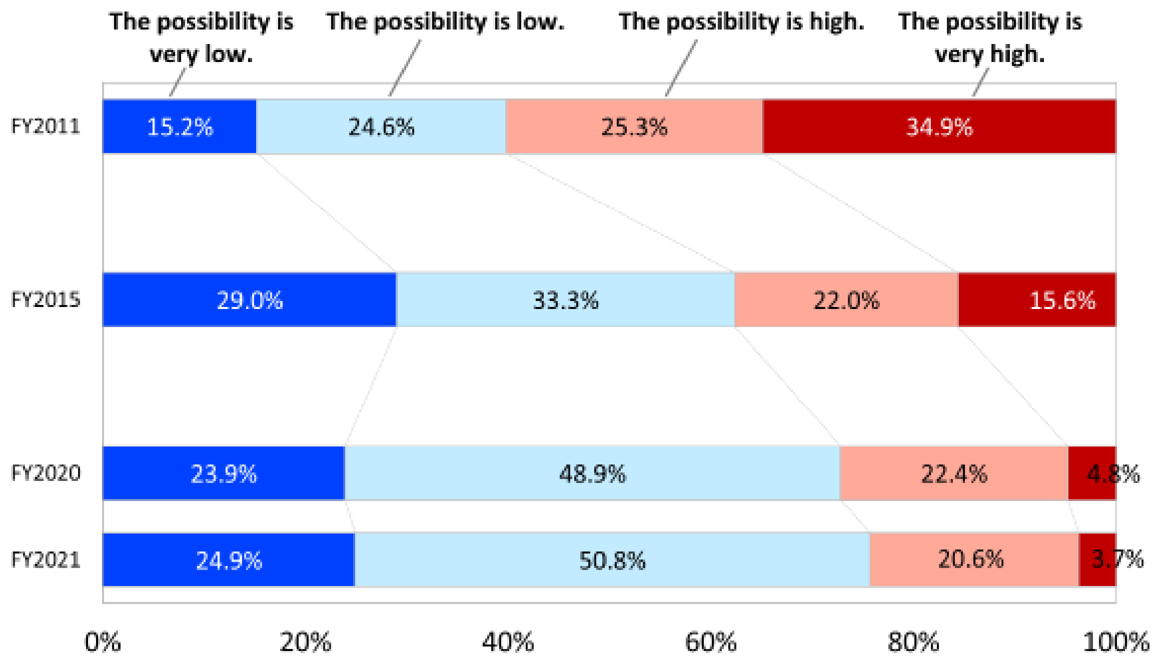
Updated on March 31, 2022

Psychological Effects

## Changes in Perception of Radiation Risks (Next-generation Effects)




Source: Prepared based on the materials of the 45th and 48th Prefectural Oversight Committee Meeting for Fukushima Health Management Survey

As shown on p.151 of Vol. 1, “Relationship between Mental Health and Perception of Risks Concerning Health Effects of Radiation,” the Fukushima Health Management Survey examines perception of risks concerning health effects of radiation (late effects and next-generation effects) every year. The percentages of respondents answering that the possibility is high are gradually decreasing for both questions. However, what should be noted is the fact that a larger number of people every year worry about next-generation effects rather than late effects. The figure shows changes over the years in responses to questions about next-generation effects. The percentage of people worrying about next-generation effects is decreasing gradually but still remains at around 30% as of FY2021.

Such worries over next-generation effects of radiation tend to cause discrimination and prejudice and doubt about future chances of getting married or having children. If affected people themselves feel in this manner or have self-stigmas (self-prejudice), their confidence and identity may be shaken significantly and their future life plans may be affected accordingly. It is necessary to note the sensitiveness of such worries and prejudice for affected people (p.143 of Vol. 1, “Radiation Accidents and Health Concerns”).

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**Psychological Effects**

## Increase in Induced Abortions in Europe
**- Chornobyl NPS Accident -**

**The Chornobyl NPS Accident occurred on April 26, 1986.**

**Increase in induced abortions in remote places**

**Greece: Sharp decline in birthrate in January 1987**

⇒Induced abortions for 23% of fetuses in the early stage of fetation in May 1986 (estimation)

**Italy: Approx. 28 to 52 unnecessary abortions per day for five months after the accident (estimation)**

**Denmark: Slight increase**

**Sweden, Norway, Hungary: None**

Source: Prepared based on the Proceedings of the Symposium on the effects on pregnancy outcome in Europe following the Chernobyl accident. Biomedicine & Pharmacotherapy 45/No 6, 1991

Excessive concern over the health effects of radiation could be harmful both physically and mentally.

For example, resulting suicide attempts and alcohol addiction are harmful to the body.

There is a report that spontaneous abortions increased because of stress after the Chornobyl NPS Accident. There is also a report that induced abortions increased even in areas remote from the Chornobyl NPS. In Greece, the effect of the Chornobyl NPS Accident was minor within the level below 1 mSv, but the number of pregnant women who chose abortion increased in the next month after the accident and the number of births sharply declined in January of the next year. Based on the birth rate, it is estimated that 23% of fetuses in the early stage of fetation were aborted. On the other hand, in such countries as Hungary, where abortion is not allowed unless fetal exposure dose exceeds 100 mSv, no abortions were performed.

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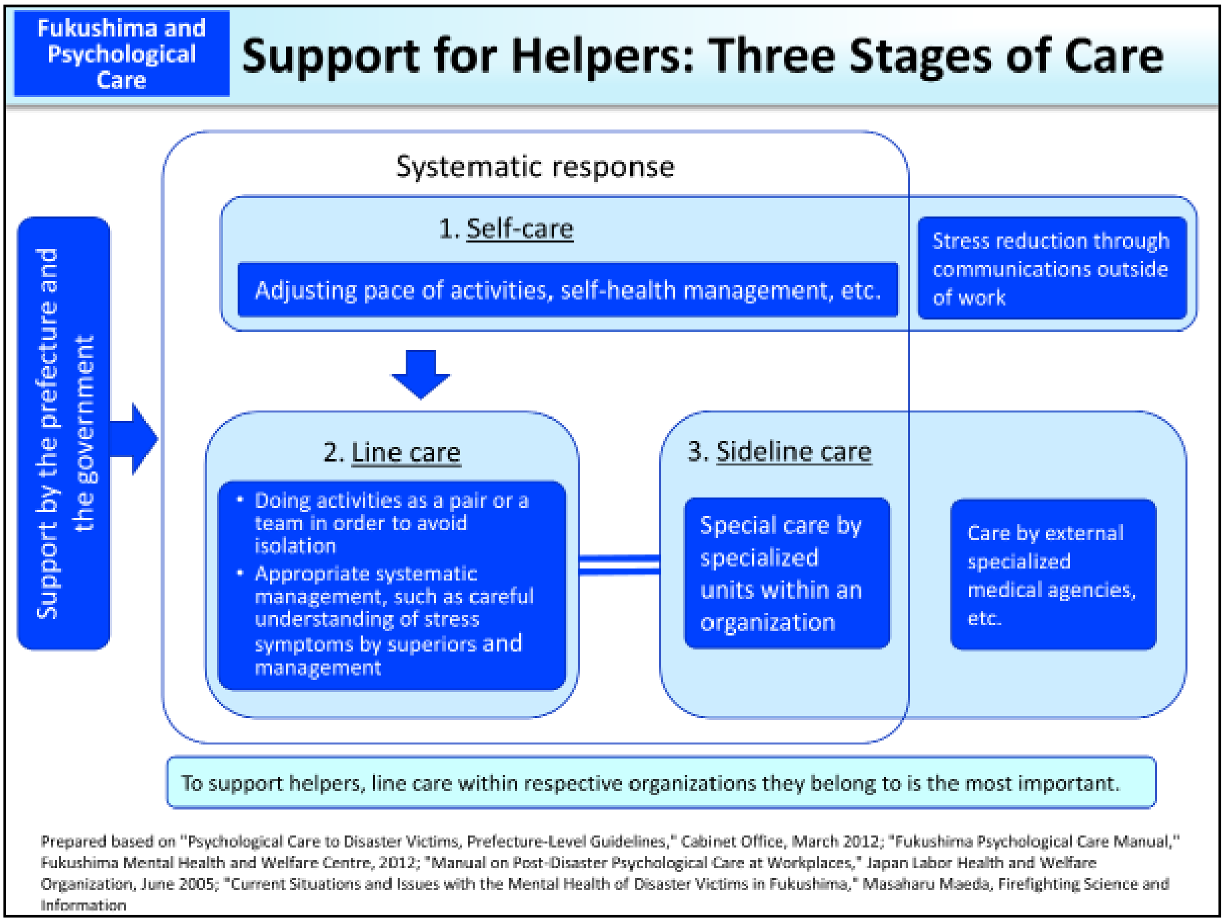



Support service providers to affected people, such as civil servants and medical personnel, are often in positions to closely witness the agony of the affected people and tend to feel helpless or guilty as no immediate solutions are available.

To provide psychological care to them, support within respective organizations they belong to is the most important and such support would help maintain the stability and constancy of the organizations. However, in Fukushima Prefecture, issues to be handled are too wide-ranging, long-term, and complex to find goals or processes for their solutions, so it is difficult to provide support solely by respective organizations.

It is important for such helpers to care for themselves by being aware of their difficult situation and trying to relieve stress by themselves in the first place. Secondly, it is also important for superiors, management or coworkers to detect any problematic symptoms at an early stage and provide care within respective organizations. Furthermore, establishing a specialized unit outside the organization that offers support would be one option. In order to construct such a support system, psychological education and awareness-raising activities targeting managers (also for their own sake) would be very important.

Fukushima Prefecture and the government are providing support for psychological care to the affected people directly and indirectly through psychological care support projects for the affected people, etc.

(Related to p.155 of Vol. 1, “Stress Measures for Helpers”)

Included in this reference material on March 31, 2016

Fukushima and Psychological Care

## Stress Measures for Helpers

**Support for helpers within respective organizations**

1. **Set work goals**
   - Clarify the importance and goals of jobs
   - Keep daily reports, diary or a note of activities to organize thoughts
2. **Maintain the pace of life**
   - Get enough sleep, nutrition and water
3. **Take rest when possible**
4. **Figure out how to get refreshed**
   - Take a deep breath, close eyes, meditate, do stretches
   - Take a walk, do exercise, listen to music, have meals, take a bath, etc.
5. **Socialize as a way of relieving stress**
   - Contact family, friends, etc. when possible (preferably people unrelated to work)

**Self-support of helpers**

a. **Avoid overworking**
   - Know your limits and adjust the pace of activities

b. **Be aware of stress**
   - Manage your own health and detect stress symptoms at an early stage

c. **Try to relieve stress**
   - Relaxation, body care, refreshment
   - Communicate with people outside work (family, friends, etc.)

d. **Avoid isolation**
   - Work as a pair or a team

e. **See things differently**

Source: Prepared based on the "Fukushima Psychological Care Manual," Fukushima Mental Health and Welfare Centre, 2012

"Fukushima Psychological Care Manual" by the Fukushima Mental Health and Welfare Centre provides guidelines regarding stress measures for helpers.

Helpers' self-support efforts include avoiding overworking and being aware of their own stress, etc. It might be difficult to avoid overworking given the situation they are in, but it is important for individuals to know their own limits so that they can adjust the pace of activities and to hand off work to someone else in order to avoid meeting too many affected people in a day. Having stress symptoms is not something to be ashamed of but an important clue for self-health checks. It is necessary to manage health by oneself and notice any symptoms at an early stage. Relaxation, body care, refreshment, and communication with people outside work (family, friends, etc.) are effective in relieving stress. Isolation should be avoided as much as possible in a situation where one can easily become stressed out, so it would be necessary to work as a pair or a team and to have opportunity to share experience (disaster situations individual helpers witnessed and their feelings) with coworkers on a periodic basis or to be given instructions from senior workers, etc. It is natural that individuals cannot change everything on their own, especially in difficult situations after disasters, so it is better to rate one's own activities positively and there is no need at all to have negative thoughts considering not being fit or competent for the job.

The manual also cites some concrete ways to provide care for helpers within respective organizations.

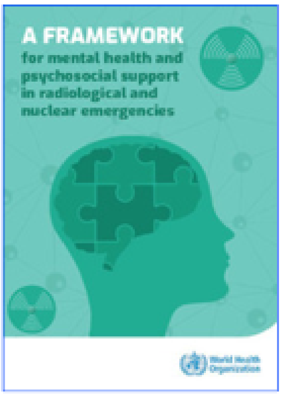
- Feeling guilty about taking a rest alone while others are working is a sign of stress.
- When noticing any physical or psychological symptoms, consult with a superior or coworkers at an early stage.
- Exchange words with coworkers as often as possible to encourage each other.
- Be careful about one's own health and coworkers' health and tell the relevant person and the supervisor if someone has too much workload.

(Related to p.154 of Vol. 1, "Support for Helpers: Three Stages of Care")

Included in this reference material on March 31, 2016

# MHPSS in Radiological and Nuclear Emergencies

◆ In 2020, the World Health Organization (WHO) published "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies," material compiling concrete recommendations concerning psychological care in all radiological and nuclear emergencies based on existing guidelines published by the WHO and the Inter-Agency Standing Committee (IASC).
◆ This publication aims to integrate and promote psychological care and radiation protection and provide guidance targeting officials and specialists involved in planning radiation protection and countermeasures and risk management as well as mental health and psychosocial support (MHPSS) experts working in health emergencies.




As a public health approach with an emphasis on MHPSS interventions, the following are essential for all phases of preparing for, responding to, and recovering from radiological and nuclear emergencies:

1. Cross-sector coordination between radiation protection and MHPSS actors
2. Community engagement
3. Risk communication
4. Application of core-ethics principles

Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO [The Japanese version is posted on the website of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

"A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" published by the WHO in 2020 states that psychological care is indispensable at all phases of preparing (planning) for, responding to, and recovering from radiological and nuclear emergencies. Additionally, the significance of cross-sector coordination for bringing about successful recovery is emphasized.

For achieving timely and proper MHPSS interventions, the following are specifically recommended: General health and mental health professionals should advocate and work in partnership with other sectors (for instance, communication, education, community development, disaster coordination, child protection, police); A community-based approach should be adopted to encourage risk communication and community engagement so that affected people can play positive roles in activities for improving their own wellbeing.

This publication also explains key measures at the phases of planning and making responses concretely, such as the need to ensure consistency in messages and information provided by public organizations, to prepare messages regarding health risks and prediction thereof, protective measures and preventive measures that are clear and easy to understand for affected people, and to provide psychosocial support intensively to at-risk groups and to people having psychological distress. Additionally, core ethical considerations necessary for all people involved in the provision of psychological care are also explained.

Included in this reference material on March 31, 2022

Psychological Care in Nuclear Emergencies

## People Especially in Need of Psychological Support after Emergencies

- People **directly** affected
- **Parents** concerned about the long-term impact on their children's health and prospective parents
- **Children** from affected areas
- People **with underlying health concerns**, such as people suffering from diseases, elderly people, and people with disabilities
- People **with low literacy levels**
- **Responders*** working in stressful conditions
- People living in **facilities for the elderly or other residential facilities and institutions**
- **Evacuees** and members of **hosting communities**
- People with pre-existing mental health and **psychosocial concerns**
- **Workers of the nuclear facility** where the accident occurred and their families

* Respondents: Healthcare workers, clean-up workers at the accident site, reporters and other responders

Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO [The Japanese version is posted on the website for lectures of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

“A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies” published by the WHO in 2020 states that even in the case of a nuclear disaster, many people show resilience, meaning they are able to cope relatively well in adverse situations, and not everyone has significant psychological problems or develops depression, anxiety disorders or PTSD. However, it also calls for attention to the fact that risks for psychosocial problems may increase among specific groups of people depending on the circumstances of an emergency.

This framework points out, as responses to people particularly at risk, the significance of providing psychological care covering affected people as a whole and at the same time formulating good programs suited to individual groups, based on the understanding that those with higher risks also have resilience.

Included in this reference material on March 31, 2022

## Psychological Care in Nuclear Emergencies

# Key MHPSS Elements at Each Phase after Emergencies

| | |
|---|---|
| **Preparation and planning phase** | 1) A risk and vulnerability analysis and needs assessment |
| | 2) Formulation of general mental health policy while involving diverse sectors and people |
| | 3) Mapping of existing resources |
| | 4) Mental health and psychosocial support (MHPSS) integration into general health care |
| | 5) Monitoring and evaluation of MHPSS implementation |
| **Emergency response phase** | 1) Understanding of psychological impacts due to emergency protective actions |
| | 2) Explanation of proper methods of emergency protective actions and communication |
| | 3) Decision-making concerning the implementation of protective measures |
| | 4) Identification of people at risk, interventions and advocacy |
| | 5) Re-establishment of normal cultural and religious events, resumption of schooling, and re-establishment of healthy events |
| **Recovery phase** | 1) Engagement of related parties in diverse fields for the recovery of communities |
| | 2) Development of support services within a long-term perspective |
| | 3) Appropriate responses to stigma |
| | 4) Community-based interventions |
| | 5) Planning and implementation of care for groups at risk (children, people with disabilities, etc.) |
| | 6) Efforts to deal with a lack of financial resources and human capacity |

Source: Prepared based on "A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" (2020), WHO [The Japanese version is posted on the website for lectures of the Department of Disaster Psychiatry, Fukushima Medical University (https://www.d-kokoro.com/).]

"A Framework for Mental Health and Psychosocial Support in Radiological and Nuclear Emergencies" published by the WHO in 2020 compiles key MHPSS elements at the planning, response, and recovery phases after emergencies respectively by separating chapters.

Throughout all chapters, it is emphasized that MHPSS should never jeopardize the implementation of protective actions to reduce people's exposure to radiation at any phase, and for that purpose, radiation protection and MHPSS should be well-balanced with the involvement of individual communities.

At the preparation and planning phase, the assessment of actual radiation hazards and risks as well as mapping (positioning and description) of resources should be conducted to set priorities in MHPSS methods for individual protective actions, and plans for MHPSS integrating into general health care should be formulated. At the response phase, training should be provided to responders so that they can understand psychological impacts due to protective measures and can provide explanations focused on health regarding reasons why protective actions are necessary and offer support for decision-making. At the recovery phase, it is important to develop support services from a long-term perspective, while focusing on medium- and long-term development of community, and on evidence-based mental health services and psychosocial interventions, and conduct care for groups at risk and countermeasures against stigma on an ongoing basis.

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