Dosimetry study and its meanings
-From the studies of Hiroshima and Nagasaki, Semipalatinsk, Chernobyl and Fukushima-

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I. Introduction

Radiation was found by Roentgen, using his X-ray apparatus, in 1895. This was about 100 years ago. Immediately after the finding, the first applications for medical use began. For example the photograph of his wife's hand is very famous even till now. This was the very beginning not only of medical use but also of many other uses over a very wide field within human life. After this Becquerel found radiation emitters in natural rock and Curie and her husband found radium and polonium, elements which emit radiations. After this, Rutherford found types of radiation such as alpha, beta and gamma rays. After these findings, radiation emitters were artificially made and very wide use of radiation began which promoted various scientific developments.

By the use of radiation, people get many benefits, however simultaneously they recognize there are harmful aspects to this radiation. Now without radiation our human life can hardly proceed.

To understand radiation risk, systematic study of radiation effects have been mainly examined in theRadiation Effects Research Foundation (RERF) for the atomic bomb survivors from Hiroshima and Nagasaki. Following this study, the International Commission on Radiological Protection (ICRP) has discussed the risks of radiation and many countries have used their recommended evaluation of the risks for their laws of radiation protection.

Simply expressed, the risks of radiation are determined by the following equation:

$$\frac{\text{Health effects of exposed people}}{\text{Radiation dose}} = \text{risk} \qquad (1)$$

RERF has medically examined 120,000 of the atomic bomb survivors every two years and estimated radiation doses for each survivor. After this estimation, the relationships in equation (1) were precisely studied and risk for the cancer inductions etc was obtained. This radiation dose estimation system is officially called "Dosimetry system 2002 (DS02)" [1], which was determined during a very large collaboration between America and Japan including the author, in 2003.

There are two major meanings for radiation dosimetry.

1) For the exposed people. This is the measure needed when people are exposed accidentally to judge whether the exposed people should go to the hospital immediately, or due to very low level

exposure there is no problem etc. and uses the known dose level of radiation.

2) For the general public. This is for ourselves. If risk is known and also the exposed dose is known, our future health effects will be obtained using equation (1). As explained here, the dose limits for radiation workers and for the general public will be determined by law.

There are two types of radiation effects. One is deterministic effects, which will be induced only when doses are more than a critical value. The other is stochastic effects, which occur according to each probability of cancer induction.

It should be noted that stochastic effect risks are not only found in radiation effects. Risks exist in all aspects of everyday life such as traffic accidents, smoking and so on.

Table 1. Number of deaths per year of Japanese. Estimated value per 100,000 people (From reference 2).

Everyday life			Workers	
Traffic accidents	10.8 persons		Forestry	49.2 persons
Items:			Fishery	58.3
Cars	10		Mining	131
Ships	0.4		Building	19.9
Rail ways	0.36		Manufacturing	5.4
Air ways	0.044		Transportation	12.7
Smoking	**28 persons**			
Natural radiation	2			
Medical radiation	3			

As shown in Table 1, the risk of smoking is 28 deaths per 100,000 people. This is a very large value compared with the obtained estimation of 2 and 3 for natural and medical radiation, respectively. Also the right column for the risk to workers shows high risks such as for forestry at 49.2. The risks of radiation are calculated assuming ICRP recommendations. We should thus consider all of the risks equally, including that of radiation. The risks of radiation are not special compared with the other risks. For example we use insurance for driving etc. because there are risks while driving. Thus all of the risks cannot be reduced to zero. Risks can of course be reduced by using safety apparatus etc. For example we can use a pedestrian over-pass rather than a pedestrian crossing. Radiation is the same as this. We should make efforts to reduce radiation risks by shielding or in other ways.

1. Dosimetry study of the atomic bomb survivors from Hiroshima and Nagasaki

The efforts to construct the "Dosimetry study 2002 (DS02)" [1] were made during the collaboration between America and Japan from 1994 on. The DS02 was derived from a reevaluation of the old DS86 dosimetry system. Our Japanese group found some problems in DS86. There was contradiction between the measured data and calculation based on DS86. To solve this problem from 1994 on, official teams soon formed including our study groups from America and Japan. The study needed time, due to the difficulty of neutron dosimetry and finally in 2002 we found the reason for the contradiction. We corrected bomb burst height and measured data at long distances and finally the measured data and calculated data agreed with each other.

The main change from DS86 is about a 10% increase of the gamma-ray dose both in Hiroshima and Nagasaki. From equation (1), the denominator of the left side increased 10%. Consequently and roughly, "risk" on the right side decreased 10%.

This dosimetry study was not easy during that period because we needed time to collect samples and to measure radiation from hundreds of samples. We collected in total more than 2000 samples such as concrete, granite rock, iron, brick, tiles, roof tiles etc. These samples are sent to special laboratories such as Kanazawa University, Tsukuba University, Hiroshima University, others in America and Germany. They measured Eu-152, Co-60 and Cl-36 for neutron dosimetry. These laboratories are all special laboratories since very low level radioactivity must be measured. For gamma-ray dosimetry, former thermo-luminescence dosimetry data were used because problems were not so large.

The results have been used for the organ dose calculation by using computers and obtaining each atomic bomb survivor's organ doses. After this, the relationship sbetween radiation dose and induction of cancers etc. have been studied and their risks obtained. The risks are being calculated and discussed in the ICRP. After this discussion these corrected risks will be used to change dose limits in the laws of radiation protection.

2. Semipalatinsk study

The risks of radiation discussed above are obtained almost entirely from Hiroshima and Nagasaki studies as discussed section 2. However, these risks correspond to very short-time irradiation in the order of micro second to seconds. Normally radiation workers are not exposed to instantaneous exposure. There are many discussions therefore of the applicability of instantaneous irradiation. Risks will be different in chronic exposure and instantaneous exposure. To determine such radiation risks we started the Semipalatinsk study since duration of the exposure was a few weeks to a few months or rather longer. In Semipalatinsk a radioactive plume passed through villages after the explosion.

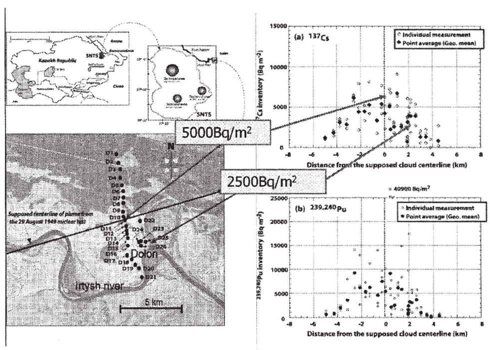
In the Semipalatinsk area there is the former Soviet Union's nuclear test site and we began to study this from 1994. At first we began a dosimetry study. We collected brick samples to measure gamma-ray doses and collected soil samples and measured fallout of Cs-137, and Pu isotopes. The most highly exposed village is Dolon about 110km distant from the test site. Previous reports are only studies by the scientists of the former Soviet Union. They reported more than 4000mGy of dose including internal and external exposure. This is very large value since given such a whole body exposure in a short time almost half the people will die within 30 days. At first we selected gamma-ray dosimetry using bricks for the estimation of external exposure, since this method has been verified to be the most reliable from the study of Hiroshima and Nagasaki. The results reduced to a dose of about 400mGy but are still very high values.

The test site has an area close to that of the Shikoku-island in Japan (18,000km^2) and experiments were made 459 times from 1949 to 1989. The explosions comprised 26 surface tests, 87 in air and 346 times underground. From the Russian reports, the total output of surface explosions is 0.6Mt, 6Mt in air and 11Mt under-ground. These are about 1100 times that of the Hiroshima atomic bomb. This is 6% of the total explosions within the former Soviet Union and these areas include many villages, so they said there were many hard radiation effects in this area.

After the explosion of atomic bombs, plumes including fission products passed through the area outside and exposed people living nearby. It is not rather simple like the direct exposure within a 2km area at Hiroshima and Nagasaki but includes internal exposure. This exposure is complex since people are exposed through foods and through inhalation.

The study of the health effects for these people has been undertaken by the Institute of Radiation Medicine and Ecology located in Semipalatinsk. From 1991 this institution was separated from the former Soviet Union due to the independence of Kazakhstan. After this independence these data were made accessible for foreign scientists. One radiation dose for Dolon village was evaluated to be 4000mGy as noted before. There were many questions since some of the data were taken back to Russia and are still kept classified. From the results of the institution a high incidence of cancers were observed for leukemia, thyroid, esophagus, stomach, liver, intestine, lung and breast. They also reported chromosome aberration and malformation. These studies had to be reevaluated according to universally agreed standards of examination.

Our first study was brick measurements and 400mGy of external doses was obtained in Dolon. Then we continued the study of the dosimetry in Dolon by other methods. Chromosome aberration, tooth enamel dosimetry, calculation of radioactive plume, estimation of doses from soil contamination by Cs-137: all of



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these data agreed each other. The dose outside was about 400mGy and inside was about 1/3 to 1/2 of the outside dose, since bricks are always outside and people are sometimes inside and shielded from the radiation. [3]

Figure 1. Results of the Cs-137 and Pu isotope measurements.[4]

In the case of Dolon as shown in Fig 1, Yamamoto et al [4] collected soil samples across the plume trace each 500m giving a total distance of 5km to the northwest and 5km to the southeast. So in total samples were collected from a 10km line across the trace. He measured Cs-137 and Pu-239, 240 and plotted the results as shown in Fig. 1. Although almost 60 years had passed, we can see a clear peak from these results. At the center of the peak Cs-137 deposition was about 5000Bq/m^2 (also at Dolon) while at 2km distant it was 2500Bq/m^2. This is about half of the center value. At Dolon the dose was 400mGy as already explained. From these results, we concluded all of the different methods of the dosimetry study agreed with each other and even from the Cs-137 deposition data we could estimate radiation doses for the people living there.

There were also other studies examining of teeth by Okamoto, and thyroid examination by Takeichi[3)], which are not mentioned here.

3. Fukushima Nuclear Power Plant: accidents and the future

On March 11, 2011, a very heavy earthquake of magnitude 9 happened in a region 130km offshore of the Tohoku area. Soon after this, one of the biggest Tsunamis ever recorded reached a long seashore; more than 500km in length from the north part of Tohoku to the Kanto area. The Tsunami destroyed many cities and villages.

At the Fukushima Daiichi nuclear power plants, due to the earthquake, all of the power supplies from the exterior were destroyed and the interior emergency power supply was also destroyed by flooding from the Tsunami. Thus all power supplies failed to work. No one yet knows exactly what happened inside the power plant but after several hours three of the nuclear power plants (No.1 to No.3) began to melt down. I think material melted through the pressure containers of the nuclear fuel and possibly the housings of the pressure containers were broken or melted through. To know what was happening was not easy because visual inspection was not possible due to the very high radiation levels inside. Maybe it will take a long time to gain visual access and to know exactly what occurred.

The time courses of the accidents are as follows:

1. At 14:46 March 11: East Japan earthquake happened.
2. At 15:27 March 11: Tsunami reached the power plants.
3. At 20:50 March 11: Evacuation of the people began.
4. At 15:36 March 12: Hydrogen explosion happened at No.1 nuclear power plant.
5. At 11:01 March 14: Hydrogen explosion happened at No. 3 nuclear power plant. Melt-through occurred following this explosion.
6. At 06:00 March 15: Sound of explosion from No. 2 nuclear power plant. At 06:10 in No. 4 nuclear power plant, hydrogen explosion.

Major high-level release of radioactivity began from this time and continued. The first release at 15:36 on March 12, went along the east coast to the north and reached Onagawa. From this release the actual residual activity was not so large. Following the explosion of No. 3 reactor on March 14 activity went down along the east coast to the south and passed through the east part of Tokyo. In this case also the residual activity was not large.

The highest release happened on 15 March from No. 2 (or No. 4) reactor. This radioactive plume descended in a southwest direction then ascended in a northwest direction. Unfortunately it snowed there and created very much contamination. This area almost aligned northwest has significant width of over 30km and reaches up to Iidate-mura village. This contamination is called wet deposition. (In the case of dry deposition, major radioactivity components I-132, I-131, Cs-134, Cs-137 pass through an area with relatively small residual fallout comparing with wet deposition.) The wet deposition fell to the ground surface as rain and snow and attached to soil particles within a few cm depth. The radioactivity similarly attached very strongly in the case of Semipalatinsk soil etc. and we were able to measure it even after 60 years. The reactor radioactivity release continued after this and contamination spread much wider over Fukushima prefecture and came also to neighboring prefectures. We (including the author) collected soil samples within a 80km area using a 2km mesh. These results have been publicised on the web-site of the Research Center for Nuclear Physics, Osaka University.[7)]

As we found at Chernobyl, radiation passed through and irradiated people living there through inhalation and ingestion. When it rained radioactive products were also precipitated, and attached to the ground surface firmly. The half life of radioactive I-132 is short and for I-131 is about 8 days. Therefore these activities decay out within a few months. However, half-lives of Cs-134 and Cs-137 are 2 years and 30 years, respectively. Therefore these activities are the cause of a long exposure problem for the people living there. Efforts for decontamination have already begun and this is decontamination mainly of Cs-137 deposition.

As we discovered from Chernobyl and other contaminated places, exposure and contamination are different between wet and dry conditions. Without rain we can avoid some radiation exposure by covering with coats and masks. In this case after these radioactive plumes have passed through, residual contamination is less than from wet deposition. Rainfall sometimes creates small size spots because it is localised. If these spots include radioactivity this should create spot-like contamination. In the case of Chernobyl one house may be contaminated but the next house not so much band I have found actual cases of this within my research experience. This chernobyl case was an example of small spots, however spots are sometimes larger, like several hundred meters, and sometimes even spots of several thousand meters will occur. That means that it is important to know and to decontaminate only after precise measurement using dose meters. We must note again that sometimes the spots travel far from the origin, 100km, 300km or more. In the case of the Fukushma emissions, some deposition was found in the Matsudo area in Tokyo about 200km southwest, not a particularly high radiation level, but constituting observational evidence of such hot spots. Looking locally, roads with concrete or asphalt surfaces are easier to wash with rain, and contamination moves to the roadside where the surface is soil. There radionuclides like Cs-137 are attached firmly and we sometimes observe high level exposure. Therefore we are experiencing such small size hot spots also at roadsides and beside gutters.

The level of the disaster compared with Chernobyl is as follows:

Chernobyl [5)]:

1. Number of people evacuated: about 400,000
2. Contaminated area (more than $37kBq/m^2$): 145,000

3. Area of forced evacua area: 13,000 km^2,
4. Total released radioactivity: 520 TBq,

Fukushima [6]:

1. Restricted and planned evacuated area: about 85,000 people, (Planned evacuated area 10,000, restricted area 75,000. (Total including evacuated voluntarily: about 150,000)).
2. Contaminated area (more than 30 kBq/m^2): 8,000 km^2,
3. Restricted and planned evacuated area: 800 km^2,
4. Released radioactivity: 77 TBq.

These estimated numbers cannot be compared directly, however the contaminated area is less than 1/10 compared with Chernobyl although the people living there are about 20% of those at Chernobyl. The disaster for people is comparably large as the Chernobyl case. Compared with the Hiroshima atomic bomb, the released activity is said to be a few tens of times more.

In addition, the Fukushima accident includes contamination of the ocean. In the early stages, major radioactivity was released to the Pacific Ocean. There are some available measurements in sea water but so far they are not very precise and there are also some calculations for the spread of the activity. But detailed understanding of this process of the spread of radioactivity in the ocean is so far not clear. Also the food chain is a problem. Plankton absorb radioactivity, then small fish eat plankton, large fish eat small fish and people eat large fish. This is a food chain which may increase the level of radioactivity step by step. This is not so far clarified by research. Therefore more investigation will be necessary in this area as for the example of the heavy metal food chain. In addition, contamination on the sediments in the ocean should be measured and such investigation is also necessary since fish living near the sediments on the ocean floor will receive different contamination. Thus the case of the Fukushima nuclear power plant disaster includes many aspects and we need more help to know what happened and what will be the results for the people involved and this process may need large budgets.

I mentioned contamination around the Fukushima nuclear power plants. We need to discuss how to clean up and how to do this in future for the exploded reactors themselves. The discussion I hear so far is how to remove contaminated fuels and concrete etc. and to clean up the area. However I want to make clear; there is a problem. I have a question for all specialists and people involved in the discussion; where we will take these contaminated discarded wastes? In these wastes very high levels of melted nuclear fuels are included. I do not know where to take them. Is there anyone at all who knows where to take them? Another problem, now under discussion, is where to take contaminated soil (not high level like melted fuel) from many and extensive areas. This is not solved yet, since no one likes to keep it in their area. And there are levels of such radioactivity in some materials very much higher than such contaminated soil. We must solve the problem of disposal area first and then we must discuss how to do the clean up. I am sure no one knows where to put the wastes within Japan.

Another problem is the health effects for the people living there. Those health effects can be discussed from the studies of Hiroshima and Nagasaki, Chernobyl etc. For example, from studies following Hiroshima and Nagasaki, 100 mGy of exposure increases cancer induction by 0.5%. From Chernobyl clearly visible effects for induction of cancer is seen for thyroid only and the number of people deceased as a direct effect of Chernobyl exposure is reported to be about 10 people, following the United Nations report. These are already known figures, however because there may be other numbers not yet published this does not mean “no effects”. It means “we do not know the effects”. This must be noted because following more precise study those effects may possibly become known. Moreover, the conditions of the exposure differ from each other, for example dose rate in the case of Hiroshima and Nagasaki is of the order of seconds, however following Chernobyl it was months or more. Risks of the radiation may be different according to such difference of exposure types. Although we do not know such effects, we must start to help people as soon as possible using the known possible effects from Hiroshima and Nagasaki, Chernobyl and so on. We cannot wait until after we know the actual effects because it will take 10 years or much more, as found in the RERF study in Hiroshima and Nagasaki. They are still studying the effects more than 60 years after the atomic bomb.

Similar to the other problems at Fukushima is the delay in publication of the data by government and the power plant company related to contamination etc. It was a very big problem for us. For example there is a computer code named “SPEEDI” which we used to calculated movement of the plume of radioactivity and deduce doses for the people living in Fukushima. The calculated results obtained were not communicated to top levels of the government and were restricted to the specialists. Because these results were not used, evacuated people near the power plants escaped to much more highly contaminated areas and were exposed unnecessarily. Long after (a few months) the survey data were made freely available, and we knew now the calculated results were accurate compared with measured data.

I must discuss more about “release of the necessary data for people”. That is, to determine whether defining the evacuated area as that giving a dose of 20 mSv/year is the appropriate number for the limitation exposure now. Following the Japanese law of radiation the limit of the radiation exposure from a facility must be below 1 mSv/year. More than 20 mSv/year is now the limit for the evacuated area but less than 1 mSv/year is the limitation by the law related to radiation. There are many discussions how to regulate inside the range from 1 to 20 mSv/year. In Fukushima many effects are unknown. What we can do is to estimate effects from the known results such as those from Hiroshima and Nagasaki, Chernobyl etc. and such data should be publicly available for people as understandable expressions. Also contamination data area by area also should be openly tabulated. Finally, all people should be able to know and understand the data and implicaions by themselves. After this they will be able to consider how to react. In the case of care for old people and for infants or children such judgment by each person may possibly differ. It is not easy to explain plainly but we should accept the challenge to do so. It is the way to be fair and to be reliable to people.

Considerations of risks are difficult to understand for people. For example in the case of cars we use insurance because we are estimating risks of car accidents. After such accidents happen insurance will cover economic loss. There are many risks even in our everyday lives. For example I know some people who have died due to a fall down the stairs. Sometimes when we walk along the sidewalk, cars may come and hit us. Such risks cannot become zero. Such risks can be reduced using the pedestrian overpass and so on. It is possible in general to reduce risks. For example to stop smoking reduces risks for lung cancers very effectively. In the case of radiation the dose rate level from 1 to 20 m Sv/year will be considered as risks. We should understand such estimated risks and compare with those of traffic accidents, smoking and the many other risks. We should understand as individuals , reflect and determine how to react. The case of the contamination of food is the same. From such reasons, I say again open availability of data on all risks including radiation is necessary.

5. Conclusion

These studies noted in this paper have been made by many collaborators as in references 1,3). The other study, "black rain" problems in Hiroshima is still continuing. We are trying to find Cs-137 and Pu isotopes in this area however this is almost achieved and finally to estimate radiation doses in this area.

In all these cases of radiation exposure study, there are actually many exposed people who are anxious about their health. The examination of health effects of these people will be necessary based on these radiation studies. However to conclude what their effects may be more than 10 years is usually necessary and we cannot wait until that time. Therefore such examination must be started soon after we can predict the possibility of health effects. Also these effects are stochastic so we need to be familiar with such effects and compare them with the all of the risks in everyday life. After this we should consider risk magnitude and compare this with all of the other risks. Finally we will be able to choose which way to react in everyday life. Such consideration of risks should be opened not only to general people but also to the specialists. This is for people to chose by themselves in their every-day life.

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