Current Topics about the Radiological Consequences by the Chernobyl Accident

Tetsuji IMANAKA

Research Reactor Institute, Kyoto University
Kumatori-cho, Sennan-gun, Osaka, 590-0494 Japan: imanaka@rri.kyoto-u.ac.jp

Abstract

Basic radiological factors of the Chernobyl accident are reviewed such as radioactivity discharge, the size of contaminated area, radiation dose, radiation risk assessment *etc*. Roughly estimating, 50-60 % of ^{131}I and 30-50 % of ^{137}Cs in the reactor core were released into the environment, which correspond to 40-50 MCi and 2-4 MCi, respectively, as the activities at the time of the accident. The total area in 13 European countries with the ^{137}Cs contamination more than 1 Ci/km^2 amounts to 190,000 km^2. The collective thyroid dose for the entire populations in the most affected three countries (Belarus, Ukraine and Russia) is estimated 1.6×10^6 person-Gy. The collective effective dose (excluding thyroid dose) for 5.16 million people living in the main contaminated territories in three countries is estimated 4.26×10^4 person-Sv during 10 years after the accident. Using these collective doses together with radiation risk coefficients of ICRP (1990), 13,000 thyroid cancer and 2,100 other cancer deaths are expected among the corresponding populations.

Other articles in this report indicate the followings. About 4,400 cases of radiation-induced thyroid cancer were observed in Belarus by the end of 2000. There are also observed some increasing tendencies of other cancers among inhabitants in the contaminated areas and liquidators. Health deteriorations and mental retardations are observed among the children living in the contaminated areas and having received irradiation *in utero*. All these findings suggest the necessity of well organized epidemiological studies before giving conclusions about the health consequences of the Chernobyl accident as well as applicability of ICRP radiation risks to the related populations.

An interesting map is shown representing dose rate around the Chernobyl NPP on June 1, 1986. Using the dose rate in this map for reconstructing radiation dose for evacuees, the possibility of acute radiation sickness was confirmed among a substantial part of evacuees from some villages within the 30 km zone.

1. Introduction

It was more than a quarter of century ago that our group, Nuclear Safety Research Group of Kyoto University began to raise the alarm for catastrophic consequences in case of large nuclear accidents in Japan. According to our assessment based on the methodology developed by Reactor Safety Study of USNRC (1975), about 5,000 acute deaths were forecast when a severe loss-of-coolant accident would happen at the Ikata-1 NPP (560 MW, PWR) [1]. The high level of radioactive contamination was expected to extend more than 100 km along the wind stream. The Japanese authorities, however, neglected possibilities of such accidents, saying every time that nuclear power plants were designed and constructed under conceptions; “Fail Safe” and “Fool Proof”.

In March 1979, a large loss-of-coolant accident happened at Three Mile Island-2 NPP (1,000 MW, PWR) in USA, which resulted in a partial meltdown of the reactor core. Fortunately, the containment of TMI-2 could keep radioactive particulates from escaping although a large amount of radioactive gases were released [2]. The radiological consequences due to the TMI-2 accident were considered rather small in comparison with the worst ones. This accident, however, demonstrated the reality of possible catastrophic accidents at NPPs.

On April 26, 1986 an excursion accident occurred at the Chernobyl-4 (1,000 MW, RBMK) in the former USSR and destroyed the reactor and the building at a moment, which released a huge amount of radioactivity into the environment. Sixteen years have already passed since the occurrence of the Chernobyl accident. There remain, however, many questions that were not yet answered. For example, according to *Malko's article* [3], the primary causes of the Chernobyl accident were design defects of the reactor and inadequate operation manuals, while unprofessional actions of the operators of the Unit-4 were responsible for the accident, according to *Gorbachev's article* [4].

In this article, current topics about the radiological consequences of the Chernobyl accident are summarized, referring to activities of our group and the contents of the other articles in this report.

2. Radioactivity release

The amount of radioactivities released into the environment is the basic factor characterizing the scale of nuclear accidents. So far a number of estimations have been made by various authors about the radioactivity discharge by the Chernobyl accident [5-12]. Table 1 summarizes several estimations for main radionuclides.

USSR 1986 Report:

In August 1986 the Soviet government sent a delegation to the post-accident review meeting on the Chernobyl accident held in Vienna by IAEA. According to the report of the Soviet delegation [5], the total release of non-gaseous radionuclides and gaseous ones were estimated to be 50 MCi and 50 MCi, respectively. These figures were decay-corrected to the activities on May 5. The USSR 1986 Report included valuable information, but the detailed methods of their estimation were not clear. I would like to note one episode of our group with the USSR report. Our group was independently involved in the task to estimate the radioactivity release by the Chernobyl accident. In October 1986, after reading through the USSR Report extensively, Seo of our group wrote a letter to Legasov, the head of the Soviet delegation in Vienna, asking various unclearness and inconsistencies in the Soviet estimations. More than one year later, in January 1988, Seo received a kind answer from Legasov, writing "the discharge estimate has been obtained measuring fall-outs from the initial discharge, radionuclide concentration in the air in the direction of air mass motion and on the basis of model calculations" [13].

Estimation by our group:

By the end of 1986, we could collect radioactive deposition data by the Chernobyl accident from all over the northern hemisphere except for the Soviet territories. Our primary attention was directed to the ground deposition of ^{137}Cs. It was strange that our estimate for the ^{137}Cs deposition on all European countries except USSR was about 1 MCi, which was the same as the total release of ^{137}Cs estimated in the USSR 1986 Report.

Using the level of ^{137}Cs deposition as the reference nuclide of the radioactive contamination, we have analyzed dependencies of radionuclide composition on the direction and the distance from Chernobyl.

Table 1. Estimates of released radioactivity of major nuclides by the Chernobyl accident.

Nuclide	Half life	Inventory, MCi	Estimated released radioactivity, MCi (% of core inventory)				
			USSR report (1986) [5]	Seo (1988) [7]	Imanaka (1993) [9]	Ukraine (1996) [10]	Borovoi (2001) [12]
^{131}I	8.05 d	36.5	7.3 (20)	25.40 (70)	(49)	(50-60)	(50-60)
^{137}Cs	30.2 y	7.7	1.0 (13)	4.35 (57)	(31)	(20-40)	(33±10)
^{95}Zr	64 d	119	3.8 (3.2)	5.60 (4.7)	(5.0)	(3.5)	-
^{90}Sr	28 y	5.5	0.23 (4.0)	0.53 (9.6)	-	(4-6)	-

- All activities are decay-normalized to values on May 6, 1986.
- Values of reactor inventory are cited from the USSR 1986 Report.

Then, by integrating the deposition functions, the total depositions were calculated up to 3,000 km from Chernobyl [7]. The obtained results showed larger depositions than the USSR 1986 Report by factors of 4.4 and 3.5 for ^{137}Cs and ^{131}I, respectively (Table 1).

In our first estimation, only small data in the USSR 1986 Report were used for the contamination within the USSR territories. The collapse of USSR at the end of 1991 changed the situation around Chernobyl problems. In 1993 we organized a collaborative study with Belarusian scientists under a research-grant from the Toyota foundation [14]. We made new estimation using more data provided from Belarusian side [9]. Our new estimates were smaller than the previous ones and by 2.4 and 2.5 times larger than the USSR 1986 Report for ^{137}Cs and ^{131}I, respectively (Table 1).

Estimation based on the radioactivities remaining within Sarcophagus:

Another method for estimation of radionuclide discharge is to investigate the amounts of radioactivities that remain within "Sarcophagus" (the concrete building containing the destroyed 4th unit). *Pavlovych's article* [15] describes the current situation of nuclear fuel within Sarcophagus. 190 ton of uranium was loaded in the reactor core at the time of the accident. Now within Sarcophagus, uranium fuel exists mainly in three forms: fuel fragments, LFCM (Lava-like Fuel Containing Material) and dusts. The amount of uranium in LFCM is estimated about 120 ton (min; 65, max; 165) [15]. According to Borovoi and Gagarinsky [12], it was found that 60 % of ^{137}Cs escaped from LFCM from the analysis of LFCM samples, while no amount of ^{129}I was detected in LFCM. Concerning fuel fragments dispersed from the reactor core at the time of the explosions, 25 – 37 % of ^{129}I remain within them and ^{137}Cs was retained as it was in the core. Based on these data, they concluded that 33 ± 10 % of ^{137}Cs and 50 – 60 % of ^{131}I were released from the reactor core of the Chernobyl-4.

Looking at the values in Table 1, we can roughly say that 50 - 60 % of ^{131}I, 30 - 50 % of ^{137}Cs and about 5 % of non-volatile nuclides in the reactor inventory were discharged into the environment by the Chernobyl accident. These values correspond to round estimates of radioactivities: 40 - 50 MCi of ^{131}I, 2 - 4 MCi of ^{137}Cs and 0.3 MCi of ^{90}Sr. These activities are adjusted at the time of the accident.

3. Radioactive contamination

One of unexpected features of the Chernobyl accident is that the contamination extended over a vast area on the Earth. This was caused partly by the fact that radioactive plumes reached high altitude of the atmosphere by the first explosions and the consequent fire, and partly by the fact that the radioactive discharge continued more than 10 days changing the direction of the radioactive plumes. These conditions can not be supposed in case of accidents at water power reactors such as PWR and BWR.

Cesium-137 is the most important nuclide from the point of the long-term effects of radioactive contamination. The areas of ^{137}Cs contamination more than 1 Ci/km^2 in European countries are summarized in Table 2 [16]. As the value of the total deposition on the northern hemisphere, 70 PBq (1.9 MCi) of ^{137}Cs is given in UNSCEAR 1988 Report [8]. This value is near the lower limit of our round estimate of ^{137}Cs release (2-4 MCi). The following two points should be noted about the estimate in UNSCEAR 1988. At first, UNSCEAR 1988 was made before the detailed information about the highly contaminated within USSR was disclosed in 1989. Based on the more recent ^{137}Cs contamination data in Table 2, the amount of total ^{137}Cs deposition in the most affected three countries (Belarus, Russia, Ukraine) is calculated to be 1.2 MCi, which is 0.5 MCi larger than the value given for the USSR territories in UNSCEAR 1988. At second, the UNCEAER 1988 estimate did not seem to include the radioactivities in the 30 km zone. The ^{137}Cs activity in the Ukrainian territory within the 30 km zone is reported to be about 0.5 MCi: 0.11 MCi on soil and 0.41 MCi in radioactive waste pits [10]. Considering these factors, the UNSCEAR 1988 estimate should be revised to 2.9 MCi, which lies in the middle of our round range. Meanwhile, according to *Nasvit's article* [17], ^{137}Cs activity contained in the lake sediments of the cooling

Table 2 Area of ^{137}Cs contamination in European countries with more than 1 Ci/km^2 (km^2) [16]

Country	Area (km^2)	Level of ^{137}Cs contamination, kBq/m^2 (Ci/km^2)					
		10 - 20	20 - 37	37 - 185 (1 - 5)	185 - 555 (5 – 15)	555 - 1480 (15 - 40)	>1480 (>40)
Belarus	208,000	60,000	30,000	29,900	10,200	4,200	2,200
Russia	17,075,000	300,000	100,000	48,800	5,700	2,100	300
Ukraine	604,000	150,000	65,000	37,200	3,200	900	600
Sweden	450,000	37,400	42,600	12,000	-	-	-
Finland	337,000	48,800	37,400	11,500	-	-	-
Bulgaria	111,000	27,500	40,400	4,800	-	-	-
Austria	84,000	27,600	24,700	8,600	-	-	-
Norway	324,000	51,800	13,000	5,200	-	-	-
Greece	132,000	16,600	6,400	1,200	-	-	-
Slovenia	20,000	8,600	8,000	300	-	-	-
Italy	301,000	10,900	5,600	300	-	-	-
Moldova	34,000	20,000	100	60	-	-	-
Switzerland	41,000	5,900	1,900	1,300	-	-	-
Total		765,100	375,100	161,160	19,100	7,200	3,100

Note-1: ^{137}Cs level in European countries due to global fallouts by nuclear test was 2 - 3 kBq/m^2 in early 1990s.
Note-2: According to Chernobyl laws in Belarus, Russia and Ukraine, the contaminated territories are legally divided into the following categories depending on ^{137}Cs density:
(1) 1-5 Ci/km^2 - zone of radiation control, (2) 5-15 Ci/km^2 - zone of guaranteed voluntary resettlement,
(3) 15-40 Ci/km^2 - zone of obligatory resettlement, (4) > 40 Ci/km^2 - zone of alienation.

pond of the Chernobyl NPP is estimated to be 4,400 Ci.

The processes forming radioactive contamination around the territories adjacent to the Chernobyl NPP and their nuclide compositions were extensively analyzed in *Gaydar's article* [18], taking into considerations geological features of the contaminated territories. Detailed contamination maps were presented for ^{137}Cs and Pu isotopes and ^{241}Am. Interesting data are presented in *Stepaneko's article* [19] about the radioactive plume arrival and departure in contaminated settlements in Bryask, Tula and Kaluga regions of Russia. According to *Stepanenko's article* [19], about 80 % of the total ^{131}I deposition was formed during the first week after the accident.

Recent data about the food contamination of ^{137}Cs and ^{90}Sr in Belarus are reviewed in *Matsko's article* [20]. They noted that special attention should be paid to non-farm products such as mushrooms, berries and meat of wild animals. For example, about 37,000 Bq/kg of ^{137}Cs in fresh mushroom was registered in a settlement of Gomel region in 1999. *Tykhyy's article* [21] presents the results of two series of measurements that were conducted in 1992 and in 2001 at the same village in Zhytomyr region, Ukraine. The ^{137}Cs activity in milk in the village was decreased by 9 times in 2001 in comparison with 1992, while the ^{90}Sr concentration was 3 times higher in 2001 than in 1992.

Dynamics of ^{137}Cs accumulation in fish in various water bodies are described in *Ryabov's article* [22]. Although a general decreasing trend of ^{137}Cs accumulation has been observed, lowering rates are quite different, depending on fish species and conditions of water bodies. High levels of ^{137}Cs accumulation are still observed in some lakes with stagnant water. *Nasvit's article* [17] provides the results of recent radioecological monitoring of the cooling pond of the Chernobyl NPP.

3. Radiation dose and risk assessment

UNSCEAR 2000 report [11] provides a series of interesting information about radioactive contamination, dose reconstruction and health effects due to the Chernobyl accident.

Table 3. Thyroid dose for the population in the main contaminated areas.

Country	Population	Collective thyroid dose, person-Gy	Average individual thyroid dose, mGy
Belarus [11]	3,100,000	402,000	130
Russia [19]	3,100,000	106,000	34
Ukraine [11]	3,500,000	300,000	86
Total	9,700,000	808,000	83

Note; Belarus- Gomel and Brest regions. Russia - territories with ^{137}Cs contamination more than 1 Ci/km^2 in Bryansk, Orel, Tula and Kaluga regions. Ukraine - 8 districts around Chernobyl and Kiev city.

Thyroid dose and thyroid cancer risk:

Thyroid dose for the populations in the main contaminated areas in the most affected three countries is summarized in Table 3 [11, 19]. The highest average thyroid of 130 mSv is given in Belarus, while the lowest of 34 mSv is in Russia. Thyroid dose in Table 3 are given for the population including all ages. As is well known, thyroid dose to children is larger than adults. For example, among 1,988 children less than 1 year old living in the contaminated district of Gomel region, Belarus, 667 children (34 %) received thyroid dose more than 2 Gy [11]. For the evacuees from Ukrainian villages within the 30 km zone, the mean thyroid dose of 3.9 Gy is estimated for 369 children less than 1 year old, while the average thyroid dose for the people more than 18 years old is 0.40 Gy [11].

Collective thyroid dose for the entire populations of three countries are given as follows: 5.53×10^5 person-Gy for Belarus, 7.4×10^5 person-Gy for Ukraine and $(2 - 3) \times 10^5$ person-Gy for Russia. Using the total collective thyroid dose of 1.6×10^6 person-Gy for three countries and the radiation risk factor for thyroid cancer of 8×10^{-2} Gy^{-1} from ICRP Publication 60 [23], about 13,000 thyroid cancer cases are expected in these countries as the consequences by the Chernobyl accident. 10 % of them, that is, 1,300 cases will be fatal.

UNSCEAR 2000 Report [11] presents the data that about 1,800 thyroid cancers were observed during 1990 – 1998 in children 0 – 17 years old at the time of the Chernobyl accident: 1,067 cases in Belarus, 205 cases in Russia and 519 cases in Ukraine.

According to *Malko's article* [24], 4,400 cases of radiation-induced thyroid cancer have been already observed in the whole population of Belarus by the end of 2000: about 700 cases in children under 15 years old and 3,700 cases in adolescents and adults at the time of diagnosis. The number of additional thyroid cancer in Ukraine and Russia can be calculated using the ratio of their collective thyroid dose to Belarus. Thus, about 12,000 cases of thyroid cancer are considered to have already appeared in the affected three countries. Anyway, we have to carefully watch the results of future follow-up studies in order to give conclusions about the total outcome of thyroid cancer by the Chernobyl accident.

Knatko's article [25] describes a method to estimate thyroid dose from ^{131}I inhalation in the contaminated territories in Belarus. Average thyroid dose from inhalation for adults are estimated to be 20 and 130 mSv for the eastern and southern contaminated areas, respectively. The difference between two areas was mainly due to the differences of the ^{131}I/^{137}Cs ratio and the type of ^{131}I deposition (dry deposition in the southern and wet deposition in the eastern).

Effective dose and health effects other than thyroid cancer:

Estimates of effective dose for the total body (excluding thyroid dose) during the period 1986-1995 for the populations living in the contaminated areas with more than 1 Ci/km^2 are summarized in Table 4 [11]. Compared with the values for thyroid dose in Table 3, about 10 times less values are shown for effective dose. The difference among three countries is rather small. In addition, age dependency of effective dose is reported to be small compared with the case of thyroid dose [11].

Forecasts of effective dose for 70 years after the accident (1986 – 2056) are also shown in

Table 4. Effective dose for the population living in the contaminated territories more than 1 Ci/km² of ^{137}Cs for the period 1986-1995 (excluding thyroid dose) [11].

Country	Population	Collective effective dose (person-Sv)			Average effective dose (mSv)		
		External	Internal	Total	External	Internal	Total
Belarus	1,880,000	9,600	5,500	15,100	5.1	2.9	8.0
Russia	1,980,000	8,500	5,000	13,500	4.3	2.5	6.8
Ukraine	1,300,000	6,100	7,900	14,000	4.7	6.1	10.8
Total	5,160,000	24,200	18,400	42,600	4.7	3.5	8.2

UNSCEAR 2000 [11]. Effective dose during 10 years after the accident (1986 -1995) consists of 60 – 70 % of the 70 years dose, within which the first year (1986) contributed 23 – 28 %.

Using the collective dose of 42,600 person-Sv in Table 4 and the radiation risk coefficient for cancer mortality of 5×10^{-2} Sv^{-1} from ICRP [23], we can expect 2,100 cancer deaths among the 5.16 million people other than thyroid cancer. Assuming that 15 % of this population will die of spontaneous cancer, the number of cancer deaths without irradiation will amount around 770,000. Therefore, 2,100 cases of radiation-induced cancer deaths will increase the cancer death rate about 0.3 %. If the cancer risk coefficient from ICRP is applicable to the population suffering from the Chernobyl accident, it will be absolutely impossible to observe such small increase of cancer death by means of epidemiological studies.

A new cancer risk model based on recent knowledge about dose-effect relationship is proposed in *Knatko's article* [26]. According to their cancer risk assessment for 250,000 inhabitants (average effective dose, 43 mSv) living in the contaminated areas in Belarus more than 5 Ci/km² of ^{137}Cs, 5 – 6 % of ERR (excess relative risk) is expected during the whole life, which is about 6 times larger than the value based on the risk coefficient from ICRP. In this case 2,200 cancer deaths will be added on 37,000 spontaneous cancer deaths.

Meanwhile, a significant increase of cancer deaths among 66,000 Russian liquidators (the mean dose, about 100 mSv) is reported for the observation period 1991 – 1998 in *Maksioutov's article* [27]. The ERR coefficient is estimated to be 2.04 Sv^{-1} (95%CI: 0.45, 4.31). This value is about 60 % higher than the corresponding coefficient derived from ERR in *Kantko's article* [26]. It should be noted that a significant increase of deaths from cardiovascular diseases (0.79 Sv^{-1}, 95%CI: 0.07 – 1.64) is also observed among Russian liquidators in *Maksioutov's article* [27].

Prysyazhnyuk's article [28] presents analysis of medical statistics in Ukraine mainly based on the National Cancer Registry that was established in 1989. The results suggest increasing tendencies of female breast cancer among women liquidators, inhabitants in the most contaminated districts and evacuees from the 30 km zone. *Arynchyn's article* [29] reports the results of a prospective cohort study of children in Belarus: the main group consists of 133 children living in the contaminated territories and the control group is 186 children in clean territories. Through clinical examinations they found significantly high relative risks of the main group for diseases such as arterial hypotension and cardic metabolic dysfunction. *Nyagu's article* [30] presents the results of medical investigation concerning brain functions of 100 children prenatally irradiated at the time of the accident and born to mothers evacuated to Kiev from the 30 km zone. Bain damages expressed as decreases of IQ indices, mental disorders *etc.* were observed among the prenatally irradiated children, compared with the control children consisting of their classmates.

Considering the findings shown in a series of epidemiological studies performed in Belarus, Ukraine and Russia, it is early to say that the radiation risk from ICRP is applicable to the populations suffering from irradiation due to the Chernobyl accident. The author would like to address the necessity of well designed and organized epidemiological studies in order to conclude about the radiation consequences by the Chernobyl accident.

Concerning the efforts to reconstruct effective dose more precisely, *Chumak's article* [31] overviews the current situation in Ukraine about EPR dosimetry using tooth enamel. Based on the EPR measurements of 465 Ukrainian liquidators who worked in 1986-1987, the average dose of 110 mSv is obtained. This value is comparative to the average value of 130 mSv for Russian liquidators in 1986-1987 based on official records. Application of EPR dosimetry in Russia for the population living in the contaminated territories is described in *Ivannikov's article* [32]. From the regression analysys between EPR dose and ^{137}Cs contamination density, the normalized dose of 0.068 mGy per kBq/m^2 of ^{137}Cs was obtained during 8 years after the accident, while UNSCEAR 2000 [11] gives the value of 0.037 mSv per kBq/m^2 of ^{137}Cs for the rural area in Russia.

4. Cytogenetic research

Cytogenetic disturbances in cells are primary markers of irradiation effects on biological organism. *Geraskin's article* [33] presents the results of a cytogenetic experiment on plants in the first years after the accident within the 30 km zone of Chernobyl. They observed chromosome aberration in rye and wheat. Through the experiment of subsequent generations for 3 years, an increasing tendency of radiation sensitivity of chromosome aberration was observed both for rye and wheat.

Chromosome aberrations in human lymphocyte have been investigated for more than 1,500 liquidators in *Snigiryova's article* [34]. Even 15 years after the accident a significantly higher level of dicentrics frequencies is still observed among liquidators although there is a general tendency of decrease for this index. In *Slozina's article* [35], an incresed level of chromosome abberation in lymphocyte is also observed among the liquidators. An interesting tendency is reported that the dicentric frequency among the liquidators shows an increase for the period 8-12 years after irradiation. *Bezdrobna's article* [36] presents the results of a cytogenetic examination of 33 self-settlers in the 30 km zone of the Chernobyl NPP. The frequencies of chromosome abberation among the self-settlers were found to be significantly higher than the control group living in relatively clean territories.

5. New information about radiation situation within the 30 km zone

According to UNSCEAR 2000 [11], 49,614 people in Pripyat city and Yanov railway station were evacuated on April 27, 1986, the next day of the Chernobyl accident. Another 41,792 people evacuated from Ukrainian territory within the 30 km zone, mainly in May 3 – 7. From the Belarusian territory within the 30 km zone, 24,725 people evacuated mainly in May 2 – 7. In total, 116,231 people were evacuated from the 30 km zone. A large part of evacuees stayed at their places for 6 – 11 days before evacuation.

There are two confronting opinions about acute radiation syndromes among the inhabitants. The first one is official opinions beginning from USSR 1986 Report up to UNSCEAR 2000 Report that no case of acute radiation disease occurred among the inhabitants around the Chernobyl NPP. According to the second opinion, there should be a lot of acute radiation sicknesses among inhabitants. For example, according to the secret protocols of the Special Operative Group of the Central Committee of the USSR Communist Party [37, 38], the number of patient with radiation sickness was periodically reported to Moscow, including cases of children. Acute radiation syndromes were also confirmed from the investigation of medical records made in May – June 1986 at the Central Hospital of Khoyniki district adjacent to the Chernobyl NPP [39, 40].

The level of radiation dose to evacuees is crucial in order to judge which side of two confronting opinions is reflecting the real fact. According to UNSCEAR 2000 Report [11], the average external dose for the Ukrainian evacuees is estimated 17 mSv with the maximum individual dose of 380 mSv. Concerning Belarusian evacuees, the average eternal dose of 31 mSv is given for the whole evacuees, while the highest average dose of about 300 mSv is estimated for the population in two villages; Chamkov and Masany. These pieces of information are supporting the official opinion that no cases of acute radiation sickness occurred among the inhabitants.

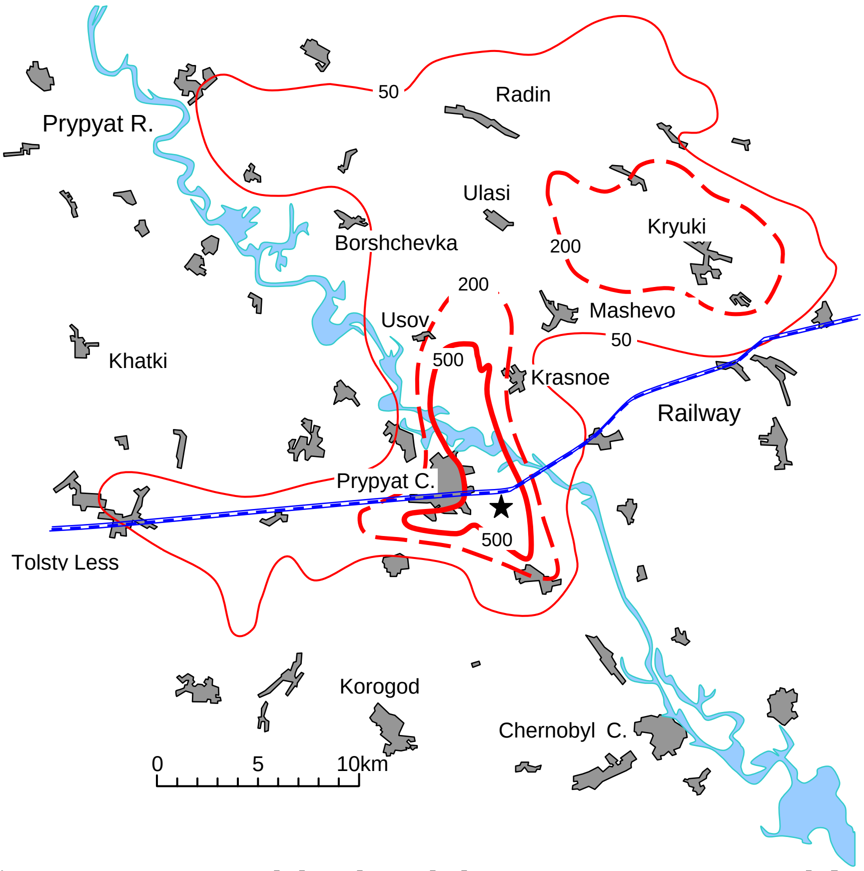

Fig. 1. Dose rate around the Chernobyl NPP on June 1, 1986; mR/h [44].

On the other hand, Imanaka [41, 42] suggested a possibility that a substantial fraction of evacuees from the most contaminated villages could receive effective dose more than 1 Sv, which is a criteria for acute radiation sickness, using the dose rate map on May 1, 1986 presented at CIS/EC Minsk conference in 1996 [43] and temporal changes of dose rate until the evacuation.

After these works Imanaka happened to find another map representing the radiation situation around Chernobyl on June 1, 1986 compiled by USSR scientists in 1991 (Fig. 1) [44]. As seen in Fig. 1, the dose rate in Usov village on June 1 was around 200 mR/h. Our previous calculations [41, 42] indicate that the dose rate on May 1 was about 10 times higher than June 1, which means that a dose rate about 2 R/h can be supposed in Usov village on May 1, 1986, from where inhabitants were evacuated on May 3.

In our previous works the average external dose of 0.32 Sv was estimated for the evacuees from Usov village based on a dose rate of 350 mR/h on May 1 in the previous map [43]. If a dose rate of 2 R/h is used for May 1 instead of 350 mR/h, the average external dose for the inhabitants in Usov village becomes about 2 Sv before the evacuation. In this case, the following description in the secret protocols of the USSR Communist is seriously realistic: "By the situation at 9:00 on May 6, the total number of hospitalized reached 3,454 persons. Among them, 2,609 persons are in hospital for treatment, including 471 infants. According to confirmed data, the number of radiation disease is 367 cases, including 19 children." (from the protocol of the meeting on May 6, 1986).

6. Final remarks

For these 16 years our group has been studying the radiological consequences by the Chernobyl accident, the worst accident in the history of nuclear energy development. We have visited contaminated areas, measured radiation, took samples, discussed with scientists, met people and participated in meetings. Then we clearly understood that the radiological aspect of the accident is only a small part of the tragedy that happened to the people around Chernobyl.

We were overwhelmed by the followings. Just after the accident about 120,000 people were evacuated from the 30 km zone. Several years later, resettlement of much more people began from the highly contaminated areas. The total area for evacuation and resettlement amounted to 10,000 km^2. About 500 villages and towns within the 30 km zone and in highly contaminated areas disappeared. We can say the local societies have entirely vanished. A recent report [45] indicates that totally 350,400 people had to leave their homes.

We are sure that the Chernobyl tragedy can not be described without referring the pain of these people. We should not consider that the whole aspect of the Chernobyl accident can be revealed by scientific approaches. Of course, the pain of these people is not the direct target of our scientific works. We are thinking that scientific efforts, only by cooperating with other efforts such as films, photos, documentaries, novels and so on, can be successful to draw the whole aspect of the Chernobyl tragedy.

Acknowledgement

The author should be grateful to Koide H., Kawano S., Kobayashi K. and Ebisawa T. of Nuclear Safety Research Group for their encouragement in promoting the present studies. The leadership by late Seo T. should be noted to begin collaborative works with former USSR scientists. This study is supported by Grant-in-Aid for Scientific Research from Japan Society for Promotion of Science.

References

1. Seo T. *et.al.*; “Safety Problems of Nuclear Power Plants. Vol.1”, pp.113-131, Nuclear Energy Information Center, Osaka (1976) (in Japanese).
2. Seo. T and Imanaka T.; Discharge of Radioactive Rare Gases by the NPP Accident: In case of TMI-2, *kagaku*, **52** No.1 (1982) 42-52 (in Japanese).
3. Malko M. V.; The Chernobyl Reactor: Design Features and Reasons for Accident, ***in this report***, p.11-27.
4. Gorbachev B. I.; The Causes and Scenario of the Chernobyl Accident, and Radioactive Release on the CHNPP Unit-4 Site, ***in this report***, p.11-27.
5. USSR State Committee on the Utilization of Atomic Energy; “The Accident at the Chernobyl Nuclear Power Plant and Its Consequences”, August 1986.
6. S. A. Khan; The Chernobyl Source Term: A Critical Review, *Nuclear Safety*, **31**, No.3 (1990) 353-74.
7. Seo T., Imanaka T. and Koide H.; Released Radioactivity by the Chernobyl Accident, *Kagaku*, **58** No.2 (1988)108-117 (in Japanese).
8. United Nations Scientific Committee on the Effects of Atomic Radiation; UNSCEAR 1988 Report, Annex D (1988).
9. Imanaka T. *et.al.*; The Final Report of the Research Grant of the Toyota Foundation in 1993 (in Japanese).
10. Minchernobyl; Ten years after the accident at Chernobyl NPP: National Report of Ukraine, 1996 (in Russian).
11. United Nations Scientific Committee on the Effects of Atomic Radiation; UNSCEAR 2000 Report, Annex J (2000).
12. Borovoi A. A. and Gagarinsky A. Yu.; Release of Radionuclides from the Destroyed Reactor at Chernobyl NPP, *Atomnaya Energiya*, **90** No.2 (2001) 137-45 (in Russian).
13. Letter from Legasov to Seo received on January 6, 1988.
14. Imanaka T.; Research Activities of the Nuclear Safety Research Group of KURRI with Belarusian, Russian and Ukrainian Colleagues about the Chernobyl Accident, in “Research Activities about the Radiological Consequences of the Chernobyl NPS Accident and Social Activities to Assist the Sufferers by the Accident”, KURRI-KR-21, p.1-4, 1998.
15. Pavlovych V. M.; Nuclear Fuel in the Destroyed 4th Unit of Chernobyl NPP, ***in this report***, p.45-58.
16. M. De Cort and Yu. S. Tsaturov ed., "Atlas on caesium contamination of Europe after the Chernobyl nuclear plant accident", EC/CIS international scientific collaboration, EUR 16542 EN (1996).
17. Nasvit O.; Radioecological Situation in the Cooling Pond of Chornobyl NPP, ***in this report***, p.74-85.
18. Gaydar A. and Nasvit O.; Analysis of Radioactive Contamination in the Near Zone of Chornobyl NPP, ***in this report***, p.59-73.

19. Stepanenko V. F. *et.al.*; Iodine-131 Contamination, Thyroid Doses and Thyroid Cancer in the Contaminated Areas of Russia, ***in this report***, p.86-96.
20. Matsko V. P. and Imanaka T.; Content of Radionuclides of Chernobyl Origin in Food Products for the Belarusian Population, ***in this report***, p.105-113.
21. Tykhyy V.; Radioactive Contamination of Food in Stepanivka Village, Zhytomyr Region, Ukraine: in 1992 and in 2001, ***in this report***, p.97-104.
22. Ryabov I. N.; Long-Term Observation of Radioactivity Contamination in Fish around Chernobyl, ***in this report***, p.114-124.
23. 1990 Recommendation of ICRP, ICRP Publication 60 (1990).
24. Malko M. V.; Chernobyl Radiation-induced Thyroid Cancers in Belarus, ***in this report***, p.242-257.
25. Knatko V. A. and Dorzhok I. N.; Estimation of Thyroid Doses from Inhalation of 131I for Population of Contaminated Regions of Belarus, ***in this report***, p.154-161.
26. Knatko V. A., M. M. Komochkov M. M. and Yanush A. E.; Estimations of Radiation Risk for the Population of Contaminated Territory of Belarus, ***in this report***, p.162-169.
27. Maksioutov M. M.; Radiation Epidemiological Studies in Russian National Medical and Dosimetric Registry: Estimation of Cancer and Non-cancer Consequences Observed among Chernobyl Liquidators ***in this report***, p.11-27.
28. Pryshazhnyuk A. Ye et.al.; Review of Epidemiological Finding in Study of Medical Consequences of the Chernobyl Accident in Ukrainian Population, ***in this report***, p.190-203.
29. Arynchyn A. N. et.al.; Health State of Belarusian Children Suffering from the Chernobyl Accident: Sixteen Years after the Catastrophe, ***in this report***, p.233-241.
30. Nyagu A. I. et.al.; Intelligence and Brain Damage in Children Acutely Irradiated in Utero As a Result of the Chernobyl Accident, ***in this report***, p.204-232
31. Chumak V.; EPR Dosimetry of Chernobyl Liquidators, ***in this report***, p.125-143.
32. Ivannikov A., Skvortsov V. G. and Valeri F. STtepanenko V. F.; Retrospective Dose Assessment of Inhabitants in the Contaminated Areas of Russia by EPR Measurement of Tooth Enamel, ***in this report***, p.144-153.
33. Geraskin S. A. et.al.; Cytogenetic Effects of Radiation on Agricultural Plants Observed in the Chernobyl region during the First Years after the Accident, ***in this report***, p.289-298.
34. Snigryova G. and Shevchenko V.; Analysis of Chromosome Aberrations in Human Lymphocytes after Accidental Exposure to Ionizing Radiation, ***in this report***, p.258-269.
35. Slozina N. M. and Neronova E. G.; he Follow-up Study of Chromosomal aberrations in Chernobyl Clean-up Workers, ***in this report***, p.270-278.
36. Bezdrovna L. et.al.; Chromosomal Aberrations in Blood Lymphocytes of the Residents of 30-km Chornobyl NPP Exclusion Zone, ***in this report***, p.279-288.
37. A. Yaroshinskaya, “Chernobyl: Top Secret”, Drugie-berega, Moscow, 1992. (in Russian).
38. A Yaroshinskaya; Impact of Radiation on the Population during the First Weeks and Months after the Chernobyl Accident and Health State of the Population 10 Years Later, KURRI-KR-21, p.104-107, 1998.
39. V. Lupandin, Invisible Victims, *NABAT* **36**, Minsk, October 1992.
40. V. Lupandin; Chernobyl 1996: New Materials concerning Acute Radiation Syndrome around Chernobyl KURRI-KR-21, p.108-113, 1998.
41. T. Imanaka and H. Koide; Dose Assessment for Inhabitants Evacuated from the 30-km Zone Soon after the Chernobyl Accident, KURRI-KR-21, p.121-126, 1998.
42. T. Imanaka and H. Koide; Assessment of External Dose to Inhabitants Evacuated from the 30-km Zone soon after the Chernobyl Accident, *Radiation Biology Radioecology*, **40** (2000) 582-588.
43. I.K.Baliff and V.Stepanenko ed., “Retrospective Dosimetry and Dose Reconstruction”, Experimantal Collaboration Project ECP-10. EUR 16540, EC, 1996.
44. G. M. Kozubov et.al.; The Map-scheme of Radiation Damage of Coniferous Forests in the Region of Accident on the Chernobyl Nuclear Power Plant, Institute of Biology, Komi Scientific Center, Ural Division of USSR Academy of Sciences, 1991.
45. UNDP and UNICEFF; The human consequences of the Chernobyl nuclear accident: A strategy for recovery, 25 January 2002.