Risks Associated with Utilization of Nuclear Energy and Radiation
and
Lessons Learned from Accidents and Disasters

2007

JNES

Contents

1. Preface

One of the most important matters for promotion of peaceful utilization of nuclear energy is to ensure safety. Human beings ensure nuclear safety. However, human beings can never be perfect. Therefore, continuous efforts are always required to fully accomplish safety. It is important to improve safety with continuous efforts, based on the complete recognition of human beings' imperfectness and maintain the socially accepted maximum safety.

For that purpose, it is important for anyone who works in the nuclear safety to address the safety fitness through design, construction, operation of facilities, and monitor potential risks and to implement preventive measures against accidents.

First of all, it is necessary to identify what should be addressed to ensure nuclear safety. In what follows, potential risks associated with utilization of nuclear energy and accidents and disasters in the past are discussed.

Note: Safety Fitness is efforts to ensure safety and to meet the safety requirements.

2. Potential Risks Associated with the Utilization of Nuclear Energy

2.1 Nuclear Energy and Radiation

The peaceful utilization of nuclear energy is generally divided into tow forms: (1) nuclear power generation as a big electric energy source, and (2) radiation sources used for X-ray inspections, radiation treatment at hospitals.

First, potential risk factors involved in the nuclear power generation as an electric energy source are discussed. The energy in a nuclear power plant is generated by nuclear fission reactions of atoms. This energy has an outstanding difference from that of chemical energy having been used by human beings until now such as fossil fuels. The amount of energy generated by nuclear fission of one uranium atom is about millions times larger than that by combustion of one carbon atom.

Materials containing atoms of uranium, plutonium etc., which prone to cause nuclear fissions of atomic nuclei when collided with neutrons, are used to produce energy. The energy generated by nuclear fission is taken out artificially for utilization as electricity, technically controlling the nuclear fission rate (Reference Sheet 1). Fragments produced by nuclear fission are called “fission products” and almost all of them are radioactive. Therefore, a large amount of radioactive materials are accumulated in a core as a result of operation. Moreover, the reactor structure is activated*1 by the neutrons collisions.

The energy produced and these radioactive materials generated and accumulated by nuclear fission are major factors for the potential risks of nuclear power generation.

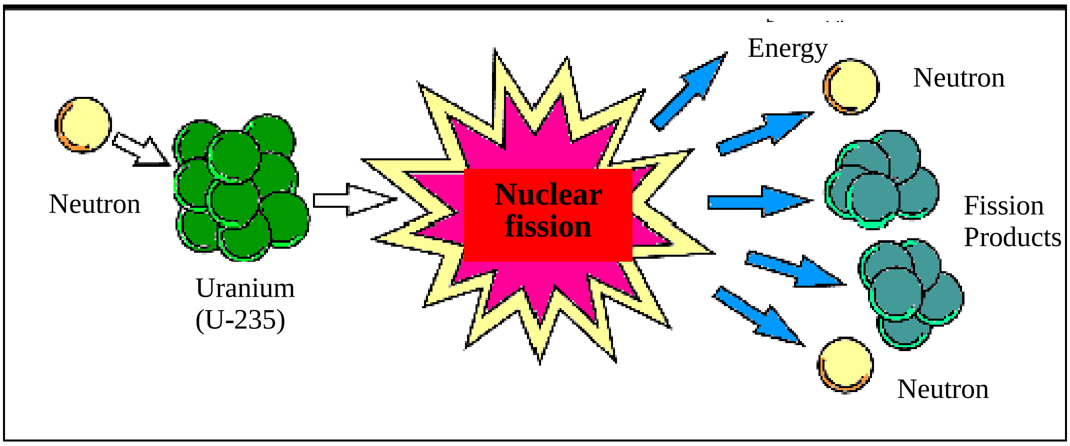


Figure-1: Mechanism of nuclear fission

Next, merits and demerits of the X-ray inspection and radiation treatment in the medical field and the radiation utilization in the industrial fields are discussed. The inspection, diagnosis, and the cancer therapy by X-ray, etc. at hospitals in the medical field (Reference Sheet 2) are essential. And property improvements such as, plastics, manufacturing of semiconductor devices and nondestructive inspections are conducted in the industry field using X-ray. Moreover, radiation irradiation has been widely used even in our everyday life for sterilization and deterioration prevention of foods, and sterilization of medical devices. Furthermore, the nuclear is essential means also in the field of cutting-edge research and development including observation, measurement, micro fabrication, etc. in the microscopic world (submicroscopic) such as atoms and molecules.

Radiation is a flow of particles or waves with energy, including electromagnetic waves and particle rays that are emitted when energetically unstable atomic nuclei change to more stable atomic nuclei. The nature to emit radiation is called radioactivity and materials with radioactivity are called radioactive materials.

Besides, the cosmic rays always showering from the cosmos are also radiation, and the accelerators used for nuclear physics research and medical applications generate radiation.

Our five senses cannot detect radiation, but appropriate instruments could measure an ultra-micro amount of radiation down to each electron flow existing in the nature.

While radiation brings many benefits, exposures to radiations exceeding the permissible dosage due to wrong usage or treatment, or careless control, etc. will cause adverse effects.

As mentioned above, it is important to thoroughly conduct radiation protection and radiation control not to cause a careless exposure to radiation by securing radioactive materials in a container by shielding the radiation generated in fission reactions and the radiation in the medical and industry uses.

2.2 What Are the Potential Risks Involved in Utilization of Nuclear Energy?

The radiation from radioactive materials, an accelerator or an X-ray generator etc. has potential to pollute the surrounding environment, or give unexpected excessive radiological exposures or health hazards to persons engaged or residents in the vicinity. The danger due to an accident is called "**Potential Risk**."

In the most serious case, release of a large amount of radioactive materials due to an accident at a nuclear reactor facility causes early effects (also called as the acute effect) and late effects such as cancer to a human body. The accident occurred at the Chernobyl Nuclear Power Plant in the former Soviet Union in 1986 is an obvious example of such potential risks occurred unfortunately due to a defective design and violations of the operating rules, etc. Moreover, as nuclear fuel use facilities process nuclear substances such as uranium and plutonium, there is a risk of radiological exposure in a nuclear criticality accident. The nuclear criticality accident (hereinafter referred to as the "JCO accident"), which occurred on September 30, 1999 at the JCO uranium processing plant in the Tokai Village, Ibaragi Prefecture in Japan is an example of such cases.

The amount of radioactive materials used in medical and industrial applications is much smaller compared with that of nuclear facilities and they are usually used in a form of sealed source. Therefore, the risk of exposure is small, but it is possible to cause an excessive exposure with a radiation source directly contacted to a human body if the source is not properly controlled. In February 2000, there was a report in Thailand that workers received extensive exposures during dismantlement of a stolen radiation treatment device left without safety measures and three persons died.

Such potential risks involved in utilization of nuclear energy must be strictly controlled in accordance with requirements, criteria and procedures stipulated for each phase of design, construction, operation or maintenance, so that the risks would not become surfaced. The reasons come from the facts such as: (1) in case of radioactive materials release with failed control, the subsequent treatment such as decontamination is not easy, (2) since radiation cannot be detected by human beings' five senses, it is difficult to conduct radiological protection without special knowledge, equipment and/or components, and (3) as the degree of effects by radiation on a human body depends on conditions, the expert judgment is required,

On the other hand, radiation has a special characteristic that it can be measured easily even with a very small amount by equipment dedicated to radiation. Nuclear facilities or radiation handling facilities should be designed and equipped so as to detect very small amount of radiation and to take actions. Moreover, occupational radiation workers should work equipped with radiation measurement devices (film badges, dosimeters etc.) by monitoring their radiological exposure level.

2.3 Risks and Profits Involved in Utilization of Nuclear Energy

Potential risks involved in the utilization of nuclear energy cannot be a reason to determine that nuclear energy cannot be used. People often judge based on a risk that is obtained by multiplying the damage that a hazard could cause by the probability that the damage could be surfaced. In utilizing nuclear energy, various measures are employed to reduce the risk. The reason why the utilization of nuclear energy has been accepted despite its potential risks comes from the fact that the benefits for people’s life and industrial activities exceed the potential risks. It is considered that nuclear contributes to securing long-term energy sources for human beings, a wide range of radiation utilization in the fields of medical, industrial, and agricultural applications, and promotion of technology in the microscopic world.

Such comparison and judgment are usually made in the utilization of all technologies. There are many cases around us that are being used because of their obtainable profits even if accidents are expected to occur at certain probabilities. Airplanes and railways are such examples. The reason is that their returns are socially considered to be greater than their risks involved. （Reference Sheet 3 ）

2.4 Effects of Radiological Exposure

Then, what effect does the radiological exposure have on the human body? Our body is exposed to various stimuli from the environment. They include chemical irritation by absorption of a small amount of pollutants in air and hazardous materials in foods, and intrusion of microorganisms such as invisible viruses, bacteria and mold, as well as cosmic rays continually showering to us, radiation from rocks and buildings, physical irritation of the ultraviolet ray in the sunlight, and temperature change. As to radiation, human beings are always exposed to the natural radiation from the time of birth, and take in radioactive elements such as potassium-40 through meals. Moreover, we are exposed to artificial radiation*4 in everyday life, such as X-ray inspections. Hazards to living bodies such as radiation, oxygen, ozone, nitrogen dioxide, foreign materials, and a certain kind of carcinogens and defense mechanisms against them are largely common, and basically free radicals*6 such as active oxygen*5 are involved with them.

Living organisms survive conquering various kinds of daily-exposed stimuli around us because living bodies have very skillful and powerful defense mechanisms. Free radicals, such as active oxygen, are produced physiologically and daily also within our body. De-oxidation materials such as glutathione, vitamin C, vitamin E, also exist within the body to limit the amount of free radicals not to increase more than a certain level. When the defending system for free radicals does not fully work, the organisms receive damage through a process as shown in Figure-2. Radiation damage to living organisms is mainly caused by the free radicals generated in the body by radiation. Radiation and free radicals damage DNA*7 molecules directly, and if they do not heal and also the damaged abnormal cells cannot be removed by the immunity ability etc., they are likely to lead to cancers afer a long lapse of years.

When exposed to the radiation exceeding the defensive ability of the human body, we receive radiological effects that differ in nature and their degrees depending on the exposure level as shown in Table-1. Namely, radiation effects on human body (Reference Sheet 4) are diverse depending on the received doses. When exposed to excessive radiation unfortunately, various early effects (called acute effect) and latent effects occur depending on the exposure dose.

The early effect develops within ten days after radiological exposure, but it is said that this effect, if the dose level below a certain level, will not develop to the extent that is medically detectable. This dose level is called the "threshold dose." According to the current knowledge, the organ of human being (except embryo) with the lowest threshold dose (i.e., most vulnerable to radiological consequence) is male genital gland, which will cause temporary infertility if exposed to radiation equal to or more than 150 mSv*8. And, if a whole body is exposed to radiation of 500 mSv or more, the radiological effect is medically detectable as the lymphocyte in peripheral blood decreases temporarily. If exposed to a large amount of radiation, for an example, more than 1 Sv (=1000 mSv), various harmful effects develop as shown in Table-1.

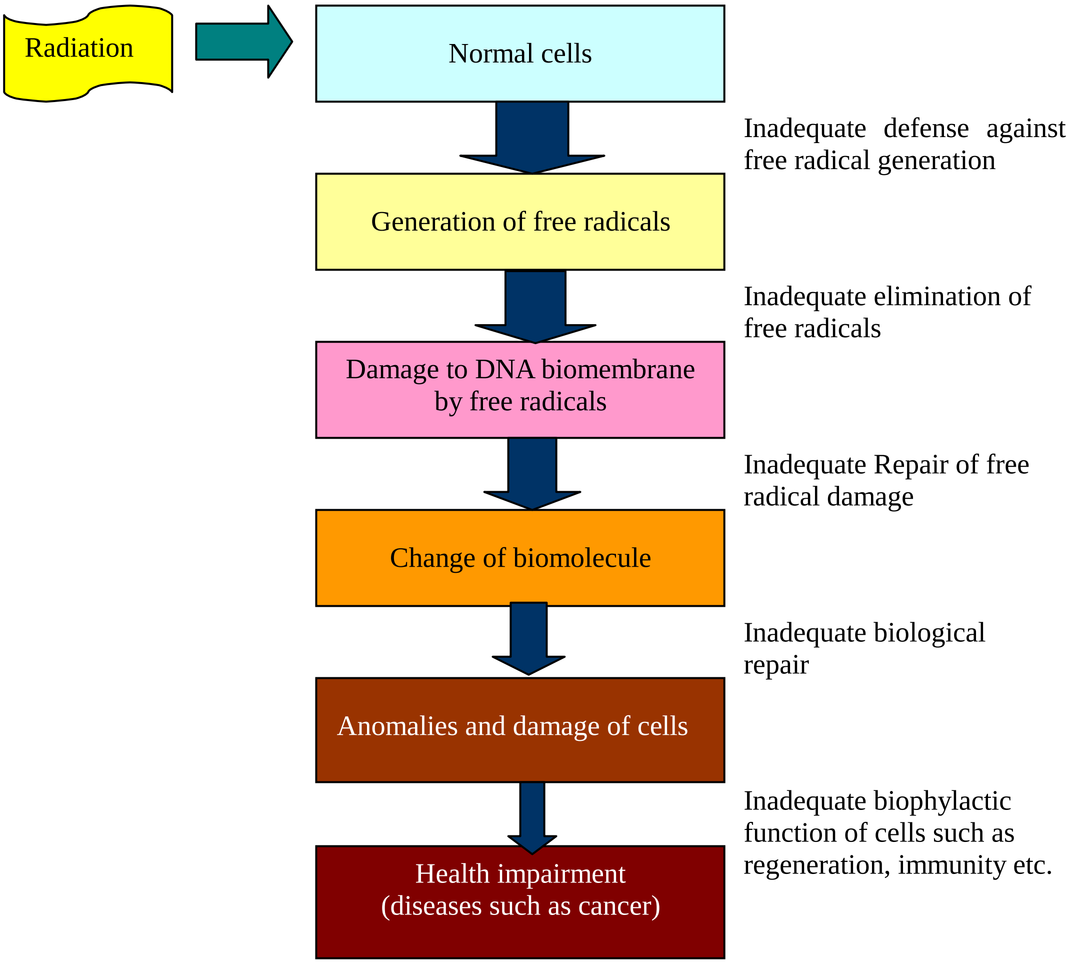


Figure-2: Appearance and defense mechanism of the physical damage produced to a living body with radiation (Reference Sheet 5)

The living body is provided with various "defense mechanisms" which prevent the change of cells caused by radiation, hazardous materials etc. from developing into physical damage. As radiation effects to the living body, there are "direct effect" caused when DNA of cells are directly exposed to radiation and "indirect effect" caused when DNA etc. are damaged by free radicals that are produced by radiation exposure to intracellular water and organic substances, etc. Various defense mechanisms exist and work for either of those effects. One of the simplified defensive processes is shown in Figure-2. When defense and healing are inadequate at each stage, it proceeds to the next stage.

Typical effects develop when a whole body is exposed to radiation as shown in Table-1 (Data was summarized referring to 1990 recommendations, the 2000 report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)), etc.). When focusing on one certain effect, the way the effect occurs differs depending on the physical conditions such as dose rate and the biological conditions of human body such as age and nutritional status.

Table-1: Effect of a human body by whole-body radiation exposure

Exposure doses	Effect to human body (one short-time exposure)
Equal to or more than 100,000 mSvs (100 Sv)	Acute nervous shock
Equal to or more than 15,000 mSvs (15 Sv)	Death due to the nervous damage
From 5,000 to 15,000 mSv (5 to 15 Sv)	Damage to the alimentary canal and lungs
From 3,000 to 5,000 mSv (3 to 5 Sv)	Marrow damage
Equal to or more than 1,000 mSv (1 Sv)	Appearance with self-conscious and medical view (nausea vomiting etc.)
Equal to or more than 500 mSv	Possible view for temporary blood count reduction etc.
About 100 mSv	Threshold value of causing a deformity of people
More than 50 to 200 mSv	Detection of a carcinogenic stochastic effect by an epidemiologic survey

An example of the radiation control criteria established for the radiological protection is shown in Table-2 (limits by the 1990 Recommendations of the International Commission on Radiation Protection (ICRP) and the relevant laws).

Table-2: Example of radiation control criteria

100 mSv	Occupational dose limit in an emergency
100 mSvs / 5 years	Occupational dose limit in an emergency in 5 years (but not exceeding 50 mSv in one year)
10 - 50 mSv	Sheltering level in an emeregency
1 mSv	Dose limit of the public in one year

The latent radiation effect is an effect that appears after several years or more after radiological exposure, which is known to generate malignant tumor (cancer) or leukemia. As carcinogenesis evolves through many stages as shown in Figure-2 taking a long time and interacting with a human body and the environment, it is believed that the probability becomes high in proportion to the amount of radiation, though the same effect does not necessarily occur to all exposed persons.

The epidemiologic surveys on survivors of the atomic bombings of Hiroshima and Nagasaki over 40 years and those of the A-bomb explosion test victims and nuclear facility workers show that an extensive radiological exposure is likely to induce a certain kind of cancer such as leukemia. On the other hand, the effect of Chernobyl accident which released a large amount of radioactive materials into the environment is confirmed up to now to have increased only an infant thyroid cancer as the health effect to general population, but it is likely that there is a risk of thyroid cancer and other cancers among people exposed to radiation by this accident at the time of childhood.

The 1990 Recommendations of International Commission on Radiological Protection (ICRP) *9 estimates that the possibility of carcinogenesis by radiation (risk) for a person exposed to 1 Sv has about 5 % or 10 % larger cancer risk during their life time compared with those not exposed, and this trend is expected to extend to the low-dosage range, proportional to the dosage. This is a rough estimate based on the hypothesis, but, as about 25 to 30 % of us usually die of cancer, it means that the probability increases to about 30 to 40 %. Therefore, if exposed to ten mSvs, the final carcinogenic probability will increase about 0.05 % to 0.1 % statistically.

Although a possibility of genetic effect (Reference Sheet 6) on the descendant of the exposed person is also expected as another radiological exposure effect, it is not detected in the epidemiologic survey after an exposure of Hiroshima and Nagasaki, or Chernobyl.

2.5 Dose Limits for Radiation Control

The 1990 Recommendations of the International Commission on Radiological Protection (ICRP) specified 1 mSv/year as the public exposure dose limit, but, this is the criteria for not giving the general public the increase in a risk by unnecessary radiological exposure, and does not indicate limits on whether radiation effects on people exists or not.

According to the 2000 Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), people are exposed to about 2.4 mSvs/year from the natural world as the world average, about 0.4 mSvs/y in average from medical diagnoses etc., and about 2.8 mSvs/year in total.

The dose limit for the public of 1 mSv/year is a control criterion that is the limiting goal to exposure other than the above-mentioned everyday-life exposure (refer to Table-2). Administrative parties and the licensees involved in nuclear or radiation businesses have made efforts to strictly comply with the radiological protection criteria in order to avoid unnecessary radiological exposure of workers or the public.

The International Commission on Radiological Protection (ICRP) recommends the fundamental concept of ALARA (As Low As Reasonably Achievable): "All exposures, taking economical and social factors into considerations, shall be kept as low as reasonably achievable" from a radiological protection standpoint even if the dose is very low below the level supposed to have effects, and this principle is observed in both overseas and Japan.

3. History of Accidents and Disasters and the Lessons Learned

While human beings have benefited from nuclear power, they have turned the potential risks into actual risks, and experienced many accidents and disasters. This section shows examples of accidents that have caused significant consequences on the safety, discusses how those accidents and disasters occurred, and what lessons nuclear-related persons have learned from those. The importance of teaching the lessons learned to nuclear-related persons and constant efforts to resolve the issues are suggested.

3.1 Major Accidents at Nuclear Facilities

(1) Three Mile Island (TMI) Nuclear Power Plant Accident in U.S.

On March 28, 1979, the reactor of TMI Nuclear Power Plant Unit-2 was operated with violated procedures: Namely,

(1) operators did not take proper actions for reactor coolant leakage, and

(2) operators operated a valve in the closed position which should have been open to supply emergency water in the event of an incident.

In addition to the above-mentioned failures, stoppage of the main feed water pump of the secondary system and the turbine combined with failures of equipment such as pressurizer relief valves and operator's confused analytic judgment by many alarms on the operation panel and operator's wrong manual action to stop the emergency coolant injection actuated by safety devices led to the accident, which resulted in evaporation of reactor coolant water, then about 2/3 of upper part of the reactor core uncovered and core damage (INES*10 Level 5). （INES；International Nuclear Event Scale：Reference Sheet 7）

As a result of the accident, the radioactive materials, mainly noble gases*11, were released to the surrounding environment, but, most parts of radioactive materials remained inside of the main coolant system without release to the environment. It was fortunate that the resulting effects on the health of residents living in the vicinity were negligibly small.

The results of this accident showed that this reactor facility was able to cope with an accident beyond the hypothetical design accident in a manner not to release a large amount of radioactive materials by the reactor safety measures based on the principle of defense-in-depth *12. It actually demonstrated, however, that the complicated involvement of human factors could cause serious reactor core damage beyond design measures, and gave a serious warning to the safety regulations of countries in the world.

In Japan, the lessons learned from the TMI accident were reflected in a broad range of disciplines, such as safety standards, safety design, operations, emergency preparedness and safety researches and further enhancement of safety management was made. Especially, along with measures for prevention of human errors such as improvement of operation panels and further enhancement of emergency preparedness, this accident gave opportunity to accelerate research on the probabilistic safety assessment that is very effective to find out the vulnerability in terms of the safety assurance of a complicated and huge facility, safety researches on reactor cooling during an accident*13 and safety studies on the severe accident*14, etc. It can be said that the accident made a renewed start of improvement to ensure safety of nuclear power plants in Japan.

(2) Chernobyl Nuclear Power Plant Accident in the Former Soviet Union

The Chernobyl Nuclear Power Station in the former Soviet Union (currently in Ukraine) used graphite moderated light-water cooled boiling water reactors developed uniquely by the Soviet Union. This type of reactor has some problems in the philosophy to ensure safety in addition to a unique characteristic of power increase with increasing boiling in the reactor core. It has also the following design defects:

(i) In the low power condition, there is a characteristic that the nuclear fission further increases with power increase (nuclear power plants in Japan have a characteristic of decreasing fissions with power increase).

(ii) The insertion speed of control rods to shut the reactor down is slow. This is a deficiency in the emergency shutdown facility (and in some conditions, the power could increase during the early stage of control rod insertion.)

(iii) The air-tight pressure-resistant containment, which is common to the light water reactors in Japan and Western countries, is not provided.

On April 26, 1986, the experiment on equipment was conducted under these defects at the Chernobyl Unit 4 with the poorly defined experiment plan. (There were no safety measures, no approval of the experiment by the manager. The experiment was led by an electrical engineer as opposed to a reactor engineer. During the experiment, operation at an unplanned power combined with operator's violation of the rules (The operator did not shut the reactor down despite the conditions that necessitated an emergency shutdown), caused a reactor power runaway and this resulted in a destruction of the facility. This led to the release and spread of a large amount of radioactive materials beyond the national border. (INES Level 7)

In this accident, it was estimated that about 100% of noble-gas nuclides and considerably large amount of other nuclides that existed in the core were released, which had a significant effect on residents in the vicinity or the environment resulting in deaths of 31 persons (including three persons who died of the burn etc., 1996 (1996) OECD/NEA*15 report) and a large number of people exposed to radiation. The effects remain even these days in the Ukraine and its neighboring countries. The effective dose of the individual averaged by the people of OECD countries, mainly industrialized ones due to this accident was estimated to be comparable as the annual exposure by the natural background radiation, even at the maximum.

The epidemiologic survey on the effects on residents in the vicinity has been continuously performed after the accident. This survey shows that thyroid cancer has increased among infants and children who were low age at the time of accident (about 1,800 persons in the surrounding three countries, as of 1998), but the increase in neither cancer nor leukemia has not been confirmed (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2000 report.)

During the process of the accident investigation promoted mainly by the International Atomic Energy Agency (IAEA)*16, it became clear that there was a lack of safety awareness by designers on a defense-in-depth philosophy of design and a violation of rules by operators. This has led to a heightened momentum for **raising safety awareness** by redefining the philosophy of nuclear safety culture that an awareness to ensure safety is the top priority and a thorough effort to ensure safety should be practiced by individuals and organizations. In this way, the importance of "safety culture" has been recognized as the most important lesson learned from this accident. Together with this, the importance of international cooperation in the area of nuclear safety has been recognized, resulting in the active cooperation among the nuclear community.

(3) Criticality Accident of JCO Uranium Processing Plant in Japan

On September 30, 1999, workers at JCO of Tokai Village, Ibaragi Prefecture, during the work to homogenize the enriched-uranium solution, poured the uranium solution with more than a critical mass into a precipitation tank in violation of the safety fitness program approved by the Government and a company manual and caused a nuclear criticality accident. After the initial instantaneous nuclear fission, the slow nuclear-fission continued, which kept the critical state more than 20 hours. During this period, radiation was continuously emitted to the neighborhood and a small quantity of radioactive gaseous materials generated by the nuclear fission was released to the atmosphere. It was estimated that 319 persons including employees, persons involved in the emergency response actions and residents living in the vicinity (130 residents) received radiation exceeding 1 mSv (the annual dose limit of the general public). Moreover, it resulted in the death of two workers who were excessively exposed to radiation. Although gaseous radioactive materials generated by the nuclear fission were released to the atmosphere, the radioactivity level was too low to affect residents and the surrounding environment (INES Level 4).

The causes of this accident were inadequate process controls and lack of safety management in the special small-lot production by the licensee who has the prime responsibility to ensure safety. Deviation from the

Code of Conduct by employees was escalated due to poor understanding of potential risks and lack of crisis awareness that the violation of rules could lead to an accident.

The Government identified problems in the safety regulation, operational management system, and emergency preparedness and response for an accident, and strengthened regulation by introducing the fitness-for-safety inspection system by amending the Act for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (hereinafter referred to as the "Reactor Regulation Act".), etc. Moreover, the emergency preparedness alignments were established in accordance with the enactment of the Special Act for Nuclear Emergency.

There was a lack or decline in crisis awareness regarding criticality. Prompted by this accident, abolishing what is called the "nuclear safety legend and the ideological catchphrase of "absolute safety" and turning people’s mind to "risk based safety evaluation" were required.

Simultaneously, the importance of making efforts to establish and disseminate the safety culture---the basic philosophy to support safety---to the rank and file was reconfirmed.

3.2 Radiation Exposure Accidents Involved in Radiation Utilization in the World

Radiation is utilized widely in many countries in the world. Utilization of radiation far exceeds the utilization in nuclear power generation. The number of IAEA member states reached 130 countries at the end of 1999. And almost all of the member states use the radioisotope and radiation in various fields such as medical examination, industrial instrumentation, irradiation utilization etc. On the other hand, a total of 425 units of power reactors are in service in 31 countries. The number of the countries adds up to only 37 countries even if even it included the countries with plans of construction. This is easily understandable how extensively radiation is utilized.

Compared with nuclear power plants or nuclear fuel utilization facilities, radiation is used at very near places to the general public, such as hospitals and factories. Therefore, adequate control of the radiation sources such as RIs and X-ray equipment is essential for ensuring safety. It is the actually the case, however, that accidents of radiation exposures still occur at many places in the world.

Since 1945, the number of major radiation-exposure accidents occurred worldwide up to 2001 is 169 in total. The breakdown of these accidents is shown in the following table:

Table Radiation-exposure accidents occurred in the world; 1945 through 2001

Contents of accidents		Number of accidents	Number of persons excessively exposed *	Number of Death
RI radioactivity	Accelerator, X-ray etc.	31	94	16
	Sealed RI source	87	476	58
	Internal exposure	22	37	7
	Subtotal	140	607	81
Criticality assemblies and reactors**		29 (1)	259 (134)	53 (28***)
Total		169	866	134

* (Whole-body > 0.25 Sv, local > 6 Gy)

* * (Numbers in parentheses are those of the Chernobyl accident (included))

* ** (Death within three months by acute radiation sickness)

Reference: IAEA BULLETIN, 41/3/1999, Radiation Science, Vol. 42, No. 9 p. 282 (1999), etc.

Apart from 29 nuclear criticality accidents and reactor accidents, the number of accidents involved in radiation utilization is 140 and among them, the external exposure by sealed RI sources is 87 cases. Although 81 persons are reported to have died in the accident of radiation utilization, it is reported that, apart from those included in the Table, there were fatality cases due to errors in radiation medical treatment in the U.S., Soviet Union etc. Amazingly enough, 58 persons out of 81 (about 71%) died in accidents of sealed RI sources such as Cesium-37 (Cs-137), Cobalt-60 (Co-60), Iridium-192 (Ir-192) etc.

(1) Gamma-ray irradiation facilities

Around 1990, fatal accidents occurred in the gamma-ray irradiation facilities using a large amount of cobalt-60 sources in El Salvador, China, Israel, and Belarus, etc. All of the cases are workers' accidental exposure entering rooms with sources in the irradiation condition. Direct causes were faults or inappropriate use of interlocks, failures of access doors, etc. The fact that all safety-related directions posted on the facilities were written in English and workers ware not able to understand English well was said to be the indirect cause.

(2) Medical sources and industrial radiography sources

As the cesium compound is easily soluble to water, the Cesium-137 source, when its capsule is damaged, may cause serious problems such as the radiological external exposure, radioactivity pollution of the surrounding environment and internal exposure by ingestion. The accident that occurred in Goiania in Brazil in 1987 was a typical example of such events. Fatal accidents occurred in Thailand in February 2000 and in Egypt in June 2000.

In the Thailand accident, nine persons were exposed to radiation and killed three persons were dead. The victims were cutting the shield of a container which contained a Cobalt 60 source (about 20 TBq), which was stolen from the stored medical treatment equipment. In Egypt, two members of a family resided in a farmhouse were dead and five members were seriously exposed to radiation. In this accident, a lost Iridium 192 source for non-destructive test (about 2 TBq) was brought home without knowing it. Similar accidents regarding Iridium 192 source occurred successively also in China and Iran in 1996, both of which did not result in any fatality, but caused serious exposure damage on a hand and a foot which had to be amputated.

An accident occurred in Japan in 1971. It is the only case in Japan.

(3) Medical accident

There is one case in which a patient was killed in a radiation treatment accident. It occurred in U.S. in 1992. In this accident, the top part of a very thin Iridium 192 source tube with an outside diameter of 0.6 mm broke and was left in the patient's body, resulting in exposure. Moreover, a broken part of the source fell off from the patient and was taken out as garbage. Many people were exposed to radiation unknowingly until a gate monitor of the waste disposal site detected the radiation. In Costa Rica in 1996, since a wrong half-life was unintentionally input to the medical treatment equipment regarding a Cobalt-60 source, 115 patients were exposed to a surplus dosage of no less than 50 to 60% for a long time. It resulted in 13 persons victims until the end of 1998. Also in Spain in 1990, there were patients who received excessive irradiation by the accelerator medical treatment. 27 persons were exposed to radiation and 11 persons were killed.

(4) Mixing of lost orphan sources

If scrap steel that mingles an orphan source is recycled unknowingly, the steel products would be radioactively contaminated. In Taiwan in 1983 through 1984, the steel beams contaminated with Cobalt 60 were used. The contamination of 180 buildings including a building which has 1,601 residential units was confirmed at present. Around that time, U.S. NRC observed the contamination of Cobalt 60 in steel products imported from Taiwan, Mexico and Brazil, and raised awareness of the general public.

As can be seen from the cases mentioned above, accidents to cause serious excessive exposures in the utilization of radiation are mostly related to sealed sources, especially when persons unknowingly approached an orphan source. Moreover, if an orphan source is mingled with raw scrap materials, the steel products will be contaminated. To prevent such cases, sources should be strictly secured and spent sources should be disposed of at appropriate places throughout the world, but in fact, such an accident still happens even these days.

4. Summary

As mentioned above, we have unfortunately experienced accidents which affected residents living in the vicinity of the nuclear facilities. And in Japan, we have not experienced a major nuclear accident like Three Mile Island (TMI) and Chernobyl. Japan, however experienced JCO accident on September 30, 1999 that caused death of workers, and exposure and evacuation of residents in the vicinity. This cast a doubt to nuclear-related people who had believed the "legend" that "nuclear is absolutely safe."

In fact, almost all of the nuclear related people have never believed that "nuclear is absolutely safe." Why has such a misleading "myth" been developed? The following elements can be listed as the probable causes:

- Excessive reliance in the design that seeks higher safety than that of other areas.
- Overconfidence generated due to the safety record that there has been no accident which affects human lives over a long period of time.
- Faded memories of past accident experiences
- Pursuit of reader-friendly expressions regarding PA (public acceptance; acceptance by the public) activities to promote siting of nuclear facilities
- Wish for absolute safety

Such conditions are really contrary to the "safety culture" to maintain and improve the level of safety fitness through efforts of the parties involved. As many of the past accidents and failures were occurred by human factors, nuclear-related people should continue their efforts to ensure safety by reducing the risks as low as reasonably achievable. Nuclear-related people should clarify potential risks which nuclear always has rather than averting their eyes from the risks. Nuclear-related people mainly consists of designers, constructors, licensees who operate nuclear facilities, and the regulators who monitor and implement regulation of nuclear facilities. These people should make a united effort to solve safety issues.

Glossary

Activation*1; generation of radio-nuclides in a material by nuclear reaction produced when the material is irradiated by high-energy radiation such as neutron beam etc.

Deuterium*2; one of hydrogen isotopes existing in the nature. The atomic nucleus consists of one proton and one neutron. The atomic nucleus of the ordinary hydrogen has only one proton.) The mass is about the twice of the ordinary hydrogen atom.

Tritium*3; one of hydrogen isotopes existing in the nature. The atomic nucleus consists of one proton and two neutrons, not one proton like ordinary hydrogen, and the mass is about the three times that of ordinary hydrogen atom. It is also called tritium.

Man-made radiation*4; radiation consists of man-made radiation and natural background radiation. Man-made radiation from nuclear power plants, X-ray generator etc., and natural background radiation stems from cosmic rays and natural radioactive substances existing in the natural environment. The human beings are daily exposed to the natural background radiation since ancient times. Although generating sources for man-made radiation and natural background radiation are different, health effects from these sources of radiation are the same.

Active oxygen*5; a type of oxygen that has a characteristic easy to cause a chemical reaction compared with ordinary oxygen. It involves in generation of harmful materials inside the body.

Free radical*6; by nature, electrons are stable when a pair is formed within one orbit. An unstable atom or unstable molecule which has an electron not paired (unpaired electron) have a property to rob others of their electrons to get paired and stable. Free radicals are strongly reactive atoms or molecules with such unpaired electrons. They are also called simply "radical".

DNA*7; abbreviated name of deoxyribonucleic acid. It is an important component of chromosome in a cell nucleus, and it involves in preservation and replication of genetic information as a main body of gene.

Mili-Sievert *8; one of the radiation units. Major radiation units and their explanation are shown in the followng;

Unit name	Symbol	Explanation
Gray	Gy	The unit of dosage expressed in terms of the amount of absorbed energy per unit weight of the organization that received radiation.
Sievert	Sv	Dosage unit that indicates the magnitude of effect to a living body. It is obtained from the dosage expressed in the unit of gray (Gy) multiplied by the coefficient accounted for type of radiation and tissue.
Mili-Sievert	mSv	The amount of one-thousandth of 1 Sv.
Becquerel	Bq	It is a unit of radioactivity expressed in terms of the number of atomic nuclei to disintegrate in one second to indicate the magnitude of radioactivity of a radioactive material. (1 Bq = 1 disintegration / second)

International Commission on Radiological Protection (ICRP)*9; the international organization that provides advices and recommendations on radiological protection from the viewpoint of experts.

INES*10; International Nuclear Event Scale. The international rating scale for judging the significance of events at nuclear facilities concisely and objectively. The rating scale of nuclear events established by cooperation of the International Atomic Energy Agency (IAEA) and OECD/NEA (Organization for Economic Cooperation and Development / Nuclear Energy Agency)

Noble-gas*11; generic name of six elements of the zero group of periodic table: helium (He, neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). Since they are hard to combine each other or with other element, it is also called inert gas. In the nuclear field, processing of radioactive noble gases (krypton-85, xenon-133 etc.) is an issue.

Defense-in-depth*12; it is one of the fundamental concepts to ensure safety of nuclear facilities and means that measures for safety of nuclear facilities are multi-layered for safety assurance design, accident propagation prevention and radioactive materials release prevention, etc. Especially in Japan, it is considered as the basic design concept of a nuclear power plant.

Safety study associated with reactor cooling during an accident*13; study on complicated thermo and coolant behavior in terminating an accident by transferring heat in the core to coolant (water for light water reactor) and ultimately releasing the heat outside the reactor during an accident.

Severe-accident*14; an event significantly exceeding the design basis of reactor facilities which will result in conditions that proper reactor core cooling or nuclear fission reaction control cannot be performed with the means assumed for their safety design, and lead to serious damage to a reactor core.

OECD/NEA*15; Organization for Economic Cooperation and Development / Nuclear Energy Agency: international organization under OECD, of which predecessor was established with the purpose to promote cooperation on peaceful use of nuclear in 1958 and which name was changed to NEA in 1972 when Japan formally joined it, where opinion exchanges on nuclear policies, studies on administrative and regulatory issues, studies on atomic laws of each country, researches on economical aspect of nuclear, and exchanges of information, etc. are performed. Twenty-seven nations participated there as of the end of 2000, and headquarter is located in Paris.

IAEA*16; the International Atomic Energy Agency: international agency founded in 1957 (headquarters located in Vienna) for the purposes to (1) promote and increase nuclear contributions to global peace, health and prosperity, and to (2) ensure that the aid supplied through the IAEA or under the IAEA's management is not converted to military purposes. 130 nations have participated there as of the end of 2000, and Japan has participated as a member of council.

Reference Sheet 1   Nuclear Energy and Nuclear Power Generation

An atomic nucleus consists of protons with positive electric charge and neutrons without electric charge combined by the force that is called nuclear force. And, the magnitude of potential energy that a proton and a neutron posses is about one million times as much as that of an atomic nucleus and an electron have in the electrostatic field of an atom or a molecule. Therefore, when nuclear reaction occurs, it generates nuclear energy millions of times as much as energy by chemical reaction.

If a neutron hits an atomic nucleus, as the neutron is not charged, it can easily enter into the atomic nucleus and causes a nuclear reaction. Besides, there is a neutron that might scatter or pass through without causing a nuclear reaction.

There are two types of nuclear reaction, one is nuclear fusion reaction where light atomic nuclei collide and produce a heavy atomic nucleus and another nuclear fission reaction where a heavy atomic nucleus breaks into several nuclei. The nuclear reaction used for the current nuclear power generation is the nuclear fission reaction where heavy atomic nuclei absorbs neutrons, which was discovered by Otto Hahn and Firitz Strassmann of Germany in 1938.

Nuclear fission reaction is used in nuclear power generation. The heavy atomic nucleus used as fuel is uranium of the mass number-235. The uranium-235 is composed of 92 protons and 143 neutrons combined by nuclear force. Although there are several uranium isotopes (atomic nucleus which number of protons is the same but their number of neutrons is different) with their mass number different from uranium-235, uranium-235 is the easiest to fission. However, natural uranium contains only 0.7 % of uranium-235, and the rest is about 99.3% of uranium-238 and very small quantity of uranium-234. Therefore, the enriched uranium that is uranium-235-enriched from natural uranium is used as reactor fuel.

When uranium fuel is burned in a reactor, uranium-238 contained in the fuel absorbs neutrons and converts to uranium-239, which then, changes to plutonium by spontaneous disintegration. Since the plutonium-239 is easy to produce a nuclear fission reaction, it can be extracted from the spent fuel and used again as fuel. If this process is used, a system like a magic to produce fuel by burning fuel can be realized.

When uranium-235 absorbs a neutron to cause nuclear fission reaction, the uranium breaks into two or more atomic nuclei and neutrons are also released simultaneously. At this moment, large potential energy having been contained in the atomic nucleus is released and comes out. The energy obtained by the nuclear fission reaction of uranium 1g is equivalent to the combustion energy of 2000 liters of oil. Nuclear reactor can produce a huge amount of energy with a small amount of fuel.

Reference Sheet 2   Medical Utilization of Radiation and Medical Exposure

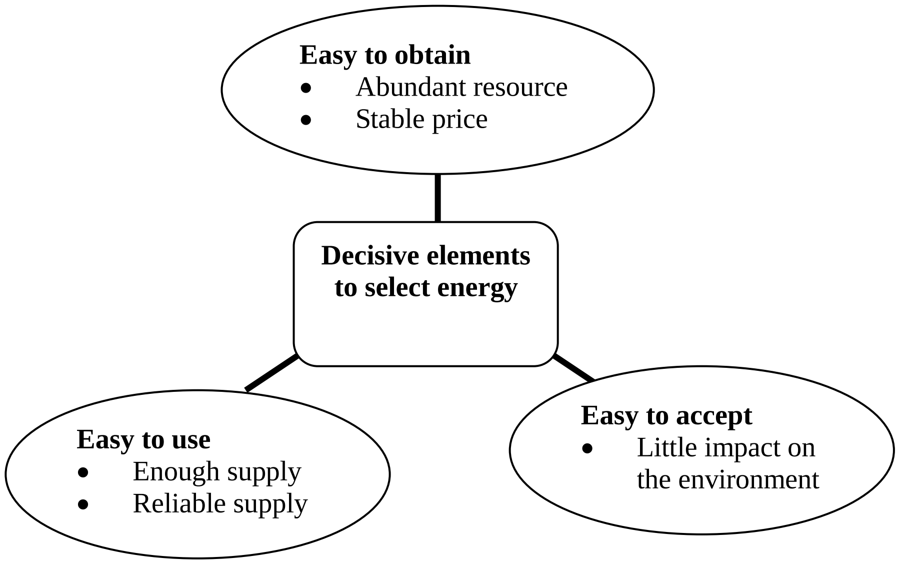
As radiation has excellent physical properties like electrolytic dissociation or transparency, it plays an important role for diagnosis and medical treatment in the medical field. It is extensively used for diagnosis from a familiar chest radiography shot to the newest technology: nuclear medicine diagnosis using radioactive drugs (PET: Positron Emission Tomography). For the purpose of medical treatment, it is mainly used to cure diseases such as cancer and other malignant tumors. Since malignant tumor cells are highly susceptible to radiation compared with normal cells, a large dose of radiation necroses malignant tumor cells. In order to make maximum destruction of the morbid tissues and to lessen the damage to normal tissues, type of the radiation ray and the irradiation method are to be selected for the medical treatment. The comparisons with operation and chemotherapy are given in Table-2.3.1.

Radiation sources other than X-ray generators include gamma ray of Co-60, beta ray of Ir-192, I-131, etc. Moreover, cyclotrons and linear accelerators are generators of proton beam and electron beam.

A large-scale and complex irradiation equipment of heavy particle beam has also entered into the field, and very effective for the medical treatment of a tumor etc. using mainly carbon ions. The heavy ion radiotherapy has an excellent ability to kill cancer cells (the ratio of biological effect (RBE) is high) and the advantage that it is less subject to the effect of oxygen surrounding the cancer cells (Oxygen Enhancement Ratio (OER) is small.) Therefore, it can kill the cancer cells inside a tumor, which is hard to treat with gamma ray or electron ray. Moreover, the heavy particle beam has a property to release the largest energy to tissues and stop at a certain depth corresponding to its magnitude of energy after entering into the body. Making use of this property, it is possible to kill cancer cells with a little amount of dosage given to normal tissues and a large amount of it intensively released to cancer tissues (cells) at arbitrary depths, and to make the side-effect damage to normal tissues small.

Reference Sheet 3　Basic requirements of energy supply

Energy supports industrial activities in society and people’s life. They demand energy supply in the same manner as water or air. Therefore, it is necessary to supply easy-to-use energy cheaply and in large quantity without any concern to the environment or safety. Essential factors for energy supply are "easy to obtain," "easy to use" and "easy to accept."



To ensure "easy to obtain" energy, it should be one from the stably secured energy resources required for society over a long period of time, which quantity is abundant without any concern of supply disruption and with small price fluctuation.

The "easy to use" means that supplied energy is easy to use for consumers, which is to convert the obtained energy into the easy-to-use energy form. The "easy to accept" means not causing any concern to people in respects of the environment or safety in the energy supply process of mining, production, and distribution. In order to continuously supply cheap energy it is necessary to continue to meet the basic requirements of "easy to obtain," "easy to use" and "easy to accept," while taking economical efficiency into consideration.

Energy sources currently used in society include fossil fuels, nuclear and renewable energy. Each energy source has advantages and shortcomings, and can't satisfy all of the basic requirements for energy supply. Therefore, under the constraint of economical efficiency, it is necessary to study how to use each energy sources best taking full advantages of them.

Fossil fuel, nuclear and renewable energy are characterized in terms of their advantages and shortcomings from viewpoints of basic requirements; "easy to obtain," "easy to use" and "easy to accept," and the results are as shown in the following table:

	Fossil fuel	Nuclear energy	Renewable energy
Easy to obtain (abundant resource and stable price)	• The resources including coal are abundant and their cost is cheap. • There is concern about price fluctuation and supply disruption of oil.	• The resource including plutonium is abundant and the cost is cheap. • Small concern about fuel disruption	• The potential resource is abundant, but the cost is high. • No supply disruption
Easy to use (sufficient and reliable supply)	• Necessity to establish infrastructures for supplying fuel • Excellent reliability and operability of facilities • High electric quality	• Necessity to establish nuclear fuel cycle facilities • High reliability of facilities and the electric quality	• The output fluctuation by a season, a week and a day • Voltage and frequency fluctuation
Easy to accept (small impact on the environment, and safe)	• Air pollution and greenhouse gas release • Concern about stranded tanker, gas explosion, and coalmine accident	• Necessity to isolate radioactive wastes • Concern about significant accident and nuclear proliferation issue	• Reputed to be the cleanest and safest

Nuclear power generation has advantages of abundant resources for uranium used as the fuel for electricity production and plutonium manufactured from the uranium and their cheap cost, but on the other hand, it is necessary to take into special consideration the handling and isolation of radioactive wastes, and measures for protection of the residents in the vicinity from radiological exposure and facility employees in the event of a significant accident. As for "easy to use," the reliability of nuclear power facilities and their electric quality are reputed to be high, but we should not forget that the high quality could be realized only with constant efforts aiming at safety.

The most important points are that measures to protect the environment and to ensure safety are indispensable, and promotion of technology development, system establishment and adherence to the system must be done without fail. The efforts to ensure such safety should be made primarily by utilities that own nuclear power plants. Efforts for safety should be addressed by the Government. Nuclear safety regulation must attain safety from cool-headed, appropriate and neutral viewpoints with abundant and deep knowledge and experience.

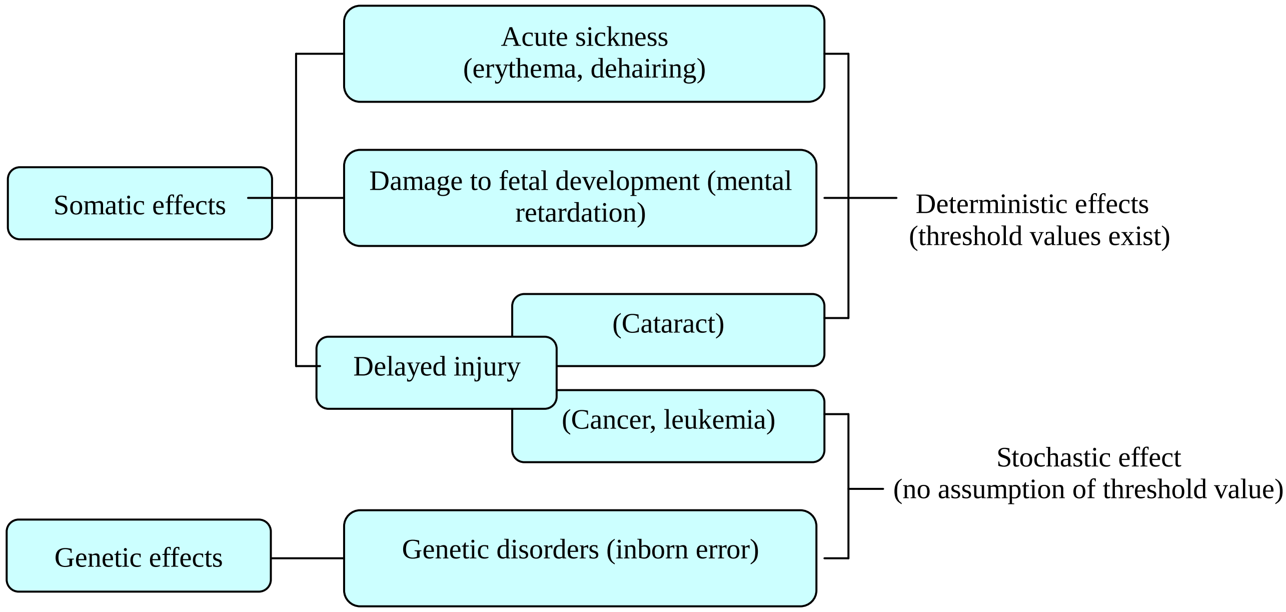
Reference: "All about Nuclear"

Reference Sheet 4 Radiation Effect to a Human Body

Radiation effects on a human body vary significantly depending on the radiation dosage received. The radiation effects are classified as shown in Figure-1 when exposed to a comparatively large amount of radiation (tens mSv or more.) The effects appearing in the human body exposed are called "somatic effect" and the effects on the descendant "genetic effect." The somatic effect has different times in effect appearing depending on the exposed part (organ) and the magnitude of exposure. The effect that appears within several weeks after exposed with a high dosage in a short time is called the "acute sickness (acute effect)" and the effect appears after several months or several years or more after exposed to a relatively low dosage is called the "latent sickness (late effect)." The acute sickness is known to have the so-called "threshold dose (threshold value)" below which the dose effect does not appear but above which it does. As shown in Figure-2, for examples, in terms of an effective dose equivalent, leucocytes will decrease at 500 mSv or more, nausea and vomit happen at 1000 mSv or more, 100 % of the exposed dies at 7,000 mSv or more. Moreover, as a "tissue dose equivalent" to a local part, there are effects of depilation, infertility etc. at 3,000 to 5,000 mSv. Therefore, this is called deterministic effect (it used to be called non-stochastic effect before.) The latent sicknesses are carcinogenesis caused by a low dosage and cataract induced only by a high dosage. It is recognized that the radiation carcinogenesis (leukemia and solid cancer) has occurred by the exposure of about 0.2 Gy or more (0.05 Gy or more according to the atomic bomb survey done by 1990.) But, it is assumed that carcinogenesis can occur even at a lower dosage from a radiological-protection view, and this is called the stochastic effect. As the latent cataract (cloudiness of the eye lens) occurs without fail at 5 Gy or more, it is classified as the deterministic effect. The unit of Gy in this text is the amount of the energy absorbed indicating a energy loss within a material (absorbed dosage), and the dosage accounted for biological effect is Sv. One Sv is almost equal to one Gy for X ray, gamma ray, and electron beam (beta ray.)

As the somatic effects of the exposure on a germ and embryo in a mother's womb before birth, there are generative / developmental disease and the mental retardation and carcinogenic after birth. This carcinogenesis is classified as the stochastic effect, and others as the deterministic effect.

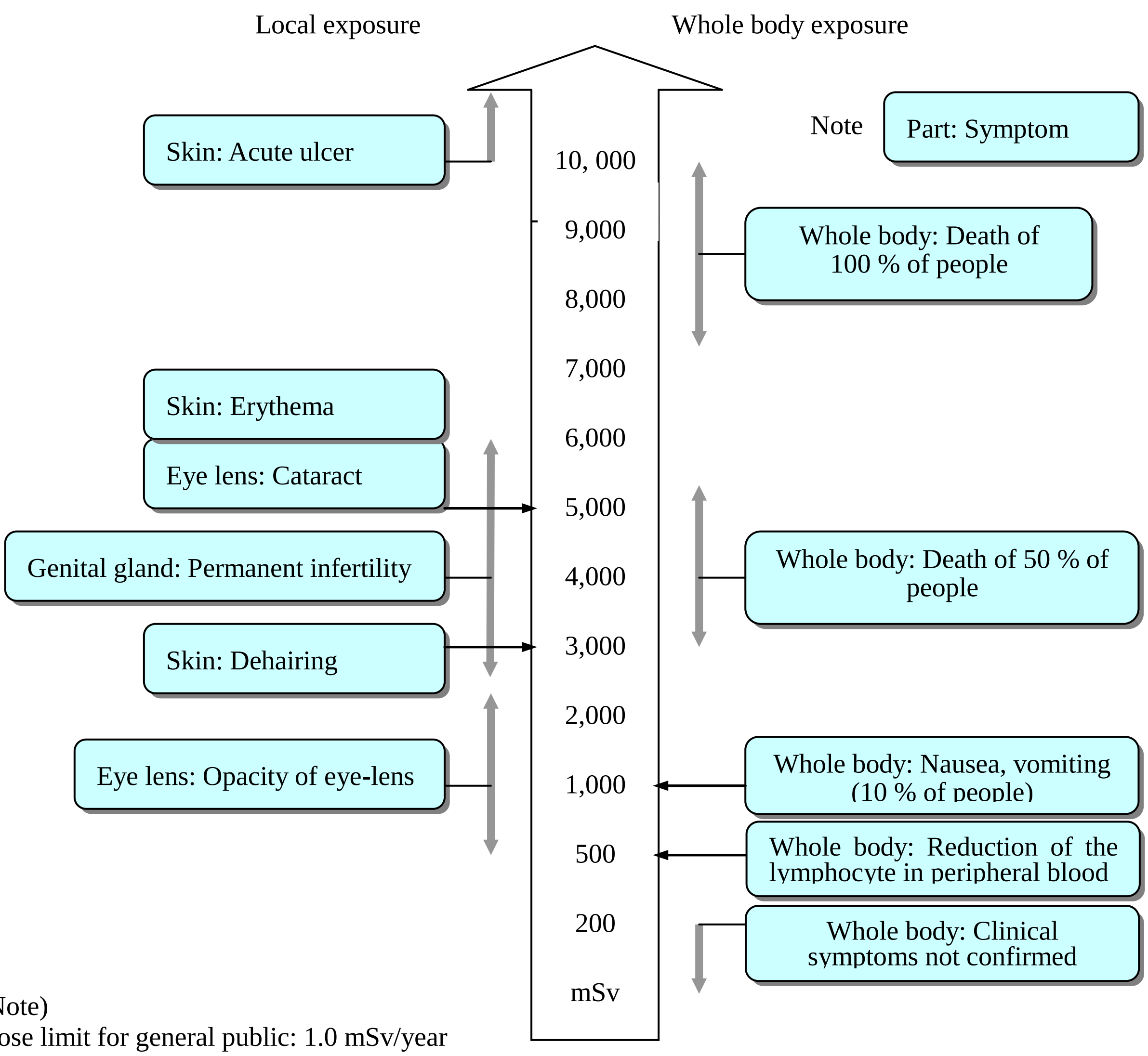
Figure-1 Radiation Effect on Human Body



Source: Radiation Effects Association
"Book to Understand Effects of Radioactivity"

Figure-1 Radiation effect on the human body

Figure-2 Acute Radiation Effect



(Note)
Dose limit for general public: 1.0 mSv/year
Dose target in the vicinity of nuclear power plants: 0.05 mSv/year

Source: ICRP Publication 60 and Others

Figure-2 Acute radiation effect

Reference Sheet 5 Adaptive Response to Stress

Living organisms have a certain extent of resistance to stress from various environments. It can be said that the health is impaired when the limit of this resistance is exceeded. And, the growth environment of the living organisms and the interaction with other stresses also influence the resistance. Radiation could be harmful even if it is small, and also, it is said that there is a risk of carcinogenesis according to dosage no matter how small it is. But, this is a assumption from very conservative viewpoint, which is a hypothesis made extrapolating the knowledge obtained at high dosage to low-dose range with little data (Linear Non-Threshold Hypothesis, Figure-1.) Since the second half of 1980s, the living organisms exposed to a low dose of radiation have been studied at an individual and tissue, cell, or molecular level, and as the results, it has become clear that living organisms show an exquisite response to radiation of very small amount. Those responses include induction of materials to protect cells from active oxygen (antioxidants), enhancement of functions to restore the damage made on genes (DNA repair capability), activation of the mechanism to remove mutant cells produced inside of the body (apotosis, self-destruction mechanism of cell), enhancement of immune system. That is, as living organisms have the resistance to some extent against radiation, it can be said that there is no need to have unnecessary fear about a small amount of radiation.

Due to progress of recent researches, the carcinogenic mechanism has become clear. If this carcinogenic mechanism induced the antioxidants by low dose radiation, active oxygen and other free radicals to cause damage to genes would be removed, and, together with the enhancement of DNA repair capacity, gene damage would be reduced. Moreover, it is expected that the activated apotosis mechanism would remove the mutant cells with the remaining not-yet-restored damage in genes (reserve of cancer cells), and the activated immune system would cope with the already produced cancer cells (Figure-2).

In order to clarify the adaptive response in individuals, verification experiments using mice have been started using low-dose-rate radiation irradiation facilities. When cultured cells are irradiated with more than the median amount (about 500 Gy or more) of radiation, cell biological effects such as death of cell, mutation, chromosome aberration, transformation (in vitro carcinogenesis), etc. are induced. Their probability increases usually with radiation dosage, but with cultured cells having been irradiated with a very minute amount of radiation (several Gy or less) beforehand, the phenomenon to induce the resistance against these effects by the subsequent irradiation with more than the median amount has been observed.

Moreover, as a radiation adaptive response at an individual level, it has been observed that the low-dose irradiation to a mouse (50 to 500 mGy) induces the resistance to a lethal-dose irradiation as shown in Figure-3.

Such effect phenomenon induced by a prior treatment with the low-dose radiation or a very minute amount of chemical materials is generally called adaptive response. The adaptive response is understood as a reaction of cell or organ level to the external stimulation (stress) by radiation, chemical materials etc.

Many of the experimental studies on the radiation adaptive response using microorganisms, cultured cells or human lymphocytes have been performed from the beginning of the 1980s. These experimental results have revealed action mechanisms:

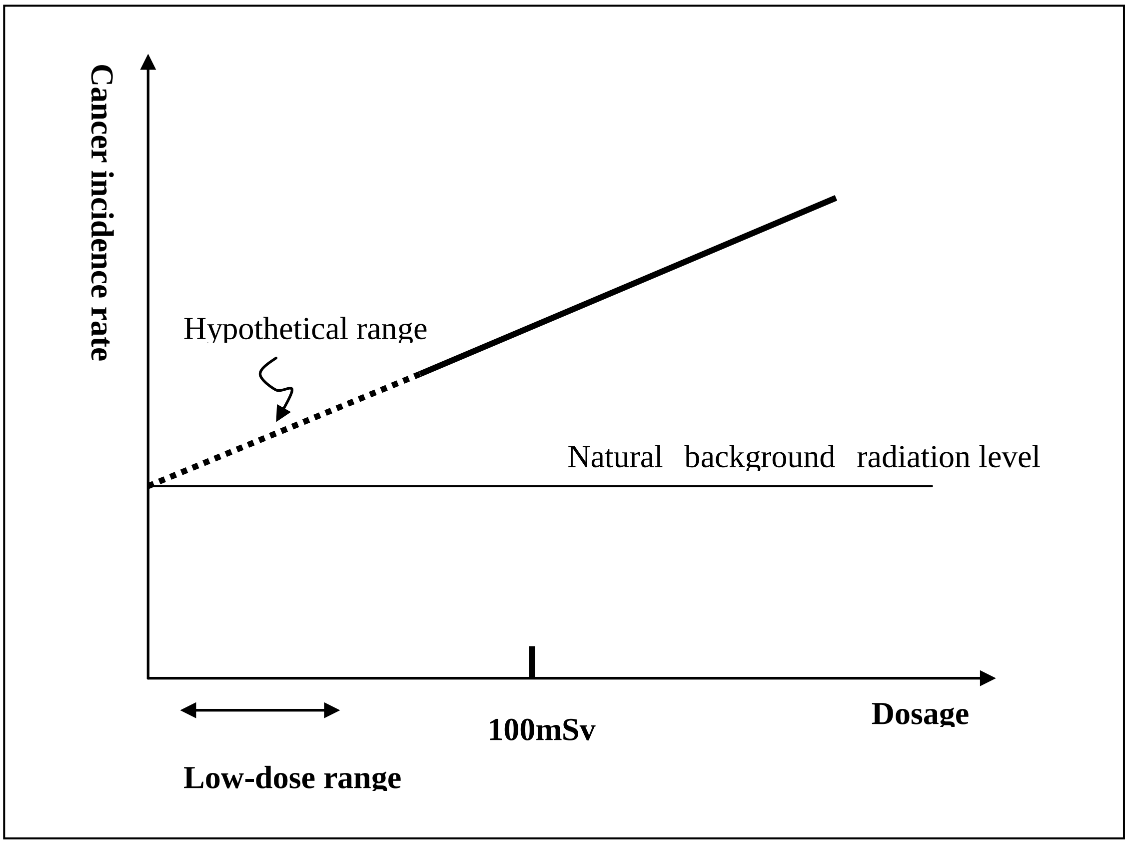
(1) there are limiting values (the minimum and maximum values) for the first irradiation dose, and the adaptive response will not be induced when these values are exceeded,

(2) there is a limit of the time period during which the adaptive response works, and

(3) manifestation of genes and protein synthetic process are required for the adaptive response to work, and also several genes that begin to work by low dose irradiation. The researches to explore the action mechanism based on the identification of related genes and proteins are focused on from now on.

Generally, a large amount of chemicals including metal materials is harmful to a living body, but conversely, there are some cases that a very minute amount of chemicals has a good effect on a living body, which phenomenon is called hormesis. It is because a moderate stimulation activates the defense power of a living body. For the radiation hormesis, such as the strong survival ability of a living organism that has received a very minute amount of pre-irradiation, the conventional epidemiology data have been reexamined and experiments have been promoted in the 1990s, and the systematic research results began to appear in the latter half of the 1990s.

Anyway, these phenomena suggest that there is a unique living organism response in the low-dose region of the radiation effect that cannot be explained by simply extrapolating the living organism effect in a high-dose region into a low-dose region. The exploration of the living organism effect by the low dose radiation is a fundamental key issue of radiation protection, and further progress of the researches is expected.



Source: Homepage of the Central Research Institute of Electric Power Industry, "Confirmed Carcinogenic Inhibition of Low Level Radiation"

Figure-1 Linear Non-Threshold Hypothesis

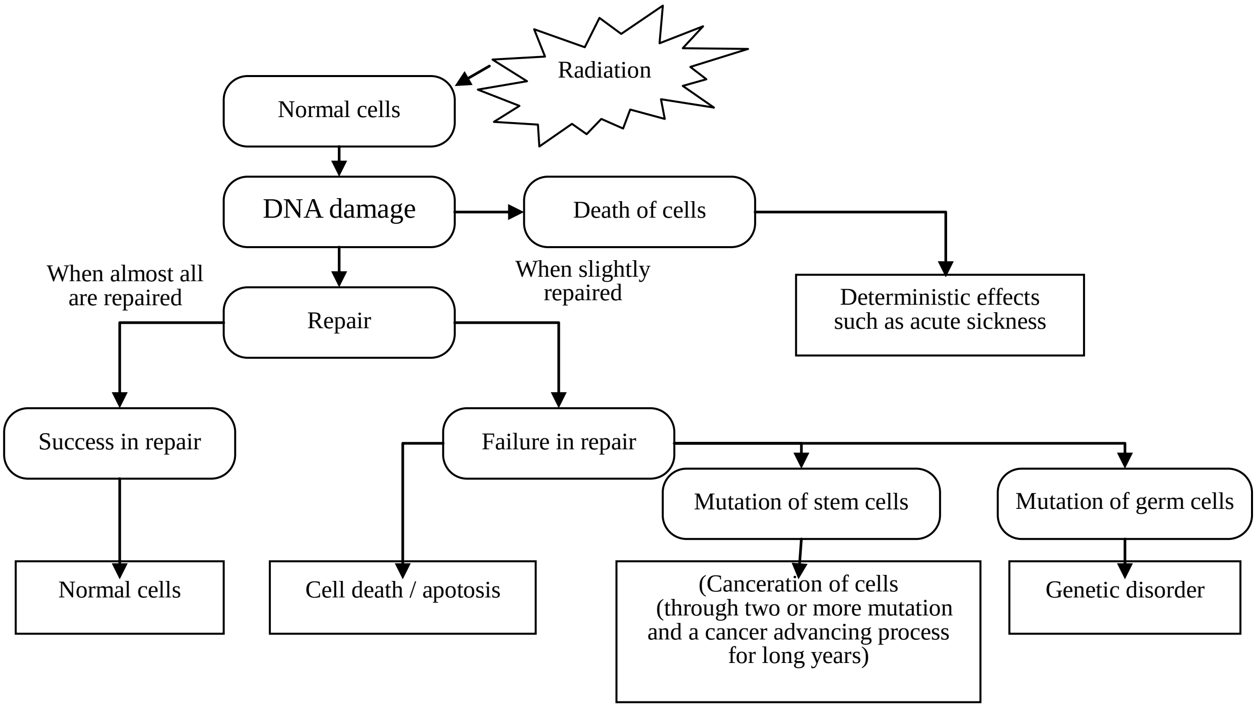
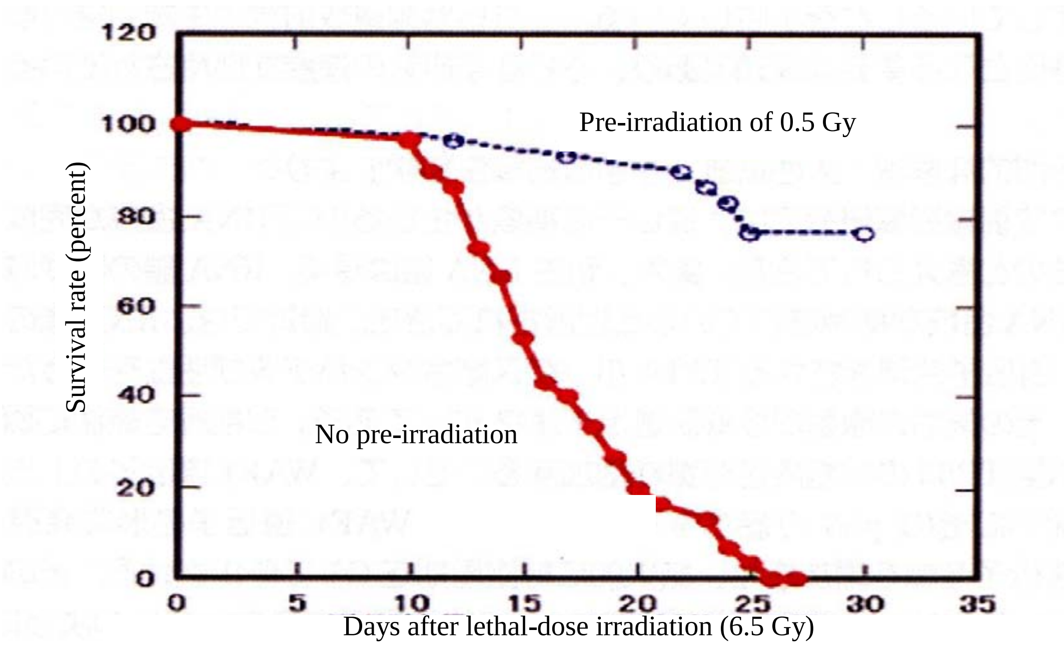


Figure-2 Radiation Effect on the Cells



By the method of Yonezawa and others (at Osaka Prefecture University), when 0.5 Gy was irradiated two weeks prior to the lethal-dose irradiation (6.5 Gy), the 30-day survival rate increased remarkably from 0 % up to about 80 %.

(Source) National Institute of Radiological Sciences

Figure-3 Effect of a low dose pre-radiation to the lethal dose irradiated mouse

Reference Sheet 6　Genetic Effect

The estimation of the extent that severe hereditary disease (also called a genetically determined disease) manifests itself to the subsequent descendants when their parents' reproductive cells are radiation exposed is the "genetic effect risk by radiation." The only direct data of the human being are the descendants' data of the atomic bomb victims of Hiroshima and Nagasaki, and the genetic effects have not been observed yet until now. Therefore, the genetic effect risks are estimated based on the experimental study using laboratory animals such as mice, monkeys and apes. There are two estimation methods: one is the dose- doubling method based on the calculation of the radiation dose that makes the frequency of manifestation double of the naturally occurring hereditary disease and another the method to obtain the dosage reaction relation by animal experiments and apply the results to a human being. The estimated values of the genetic effect risks by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) are shown in Table-1. This Committee has estimated the doubling dose to be 1 Gy. The incidence rate of serious genetically determined diseases when one of parents is exposed to 0.01 Gy is 18 persons per one million persons at a child (the 1st generation), and will become 100 persons per one million persons in the equilibrium state after that. About 80% of the genetic effects are due to the dominant mutation and X chromosomal mutation, and about 15% of them appear within the first two generations. Although the recessive mutations hardly appear in the first 2 to 3 generations, but the hereditary disorders accumulate and appear gradually in the subsequent generations. The sum of naturally occurring rate of the dominant and sex-linked inherited diseases, recessive heredities, anomalies in chromosome configurations, etc. is about 13,000 persons per one million persons. For all of the population (including the old and children), 0.1% of the naturally occurring rate (10% per 1 Sv) per 0.01 Sv of the absorbed dose of genital gland will increase. Although ICRP has set the conservative criteria for radiation protection based on this value, but even when exposed to a large amount of radiation like at Hiroshima and Nagasaki, the increase in hereditary disorders has not been recognized.

Table-1 Genetic disorder risk of radiation by UNSCEAR (UNSCEAR'88)

Damage to organisms	**Naturally occurring rate**	Added part by radiation		
		First generation	Second generation	Equilibrium state
Dominant and sex-linked	**10,000**	15	13	100
Recessive	2,500	An increase has not been recognized.		**15(a)**
Chromosome aberration Structural anomalies	400	2.4	1	4
Total (about)	13,000	18	14	120
Inborn anomaly	60,000	It was not estimated.		
Other multiple-factor diseases	600,000	Same as the above		
Chromosome aberration Anomalies of number	3,400	Probably a extremely small number.		

(a): Values up to the tenth generation

The naturally occurring rate of the disease is expressed in terms of occurring rate per one1 million newborn babies.

The added part by radiation is the number of occurrences per 0.01 Sv per one 1 million men and women up to 30 years old.

Source: 1993 UNSCEAR Report Japanese version: "Radiation Sources and Their Effects", Jitsugyo-kouhousha, (1995)

Reference Sheet 7　Accidents and Incidents According to Levels of the International Nuclear Event Scale

The INES (International Nuclear Event Scale) was, aiming at promoting common understanding between the nuclear-related persons and the press/general publics, established as a means for informing the public in a quick and easy-to-understand manner of the safety significance of an event occurred in a nuclear facility, and it started to be used formally in 1992 after test use from 1990. This scale is from Level 0 for an event not important to safety to Level 7 for a major accident. This section shows the number of accident and event cases reported by INES by now according to the INES scale.

As a principle, when an event falls into any of the following, the formal information on the event is to be distributed to member states through IAEA within 24 hours;

1) when its safety significance Level 2 or above, or

2) when an event attracts public concern outside of the country directly involved and press reports etc. are needed (Level 1 and Level 0.)

As events classified as Level 1 and Level 0 are reported as necessary to the INES Information Service based on the judgment of the country directly involved, it is impossible to account for the total number of cases including these levels, but about 500 reports have been distributed to Japan including events classified as Level 1 and Level 0 by now. The following show only events classified as Level 2 or above.

Table Accidents and Incidents Based on the International Nuclear Event Scale

April 1990 - December 2000

Level 7 (0)	(Chernobyl Nuclear Power Plant accident in the former Soviet Union, before use of the INES)
Level 6 (0)	
Level 5 (0)	(Three Mile Island accident in U.S., before use of the INES)
Level 4 (2)	Fuel manufacturing plant (1) ・ JCO uranium processing plant criticality accident (Japan) Others (1) ・ Radiation accident due to orphan source at Meetharufa Village, Egypt
Level 3 (15)	Entire nuclear power plants (6) ・ RBMK (Former Soviet Union type graphite moderated light-water cool boiling water reactor) (3) ・ PHWR (pressurized heavy-water reactor) (1) ・ PWR (pressurized water reactor) (2) Reprocessing facility (2) Two reported cases of the reprocessing facility include the fire and explosion at the asphalt solidification treatment facility that occurred in the Tokai Reprocessing Plant of the former Power Reactor and Nuclear Fuel Development Corporation in 1997. Others (accelerator, experimental facility etc.) (7) ・ Loss of sources and exposure by orphan sources (5) (As the INES is for private utilization facilities, the explosion event of a welded tank in the Tomsk reprocessing facility (military facility) was not reported by the country directly involved. But the accident is equivalent to Level 3)

Level 2 (114)	Entire nuclear power plants (73) ・ BWR (boiling water reactor) (4) ・ FBR (fast breeder reactor) (1) ・ GCR (gas cooled reactor) (2) ・ RBMK (former Soviet Union type graphite moderated light-water cool boiling water reactor) (8) ・ PHWR (pressurized heavy-water reactor) (7) ・ PWR (pressurized water reactor) (51) Fifty-one reported cases of PWR include the steam generator tubing damage accident that occurred at the Unit 2 of the Mihama NPS in 1991. Reprocessing facility (14) / fuel manufacturing plant (3) Forty-one reported cases of reprocessing facilities include at least six overexposure events exceeding the legal limit (regulatory limit) of the countries directly involved, such as worker's overexposure event occurred in the Tokai Reprocessing Plant of the former Power Reactor and Nuclear Fuel Development Corporation in 1994. Research reactor/test reactor (8) Others (accelerator, experimental facility etc.) (16) ・ Loss or discovery of sources (7)

(Based on the JAERI INES Japanese-version information database)