Jpn. J. Health Phys., **45** (4), 370 ～ 378 (2010)

Review

Latest Knowledge on Radiological Effects: Radiation Health Effects of Atomic Bomb Explosions and Nuclear Power Plant Accidents

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(Received on July 23, 2010)
(Accepted on July 23, 2010)

The latest knowledge encompass findings presented both in individual scientific publications and in internationally accepted reports. This review summarizes the latest knowledge on radiobiological effects on the latter level, using studies of atomic bomb survivors and victims of Chernobyl nuclear power plant accident. First of all, it is important to note that while examining individual patient, it is impossible to distinguish a radiation-induced cancer patient and non-radiation-induced cancer patient even when using state-of-the-art techniques. Therefore, investigation of radiation effects on humans, especially late health effects has been based on the epidemiological and statistical methods. Based on studies on atomic bomb survivors, it is well accepted that there is a linear increase in the risk of cancer with the increase of radiation dose. However, the existence of a threshold is a controversial issue, and health effects with regards to non-cancer diseases are not yet accepted by international authorities. Childhood thyroid cancer has increased after the Chernobyl accident and more than several thousands children are affected by it. However, there is no proof that any disease, with the exception of thyroid cancer and acute radiation effects, has increased after the Chernobyl accident. Finally, it should be mentioned that providing scientific explanation of the results to general public is an honorable duty of concerned scientists.

KEY WORDS: radiation health effects, cancer, non-cancer, linear dose relation, threshold, atomic bomb survivors, Chernobyl nuclear power plant accident.

I INTRODUCTION

1. Latest knowledge

The starting point of this review was an invitation from the President of the 3rd Asian and Oceanic Congress of Radiation Protection to deliver a lecture entitled "Newest knowledge of radiological biological effects" at the Congress. The latest knowledge is comprised both of findings presented in individual scientific publications and in internationally accepted reports. Usually, novel findings first appear as individual publications, which are often debated with respect to their validity, the interpretation of results, and conflicting ideas. A debate is important for developing scientific knowledge, confirming the significance of results, and searching for the next valuable studies. However, in this review the latest knowledge on radiological effects is summarized mainly at the level of internationally accepted reports (**Fig. 1**).

Health effects of radiation are pertinent to various very important social concerns, such as the use of nuclear power, medical use of radiation, relief for atomic bomb (A-bomb) survivors, etc. Therefore, scientific information on health effects of radiation, provided to the public, must be as clear-cut as possible and accepted internationally. The purpose of this review is to provide information to the public through

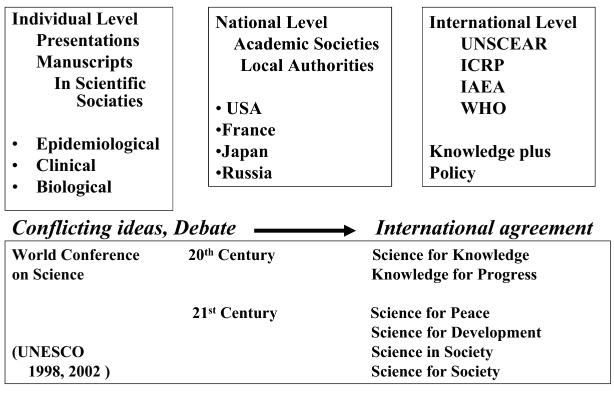

Fig. 1 Latest knowledge on radiobiological effects. What is the latest knowledge?

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2. Characteristics of late health effects of radiation

It should be noted that while examining particular patients, it is impossible to distinguish a radiation-induced cancer patients and non-radiation-induced cancer patients even with state-of-the art medical and scientific techniques. Therefore, investigation of radiation effects on humans, especially late health effects has been based on epidemiological and statistical methods. In brief, studies of radiation health effects have been focused on the relation between the degree of exposure to radiation (radiation dose) and the incidence of diseases in study cohorts.

3. Sources of information on radiation effects on humans in the 20th century

As shown in **Table 1**, sources of information on radiation effects are atomic bombings, A-bomb/H-bomb tests, A-bomb production accidents, accidents at nuclear power plants, occupational exposure, medical radiation, medical accidents, radiation sources, etc. Atomic bombings of Hiroshima and Nagasaki and the accident at Chernobyl Nuclear Power Plant (ChNPP) are selected for this review mainly because the author has been deeply involved in both investigations. Also, A-bombings of Hiroshima and Nagasaki are still the gold standard of radiation effects, and the Chernobyl accident affected the largest number of victims.

This review utilizes the following strategy: the level of individual reports to summarize knowledge at the level of internationally accepted findings.

II ATOMIC BOMBINGS OF HIROSHIMA AND NAGASAKI

1. Acute radiation effects

Atomic bombs were dropped on Hiroshima and Nagasaki respectively on August 6 and August 9 1945. Initial reports were compiled by Imperial Headquarters, the Japanese Army, Navy, Universities (Tokyo, Kyoto, Osaka), Scientific Institutes (Physical and Chemical Institute), Hiroshima Medical Association and Nagasaki University. A precise summary report was published by Hiroshima and Nagasaki Cities in 1979.[1)] "Medical Effects of Atomic Bombs: The report of the joint commission for the investigation of the effects of the atomic bomb in Japan, Volume 1-VI" a summary report in English, was published on April 19, 1951 by the Army Institute of Pathology, United States Atomic Energy Commission.[2)]

Energy of atomic bomb was estimated by A-bomb test using a similar type and size bomb (equivalent to TNT 20 kiloton) and it was reported that 50% of the energy was blast, 35% for heat, and 15% for radiation. A book on the effects of nuclear weapons was published in 1977, and the third edition was published in 2006.[3)]

(1) Acute death

Table 2 is the summary of these reports. In total, 140,000 people in Hiroshima (38.9% of the population) and 70,000 people in Nagasaki (28.0% of the population) died in 1945, but how many died particularly from the blast, heat, or due to radiation is unknown.

However, there was a report on "individuals who died 20 days after the bombing or later". Of the 6,882 people examined in Hiroshima, and of the 6,621 people examined in Nagasaki, 254 (3.7%) and 174 (2.6%), respectively, died later. About half of these deaths occurred between the 20th and the 29th day after the bombing and most of the remainder between the 30th and the 49th day. 99% of deaths in Hiroshima and 91% of deaths in Nagasaki occurred in areas located within 2,000 meters from the hypocenter. However, it should be mentioned that, most of the people residing within a distance of 500 meters from hypocenter died within less than 20 days after the bombing.[2, 3)]

Current analyses of extensive records at the Radiation Effects Research Foundation (RERF) were able to make estimates of shielding. It was calculated that a bone marrow dose of 2.9–3.3 Gy caused 50% mortality within 60 days. These data were based on about 7,600 survivors in 2,500 households who were exposed inside of their Japanese houses, located within 1,600 meters of the hypocenter in Hiroshima.[4)]

International organizations, such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have estimated the bone marrow LD50 is about 2.5 Gy in cases when little to no medical treatment is available, and at 5 Gy or more when extensive medical treatment is provided.

(2) Signs and symptoms caused by atomic bombing radiation

According to reports, nausea, vomiting, anorexia and malaise occurred in most of the cases on the day of the bombing. Subsequently, diarrhea, bloody diarrhea, purpura, epilation, and oropharygeal lesions occurred within a few days to several weeks after the bombing. In areas very close to the hypocenter, lower white blood cell counts, secondary infections, high fever, and death occurred within a few days.[2, 3)]

(3) Acute radiation syndrome

According to the RERF's current brief description,[4)] the illnesses called "acute radiation syndrome" occurs within a

Table 1 Sources of information on radiation effects on humans in the 20th century.

Atomic bombings	Hiroshima, Nagasaki
A-bomb/H-bomb tests	Marshall (Bikini, Bravo Test) Nevada (USA), Semipalatinsk (USSR) UK, France, China, India, Pakistan
A-bomb production accidents	Hanford (USA), Southern Ural (USSR)
Nuclear power plant accidents	Three Mile Island, Chernobyl, JCO (Tokaimura)
Occupational exposure	Uranium mines, Fluorescent Paint, Nuclear Plants
Medical radiation	Diagnosis and treatment
Medical accidents	Reported to IAEA, WHO all over the world
Radiation sources	Reported to IAEA, WHO all over the world

Table 2 Acute effects of radiation from atomic bomb on Humans.

Death

Place	Death / Population
Hiroshima	140,000/360,000 (38.9%)
Nagasaki	70,000/250,000 (28.0%)

It is not known how many died by blast, heat or due to radiation

Signs and symptoms

Nausea, vomiting, anorexia, malaise occurred in most of the cases on the day of the bombing. Subsequently, diarrhea, bloody diarrhea, purpura, epilation, and oropharyngeal lesion occurred within a few days to several weeks after the bombing. In areas very close to hypocenter, lower white blood cell counts, secondary infection, high fever, and death occurred within a few days.

few hours to months after an exposure to high-dose radiation (from approximately 1−2 Gy to 10 Gy). The most common signs and symptoms include vomiting occurring within a few hours, followed within days to weeks by diarrhea, reduced blood cell counts, bleeding, hair loss (epilation), and temporary male sterility. Diarrhea results from the damage to cells lining the intestines, reduction in blood cell counts from death of hematopoietic stem cells in bone marrow, and bleeding from declining number of blood platelets generated from stem cells. Hair is lost due to the damage to hair-root cells. Hair does not fall out but rather becomes thinner and eventually breaks off. Sterility in men occurs due to the damage to sperm-generating stem cells. Except for vomiting, these signs and symptoms are related to the frequency of cell division, rapid cell division being more sensitive to radiation than slow division (e. g., muscle and nerve cells). If radiation dose is low, this syndrome will seldom if ever occur (threshold). Conversely, if dose is high, death can occur within 10 to 20 days after exposure due to severe intestinal damage, or subsequently within one or two months, mainly from bone marrow failure.

These descriptions of acute radiation syndrome have been adopted by international scientific organizations.

2. Late effects of radiation

Studies on radiation health effects of atomic bomb survivors are still the world's gold standard. In this review, the current knowledge about radiation health effects on humans and limitations therefore are shown based on results of studies of atomic bomb survivors. The majority of epidemiological studies of survivors were performed by RERF, and data used in this review are obtained primarily from the brief description of the RERF.[4)]

(1) Radiation Effects Research Foundation (RERF, the former ABCC)

The Atomic Bomb Casualty Commission (ABCC) was established in Hiroshima and Nagasaki by the US National Academy of Sciences in 1947 in order to study health effects among atomic-bomb survivors in the two cities. The Radiation Effects Research Foundation (RERF) was established in 1975 as the successor organization to the ABCC with joint funding from the US and Japanese governments.

The aim of the ABCC-RERF's research is to determine long-term effects of radiation exposure. This matter had been an uncharted territory for scientific research. The RERF's research is noted for its long-term follow-up of a large, well-defined population cohort. Another strength of the RERF's research is that the radiation dose of each A-bomb survivors has been estimated with a high degree of accuracy. The first RERF's radiation dosimetry system was announced in 1965, followed by two revisions in 1986 (DS86) and in 2002 (DS02).

(2) Study Populations of RERF

In order to develop a comprehensive roster of persons eligible for inclusion in fixed study cohorts, the ABCC used data from the A-bomb survivors survey, conducted at the time of the 1950 Japanese national census. The survey identified 284,000 Japanese survivors, nearly 200,000 of whom were residents of either city at the time of the census. Subsamples of this original Master Sample have formed the basis for all studies conducted by the ABCC-RERF since the late 1950s. In all mortality studies, information on the cause of death is obtained through official permission from the Ministry of Health, Labor and Welfare and the Ministry of Justice regardless of location in Japan. Information on cancer incidence is obtained through local tumor and tissue registries and is limited to current residents of Hiroshima and Nagasaki prefectures. Additional information on disease incidence and health status is available for Adult Health Study participants.

As shown in **Table 3**, ABCC/RERF study cohorts include 120,000 participants of Life Span Study, 23,000 participants of Adult Health Study, 3,600 participants of In Utero exposed Survivors study, and 77,000 participants of Children of Survivors. Individual exposure doses were estimated by US and Japanese experts (DS86, DS 02).

(3) Radiation Dosimetry of Study Populations

The dosimetry system 2002 (DS02) provides individual dose estimates dependent on information regarding each survivor's location and shielding situation at the time of the bombing. The system is based on the physical nature of the bombs that were dropped, and theoretical models, developed by nuclear physicists for the following parameters: the amount of radiation released, the manner radiation was transported through the air, and the manner it was affected by passage through physical structures and human tissue. Individual dose estimates are imprecise for various reasons, including inaccuracies in reported survivor locations and the impossibility of accounting for all aspects of shielding in detail. It is believed that standard errors in individual dose

Table 3 Long-term follow-up study on A-bomb survivors by ABCC and Radiation Effects Research Foundation (RERF 1975–) –COHORTS–.

Cohorts	Size
1) Life Span Study (1950–)	120,000
2) Adult Health Study (1958–) biennial examination	23,000
3) In Utero exposed survivors Study (1950–)	3,600
4) Children of Survivors (1946–)	77,000

Individual exposure doses were estimated by US and Japanese experts (DS86)–(DS02).

estimates may be on the order of 35%.

(4) Late Radiation Effects: Studies at RERF

Early radiation effects, such as acute radiation syndrome, result from doses high enough to kill cells and thus cause direct tissue damage (1 Gy or greater). In contrast, late effects, such as cancer reflect DNA mutations in living cells induced by radiation exposure. While the exact mechanisms by which such mutations lead to cancer are not clear, it is believed that the process requires a series of mutations, accumulated over years. Mutations can occur either spontaneously or as a result of exposure to any of a wide range of environmental mutagens, including radiation. Since many years must pass before a given cell and its progeny acquire mutations sufficient to result in clinical disease, excess cancers attributable to radiation do not become evident until years after exposure (or somewhat fewer years in the case of leukemia). The RERF's data shows that excess cancer risks correspond broadly to age-time patterns predicted by such hypothetical considerations.

(i) Solid Cancers

Increased risk of cancer is the most important late effect of radiation exposure seen in A-bomb survivors. For cancers other than leukemia (solid cancers), excess risk associated with radiation started to appear about ten years after exposure. For most solid cancers, acute radiation exposure at any age increases cancer risk for the rest of a person's life. As survivors have aged, radiation-associated excess rates of solid cancer have increased along with the background rates. The average radiation exposure of survivors within 2,500 meters (about 0.2 Gy) resulted inthe increase of about 10% above normal age-specific rates. For a dose of 1.0 Gy, the corresponding cancer excess is about 50% (relative risk = 1.5).

During the period from 1958 to 1998, 7,851 malignancies (first primary) were observed among 44,635 LSS (the Life Span Study) survivors exposed to estimated doses of >0.005 Gy. The excess number of solid cancers is estimated as 848 (10.7%) (**Table 4**). The dose-response relationship appears to be linear, without any apparent threshold below which effects may not occur (linear non-threshold, the LNT hypothesis) (**Fig. 2**).

The probability that an A-bomb survivor may develop a cancer caused by A-bomb radiation (excess lifetime risk) depends on the dose received, the age at the time of exposure, and sex. Higher risks are associated with younger age at the time of exposure. Other analyses indicate that females have somewhat higher risks of cancer induced by radiation exposure than males..

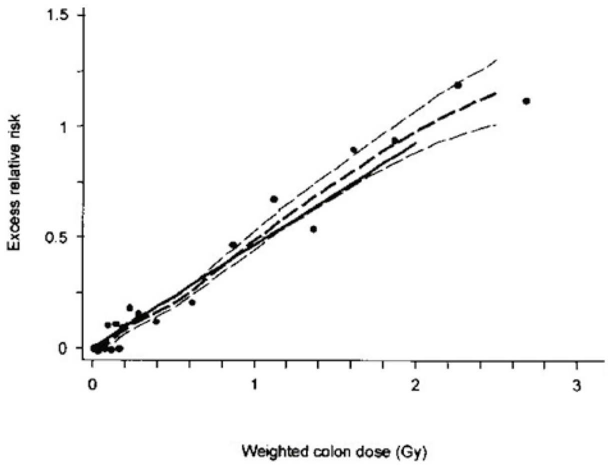

Fig. 2 LSS solid cancer incidence, excess relative risk by radiation dose, 1958–1998. The thick solid line is the fitted linear sex-averaged excess relative risk (ERR) dose response at age 70 after exposure at age 30. The thick dashed line is a non-parametric smoothed estimate of the dose category-specific risks and the thin dashed lines are one standard error above and below this smoothed estimate.

(ii) Linear dose response, no threshold (LNT)

As it was mentioned, the dose–response relationship appears to be linear, without any apparent threshold below which effects may not occur. **Figure 3** shows problems with LNT. In studies of mortality as well as incidence in LSS cohort, it was shown that the minimum dose necessary for health effects is 0.1 Sv. There is no evidence of departure from linearity over the 0–4 Sv range, that is, the relationship between radiation dose and cancer incidence is not different from a linear dose response in the 0–4 Sv range. Linearity of the 0–0.1 Sv range is not different from that of the 0–4 Sv range, indicating that estimated threshold is essentially 0. However, linearity of the 0–0.1Sv range is not different from the zero slope. This is the author's simplified explanation of problems with LNT.

The etiology of various solid cancers is another important

Table 4 Excess risk of developing solid cancers in LSS,1958–1998.

Weighted colon dose (Gy)	LSS subjects	Cancers			Artributable fraction**
		Observed	Estimates based on an model*		
			Cases if Unexposed(C)	Excess by Exposure(E)	
0.005–0.1	27,789	4,406	4,374	81	1.8%
0.1–0.2	5,527	968	910	75	7.6%
0.2–0.5	5,935	1,144	963	179	15.7%
0.5–1.0	3,173	688	493	206	29.5%
1.0–2.0	1,647	460	248	196	44.2%
>2.0	564	185	71	111	61.0%
Total	44,635	7,851	7,059	848	10.7%

* Estimated based on an excess relative risk model for linear dose response modified by age at the time of bombing, attained age, and sex.

** E/(C+E) (%)

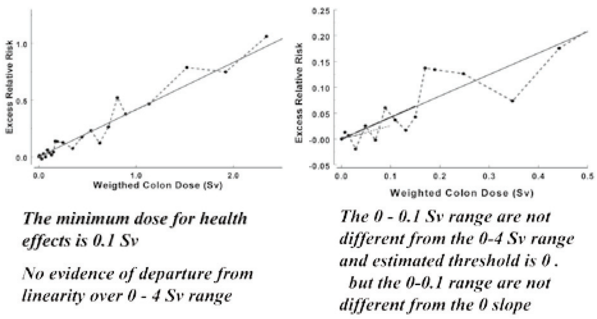

Fig. 3 Linear Dose Response, No Threshold (LNT): Relationship between radiation dose and excess relative risk of cancer is linear and has no threshold.

problem. It is well known that some cancers have cancer–specific etiology, and that etiology of various cancers is different. In spite of this medical knowledge about cancers, a linear dose response of solid cancers in atomic bomb survivors was obtained using all solid cancers as one group. This is another limitation of statistical analysis of the data.

(iii) Leukemia

Excess leukemia was the earliest delayed effect of radiation exposure seen in A-bomb survivors. Risks for radiation-induced leukemia differ from risk for most solid cancers in two major respects. Firstly, radiation causes a larger percent increase in leukemia rates; secondly, the increase appears sooner after exposure, especially in children. Excess leukemia began appearing about two years after radiation exposure, and the excess peaked at about 6–8 years after exposure. Today, little if any excess leukemia is occurring.

Leukemia risk among LSS survivors has been increased only for acute and chronic myelocytic leukemia and for acute lymphocytic leukemia. No evidence of increased risk is seen for adult T-cell leukemia (endemic in Nagasaki but virtually non-existent in Hiroshima) or for chronic lymphocytic leukemia, which, in marked contrast to western countries, is extremely rare in Japan.

(iv) Summary of late effects of A-bomb radiation reported by RERF

Even a brief description published by the RERF provides extensive information on human late health effects after atomic bomb explosion. This information is summarized by the author in **Table 5** . In addition to early mentioned solid cancers and leukemia it has been reported that A-bomb survivors suffer from several non-cancer diseases. Mortality data show dose-related excesses of respiratory diseases, stroke, and heart diseases. Moreover adult health incidence studies of non-cancer diseases show that there is a relationship between atomic bomb radiation dose and benign uterine tumors, thyroid disease, chronic liver disease, cataract and hypertension.

In-utero exposed survivors developed radiation-dose related microcephaly, mental retardation, and delayed growth. Finally, it should be noted that children of atomic bomb survivors showed no radiation-dose related health effects whatsoever.

5. RERF's reports and internationally accepted reports

First of all, it should be noted that a significant number of the RERF's reports have been accepted by international scientific organizations and the RERF's data has been regarded as the gold standard. However, two issues arise to illustrate a difference between the RERF's publications and internationally accepted reports.

The first issue is the LNT hypothesis. The RERF's data suggest that the LNT hypothesis, or LNT, is a model for interpretation of the RERF's data. However, there is a controversy as to whether the threshold exists, therefore, the LNT hypothesis can be accepted or rejected. Many entities around the world are involved in a continuous debate on LNT. A typical example is that the National Academy of Sciences (USA) supports LNT,[5] while the National Academy of Medicine (France) does not.[6] When low dose radiation is defined as a dose lower than 100 mSv, it can be considered that 75% of atomic bomb survivors in LSS cohort received low dose radiation, and most of nuclear power plant workers (more than half million) are also receiving low doses of radiation. However, it would be impossible to obtain clear a conclusion from epidemiological studies of these populations within a decade or more.. The International Commission on Radiological Protection (ICRP) has accepted LNT, as the radiation protection policy.

The second issue is radiation effects on non-cancer diseases. As shown in **Table 5**, the RERF reported that respiratory diseases, stroke, heart diseases, benign uterine tumors, thyroid disease, chronic liver disease, cataract and hypertension have increased significantly after exposure to atomic bomb radiation. However, both the ICRP and the UNSCEAR reviewed reports on cardiovascular diseases, and they concluded that in the absence of known biological mechanisms, scientific data are not sufficient to prove that the increase in cardiovascular diseases is due to radiation.[7, 8]

These are limitations of our knowledge about radiation health effects derived from studies of atomic bomb survivors.

Table 5 Late health effects of A-bomb radiation − Statistically significant results obtained from more than one study and risks clearly related to radiation dose−.

A) A-bomb survivors

(1) Malignant diseases

Leukemia:

acute and chronic myelocytic leukemia and acute lymphocytic leukemia.

no excess seen for chronic lymphatic leukemia or adult T-cell leukemia

Solid cancers:

Solid cancers, urinary bladder, breast, lung, thyroid, colon, ovary, stomach, hepatocellular, skin

(2) Non-cancer diseases

LSS: Heart diseases, Stroke, Respiratory diseases

AHS: Benign tumors (thyroid, parathyroid, salivary gland, uterus), thyroid diseases, chronic liver disease, cataracts, hypertension

B) In-utero exposed survivors

microcephaly, mental retardation, delayed growth

C) Children of A-bomb survivors

no significant effects

III ACCIDENT AT CHERNOBYL NUCLEAR POWER PLANT

1. Initial period (1986–1996)

The Chernobyl Nuclear Power Plant (ChNPP) accident occurred in 1986. Extensive international collaboration to study radiation related health effects started around 1990. International organizations the author collaborated with were the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the European Union (EU). Around the same time, the Ministry of Foreign Affairs, Japan and Sasakawa Memorial Health Foundation signed a bilateral agreement with the former Soviet Union and began collaboration.

In 1990, when international mass media were allowed to visit contaminated areas, it was repeatedly reported that "several hundred thousand people died due to the accident", that "huge areas were contaminated and people had to be removed", that "malformation appeared not only in humans but also in animals and plants", that "many babies and children were suffering from leukemia", etc. Inhabitants of the contaminated areas were consumed with fear and anxiety because of mass media news. It was reported that many women terminated their pregnancy. The author visited the contaminated areas in 1990 and met with many inhabitants (**Fig. 4**). It seemed that psychological effects such as panic, fear, and anxiety were the most serious matters that had to be dealt with. To abate the widespread panic, it was recommended that individual screening starts as soon as possible to detect potential patients as well as assure individuals that they were not affected by any diseases.

In 1989, the USSR Government requested that the IAEA examined the assessment of radiological situation in the contaminated areas. As the result of this request, in 1991, the IAEA published a technical report titled: "The International Chernobyl Project" written by an international advisory committee (Chairman: Dr. Itsuzou Shigematsu from the RERF).[9] The report contained following conclusions: at the time of the project study, there were significant non-radiation related health disorders, but no health disorders that could be attributed directly to radiation exposure. The accident had substantial negative psychological consequences in terms of anxiety and stress due to continuing high level of uncertainty. However, when published, this scientific report met with heated accusations from people living in the contaminated areas and from numerous mass media.

In parallel with international investigations, there have been published many individual reports and publications that were similar to mass media reports. They exacerbated already severe psychological conditions of people living in the contaminated areas such as fear and anxiety due to potential radiation health effects. The author was one of international experts involved in international investigation project, and one of the author's important duties was evaluating the validity of reports, considering psychological effects on people living in the contaminated areas.

In September 1992, a paper, "Thyroid cancer after Chernobyl" was published in Nature as scientific correspondence by the Minister of Health, Chairman of Thyroid Tumor Center, and Radiation Medicine Institute of Belarus.[10] As shown in **Fig. 5**, the following month a European Union mission was sent to Minsk. Members of the mission, the author included, were perturbed by seeing so many children with thyroid carcinoma, since the incidence of childhood thyroid carcinoma is one/one million in Japan, Europe and the US. While it was agreed by members of the mission that many children presented with thyroid papillary carcinoma, there had been no agreement between the EU and the USA experts on the cause of carcinoma.

International meetings and symposia to discuss scientific results of various studies, including thyroid carcinoma, have been held at least once a year ever since. Finally international symposia were held by the WHO, the EU and the IAEA 10 years after the Chernobyl accident.

2. International symposia 10 years after the accident

In 1995–6, the WHO and the EU held international symposiums independently from each other. In April 1996, the WHO, the EU and the IAEA held joint International Conference "One decade after Chernobyl" in Vienna.[11] The author summarized extensive presentations, discussions, summaries, and recommendations in **Table 6**.

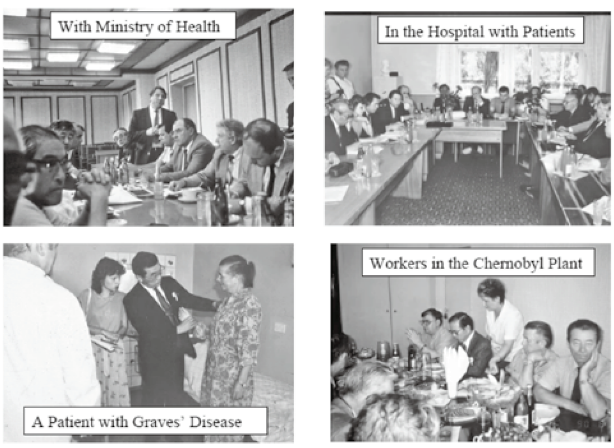

Fig. 4 People in Contaminated Areas.

Fig. 5 Many patients with childhood thyroid cancer were presented to Members of the EU Mission (including the author).
Prof. Demidchick at Thyroid Tumor Center in Minsk October 1992.

As far as acute radiation effects are concerned, medical findings on acute radiation syndrome patients and patients who died from radiation exposure were published in leading international scientific journals and widely acknowledged. Acute radiation syndrome was observed only in workers and firemen who were working inside the nuclear plant. There was no extensive debate on acute effects. As far as late effects are concerned, the international community was first made aware of the increase in childhood thyroid cancer at the time of an extensive discussion even during the symposium. However, the increase was accepted largely because of strong circumstantial evidence; chronological (studies starting around 1960) and geographical (three contaminated countries: the Russian Federation, the Republic of Belarus and Ukraine). **Figure 6** depicts a number of cases in Belarus as presented at the international conference. There were numerous publications and reports on the increase of leukemia and other diseases, but these reports were not accepted at this conference.

3. International symposia 20 years after the accident

In 2005, a report compiled by 8 international organizations including the IAEA, the WHO, etc. and 3 affected countries: the Russian Federation, the Republic of Belarus, and Ukraine was published as the Chernobyl Forum, and the scientific symposium on the Chernobyl Forum was held in Vienna. A report on health effects: "Health Effects of the Chernobyl Accident and Special Health Care Program by Expert Group "Health". was published. The report had over 50 contributors (Chairman: Dr. Burton G. Bennett from the RERF). Its summary on cancer and non-cancer was presented by two speakers at the symposium, which appeared to be a ceremony dedicated to the publication of the Chernobyl Forum. This style of presentation was very different from "One decade after Chernobyl", when each topic was presented by a group of experts and presentations were discussed extensively at the sumposium.

The Forum was finally presented by an IAEA expert at memorial symposium held in Kiev in 2006.[12] **Table 7** summarizes extensive conclusions and the discussion of the Chernobyl Forum. The only demonstrated late health effects of radiation were the increase in thyroid cancer in children. The

Table 6 International Symposia 10 Years after Chernobyl Accident IAEA/WHO/EC Joint Symposium.

People considered to have been exposed	Size
1. Power plant workers, firemen, etc.	Several hundred subjects
2. Liquidators	Hundreds of thousands
3. Those exposed to radioactive fallout	4 million

People with demonstrated health effects	Size
1. People with symptoms of acute radiation syndrome	134 (237 were hospitalized) 28 died within 3 months 14 died within the subsequent 10 years (2 died of blood disease)
2. Childhood thyroid cancer	About 800 3 died because of thyroid cancer
3. Increase of other diseases including leukemia	Not been confirmed.

Table 7 Chernobyl forum.

■ Categorization of radiation-exposed subgroup

Population groups	Size	mSv
1. Emergency workers on-site	237	lethal dose
2. Liquidators (1986–7) (30 km zone)	240,000	100
3. Evacuees of 1986	116,000	33
4. Persons in living at deposition density of Cs137		
more than 37 kBq/m^2	5,200,000	10
more than 555 kBq/m^2	270,000	50

■ People with demonstrated health effects

Health effects	Size
1. Symptoms of acute radiation syndrome	134 (237 hospitalized) 28 died within 3 months 15 died within the subsequent 20 years
2. Childhood thyroid cancer	more than 4,000 9 (-15) died confirmed
3. Leukemia and other solid cancers	No increase
4. Subclinical psychological effects	Major impact

increase in leukemia and other diseases was not demonstrated. Another major impact reported and demonstrated was subclinical psychological effects. **Figure 7** shows changes in thyroid carcinoma incidence in young people. It should be noted that incidence of carcinoma in children decreased from 1996 and was almost 0 in 2002. In contrast to the decrease in children, cancer incidence has begun increasing in adolescents and adults.

There is no significant difference between reports produced at 10 and 20 years after the accident, with the exception of reporting the average radiation dose received by each group.. When radiation dose and the LNT hypothesis were taken into account, it was shown that there were 4,000 deaths from cancer precipitated by radiation. Most of mass media reports quoted numbers only; no explanation of the background was provided.However, the above-referenced estimation was not accepted after discussions within international organizations.

4. The report compiled by international organizations has to be explained to the public

One of the concepts to be explained to the public is “demonstrated health effects”. The word “demonstrated” or proved means that some health effects are demonstrated or proved by epidemiological studies and statistical methods to be a consequence of radiation exposure. However, “not demonstrated” does not mean that there are no effects. “Not demonstrated” may change to “demonstrated” when sufficient data are obtained, yet when, the probability that given health effects are a consequence of radiation exposure is smaller, the effects are called “not demonstrated”.

As mentioned above, the investigation of radiation health effects implies finding a relation between exposed radiation doses and the incidence of diseases in study cohorts. Therefore, if data on exposed radiation doses are not sufficient, no radiation health effects are demonstrated. Similarly, if data on the incidence of diseases in study cohorts are insufficient, no radiation health effects are demonstrated. It should be noted that the increase in childhood thyroid cancer was recognized largely because of strong circumstantial evidence; chronological (starting around 1960) and geographical (three contaminated countries, the Russian Federation, the Republic of Belarus, and Ukraine).

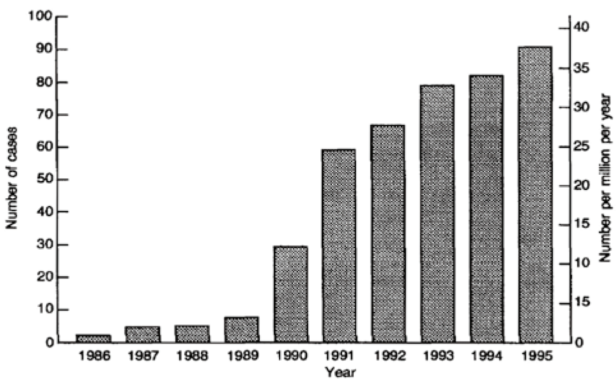

Fig. 6 Annual number of childhood carcinomas (age under 15 years at the time of operation) in Belarus, 1986–1995.

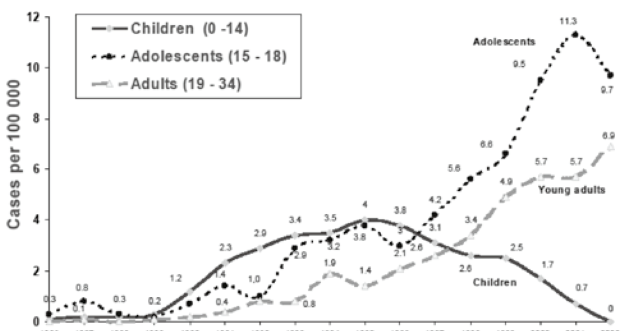

Fig. 7 Increase in thyroid cancer incidence in young people. Incidence per 100000 in Belarus ~Courtesy of Yuri. E. Demidchik~.

IV EXPLAINING SCIENTIFIC RESULTS TO THE PUBLIC IS THE DUTY OF CONCERNED SCIENTISTS

The dissociation between scientific results and general public understanding has often been found in many fields. The dissociation between the Chernobyl Forum and the public understanding of the Chernobyl accident is a typical example. While providing explanation to the public, it is important to rely on information that is accepted by all experts on international and national levels. Local governments are of key importance in promoting public understanding.

However, as scientists we have a duty to generate a new knowledge, which starts with individual investigations. Before new knowledge is established internationally, it needs to be purified and solidified in the process of disagreement and debates among individual scientists, and, for the purpose of obtaining funding for further research, it is necessary that the public be made aware of the unknowns, uncertainty, and disagreement about results.

Scientists must inform the public that there are areas of scientific certainty and uncertainty. In regards to areas of scientific certainty, we should ask the public to accept scientific knowledge as much as feasible. Speaking of areas of scientific uncertainty, scientists must strive to change uncertainty into certainty. Scientists have a duty to present and publish results of all scientific investigations and discuss them with the scientific community to assess their validity.

Also it is imperative to recognize that there are many fields that call for further scientific knowledge, such as:

(1) Health and well-being of, and compensation of atomic bomb survivors and other surviving victims of radiation (HIBAKUSHA) in the world,
(2) Preparedness for radiation emergencies,,
(3) Safety and security of the utilization of atomic energy,
(4) Safety and security of the utilization of radiation,
(5) Radiation protection,
(6) Utilization of radiation in medicine,
(7) Protecting of the environment, etc.

In regards to areas of scientific uncertainty, scientists must request that responsible individuals stakeholders, and decision makers in relevant fields explain to the public the reasons behind their decision making not in terms of uncertain scientific knowledge but rather in terms of their own actual policy. Wisdom acquired by mankind since the birth of humans must play a central role in decisions pertaining to areas of scientific uncertainty.

Finally, it should be emphasized that providing the public with explanations about various stages of scientific progress, agreements and disagreements developing in the process of research is the duty of scientists. Scientists must do everything in their power to enable public understanding of scientific results.

ACKNOWLEDGEMENT

The author would like to thank Prof. Itsuzou Shigematsu, Honorary Advisor of the RERF, and Prof. Toshiteru Okubo, Current Chairman of the RERF, for their kind revision of the manuscript and Dr. Misa Imaizumi, Nagasaki University and the RERF Nagasaki Laboratory, and Ms. Ayako Ishibe, the RERF, for their valuable assistance with editing.

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