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Proceedings of the 17th Hiroshima International Symposium

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Kojin-Kaikan, Hiroshima University

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Tetsuji Imanaka
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March, 2012

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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.

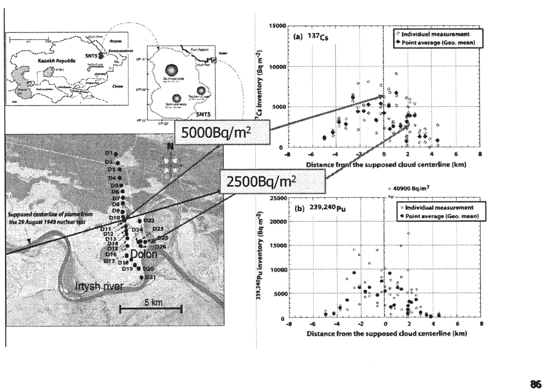
In the Semipalatinsk area there is the former Soviet Union's nuclear test site and we began to study this from 1994. At first we began a dosimetry study. We collected brick samples to measure gamma-ray doses and collected soil samples and measured fallout of Cs-137, and Pu isotopes. The most highly exposed 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



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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Initial process of the nuclear explosion and cloud formation by the Hiroshima atomic bomb

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Introduction

The atomic bomb, named Little Boy exploded over the Hiroshima city at 0815 on August 6, 1945. According to the report of radiation dosimetry system DS02 (Young and Kerr 2005), the height of burst (HOB) and the energy yield of explosion are estimated to be 600 ± 20 m and 16 ± 2 kt TNT, respectively. Although the official information is not yet available about the detailed structure and composition of Little Boy, the amount of initially loaded uranium is reported to be 64.15 kg, the average ^{235}U enrichment of which is 80 % (Coster-Mullen 2008). Using equivalent values per yield of 1 kt TNT (Glasstone and Dolan 1977), the 16 kt TNT explosion can be converted to the total fission number of 2.32×10^{24} corresponding to ^{235}U mass of 910 g as well as the total released energy of 1.6×10^{13} cal. If a spherical ball is made from 64.15 kg of uranium with a density of 19.05 g cm^{-3}, its diameter will be 18 cm, something like a valley ball. The duration time of the fission chain reaction that continued in Little Boy is considered to be about 1 μsec.

The most outstanding feature of the atomic bomb explosion is that a huge amount of energy is released within a very short time in a very small space, which produces a core with extremely high temperature (> 10^7 °K) and pressure (> 10^6 atm). This core expands very rapidly transmitting its energy to the surrounding materials mainly by low energy X-ray. The whole bomb material is engulfed and vaporized by the expanding core, which is called fireball. According to the description in *The Effects of Nuclear Weapons*

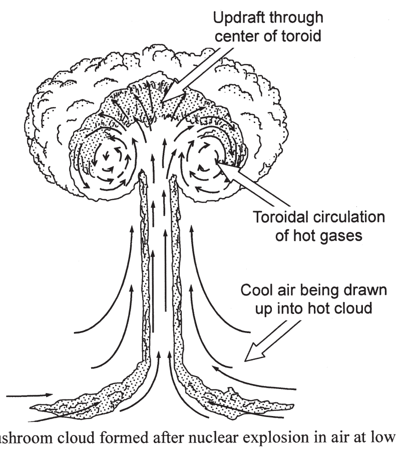

Fig. 1. Mushroom cloud formed after nuclear explosion in air at low altitude.

(Glasstone and Dolan 1977), at 0.1 msec after 20 kt explosion, the temperature of the fireball decreases to 300,000 °K with a radius of 40 feet (about 12 m). At this temperature, as the expansion velocity of the fireball decreases comparable to the local acoustic velocity, a shock wave appears at the fireball surface and its front moves ahead of the fireball expansion. At this stage, because of the opacity of shock wave heated air, the internal fireball is not visible through the shock wave front. Then, at 0.1 – 0.3 sec after the detonation, as the air becomes less opaque with the temperature decrease, the luminous inner fireball can be seen with the surface temperature of 6,000 – 7,000 °K. The fireball loses its luminousness in several seconds.

In case of the Hiroshima explosion, the shock wave blast was considered to arrive at the ground about 1 sec after the detonation, while the fireball began to ascend without touching the ground. As the fireball rose up, a strong upstream of air followed it like a chimney. Then so-called 'mushroom cloud' was formed. A simple scheme of mushroom cloud structure is drawn in Fig. 1. The formation process and radioactivity distribution of the Hiroshima atomic bomb are discussed in this paper.

Hydrodynamic simulation for Little Boy explosion

During the processes elaborating DS86/DS02, US working group carried out hydrodynamic simulation of Little Boy and Fatman (Nagasaki bomb) for the purpose determining the position of the rising fireball as well as air density disturbance by the explosion, using STLAMB code that was developed to simulate hydrodynamic processes for low altitude nuclear explosions. An example of air density contour plot obtained by STLAMB calculation in DS86 is shown in Fig. 2 for the Little Boy explosion (height of burst: 580 m, yield: 15 kt) (Roesch 1987). After the initial rapid growth up to a radius of about 260 m, the

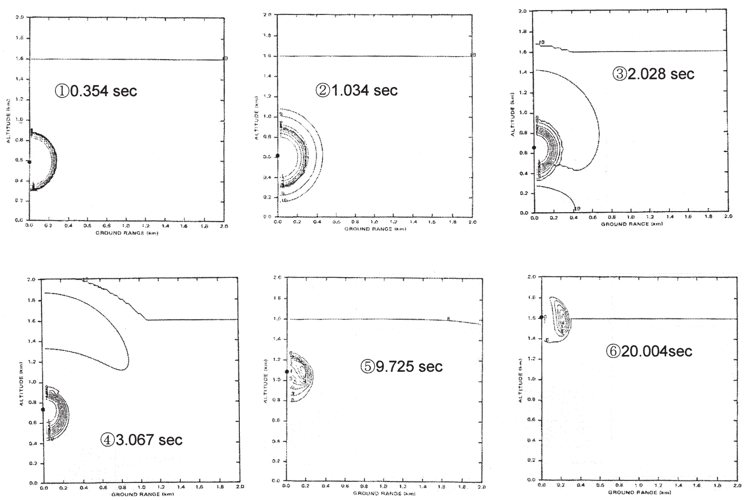

Fig. 2. STLAMB simulation of Little Boy explosion in DS86. Air density contour.

internal pressure of the fireball reached equilibrium with the ambient air at 0.35 sec after the detonation. At this moment the height of the fireball center did not move yet from HOB of 580 m. The air density of the fireball center was 2.26×10^{-5} g cm^{-3}, while 1.11×10^{-3} in the ambient air. The shock wave front already went ahead of the fireball, at 120 m from the fireball surface, but it can not be seen in Fig. 2. At 2.028 sec, the shock wave was already reflected at the ground surface. At 3.067 sec, the reflected wave passed through the fireball. The fireball began rising at a speed of 50-60 m sec^{-1}. It went up to 1100 m at 10 sec, and 1600 m at 20 sec. The shape of the fireball was changing from spherical to toroidal.

Similar STLAMB simulation was carried out during the process developing DS02. The author received the output lists of STLAMB calculation for Little Boy (HOB: 600 m, 16 kt) up to 3 min after the explosion (Egbert 2010). Two sets of STLAMB results were obtained: one (STLAMB-1) is up to 30 sec with 18 time intervals and another (STLAMB-2) is up to 3 min with 12 time intervals. From these data temporal change of the height of the fireball center is plotted in Fig. 3. At 3 min after the explosion, the fireball rises up to 7,000 m.

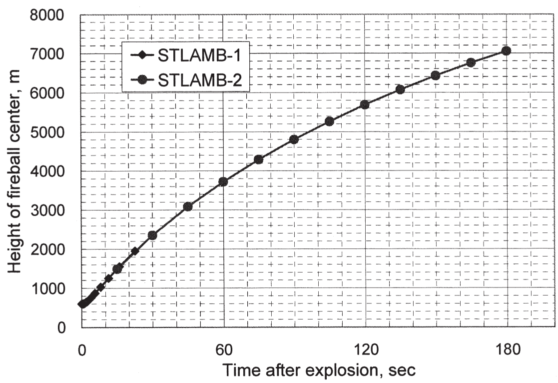

Fig. 3. Height of cloud center after the bombing

Comparison with observation in Nevada test site

A large report that compiled observation for all atmospheric nuclear tests in the Nevada test site was obtained through Internet (Hawthone 1979). From this report, seven tests comparable to the Little Boy explosion were chosen that were conducted by airdrop and exploded at the height where the fireball did not touch the ground. Rising pattern of the atomic bomb cloud for these seven tests were compared in Fig. 4 with the STLAMB simulation for Little Boy.

In Fig. 4, HOB values for Nevada tests are adjusted to be the same HOB (600 m) as Little Boy. The result of STLAMB simulation is similar to BJ Charlie（14kt）and BJ Dog（21kt）. By extrapolating the tendency of STLAMB simulation to the later period, it can be roughly said "The cloud height of Little Boy was about 8000 m at 4 min, and ascended about 12000 at 12 min".

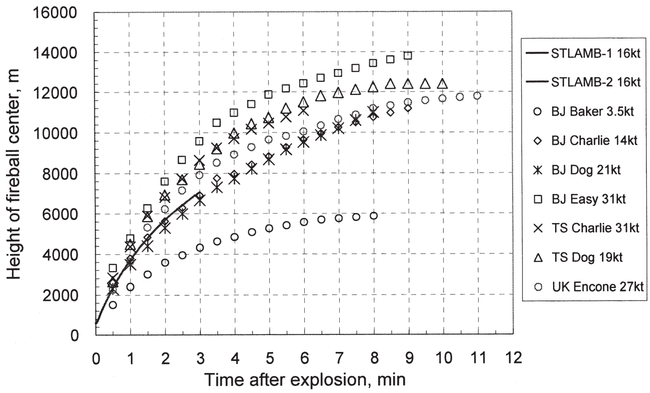

Fig.4 Comparison of cloud rising between STLAMB simulation and Nevada observations.

Size of the atomic bomb cloud

Values of the fireball radius obtained by STLAMB simulation are plotted in Fig. 5. RFB indicates horizontal radius of the cloud, while RFBM is considered to be vertical radius of spheroidal cloud or toroidal cloud. Several observations are also reported for Nevada tests about the cloud size increase. According to these observations, the horizontal diameter increased almost linearly with time up to 20 – 30 min after explosion. The horizontal width (cloud top – cloud bottom), however, seemed to saturate at a constant value after the cloud stopped to ascend.

Taking into account the results of STLAMB simulation (Fig. 5) as well as observations of nuclear tests in Nevada, an ideal case of the atomic bomb cloud formation with the same bomb parameters as Little Boy is plotted in Fig. 6 up to 20 min after the explosion. The cloud ascends until 12 min after the explosion up to the center height of 12 km. The horizontal radius increases linearly with the elapsed time

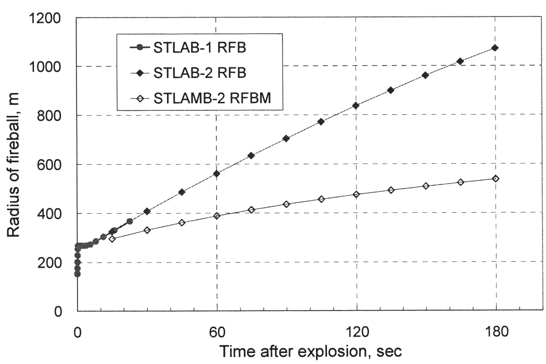

Fig. 5. Cloud radius by STLAMB simulation: RFB and RFBM.

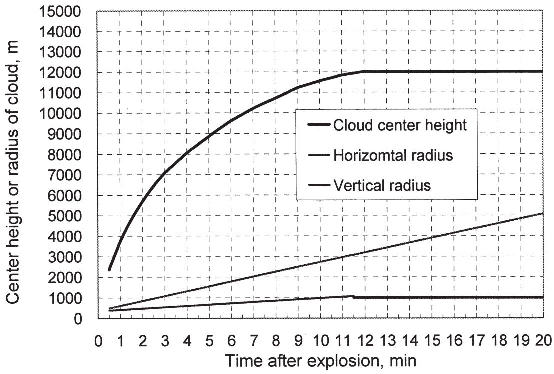

Fig.6 A-bomb cloud formation in case of the same parameters as Little Boy: HOB; 600 m, 16 kt.

and it becomes 5 km at 20 min, while the vertical radius (half value of the cloud thickness) saturates at 1 km at 12 min.

Temperature decrease and particle formation

As the fireball rise up, its temperature decreases by various mechanisms of thermal radiation, adiabatic expansion and mixing with cool air. With decrease of temperature, vaporized materials of the bomb components begin condensate and solidify, forming small particles that absorb and/or adsorb fission product nuclides. In order to consider the process of particle formation, time sequence for temperature decrease of the fireball is estimated based on STLABM simulation as well as literature data.

Although temperature data are not included in the output of STLAMB simulation, the air density at the fireball center is provided in the list. Considering that "pressure equilibrium" between the fireball and the ambient atmosphere is attained at 0.4 sec after explosion, the air density can be related with temperature

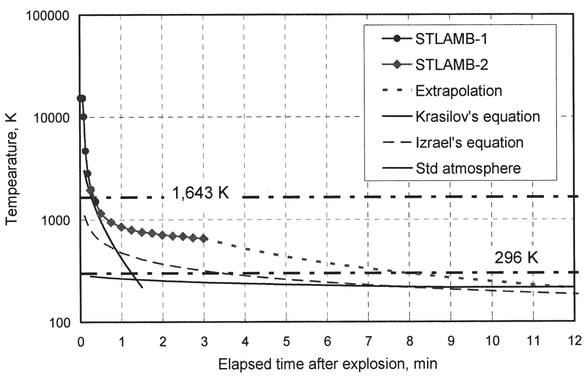

Fig. 7. Temperature change of the fireball/atomic bomb cloud.

based on the ideal gas equation of $PV = nRT$. For example, compared with air density of 1.16 × 10^{-3} g cm^{-3} in the ambient air of about 300 °K, air density of 2.26 × 10^{-5} g cm^{-3} at 1 sec corresponds to 15,400 °K. Temperature decrease obtained by this way from STLAMB calculation is plotted in Fig. 7 together with temperature curves proposed from Russian scientists. Black solid line is equation; $T(t) = 7500°K \exp\left(-\frac{1}{3}\sqrt{\frac{20}{q}}t\right)$ by Dr. Krasilov (2008), while red broken line is taken Izrael' s book (1995); $T(t) = 4000t^{-0.588}$ (t<40sec) or $2183t^{-0.374}$ (t>40 sec) for 20 kt air burst. Green dot line is extrapolation of STLAMB-2 up to the point of ambient temperature at 12 min using Izrael's equation of $T(t) = a \cdot t^{-b}$. Blue line indicates ambient air temperature at the height of the fireball (Fig. 6). Values of 1,643 and 296 °K are melting point of iron oxide (FeO) and dew point for the air of 27 °C and relative humidity of 80 %, respectively. STLAMB plot in Fig. 7 indicates that droplets of FeO begin to solidify at about 20 sec after the explosion.

Size distribution of particles in the atomic bomb cloud

According to *The Effects of Nuclear Weapons* (Glasstone and Dolan 1977), in case of air explosion by which no appreciable quantities of surface materials are taken up into the fireball, small particles with the range of 0.01 to 20 μm are formed from condensed residues of the bomb materials. Although it is difficult to say definitely how was the real situation in Hiroshima, the photo taken from the B28 bomber at 2 – 3 min after the bombing (Fig. 8) supports the idea that particles of dirt and dust raised by the bomb blast almost remained at low altitude and were not substantially sucked into the fireball or the cap part of mushroom cloud.

The process of particle formation from vaporized materials is discussed in detail by Storebo (1974) dividing the process into nucleation, condensation and coagulation. The size distribution of particles is

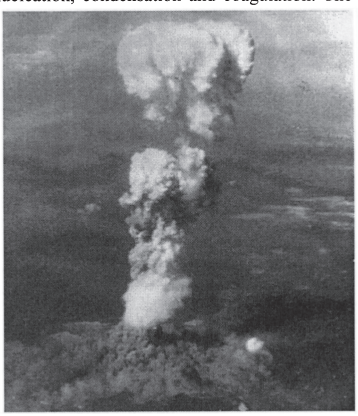

Fig. 8. Photo of the Hiroshima bomb cloud taken from the B29, Enola Gay at several min after the bombing.

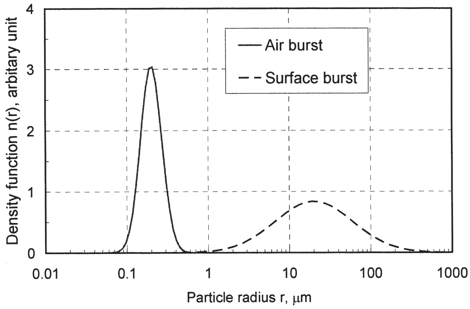

Fig. 9. Examples of particle-size distribution for air burst and surface burst. Air burst; mean 0.2 μm and GSD 1.35, Surface burst; mean 20 μm and GSD 3.

considered to follow a log-normal law;

$$\frac{dn(r)}{d\ln r} = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(\frac{-(\ln r - \mu)^2)}{2\sigma^2}\right)$$

Here, *n(r)*: particle density function for diameter, *r*,

μ, σ; geometric mean and geometric standard deviation, respectively.

In Storebo's paper (1974) μ and σ values are evaluated as parameters depending on the initial condition of vapour-to-air mass ratio in the fireball. Assuming that 4 ton of iron was vaporized by the Little Boy explosion and mixed with the spherical air mass of 260 m radius and 2.26×10^{-5} g cm^{-3} density, a value of 0.002 was obtained as a vapour-to-air mass ratio. Then, values of geometric mean and GSD (geometric standard deviation) were obtained to be 0.2 μm and 1.35, respectively. Histograms of log-normal particle-size distribution are shown in Fig. 9 together with a case for a surface explosion for which particle distribution were arbitrarily chosen as geometric mean of 20 μm and GSD of 3.

As an information to consider a possibility of local fallout by gravitational deposition on the ground,

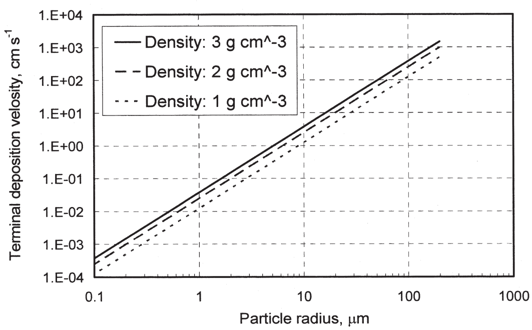

Fig. 10. Particle-size dependency of terminal descent velocity for particle density of 1, 2 and 3 g cm^{-3}.

terminal velocity of descending particles is calculated based on Stokes' equation;

$$V_t(D) = \frac{D^2 \rho g}{18\eta}$$

Here, $V_t(D)$; terminal velocity of particle with diameter, D,

ρ, g and η are density, gravitational acceleration and viscosity.

The results are shown in Fig. 10 as a function of particle radius for three values of particle density. Terminal velocity for particle radius more than 200 μm is not plotted in the figure because deviations from the simple Stokes's equation become significantly lower in this region than those based on Stokes's equation. As can be seen in Fig. 10, deposition velocity drastically changes with particle size. Considering that the fireball by Little Boy could rise up to about 10,000 m at 10 min after the explosion and the deposition velocity for the supposed particle-size distribution (Air burst in Fig. 9) would be less than 0.1 cm s^{-1}, the possibility of local fallout due to gravitational deposition, so-called 'dry deposition' can be excluded. The only realistic path of local fallout is considered to be deposition on the ground with rainfall, so-called 'wet deposition'. In case, however, particles more than 100 μm were somehow included in the atomic bomb cloud, they could descend to the ground by gravity after several hours after the explosion.

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Estimation of heat, water, and black carbon fluxes during the fire induced by the Hiroshima A-bomb in 1945

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Abstract

The amount of flammable materials in traditional Japanese houses in the Hiroshima region in the 1940s is estimated to calculate heat, water and carbon fluxes during the induced urban fire by the Hiroshima A-bomb in 1945. Traditional houses remaining in the Fukuyama region were examined to estimate the total amount of flammable resources in each house classified into three categories based on number of stories and size of the houses. The density of wood was estimated to be 112 kg m^{-2} for one-story houses while it was 72 kg m^{-2} for two-story houses (Okada and Aoyama, 2011). Then, the amount of flammable materials in traditional Japanese houses in each 50-m grid was estimated based on a digital map of the entire city of Hiroshima just before the atomic bombing and a detailed damage distribution map which were both created from the aerial photographs (Koizumi et al., 2011) and . The amount of flammable materials was converted to heat, water, and black carbon fluxes based on the duration of the fire induced by the A-bomb as a function of time and space. The average heat flux in the region was 14.4 kJ s^{-1} m^{-2}, and it ranged from 0.5 to 96.5 kJ s^{-1} m^{-2}. The average heat flux obtained in this study is about half of a value used in previous study (Yoshikawa, 1999) and is 7 times larger than that in Shouno, 1953. The total heat released during the fire was 7 PJ. In total, 0.22 Tg of water was produced and released during the fire. The total amount of black carbon produced and released during the fire was 0.02 Tg, when we assume that 10% of the fuel was under reducing conditions. To confirm this assumption for under reducting conditions, we prepared dummy black rain sample of which black carbon concentration ranged from 1 % to 70 % and asked witnesses of black rain to choose one of the samples as most similar one with black rain they observed in 1945. 37 replies were obtained and the 34 of 37 replies concentrated with a range from 5 % to 15 %. The time-dependent fluxes of heat, water, and carbon were also calculated.

1. Introduction

To simulate the clouds and precipitation due to the Hiroshima A-bomb, it is necessary to estimate the heat, water, carbon dioxide, and black carbon fluxes during the fire induced by the bomb as a function of time and space. It already passed two decades from the first numerical model simulation of fallout of the Hiroshima A-bomb in 1990, it might possible to conduct improved numerical model simulations using latest chemical transport models and high performance super computers. If so, heat flux and water flux during the induced urban fire by the Hiroshima A-bomb are important to simulate the clouds and precipitation due to the Hiroshima A-bomb.Therefore, the amount of flammable materials in traditional Japanese houses in the Hiroshima region in the 1940s is estimated to calculate heat, water and carbon fluxes during the induced urban fire by the Hiroshima A-bomb in 1945.

2. Method

The amount of flammable materials in traditional Japanese houses in the Hiroshima region in the 1940s is estimated to calculate heat, water and carbon fluxes during the induced urban fire by the Hiroshima A-bomb in 1945. Traditional houses remaining in the Fukuyama region were examined to estimate the total amount of flammable resources in each house classified into three categories based on number of stories and size of the houses. The density of wood was estimated to be 112 kg m^{-2} for one-story houses while it was 72 kg m^{-2} for two-story houses (Okada and Aoyama, 2011). Then, the amount of flammable materials in traditional Japanese houses in each 50-m grid was estimated based on a digital map of the entire city of Hiroshima just before the atomic bombing and a detailed damage distribution map which were both created from the aerial photographs (Koizumi et al., 2011) and . The amount of flammable materials was converted to heat, water, and black carbon fluxes based on the duration of the fire induced by the A-bomb as a function of time and space. The details of this estimation are described in Aoyama et al., 2011.

3. Results and discussion

3.1 Heat flux

In Figures 1 and 2, distributions of average heat flux (MJ s^{-1} m^{-2}) in each 50-m grid within the 4 km × 4 km and 8 km × 8 km are shown, respectively. A part of the destroyed area located southwest of the hypocenter could not be analyzed because clouds covered the area when the aerial photographs were taken. Although the average heat flux in the region was 14.4 kJ s^{-1} m^{-2}, it ranged from 0.5 to 96.5 kJ s^{-1} m^{-2} as shown in the Figures 1 and 2. When we look at within 1 km × 1 km region from the hypocenter, the averaged heat flux at north-west region is relatively high rather than those in north-east, shouth-west and south-east regions.

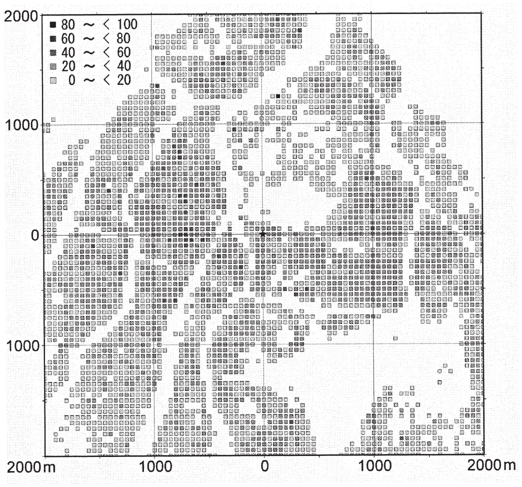

Figure 1 Distribution of average heat flux in each 50 m grid within 4 km × 4km area of hypocenter of the A-bomb as a same area as shown in figure 1. A star marked at a location (0 m, 0 m) is the hypocenter of A-bomb. Unit: MJ s^{-1} m^{-2} (Figure 4 in Aoyama et al., 2011)

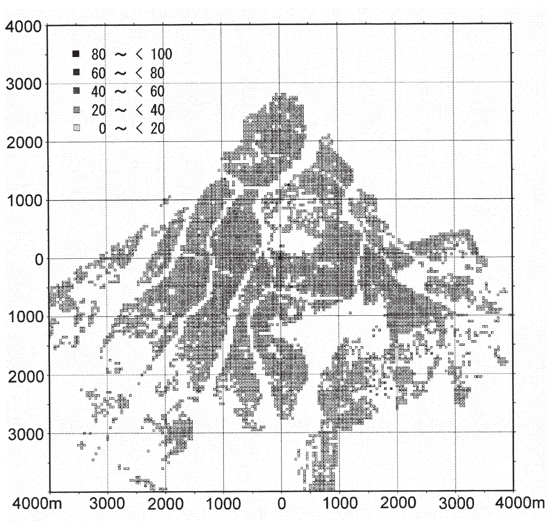

Figure 2 Distribution of average heat flux in each 50 m grid within 8 km x 8 km area of hypocenter of the A-bomb. A star marked at a location (0 m, 0 m) is the hypocenter of A-bomb. Unit: MJ s^{-1} m^{-2} (Figure 5 in Aoyama et al., 2011)

We estimated the total mass of flammable materials to be 0.39 × 10^9 kg, such that the total heat released during the fire induced by the A-bomb was estimated to be 7.02 × 10^{15} J (see Table 1 for representative values from nine grids). A part of the destroyed area located southwest of the hypocenter could not be analyzed because clouds covered the area when the aerial photographs were taken. Therefore, our estimation of total mass of flammable materials and some resulting values might be underestimated by a few percent. In the database, the average value of the mass of flammable materials in a 50-m grid will be inserted for the area lacking data.

Table 1. Examples of the total area of houses, coverage, total mass of flammable materials, total heat produced, heat produced per unit area, and average heat flux for nine 50-m grids around the hypocenter of the A-bomb.

Distance (m)	Direction (degree)	Area (m^2)	Coverage (%)	Total mass of flammable materials (10^3 kg)	Total heat produced (TJ)	Heat produced per unit area (MJ m^{-2})	Average heat flux (MJ s^{-1} m^{-2})
0	0	553	22	70	1.24	498	0.017
50	0	928	37	104	1.86	744	0.026
50	90	763	31	85	1.53	612	0.021
50	180	1192	48	96	1.72	688	0.024
50	270	601	24	47	0.84	335	0.012
71	45	988	40	82	1.47	587	0.020
71	135	1276	51	95	1.70	681	0.024
71	225	1029	41	120	2.15	858	0.030
71	315	1195	48	137	2.45	981	0.034

(Table 3 in Aoyama et al., 2011)

For the time-dependent heat flux, we assumed that the progress of combustion of houses follows a scenario as described by DiNenno et al. (1995b). In general, compartment fires are discussed in terms of the following stages: ignition, growth, flashover, fully developed fire, and decay. Because no fire control measures were undertaken due to the total destruction of fire control systems in Hiroshima after the A-bomb, we assumed the fire followed this scenario. We assumed that the growth period was about 3 h, based on the analysis by Kawano et al. (2011), which shows good agreement with DiNenno et al. (1995b), when we consider a larger opening factor. A scenario of the rate of heat release is shown in Figure 3.

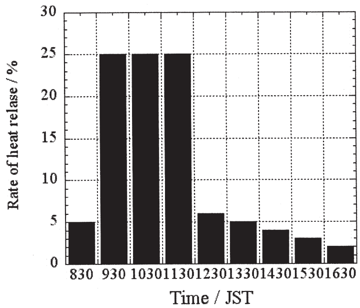

Figure 3 A scenario of a rate of heat release for the urban fire of which duration is 8 hours just after A-bomb explosion. (Figure 6 in Aoyama et al., 2011)

Therefore using total mass of flammable materials in each grid and the times that the fire began and ended in each grid, the time-dependent heat flux can be calculated, as shown in Table 2.

Table 2. Examples of time-dependent heat flux for nine 50-m grids around the hypocenter of the A-bomb. The bomb was dropped at 08:15 h.

Distance (m)	0	50	50	50	50	71	71	71	71
Direction (degree)	0	0	90	180	270	45	135	225	315
Time of day	Time-dependent heat flux (MJ s^{-1} m^{-2})								
08:30	0.028	0.041	0.034	0.038	0.019	0.033	0.038	0.048	0.054
09:30	0.035	0.052	0.043	0.048	0.023	0.041	0.047	0.060	0.068
10:30	0.035	0.052	0.043	0.048	0.023	0.041	0.047	0.060	0.068
11:30	0.035	0.052	0.043	0.048	0.023	0.041	0.047	0.060	0.068
12:30	0.008	0.012	0.010	0.011	0.006	0.010	0.011	0.014	0.016
13:30	0.007	0.010	0.009	0.010	0.005	0.008	0.009	0.012	0.014
14:30	0.006	0.008	0.007	0.008	0.004	0.007	0.008	0.010	0.011
15:30	0.004	0.006	0.005	0.006	0.003	0.005	0.006	0.007	0.008
16:30	0.003	0.004	0.003	0.004	0.002	0.003	0.004	0.005	0.005
Average	0.017	0.026	0.021	0.024	0.012	0.020	0.024	0.030	0.034

(Table 4 in Aoyama et al., 2011)

The heat produced by the fire would have been proportional to the oxygen condition, which is unknown. Given our assumption that 10% of the fuel was under reducing conditions, the total produced heat of 7.02×10^{15} J is decreased to 6.32×10^{15} J.

3.2 Water flux

An estimate of the water flux from the fire induced by the A-bomb was calculated based on the total mass of flammable materials in each grid and the production constant of water . The distribution of averaged water flux for the region is shown in Figure 4.

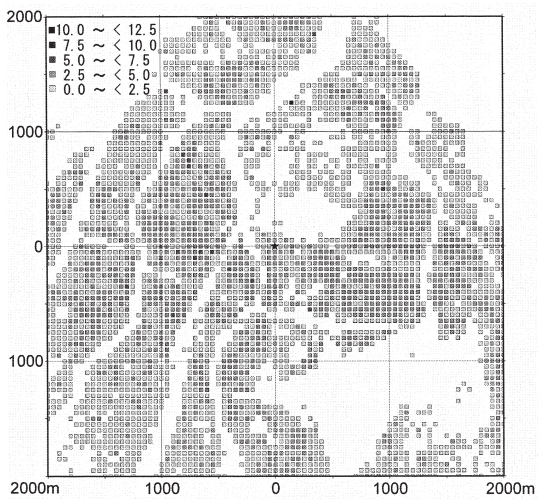

Figure 4 Distribution of average water flux in each 50 m grid within 4km × 4km area of hypocenter of the A-bomb. A star marked at a location (0 m, 0 m) is the hypocenter of A-bomb. Unit: mm h^{-1} m^{-2}(Figure 7 in Aoyama et al., 2011)

3.3 Black carbon flux

The estimated carbon flux from the fire induced by the A-bomb was calculated based on the total mass of flammable materials in each grid and the production constant of black carbon. As discussed above, heat and water are produced in proportion to the amount of flammable materials, whereas the amount of carbon produced depends upon the oxygen condition during the fire, which is unknown. We assumed that 10% of flammable materials was under reducing conditions; thus, the total amount of black carbon produced and released during the fire was estimated to be 0.02 Tg.

To confirm this assumption for under reducting conditions, we prepared dummy black rain sample of which black carbon concentration ranged from 1 % to 70 % and asked witnesses of black rain to choose one of the samples as most similar one with black rain they observed in August 1945. 37 replies were obtained and the 34 of 37 replies concentrated with a range from 5 % to 15 %.Therefore we concluded that about 10 % would be appropriate as under reducting condition for heat, water, black carbon flux estimation.

4. Conclusion

The average heat flux in the region was 14.4 kJ s^{-1} m^{-2} and it ranged from 0.5 to 96.5 kJ s^{-1} m^{-2}.

The total heat released during the fire was 7 PJ. The average heat flux obtained in this study is about half of a value used in previous study (Yoshikawa, 1999) and the total heat flux is 7 times larger than that in Shouno, 1953. In total, 0.22 Tg of water was produced and released during the fire. The total amount of black carbon produced and released during the fire was 0.02 Tg, when we assume that 10% of the fuel was under reducing conditions.

Acknowledgemen

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Activation analysis for soils of Hiroshima city and estimation of gamma-ray dose rate due to neutron induced activated soil by Hiroshima atom bomb

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Abstract

For the early entrance survivors in Hiroshima and Nagasaki atomic bomb (A-bomb), radiation doses from activated materials induced by the A-bomb neutrons are dominant. For estimation of such doses, element compositions of surrounded materials such as soil and rubbles are necessary. Especially Sc density in soil is important for estimating radiation doses at the time of a few 10 days after explosion. Because ^{46}Sc which has the half-life of 84 days, is induced the A-bomb neutrons. However, few data of Sc density in soil are available in both of Hiroshima and Nagasaki cities. Purpose of this study is evaluation of Sc density in soil and the uncertainty using activation analysis.

Soil samples were taken from 11 locations within 4 km from A-bomb hypocenter at Hiroshima city. The soil samples and reference rock sample of JA-11) were activated in Kyoto University Reactor (KUR). Element compositions are relatively obtained from each identified radionuclide counting rates in soil and reference rock by Ge-detectors.

Twenty three element compositions including Al, Mn, Na and Sc are obtained by the activation analysis. The obtained element compositions are compared with values in Dosimetric System 1986 (DS86) and those are roughly the same as the reported values in DS86. Sc density in Hiroshima soil was estimated to be 5.12±0.59 (ppm). It was found the unevenness of Sc density in soils for 11 location of Hiroshima city is about 12%.

Using element compositions by the activation analysis, time variation of the exposure rate by activated soil are estimated. It was found that exposure rate in the few minute time range is dominated by ^{28}Al, in the several days by ^{24}Na, and in the a few 10 days by ^{46}Sc. This estimated result is compared with measured dose rate measured after a few months after explosion. It was found that the estimated dose rate is quite similar to the measured one.

INTRODUCTION

In dosimetric system 1986 (DS85), cumulative radiation exposure due to activated soil around hypocenter of Hiroshima atomic bomb (A-bomb) had been estimated to be 0.8 Gy at maximum[1]. And then, the exposure from activated soil had not been updated in the reevaluated dosimetric system 2002 (DS02)[2]. On the other hand, Imanaka et al. evaluated and updated the exposure from activated materials based on DS02 neutron fluence using thermal neutron fluence ratio (DS02/DS86) and ^{60}Co activation comparing with the results by Gritzner et al. in DS86 [3]. It was concluded that the exposure at 1m height after 1 minute after from the Hiroshima bombing was estimated to be 4Gy/h[4]. Tanaka et al. also evaluated that the gamma- and beta- ray exposure in air and on skin from the induced activities of ^{24}Na, ^{56}Mn, ^{42}K and ^{46}Sc in soil according to the DS02 neutron fluence using Monte Carlo transport calculation[5]。 It shows that exposures from activated soil are estimated to be ~50mGy/h by Imanaka et al.[3] and ~40mGy/h by Tanaka et al [5] at 1 hour after the bombing, respectively. In these estimation, the element composition in soil summarized in DS86 was used.

Element composition is measured for only two locations (Hiroshima Castle and A-bomb Dome) in DS86. Variation of the composition over Hiroshima City is unknown. Before established DS86, element composition analysis for 16 locations for Hiroshima City were carried out by Hashizume et al. in 1967. However, they concentrated into Na and Mn density, and measured just one location for Sc density[6]. Sc is activated to ^{46}Sc which has relatively longer half life of 83.79d. The exposure of the early entrance survivors at 10 days or later after bombing is dominated by ^{46}Sc, therefore the Sc concentration is important parameter for the early entrance survivors. In this report, the element concentration, especially Sc concentration and it's unevenness in soil of Hiroshima City have been obtain by the activation analysis. And also, the exposure rate by the induced radioactivities in soil has been estimated.

Soil sampling

Eleven soil samples were collected from 10 locations including Hiroshima Castle and Atomic bomb dome where the element concentration analysis were performed in DS86. The soil core (5cmϕ x 20cm) were taken using stainless steel pipes. The sapling location are shown in Fig. 1. The GPS coordinate of the sampling locations are summarized in Table 2.

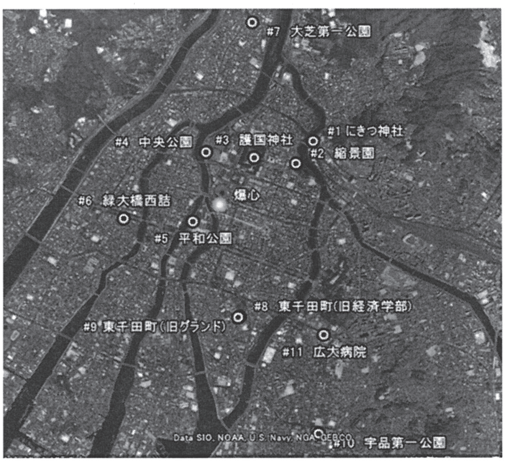

Fig. 1 Sampling locations

These samples were dried by an oven at 120 degrees for over night. The dried samples are sieved through a 2-mm mesh to remove small rocks and big plant remains. The sample for activation analysis was prepared with 10 g soil grained with mortar for uniformity in the sample. About 0.1 g grained soil was packed into about 5 mm square with polyethylene film. The neutron irradiation has been carried out at Kyoto University Reactor (KUR).

Table 1 Sampling locations and GPS coordinates

ID	Sampling location	GPS	
1	Nikitsu shrine	34°24'15.40"N	132°28'8.20"E
2	Shukeen Garden	34°24'4.50"N	132°27'59.30"E
3	Gokoku Shrine	34°24'6.20"N	132°27'35.80"E
4	Chuo Park	34°24'7.60"N	132°27'8.70"E
5	Peace Memorial Park	34°23'34.80"N	132°27'3.60"E
6	Midori Ohashi West side	34°23'34.50"N	132°26'25.10"E
7	Oshiba Daiichi Park	34°25'10.50"N	132°27'30.50"E
8	Higashi-Senda 1	34°22'51.50"N	132°27'32.50"E
9	Higashi-Senda 2	34°22'51.10"N	132°27'31.70"E
10	Ujina Daiich Park	34°21'59.50"N	132°28'19.60"E
11	Hiroshima Univ Hospital	34°22'45.10"N	132°28'53.40"E

The soils have been neutron-irradiated for 30 s, to identified short-life radionuclides. The gamma-ray spectrometry has been carried out at about 2 min and 1 hours after the irradiation using Ge-detector (EG& G ORTEC, GEM-25185) at KUR. The first measurement is mainly for ^{28}Al-concentration determination. The second measurement is mainly for ^{56}Mn and ^{24}Na--concentration determination. The soils have been neutron-irradiated for 20 min, to identified medium and long-life radionuclides. The gamma-ray spectrometry has been carried out at about 10 days and 40 days after the irradiation using Ge-detector (EG &G ORTEC, GEM-30200-P) at Hiroshima University.

The element concentrations have been relatively obtained using reference rock sample JA-1 which is andesite taken from Hakone Mountain in 1989. The reference sample is distributed by National Institute of Advanced Industrial Science and Technology (AIST) and measured element concentration at 460 Institutes in 43 nations[7].

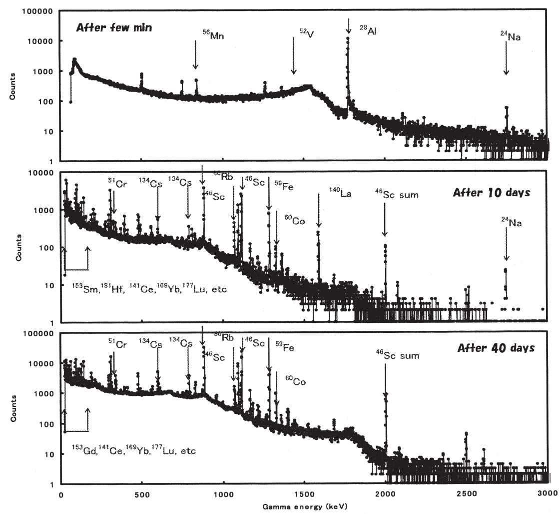

Fig. 2 Example of gamma-ray spectrum

Results

The gamma-ray spectra for #3 (Gokoku Shrine) are shown in Fig.2. Short-life radionuclides of ^{28}Al, ^{56}Mn, ^{52}V and ^{24}Na are identified in Fig 2 (a). Medium- and long-life

Table 2 Averaged values of element cencetration in soil and DS86 values[1)]

element	Z	Concentration (ppm)		DS86 value (ppm) Hiroshima Castle	DS86 value (ppm) A-bomb Dome
Na	11	19300	±20%	16000	12400
Al	13	63300	±14%	71000	64900
Sc	21	5.12	±12%	5	5
V	23	21.4	±26%	22.3	25.3
Cr	24	20	±65%	20.5	27.3
Mn	25	517	±13%	467	587
Fe	26	17100	±16%	17700	20600
Co	27	4.13	±23%	3.7	3.8
Rb	37	137	±12%	230	225
Sr	38	45	±38%	88	70
Zr	40	105	±40%	41	35
Nb	41	2.0	±60%	7	5
Sb	51	1.87	±11%	1.4	0.8
Cs	55	4.4	±14%	5	5
La	57	27.4	±23%	23	21
Ce	58	88	±24%	40	36
Sm	62	3.7	±27%	3.4	3
Eu	63	0.81	±15%	0.9	0.9
Gd	64	2.23	±44%		
Lu	71	0.133	±33%		
Hf	72	4.17	±19%	4	4
Th	90	14.3	±30%	13.3	9.9
U	92	0.85	±18%	2.8	2.6

radionuclides of ^{153}Sm, ^{181}Hf, ^{141}Ce, ^{169}Yb, ^{177}Lu, ^{85}Sr, ^{51}Cr, ^{140}La, ^{134}Cs, ^{95}Zr, ^{134}Cs, ^{46}Sc, ^{86}Rb, ^{233}Pa, ^{152}Eu, ^{153}Gd, ^{60}Co and ^{59}Feare identified in Fig. 2 (b) and (c). Counting rate ratio of soil samples to reference samples decay-corrected at just irradiation finished are multiplied to the known element concentrations. The 23 element concentrations including Al, Mn, Na and Sc, for 11 soil samples are obtained and the averaged values over 11 samples is listed in Table 2. The concentration of main components such as Al, Mn, Na, Sc and Fe are varied about 11-15%, the other trace elements show 20-30% unevenness. Present values of element concentrations are consistent with DS86 values of Hiroshima Castle and A-bomb Dome shown in Table 2.

Sc, Mn and Nacocentration and their unevenness

Obtained element concentrations of Sc, Mn and Na are shown by scatter plots in Fig. 3. Figure 3(a) correlation of Mn-Na concentration and (b) correlation of Sc-Na concentration are shown. And also, element concentration by Hashizume et al[6)] and DS86 values[1)] are shown in the same figures. There are no correlation in both of the Sc-Na and Mn-Na. In Fig. 3(a) and (b), the Na and Sc concentration shows consistency with those of DS86 and Hashizume et al. within their unevenness, however the Mn concentration shows a half of Hashizume's values. The unevenness of Na, Mn and Sc concentration are 19300±3900 (±20%) ppm, 517±68 (±13%) ppm and 5.12±0.59 (±12%) ppm, respectively.

Exposure from activated soil

Exposure from activated soil are estimated using the obtained element concentration. Induced radioactivities in 1 g soil by A-bomb neutrons can be calculated using the element concentration, DS02 thermal neutron fluence and activation cross sections. However, to estimate the exposure, shielding factor and scattering factor (called conversion factor, here) in soil and air are needed. In this estimation, results by Tanaka's Monte Carlo calculation [5] are used for such factor. The factor of induced radioactivity of ^{24}Na to dose in air by ^{24}Na are calculated and applied to all induced radioactivities of ^{56}Mn, ^{46}Sc, ^{60}Co, ^{134}Cs, ^{59}Fe, ^{42}K, ^{51}Cr, ^{28}Al and ^{233}Pa. The conversion factor for each radionuclide should be different from that of ^{24}Na. Therefore this estimate of exposure rate is approximation. Time variation of each exposure rate by radionuclide is calculated to be decreased by each half-life. Figure 4 shows the time variation of exposure rate at around the hypo center of Hiroshima A-bomb. There are few measured data after bombing. There are only 4 measured data at one to three month after bombing by Miyazaki and Masuda[8] and by Manhattan Engineering District[9]. For comparison with our estimation, these data also plotted in the same figure. The estimation and measured data show the good agreement.

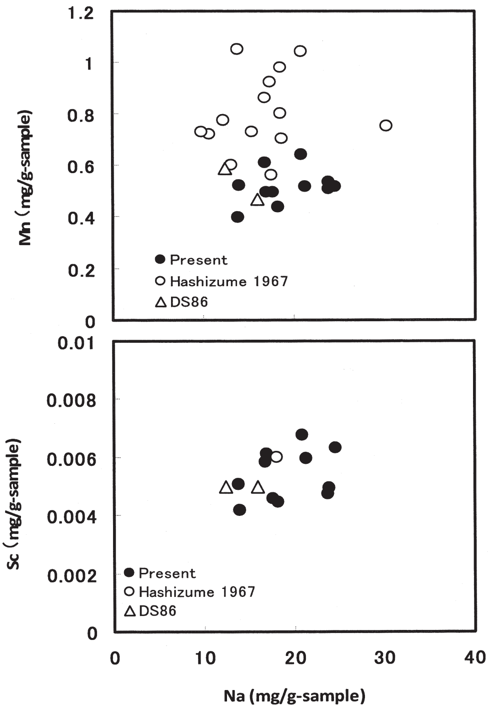

Fig. 3 (a) Mn-Na and (b)Sc-Na correlation

The exposure rate at a few minute after bombing is estimated to be 7-5Gy/h(due to ^{28}Al), at a few hours to be 0.1−0.02Gy/h (due to ^{56}Mn and ^{24}Na) and a few month to be 1mGy/h (due to ^{46}Sc). From these results, it was ascertained that exposure rate dominated by ^{28}Al during a few minute, by ^{24}Na in a few minute to about 10 days and by ^{46}Sc in a few 10 days to 1 year.

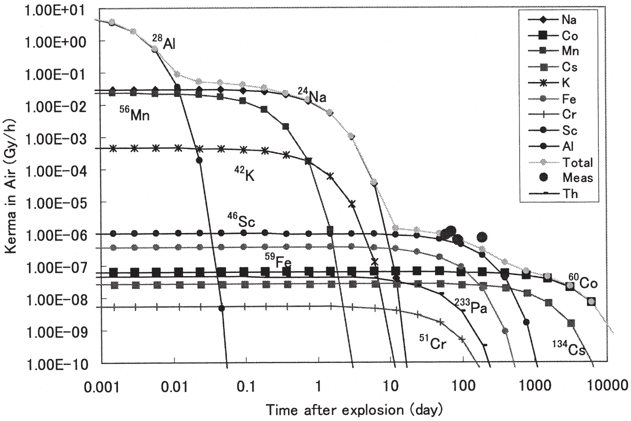

Fig. 4 Time variation of exposure rate estimated by element concentrations.

Summary

In order to estimate exposure from activated soil by Hiroshima atomic bomb, element concentration in soil of Hiroshima City are analyzed by the activation analysis at Kyoto University Reactor. Eleven soil samples were collected from Hiroshima City within 4 km from hypocenter.

As a result of the activation analysis, 23 element concentations including Al, Mn, Na and Sc are obtained. Sc concentration relate to exposure rate at about 10 days after bombing due to lack of data in DS86 is obtained. Sc concentration and unevenness are obtained to be 5.12±0.59 (±12%) ppm.

Mn concentration is a half of value by Hashizume et al [5], however Mn and Na concentration are consist with DS86 values. The averaged value of Mn and Na concentrations over 11 soil samples are Mn: 517±68 (±13%) ppm and Na: 19300±3900 (±20%) ppm, respectively.

The exposure rate at a few minute after bombing is estimated to be 7-5Gy/h(due to ^{28}Al), at a few hours to be 0.1−0.02Gy/h (due to ^{56}Mn and ^{24}Na) and a few month to be 1mGy/h (due to ^{46}Sc). From these results, it was ascertained that exposure rate dominated by ^{28}Al during a few minute, by ^{24}Na in a few minute to about 10 days and by ^{46}Sc in a few 10 days to 1 year. The estimated exposure rate is the good agreement with by Miyazaki and Masuda[8] and by Manhattan Engineering District[9].

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Preliminary results on soil core samples collected from the under-floors of houses built within 1-4 years after the Hiroshima Atomic Bomb

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Introduction

Twenty to 30 minutes after the explosion of the Hiroshima atomic bomb (A-bomb), rainfall occurred in and around Hiroshima city. That rain, the so-called Black-rain, might transport fission products, induced radionuclides and fissile materials of the A-bomb to the ground, and causes radiation exposure to people living there. According to the report by Uda et al. (1953), the heavy rain area extending to the north-west and north direction from the hypocenter was an oval shape with axes of 11 × 19 km (66 km^2) (Figure 1). This estimated area was based on the condition of the weather on the day and inquiry of affected people in the city. Later, a wider estimate of the black rain area was proposed by Masuda (1989) (Figure 1). Several studies have been conducted to estimate the rainfall area and radioactivity fallout caused by the Black-rain with the analysis of radionuclide composition. However, the Black-rain area and radionuclide deposition rate have not been clarilied, since global-fallout nuclides originated from atmospheric nuclear testing from 1950s to 1960s can disturb accurate determination of the rainfall area and amount of the radionuclides.

The purpose of this study is to clarify the nuclide composition and deposition area of Black-Rain by means of analyzing radionuclides (^{137}Cs, ^{236}U, and ^{239,240}Pu) in soil and wall samples collected from (i) under the floor of houses which were built between 1945 and 1948, (ii) around the hypocenter immediately after the explosion of the Hiroshima A-bomb (Nishina sample), and (iii) a wall which has streak-trails of Black-rain.

Material and method

Black-rain streaks on wall

A roof of a house at 3.7 km west of the hypocenter was blow off due to the strong wind of A-bomb at that time, and the Black-rain were come into the house and made the streaks. In 1967, the tainted part of the wall was excised by the residents when the house was renovated. And then, the wall had been preserved until the donation to the Hiroshima Peace Memorial Museum. It is expected that the streaks have not been affected by global-fallout. So this Black-rain streaks will give some of the information on fissile nuclide and bomb material, and will serve as an aid to clarify the Black-rain matter. Three black parts were shaved from the wall's surface and the black surface plaster was separated from the underlying white plaster layer. These were analyzed for ^{137}Cs by non-destructive gamma-ray spectrometry. After that, a portion of wall samples was digested with concentrated HNO_3 and H_2O_2 for 3 h on a hot place (160°C). The sample solution was filtrated (0.20 μm) and separated into two aliquots: (i) for determining the total amount of leached ^{238}U by inductively coupled plasma mass spectrometry (ICP-MS) and (ii) for chemical separation for uranium and plutonium isotopic analysis. Uranium and plutonium were purified from the latter sample using an anion exchange resin column method (Sakaguchi et al., 2004). Uranium fraction was separated into two aliquots (i) for determining the $^{235}U/^{238}U$ atom ratio by multi collector inductively coupled plasma mass spectrometry (MC-ICP-MS) and (ii) for determining the $^{236}U/^{238}U$ atom ratio by accelerator mass spectrometry (AMS). Plutonium concentration and $^{240}Pu/^{239}Pu$ atom ratio were measured with AMS.

Nishina soil samples

9th August 1945, Nishina research team conducted an early survey to find out the radioactive situation of Hiroshima city. The soil samples were collected within the area of 5 km from the hypocenter. Since these samples were collected just 3 days after the explosion, they are not affected by global-fallout. It is also expected that these samples contains radionuclides originated from Hiroshima A-bomb. The samples, which ^{137}Cs could be detected, were measured for uranium and plutonium isotopes with similar methods already mentioned above.

Soil core samples from under-floor

To evaluate the level and spatial distribution of close-in fallout nuclide related to Black-rain, soil core samples were taken from under floor of houses built within 1-3 years after detonation of the Hiroshima A-bomb. These soil samples might not be affected global-fallout so much. In May 2010, four under-floor

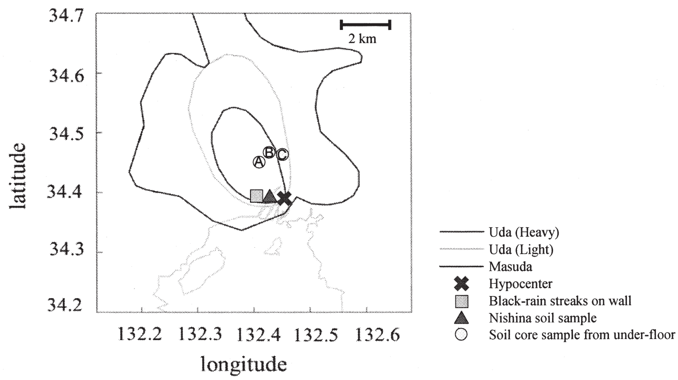

Figure 1 Black-rainfall area and sampling sites. The Black-rain areas were estimated by Uda et al. (1953) and Masuda (1989).

soil cores up to a depth of 30 cm (11 cm in diameter) were collected from 3 locations around Hiroshima City(A, B and C in Figure 1). Two cores were collected at Point A. Each core sample was divided into 5 or 6 parts: 0-3, 3-6, 6-9, 9-15, 15-20 and 20-30 cm in depth. The soil sample was leached with conc. HNO_3+H_2O_2 on hot plate (160°C) for three hours. The leaching solution of each sample was weighed and separated into three aliquots: (i) 1/200 for determining the total amount of leached ^{238}U by ICP-MS, (ii) 3/100 for determining the ^{235}U/^{238}U and ^{236}U/^{238}U atom ratios by MC-ICP-MS and AMS, and (iii) the rest was used for ^{137}Cs and Pu isotope measurements with Ge semiconductor detector and AMS.

The methods of sample treatment has been already reported in Sakaguchi et al. (2009 and 2010).

Results and discussion

Radionuclide composition in Black-rain from Hiroshima A-bomb

$^{239,\,240}$Pu in Nishina and rain-streak samples were not detected due to the tiny amount of samples available for our analyses. The ^{236}U/^{137}Cs (atom/activity) ratios in the streaks and Nishina samples showed (4.68-7.23) × 10^7 atom/Bq and 3.09 × 10^8 atom/Bq (decay corrected to 1945), respectively. These values were smaller compared with the production ratio from the explosion of the A-bomb (1.8 × 10^9 atom/Bq). It

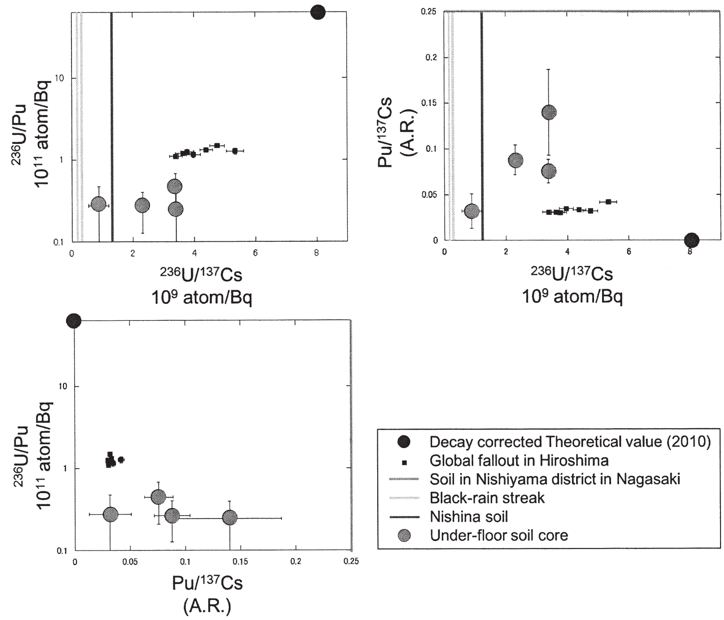

Figure 2 Result of ^{236}U/^{137}Cs, ^{236}U/Pu and Pu/^{137}Cs ratios in Nishina soil, streaks on wall and soil cores from under-floor.

is indicated that the radionuclides have been fractionated between refractory and volatile elements during the explosion and deposition of these nuclides. R/V (refractory/volatile) factors of Hiroshima A-bomb were calculated to be 0.17 and 0.026-0.040 from $^{236}U/^{137}Cs$ ratios of Nishina sample and the streaks on the wall. These values are nearly same value as 0.06-0.5 which was calculated by using $^{235}U/^{238}U$ and ^{137}Cs in a streaks on the wall (Imanaka, 2010). Thus, our values might be recognized as one of the representative value of radionuclide composition in Black-rain.

Radionuclide composition in soil cores from under-floor

The depth profiles of ^{137}Cs in terms of an accumulated level showed that 100% of the ^{137}Cs were retained within the layers up to the depth of 9 cm except for one core among the under-floor soil core samples. The ranges of areal inventories of ^{137}Cs were 19-62 Bq/m^2, and these levels were less than thirtieth of the global-fallout level (2000-3000 Bq/m^2) found in Hiroshima (Yamamoto et al., 2010; Sakaguchi et al., 2010). This suggests that significant amounts of radionuclides deposited locally due to close-in fallout, if soil samples used in this study were uncontaminated by global-fallout (Sakaguchi et al., 2011).

$^{236}U/^{137}Cs$, ^{236}U/Pu and Pu/^{137}Cs ratios in the under-floor soil cores were (0.88-3.40) × 10^9 atom/Bq, (2.42-4.44) × 10^{10} atom/Bq and 0.032-0.140 (activity ratio; A.R.), respectively (Figure 2). Some of these results from the soil samples are significantly different from the value of global-fallout composition, (3.40-5.34) × 10^9 atom/Bq, (1.10-1.48) × 10^{11} atom/Bq and 0.0303-0.0420 (A.R.). These values in the soil samples are also different from the values which were estimated from Nishina sample and the streaks on the wall. It can be said that the radiological composition from these soil core samples may have the mixture information, e.g. A-bomb composition in Nishina and streaks, global-fallout and some other end-member. Actually, Pu/^{137}Cs ratios in the under-floor soil cores show the higher values than that of global-fallout and expected value from the R/V factor. It might suggest that other origin contributed to these values. For example, Pu/^{137}Cs ratio in Nishiyama district in Nagasaki City was about 0.25 (calculated with the values from Kokubu et al., 2007, and decay corrected to 2011). That is, plutonium originated from Nagasaki A-bomb can be a one of the candidate which affected to the value from the under-floor soil samples. For other possibility, there is a specific R/V factor for each element (between Pu/Cs and U/Cs) due to the adsorbent of radionuclides in the atmosphere.

From these results, there is a possibility to identify the fingerprint of Black-rain and to clarify the area of the rain from these soil samples, because the value of our samples were different from the global-fallout values. However, further precise analysis, such as radionuclides in Nishina samples and other material which has the A-bomb radiological composition, are needed to identify the nuclide composition originated from Black-Rain.

Acknowledgements

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What is the origin of ^{137}Cs detected in under-floor soil samples of houses built in 1-3 years after the Hiroshima atomic bomb ?

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1. Introduction

Other than direct radiation by Hiroshima atomic bomb (A-bomb), from twenty to third minutes after the explosion, so-called "black rain" fell down over the north and northwest areas of Hiroshima City. Radiation exposure due to close-in fallout by this event was not taken into consideration in DS02 (Young and Kerr, 2005) because its contribution was considered to be small for RERF cohort members who were mainly inside the city at the time of the bombing. Recently, in relation with enlargement of social compensation for A-bomb survivors, concern on radiation exposure due to close-in fallout has been raised among the people who experienced the black-rain.

Until now, to evaluate the possible radiation exposure by the close-in fallout related to the black rain, long-lived fission product ^{137}Cs has been actively measured in surface soil samples, accompanied by much smaller amounts of data on ^{90}Sr (JPHA, 1976, 1978). Excess ^{137}Cs activity from the close-in fallout, however, could not be clearly recognized due to much larger quantity of global fallout ^{137}Cs deposition originating from atmospheric nuclear tests in 1950s and 1960s. Thus, radioactive characteristics as well as spatial distribution of the close-in fallout by the Hiroshima A-bomb have not been specified even after 60 years from the A-bombing.

Therefore, measurements of ^{137}Cs and Pu isotopes in under-floor soil samples from about 20 houses built in 1-3 years after 1945 have been attempted since 2008, in order to evaluate the close-in fallout deposition at the time of Hiroshima atomic explosion (Yamamoto et al. 2010). The ^{239,240}Pu was used as indicator to evaluate the contamination from global fallout ^{137}Cs other than Hiroshima A-bomb derived ^{137}Cs. If a fission product ^{137}Cs is detected in soil samples under houses, this finding will give us convincing evidence that the close-in fallout felt down, indicating the possibility that details of level and spatial distributions of the close-in fallout become apparent. As a result, ^{137}Cs (several to several 100 Bq/m^2, mostly being 10-50 Bq/m^2) and trace of ^{239,240}Pu (0.1-24 Bq/m^2, mostly being around 1Bq/m^2) were detected for all samples measured, although their ^{137}Cs levels were very low compared with their levels (1000-2500 Bq/m^2) in undisturbed forest soils around Hiroshima. To elucidate the origin of ^{137}Cs (and

$^{239,240}Pu$) detected in the under-floor soil samples, attempts were also made to determine the $^{240}Pu/^{239}Pu$ atomic ratios in some of those soil samples. These results will be presented and discussed from the standpoint of the evaluation of Hiroshima atomic bomb derived ^{137}Cs fallout level.

2. Materials and methods

2.1. Soil sampling

Sampling locations of 20 houses where under-floor soil samples were collected are shown in Fig.1. The samples were mainly collected from the under-floor of old houses built in 1-4 years after A-bomb at the north and northwest areas. Most of the locations

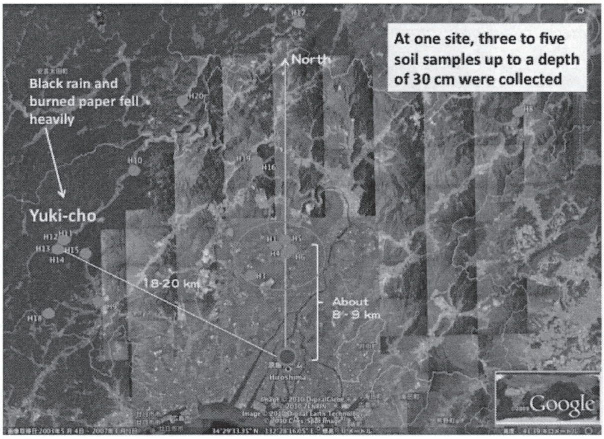

Fig. 1 Sampling locations of under-floor soil samples of houses built in 1-3 years after the Hiroshima atomic bomb explosion.

where houses were built at that time were in the paddy and dry fields. At one house, three to five under-floor soil samples up to a depth of 30 cm were taken by using stainless steel pipe (5.0 cm$^{\varphi}$ x 30 cm). Around the Yuki-cho far away from about 20 km northwest from the hypocenter, it is well known that the black rain and burned paper heavily dropped at that time.

2.2. Measurement

The obtained samples were air-dried, sieved through a 2-mm mesh screen to remove pebbles, and pulverized using an agate mortar to obtain samples as homogeneous as possible. A soil sample (60-80g) was at first subjected to non-destructive γ-ray spectrometry using a Ge detector to determine ^{137}Cs concentration. However, ^{137}Cs was not clearly detected for most of the samples, except for several samples. To measure accurately low level ^{137}Cs in all soil samples, chemical separation of Cs (^{137}Cs) using about 100 g soil sample was carried out by Kyushu Environmental Evaluation Agency (Fukuoka, Japan), and the obtained AMP samples were measured using extremely low-background Ge detector installed at the

Ogoya underground laboratory at LLRL. Ogoya underground laboratory is about 20 km southeast of LLRL. The laboratory is in a 550 m tunnel of the former Ogoya copper mine where closed in 1971. It is located 270 m from the tunnel entrance, where the overburden is 270 mwe. The muon intensity is 1/100 of the above ground value. Measurement time is more than one week or further long. Low-level ^{137}Cs was clearly detected for all soil samples examined.

After γ-ray spectrometric analysis, plutonium analysis was carried out radiochemically (Yamamoto et al. 1983, 2008). In brief, an aliquot of 70-100 g of soil sample was leached twice with conc. HNO_3 containing a small amount of H_2O_2 on a hot plate, with the addition of a known amount of ^{242}Pu as a yield tracer. The Pu in the leached fraction was then separated and purified carefully by passing through an anion exchange resin column (Dowex 1-X8, 100-200 mesh). The purified Pu was electroplated onto a polished stainless steel disc and its α-ray activities (^{238}Pu, $^{239,240}Pu$ and ^{242}Pu) were measured by a surface barrier Si detector coupled with 1 k channel pulse height analyzer. The measurements were continued for more than 3-4 weeks to minimize the statistical error by counting.

Other than α-spectrometry, Pu fraction separated and purified from some of soil samples with the non-addition of ^{242}Pu as a yield tracer was subjected to determination of $^{240}Pu/^{239}Pu$ atomic ratio by means of thermal ionization mass spectrometry (TIMS), which is installed at JAEA.

3. Results and discussion

The results of ^{137}Cs measurements for under-floor soil samples are shown in Fig. 2. As can be seen from this figure, ^{137}Cs was more or less detected for all of samples measured. Sample numbers H1-H6, H16-H17 and H19 are from areas in a northern direction, numbers H7-H14 and H20 from a northwestern direction, mainly from Yuki-cho, and number H18 from a northeastern direction. Among them, higher values ranging from 150-800 Bq/m^2 were observed at H2, H3, H6, H8 and H14 locations. The ^{137}Cs levels found are some changeable even in under-floor samples from the same house. Other locations showed relatively low values of less than 50 Bq/m^2

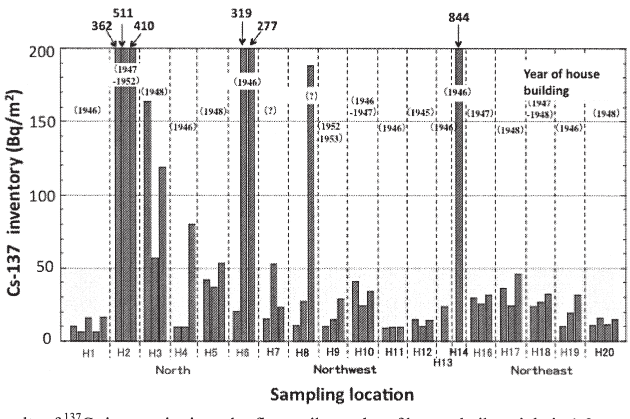

Fig. 2 Results of ^{137}Cs inventories in under-floor soil samples of houses built mainly in 1-3 years after 1945.

In Fig. 3, the results for samples which $^{239,240}Pu$ was measured are shown, together with ^{137}Cs levels. Plutonium-239,240 was detected with low levels for all samples examined. The $^{239,240}Pu$ levels were higher in samples where ^{137}Cs was observed in higher level. Except for the samples detected with higher $^{239,240}Pu$ levels, other most of the samples showed the values of less than 1 Bq/m^2.

In addition to those $^{239,240}Pu$ concentrations, this time, measurement of $^{240}Pu/^{239}Pu$ atomic ratio was examined for four soil samples by using TIMS. Detected atomic ratios ranged from 0.13 to 0.19, as shown in Fig. 3. For global fallout Pu, usually, value of 0.18 has been observed in soil samples. Although detected values for three samples seems to be a little lower than 0.18, these findings seem to indicate that these soil samples received some influence from global fallout. Current ^{137}Cs and $^{239,240}Pu$ levels in forest and plat areas in Hiroshima are in the range from 1,000 to 2,500 Bq/m^2 and from 40 to 80 Bq/m^2, respectively, and the activity ratios of $^{239,240}Pu/^{137}Cs$ is around 0.03-0.04. These levels should be compared with ^{137}Cs and $^{239,240}Pu$ levels found in the under-floor soil samples.

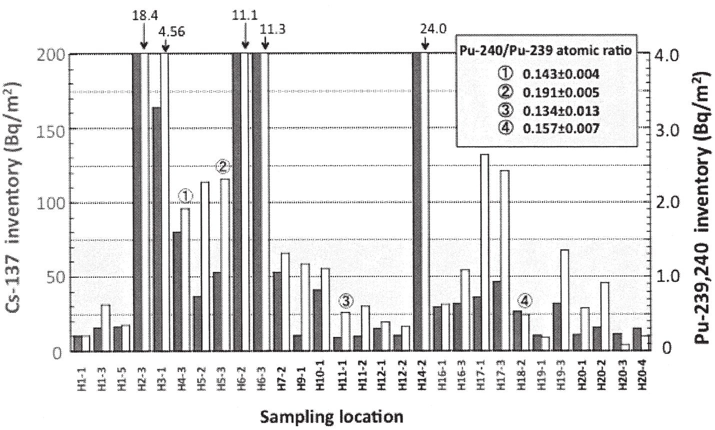

Fig. 3 Results of $^{239,240}Pu$ inventories and $^{240}Pu/^{239}Pu$ atomic ratios in some of under-floor soil samples of houses built in 1-3 years after 1945

Then, let me refresh your memory on Hiroshima and other worldwide atomic bombs.

As shown in Fg.4, under-floor soil samples were mostly collected from houses built during the period of 1945-1949. During this period, other than Hiroshima atomic bomb, some nuclear atomic bombs were exploded in the atmosphere. Pu originating from Hiroshima A-bomb is assumed to be negligibly small, but it seems likely that global fallout Pu from atomic bombs conducted at Almogordoo, Nagasaki and Bikini and Enewetak during this period deposited more or less. Furthermore, soil samples may be affected by global fallout in 1962-1963 with maximum fallout level.

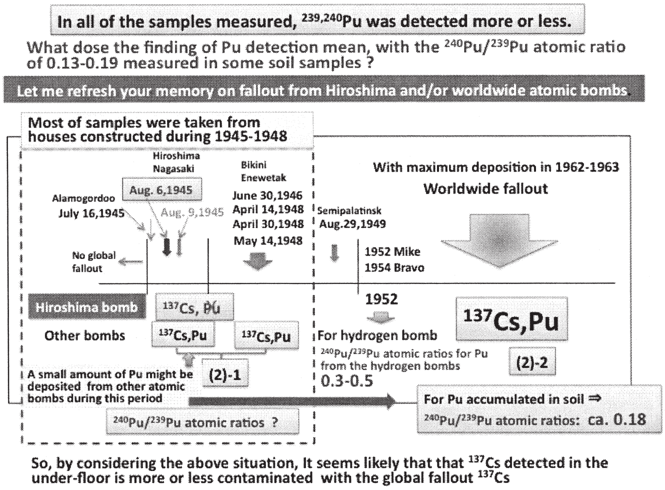

Fig. 4 Relationship between Hiroshima atomic bomb and other atomic bombs.

In Fig. 5, the result of ^{239,240}Pu and ^{137}Cs depositions found in ice cores at Canada by Kudo et al. (1998) is shown. The ^{239,240}Pu originating from Nagasaki A-bomb is detected with extremely low level, indicating that Pu had been scattered globally from 1945.

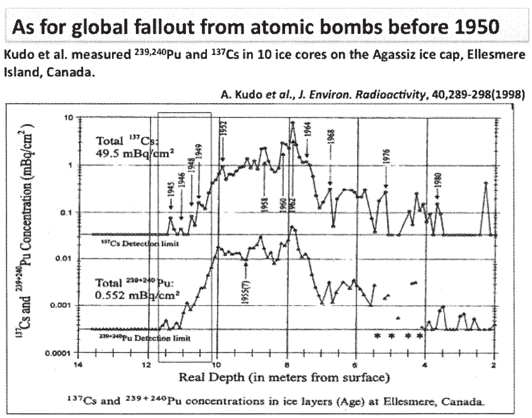

Fig. 5 ^{137}Cs and ^{239,240}Pu levels in ice core at Ellesmere, Canada by Kudo et al. (1998).

An occurrence of global fallout Pu deposition from atomic bombs other than Nagasaki atomic bomb after 1945 is also recognized.

By taking into account the above-mentioned findings, Hiroshima A-bomb derived ^{137}Cs at that time may be roughly estimated by using ^{137}Cs level found in the under-floor soil. Here, we considered two approaches for discrimination: one is based on assumption that all of the $^{239,240}Pu$ detected was derived from global fallout. In this case, Hiroshima derived ^{137}Cs can be calculated simply by subtracting the global fallout ^{137}Cs estimated by $^{239,240}Pu$ from total amount of measured ^{137}Cs, as shown in Fig.6. The second approach is the assumption that $^{239,240}Pu$ detected was only due to fallout from atomic bombs conducted during the periods of 1945-1949. The cumulative deposition of ^{137}Cs in Tokyo is reported by Aoyama (2006). Its deposition is about 10 Bq/m^2 up to the year of 1949. By assuming that this value is the case for Hiroshima area, today's level is around 2.3 Bq/m^2 by considering decay, and further by assuming that current $^{239,240}Pu$ /^{137}Cs ratio of 0.033 is the case for both fallout nuclides during this period, Pu deposition can be roughly estimated to be around 0.1 Bq/m^2. This value is consistent with the estimated value in1945-1949 by Hirose et al. (2001). Then, in case that $^{239,240}Pu$ found is less than at least 0.5 Bq/m^2, it seems to be reasonable to assume that its Pu was already contaminated by fallout Pu during 1945-1949, although it is speculative. In this case, ^{137}Cs contamination from global fallout during this period seems to be neglected.

Discrimination of ^{137}Cs between Hiroshima A-bomb and global fallout

1) By assuming that All of the Pu detected was derived from global fallout,

Hiroshima A-bomb derived ^{137}Cs =

^{137}Cs (Bq/m^2) –$^{239,240}Pu$(Bq/m^2)/ 0.033 (current global $^{239,240}Pu/^{137}Cs$ ratio)

2) By assuming that Pu detected was only derived from fallout during 1945-1948

^{137}Cs fallout levels in Tokyo (Tsukuba) up to the year of 1949

	(A)		(B)	
Year	Cs-137 deposition Bq/m^2	Cummulative deposition Bq/m^2	Cs-137 deposition Bq/m^2	Cummulative deposition Bq/m^2
1945	5.78	5.78	2.60	2.60
1946	2.20	7.85	1.92	4.46
1947	0.00	7.67	0.00	4.36
1948	6.53	14.0	4.75	9.02
1949	1.01	14.7	1.91	10.7

(A): From Canadian Arctic ice cores, (B): From each nuclear test's energy

M. Aoyama, Doctor thesis (1999)

Accumulated ^{137}Cs: about 10 Bq/m^2⇒ decay to 2010: 2.3Bq/m^2

$^{239,240}Pu$ at that time : 2.3x 0.033 (?)= ca. 0.1 Bq/m^2

Pre-1959: $^{239,240}Pu/^{137}Cs$=0.018 (Koide et al.)→$^{239,240}Pu$ at that time:10x0.018=0.2 Bq/m^2

Pre-1959: $^{239,240}Pu/^{137}Cs$=0.012

In case that $^{239,240}Pu$ found is less than at least 0.5 Bq/m^2 (it is speculative),
it seems to be reasonable to think that Its Pu in under-floor soil was already contaminated by fallout Pu during 1945-1948. ⇨ ^{137}Cs contamination from global fallout is neglected.

Fig. 6 Discrimination of ^{137}Cs between Hiroshima A-bomb and global fallout.

Table 1 Estimation of the Hiroshima atomic bomb derived ^{137}Cs deposition.

^{137}Cs deposition expected from the Hiroshima A-bomb

Sample No.	Pu-239,240 (Bq/m²)	Sampling date Cs-137 (Bq/m²)	240/239 atomic ratio	Global origin Cs Pu/Cs=0.033 (Bq/m²)	Cs from Hiroshima A-bomb (Bq/m²)	Elapsed time (year)	(1) Cs-137 at 1945 from A-bomb (Bq/m²)	(2) Cs-137 at 1945 without corretion (Bq/m²)
H1-1	0.20 ±0.04	10.54 ± 1.62		6.18	4.36	62.92	18.6	45.1
H1-3	0.63 ±0.14	15.78 ± 1.83		19.23	(3.45)	62.92		67.5
H1-5	0.35 ±0.17	16.57 ± 1.71		10.54	6.03	62.92	25.8	70.9
H2-3	18.40 ±1.06	410.3 ± 8.0		557.46	(147.18)	63.55		
H3-1	4.56 ±0.27	163.7 ± 7.8		138.28	25.39	63.70	110.6	
H4-3	1.92 ±0.35	79.91 ± 3.10	0.143 ±0.004	58.18	21.72	63.70	94.6	
H5-2	2.28 ±0.38	37.04 ± 4.33		69.09	(32.05)	63.70		
H5-3	2.32 ±0.41	53.33 ± 2.88	0.191 ±0.005	70.30	(16.97)	63.70		
H6-2	11.12 ±0.80	318.9 ± 5.1		336.82	(17.97)	63.70		
H6-3	11.26 ±0.49	276.6 ± 9.8		341.28	(64.66)	63.70		
H7-2	1.31 ±0.21	53.02 ± 3.02		39.71	13.31	63.70	58.0	230.9
H9-1	1.17 ±0.14	10.49 ± 1.15		35.57	(25.08)	64.27		46.3
H10-1	1.11 ±0.17	40.89 ± 1.98		33.62	7.27	64.27	32.1	180.5
H11-1	0.52 ±0.13	9.38 ± 1.01	0.134 ±0.013	15.80	(6.42)	64.27		41.4
H11-2	0.60 ±0.13	9.61 ± 1.28		18.20	(8.59)	64.27		42.4
H12-1	0.39 ±0.17	14.95 ± 1.56		11.79	3.16	64.50	14.0	66.3
H12-2	0.33 ±0.08	10.37 ± 1.55		9.91	0.46	64.50	2.0	46.0
H14-2	24.02 ±0.52	843.8 ± 6.5		727.88	115.95	64.50		
H16-1	0.63 ±0.11	29.27 ± 1.45		19.08	10.19	64.82	45.5	130.8
H16-3	1.09 ±0.20	31.76 ± 2.56		32.99	(1.23)	64.82		142.0
H17-1	2.64 ±0.32	36.27 ± 1.75		80.00	(43.73)	64.82		
H17-3	2.42 ±0.36	46.15 ± 3.55		73.33	(27.18)	64.82		
H18-2	0.48 ±0.08	26.62 ± 3.28	0.157 ±0.007	14.53	12.09	64.82	54.0	119.0
H19-1	0.18 ±0.08	10.44 ± 1		5.46	4.98	64.86	22.3	46.7
H19-3	1.35 ±0.28	31.91 ± 1.7		40.88	(8.97)	64.86		142.7
H20-1	0.58 ±0.13	10.94 ± 1.7		17.61	(6.66)	64.94		49.0
H20-2	0.92 ±0.17	15.70 ± 1.1		27.99	(12.28)	64.94		70.4
H20-3	0.08 ±0.03	11.38 ± 1.1		2.36	9.02	64.94	40.4	51.0
H20-4	0.19 ±0.08	14.96 ± 1.6		5.77	9.19	64.94	41.2	67.1
						Max	ca. 50	100

The result of calculation is listed in Table 1. The global fallout derived ^{137}Cs levels estimated by using both detected $^{239,240}Pu$ and current $^{239,240}Pu/^{137}Cs$ activity ratio of 0.033 are given in the fifth column of this Table. The value given in the sixth column is the estimated Hiroshima derived ^{137}Cs level. In this case, many samples give negative value. Although further consideration is required, maximum value of 50 Bq/m^2 is tentatively more likely. The values listed in the last column in Table 1 show the result of second assumption for samples, which Pu levels are less than 0.5 Bq/m^2, probably these values seem to correspond to the upper limit. In this case, maximal deposition of 100 Bq/m^2 is more likely.

Thus, as a whole, we estimated roughly the Hiroshima atomic bomb derived ^{137}Cs deposition by using the under-floor soil samples of houses built in 1-3 years after the Hiroshima atomic bomb. However, most important issue depends on the soil preparation under houses at that time. Usually, before building a new house, soil preparation such as dipping out surface soil, clearing the land and so on are carried out. According to carpenter, most of the wooden houses at that time were built without causing large disarrangement of surface soil. Further information and data are needed.

4. Summary

Since 2008, we have measured ^{137}Cs and $^{239,240}Pu$ isotopes in about 60 soil samples from the under-floor of 20 houses built within 1-3 years after 1945, in order to evaluate the close-in fallout deposition due to the "Black rain" at the time of Hiroshima atomic explosion. $^{239,240}Pu$ was used as indicator to evaluate the

contamination from global fallout ^{137}Cs other than Hiroshima A-bomb derived ^{137}Cs.
As a result, it seems likely that ^{137}Cs deposition at that time due to the Hiroshima A-bomb is 50-100 Bq/m^2.

Acknowledgement: We are grateful the staffs of Kyushu Environmental Evaluation Agency (Fukuoka, Japan) for preparing AMP samples for measurement of ^{137}Cs through the chemical leaching of Cs from a large amount of soil.

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Reported Occurrence of Severe Epilation vs. Location and Dose Estimates among the Life Span Study Cohort of Atomic-Bomb Survivors

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Abstract

There has long been a concern that clinical symptoms of acute radiation injury, reported by survivors in the questionnaires used by the Atomic Bomb Casualty Commission (ABCC) in the 1950s to gather information for creation of the Life Span Study cohort, were reported at low but non-zero proportions in relatively distal survivors. Because the data were self-reported, there were various potential sources of error that could have resulted in false-positive data. In the most definitive RERF studies, severe epilation (of scalp hair) has been considered to be the most specific and reliable of the reported symptoms potentially related to acute radiation injury. The data on severe epilation: 1,288 cases in Hiroshima and 384 in Nagasaki, have been subjected to a new, exploratory spatial analysis, to see if there are any patterns that might plausibly be associated with exposure to residual radiation. A method used by RERF investigators in 1983 to check for circular asymmetry about the hypocenters, by comparing compass octants in various directions, was repeated with DS02 dose estimates, and a parametric model for dose response including octant indicators was also fitted. In addition, the cities were divided into 200-yard-square geospatial cells and spatial plots were made of the proportions in the cells to allow visualization of any patterns that might exist. A result was that all of the cells with more than a few cases of severe epilation were within about 1.6 km of the hypocenters, consistent with the epilation expected for the corresponding DS02 doses. Among the more distal cells were a number of cells with one or two cases per cell, which are increasingly sparse at longer distances and otherwise appear to be randomly distributed in location – no pattern potentially associated with fallout is obvious on visual inspection. In the future these data may be further analyzed with spatial methods appropriate for binomial random variables with possible spatial autocorrelation, which must also correct for expected proportions due to DS02 dose.

Introduction

Several of the main forms used to collect data on atomic-bomb survivors in the early days of ABCC, such as the Radiation Questionnaire, Migration Questionnaire, and Master Sample Questionnaire(1), were designed to record information on symptoms known at the time to be associated with acute exposure to relatively large doses of ionizing radiation. Individual data on three of those symptoms: epilation (loss of scalp hair), purpura (bleeding under the skin), and oropharyngeal lesions (sores of the mouth and throat) are coded in a database at RERF that dates from the time of dosimetry system T65D(2), and were available for this work. These data were studied in various early reports, such as an early report on the Life-Span Study (LSS) cohort of atomic-bomb survivors studied by ABCC and RERF(3). It was noted that very small but non-zero proportions of survivors reported symptoms at distances where the estimated doses received directly from the bombs were far smaller than the estimated threshold dose for occurrence of the symptoms[3]. In 1983, Gilbert and Ohara studied severe epilation and purpura in a report motivated by issues that had been raised about T65D, using dose estimates made with early prototypes of Dosimetry System DS86[4]. They studied the dose response in different shielding categories and performed a partial spatial analysis in which they looked at compass direction from the bomb hypocenters by dividing the data into compass octants according to survivors' locations at the times of the bombings and making comparisons among octants. In 1988 Stram and Mizuno analyzed the data on severe epilation to compare results of dose-response analyses performed with DS86 doses to those performed with T65D doses[5].

The investigations reported in 1983 and 1988 were aimed at resolving issues about the direct doses calculated by the dosimetry systems, and not residual radiation sources. Among other considerations, estimated maximal doses from residual sources, which were analyzed in detail in Chapter 6 of the DS86 Final Report, were far too low to produce such symptoms. However, in recent years, there have continued to be questions raised about the possibility of fallout associated with "black rain" that may have occurred in areas not well documented by the field surveys of gamma-ray exposure rates performed by U.S. and Japanese teams in 1945 and 1946[6], particularly in Hiroshima. In addition, Endo and colleagues have suggested that previously unaccounted beta dose may have increased the total skin dose associated with exposure to local fallout and made it more plausible that some cases of epilation could have been caused by fallout[7]. For these reasons it may be of interest to know whether there are apparent spatial patterns in the occurrence of the symptoms after adjusting for the effect of direct doses calculated by the newest dosimetry system, DS02.

Choice of Outcome Measure for Analysis

Table 1 presents a complete cross-tabulation of members of the LSS with data on acute symptoms, including the vast majority with no symptoms, showing all possible combinations of symptoms. There are 25,930 members, virtually all in the "not in city" control group, who lack data on symptoms; only 440 survivors with known DS02 doses and located at distances < 2,000 m in either city have missing data.

The proportions reporting the various symptoms are plotted in Figure 1 with linear segments connecting them; the category boundaries are at 0.1, 0.5, 1, 2, 3, 4, and 5 Gy, and the proportion for each category is plotted at the category midpoint; the value for the final category – all survivors with dose estimates exceeding 5 Gy – is plotted at 5.5 Gy, although a few survivors in this category have dose estimates much greater than 6 Gy. Severe epilation exhibits a typical sinusoidal (S-shaped) response, which can be fitted with a standard function used in plotting the probability of binary responses vs. dose, such as a logit or probit. Purpura, although it attains a maximum response almost equal to that of severe epilation, exhibits an oddly convex shape over the entire dose range above 0.5 Gy, and would require further study to determine whether a plausible dose-response function could be fitted, perhaps with some re-scaling of the dose metric. Oropharyngeal lesions exhibit an odd pattern similar to purpura, but with a maximum response about 70% of severe epilation. Mild and moderate grades of epilation show almost no dose response.

Table 1 Cross-tabulation of three symptoms of acute radiation exposure in RERF database.

			Hiroshima		Nagasaki	
Purpura	Oropharyngeal lesions	Severe Epilation	N	%	N	%
-	-	-	58,258	92.7	30,022	93.6
+	-	-	1,705	2.7	667	2.1
-	+	-	732	1.2	491	1.5
-	-	+	381	0.6	141	0.4
+	+	-	858	1.4	527	1.6
+	-	+	349	0.6	60	0.2
-	+	+	78	0.1	30	0.1
+	+	+	479	0.8	153	0.5
		Total	62,840		32,091	

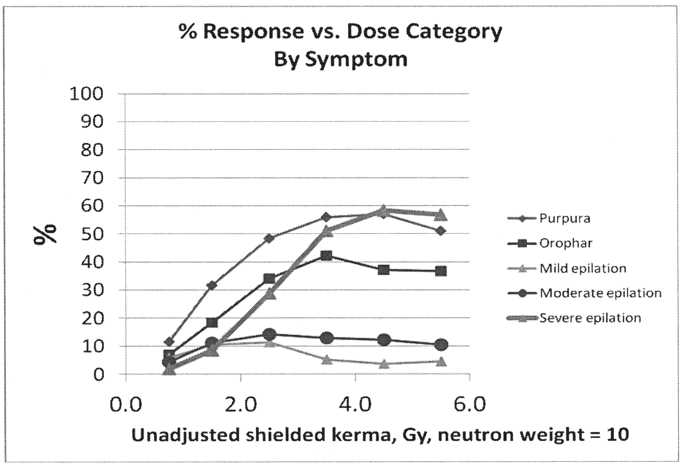


Figure 1 Crude dose-response of available symptoms.

Severe epilation is thought to be the most specific symptom for acute exposure to ionizing radiation, and has been the main symptom of choice in previous studies(3,4,5). The combination of all three symptoms (severe epilation, purpura, and oropharyngeal lesions) is expected to be even more specific to ionizing radiation than severe epilation alone, and indeed the survivors reporting all three symptoms have a substantially smaller proportion at distances > 1.6 km than the totality of those reporting all combinations including severe epilation; however, the total numbers are much smaller, as shown in Table 1. Based on these considerations, all of the analyses reported here were done with severe epilation alone as the outcome. Some analyses were repeated with the simultaneous occurrence of all three symptoms as an outcome, but patterns were similar to severe epilation alone.

Re-analysis of Compass Octants Using the Non-parametric Methods of Gilbert and Ohara with DS02 Doses

Gilbert and Ohara used a special method to correct for the effect of several covariates (age, sex, direct radiation dose estimate) on severe epilation, without assuming a parametric model for the risk as a function of the covariates[(4)]. They divided the data into many strata based on cross-classification by ordered categorical values of the covariates, and then they used the Mantel-Haenszel formulation to sum the results of the 2x2 tables, one table per stratum, that compare each compass octant to all of the other octants. For example, males who were in their 30s at the time of the bombings and had neutron and gamma doses in particular ranges might define one stratum, and one would make a 2x2 table for that stratum comparing the proportion with severe epilation in Octant 1 vs. the total proportion with severe epilation in Octants 2 through 8. Gilbert and Ohara used prototype pre-DS86 doses that were available at the time from the Lawrence Livermore National Laboratories (LLNL) in the U.S., with a correction for house shielding developed by Marcum of Oak Ridge National Laboratories[(4)]. Their analysis was repeated for the present work using DS02 doses, but two shielding categories that were calculated by LLNL are not available in DS02: survivors in concrete buildings, and those in miscellaneous shielding not modeled by DS86 or DS02, such as streetcars, other vehicles, etc.[(2)]. Therefore these shielding categories were analyzed as a separate dose category with unknown dose for this work. Proximal and distal survivors were analyzed separately, as by Gilbert and Ohara, using 1.6 km in Hiroshima and 2 km in Nagasaki to distinguish proximal from distal.

Table 2 Results of Nonparametric Analysis Using Compass Octants: All Proximal Survivors

		ENE	NNE	NNW	WNW	WSW	SSW	SSE	ESE
Gilbert, Hiroshima	OR	1.18	1.64	1.82	0.81	0.69	0.90	1.16	0.87
	p-val	0.26	0.025	<0.001	0.08	0.005	0.43	0.24	0.18
This work, Hiroshima	OR	1.10	1.19	1.51	0.75	0.88	1.07	1.14	0.88
	p-val	>0.5	0.49	0.002	0.023	0.34	>0.5	0.32	0.23
Gilbert, Nagasaki	OR	1.04	1.14	0.63	1.05	1.97	1.03	0.86	0.91
	p-val	0.50	0.46	0.14	>0.5	0.043	>0.5	0.38	>0.5
This work, Nagasaki	OR	0.66	1.03	0.86	0.77	1.05	1.22	1.10	1.03
	p-val	0.31	>0.5	>0.5	0.37	>0.5	0.32	>0.5	>0.5

Results for all proximal survivors combined, from the present work, are compared to those of Gilbert and Ohara in Table 2, and results from this work for the more detailed classifications of Gilbert and Ohara, based on dose and distance, are shown in Table 3. In Table 3, to save space, only the odds ratios with p-values < 0.05 are shown. Note that the p-values have not been corrected for the multiple comparisons involved. In considering only the eight octants for proximal survivors in two cities in Table 2, a conservative Bonferroni correction would

Table 3 Results of Nonparametric Analysis Using Compass Octants: Odds Ratios for Detailed Categories: Octants with p-values < 0.05.

Hiroshima				Nagasaki			
Category	Octant	OR	p-value	Category	Octant	OR	p-value
Proximal, 0 to 500 mGy	SSE	1.99	0.014	Proximal, 0 to 500 mGy	SSW	2.71	0.007
Proximal, 500 to 2000 mGy	NNW	1.94	<0.001	DS02 dose unknown	WNW	2.51	0.004
DS02 dose unknown	SSW	0.29	0.003	DS02 dose unknown	WSW	4.96	<0.001
DS02 dose unknown	SSE	1.70	0.003	DS02 dose unknown	SSW	0.46	0.01
Distal	NNW	0.50	0.028	Distal	NNE	3.75	0.022

suggest that an experiment-wise p-value of 0.05 requires an individual comparison to have $p < 0.05/16 = 0.0032$, by which only the high odds ratio for the north-northwest quadrant, found in both the analyses of Gilbert and Ohara and in this work, is significant. The detailed categories, which involve five times more comparisons, for three proximal dose categories plus a distal category and a category for unknown DS02 dose, require a correspondingly smaller p, and perhaps the only significant results are the high odds ratios for the middle proximal dose category in the NNW octant in Hiroshima, and the unknown dose category in the WSW octant in Nagasaki. Less conservative methods than Bonferroni are available for adjusting the p-values for multiple comparisons, but the emphasis here will be placed on the parametric models and spatial plots to be described next, rather than debating the statistical significance of the odds ratios in Table 3. The three dose categories of Gilbert and Ohara have unclear spatial boundaries due to variable shielding among individual survivors, and the detailed octant comparisons are not as useful as some of the other spatial methods described below and being investigated for future work.

Analysis by Parametric Models

Proportions with severe epilation vs. dose category are shown separately for the main DS02 shielding categories[2] in Figure 2. One clear feature is that the response for Nagasaki factories is distinctly lower than the other shielding categories. Another is a pronounced downturn at high doses for the "average house" category. This is a category for survivors who had some indication from one of the questionnaires that they were in a light wooden building, but did not have a shielding history collected. The downturn at high doses is consistent with the idea that, in the "average house" category even more than the other shielding categories, a large proportion of the dose estimates > 4 Gy are erroneous, because they are inconsistent with the estimated median lethal dose (LD_{50}) for humans. The human LD_{50} is typically considered to be in the range from 3 to 4 Gy[8], although it may be less than this for the atomic-bomb survivors, particularly in that many survivors suffered combined injury involving blast trauma or thermal injury, many other stresses and lack of medical care. Questionably high doses were avoided in the model fitting for this work by using only survivors whose estimated weighted shielded kerma, with a neutron weight of ten, was less than 4 Gy. In addition, the doses used were adjusted for the effect of dose error by applying factors derived by Pierce, Stram and Vaeth[9], and model fitting was restricted to proximal survivors, i.e., < 1.6 km in Hiroshima or 2 km in Nagasaki. The shape of the dose response for severe epilation in the corresponding dose range suggested that the observed response was due completely or preponderantly to direct DS02 dose, and that fitting a model using DS02 dose estimates and other covariates would allow the proportion of epilation due to direct dose to be subtracted out so that any excesses due to other causes in geographically limited parts of the proximal areas would be more apparent.

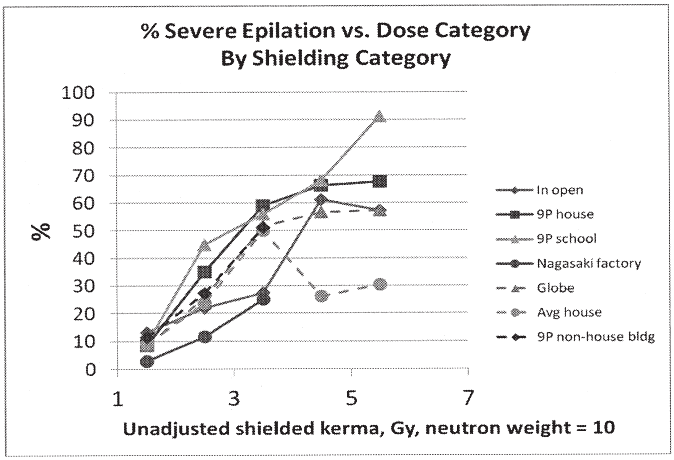


Figure 2 Crude dose response of severe epilation in different shielding categories.

If the aforementioned restrictions are used, the proportions with severe epilation can be fitted well with a logistic regression using only DS02 dose as the independent variable, as shown in Figure 3, which compares the proportions for individual dose categories to the fitted curve. A neutron weight of ten gives an estimated median dose of about 3 Gy, which is more consistent with accepted values for epilation than the median dose ~2 Gy suggested by a neutron weight of one. For example, the ICRP suggests a threshold of 3 Gy for temporary epilation[10], and it is well established that *tinea capitis* (ringworm) was routinely treated by using a dose of 3.3 to 3.5 Gy to the scalp to induce temporary complete epilation[11]. A neutron weight of ten is also consistent with the findings of Stram and Mizuno[5]. The fitted logistic function for a neutron weight of ten in Figure 3 suggests that fallout deposition would have to be quite large to substantially affect the probability of epilation. For example, a dose ~1.8 Gy would be necessary to cause ~10% epilation in the absence of any appreciable direct dose. Even using the integrated first-month beta dose per unit ^{137}Cs deposition of 500 mGy kBq^{-1} m^{2} ^{137}Cs calculated by Endo *et al.*[(7)], which is at least 17 times larger than corresponding integral of gamma dose calculated by Imanaka[(12)], this would require fallout deposition corresponding to at least 1800 mGy/500 mGy kBq^{-1} m^{2} ^{137}Cs = 3.6 kBq m^{-2} ^{137}Cs, a larger deposition than any known for the Hiroshima bomb, and on the order of the Nishiyama fallout in Nagasaki. For example, deposition in a sample near the known Koi-Takasu fallout area of Hiroshima was estimated at about 0.36 kBq m^{-2} ^{137}Cs by Shizuma *et al.*, based on analysis of the Nishina soil samples[(13)].

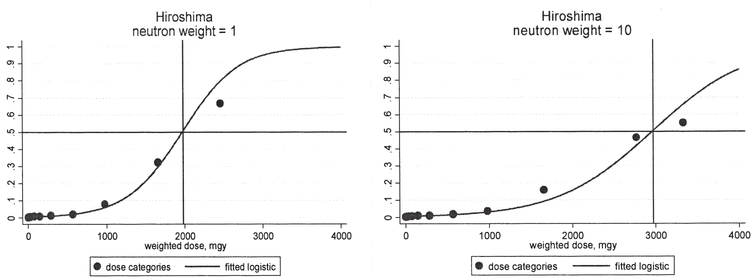


Figure 3 Fitted logistic regression models using only DS02 adjusted shielded kerma.

A complete model-selection procedure was performed separately for each city to find the best model for severe epilation using the same inclusion criteria, with indicators for combinations of age and sex, for shielding categories, and for compass octants. The only octant indicator that was retained in the final model for either city was that for a high OR in the NNW octant in Hiroshima, consistent with the results of the nonparametric analysis. Based on the results for the two cities, a combined model was developed. No octant indicators were used in the combined model, because the intent was to correct for direct dose and other covariates and then use spatial methods other than compass octants to look for remaining patterns. Terms for city and interaction of city with direct dose (i.e., a different dose response in each city) were also tested and rejected in developing the model. The final model, shown in Table 4, has interesting implications.

In the table we report the estimated coefficients rather than the associated odds ratios, i.e., we report the estimated β_is in the equation $\Pr(\mathit{severe\ epilation}) = \frac{e^{\beta_0+\beta_1 I_1+\ldots+\beta_{k-1}I_{k-1}+\beta_k SK}}{1+e^{\beta_0+\beta_1 I_1+\ldots+\beta_{k-1}I_{k-1}+\beta_k SK}}$, where I_i is the indicator for the i^{th} category of shielding or age and sex, SK is shielded kerma, and the reference category is males aged 21 to 30 at the time of bombing, shielded by wooden houses with full coded "9-parameter" data. The estimated coefficient for wooden schools suggests that the probability of epilation is slightly higher than in wooden houses at the same dose, indicating that possibly the model for wooden schools produces slightly low dose estimates: the point estimate being about 28% low, but the 95% confidence interval is from about

0.3% low to 48% low. The coefficient for Nagasaki factories suggests that the dose estimates are quite a bit too high, consistent with Figure 2. The coefficient for "average house" suggests that the doses are too high, but this effect may be partly or completely due to random errors in survivor's location data for this shielding category's being larger than the errors for categories with full coded shielding data, as suggested above in relation to Figure 2. The next entry is for survivors in wooden buildings other than houses or schools, that have the full coded "9-parameter" shielding data, and suggests that the use of the "9-parameter house model" for these buildings may result in doses that are too low. The entries for sex and age categories suggest that survivors who were girls or boys at the time of the bombings reported less epilation than young men, and the same for middle-aged and older men, with a very pronounced under-reporting for men over 60. On the other hand, women in their 30s and 40s reported more epilation than young men. Many of these results have logical interpretations or similarities to other findings in RERF studies, but a full discussion would be too long for this report.

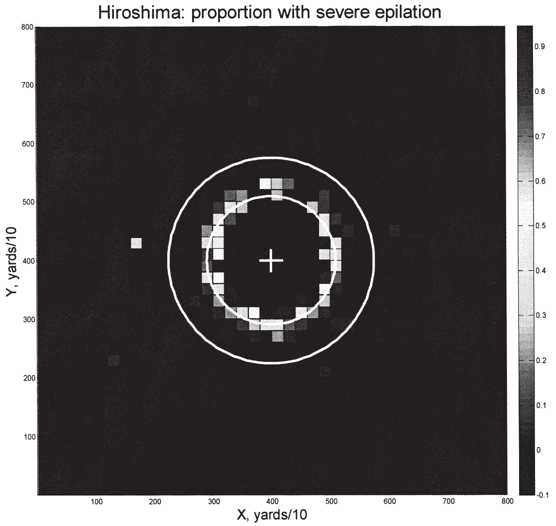
Table 4 Combined Logistic Regression Model for Severe Epilation in Hiroshima and Nagasaki

covariate	coefficient	p-value	covariate	coefficient	p-value
Wooden school	0.34	0.041	Male, ages >60	-2.35	<0.001
Nagasaki factory	-1.13	<0.001	Female, ages 0-10	-0.41	0.009
Average house	-0.51	<0.001	Female, ages 30-40	0.36	0.004
Non-house wooden building	0.57	0.051	Female, ages 40-50	0.35	0.005
Male, ages 0-10	-0.44	0.006	Shielded kerma, mGy	0.0015	<0.001
Male, ages 40-50	-0.45	0.007	Constant	-4.54	<0.001
Male, ages 50-60	-1.25	<0.001			

Spatial Plots

The proportions reporting severe epilation among survivors with known DS02 doses are plotted in Figure 4 for 200x200-yard square spatial cells. It is clear that the vast preponderance of epilation occurs at proximal distances, inside the outer white circles, which are at the previously stated boundaries of 1.6 km in Hiroshima and 2 km in Nagasaki. (The inner white circles are 1 km in radius.) In both plots, the darkest blue cells are those with no data, shown at a value of -0.1 on the color scale, and the cells with data are covered by the values between 0 and 1 on the remainder of the color scale.

In Figure 5, the expected proportions for Hiroshima in each cell from the combined logistic-regression model have been subtracted from the observed proportions and the resulting excess proportions are shown using a different color scale. The scale now uses -0.6 for cells with no data, and a range from -0.5 to 0.5 for the cells with data. It should be noted that this plot can be misleading, because under the null hypothesis that the true proportion in each cell is equal to that predicted by the regression model, i.e., that the true excess proportion is zero in all cells, the distribution of *observed* proportions becomes



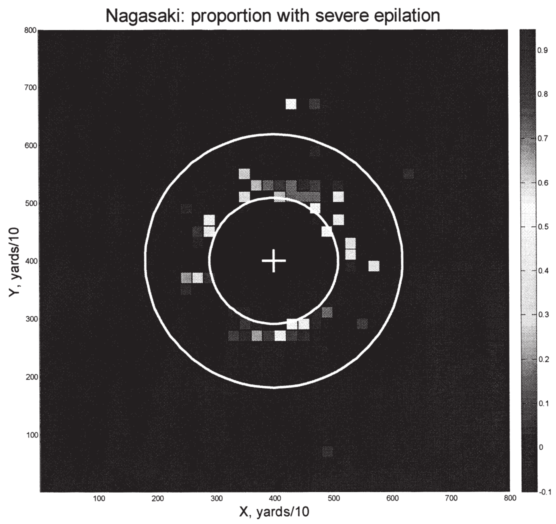


Figure 4 Observed proportions with epilation in spatial cells, Hiroshima and Nagasaki.

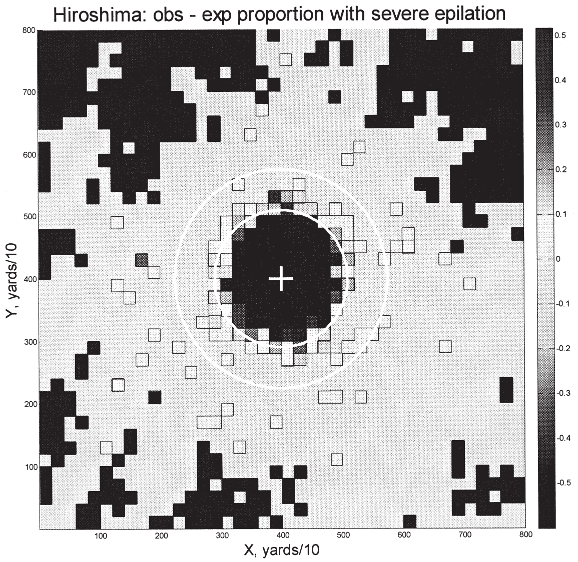


Figure 5 Observed – expected proportions with severe epilation in spatial cells, Hiroshima.

increasingly skewed for small numbers of expected cases in a cell. At the limit, for cells with a few survivors and a small probability of epilation, say 1/100, we expect to see a vast preponderance of cells with no cases, hence a proportion of zero, and a few cells with one case of epilation, hence an excess proportion of 1/N – 1/100, which is a large fraction for N = 1, 2, 3, etc. Unfortunately there is no simple way to correct the plot for this situation in which we expect to see rare occurrences of high-appearing values due to small discrete numbers of events in cells with only a few survivors.

Figure 5 shows small numbers of cells with positive excess proportions due to small numbers of events, which become increasingly sparse at longer distances and appear to be fairly random in spatial distribution. There is one cell with a high-appearing value, about 2100 m west of the hypocenter, which has 2 cases of severe epilation among 6 survivors in the cell. To determine whether there are any statistically significant patterns, i.e., localized areas with proportions in excess of those predicted by the covariates, it will be necessary to carefully choose a spatial statistical method for binomial data that can handle the necessary covariate adjustment and the range from sizeable numbers of expected events in proximal cells to very rare events in distal cells, or restrict the analysis to distal areas where the expected proportion epilating due to direct dose is very small. Methods for further analysis are being investigated.

Conclusions

Previously observed anomalies in the direct (i.e., DS02) dose dependence of severe epilation at high doses may be explainable by errors in self-diagnosis or self-reported location and shielding by some individual survivors, along with the mortality at high doses in the range above about 3 Gy that is expected from estimates of the human LD_{50} for ionizing radiation. For severe epilation, a standard logistic regression model can be fitted on a suitable range of the data, with interesting results. The scattered cases at longer distances that cannot be explained by direct dose under the resulting model lack an apparent spatial pattern, and may be due to misclassification arising because the data were taken from self-diagnosis a number of years after the bombings. Although there may be some subtle spatial patterns in proportions with severe epilation after correction for proportions expected from direct dose, such patterns are not obvious, other than perhaps a low area in the distal part of the NNW octant of Hiroshima. Features of the data make spatial statistical analysis difficult, but methods are being investigated.

Acknowledgement

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Investigation on circular asymmetry of geographical distribution of mortality risk in Hiroshima atomic bomb survivors

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ABSTRACT

While there are a considerable number of studies on the relationship between the risk of disease or death and direct exposure from the atomic bomb in Hiroshima, the risk for indirect exposure caused by residual radioactivity has not yet been fully evaluated. One of the reasons is that risk assessments have utilized estimated radiation doses, but that it is difficult to estimate indirect exposure. To evaluate risks for other causes, including indirect radiation exposure, as well as direct exposure, a statistical method is described here that evaluates risk with respect to individual location at the time of atomic bomb exposure instead of radiation dose. The proposed method is applied to a cohort study of Hiroshima atomic bomb survivors. The resultant contour map suggests that the region north-west to the hypocenter has a higher risk compared to other areas. This in turn suggests that there exists an impact on risk that cannot be explained by direct exposure.

INTRODUCTION

The risk of disease or death caused by exposure to atomic bomb radiation has been evaluated using estimated radiation doses based on information concerning age, shielding conditions and distance from the hypocenter under the assumption that the radiation dose decreases with increasing distance from the hypocenter (see, e.g., Preston et al 2007; Matsuura et al. 1997). For details of the dosimetry system used, see e.g. DS02 system (Cullings et al. 2006; Young and Kerr 2005). The corresponding risk analyses focused solely on the risk from direct exposure to the atomic bomb, while the risk from indirect exposure due to residual radioactivity has been not evaluated in previous analyses. This means that the geographical distribution of risk has been structurally restricted to concentric circles under the assumption that the influence of direct exposure essentially depends on the distance from the hypocenter. For example, Peterson et al. (1983) have fitted Cox's proportional hazard models to cancer mortality rates, to investigate circular asymmetry around the hypocenter in Hiroshima and Nagasaki. Gilbert and Ohara (1983) have analyzed data on acute symptoms. They divided the survivors in the Life Span Study (LSS) cohort, registered at the Radiation Effect Research Foundation (RERF), into eight groups according to the survivors' location at the time of atomic bomb exposure relative to the hypocenter and evaluated the relative risk of each octant compared with that for survivors in the octant of east-north-east direction. However, we consider their approach to be not enough to investigate circular asymmetry around the hypocenter, because they evaluated only relative risks for each octant with respect to the location at exposure relative to the hypocenter and did not consider heterogeneity of risk in each octant.

Recently, survivors suspected of having suffered from indirect exposure were reported by Kamada et al. (2006), Kamada and Kawakami (2008), and Tonda et al. (2008) through biological studies and statistical analyses of the incidence of leukemia among the survivors who entered Hiroshima City on August 6, 1945, after the explosion of the atomic bomb. Furthermore, several questionnaire surveys (Uda et al. 1953; Masuda 1989) showed that so-called "Black Rain", which might have included radioactivity, fell around the western part of Hiroshima City and the northwest suburbs for several hours just after the explosion. Ohtaki (2011) demonstrated spatial-time distributions of Black Rain using a nonparametric smoothing method applied to data from a questionnaire survey conducted by Hiroshima City in 2008, of about 37,000 inhabitants of Hiroshima and its suburbs who might have experienced Black Rain.

In the present paper, a statistical method is applied to evaluate the risk with respect to individual location at exposure rather than dose, and construct a "risk map", i.e. a map based on the risk evaluated by location, to visually grasp the geographical distribution of risk without structural restrictions. The risk map allows discussing possible effects of indirect exposure due to "Black Rain" and other radioactivity on risk of mortality.

DATA

The database of Atomic Bomb Survivors (ABS), registered at the Research Institute for Radiation and Medicine (RIRBM) at Hiroshima University, was used in the present study. The ABS differs from the LSS of the RERF, because the ABS cohort includes examined survivors residing in Hiroshima Prefecture, and data on health status for survivors also have been cumulatively compiled in the database. The extent of overlap between survivors in the ABS and the LSS was examined by Hayakawa et al. (1994) and Hoshi et

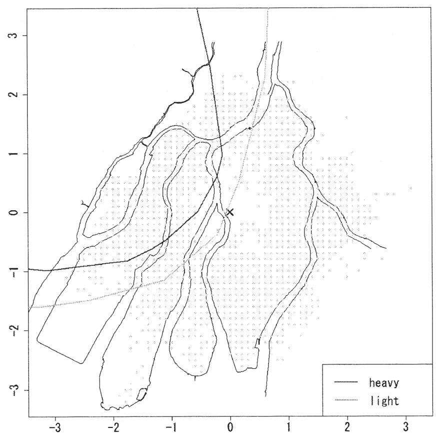

FIGURE 1. Plot of location at exposure on the map of Hiroshima City, where the vertical and horizontal scales are the coordinates in units of kilometers with the origin being the hypocenter (red cross); Gray points represent locations of survivors at the time of exposure; Red and green lines represent the boundary of heavy and light rainfall area of "Black Rain" based on Uda's questionnaire survey.

al. (1996). Hayakawa et al. (1994) showed that the dose estimates of the ABS were close to those of the LSS among the overlapped subjects. However, it has not been tested how they agree to DS02.

From the ABS, we chose 37,382 subjects for analysis who satisfied the following conditions: (i) being alive and recognized as an atomic bomb survivor as of January 1, 1970 and (ii) having coordinate information on location at the time of atomic bomb exposure (abbreviated in the following as "location at exposure"). These subjects were followed until December 31, 2009. The endpoint is death from all causes (number of deaths: 19,119). Subjects were treated alive at the end of follow-up, in case migration and loss to follow-up for other reasons as censoring (number of subjects: 18,263). Mesh coordinates of 100 m in width were used to define location at exposure (Hoshi et al. 1996). Sex, age at atomic bomb exposure (abbreviated in the following as "age at exposure") and shielding condition were used as covariates. Figure 1 is the scatter plot of location at exposure with the hypocenter as the origin (cross). Gray lines represent the map of Hiroshima city according to the town planning map made between 1925 and 1928. The vertical and horizontal scales are the coordinates in units of kilometers with the origin being the hypocenter. The red and green lines are boundary of heavy and light rainfall area of "Black Rain" based on Uda's questionnaire survey (Uda, et al. 1953). Note that upper left region of boundary is rainfall area.

STATISTICAL METHOD

Data containing information on location are called "spatial data". Several methods for analyzing spatial data have been proposed, depending on the type of outcome. Geographically weighted regression (GWR), proposed by Fotheringham et al. (2002), corresponds to multiple linear regression analysis of spatial data. GWR is essentially repeated local multiple linear regressions applied to data in the neighborhood of a given location. The GWR approach can be extended to logistic regression for spatial binary data and Poisson regression for spatial count data, but the methodology for spatial survival data, such as those in the study of atomic bomb survivors, still remains to be developed. Recently, Tonda and coworkers (Tonda et al. 2010) proposed a statistical method for spatial data by extending a method proposed for longitudinal data (Satoh and Yanagihara 2010; and Satoh et al. 2009). Their approach is applicable not only to spatial continuous and discrete data but also to spatial survival data. In the present paper a method is developed for estimating the geographical distribution of mortality risk for atomic bomb exposure by extending Cox's proportional hazards model for spatial survival data (Tonda et al. 2010); the resulting method is applied to a cohort study of Hiroshima atomic bomb survivors.

Consider the proportional hazards model with spatially varying coefficients, which allows the effect of covariates to vary with location. Let (u,v), r, t, sex and atb denote location at exposure, registered age, attained age, gender ($sex=1$ if male, $sex=0$ if female), and age at exposure. The proportional hazards function with spatially varying coefficient is then given by

$$h(t \mid u,v,t>r) = h_0(t \mid shielding)\exp\left(\beta_l(u,v) + \beta_s \times sex + \beta_a \times atb\right) \qquad (1)$$

where $h_0(t \mid shielding)$ is the baseline hazard function dependent on the shielding condition, and $\beta_l(u,v)$ is the spatially varying coefficient, and β_s and β_a are ordinary regression coefficients that are constant with regard to location at exposure. Note that Eq. 1 represents an ordinary Cox model if the spatially varying coefficients are replaced by constant coefficients. Therefore, Eq. 1 represents an extension of a Cox model, and the interpretation of coefficients in Eq. 1 is similar to that with a Cox model. In particular, $\exp(\beta_l(u,v))$ denotes the hazard ratio compared with the location as the reference.

It is assumed that the shape of $\beta_l(u,v)$ is in a class described by linear combinations of unknown parameters $\boldsymbol{\theta}$ and known basis functions $\boldsymbol{x}(u,v)$. We use a polynomial surface basis, which is commonly used in the field of spatial interpolation (Ripley 1981; Venables and Ripley 2002). For example, a quadratic polynomial surface basis is given by $\boldsymbol{x}(u,v)=\left(1,u,v,u^2,v^2,uv,u^2v,uv^2,u^2v^2\right)'$. To obtain a smoother shape for the spatially varying coefficient, one can use, for example, a B-spline or a Gaussian basis. Details are given in Satoh et al. (2003), Ruppert et al. (2003), and Konishi and Kitagawa (2010).

For spatial survival data, $\{(u_i,v_i),\ \delta_i,\ t_i,\ sex_i,\ atb_i\ ;\ i=1,\ldots,n\}$, where δ_i denotes the indicator variable specifying whether subject i is censored or not at time t_i, with 1 denoting a failure and 0 denoting censored, the unknown parameters $\boldsymbol{\theta}$, β_s and β_a can be estimated by maximizing the partial likelihood (Cox 1972; 1975). Let $\hat{\boldsymbol{\theta}}$ denote the estimator of $\boldsymbol{\theta}$; the estimator of $\beta_l(u,v)$ is expressed by $\hat{\beta}_l(u,v)=\hat{\boldsymbol{\theta}}'\boldsymbol{x}(u,v)$. Theoretical properties of $\hat{\beta}_l(u,v)$ are given in Tonda et al. (2010). Any further discussion of the methodology for confidence regions and tests for $\beta_l(u,v)$ are beyond the scope of this paper; for additional information, see Tonda et al. (2010).

RESULTS

The proposed method was applied to data from a cohort study of Hiroshima atomic bomb survivors. The method is easy to implement using statistical packages that execute Cox model, such as SAS, SPSS,

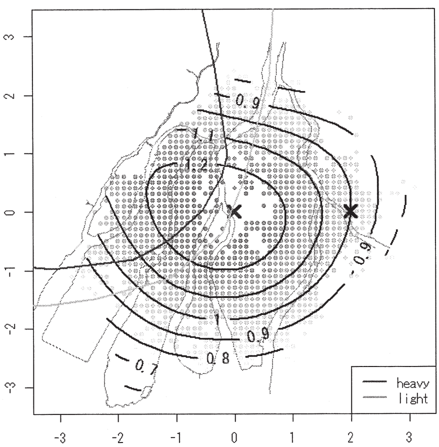

FIGURE 2. Estimated risk map of mortality based on the quadratic polynomial model. Values on the contours are hazard ratios compared with the reference location (blue cross) that is 2 km from the hypocenter to the east. The red and green lines represent the boundary of heavy and light reainfall area of "Black Rain" based on Uda's questionnaire survey.

STATA and R. We here used the "survival" package version 2.36-10 in R version 2.14.1 (R Development Core Team 2010).

TABLE 1. Estimated coefficients for the quadratic polynomial model.

Parameter	Estimates	Standard Error	z-value	p-value
β_s	0.569	0.0149	38.296	< 0.001
β_a	0.007	0.0006	12.388	< 0.001

Figure 2 shows the estimated risk map of mortality risk based on the quadratic polynomial model, while Table 1 shows the estimated coefficients of β_s and β_a. In Figure 2, the contours on the map represent the hazard ratio, $\exp(\beta_l(u,v))$, for each location compared with the reference location, marked as the blue cross, that is 2 km from the hypocenter towards the east. From Figure 2 it can be seen that the mortality risk decreases with increasing distance from the hypocenter, but the geographical distribution of the risk map is not concentric: The north-west area appears to have a higher risk compared with other areas.

In Figure 3, the decreasing trend of risk with distance from the hypocenter by direction of location at exposure defined by angle from the hypocenter is compared. Angles 160° (about west-direction) and 73° (about north-north-east direction) had highest and lowest relative risks, respectively. Figure 3 also suggests that the risk at 2 km from the hypocenter at angle 160° corresponds to the risk at 803 m at angle 73°. Figure 4 shows the differences of relative risks by angle from the hypocenter compared with those of angle 73° (about north-north-east direction). Figure 4 suggests that the differences of relative risks become

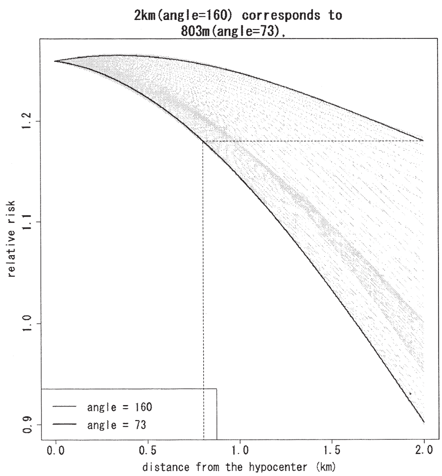

FIGURE 3. Comparison of decreasing trend of relative risks with distance from the hypocenter by angles of location at exposure. The red and blue curves denote the highest and lowest trend, whose angles are 160° (about west-direction) and 73° (about north-north-east direction).

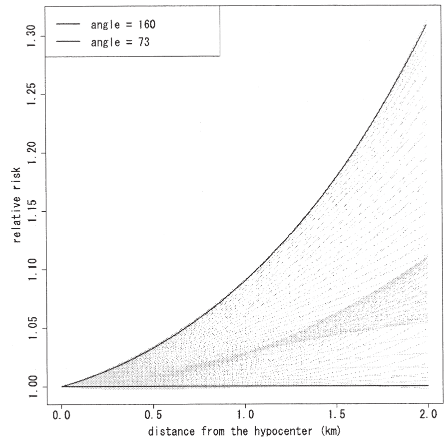

FIGURE 4. Comparison of increasing trend of relative risks, relative to those at angle 73° (about north-north-east direction), with distance from the hypocenter by angles of location at exposure..

large with distance from the hypocenter.

DISCUSSIONS

Figure 5 presents the contour map based on estimated direct radiation dose (Hoshi et al. 1996; Matsuura et al. 1997) averaged by location at exposure, where the red and green lines are boundary of heavy and light rainfall area of "Black Rain" based on Uda's questionnaire survey. From Figure 5 it can be seen that

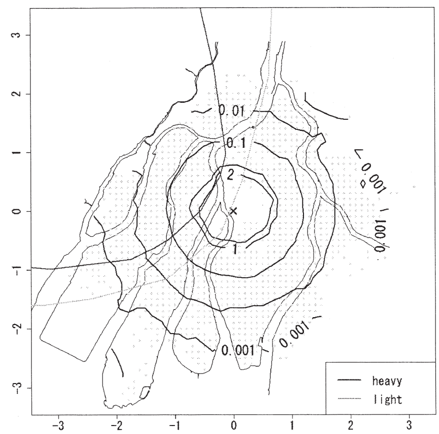

FIGURE 5. Geographical distribution of location-averaged radiation dose. Values on the contours represent the average of radiation dose (Gy) by location at exposure. The red and green lines represent the boundary of heavy and light reainfall area of "Black Rain" based on Uda's questionnaire survey.

the geographical distribution of direct radiation dose is close to concentric circles. This means that if the risk due to causes other than the direct exposure was negligible compared with that of direct exposure, then the contours in the risk map should be well approximated by concentric circles. If not, however, the risk contours should be far from concentric and circular. According to Figures 2 to 4, the resultant risk map for a cohort of Hiroshima atomic bomb survivors (Figure 2) suggests that the quadratic polynomial contours are suitable indeed, but not concentric circles. This suggests that there existed risk factors other than direct radiation exposure.

As was mentioned in the introduction, several questionnaire surveys showed that Black Rain, which might have included radioactivity, fell around the western part of Hiroshima city and north-west suburbs for several hours just after the explosion. According to the latest results on the geographical distribution of Black Rain (Ohtaki 2011) and Uda's rainfall area described in Figure 2, the area of rainfall appears roughly similar to the region of high risk in Figure 2. This similarity suggests that Black Rain might be a possible risk factor accounting for the geographical distribution of cancer mortality in Figure 2. It should be noted, however, that there might be other risk factors affecting mortality such as socioeconomic status, life style and environmental factors which are probably unrelated to radiation exposure due to the atomic bomb. These factors might correlate through association with particular regions, but this will be difficult check.

Note that Peterson et al. (1983) have also studied the circular asymmetry around the hypocenter in Hiroshima and Nagasaki for the LSS cohort of RERF. They divided the survivors into eight groups by the octants according the survivors' location at exposure and fitted a Cox's proportional hazard model. According to their results, the survivors in the west-north-west octant had the highest risk and the relative risk of survivors in the west-north-west compared with those in the east-north-east was about 1.24. As was mentioned in the introduction, their approach suffered from a lack of continuity of risks within groups and between groups. Therefore, they could not grasp any regional spatial trend of risk within and between octants. On the other hand, our results for the ABS cohort of RIRBM can be used to understand the spatial trend visually. Our result in Figure 3 is roughly consistent with the areas with higher risks in Peterson et al (1983). In addition, Figure 4 shows that the differences in the relative risk among angles of location at exposure become larger with increasing distance from the hypocenter, while Peterson e al. (1983) could only evaluate the relative risks by octants. In this sense, our results are somewhat more valuable than those of Peterson et al (1983).

In this paper, we focused on death from all causes and evaluate its risks with respect to individual location at the time of atomic bomb exposure instead of radiation dose. Tonda et al. (2012) have analyzed data on solid cancers and evaluated risks of cancer mortality by applying the similar approach. In addition, they also considered to split the risks into separate risks due to direct exposure and other causes using a mathematical model of carcinogenesis (Ohtaki et al. 1985; Pierce and Mendelsohn 1999; Ohtaki and Niwa 2001; Pierce and Vaeth 2003).

ACKNOWLEDGMENTS

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Study into epilation among residents and "black rain" fallout in the Manose district of Nagasaki City following dropping of the atomic bomb

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Abstract

It became clear from the testimony of residents that a considerable amount of black rain fell in the Manose district of Nagasaki City . The Manose district is a small settlement located in a mountainous area approximately 7.5 km northwest from the hypocenter. Not only did black rain fall, but the residents experienced high incidence of epilation. Soil sampling aimed at detecting plutonium originating from the atomic blast was conducted primarily in the Manose district in July 2011. The black rain in the Manose district is a valuable incident in terms of determining the effects on the human body of low-level radiation exposure, and further analysis appears needed.

INTRODUCTION

At 11:02 am, August 9, 1945, an atomic bomb was dropped on Nagasaki, and detonated at an altitude of 500 meters. The weather in Nagasaki at that time was sunny and clear. A light wind was blowing from the southwest. Large amounts of black ash and dust from the atomic bomb were carried eastward by the wind. Residents in this district consistently reported that the bomb explosion was followed by a shock wave. After that, the sky turned black, and the sun hung reddish-black. Much ash, dust, and debris fell from the sky (Figure 1).

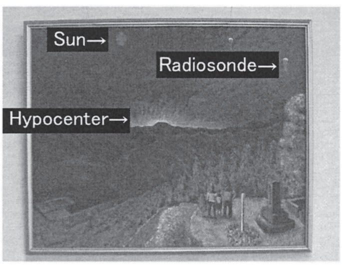

Figure 1. The picture which residents drew

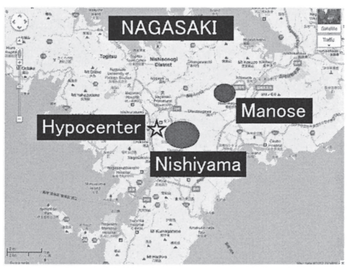

Figure 2. The map of Nagasaki

Approximately 20 minutes after the bomb was dropped, rain fell in the Nishiyama district of Nagasaki. Subsequent investigations measured high levels of radioactivity in the Nishiyama district, and amounts of lifetime radiation exposure are estimated at 200 to 400 milligrays. This corresponds to approximately 10 times the amount of radiation in the Hiroshima districts of Koi and Takasu, where black rain similarly fell following the atomic bombing there.

It has conventionally been held that, in Nagasaki, full-fledged black rain fell only in the Nishiyama district, but a recent study by the Nagasaki Doctor and Dentist Association found that fairly heavy rain also fell at the same time in the Manose district (Figure 2).

MATERIALS AND METHODS

From March 8, 2011, interview investigation was conducted to the residents in a manose area and a neighboring area who survived by the atomic bomb. It was asked whether fallout rain was caught or not after atomic bombing. Furthermore, a question was asked about the situation at that time, the time when rain began to fall, a color, and temporal duration. To the residents who experienced rain, it checked about the existence of subsequent health condition, depilation, nausea, diarrhea, and gingival bleeding.

For a ten-day period starting July 9, 2011, soil sampling was conducted by Professor Masaharu Hoshi and Associate Professor Satoru Endo of Hiroshima University and Associate Professor Toshihiro Takatsuji et al. of Nagasaki University.

To avoid effects of global fallout, this testing mainly targeted soil under the floors of old houses (Figure 3).

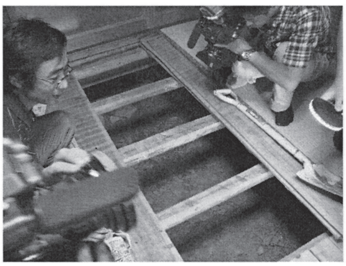

Figure 3. Under the floors of old houses

Figure 4. Another soil sampling points

The crawlspace under the floors was cramped, making it difficult to sink boring pipes, but the soil was in good condition. Areas not under floors were also sampled (Figure 4). A total of 7 samples were taken from under the floors of 3 houses.

A total of 40 samples were collected at 19 sites in the Nishiyama and Manose districts, and in adjacent districts eastward from the hypocenter. The samples were sent to Professor Masayoshi Yamamoto at Kanazawa University for the purpose of detecting plutonium..

RESULTS AND DISCUSSION

The Manose district is located in a mountainous area approximately 7.5 km northwest of the hypocenter. It is a small settlement whose residents numbered approximately 320 persons at the time of the bombing (Figure 5).

Nearly all residents were engaged in farming, and used springs or small streams as sources of water for domestic use. Terraced rice paddies and other crop fields were common, and the residents continued to farm the paddies where black rain fell, and ingested the rice and other crops they produced (Figure 6).

Figure 5. The manose district

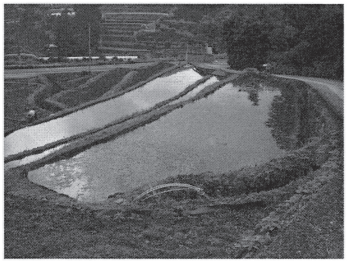

Figure 6. Terraced rice paddies

One man who was 8 years of age at the time of the bombing reported the events at the time as follows: "I was at home when the atomic bomb was dropped. I felt a powerful wind. Before long, black rain began to fall from the sky. Starting in September, I, my older brother, my mother, and my older sister experienced slight hair loss. My father lost so much hair that his scalp was visible. My father then fell ill, and after living on with occasional bouts of being bedridden, he died while in his 50s, with the cause remaining unknown."

Table 1. The interview result of the residents of the manose district

No	Age at time of bombing		black rain	Diarrhea	Nausea	Gingival bleeding	Epilation			
							Interviewee	Family	Period	Grade
1	8	m	Yes	nm	nm	nm	No	Yes	2 w	Slight
2	9	m	Yes	No	No	No	No	No		
3	11	m	Yes	No	No	No	Yes	Yes	1 y	Slight
4	10	f	Yes	uk	uk	uk	No	No		
5	14	m	Yes	uk	uk	uk	Yes	Yes	2 w	Slight
6	8	m	Yes	uk	uk	No	Yes	Yes	2 w	Slight
7	16	m	Yes	No	No	No	No	No		
8	11	m	Yes	Yes	uk	uk	Yes	Yes	1 w	Slight
9	9	m	Yes	Yes	Yes	nm	Yes	Yes	1 w	Slight
10	17	m	Yes	No	nm	nm	Yes	Yes	1 w	Slight
11	9	m	Yes	Yes	Yes	No	No	Yes	2 w	Slight
12	3	m	Yes	nm	nm	nm	nm	Yes	uk	Moderate
13	5	m	Yes	No	No	No	No	No		
14	5	f	Yes	nm	nm	nm	nm	Yes	uk	Slight

nm:no memory uk:unknown

According to tabulated figures based on interviews of 14 residents of 13 households who remembered the black rain, 6 of the 14 respondents, or 43%, experienced epilation themselves, and incidence of epilation when family members are included was 15 of 59 persons, or 25%.

In contrast to this, in adjacent districts where no black rain fell, 3 in 99 persons, or 3%, reported incidence of epilation.

Incidence of epilation decreased with distance from the hypocenter. Incidence of 25% corresponds to 1.5 km from the hypocenter. In the Manose district, at 7.5 km from the hypocenter, effects of direct exposure to radiation are near zero, and the black rain is suspected as a cause contributing to the high incidence of epilation.

Aside from epilation, various forms of damage to health have been the subject of discussion.

Table 2. The less than 55-year-old deceased in the manose district

Death year		age	sex	Cause of death	Death year		age	sex	Cause of death
1945		3	m	Unknown disease	1954		54	m	Liver disease
		54	f	Unknown disease	1955		51	m	Liver cancer
		2	f	Doubt of leukemia	1957		53	f	Lung cancer
1946		29	f	Uterine cancer	1958		19	f	Brain disease
		48	m	Unknown disease	1959		27	f	Brain disease
	*	1	f	Unknown disease	1960		53	f	Uterine cancer
1947		3	f	Unknown disease	1961	*	1	f	Leukemia
1948		18	m	Lung cancer	1966		41	m	Hypertension
		45	f	Apoplexy	1968	*	11	f	Leukemia
	*	1	m	Unknown disease	1971		42	f	Uterine cancer
1950		26	m	Unknown disease	1973		46	f	Apoplexy
		50	f	Uterine cancer			44	m	Heart failure
	*	1	m	Pneumonia	1975	*	4	f	Heart disease
1952		29	f	Cardiac disease	1980		54	m	Lung cancer
1953	*	5	m	Unknown disease	1984		42	m	Liver cirrhosis
		10	m	Doubt of leukemia	1985		44	m	Thyroid cancer
		39	f	Pyelitis	1987		42	m	Stomach cancer

* Children of Survivors

The result which the residents in the manose district investigated in collaboration with the Yomiuri Newspaper

The reason or reasons for the high incidence of epilation in the Manose district remain unknown, but internal exposure or beta-ray exposure via the hair is a suspected cause. The results of analysis are eagerly awaited in hopes that they will shed light on relationship between black rain and epilation in the Manose district.

Nuclide identification of alpha-emitters by autoradiography in specimen of atomic victims at Nagasaki

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Abstract

The explosion of a plutonium Atomic bomb over Nagasaki city in Japan took place at 1102h on August 9, 1945. Radiation dose of A-bomb survivor is practically estimated from external radiation. The alpha particles can be disregarded science they travel only a short distance through air. Plutonium remaining in the soil at Nagasaki after 24yr has been determined in 1971. In the patients subjected to the Atomic bomb there was no evidence of the introduction of radioactive material. We have already studied the preserved body cells of seven A-bombed victims in 1945, and became the first one to prove that plutonium is continuing to emit radiations after more than 60 years since the A-bomb attack. In this study, the nuclide identification of alpha-emitters in environmental samples and calibration standards has been attempted by the measurement of the alpha track length using autoradiography. Alpha track length in Nagasaki soil; Ground surface soil collected in 1979 from the Nishiyama area in Nagasaki City, ^{210}Po, ^{241}Am and ^{243}Am fitted the relation curve between energy and track length of alpha-particles in the photo emulsion. Moreover, the alpha track length in Nagasaki soil was consisted with that in paraffin-embedded specimen of A-bomb cases. Therefore, the nuclide of alpha-emitters in specimen of atomic victims at Nagasaki was identified with ^{239,240}Pu by autoradiography.

Introduction

The explosion of a plutonium Atomic bomb over Nagasaki city in Japan took place at 1102h on August 9, 1945. Radiation dose of A-bomb survivor is practically estimated from external radiation (the Dosimetry System 2002:DS02)[1]. Alpha particles emitted from plutonium, consisting of two protons and two neutrons, are a densely ionizing type of radiation with low capacity to penetrate living tissue. The alpha particles can be disregarded science they travel only a short distance through air. Plutonium remaining in the soil at Nagasaki after 24yr has been determined in 1971[2]. In the patients subjected to the Atomic bomb there was no evidence of the introduction of radioactive material. A much more palpable danger would exist from the ingestion or inhalation of radioactive material.

We have already studied the preserved body cells of seven A-bombed victims in 1945, and became the first one to prove that plutonium is continuing to emit radiations after more than 60 years since the A-bomb attack.

Alpha particles emitted from the paraffin-embedded specimen, such as lung, liver, bone etc. were detected by a classical method of autoradiography. The frequency distribution of alpha-particle track lengths of the A-bomb cases was consistent with the pattern of alpha-particles emitted from $^{239,240}Pu$, and different from that of non-A-bomb cases. The calculated radioactivity of A-bomb cases was higher than that of non-A-bomb cases and relevant for factors of shielding and death time (unpublished data).

In this study, the nuclide identification of alpha-emitters in environmental samples and calibration standards has been attempted by the measurement of the alpha track length using autoradiography.

Material methods

Particle forms in the tissue specimen were detected using the classical method of alpha-particle track autoradiography[4], and nuclear emulsion method for environmental samples and calibration standards. Alpha tracks were observed in Nagasaki soil; Ground surface soil collected in 1979 from the Nishiyama area in Nagasaki City[3], ^{210}Po, ^{241}Am and ^{243}Am (Table 1). Four um-thick sections of tissue were mounted on glass slides, and the unstained sections were dipped in liquid photographic emulsion. The emulsion was developed with developer. After development, the slides were stained with H&E. Particle were measured lengths using a standard optical microscope at 1000x magnification. At least two individuals shared in counting the particles in each case.

Results

Alpha track length in Nagasaki soil; Ground surface soil collected in 1979 from the Nishiyama area in Nagasaki City[3], ^{210}Po, ^{241}Am and ^{243}Am fitted the relation curve between energy and track length of alpha-particles in the photo emulsion[5] (Figure 1 and Figure 2). The alpha track length in Nagasaki soil was consisted with that in paraffin-embedded specimen of A-bomb cases (data not shown).

Discussion

We have already demonstrated that the evidence of internal deposition of alpha-emitters in the specimen of Nagasaki A-bomb cases which had been within approximately 1 km from the hypocenter and died from acute A-bomb disease. Alpha-emitters had been introduced to the human body after the A-bomb explosion. The probability distribution pattern of alpha track length observed in A-bomb cases was apparently consistent with those characteristic of $^{239,240}Pu$, but not those of the controls.

In this study, Alpha track length in Nagasaki soil from the Nishiyama area, ^{210}Po, ^{241}Am and ^{243}Am fitted the relation curve between energy and track length of alpha-particles in the photo emulsion.

Table 1. Sample

		E(keV)
1	PuNaSoil a-LEPS 82.5.4	5156.59
2	PuBiSoil a-LEPS82.5.13	5156.59
3	210Po82.1.15	5304.33
4	241Am82.1.15	5485.56
5	243Am82.1.15	5275.3
6	210PbNasoil11.4.12	5304.33

Moreover, the alpha track length in Nagasaki soil was consisted with that in paraffin-embedded specimen of A-bomb cases. Therefore, the nuclide of alpha-emitters in specimen of atomic victims at Nagasaki was identified with $^{239,240}Pu$ by autoradiography, which was clearly distinguished from ^{210}Po, ^{241}Am and ^{243}Am.

Figure 1. Autoradiographs

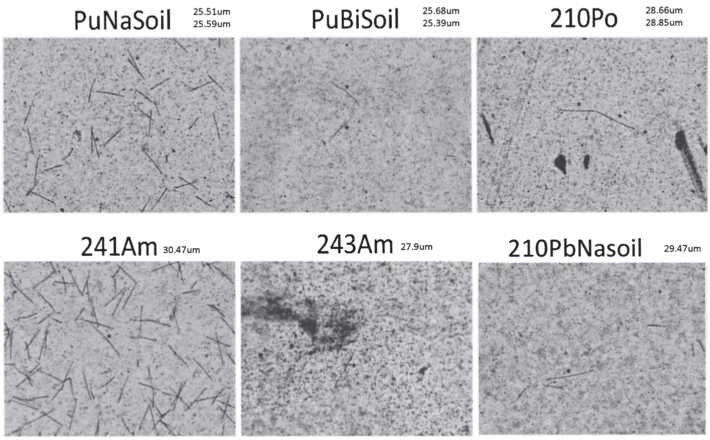
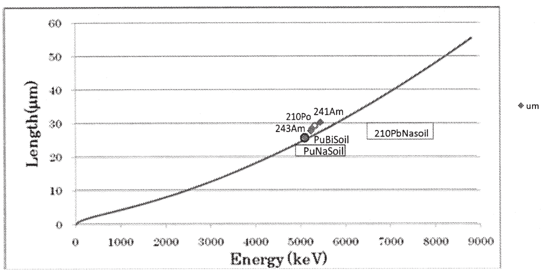


Figure 2. Calculated track length

Emulsion is composed of dry emulsion, water and gelatin. Content of gelatin is not unknown and the content was adjusted so that the calculated track length of Po-212 α、8.785 MeV (highest energy α emitted from Thorotrast) coincided with observed length 55μm.



Elemental composition of dry emulsion, water content was referred from Norris and Woodruff (1955) Annu. Rev. Nucl. Sci. 297-326, that of gelatin from ICRU (1964).

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An Assessment of Low-dose Health Effects of A-bomb Radiation by Neural Networks Theorem

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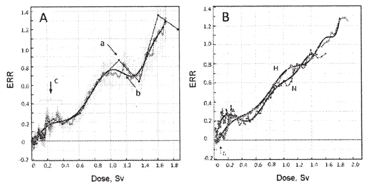
Cancer risk at low doses of ionizing radiation remains poorly defined due largely to the ambiguity at low doses in A-bomb survivors stemming from limitations in statistical power and information available on overall radiation dose. To deal with these difficulties, a novel nonparametric statistics system was developed based on the "*integrate-and-fire*" model of artificial neural networks (ANN) and tested on cancer databases of A-bomb survivors which were publicly available from Radiation Effects Research Foundation (RERF). The analysis revealed a small but significant elevation of cancer risk at low doses in Nagasaki survivors, which hampered the precise estimate of cancer risk at low doses. When Hiroshima survivors were treated separately, the analysis disclosed a threshold with upper dose limit of 0.1-0.2 Sv, which varied with cancer site, gender and age at exposure. Curiously, the threshold was manifested as a negative excess relative risk, or a reduction of spontaneous cancer rates. Furthermore, such threshold was also observed in cardiovascular diseases, suggesting that cancer and atherosclerosis may entail fundamentally common biological mechanisms.

In a single perceptron model of ANN, the '*integrate-and-fire*' response is described by

$$S(x) = \varphi\{\sum w_i \lambda(x_i) - \mu\} \quad , \qquad (1)$$

where φ(..) is a gain function, $\lambda(x_i)$ is the *i*th input variable with weight w_i and μ is threshold (McCulloch and Pitts, Bull. Math. Biophys., 5:115, 1943). In the implementation of the ANN theorem into cancer risk assessment, the relative risk (*RR*) of cancer at dose *x*, $\lambda(x)$, was regarded as an input variable and we dropped the threshold term but left to be automatically determined *in situ* because the threshold was not known *a priori*. The discrete function of the weighted sum of *RR* thus given in Eq. 1 was fitted by aid of AIC, ML and bootstrap to a continuously differentiable polynomial function, $\Psi_{RR}(x)$, which was then differentiated to obtain continuous probability density function of relative risk, $RR(x)=\Psi_{RR}'(x)$, or excess relative risk, $ERR(x)=RR(x)-1$. When conventional piecewise dose category method as adopted by Preson *et al.* (Radiat. Res., 168:1, 2007) and present ANN method were compared for the excess relative risk (*ERR*) of solid cancers in combined Hiroshima and Nagasaki cohort, the two methods gave very comparable results including an abnormal elevation at low doses as previously noted by Pierce and Preston (Radiat. Res., 154:178, 2000) (Fig. 1). When the ANN analysis was performed in two cities separately, it became evident that the abnormality at low dose was solely due to cancer of lung, liver and gallbladder in Nagasaki survivors. Its city- and organ-specificity suggests an involvement of internal deposit of plutonium in some distally exposed survivors. Indeed, fallout of $^{239/240}$Pu has been detected in the East to the hypocenter (Saito-Kokubu, J. Geosci. Osaka City Univ., 50:7, 2007). Avoiding disturbance by yet unproven origin of the low dose abnormality in Nagasaki, the representative dose response of *ERR* was determined in Hiroshima survivors alone, which was Y_H=(0.584±0.018)Sv+(0.040±0.001)Sv^2.



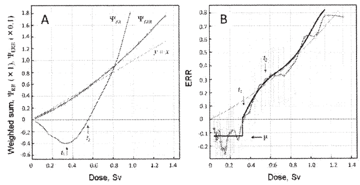


Fig. 1 **Fig. 2**

Fig. 1. The *ERR* of solid cancer. **A**: Cross-validation of the statistics methods; conventional piecewise dose category method (a) and ANN method (b). Abnormal elevation of *ERR* at low doses is shown by arrow (c). *ERR* data obtained by moving window averaging are shown by open circles together with 80% CI. **B**: Comparison of *ERR* between Hiroshima (H) and Nagasaki (N) as assessed by ANN method. Abnormality at low doses is evident in Nagasaki.

Fig. 2. Methodological representation in a sample cohort, *i.e.*, lung cancer in Hiroshima male survivors exposed at 20 yrs or older at the time of bombing. **A**: Weighted sum and optimization by fitting to continuous function of dose. $\Psi_{ERR}(x)=\Psi_{RR}(x)-x$. **B**: Dose-dependent probability density function of *ERR* as determined by $\Psi_{ERR}(x)=\Psi_{RR}(x)-1$. Dotted line: Dose-response independent of the threshold response ($x>t_2$), Y=(0.359±0.066)Sv+(0.219±0.066)Sv^2.

A significant finding was the presence of threshold in some cancer. Unexpectedly, the threshold was identified as a negative *ERR*, or a reduction of the spontaneous cancer rate (Fig. 2). The integrated *ERR*, Ψ_{ERR}, decreased linearly with dose at low doses then increased with further increase of dose. The threshold dose, t_1, was determined as the dose that satisfied the derivate $\Psi_{ERR}'=0$ by numerical differentiation of Lagrange. The linearly decreasing part ($x \leqq t_1$) was fitted to a linear regression $\Psi_{ERR}=a+\mu x$, the derivation of which gave the *ERR* at threshold, *ERR*=μ. The dose, t_2, at which $\Psi_{ERR}=0$, corresponds to the dose thereafter all survivors in a moving block have a non-threshold dose $x>t_1$. Thus, the *ERR* is discontinuous with a breakpoint at t_1, followed by a transient phase $t_1<x<t_2$, and then the dose range that is free of the threshold response $x>t_2$, where a fundamental dose-response may be calculated (Fig. 2b).

The threshold response was dependent on cancer site, gender and age at the time of bombing (ATB). Considering variability of absorbed radiation dose according to the variability in organ (target) size and distribution in the body, the relevant dose appears to be below 100-200 mSv. When appeared, its magnitude was generally 10-20 % reduction of spontaneous frequency, *i.e.*, μ=-(0.1~0.2). It was prominent in cancer of lung, stomach, liver, gallbladder, pancreas and prostate in male survivors with age ATB>20 yrs. The threshold was not noticeable in female cancer except for liver and breast cancer. As a consequence, the threshold was clearly seen in male solid cancer combined whereas it was small, if any at all, in female survivors (Fig. 3 left panel). It should be noted that there was no radiation effects, neither in its reduction nor in promotion, on the development of cervical cancer (Fig. 3 right panel). The refractoriness of cervical cancer to radiation could explain a direct role of functional inactivation of p53 and RB1 tumor-suppressor proteins by papillomavirus (HPV) early antigens, E6 and E7.

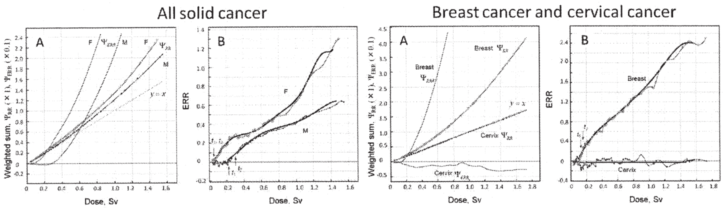


Fig. 3. Characteristics of dose response of solid cancer, breast cancer and cervical cancer (Hiroshima). **A**: Weighted sum of *RR* and *ERR*. **B**: Probability density of *ERR*. M: male survivors. F: female survivors.

The radiation effects on leukemia are presented in Fig. 4. In Hiroshima, both males and females survivors were characterized by the threshold, and the dose responses of *ERR* for non-threshold doses were linear-quadratic, $Y=(0.924\pm0.066)Sv+(0.563\pm0.053)Sv^2$ for males and $Y=(0.089\pm0.147)Sv+(0.737\pm0.104)Sv^2$ for female (Fig. 4 left panel). The linear-quadratic (L-Q) dose response suggests a common mechanism in the causation shared by leukemia and solid cancer, and does not support the hypothesis of clone selection by radiation of pre-existing preleukemic cells (Nakamura, Radiat Res., 163:258, 2005). Response of leukemia in Nagasaki differed from that in Hiroshima. In addition to being superimposed by abnormal elevation at low doses like in solid cancer, the reduction of *ERR* at moderate doses seen in female survivors was not seen in male survivors, where *ERR* continued to increase with dose (data not shown). However, when analysis was made after exclusion of factory workers, both sex showed very comparable response patterns (Fig. 4 right panels).

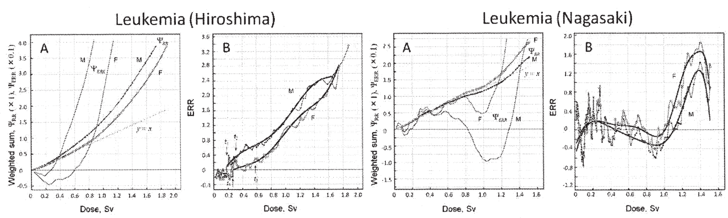


Fig. 4. The dose responses of leukemia in Hiroshima and Nagasaki. In Nagasaki survivors, factory workers have been excluded. **A**: Weighted sum of *RR* and *ERR*. **B**: Probability density of *ERR*. M: male survivors. F: female survivors.

In Nagasaki survivors, about 17 % of leukemia is adult T-cell leukemia (ATL), in which HTLV-1 retrovirus plays a causative role in its development. ATL is endemic to South-West part of Japan including Nagasaki. The observations suggest that most factory workers are not Nagasaki natives and that radiation suppressed the clinical manifestation of ATL in HTLV-1 carriers, giving rise to the negative *ERR* at low doses. This unique response could be the reason of purely quadratic function of dose previously reported for leukemia in Nagasaki survivors.

When the ANN statistics was applied to noncancer diseases, the threshold response was also found in cardiovascular diseases but not in other noncancer diseases tested, indicating that the cardiovascular diseases and cancer may entail common biological mechanism. The mechanism of threshold response at low doses remains to be elucidated. Yet, it is tempting to correlate with recently growing evidence for the pathway choice in the repair of DNA double-strand break (DSB). The DSBs are the subject to be repaired either by restitutional non-homologous end-joining (C-NHEJ), or mutagenic alternative end-joining (Alt-NHEJ) or homologous recombination (HR) including single-strand annealing (SSA). C-NHEJ is activated by low-dose radiation, which in turn suppresses Alt-NHEJ and HR (Liever *et al.*, Nat. Rev. Mol. Cell Biol., 4:712, 2003; Mladenov and Iliakis, Mut. Res., 711:61, 2010). The DSBs generated at DNA replication stalled at fork triggered by DNA damage associated with exogenous or endogenous genotoxin are also the subject to be repaired by C-NHEJ, Alt-NHEJ or HR. The activation of C-NHEJ by low-dose radiation (Tachibana, Adv. Biophys., 38:21, 2004; Klammer *et al.*, Cancer Res., 2010), and hence suppression of Alt-NHEJ and HR, may eventually suppress the mutagenic process and thus suppresses spontaneously occurring cancer rate.

Prevalence of threshold in male survivors exposed at adulthood suggests the involvement of smoking in spontaneous cancer and its suppression by low doses. It is also known that C-NHEJ or deficiency in Alt-NHEJ suppresses the integration of retroviral DNA into host DNA. This may account for the suppressive effect on ATL at low doses. Long-term, or life-time long, sustainability of low dose effects *in vivo* has been suggested by Kakinuma *et al.* (J. Radit. Res, 50:401, 2009) for the suppression of spontaneous and chemical-induced tumor in mice pre-irradiated with low dose X-rays. Altogether, the present finding brings about a new paradigm in radiation protection and risk assessment where low-dose health effects are not a simple stochastic process against radiation but an integrated consequence of highly ordered biological response of the genome to threat.

The present ANN statistics was conceived, programmed by MSS and tested on the cancer databases released from RERF. The RERF is a private foundation funded equally by the Ministry of Health, Welfare and Labor of Japan and the U.S. Department of Energy through the U.S. National Academy of sciences. The conclusions in this report are those of the author and do not necessarily reflect the scientific judgment of the RERF or its funding agencies.

Radioactivity of the aerosol collected in Nagasaki City due to the Fukushima Daiichi Nuclear Power Plant Accident

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Abstract

Radioactivity of ^{134}Cs and ^{137}Cs was detected in the aerosol collected in Nagasaki prefectural forest park "Nagasaki Kenmin No Mori" about 20 km north-west from central Nagasaki City from Mar. 23 to Jul. 27, 2011. The highest concentrations of the nuclides were detected in the sample collected from Apr. 6 to Apr. 13 and ^{110m}Ag was also detected in the sample. The wind of Apr. 6 in the park was found to come via Fukushima with back-trajectory analysis in the web-site of National Oceanic Atmospheric Administration (NOAA), United States Department of Commerce. The concentrations in the air of ^{134}Cs, ^{137}Cs and ^{110m}Ag evaluated were as small as 0.47, 0.52 and 0.0054 mBq/m^3 respectively. However, the concentrations of them in the collected aerosol were as large as 11.3, 12.4 and 0.12 kBq/kg, and equivalent to the level of surface soil of 5 cm in Warabidaira Iitate Fukushima, highly contaminated area. It indicates that air filters in air-conditioning facilities should be handled carefully also at Nagasaki about 1,000 km apart from Fukushima Daiichi Nuclear Power Plant. In addition, the concentration of natural radioactivity Pb-210 was found as large as 19.9 kBq/kg. Therefore, it was ascertained that the risk of air filters was already existed before the accident and the radioactivity arisen from the accident increased the risk.

INTRODUCTION

The nuclear accident at the Fukushima Daiichi Nuclear Power Plant occurred on 11 March 2011.

Many types of radioactive nuclides, ^{129m}Te, ^{129}Te, ^{131}I, ^{132}Te, ^{132}I, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{140}Ba, ^{140}La, ^{99m}Tc, ^{95}Nb and ^{110m}Ag were detected from soil samples collected near the nuclear power plant from 15 March.[1)] Detection of ^{99m}Tc, ^{95}Nb and ^{110m}Ag were not reported in the paper in the sake of some measurement difficulty. Now the detection has been confirmed.

We are continuing to measure various new samples sent from Fukushima with the request of the measurement of the people and for the purpose of study. However, detection of the nuclides other than ^{134}Cs, ^{137}Cs and ^{110m}Ag became difficult now because of these short half-lives.

Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japanese government presented the distribution maps of radioactivity concentration of ^{134}Cs, ^{137}Cs, ^{129m}Te and ^{110m}Ag around the nuclear power plant[2, 3, 4)]. These maps show the distribution of the nuclides on land in the range of 100 km from the power plant. MEXT is also presented distribution map in the seawater around the power plant[5)]. They indicated that ^{131}I, ^{134}Cs and ^{137}Cs were not detected in all the seawater samples except at the point just in front of the power plant. However, we detected ^{134}Cs and ^{137}Cs from seawater of Hisanohama, about 30 km south of the power plant. The radionuclides were also detected in the sediment of the seabed. Higher concentrations than the seawater of ^{134}Cs, ^{137}Cs and ^{110m}Ag were found in abalones and sea urchins.

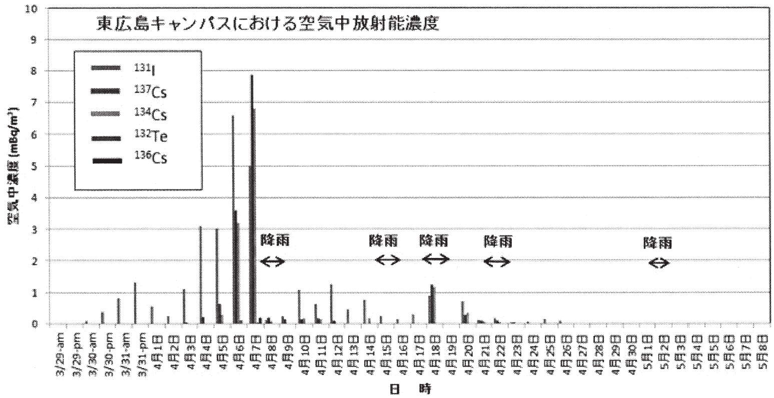

Fig. 1. Radioactivity of aerosol collected in Higashihiroshima Campus, Hiroshima University by Shizuma[6]. The figure was reprinted from the reference. Horizontal axis is sampling time written in Japanese. For example, "4 月 7 日" means April 7. Vertical axis is radioactivity of the aerosol per air volume. Arrows indicate rainfall. Largest radioactivity was detected on April 7.

^{110m}Ag concentration of the abalones and sea urchins was higher than the seabed sediments near the sampling points . These were reported in a television program of Japan Broadcasting Corporation (NHK) at November 27, 2011.

Shizuma[6] reported that ^{131}I, ^{137}Cs, ^{134}Cs ^{132}Te and ^{136}Cs were detected in the aerosol collected in Higashihiroshima Campus, Hiroshima University. The concentration was largest on April 7, 2011 (Fig. 1).

We now present that the radioactive materials due to the nuclear power plant accident have been spread out also to Nagasaki city about 1,000 km from the power plant.

MATERIALS AND METHODS

Sampling of aerosol

A high volume air sampler (Shibata AH600-F) has been installed at Nagasaki prefectural forest park "Nagasaki Kenmin No Mori" (Fig. 1) about 20 km north-west from central Nagasaki City intended for study of transboundary air pollution across East China Sea.

Aerosol was collected with quartz fiber filters (Advantec QR-100). The mass of collected aerosol was estimated subtracting mass of the filter before collecting aerosol from the mass after collecting. The mass of the filter was

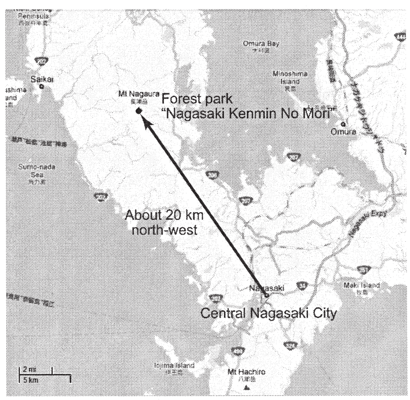

Fig. 2. Nagasaki prefectural forest park "Nagasaki Kenmin No Mori

weighed after keeping 30～40%RH of humidity in a desiccator cabinet (Sanplatec Type A-3) because the mass depend on the humidity.

Measurement of Radioactivity in the aerosol

The filter was pressed into a disk in a die with a press machine. Radioactivity was measured with a germanium detector (Ortec GMX30). The detection efficiency was determined using mixed large volume calibration standards (Isotope products laboratories EG-ML) containing radionuclides of ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{85}Sr, ^{137}Cs, ^{54}Mn, ^{88}Y and ^{60}Co, the uncertainty of the activities was certified less than 5%, samples of natural uranium rich grinded rock and ^{210}Pb rich surface soil samples collected near Nagasaki University to determine detection efficiency of ^{210}Pb.

Air Trajectory Analysis

Air trajectory analysis was performed in the web-site of National Oceanic Atmospheric Administration (NOAA), United States Department of Commerce[7]. In the web page, link of "Run HYSPLIT Trajectory Model" was selected in the category of HYSPLIT-WEB (Internet-based). In the web page opened, link of "Compute archive trajectories" was selected. In the web page opened, "Next" button was clicked with the default settings (Number of Trajectory Starting Locations: 1, Type of Trajectory: Normal) in the web page. "GDAS" was selected as meteorological data. Maps of air trajectory were obtained by setting appropriate values in the subsequent web pages.

RESULT

Sampling and Measurement of Radioactivity

Table 1 shows sampling period, mass of collected aerosol, air volume introduced in the air sampler, date and measurement time. Table 2 shows radioactivity of the collected aerosol per the introduced air volume. The values of ^{134}Cs, ^{137}Cs, ^{110m}Ag and ^{210}Pb are plotted in Fig. 3. The

Table 1. Mass of collected aerosol, air volume, date and measurement time

Sampling period	Mass of collected aerosol (mg)	Air volume (m^3)	Date measurement was started	Measurement time (h)
02 Mar - 09 Mar	116	7,035	2-May	48
09 Mar - 16 Mar	116	7,035	21-Apr	48
16 Mar - 23 Mar	86.3	6,922	19-Apr	48
23 Mar - 30 Mar	304	7,032	18-Apr	24
30 Mar - 06 Apr	302	7,119	17-Apr	24
06 Apr - 13 Apr	296	6,974	7-Jul	165
13 Apr - 20 Apr	220	7,185	14-Jul	49
20 Apr - 27 Apr	142	6,917	16-Jul	72
20 Jul - 27 Jul	115	7,186	28-Jul	24
27 Jul - 03 Aug	77.4	6,852	8-Aug	46
03 Aug - 10 Aug	66.0	7,070	12-Aug	71
10 Aug - 18 Aug	105	8,023	22-Aug	25

Table 2. Radioactivity in aerosol per air volume. "±" indicate standard error expected from the γ-ray spectrometry.

Sampling period	Concentration ($\times 10^{-6}$ Bq/m^3) ^{134}Cs	^{137}Cs	^{110m}Ag	^{210}Pb	^{7}Be	^{40}K
02 Mar - 09 Mar	—	—	—	2349 ± 29	—	—
09 Mar - 16 Mar	1.3 ± 1.2	—	1.8 ± 1.6	1084 ± 22	6733 ± 59	29 ± 15
16 Mar - 23 Mar	—	3.5 ± 1.2	1.7 ± 1.7	750 ± 19	4792 ± 47	47 ± 14
23 Mar - 30 Mar	7.4 ± 1.6	5.9 ± 2.0	—	1184 ± 32	6398 ± 72	59 ± 21
30 Mar - 06 Apr	26.70 ± 0.49	299.2 ± 5.7	—	1040 ± 33	7974 ± 79	40 ± 22
06 Apr - 13 Apr	477.7 ± 2.2	523.6 ± 2.4	5.38 ± 0.99	842 ± 11	4903 ± 45	142.8 ± 7.7
13 Apr - 20 Apr	37.1 ± 1.5	39.6 ± 1.6	—	701 ± 17	3811 ± 64	133 ± 13
20 Apr - 27 Apr	23.2 ± 1.0	29.5 ± 1.1	—	687 ± 12	3358 ± 46	136 ± 11
20 Jul - 27 Jul	5.9 ± 1.6	5.2 ± 1.6	1.9 ± 1.6	322 ± 22	976 ± 59	—
27 Jul - 03 Aug	2.0 ± 1.2	2.1 ± 1.2	—	116 ± 14	1426 ± 22	129 ± 14
03 Aug - 10 Aug	—	—	1.2 ± 1.0	202 ± 12	872 ± 14	134 ± 12
10 Aug - 18 Aug	—	2.5 ± 1.3	—	187 ± 16	1305±26	152 ± 17

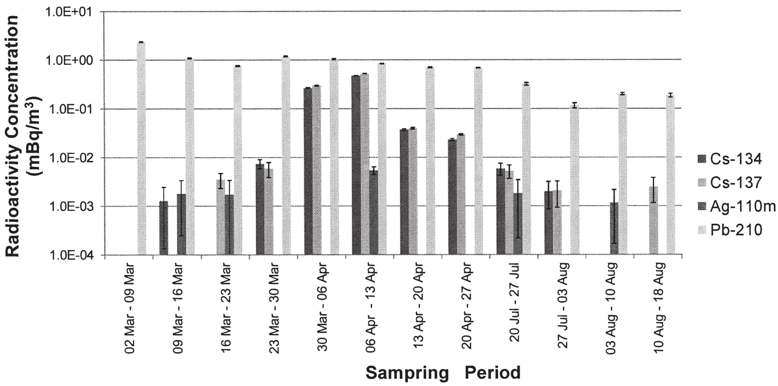

Fig. 3. Radioactivity in aerosol per air volume plotted against sampling period.

sample of the period "06 Apr –13 Apr" showed highest value of ^{134}Cs, ^{137}Cs and ^{110m}Ag. Table 3 shows the radioactivity of the aerosol per mass of the aerosol itself. The values are also plotted in Fig. 4. The values became rather large because the mass of the aerosol is small.

Air Trajectory Analysis

Fig. 5 is the results of backward trajectory analysis from "Nagasaki Kenmin No Mori". The wind from 12:00 UTC 06 to 0:00 UTC 07 was found to come via Fukushima. The wind was found not to come via Fukushima for other time in the sampling period by surveying with the analysis. Fig. 6 is the results for Higashihiroshima Campus , Hiroshima University. The wind from 18:00 UTC 06 to 12:00 UTC 07 was found to come via fukushima. The wind was also found not to come via Fukushima for other time in the sampling period. Fig. 7 is the results of forward trajectory

Table 3. Activity of radionuclides per aerosol mass

Interval of Sampling	Concentration ($\times 10^3$ Bq/kg)					
	^{134}Cs	^{137}Cs	^{110m}Ag	^{210}Pb	^{7}Be	^{40}K
02 Mar - 09 Mar	—	—	—	142.5 ± 1.7	—	—
09 Mar - 16 Mar	0.079 ± 0.071	—	0.110 ± 0.095	65.7 ± 1.3	408.5 ± 3.6	1.74 ± 0.93
16 Mar - 23 Mar	—	0.281 ± 0.095	0.14 ± 0.13	60.2 ± 1.6	384.6 ± 3.8	3.8 ± 1.1
23 Mar - 30 Mar	0.172 ± 0.038	0.136 ± 0.046	—	27.43 ± 0.73	148.2 ± 1.7	1.39 ± 0.48
30 Mar - 06 Apr	6.30 ± 0.12	7.06 ± 0.13	—	24.56 ± 0.73	188.2 ± 1.9	0.95 ± 0.52
06 Apr - 13 Apr	11.273 ± 0.053	12.357 ± 0.058	0.127 ± 0.023	19.87 ± 0.25	115.7 ± 1.1	3.37 ± 0.18
13 Apr - 20 Apr	1.21 ± 0.049	1.29 ± 0.051	—	22.91 ± 0.55	124.5 ± 2.1	4.33 ± 0.42
20 Apr - 27 Apr	1.13 ± 0.051	1.44 ± 0.054	—	33.48 ± 0.58	163.7 ± 2.3	6.62 ± 0.53
20 Jul - 27 Jul	0.37 ± 0.10	0.33 ± 1.6	0.12 ± 0.10	20.2 ± 1.4	61.2 ± 1.7	—
27 Jul - 03 Aug	0.18 ± 0.10	0.19 ± 0.10	—	10.3 ± 1.3	126.2 ± 1.9	11.4 ± 1.3
03 Aug - 10 Aug	—	—	0.13 ± 0.11	21.6 ± 1.2	93.4 ± 1.5	14.4 ± 1.3
10 Aug - 18 Aug	—	0.19 ± 0.10	—	14.3 ± 1.2	99.7 ± 2.0	11.7 ± 1.3

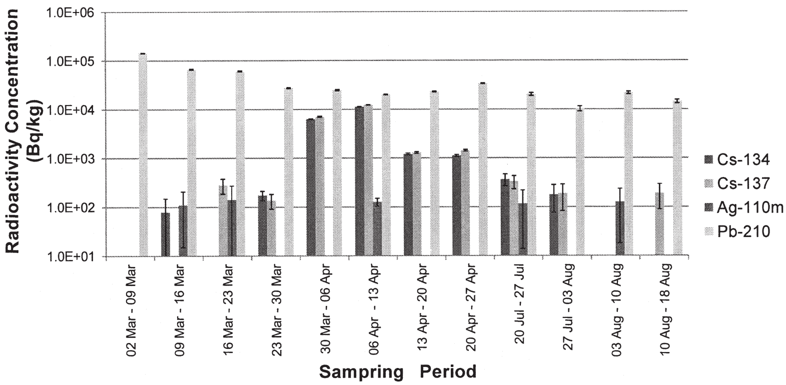

Fig. 4. Radioactivity in aerosol per mass plotted against sampling period.

analysis from Fukushima Daiichi Nuclear Power Plant. The route of air flow was found to move from west to east in the two hours. The wind going through Nagasaki at first changed to the route thorough Hiroshima.

DISCUSSION

It was found that the radioactivity of aerosol became highest when the wind came via Fukushima in both "Nagasaki Kenmin No Mori" and Higashihiroshima. It indicates that the radioactivity originated from Fukushima Daiichi Nuclear Power Plant surely has spread to Nagasaki and Hiroshima.

ICRP Publ. 23 estimates that respiratory volume of reference man per day is 22.21m^3. Dose coefficients of ^{134}Cs, ^{137}Cs and ^{110m}Ag for inhalation intake are 2.0×10^{-8}, 3.9×10^{-8} and 1.2×10^{-8} Sv/Bq according to

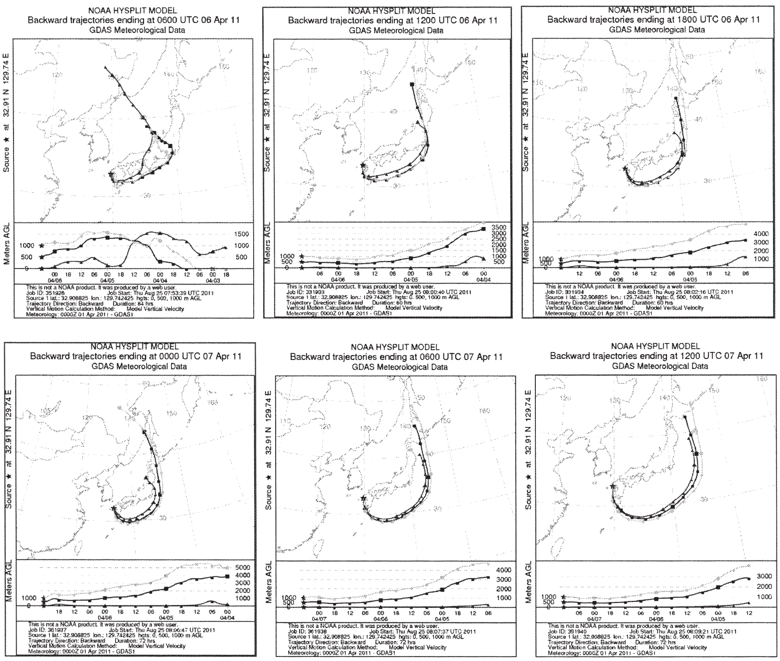

Fig. 5. Backward trajectory analysis of air flow from "Nagasaki Kenmin No Mori" at 6:00, 12:00 and 18:00 UTC 06 and 0:00, 6:00 and 12:00 UTC 07 Apr 2011. The wind from 12:00 06 to 0:00 07 was found to come via Fukushima.

ICRP Publ. 72. Using these values, the committed dose equivalent for a person breathing the air of "Nagasaki Kenmin No Mori" all in the sampling intervals was calculated as 0.008 μSv. Therefore, the radiation dose may be negligible compared with the dose of natural radiation even postulating large uncertainty for these estimations. However, the mass concentration of ^{134}Cs and ^{137}Cs of aerosol itself was awfully high and the value was equivalent to the level of surface soil of 5 cm in Warabidaira Iitate Fukushima, highly contaminated area[1)]. It indicates that cautions should be exercised for some cases for example handling of air filters in air-conditioning facilities of some big buildings also at Nagasaki about 1,000 km apart from Fukushima Daiichi Nuclear Power Plant. However, radioactivity of ^{210}Pb was higher than ^{134}Cs and ^{137}Cs. Therefore it is shown that the aerosol was dangerous before the accident with natural radioactivities and ^{134}Cs and ^{137}Cs only increases the dangerousness.

ACKNOWLEDGEMENT

We want to thank Dr. K. Kawamoto, Graduate School of Fisheries Science and Environmental Studies, Nagasaki University. He kindly introduced website of NOAA and instructed how to use.

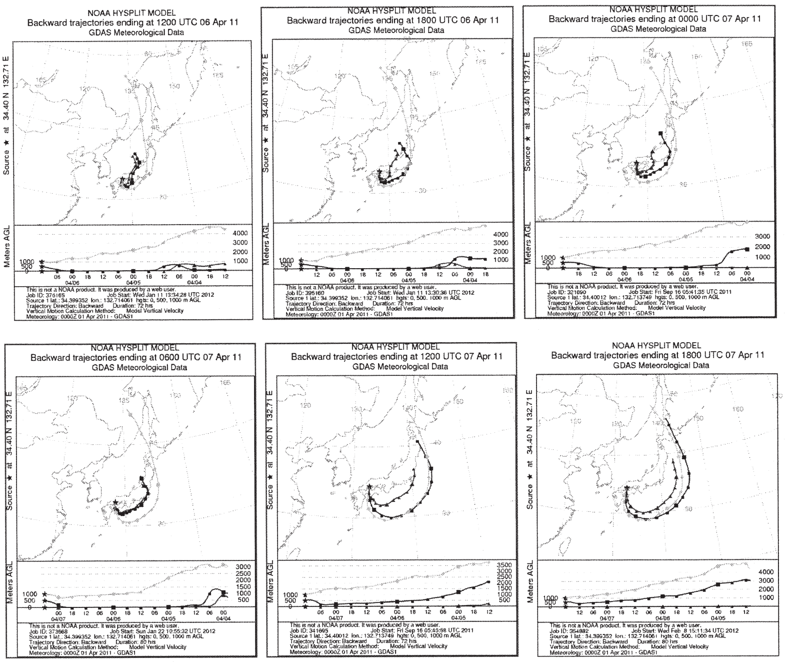

Fig. 6. Backward trajectory analysis of air flow from Higashihiroshima Campus, Hiroshima University at 12:00, 18:00 UTC 06 and 0:00, 6:00, 12:00, 18:00 UTC 07 Apr 2011. The wind from 18:00 06 to 12:00 07 was found to come via fukushima.

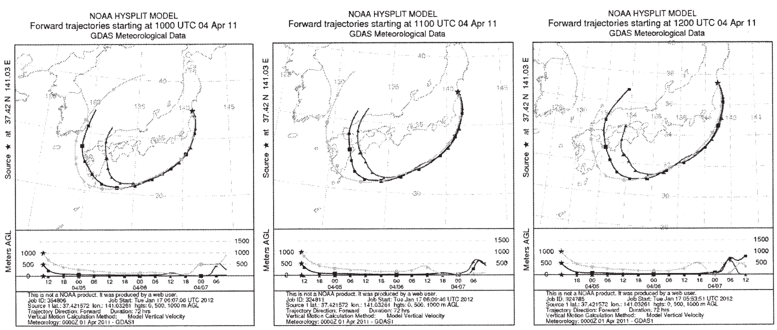

Fig. 7. Forward trajectory analysis of air flow from Fukushima Daiichi Nuclear Power Plant, at 10:00, 11:00 and 12:00 UTC 04 Apr 2011. The route of air flow was found to move from west to east in the two hours.

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Time Trend of Air Dose Rate of Radiation in Eastern Japan after the Fukushima Daiichi Nuclear Power Plants Accident

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1. Introduction

A giant earthquake (East Japan major earthquake) of M9 struck East Japan at 14:46 on March 11, 2011. Subsequently, a tsunami of going up high 14m -15m attacked Fukushima Daiichi Nuclear Power Plant and all AC power supply fell into loss state. As a result, in all of 1-3 Nuclear reactors, meltdown befell [1], and a part of the molten fuel has begun to leak out to the nuclear reactor storage container. Hydrogen that was generated by the meltdown of the nuclear reactors caused explosions and fire, which led the nuclear reactors, turbine rooms and outskirts institution demolished. The process of the accident at Fukushima Daiichi Nuclear Power Plant is summarized in Table 1. Then, significant amounts of radioactive material have been released into environment. The atmospheres, soil, marine of the east Japan including the metropolitan area have been contaminated with radioactive materials such as I131, Cs134 and Cs137. The purpose of this study is to search environmental factors, other than decreasing of radioactive materials according to their half-lives, that effect on air dose rate of radiation in each spot of the East Japan. We are especially interested in 'effect of air dose rate of the day before', 'that of elapsed days from the accident', and 'that of weather condition of the day'.

Table 1. Process of the Accident at Fukushima Daiichi Nuclear Power Plant

		1st Unit	2nd Unit	3rd Unit	4th Unit
11 March	14:46	Shutdown	Shutdown	Shutdown	During Stop
	15:41	Power Supply Loss	Power Supply Loss	Power Supply Loss	
12 March	15:36	Hydrogen Explosion			
14 March	11:01			Hydrogen Explosion	
15 March	6:10		Abnormal noise outbreak		
	6:14			Smoke	Abnormal noise outbreak
	8:25		White smoke		
	9:38				Fire
16 March	8:37			White smoke	
21 March	15:55			Black smoke	
	18:20		White smoke		

2. Materials and Methods

The data we dealt with are "the spot-specific air dose rates of radiation (μSv/h) those were observed at 36 spots in eastern Japan", which were published in the morning edition of Asahi Shimbun[2] from 13 April 2011 to 13 August 2011. The weather conditions of days were obtained from the web site of Japan Meteorological agency [3].The time trends of air dose rate of radiation of each spot around Fukushima Daiichi Nuclear Power Plant are shown in Figure 1, in which the vertical axis represents the day-specific air dose rate of radiation in a log scale.

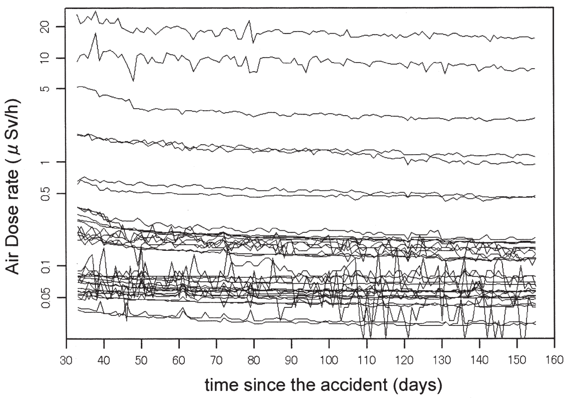

Figure 1. Spot-Specific air dose rates of radiation after the accident of Fukushima Daiichi Power Plant in eastern Japan

We assumed that the amount of emitted radiations was fixed at the day of accident and that the amounts of emitted radiations have been decreasing according to their half-lives, where the half lives of I131, Cs134 and Cs137 are 8.02 days, 2.065 years and 30.2 years [4],[5],[6], respectively. We also assumed that the initial attribution ratio of Cs134 and Cs137 to the air dose rate of radiation is 2.7 to 1, and that the mass ratio of Cs137 and Cs134 in the initial fallout is one to one[7]. Then the theoretical air dose rate of radiation at time t is expressed as

$$h(t \mid \beta_{1i}, \beta_{2i}) = C + \beta_{1i} \frac{2.7 \times 2^{-\frac{t}{753.7}} + 1.0}{3.7} + \beta_{2i} 2^{-\frac{t}{8.02}}, \qquad (1)$$
$$(t = 33, \cdots, 155;\ i = 1, \cdots, 36\ )$$

where C is the natural background of radiation dose rate having the value of 0.076μSv/h [8], and β_{1i} and β_{2i} are initial values of Cs and I131 at each spot, respectively. Let $y_i(t)$ be the air dose rate of radiation at t days after the explosion at spot i. The composite half-life model (1) is modified as follows

$$y_i(t) = h(t \mid \beta_{1i}, \beta_{2i}) \exp(\gamma_i ' z_{it} + \varepsilon_{it}), \tag{2}$$

where z_{it} denotes the vector of explanatory variables that are considered to effect on an air dose rate, γ_i denotes the vector of coefficients to be estimated, and ε_{it} denotes error term that obeys $N(0, \sigma_i^2)$ independently. Logarithmic transformation of both side of the equation (2) provides the following formula,

$$\log\{y_i(t)\} = \log\{h(t \mid \beta_{1i}, \beta_{2i})\} + \gamma_i ' z_{it} + \varepsilon_{it}. \tag{3}$$

Further, taking the effect of air dose rate of radiation at the previous day into consideration, we obtain from the equation (3) that

$$\begin{aligned} \log\{y_i(t)\} = \log\{h(t \mid \beta_{1i}, \beta_{2i})\} &+ \gamma_{1i} \times prey_{it} + \gamma_{2i} \times t \\ &+ \gamma_{3i} \times rain_{it} + \gamma_{4i} \times (rain_{it} \times t) + \gamma_{5i} \times (s\text{-}wind_{it}) + \varepsilon_{it}, \\ &(t = 34, \cdots, 155;\ i = 1, \cdots, 36) \end{aligned}$$

where '$prey_{it} \equiv \log\{y_i(t-1)\}$, '$rain_{it}$' is a dummy variable expressing the amount of precipitation on the day t at spot i, which takes 1 if the precipitation is more than 3 mm per day and 0 otherwise, '$s\text{-}wind_{it}$' is a dummy variable expressing the strength of south wind which takes 1 if the south wind is stronger than 1.5 m/sec and 0 otherwise. Using a nonlinear least square method (NLSE) [9], we estimated values of the parameters $(\hat{\beta}_{1i}, \hat{\beta}_{2i}, \hat{\gamma}_{1i}, \hat{\gamma}_{2i}, \hat{\gamma}_{3i}, \hat{\gamma}_{4i}, \hat{\gamma}_{5i}, \sigma_i)$ for each spot. The free software R-2.12.1 was used for the analysis.

3. Results

The results of our study were represented in Table 2 and Figure 2-9. Table 2 shows the spot-specific estimated vales of parameters. Figure 2 and Figure 3 show the estimated initial values of air dose rate of radiation due to Cs and I131, respectively. Relatively high values of air dose rate were estimated at the neighborhood of Fukushima Daiichi Nuclear Power Plant for both radio-nuclides. Figure 4 represents the geographical distribution of estimated coefficients of dose rates of the day before $(\hat{\gamma}_1)$, where strong auto-correlative trends can be found in almost entire region. The estimated coefficients of 't' were negative at almost all spots, which show that the air dose rates are decreasing day by day over the observed period after being adjusted for 'decreasing rate due to half-lives of radioactive materials', 'air dose rate at the previous day' and 'weather condition of a day'.

Table 2. Spot-specific estimated parameters with spot information

SID	name of spot	MCD	longitude	latitude	distance*	Cs	I131	prey	t	rain	rain*t	s-wind
1	Sendai	4100	140.87	38.27	95.4	0.195	0.000	0.4479	-0.0386	-0.0041	0.0348	0.0253
2	Shiraishi	4206	140.62	38.00	74.2	0.279	0.452	0.2992	-0.2723	0.0253	-0.0302	-0.0016
3	Yamagata	6201	140.35	34.25	111.1	0.028	0.271	0.2549	-0.0603	-0.0154	0.0207	-0.0006
4	Yonezawa	6202	140.12	37.92	98.1	0.020	0.139	0.0931	0.0402	-0.0178	0.0438	-0.0153
5	Fukushima	7201	140.45	37.75	62.2	1.393	3.554	0.2649	-0.1311	-0.0110	-0.0018	0.0032
6	Aizuwakamatsu	7202	139.92	37.50	97.8	0.162	0.459	0.1702	-0.0863	0.0407	-0.0445	-0.0197
7	Kooriyama	7203	140.37	37.40	59.6	1.398	2.646	0.3455	-0.2137	-0.0166	0.0104	-0.0026
8	Iwaki	7204	140.88	37.05	43.2	0.391	1.519	0.4154	-0.1010	0.0459	-0.0383	0.0008
9	Shirakawa	7205	140.22	37.13	79.8	0.663	1.302	0.2018	-0.1604	0.0016	0.0017	-0.0024
10	Minamisouma	7212	140.33	37.49	25.5	0.568	2.129	0.3657	0.0156	-0.0307	-0.0060	0.0058
11	Minamiaizu	7368	139.46	37.12	114.2	0.020	0.049	0.0693	-0.0693	0.0003	0.0341	0.0102
12	Akaugi(Namie)	7547	140.78	37.80	25.6	11.887	67.750	0.1603	-0.0358	-0.0550	0.0345	-0.0051
13	Shimotsushima(Namie)	7548	140.76	37.55	29.1	4.777	15.575	0.3302	-0.0605	-0.3109	0.2288	0.0238
14	Iltate	7564	140.73	37.68	38.9	1.668	9.664	0.5290	-0.0115	-0.0629	0.0350	-0.0005
15	Hitachi	8202	140.63	36.60	97.6	0.265	1.287	0.2762	-0.0947	0.0003	-0.0063	-0.0013
16	Hakahagi	8214	140.70	36.70	83.8	0.503	1.396	0.7294	0.0255	0.0265	-0.0222	0.0165
17	Kitaibaragi	8215	140.73	36.78	73.3	0.328	2.063	0.4376	-0.0187	0.0224	-0.0234	0.0113
18	Tsukuba	8220	140.08	36.03	171.6	0.087	0.351	-0.0011	-0.0594	-0.0609	0.0416	0.0111
19	Hitachinaka	8221	140.32	36.23	122.3	0.366	2.544	0.4700	-0.0289	-0.0194	0.0079	0.0103
20	Toukai	8341	140.58	36.47	113.4	0.121	1.205	0.1376	-0.1217	0.0076	-0.0050	0.0006
21	Hokota	8402	140.52	36.15	146.4	0.588	1.361	0.7232	-0.0056	0.0212	-0.0263	0.0090
22	Utsunomiya	9201	139.88	36.57	140.5	0.065	0.247	0.2935	-0.0258	0.0073	0.0205	0.0065
23	Koyama	9208	139.80	36.32	165.0	0.097	0.523	0.2534	-0.5193	-0.1879	0.2768	0.0035
24	Maoka	9209	140.02	36.43	141.9	0.053	0.366	0.1907	-0.1207	0.0057	-0.0242	0.0564
25	Nasu	9407	140.13	37.02	92.3	0.283	0.000	0.2997	-0.2364	-0.0160	0.0547	0.0078
26	Maebashi	10201	139.07	36.38	209.6	0.000	0.158	0.0097	-0.1938	0.1257	-0.1040	0.0131
27	Saitama	11100	139.38	35.51	213.3	0.048	0.152	0.2703	-0.0359	0.0203	-0.0153	-0.0082
28	Ichihara	12219	140.12	35.50	229.3	0.103	0.327	0.4405	0.0098	0.0020	0.0188	-0.0067
29	Shinjuku	13104	139.70	35.70	224.6	0.233	0.565	0.5674	0.0039	0.0090	-0.0058	-0.0026
30	Yokohama	14100	139.38	35.26	253.1	0.062	0.325	0.4251	-0.0428	0.0638	-0.0435	0.0021
31	Kawasaki	14130	139.42	35.31	241.7	0.161	0.384	0.4457	-0.0037	0.0061	-0.0034	0.0033
32	Yokosuka	14201	139.68	35.28	267.6	0.086	0.430	0.3466	-0.0662	0.0251	-0.0212	0.0022
33	Chigasaki	14207	139.40	35.33	274.3	0.079	0.137	0.3602	-0.0127	0.0413	-0.0284	-0.0001
34	Shibata	15206	139.33	37.95	161.4	0.000	0.000	0.0388	-0.0385	0.0591	-0.0181	0.0166
35	Aga	15385	139.27	37.40	141.8	0.024	0.019	0.1921	-0.0028	0.1412	-0.1038	0.0070
36	Minamiuonuma	15460	138.52	37.03	188.8	0.000	0.184	0.0233	-0.0606	0.0190	0.0455	0.0279

*'distance' denotes the distance (km) between the spot and Fukushima Daiich Power Plant.

Figure 5 shows that the estimated spot-specific air dose rate of radiation decreased at most spots after adjusting for the theoretical values due to the composite half-life model. About 8% excess reduction rates per 100 days in average were estimated. A characteristic spatial pattern of rain effect on the air dose rate was represented in the left panel of Figure 6, that is, when it was rainy day the air dose rates became lower at most 27% in a neighborhood of the nuclear power plants, on the other hand they became higher at most 15% in distant regions from the nuclear power plants. The spot-specific estimated interaction effects of rain and the elapsed time since the accident were shown in the right panel of Figure 6, where the geographical distribution suggests a negative correlation with the rain effect. As for wind effect, it is shown from Figure 7 that the air dose rate of radiation tend to low on a day with south-wind blowing in the shoreline of Tokyo bay area. In the other region we can give no clear explanation for the effect of south-wind. Figure 8 shows pair-wise correlations between residuals of two different spots, in which relatively high correlations (> 0.3) are observed among neighboring spots, and their correlations are diminishing in the distance more than 100km. Our model was fitted very well to the observed data. As an illustration, we show here the fitted values of air dose rates of radiation and observed ones at Fukushima City and Iitate Village in Figure 9, where the dashed curves represent the fitted values due to the composite half life model without any environmental explanatory variable. It is shown that the air dose rates of radiation at Iitate were almost completely explained through the composite half life model while those at Fukushima were more quickly decreasing than the expected trend through the composite half life model.

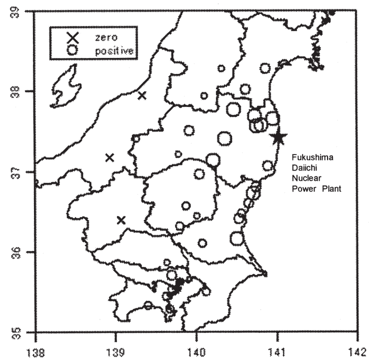

Figure 2. Estimated spot-specific initial air dose rate of radiation ($\hat{\beta}_1$) due to Cs. The symbol "★" represents the location of Fukushima Daiichi Power Plant.

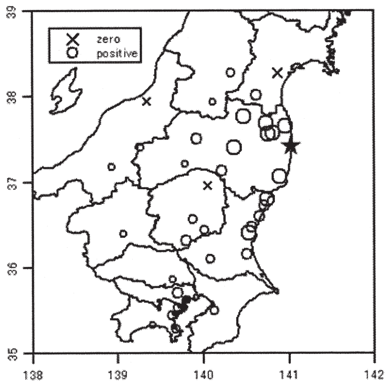

Figure 3. Estimated spot-specific initial air dose rate of radiation due to I131 ($\hat{\beta}_2$)

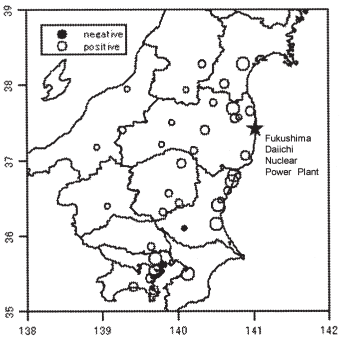

Figure 4. Spot-specific estimated effects ($\hat{\gamma}_1$) of dose rates of the day before

Black and white circles indicate positive and negative values, respectively. The size of circle indicates the magnitude of the value. The dose rate of the day is positively correlated with that of the day before at most spots.

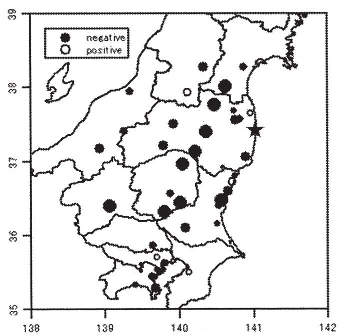

Figure 5. Spot-specific estimated effects ($\hat{\gamma}_2$) of elapsed time from the accident.

The air dose rates of radiation were decreasing day by day over the observed period at most spots after adjustment for the composite half-life model of radio-isotopes.

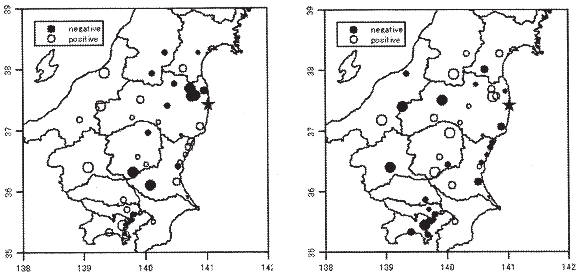

Figure 6. Spot-specific estimated coefficients of rain ($\hat{\gamma}_3$) and interactions of rain and time ($\hat{\gamma}_4$)

When it was rainy day, the dose rates decreased in around the nuclear power plants, they increased along shore lines on the other hand.

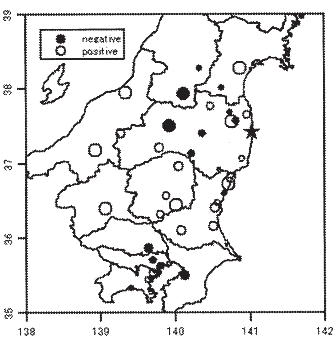

Figure 7. Spot-specific estimated effects ($\hat{\gamma}_5$) of south wind

It is shown that the air dose rates of radiation tend to low on a day with south wind blowing in the shoreline of Tokyo Bay.

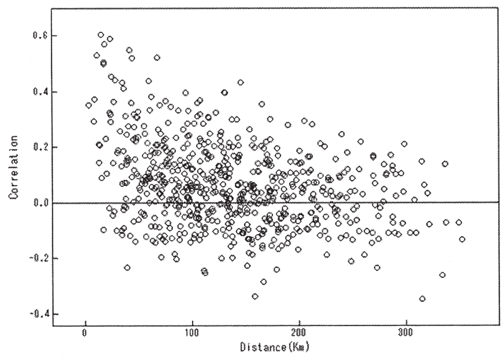

Figure 8. Correlation coefficients between residuals of two different spots by distance.

Relatively high correlation coefficients appear between residuals of two close spots, which implies that some common unknown factors are shared among them.

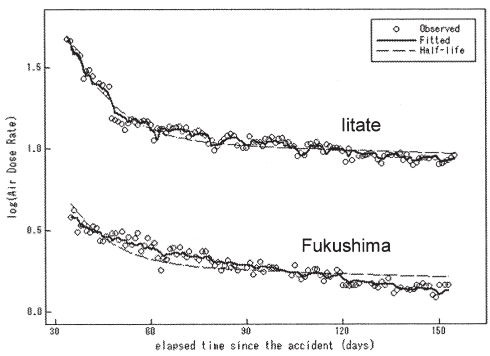

Figure 9. Observed dose rates of radiation and the fitted ones at Fukushima City and Iitate Village

The dashed curves represent the fitted values due to the composite half-life model without any environmental explanatory variable.

4. Discussion

The observed air dose rates of radiation had different fluctuations in each spots, which is thought to be due to various measurement errors such as a precision of instrument, a setting altitude of the instrument, etc. Our interest was not in a precise prediction of air dose rate but in estimations of degrees of involvement of factors that effect on air dose rates after being adjusted by decreasing due to half-lives of radioactive materials. So, we just analyzed the data of measurements for each spot separately. It is reported that intense rainfall in June and July can cause an additional air dose rate due to wet deposition of radio-nuclides [10]. Our result showed that the effects of 'rain' on air dose rates were different in each spots. Why rainfalls have the opposite effects between the neighboring region and the distant region of the nuclear power plants? So far we give no clear explanation to the question. The air dose rates of radiation in the shorelines of Kanto area tend to low on a day blowing south wind. We also cannot give the clear explanation about it. We consider that our model has a goodness of fit in a sense that every distant spots further than 150km have almost no common variation in their observed air dose rates of radiation which was implied by Figure 6. According to the results shown in Table 2, reduction of the air dose rates of radiation per one year were expected to be more than 19% in the median compared to the theoretical air dose rate obtained by the composite half-life model. It may be partly explained by migration of Cs137 in environment.

Acknowledgements

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Effective doses among residents living 37 km northwest of the Fukushima Daiichi Nuclear Power Plant

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Abstract

We estimated external and internal effective doses for 15 residents who lived approximately 37 km northwest of the Fukushima Dai-ichi Nuclear Power Plant. The average cumulative effective dose was 8.4 mSv for adults and 5.1 mSv for children. The average committed effective dose from ^{134}Cs and ^{137}Cs was 0.055 mSv for adults and 0.029 mSv for children. The committed effective doses for thyroid gland was 27-66 mSv at maximum.

Introduction

A catastrophic nuclear accident occurred on March 11, 2011, at the Fukushima Daiichi Nuclear Power Plant in Japan, which was run by the Tokyo Electric Power Company. Monitoring of air and sampling of soils have been performed and are still in progress. Radioactive plumes were not distributed uniformly, but in various directions from the power plant mainly due to wind. Iitate Village and Kawamata Town lie about 37 km northwest of the power plant and is known to be one of the highly contaminated areas. The purpose of this study was to estimate cumulative effective doses and committed effective doses of residents in the Iitate Village and Kawamata Town.area. The maximum dose for thyroid gland was also estimated through urinary bioassay method.

Materials and Methods

Samples

Iitate Village and Kawamata Town are located about 37 km northwest of the Fukushima Daiichi Nuclear Power Plant. Surveyed persons were 10 residents in Iitate Village (G6-G15) and 5 residents (G1-G5) in Kawamata Town (10 males and 5 females; age range of 4–77 years). We interviewed the residents about where they stayed, what kind of food they ate and what kind of structures (Japanese-style wooden houses or concrete buildings) they lived in from March 11 to May 5. To measure internal dose, urine samples were collected twice; on May 5 (first sample, 54 d after deposition) and from May 29 to June 6 (second sample, 78–85 d after deposition).

Air dose rate

To estimate the external exposure of residents, air dose rates over time are needed. Such data are available from monitoring post data at the Iitate Village and Kawamata Town offices through the home page of Fukushima prefecture. Moreover, the air dose rates outside the homes of each resident were measured 1 m above the ground with a scintillation survey meter (TCS-161 Aloka Co. Ltd., Tokyo, Japan) on May 5. Shielding coefficients were measured to correct the external dose rate for where each resident had been staying. Coefficients were 1, 0.8, 0.4 and 0.1 for outside, inside a car, inside a Japanese wooden house or inside a concrete building, respectively.

Bioassay of urine samples

Urine samples were poured directly into a 100 ml Teflon vial (4.5 cm diameter × 6.5 cm long; inner volume, 110 ml), and a screw cap was tightly closed. Gamma-ray measurement was performed with a low-background Ge detector. Fission products ^{131}I, ^{134}Cs and ^{137}Cs were detected. The radioactivity of each fission product was obtained in Bq/l, and the radioactivity at the time of sampling was determined by correcting the elapsed time from sampling to measurement.

Results and Discussion

Estimation of cumulative effective doses

The cumulative effective dose at the location of monitoring post can be obtained by integrating the air dose rate. Individual effective dose can be calculated from the air dose scaled by a factor of the air dose rate measured outside the individual home of each resident 1 m height above the ground divided by the monitoring post data and duration time and shielding factor (outdoor, inside Japanese wooden house or concrete building, and inside a car). A conversion factor of 0.8 from dose equivalent of 1 cm depth to effective dose was adopted. The estimated cumulative effective doses for 15 residents are shown in Fig. 1. Effective doses for adults were 6.6–11.2 mSv, with an average of 8.4 mSv, and those for children were 3.9–5.6 mSv, with an average of 5.1 mSv.

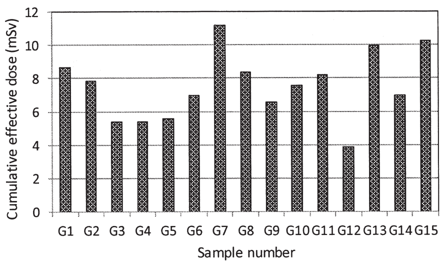

Fig. 1 Cumulative effective doses for 15 residents up to 54 d from the deposition. G3–G5 and G12 are children, and the others are adults.

In this study, we used the air dose rates 1 m above the ground to calculate the effective doses for children. However, air dose rates 50 cm above the ground would have been more suitable for children because who are generally shorter than adults and air doses at this height were 30 % higher than at 1 m. Thus, the actual effective dose for children might be 30 % higher than reported (3.9-5.4 mSv). In addition, children are known to be about three times more sensitive than adults to radiation (Preston 2003). Taking these factors into consideration and neglecting dose rate effect if any, children's doses could be 15-21 mSv. The government of Japan announced 20 mSv/y as the maximum permissive level of radiation exposure in the case of an emergency. Since residents about 37 km from the power plant were already reaching this level at 54 d after the deposition, they should have been evacuated at that time.

Estimation of committed effective doses from radiocesium

The radioactivity concentration of ^{131}I, ^{134}Cs and ^{137}Cs in urine samples were determined and ^{131}I was observed in the first sampling but not in the second sampling. Because the short-lived ^{131}I was observed in only five residents, internal radioactive contamination was considered to occur through ingestion of contaminated foods.

Total excretion of radioactivity per day is expressed by radionuclide concentration in urine A_u (Bq/l), total urinary volume per day M_u (l) and ratio of radionuclide in urine to total excretion F as $X_i=A_uM_u/F$. The total amount of urine volume per day was reported as 1–2 l for adults. In the present study, total urine volume was assumed to be 3% of bodyweight. The ratio F was taken to be 0.8 from ICRP Pub 54 (1989), which was replaced with ICRP Pub 78 (1998).

The retaining radioactivity in the whole body at *t* days after intake is expressed with initial intake I_0 (Bq) and retention function R(t) as follows, $I(t)=I_0R(t)$. The total excretion of radioactivity from the whole body at *t* days after intake is expressed as the time differential of I(t) as $X(t)=dI/dt=I_0Y(t)$, where Y(t) is the excretion rate for individual radionuclides. Thus, the initial intake radioactivity, I_0(Bq) is expressed as follows, $I_0=A_uM_u/(FY(t))$. The retention function of Cs is described with two components in Pacific Northwest National Laboratory (PNNL) report (PNNL-15614, 2009) and also ICRP Pub 78(1997) : one is 10 % with a clearance half-time of two days and second one is 90 % with a half-time of 110 days.

As a result, the committed effective dose is evaluated as $E(70)=I_0e(70)$, where, e(70) (mSv/Bq) is an effective dose conversion coefficient for the general public until 70 y old. The age-dependent effective dose coefficients for ingestion of ^{137}Cs and ^{134}Cs are given in ICRP Pub 72 (1996). Committed equivalent doses of ^{134}Cs, ^{137}Cs and total radiocesium for individuals and the ratio of external to total radiocesium doses are given in Fig. 2. Committed equivalent doses from radiocesium were 0.022–0.110 mSv for adults and 0.007–0.036 mSv for children.

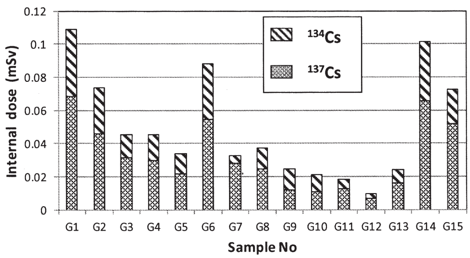

Fig. 2. Committed effective doses from ^{137}Cs and ^{134}Cs. G3–G5 and G12 are children, and the others are adults.

Estimation of effective dose from ^{131}I

Generally, 30 % of iodine is concentrated in the thyroid gland and 70% is excreted in urine at 1 d after intake. The retention function and urine excretion rate of ^{131}I ingestion are given in Fig. 7 based on PNNL-15614 (2009) and ICRP Pub 78 (1997). The urine excretion rate at 46 d was graphically obtained as 1.9×10^{-5}. The age-dependent effective dose coefficient e(70) for ^{131}I is given in ICRP Pub 72 (1996). Estimated effective doses are given in Table 2. The thyroid effective doses are 27-66 mSv for adults and 44 mSv for one of children.

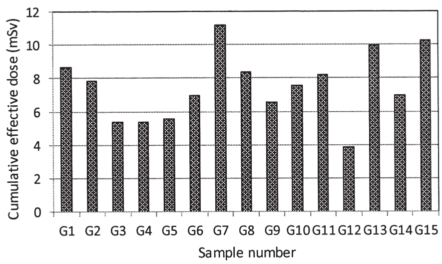

Fig.3 Thyroid effective doses for 15 residents. G3–G5 and G12 are children, and the others are adults.

Conclusion

The average cumulative effective dose of 15 residents about 37 km northwest of the Fukushima Daiichi Nuclear Power Plant was about 8.4 mSv for adults and about 5.1 mSv for children up to 54 d after deposition. The committed effective dose from radiocesium was less than 0.11 mSv for all residents surveyed, which was considerably lower than external effective dose. Committed effective dose for thyroid gland was estimated 27-66 mSv at maximum.

Acknowledgement

The authors appreciate the cooperation of the 15 surveyed residents and related persons in Fukushima. This research has been approved by the ethics committee of Hiroshima University (Epidemiological Study No. 425).

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Reconstruction of individual doses to the Semipalatinsk historical cohort subjects: methods and input parameters

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Abstract

A description of the methods to reconstruct the deterministic estimates of individual whole-body dose from external irradiation and dose to thyroid from internal irradiation to radioiodines (^{131}I and ^{133}I) for the subjects (more than 10,000 people) of the Semipalatinsk historical cohort, formed from the residents of ten settlements (Dolon, Kanonerka, Mostik, Cheremushki, Znamenka, Kainar, Karaul, Sarzhal, Kaskabulak and Kundyzhdy) radioactively contaminated during the atmospheric nuclear weapon testing at the Semipalatinsk Nuclear Test Site (SNTS) has been presented. Four significant nuclear tests (#1 - 29 August 1949, #2 - 24 September 1951, #4 - 12 August 1953, and #28 - 24 August 1956) that provided the major contribution to radiation doses to the cohort subjects were identified. For each above mentioned settlement the estimates of settlement-average absorbed dose to air from fallout arrival time to infinity and of radioiodine concentration in pasture grass at the fallout arrival time were calculated. In order to assess settlement-average absorbed dose to air from fallout arrival time to infinity the following sources of input data (if any) related to radiological conditions are used: (1) historical fallout patterns showing isopleths of dose in air from the fallout time of arrival until infinity, (2) historical survey meter readings (exposure rate measurements), (3) present-day thermoluminescence measurements in bricks, (4) present-day ^{137}Cs inventory, and (5) present-day ESR measurements of tooth enamel. Whole-body dose from external irradiation has been mainly determined by the radionuclides deposited on the ground following the passage of the radioactive cloud through a settlement. Dose to thyroid from internal irradiation to radioiodines has been mainly determined due to consumption of contaminated cow's (horse's) milk (koumiss) from grazing animals put on pasture. A joint U.S./Russian methodology has been applied to derive doses from external and internal irradiation. In order to derive estimates of individual whole-body dose from external irradiation and dose to thyroid from internal irradiation to radioiodines a restricted set of input personal data on the cohort subjects (date of birth, ethnicity, residence history) available in the registry created by the scientists from Kazakhstan and Japan is used. Because of lack of other personal data a life-style and dietary habits typical for a resident from specific age-group and ethnicity is used in dose reconstruction.

INTRODUCTION

The purpose of this paper is to describe (1) the methods and (2) input parameters that were used to reconstruct the deterministic estimates of individual whole-body dose from external irradiation and dose to thyroid from internal irradiation to radioiodines (^{131}I and ^{133}I) for the subjects (more than 10,000 people) of the Semipalatinsk historical cohort, formed from the residents of ten settlements (Dolon, Kanonerka, Mostik, Cheremushki, Znamenka, Kainar, Karaul, Sarzhal, Kaskabulak and Kundyzhdy) radioactively contaminated during the atmospheric nuclear weapon testing at the Semipalatinsk Nuclear Test Site (SNTS). Analysis of available data on radioactive fallout following atmospheric nuclear tests conducted at the SNTS allowed for identification of the most significant tests that provided the main contribution to the exposure to the residents from the considered settlements (Table 1). Each test presented in column 2 of Table 1 is responsible for contributing of more than 90% of total exposure to the residents of corresponding settlement during the whole period of the atmospheric nuclear testing (1949-1962). A joint U.S./Russian dose reconstruction methodology that combines the experience of scientists in Russia and the U.S. working in this area is used here [1, 2]. The U.S. scientists developed 10-term exponential functions describing exposure rate time profile for the U.S. nuclear test devices of three different designs: (1) Trinity for devices fueled with ^{239}Pu but surrounded with heavy steel and lead shielding, (2) Turbaloy, a simulated weapon fueled by ^{238}U, and (3) Tesla, for devices fueled by pure ^{239}Pu [1]. In the framework of the joint methodology each test at the SNTS was assigned with one of the three above-mentioned U.S. tests on the basis of similarity in design and fuel (see column 3 in Table 1).

Table 1. The most significant tests conducted at the SNTS that provided the main contribution to the exposure to the residents from the considered settlements.

Settlement	Main nuclear test (Semipalatinsk)	Surrogate nuclear test (Nevada)
Cheremushki	#1	Trinity (same as #1 at the SNTS)
Dolon	#1	
Kanonerka	#1	
Mostik	#1	
Kainar	#2	Tesla (typical Pu test)
Sarzhal	#4	Turbaloy (thermonuclear test)
Karaul	#4	
Kundyzhdy	#4	
Kaskabulak	#18	Tesla (typical Pu test)
Znamenka	#28	

Trajectories of radioactive clouds of the most significant tests conducted at the SNTS and location of the settlements considered in this paper are presented in Fig.1 [3]. Kundyzhdy (not shown in this map) is located below Karaul along the trajectory of test #4.

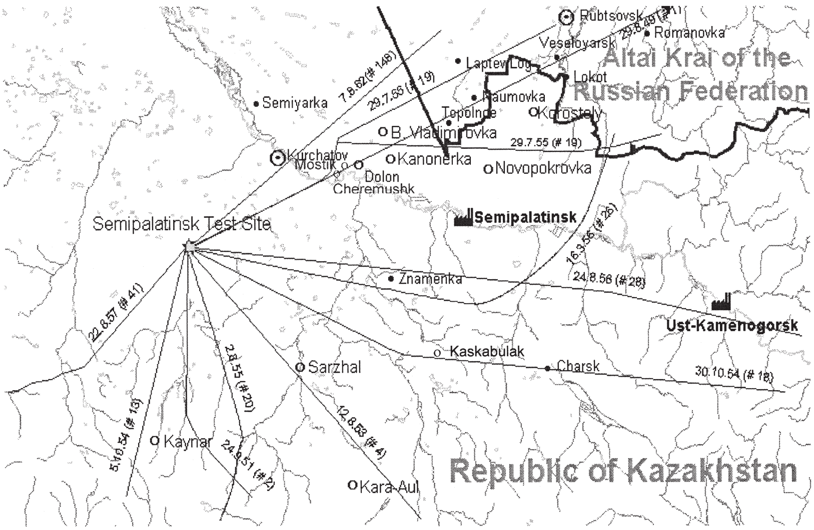

Fig. 1. Trajectories of radioactive clouds of the most significant tests conducted at the SNTS and location of the settlements considered in this paper [3].

ESTIMATION OF WHOLE-BODY DOSE FROM EXTERNAL IRRADIATION

The equation to assess a whole-body dose, D_{body}, is as follows:

$$D_{body} = D_{air} \times CF \times [t_{oudoors}+(t_{day} - t_{outdoors})/k_{shield}]/t_{day} \quad (1)$$

where D_{air} is a settlement-average dose to air from the time of fallout arrival to infinity, Gy;

CF is a conversion factor to convert absorbed dose to air to absorbed dose to the body (Gy per Gy) depending upon age (assuming 100% outdoor occupancy), dimensionless;

$t_{outdoors}$ is time spent outdoors, h;

t_{day}=24 h, hours in a day; and

k_{shield} is the shielding factor related to the ratio of the outdoor and indoor exposure rates for gamma radiation emitted from the activity deposited on the ground, dimensionless.

The age-dependent values of parameters CF and $t_{outdoors}$ are presented in Table 2. Selection of the values of parameter $t_{outdoors}$ was done accounting for the data given in publications [3, 4] according to which there is some difference in time spent outdoors between people of the same age but different ethnicity. In addition, the residents of Russian ethnicity typically lived in wooden houses, while the residents of Kazakh ethnicity lived in adobe houses. The value of shielding parameter for wooden houses regarding decrease of the exposure emitted from the activity deposited on the ground was estimated to be equal to 3, while that value for adobe houses was found to be equal to 13 [3].

Table 2. The age-dependent values of parameters CF and $t_{outdoors}$ used in assessing the estimates of whole-body dose from external irradiation.

Age	CF, conversion factor Gy per Gy [5]	Hours per day spent outdoors (h) [3, 4]	
		Kazakhs	Russians
3 mo	0.95	1	0.5
1 y	0.91	5	9
5 y	0.88	7	9
10 y	0.83	10 (5)$^{\&}$	10 (6)$^{\&}$
15 y	0.81	13 (5)$^{\&}$	11 (3)$^{\&}$
Adult	0.79	16	16

$^{\&}$ - for period starting from September 1

In order to assess settlement-average absorbed dose to air from fallout arrival time to infinity the following sources of input data (if any) related to radiological conditions were used: (1) historical fallout patterns showing isopleths of dose in air from the fallout time of arrival until infinity, (2) historical survey meter readings (exposure rate measurements), (3) present-day thermoluminescence measurements in bricks, (4) present-day ^{137}Cs inventory, and (5) present-day ESR measurements of tooth enamel. Whole-body dose from external irradiation has been mainly determined by the radionuclides deposited on the ground, while external irradiation from the radioactive cloud during its passage through a settlement contributed substantially less (a few percent) compared to the former. The most important parameter is historical record of the exposure rate measured soon following fallout in a settlement considered. However, only for five settlements of interest (Dolon, Mostik, Kainar, Sarzhal, and Karaul) such information was available for assessing dose to air D_{air}, using the method described in detail in [1]. For the other five settlements (Cheremushki, Kanonerka, Kundyzhdy, Kaskabulak, Znamenka) the other input data were used for reconstruction dose to air.

ESTIMATION OF DOSE TO THYROID FROM INTERNAL IRRADIATION TO RADIOIODINES

It is important to stress that the main pathway of radioiodines intake for the residents of the settlements around the SNTS is ingestion with milk of cows and mares. Inhalation intake of radioiodines during the passage of the radioactive cloud is negligible compared to ingestion intake. Leafy vegetables were not included in typical diet in 1949-1962. So, the equation to assess internal dose to thyroid from ingestion of i-th isotope of radioiodine for age (k) will be as follows:

$$D_{i,k} = DF_{i,k} \times V_{m,k} \times \int_0^{t_2} C_{m,i}(t)dt \,/\, p_{m,i,k} \qquad (2)$$

where $DF_{i,k}$ is age-dependent thyroid dose factor from ingestion of radioiodine i, Gy Bq^{-1};

$V_{m,k}$ is age-dependent milk consumption rate, L d^{-1};

$C_{m,i}(t)$ is concentration of radioiodine i in milk, Bq L^{-1};

$p_{m,i,k}$ is age-dependent fraction of intake of radioiodine i with milk in the entire intake, dimensionless.

Only two isotopes of radioiodine (^{131}I and ^{133}I) are important to assess dose to thyroid. Age-dependent dose factors for ingestion intake $DF_{i,k}$ are taken from [6]. One of the main differences between Russians and Kazakhs is that Russians drank only cow's milk, while Kazakhs drank both cow's and horse's (koumiss) milk. The values of parameter $V_{m,k}$ derived from [3, 4] are given in Table 3. Accounting for that ingestion of radioiodines with milk is the dominant pathway a constant value of $p_{m,i,k}$ equal to 0.9 was chosen for the residents of all ages.

Table 3. The age-dependent values of milk consumption rate $V_{m,k}$ used in assessing the estimates of dose to thyroid.

Age	Kazakhs (cow's milk)	Russians (cow's milk)	Kazakhs (koumiss)
3 mo	0.18[&]	0.4[&]	-
1 y	0.25	0.55	0.1
5 y	0.4	0.7	0.25
10 y	0.4	0.55	0.25
15 y	0.4	0.8	0.45
Adult	0.4	0.8	0.45

[&] - for non breast feeding

Concentration of radioiodine i in milk at time t is estimated as:

$$C_{m,i}(t) = \beta_i \times TF_{m,i} \times \int_0^t C_{gr,i}(\tau) \times Q_f \times \lambda_{c,i} \times e^{-(\lambda_{c,i}+\lambda_i)\times(t-\tau)} d\tau \qquad (3)$$

where $C_{gr,i}(t)$ is concentration of radioiodine i in pasture grass at time t, Bq kg^{-1};

β_i is solubility of radioiodine i in biologically active fraction of fallout [7];

$TF_{m,i}$ is feed-to-milk of cow (mare) transfer factor for radioiodine i, d L^{-1} [8];

Q_f is daily intake rate of pasture grass by cow (mare), kg d^{-1} wet [8];

$\lambda_{c,i}$ is biological removal rate of radioiodine i from cow (mare) to milk, d^{-1} [8];

λ_i is radioactive decay constant for radioiodine i, d^{-1}.

Concentration of radioiodine i in grass at time t is estimated as:

$$C_{gr,i}(t) = C_{gr,i}(0) \times \exp(-(\lambda_{gr,i} + \lambda_i)\times t) \qquad (4)$$

where $C_{gr,i}(0)$ is concentration of radioiodine i in pasture grass at time-of-arrival (TOA), Bq kg^{-1};

$\lambda_{gr,i}$ is weathering removal rate of radioiodine i from pasture grass, d^{-1} [8];

t is time counted from TOA, d.

Concentration of radioiodine i in grass at TOA is estimated as:

$$C_{gr,i}(0) = C_{gr,i}(TOA) = C_{gr,i}(H+12h) \times \exp(-(\lambda_{gr,i} + \lambda_i) \times (TOA/24-0.5)) \qquad (5)$$

where $C_{gr,i}(H+12h)$ is concentration of radioiodine i in pasture grass at 12 h after detonation, Bq kg^{-1};

TOA is fallout arrival time expressed in h.

Concentration of radioiodine i in grass at t = H+12h is estimated as:

$$C_{gr,i}(t) = P(t) \times (q_i/P)(t) \times N_{50} \times alpha \quad (6)$$

where P(t) is the exposure rate at time T=H+12h, mR/h;

$(q_i/P)(t)$ is the ratio of ground deposition density of radioiodine i to the exposure rate at H+12h, (kBq/m2)/(mR/h);

N_{50} is fraction of the activity in fallout assigned to the biologically active particles with diameter d≤50 μm [7];

alpha is mass interception factor, m^2 kg^{-1} [7].

Parameters P(t), q_i, β_i, N_{50}, TOA are derived from available input data related to: (1) a nuclear explosion, (2) meteorological conditions along the radioactive trace, and (3) radiological conditions for a settlement.

RESULTS AND DISCUSSION

Estimates of settlement-average dose to air are presented in Table 4 (third column) with indication of what input information (fourth column) was used for dose reconstruction. In addition, the estimates of ground deposition densities of the most important radionuclides (q_{137} for ^{137}Cs, q_{131} for ^{131}I, and q_{133} for ^{133}I) in the settlements are given in columns 5 through 7 in Table 4. Estimates of the values of parameters q_{137}, q_{131}, and q_{133} were done assuming various degree of fractionation between refractory and volatile elements in the settlements considered. No fractionation was assumed between volatile elements of iodine and cesium.

Table 4. Estimates of settlement-average dose and of ground deposition densities of the most important radionuclides (q_{137} for ^{137}Cs, q_{131} for ^{131}I, and q_{133} for ^{133}I) in the settlements of interest.

Settlement	TOA, h	Dose to air, mGy	Major parameters	q_{137}, kBq/m^2	q_{131}, MBq/m^2	q_{133}, MBq/m^2
Cheremushki	1.9	260	map, ^{137}Cs, ESR	2.7	2.1	28
Dolon	2.4	430	$P(t_m)$	4.7	3.8	49
Kanonerka	3.0	220	TL, map	2.6	2.1	27
Mostik	2.0	140	$P(t_m)$	1.5	1.2	16
Kainar	5.2	120	$P(t_m)$	2.9	2.7	32
Sarzhal	1.7	890	$P(t_m)$	8.4	5.3	75
Karaul	2.9	740	$P(t_m)$	8.4	6.3	81
Kundyzhdy	3.8	10	Map	0.12	0.095	1.2
Kaskabulak	5.4	5	Map	0.40	0.36	4.3
Znamenka	1.8	70	Map	0.85	0.61	8.4

It is worth noting that calculations done according to [7] showed that the major activity of radioiodines deposited on the ground in the settlements considered is attached to the fallout particles with diameter higher than 50 μm, which cannot be retained by vegetation and dropped on the ground. For example, only 3.2% of total deposited activity was thought to have been retained by pasture grass in Dolon, 2.6% - in Cheremushki, 0.7% - in Znamenka. In addition, due to low solubility only small amount of radioiodines (about 20 %) ingested with pasture grass is thought to have been absorbed from the gut to cow's (horse's) body fluids. Thus, discriminating factor of about 100-1000 resulted in much less estimates of dose to thyroid for the residents leaving in the areas neighboring to the SNTS compared to that for the residents leaving around the Chernobyl NPP in case of contamination of residential settlements with the same level of deposition density of radioiodines.

The estimates of individual whole-body dose from external irradiation and dose to thyroid from internal irradiation to radioiodines for the subjects of the Semipalatinsk historical cohort depending upon residential settlement, age, and ethnicity are presented in companion paper [9].

CONCLUSIONS

To reconstruct settlement-average dose to air the historical exposure rate measurements were used only for five settlements (Dolon, Mostik, Kainar, Sarzhal, and Karaul), while other input information (fallout patterns, TL-, ESR-measurements, ^{137}Cs deposition density) was used for five settlements (Cheremushki, Kanonerka, Kundyzhdy, Kaskabulak, Znamenka).

To reconstruct individual whole body dose from external exposure and thyroid dose to radioiodines from internal exposure available personal input data on (a) residential settlement, (b) age and (c) ethnicity were used.

Due to low fraction of total activity related to fallout particles with AMAD less than 50 μm and low solubility of them the estimates of dose to thyroid from radioiodines for the residents leaving near the SNTS are much less (by a factor of 100-1000) than the estimates of thyroid dose for the residents leaving around the Chernobyl NPP in case of contamination of residential settlements with the same level of deposition density of radioiodines.

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Reconstruction of individual doses to the Semipalatinsk historical cohort subjects: preliminary results

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Abstract

At present scientists from Russia, Japan, the U.S. and Kazakhstan take part in an international scientific research on reconstruction of individual doses for the population of 10 settlements: Dolon, Kanonerka, Mostik, Cheremushki, Znamenka, Kainar, Karaul, Sarzhal, Kaskabulak and Kundyzhdy, included in the so-called Semipalatinsk historical cohort. All the calculations are conducted in accordance with a U.S./Russian joint methodology. Individual input data, such as date of birth, ethnicity and so on, are obtained from the register of the residents who lived on the territory of local radioactive fallout due to the nuclear tests on the Semipalatinsk Nuclear Test Site. This register was created by the scientists in both Kazakhstan and Japan. The register contains data on 11,370 persons, lived in the above mentioned settlements at the time of the most significant nuclear tests. In addition, the register contains data on the persons who were born or arrived to the above mentioned settlements after the most significant tests. Individual whole body doses from external irradiation and internal doses to thyroid due to the ingestion of ^{131}I and ^{133}I for more than 11,000 persons included in the Semipalatinsk historical cohort have been estimated. According to the preliminary results of dose assessment, the maximum whole body dose (260 mGy) was received by adult non Kazakh residents of Dolon. In turn, the maximum thyroid dose (310 mGy) was received by 3-7 years old Kazakh residents of Kainar. Evacuation of the residents of villages Sarzhal and Karaul has been taken into account. Due to evacuation either whole body or thyroid dose to the residents of Sarzhal and Karaul were substantially less than they could have been without evacuation. Dose reduction factor in case of whole body dose was estimated to be equal to 4.6 (Sarzhal) and 2.8 (Karaul), while in case of thyroid dose – 10.6 (Sarzhal) and 4.6 (Karaul).

INTRODUCTION

At present scientists from Russia, Japan, the U.S. and Kazakhstan take part in an international scientific research on reconstruction of individual doses to the subjects of the Semipalatinsk historical cohort. This cohort consists of about 20 thousand residents of 10 settlements located in the vicinity of the Semipalatinsk Nuclear Test Site (SNTS): Cheremushki, Dolon, Kanonerka, Mostik, Kainar, Sarzhal, Karaul, Kundyzhdy, Kaskabulak and Znamenka. The purpose of the research is to reconstruct individual whole body doses from external irradiation and individual doses to thyroid due to internal irradiation to ^{131}I and ^{133}I.

The most significant nuclear test, in terms of radioactive contamination and exposure to the residents, is chosen for every settlement listed above. Test #1 conducted on August 29, 1949 (22 kt) is chosen for Dolon, Mostik, Kanonerka and Cheremushki, test #2 conducted on September 24, 1951 (38 kt) – for Kainar, test #4 conducted on August 12, 1953 (400 kt) – for Sarzhal, Karaul and Kundyzhdy, test #18 conducted on October 30, 1954 (10 kt) – for Kaskabulak, test #28 conducted on August 24, 1956 (27 kt) – for Znamenka. The necessary data on these nuclear tests such as date, height above ground, maximum height of radioactive cloud, average wind speed, trace of the radioactive cloud are available in the published literature [1]. All the calculations, including assessment of dose to air, are conducted in accordance with a U.S./Russian joint methodology [2].

ANALYSIS OF AVAILABLE DATA

The term "individualization" implies using individual data such as place of residence, age at the time of irradiation, gender, behavior pattern, dietary, etc. In order to obtain such information data available in the register of the residents who lived on the territory of local radioactive fallout due to the nuclear tests on the SNTS were analyzed. This register was created by the scientists in both Japan (Radiation Effects Research Foundation, Hiroshima) and Kazakhstan (Scientific Research Institute for Radiation Medicine and Ecology, Semipalatinsk). It's based on individual interviewing of the residents, special questionnaires and official documents such as passport, birth certificate, etc.

The register contains data on a great number of inhabitants of the Semipalatinsk region since the time of the nuclear tests till nowadays. The content of the register is as follows: ID number, full name, gender, ethnicity, date of birth, date and cause of death (for deceased), diseases (if any), close relatives, settlement and period of residence, occupation, work type (indoors, fieldwork, cattle management, etc.), harmful working conditions: petrochemicals, toxic substances, radioactivity, heavy metals, dust pollution, etc. (if any), date of interview. Regarding the Semipalatinsk historical cohort, data on 11,370 persons, lived in the above mentioned settlements at the time of the most significant nuclear tests, are available in the register. The distribution of them throughout the settlements under consideration is shown in Table 1. Among them 47 % are male and 53 % are female. In addition, the register contains data on the persons who were born or arrived to the settlements under consideration after the most significant tests. Unfortunately, information on the considered group of residents isn't complete. For example, occupation is specified only for about 5 % of these 11,370 persons. So, the following types of data are chosen for calculations: place of residence, date of birth, date of arrival to the settlement, ethnicity. Statistical analysis was applied to these data.

The persons under consideration are divided into six groups according to their age at the start of irradiation. Age groups are chosen according to the ICRP recommendations. Therefore, age distribution of the residents of the settlements listed above at the time of the most significant nuclear tests is as follows: 0-12 m – 2.7 %; 1-2 y – 5.7 %; 3-7 y – 9.0 %; 8-12 y – 13.9 %; 13-17 y – 14.0 %; adult (18 years and older) – 54.9 %. In turn, distribution of the considered residents by ethnicity is as follows: 47 % - Kazakh; 38 % - Russian; 11 % - other ethnicities (more than 10 different ethnicities including German, Tatar, Chechen, Ukrainian, Pole and others); 4 % - ethnicity is not specified. So, the residents were predominantly Kazakh or Russian. Moreover, at the time of the nuclear tests on the SNTS five settlements were inhabited mostly by Russians: Cheremushki (49%), Dolon (61%), Kanonerka (82%), Mostik (53%), and Znamenka (76%), and another five settlements – by Kazakhs: Kainar (95%), Sarzhal (74%), Karaul (73%), Kundyzhdy (97%) and Kaskabulak (94%).

Table 1. The distribution of the 11370 persons throughout the settlements under consideration.

Settlement	Number of persons	Settlement	Number of persons
Cheremushki	705	Sarzhal	988
Dolon	1687	Karaul	1995
Kanonerka	2929	Kundyzhdy	656
Mostik	830	Kaskabulak	536
Kainar	998	Znamenka	46

INDIVIDUAL WHOLE BODY DOSE FROM EXTERNAL IRRADIATION

Two factors sufficiently affecting individual whole body dose are considered within this work: age and ethnicity. It is supposed that gender did not have a significant influence on whole body dose. The values of age-dependent conversion factors from absorbed dose to air to absorbed dose in body (Gy per Gy) were taken from [3]. Behavior pattern and number of hours spent outdoors per day do essentially depend either on age or on ethnicity. In case of the nuclear tests #1, #4 and #28 conducted at the end of August summer vacation of schoolchildren has been taken into account [4].

Building material of a house plays an important role in protection against external irradiation. At the time of nuclear tests in rural areas of Kazakhstan Russians traditionally used to live in wooden houses and Kazakhs – in adobe houses. It should be noticed that the Semipalatinsk region has specific landscape. The Irtysh river divides it into two parts crossing Semipalatinsk. There is a lot of forest on the right bank of the river, but practically no forest, only steppe – on the left bank. Within this work it is supposed that residents of the villages located on the left bank: Kainar, Sarzhal, Karaul, Kundyzhdy, Kaskabulak and Znamenka, used to live in adobe houses regardless of ethnicity because of lack of wood; in turn, in the villages located on the right bank of Irtysh: Cheremushki, Dolon, Kanonerka and Mostik, Kazakhs used to live in traditional adobe houses and residents of other ethnicities – in wooden houses. It is important to stress, that for the activity deposited on the ground a shielding factor of a wooden house is equal to 3, while shielding factor of an adobe house is equal to 13 [1].

As noted above, at the time of the nuclear tests there were a lot of people of a wide range of ethnicities. Unfortunately, only information on the behavior pattern of Kazakhs or Russians is available in the published literature. So, it seems reasonable to assume that behavior pattern of the inhabitants of ethnicity other than Russian or Kazakh were identical to the behavior pattern of Russians.

Individual whole body doses for more than 11,000 subjects of the Semipalatinsk historical cohort have been estimated. Individual whole body dose range depending on ethnicity for the residents of the settlements under consideration is shown in Table 2. According to the preliminary results of assessment the maximum whole body dose (260 mGy) was received by adult non Kazakh residents of Dolon.

Table 2. Individual whole body dose range depending on ethnicity: K – Kazakh, O – other ethnicities.

Settlement	Dose range, mGy			
	K		O	
	Min	Max	Min	Max
Cheremushki	28	140	86	160
Dolon	47	240	140	**260**
Kanonerka	24	120	73	140
Mostik	15	76	46	86
Kainar	13	66	11	66
Sarzhal	21	110	18	110
Karaul	35	130	31	130
Kundyzhdy	1.1	5.5	3.6	5.5
Kaskabulak	0.55	2.7	0.78	2.7
Znamenka	21	21	23	38

INDIVIDUAL THYROID DOSE DUE TO INTAKE OF RADIOIODINES

Consumption of locally produced milk products is supposed to be the main path of intake of radioiodines. Consumption of leafy vegetables is assumed to be negligible at the time of the nuclear tests. By analogy with the whole body dose, two factors sufficiently affecting individual thyroid dose are considered within this work: age and ethnicity. It is also supposed that gender did not have a significant influence on internal thyroid dose. Age-dependent thyroid dose coefficients for ^{131}I and ^{133}I were taken from [3].

According to the published literature dietary substantially depends on age and ethnicity. Firstly, consumption rate of milk products depends on age. Secondly, it is assumed that only Kazakhs used to consume koumiss (horse milk product), persons of other ethnicities used to consume cow's milk. Moreover, consumption rate of cow's milk substantially depends on ethnicity: Russians consumed much more cow's milk than Kazakhs did [4]. For calculations the dietary of the inhabitants of ethnicity other than Russian or Kazakh is supposed to be identical to the dietary of Russians. Individual thyroid doses due to ingestion of radioiodines for more than 11,000 subjects of the Semipalatinsk historical cohort have been estimated. Individual thyroid dose range depending on ethnicity of the residents of the settlements under consideration is shown in Table 3. According to the preliminary results of assessment the maximum thyroid dose (310 mGy) was received by 3-7 years old Kazakh residents of Kainar.

EFFECTIVENESS OF EVACUATION

Evacuation took place in two of the considered settlements: Sarzhal and Karaul. The residents of Sarzhal were evacuated to non-exposed areas before the nuclear test #4. They returned to Sarzhal 16 days after the event. In turn, the residents of Karaul were hurriedly evacuated during about 5 hours after the nuclear test #4, because of arrival of the radioactive cloud in the settlement. They returned to Karaul 10 days after the date of the nuclear test. It's supposed that the cattle were also evacuated from both villages.

Either whole body or thyroid doses, which could be received by the residents of Sarzhal and Karaul without evacuation, have been calculated. Dose reduction factor due to evacuation in case of whole body dose was estimated to be equal to 4.6 (Sarzhal) and 2.8 (Karaul), while in case of thyroid dose – 10.6 (Sarzhal) and 4.6 (Karaul).

Table 3. Individual thyroid dose range depending on ethnicity: K – Kazakh, O – other ethnicities.

Settlement	Dose range, mGy			
	K		O	
	Min	Max	Min	Max
Cheremushki	4.2	24	2.03	12
Dolon	14	83	6.9	42
Kanonerka	14	79	6.6	40
Mostik	2.8	16	1.4	8.1
Kainar	53	**310**	26	150
Sarzhal	0.11	0.70	0.055	0.32
Karaul	1.5	10	0.79	4.5
Kundyzhdy	0.23	1.4	0.11	0.68
Kaskabulak	11	63	5.2	31
Znamenka	2.5	2.5	0.21	1.3

CONCLUSIONS

Individual whole body doses from external irradiation and internal doses to thyroid due to the ingestion of ^{131}I and ^{133}I for more than 11,000 persons included in the Semipalatinsk historical cohort have been estimated. According to the preliminary results of dose assessment, the maximum whole body dose (260 mGy) was received by adult non Kazakh residents of Dolon. In turn, the maximum thyroid dose (310 mGy) was received by 3-7 years old Kazakh residents of Kainar.

Due to evacuation either whole body or thyroid dose to the residents of Sarzhal and Karaul were substantially less than they could have been without evacuation. Dose reduction factor in case of whole body dose was estimated to be equal to 4.6 (Sarzhal) and 2.8 (Karaul), while in case of thyroid dose – 10.6 (Sarzhal) and 4.6 (Karaul).

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Data of ESR dosimetry study of population in the vicinity of Semipalatinsk Nuclear Test Site

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Abstract

The method of electron spin resonance (ESR) dosimetry was used to human tooth enamel to obtain individual absorbed doses of population of settlements in the vicinity of the Semipalatinsk Nuclear Test Site (SNTS), Kazakhstan. The distances between investigated settlements and Ground Zero (SNTS) are in the range 70 - 200 km from SNTS. Most of settlements (Dolon, Mostik, Bodene) are located near the central axis of radioactive fallout trace from the most contaminating surface nuclear test, which was conducted in 29, August 1949. The other settlements located close to radioactive fallout trace as a result of surface nuclear tests in 24, August 1956 (Ust-Kamenogorsk, Znamenka, Shemonaikha, Glubokoe, Tavriya, Gagarino), in 7, August 1962 (Kurchatov). Semipalatinsk city was included to investigation as a biggest city which located close to SNTS.

This method was applied to human tooth enamel to obtain individual absorbed doses of residents of Makanchi, Urdzhar and Taskesken settlements located near Kazakhstan-Chinese border (about 400 km to South-East from Semipalatinsk nuclear test site (SNTS) and about 1000 km from The Lop Nor Nuclear Weapons Test Base (China)). Since the ground and atmospheric nuclear tests (1964-1981) at Lop Nor, the people residing in these settlements have believed to be exposed heavily by radioactive fallout. Tooth samples were extracted according to medical reasons in a course of ordinary dental treatment. Kokpekty was chosen as control and was not subjected to any radioactive contamination and located 400 km to the Southeast from SNTS.

1. Introduction

In the period from 1949 to 1962 125 nuclear tests (including 25 near-surface nuclear tests) were conducted at the Ground Zero technical site in the territory of Semipalatinsk Nuclear Test Site (SNTS). The date of 29 August 1949 represents the first nuclear explosion, which contaminated by radioactive fallout a huge territory northeast from the epicenter. The radioactive dust cloud was transferred by the wind and its gradual precipitation formed several radioactive fallout traces [1-3]. There are no data describing the dynamics of the precipitation of the dust from the radioactive cloud on the region adjacent to the SNTS. It is a very complicated procedure to reconstruct the individual and collective radiation doses received by the local population.

On 24 August 1956, the 28th nuclear explosion with 27 kiloton total yield took place, which contaminated with radioactive fallout a huge territory to the east from the hypocenter and near Ust-Kamenogorsk city with radioactive fallout [4, 5]. Reconstruction of individual and collective doses received by the local population is a sophisticated procedure combining data of the radioactive fallout, individual doses measured by ESR, doses reconstructed from retrospective area dosimetry and individual behavior of inhabitants.

The Lop Nor Nuclear Weapons Test Base located in the Malan, Xinjiang Autonomous region of China. China conducted 45 nuclear tests at Lop Nor, including 22 atmospheric and surface tests between 1964 and 1981. According to Gusev et al. [6] about half of the 22 tests were surface tests. Here, three tests in 1964, 1966 and 1971 are explicitly mentioned but only one of them (1966) was expected to affect the population at the Kazakhstan-Chinese border.

ESR dosimetry is one of the useful tools for such dose reconstruction [7]. This method can determine the radiation doses retrospectively even more than 40 years after the exposure event. EPR measures the amount of the stable radicals created by radiation exposure in tooth enamel.

2. Materials and methods

From 2000 to March 2005, 97 teeth samples were extracted on the basis of medical indications from adult residents of Dolon, Mostik, Bodene villages, located near the radioactive fallout trace formed as result of the most hazardous nuclear test of 1949 [8, 9], Kurchatov City and Semipalatinsk City, which is located from 70 to 150 km from SNTS [10]. In 2008, 2009, 88 teeth samples have been extracted according to medical reasons from adult residents of Ust-Kamenogorsk city and the Znamenka, Glubokoe, Tavriya, Gagarino and Shemonaikha settlements [11, 12]. For the period from 2008 to 2009, thirty tooth samples were extracted on the basis of medical indications from adult residents of Makanchi, Urdzhar and Taskesken villages, which are located from 100 to 200 km from the Kazakhstan-Chinese border [13, 14]. 8 teeth were collected as controls from the population of Kokpekty village (400 km east of the test site), which was not subjected to any radioactive contamination. A description of the samples is given in the table 1.

Enamel was mechanically separated from dentine using hard alloy dental drills and diamond saws. Dentins were removed carefully with cooling water in order to prevent the sample from heating which can induce an additional ESR signal and significantly change shape of the signal [7]. Tooth enamel was crushed by cutting pliers to chips 0.5–1.5 mm in diameter. Two samples were prepared from buccal and lingual parts of each tooth.

Table 1. Information about samples from vicinity of the Semipalatinsk Nuclear Test Site

Settlements	Years of analysis	**Measured**	Enamel formed before 1949	Distance from epicenter, km
Dolon	2002	3	3	100
	2004	26	13	
	2005	9	1	
Mostik	2004	10	8	90
	2005	13	4	
Bodene	2004	20	9	90
Semipalatinsk	2002	9	4	150
Kurchatov	2002	7	5	70
Kokpekty	2004	8	-	400
Total		105	47	

The measurements were carried out in the X-band on the ESR spectrometer JEOL JES-FA100 at stabilized room temperature of 21°C. The spectrometer was equipped with a high Q-factor cylindrical TE_{011} cavity model ES-UCX2. The spectrum recording parameters were the same as previously published [15]. Specially designed computer software [16] was used for spectra processing and dose estimation.

3. Results and discussion

The doses for the residents of Semipalatinsk City and Kurchatov City were included in this report from the published data [17]. The experimentally determined dose was considered to consist of two contributions: dose from natural radiation background accumulated during a tooth enamel lifetime and dose received as a result of nuclear tests (excess dose). The last contribution is subject of the interest for present dose reconstruction. At first, the intensity of the RIS was converted into a dose absorbed by enamel D_{en} (expressed in mGy) calibrated using calibration by a ^{60}Co gamma source. Second, excess dose in enamel was determined by subtraction of contribution of the natural background radiation during the enamel existence after its formation from the absorbed dose in enamel.

For the residents of Dolon absorbed doses were found to be in the range from -24 ± 37 to 496 ± 55 mGy. For some doses, negative values were obtained. This is because the measurements were performed near the threshold of sensitivity of the method. It is natural that some of the values become negative according to their statistical distribution determined due to experimental errors. The negative doses probably are the result of the underestimation of uncertainty of the dose assessment.

For all the samples, excess doses were calculated by equation:

$$D_{ex} = D_{en} - TA * D_b,$$

Where: D_{en} - dose calculated by automatic program, in mGy

TA - teeth enamel age, years

D_b - background dose, 0.8 mGy/year [2, 3]

Uncertainty of dose determination (*Er*) was determined based on semi-empirical formula used in the previous publication [3].

The average excess dose for enamel formed before 1949 for Dolon is 153 ± 54 mGy, for enamel formed after 1949 the average dose is 25 ± 11 mGy. For Mostik excess dose before 1949 is 19 ± 15 and after 1949 is 44 ± 14. For Bodene excess dose before 1949 is 74 ± 40 and after 1949 is 17 ± 10. For Kurchatov average excess dose before 1949 is 11 ± 20 and after 1949 is 9 ± 27 and for Semipalatinsk City average excess dose before 1949 is 145 ± 68 and after 1949 is 74 ± 35. The value of average dose for Semipalatinsk City is close to the average results of Dolon village [10]. One of the explanations is the person worked in place located close to SNTS and another explanation that they were born in village that affected by fallout from Test Site. The bulk of the excess doses are near the sensitivity threshold of the method.

For control samples, excess doses are from –66 ± 39 up to 24 ± 39 mGy, for Dolon from -74 ± 38 up to 440 ± 106 mGy, for Mostik from –64±32 up to 119± 51, for Bodene from –50 ± 38 up to 356 ± 58 mGy, for Kurchatov from -47±85 up to 56±42 and for Semipalatinsk City from 0±46 up to 268±79. Low doses were found for the group with enamel formed after 1962, the end of atmospheric nuclear tests. The dose values for the group having enamel formed before 1962 are consistent with estimations based on the official registered data indicating high levels of the fallout in the period 1949-1962. The experimentally measured individual doses can be compared with data of dose reconstruction, which were shown in previous publication [8, 9] and which amount was about 0.5 Gy for Dolon.

For Tavriya and Gagarino villages all studied samples have been formed before the date of the nuclear test. For other settlements teeth samples were divided into two parts: before and after nuclear explosion. Low mean excess doses have been found for Gagarino residents, while the highest mean excess dose has been determined for Shemonaikha and Ust-Kamenogorsk residents (Table 2).

Table 2. Information about samples from the settlements located close to radioactive fallout trace as a result of surface nuclear tests in 24, August 1956 in the Semipalatinsk Nuclear Test Site.

Settlements	Population	Archival dose (mSv) [18]	ESR average excess dose (mGy)	ESR maximal excess dose (mGy)
Znamenka	-	25	41±46	268
Glubokoe	11,192	10-15	36±31	83
Tavriya	4,280	10-15	17±36	54
Ust-Kamenogorsk	298,700	80	20±25	120
Gagarino	1,038	10-15	-24±33	47
Shemonaikha	17,000	0.1	17±37	110
Kokpekty	5,301	<0.1	0.01±33	24

Given the small number of tooth samples investigated, the deduced doses should not be seen as representative for the whole population in the selected villages. The maximum dose obtained for samples from Shemonaikha was not expected, due to its large distance from the radioactive trace, but may be due to radioactivity released by some of the uranium enterprises located there. The maximum dose obtained for Znamenka village [17] can confirm that this village locating close to radioactive trace. The other settlements included in the study also have uranium enterprises, except for Tavriya and Gagarino, where agriculture is prevalent. Average excess doses in the latter two settlements are consistent with estimations based on the official registered data indicating high levels of fallout in the period 1949-1962 [18].

The individual excess dose determinations for different years of enamel formation are shown in table 3. The average excess dose for Makanchi is 62±28 mGy. For Urdzhar, the average excess dose is 64±30 mGy. For Taskesken, the average excess dose is 49±27 mGy and for Kokpekty village, the average excess dose is -19±36 mGy. The average excess doses for the investigated settlement are higher than for the control village.

Table 3. Archival data of external dose estimation [6] and results of the study of the Lop Nor nuclear test site influence to the Makanchi, Urdzhar, Taskesken settlements [14].

#	Date of explosions	External dose (mGy)		
		Makanchi	Urdzhar	Taskesken
1	28.12.1966	6.2	5.33	4.61
2	17.6.1967	220.0	196.0	166.0
3	27.6.1973	341.0	308.0	262.0
4	ESR max excess dose	123.0	118.0	107.0
5	ESR average excess dose	62.0	64.0	43.0

The dose values are consistent with estimations based on the official registered data indicating high levels of the fallout in the period 1966-1981 [19]. This dose estimation is an estimation of external dose only. Some difference between ESR dose estimation and data from Table 1 can be explained by a shielding factor (staying inside house) and a behavior factor (resident's location during the tests and migration).

According to a previous study [6] the population of Makanchi, Urdzhar and Taskesken were not heavily exposed by the Chinese test site or the Semipalatinsk test site. Some results of this study are consistent with archival data [19]. Retrospective analyses were made of the formation of the radiation situation in the population points of the South-east district of the Semipalatinsk region as a result of nuclear weapons testing. In table 3, data of dose estimations from 1967 to 1981 are shown. The territories of the Makanchi, Urdzhar and Taskesken districts were contaminated 11 times by local radioactive fallout from atmospheric, surface and underground explosions conducted at the Lop Nor test site. This was confirmed by the appearance of freshly produced fission products, particularly iodine radioisotopes, ^{90}Sr and others in the environment.

4. Conclusions

Higher average excess doses were determined in Dolon and Semipalatinsk city for residents whose tooth enamel was formed before 1949. Results of dose estimation from Dolon samples are in agreement with the fact that this village is located closer to the axis of the radioactive trace. A result from

Semipalatinsk needs special investigation.

Compared to samples from the distant Kokpekty village which chosen as controls, higher average excess doses have been obtained for Znamenka, Ust-Kamenogorsk city and Shemonaikha. This is in agreement with the fact that Znamenka village and Ust-Kamenogorsk city is locating close to the axis of the radioactive trace, but Shemonaikha is locating on the distance about 70 km from it. It is necessary to note, that the investigated area is well known for its active uranium processing plant. This may explain that higher values have also been found for samples from Shemonaikha, which is located about 70 km from the center line of the radioactive trace. At Tavriya and Gagarino no uranium enterprises exist and, accordingly, the measured doses are consistent with independent estimates of external doses from the fallout that can be found in the literature.

Calculated external doses to the population of Makanchi, Urdzhar and Taskesken from the three main dose-forming explosions are about three times larger than maximal excess doses estimated by the ESR method, but it should be noted that the number of investigated tooth samples is insufficient to make a final conclusion about the influence of the Lop Nor Test site explosions on the population of the Semipalatinsk region near the Chinese border, and required additional investigation. One of the main problems with this kind of study is following the migration of the population that moves from the investigated region into some other part of the Semipalatinsk area.

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^{90}Sr in mammal teeth taken in the Semipalatinsk Test Site measured by imaging plates

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Abstract

The concentrations of ^{90}Sr in mammal teeth taken in north-west part of Semipalatinsk Test Site were measured by using imaging plates. The highest concentration detected in the present study was 13Bq/g, being comparable with the values previously detected in cow teeth from South Ural region. It suggests that, at least locally, the soil in north-west part of the Test Site is possibly highly contaminated. It would be necessary to investigate the source of this high level of contamination, such as radiological weapon tests, before providing the land for agricultural use.

INTRODUCTION

Measurement of ^{90}Sr by imaging plate (IP) is an easy and sensitive method to determine the ^{90}Sr concentrations in materials. The concentrations of ^{90}Sr in human teeth taken from South Ural region were first measured by this method to show that the part in human teeth in which ^{90}Sr is concentrated depends on the time of intake in relation with the formation of the teeth [1]. We have investigated the best experimental conditions for the BAS-1800II system for quantitative measurements of ^{90}Sr in teeth and also shown that a KCl crystal can be used as a universal standard [2]. Subsequently, it was shown that the method is also useful to evaluate the ^{90}Sr concentrations in mammal teeth [3]. In the latter paper, it was shown that the ^{90}Sr concentrations in cow teeth are correlated with the levels of ^{90}Sr contamination in soil in South Ural region and that ^{90}Sr is also detected in mammal teeth taken from Semipalatinsk Test site region.

EXPEIMRNTEAL

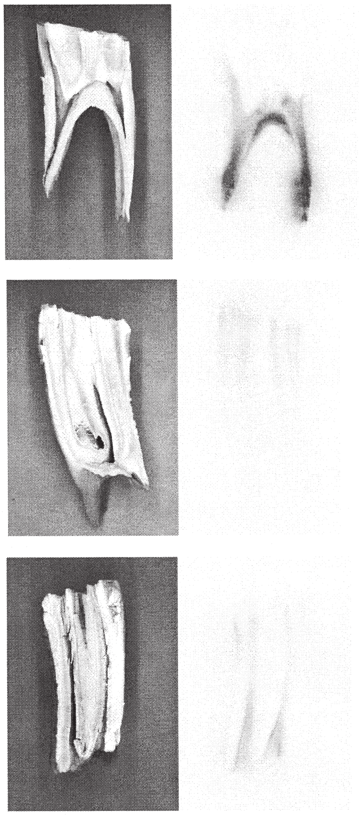
In the present study, additional mammal teeth were taken from north-west part of Semipalatinsk Test Site, such as teeth of domestic cows and goats, wild deer and hares as shown in Table 1.

The teeth were cut in half with a thickness of more than 5 mm. The pieces were placed on an IP (20×25 cm) together with a KCl crystal for 7 days (one week) in a lead cave with a wall thickness of 50 mm, with 5mm thickness acrylic plates of 5 mm thickness on the inner surface [2]. The room where measurements were taken was kept at 24°C. A black cloth covered the lead blocks to prevent the leaking of light into the inside.

The IP was then moved to a tray in BAS-1800II (Fuji, Co.) in a dark room and the images of the ^{90}Sr distribution were obtained with pixel resolution of 0.5 mm × 0.5 mm. Using software Multi Gage v.3.0, provided by Fuji Film Co., the total PSL value (a unit in the software indicating the strength of the emitted light) from a sample piece was summed up. After subtracting background, the value was divided by the total area of the piece measured by weighing the paper pieces which printed the images of the pieces. The PSL concentration was then normalized using the values for the standard KCl crystals (38.4Bq/g for one with a diameter of 30 mm and thickness of 10 mm and 37.1 for one with a diameter of 15 mm and thickness of 5 mm) to obtain the absolute ^{90}Sr concentrations in Bq/g in the sample. Finally, the concentration values were divided by a modification factor (MF) [4] in order to correct the sample thickness..

RESULTS AND DISCUSSIONS

Examples of obtained images are shown in Figs. 1. As ^{90}Y, an equilibrated daughter nuclei of ^{90}Sr, emits high energy β particles (maximum energy of 2.28 MeV, with a range of 4.1 mm in teeth), the image is somewhat vague and has "halo" around the image. Fig. 1a shows images for a tooth piece of a domestic cow from Wintering Tulpar, which has the highest ^{90}Sr concentration in the present samples. As no ^{137}Cs peaks were detected by a low background germanium gamma ray detector, the image represents the distribution of ^{90}Sr in the piece. Fig. 1b shows those for a tooth piece of a domestic horse from Bulak and Fig. 1c another horse. Higher concentrations were observed at boundaries between enamel and dentin as were the cases for cow teeth from South Ural [3]. Interestingly, the concentration is higher at roots than crown for the first cow and the last horse (Figs. 1a and 1c) while it is opposite for the second horse (Fig. 1b). This would be due to the difference in incorporation of ^{90}Sr into these animals as was observed in human teeth of South Ural region where it is related with the timing of ^{90}Sr incorporation and the formation of enamel and dentin [1]. However, presently it is not possible to argue such relationship because such information about feeding of these animals is not available.



a
b
c

Fig. 1 Images and results of measurements on three of the present samples investigated. The vertical scale is about 8 cm. a) a domestic cow from Wintering Tulpar b) a horse from Bulak c) a horse

Results of calculated average ^{90}Sr concentrations in the present mammal teeth are listed in Table 1. The values range from 0.4 to 13 Bq/g. Fig. 2 shows the locations of the samples with the concentrations in

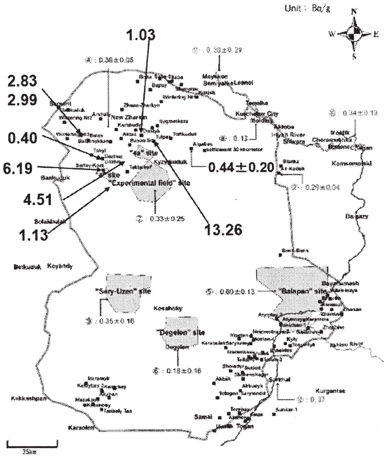


Fig. 2 Distribution of ^{90}Sr concentrations in mammal teeth obtained by IP measurements. Bold numbers shown are the present results in addition to previous ones [3].

Table 1 ^{90}Sr concentrations in mammal teeth obtained by imaging plates.

Location	Mammal	^{90}Sr (Bq/g)
Bulak	horse	2.81
		2.97
Wintering Tulpar	cow	13.2
Algabas	sheep	0.67
		0.34
Wintering Unji	cow	0.40
Dostyk	horse	4.48
	sheep	1.02
	goat	1.12
Saltay Kora	cow	6.15

addition to the values previously obtained [3]. The present values for the samples taken from north-west part of Semipalatinsk Test Site are much higher than those from other parts of Test Site and from those from outside of the Test Site. While even in Balapan, the value is lower than 1Bq/g, seven samples shows values more than 1Bq/g. These results indicate that the soil contamination level is high. We previously observed a correlation between soil contamination and ^{90}Sr in domestic cow teeth in South Ural region [3] where cows raised in the region with 100 kBq/m^2 show several Bq/g of ^{90}Sr in teeth. If this relationship is applied to the present case, the soil contamination level can be more than 100 kBq/m^2 (3 Ci/km^2). On the other hand, there are samples with values lower than 1 Bq/g. Such variability might be due to imhomogeneity of contamination. If so, we still need to be cautious about the localized contamination levels in this region.

Possible source of contamination may be the radioactive nuclei released at the time of radiological weapon tests conducted around this region to find that such weapons were not destructive, where actually spotty contamination patters have been observed [5-7]. In 20 years after the last nuclear weapon test, it would still be necessary to investigate the actual distribution of such high level of contamination before providing the land for agricultural use.

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Results and perspectives of application of the tooth enamel EPR dosimetry at wide-scale radiation accidents

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Abstract

The experience of using the tooth enamel EPR dosimetry method at wide-scale radiation accidents is analyzed in order to estimate the real possibilities and area of application of the method. The summary results of our investigations and results of other authors on the application of the EPR dosimetry method for investigation of the radiation effects of nuclear tests on the population of the Semipalatinsk region are presented. Also, our results of application of the EPR method for investigation of radiation effects on the population of radioactively contaminated territories after the Chernobyl accidents are presented in order to perform joint cross verification of the EPR method and other methods of dose reconstruction, such as the calculations based on the level of radioactive contamination and information about individual behavior. The experience of using the EPR method at control radiation uncontaminated territories is analyzed in order to estimate the real sensitivity of the method and effectiveness of its application for the population of territories with low level of radioactive contamination.

INTRODUCTION

The aim of this presentation is to estimate the real potential and perspectives of using the teeth enamel EPR dosimetry method basing on the analysis of the experience of using this method at wide scale radiation accidents (taking into account limitations on its sensitivity and possibilities of sample collection).

The main limitations of application of the EPR dosimetry method are connected with its detection limit and possibility of sample collection. Sample collection is restricted by possibility of obtaining teeth extracted by medical appointments and presence of population group in interest, which may be restricted because of medical appointments for teeth extraction and reducing the population group in interest because of long period after radiation accident. The detection limit of the method is directly connected with its accuracy.

The accuracy of the method may be estimated from analysis of the data obtained from the following investigations:

- calibration and methodical investigations;
- blind tests in the course of interlaboratory comparisons;
- measurements for population of radiation free territories;
- comparison results of EPR dosimetry with results of dose measurement and dose reconstruction by other methods.

The estimates of accuracy of the teeth enamel EPR dosimetry method achieved at these kinds of investigations are conducted in this presentation.

RESULTS AND DISCUSSION

Accuracy achieved at calibration and methodical investigations

At methodical investigations directed to find out an optimal protocol of dose determination, two types of enamel samples were used – heterogeneous samples, each was prepared from different teeth and homogeneous samples prepared from pooled enamel. Accuracy of dose determination was defined as standard deviation of determined doses from nominal doses using regression line obtained at calibration with a set of samples irradiated in different doses [2, 3, 10].

For a dose range 0 – 500 mGy for homogeneous samples at calibration the accuracy about 15 mGy is achieved [10]. This value is limited mainly by noises at spectra measurement. For heterogeneous samples, the accuracy at calibration about 20-25 mGy is achieved [3], which is limited mainly by variation of the shape native background signal in enamel, which is different for each sample. The accuracy of dose determination is improved as the sample mass and the number of repeated measurements are increased (Fig. 1). But some level of these parameters exists over which the accuracy may not be improved [10].

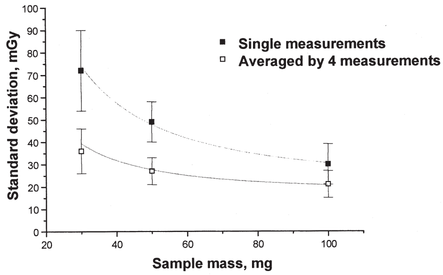
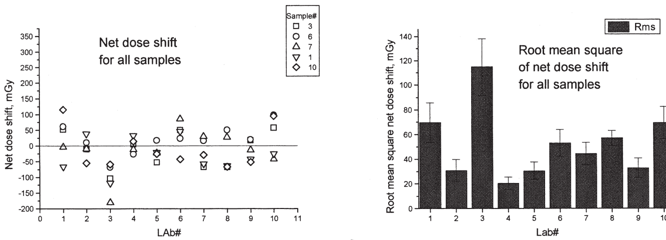


Fig.1. Dependence of the accuracy of calibration on the sample mass at different number of measurements obtained for heterogeneous samples (Ivannikov et al., 2002 [3]) .

Accuracy demonstrated at intercomparisons

Several international comparisons of the tooth enamel EPR dosimetry method were conducted in order to test its feasibility and achievable accuracy. Results of one of such intercomparisons conducted by Hiroshima University in 2006 [5] are presented in Fig. 2. The heterogeneous samples from different teeth were used the same for all laboratories: three samples irradiated in nominal dose 143 mGy and two samples - in dose 226 mGy. The same set of calibration samples was used for all laboratories. The accuracy was characterized by root mean square deviation of reported doses from nominal doses. Large variation of the accuracy is demonstrated for different laboratories. Typical accuracy demonstrated by the most of laboratories is 30-50 mGy.

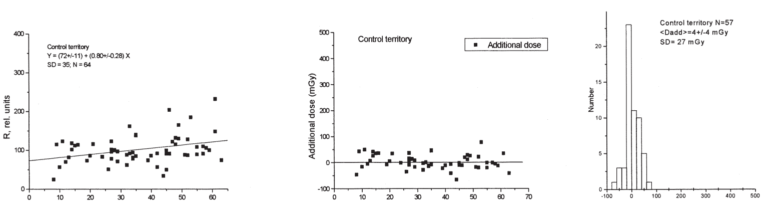


a b

Fig.2. Results of different laboratories at international comparison conducted by Hiroshima University in 2006 [5]: a – deviation of reported doses from nominal doses; b – root mean square deviation of reported doses from nominal doses.

Estimation of the accuracy of the method at investigation the population of radiation free territories

Direct estimation of the accuracy of EPR dosimetry method may be obtained from results of dose determination for population of territories, which are not contaminated by technogenic radiation. Results of EPR dosimetry for population of control radiation free territories of the central region of Russia (*Kaluzhskaya oblast*) are presented in Fig. 3 [1, 8]. The increasing of the radiation induced signal intensity in enamel samples with individual age observed in Fig. 3a is explained by effect of accumulation of natural background radiation. This effect can be easily taken into account by subtraction of the accumulated natural background dose to obtain the additional (excess) dose, age dependence for which is presented in Fig. 3b. Width of the histogram of distribution of the additional dose, 27 mGy, characterizes the accuracy of the EPR dosimetry method applied at real wide scale investigation of population.



a b c

Fig.3. Results of EPR dosimetry for population of control radiation free territories: a – dependence of the individual radiation induced signal intensity on the age of enamel after its formation; b – age dependence of the individual additional dose (excess dose) obtained after subtraction of the accumulated natural background dose; c – histogram distribution of the additional dose.

The accuracy of dose determination is increased if to perform averaging of the results for groups of population. The age dependence of measured by EPR doses absorbed in enamel averaged by five adjacent age values is presented in Fig. 4. This dependence is obtained for the same population group as presented in Fig. 3. The increasing of doses with age is caused by accumulation of natural background radiation. The accuracy of dose determination defined by standard deviation from the regression line is improved because of averaging and characterized by value of 13 mGy.

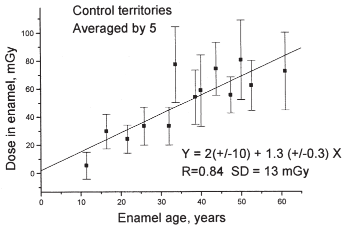


Fig. 4. Dependence of doses absorbed in enamel averaged by five adjacent age values of enamel age for radiation free territories.

Results of application of the EPR dosimetry method for the population of Chernobyl region

The EPR dosimetry method for applied for investigation of the population of radiation contaminated territories as result of Chernobyl region [8]. Results obtained for one of population group *(Bryanskaya oblast, Gordeevsky rayon)* are presented in Fig. 5. In comparison with control territories (Fig. 3), width of additional dose distribution is higher and doses are higher, which is result of technogenic radiation. Individual doses were determined by the EPR method performed for other territories, average results for population groups are presented in Table 1. In the same table results of average dose calculation according to [12] for the same population groups are presented.

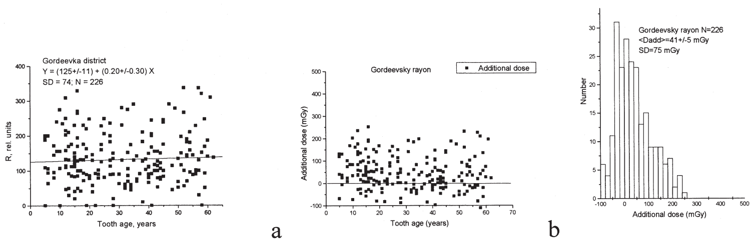


Fig. 5. Results of EPR dosimetry for population of control territories and radioactive contaminated territories after Chernobyl accident *(Bryanskaya oblast, Gordeevsky rayon).* The figure panel notations are the same as in Fig. 3.

Table 1. Average additional doses determined by EPR dosimetry method for radiation contaminated territories after Chernobyl accident and for control territories. Comparison with average calculated doses.

Notations: N – number of measurements; EPR dose – additional dose by EPR averaged for settlements and groups of population; Calculated dose – average doses for groups of population obtained by calculations [12]

	N	*EPR dose, mGy*	*Calculated dose, mGy*
Bryanskaya oblast			
Gordeevsky rayon	*226*	*29*	*33*
Gordeevka	34	51	40
Tvorishino	15	51	31
Strugova Buda	10	23	26
Klintsy	*150*	*28*	*12*
Klintsivsky rayon	*114*	*30*	*30*
Smotrova Buda	16	40	23
Smolevichi	16	40	11
Gulevka	11	19	19
Zlynkovsky rayon	*104*	*50*	*41*
Zlynka	28	28	31
Vyshkov	25	71	39
Klymovsky rayon	*34*	*12*	*16*
Klimovo	11	26	12
Kaluzhskaya oblast (control territory)			
Borovsky rayon	*64*	*1*	*1*

Relationship between average doses determined by EPR and average calculated doses is presented in Fig. 6. Discrepancy between EPR doses and calculated doses averaged for settlements is within 15 mGy. The error of doses for groups of population is reduced in comparison with error of individual dose determination because of averaging.

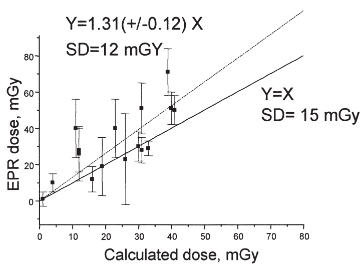


Fig. 6. Relationship between doses in enamel determined by EPR and calculated doses averaged for settlements of Bryanskaya oblast contaminated after the Chernobyl accident.

Special investigation was conducted to compare individual EPR doses and individual calculated doses absorbed in enamel for residents of Zaborie village (Bryansk region) with high level of radioactive contamination after the Chernobyl accident were compared [4, 9]. Mean square deviation between results of these two independent methods appeared to be 34 mGy. It means that dose determination by both methods is performed with uncertainty less than 30 mGy. This result verifies both methods.

Results for the Semipalatinsk region

Results of individual excess dose determination by EPR dosimetry for population of villages placed close to the radioactive trace formed after the first nuclear test in 1949, are presented in Fig. 7. Bimodal distribution is observed for all these settlements for persons with enamel formed before 1949. That may be explained by that only part of population was exposed.

- Part of distribution with center close to zero dose - not exposed population.

- Part of distribution from 250 to 450 mGy - exposed population.

- High dose for Mostik correspond to dose in air at the center of trace.

Mean dose for enamel formed after 1949 is 32 mGy. This elevated dose, probably, is caused by contribution of tests conducted after 1949.

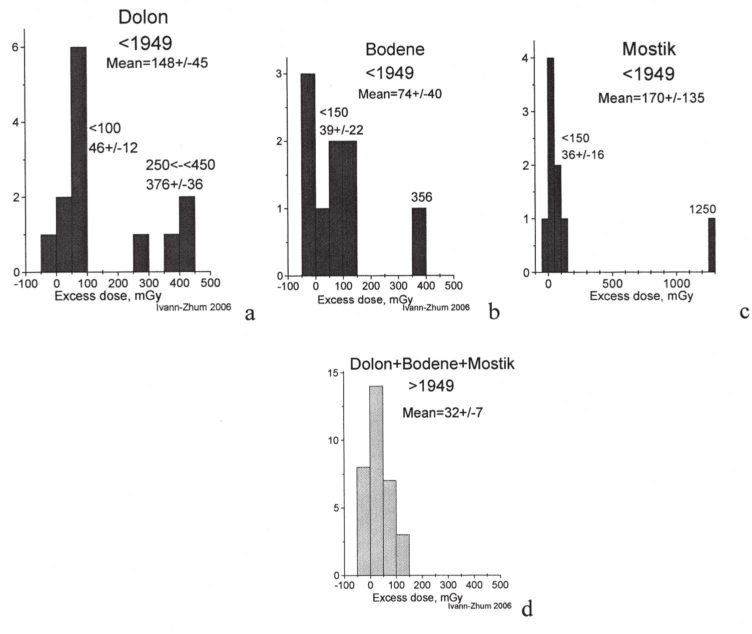


Fig. 7. Excess EPR doses for the trace of 1949 year (by Zhumadilov et al. 2006 [11]) for samples formed before (a-c) and after 1949 yr (d)..

Results of individual dose determination obtained by other research group [7] are presented in Fig. 8. Combined results of different research groups [6, 7, 11] are presented in Fig. 9. Bimodal distribution is also observed for these results.

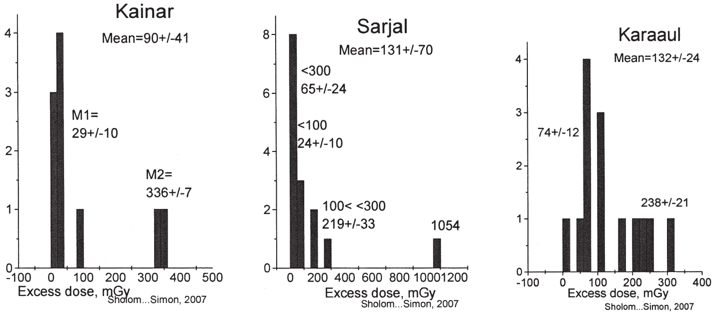


Fig. 8. Excess EPR doses for the radioactive traces of 1951 and 1953 years [7] (enamel formed before 1949. These results are used for analysis and presented here by permission of the authors.): a, b – for Kainar and Sarjal, radioactive trace of 1951 yr; c – for Karaaul settlment, trace of 1953 yr.

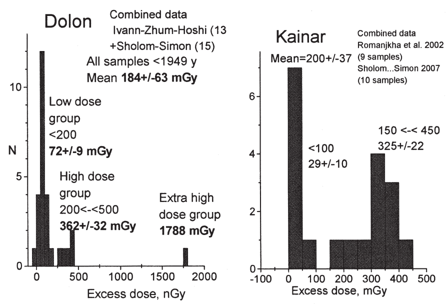


Fig. 9. Excess EPR doses for Dolon and Kainar (combined results of [6, 7, 11], enamel formed before 1949 yr).

Comparison of individual dosed for Dolon village inhabitants (with enamel formed before 1949) determined by EPR method [11] and by calculations based on the level of radiation contamination and the individual questionnaires [13] was performed. Results of such comparison are presented in Fig. 10. Mean ratio of calculated dose and EPR dose: 0.98+/-0.25. Mean root square deviation between results is 35 mGy, which is within specified errors of both methods.

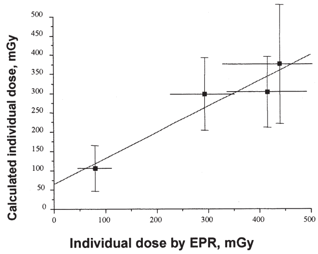


Fig. 10. Relationship between calculated individual doses and doses determined by EPR for inhabitants of Dolon with teeth formed before 1949.

CONCLUSIONS

The analysis of experience of application the tooth enamel EPR dosimetry at methodical investigations, interlaboratory comparisons and wide scale investigation of population of radiation free and contaminated territories is performed. Based on this analysis, the achievable accuracy of the EPR dosimetry method is estimated by value of 20-30 mGy. At averaging for groups of population, the error of dose determination may be reduced up to 10-15 mGy.

Results of EPR dosimetry well agree with results of dose reconstruction by calculations, which validate both methods.

Results obtained by EPR dosimetry are not always stable. In some cases the error is much higher than the lowest achievable value. In case of using the modern sensitive spectrometers, the reasons of increased error may be the following: (1) Variation of the EPR signal because of improper sample preparation. (2) Not optimal spectra processing procedure.

An optimal unified method should be developed, which involves optimal procedures of sample preparation, spectra measurement and, which is the most important, spectra processing. At present, a version of this program passed the State registration in Russia. Nevertheless, work on this program should be continued in order to develop an algorithm giving stable results with highest accuracy.

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The experience of individual dose reconstruction after uncontrolled large-scale irradiation of population

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Abstract.

There are three main methods available to obtain retrospective assessments of radiation dose:

a) computational modeling (CM), which use archive monitoring data of radioactive contamination of soils, biota and human body are applied to develop radioecological models for estimation of mean doses. Individualization of mean calculated doses is performed using results of individual questioning of the inhabitants of the contaminated territories. The evaluation of the uncertainty of doses is provided by Monte Carlo method with a variation of parameters of the models;

b) the retrospective luminescence dosimetry (RLD) and c) ESR dosimetry, determine the cumulative absorbed dose in the bricks of buildings and in human tooth enamel, respectively. RLD and ESR dosimetry methods allow the estimation of accumulated dose with accuracy of 20-30 mGy

Estimates of dose obtained by applying CM, RLD and ESR methods downwind the Chernobyl NPP and to Semipalatinsk nuclear test site (SNTS) are overviewed in the paper. The comparisons of dose estimates by different methods are presented.

Key technologies, methods and equipment, application areas, technology target, methods developed, categories of investigated subjects are the following:

Key approaches and technologies. Radioecological models and individual dosimetrical questionnaires for individual dose estimations by modeling calculations (MC), Retrospective Luminescence Dosimetry (RLD) with quartz inclusions, Electron Spin Resonance (ESR) dosimetry with human tooth enamel;

Methods and equipment. RISOE luminescence reader, Brucker ESR spectrometer, know-how spectra processing software, know-how sampling and sample preparation methodology.

Application areas:

-Individual retrospective dosimetry in support to radiation epidemiological studies;

-Retrospective dosimetry in support to making decision regarding mitigation of the health consequences of large scale radiation accidents;

-Retrospective dosimetry in a case of local radiation accidents with radioactive sources;

-Retrospective instrumental estimation of radiation doses in a cases of uncontrolled (accidental) irradiation of personnel or patients in a course or radiation therapy.

Target: to develop and to harmonize the system of methods of retrospective dosimetry for national and worldwide distribution.

Methods developed: radioecological models and individual dosimetrical questionnaires for individual dose estimations by modeling calculations; retrospective luminescence dosimetry with quartz inclusions in the bricks of the buildings; retrospective ESR dosimetry with human tooth enamel.

Categories of investigated subjects: Population of territories contaminated following the Chernobyl accident (Russian Federation) – Fig. 1.; Population of territories around Semipalatinsk nuclear test site (Russian Federation and Republic of Kazakhstan)- Fig. 2.

Fig.1. Example [1,2]. Map with indication of raions of Bryansk oblast (Russian Federation), which were contaminated resulting the Chernobyl accident. 221 km of distance from Chernobyl NPP to the most contaminated settlement - Zaborie village (soil contamination density by ^{137}Cs - 4300 kBq/m^2).

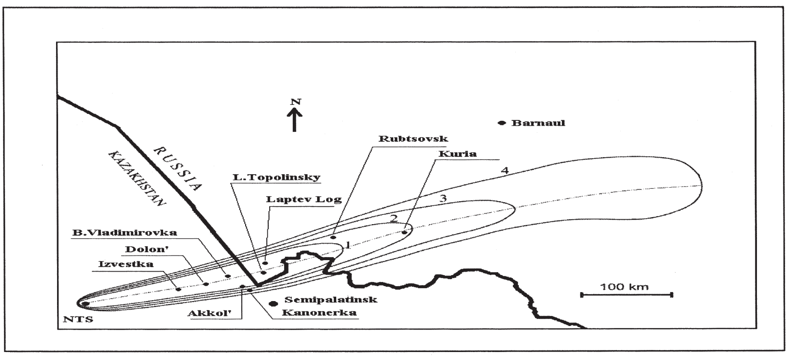

Fig.2. Example [3]. The 1st A-bomb test in former USSR (29.08.1949) – the radioactive trace in Kazakhstan and Russia with indication of investigated settlements. NTS – Semipalatinsk nuclear test site.

Monitoring of ^{131}I activity in thyroid gland and development of thyroid dose reconstruction approach among inhabitants of territories contaminated by radionuclides as a result of the Chernobyl accident (Russian Federation).

During May of 1986 the massive monitoring of ^{131}I activity in thyroid gland among inhabitants of Russian territories contaminated by radionuclides as a result of Chernobyl accident was performed [4,5]. During 3 weeks on May of 1986 26 724 inhabitants of 115 contaminated settlements of 7 subregions (raions) were monitored in Kaluga region (RF) [6]. The detailed description of developed technology of dose monitoring and of methods of thyroid dose estimations are presented in [4,5,7]. Individual thyroid doses were estimated for each monitored person with accounting for real dose forming factors on May of 1986 year [6]. As to Kaluga region, the maximal thyroid doses were estimated in 3 contaminated subregions – Ul'ianovoskiy, Zhsizdrinskiy, Khvastovochskiy (see Table 1 as well for 7 investigated subregions in total [5]).

It was found on the early stage of investigation (1986 year) that statistical distribution of individual thyroid doses is characterized by "long tail" in the individual dose range, which is much higher than mean and median doses for different age groups [4].

Table 1. Example [5]. Thyroid absorbed doses in different age groups of investigated inhabitants of 7 subregions of Kaluga region.

Values*)	Thyroid absorbed doses for different age groups, mGy. (age groups, years, are related to the moment of the accident)					
	<1	>1-2	>2-7	>7-12	>12-17	>17
N	1075	989	7491	6440	4997	5732
MID, mGy	550	530	460	320	250	250
DA, mGy	52	43	23	15	14	13
DM, mGy	31	26	14	10	8.3	8.1
GSD	2,7	2,7	2,6	2,4	2,7	2,7

*) N-number of investigated persons; MID-maximal individual dose; DA-average dose for given age group; DM-median dose for given age group; GSD- geometric standard deviation.

The results of massive monitoring of thyroid doses among inhabitants of contaminated territories of Kaluga region were combined with the similar data related to contaminated territories of Bryansk region (Russia) and Republic of Belarus. As a result the individual thyroid dose reconstruction approach was developed for persons who were not monitored just after the accident (on May, 1986): it is radioecological semiempirical model and individual dosimetrical questionnaires for individual dose estimations by modeling calculations [4,5,7-10].

The developed approach of individual thyroid dose reconstruction is still actual for implementation in a cases of possible large scale radiations accidents.

Figure 3 shows an example of comparison of individual thyroid doses: calculated individual thyroid doses VS dose estimations based on the results of ^{131}I measurements in thyroid gland among inhabitants of contaminated territories of Bryansk region are presented [7].

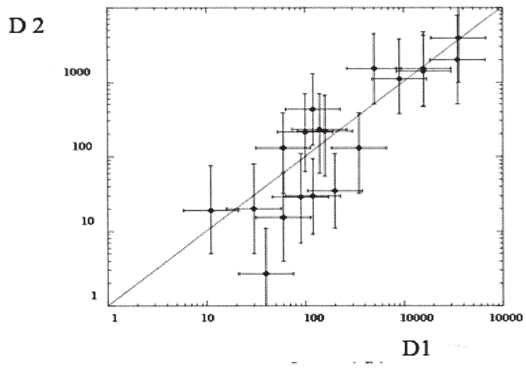

Fig. 3. An example [7] of comparison of individual thyroid doses: calculated individual doses (D 2, mGy) VS dose estimations based on the results of ^{131}I measurements in thyroid gland (D 1, mGy) among inhabitants of contaminated territories of Bryansk region.

Monitoring of ^{137}Cs activity in whole body and development of whole body internal dose reconstruction approach among inhabitants of territories contaminated by radionuclides as a result of the Chernobyl accident (Russian Federation).

Starting from the fall of 1986 year till 2001 year the massive monitoring of ^{137}Cs activity in whole body among inhabitants of Russian territories contaminated by radionuclides as a result of Chernobyl accident was performed [11]. The detailed description of methodology developed and equipment used are presented in [12].

The results of massive monitoring of ^{137}Cs activity in whole body were applied for developing of approach of individual whole body dose reconstruction for persons who were not monitored: it is radioecological model and individual dosimetrical questionnaires for individual dose estimations by modeling calculations [13].

The developed approach of individual whole body internal dose reconstruction is still actual for implementation in a cases of possible large scale radiations accidents.

As in a case of thyroid gland irradiation, it was found that statistical distribution of individual whole body doses of internal irradiation is characterized by "long tail" in the individual dose range, which is much higher than mean and median doses [12].

Figure 4 shows an example of statistical distribution of individual whole body doses of internal irradiation among inhabitants of contaminated territories of Bryansk region.

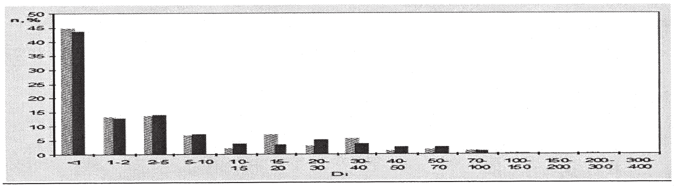

Figure 4. Statistical distribution of individual whole body doses of internal irradiation (Bryansk region).

On the horizontal axis (Di , mSv):

Results of estimation of individual whole body doses of internal irradiation on the base of ^{137}Cs activity measurements in whole body of inhabitants of contaminated territories of Bryansk region - whole body doses accumulated during 15 years after the Chernobyl accident (total number of monitored persons - 34 834);

Results of estimation of individual whole body doses of internal irradiation on the base of developed approach of dose reconstruction (radioecological model and individual dosimetrical questionnaires) - whole body doses accumulated during 15 years after the Chernobyl accident (total number of questioned persons – 1 456);

On the vertical axis n,%:

Percentage from total number of persons with available results of ^{137}Cs measurements (total number of these persons – 34 834)

Percentage from total number of personsn with available individual questionnaires (total number of these persons – 1 456)

Figures 5 and 6 shows an examples of comparison of individual whole body doses of internal irradiation: calculated individual doses VS dose estimations based on the results of ^{137}Cs measurements in whole body among inhabitants of contaminated territories of Bryansk region are presented. Comparisons were performed for the same persons, which have data of ^{137}Cs measurements and data of individual questioning as well. Figure 5 – 1st year after the accident ($D2 = (1.24 \pm 0.25) \times D1 + 1.7 \pm 2.1$; $R=0.98$, $p<0.01$). Figure 6 – 15th year after the accident ($D2 = (1.02 \pm 0.15) \times D1 + 0.12 \pm 0.41$; $R=0.94$, $p<0.01$).

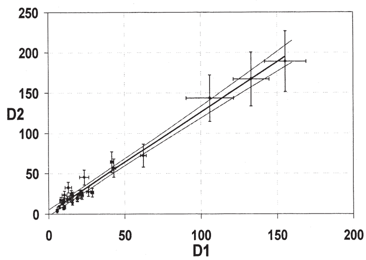

Fig 5.

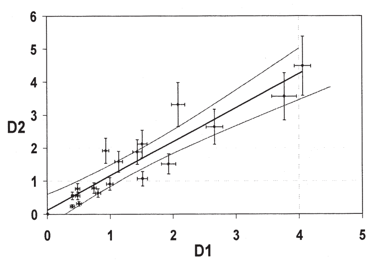

Fig.6.

Retrospective luminescence Dosimetry (RLD).

RLD employs the measurement of termo- or optical stimulated luminescence from quartz in bricks. The intensity of this luminescence is proportional to dose of external irradiation. This enables the absorbed accumulated dose due to external irradiation to be measured [1-3].

International intercomparison of RLD.

International intercomparison of RLD was performed for quartz inclusions extracted from the brick's samples of buildings in Zaborie village, Bryansk region (Russia) contaminated by Chernobyl fallout (Fig 7). Data of four Labs are presented in figure 7 - RF, UK, Germany, Finland [1,2].

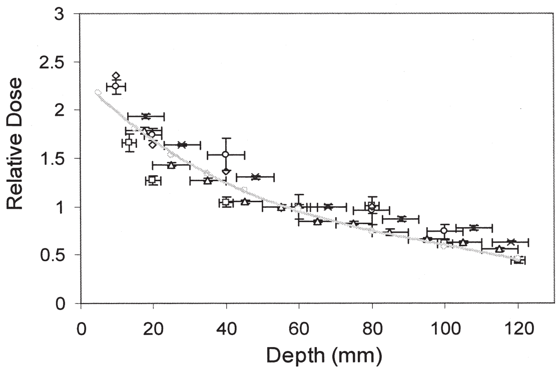

Fig.7. Example [1,2]. Results of international intercomparison: depth-dose profile in the brick's sample from Zaborie village (former textile facility), Bryansk region, Russia. Background accumulated dose is subtracted. "Age" of building is equal to 29 ± 2 years at the moment of sampling. Background accumulated dose is equal to 73 ± 7 mGy. Maximal accumulated accidental dose (during 12 years after Chernobyl accident) in the brick at the depth from the wall surface 10 mm is equal to 302±36mGy. Accumulated dose in the air near the sampling point was estimated to be equal 515±80 mGy. Soil contamination density by ^{137}Cs in the sampling point is equal to 4460 ± 340 kBq/m^2 (in 1986 year).

International intercomparison of RLD method was performed as well for 4 brick samples extracted from 3 locations (former school, former small Church, former big Church) in Dolon' village (Kzakhstan), which is the most affected populated settlement as a result of the 1st A-bomb test of the former USSR on 29 August, 1949 (see Table 2 [14-18]).

Table 2. Example [14-18]. Results of international intercomparison of RLD method near Semipalatinsk nuclear test: estimation of accumulated dose in the brick at 10 mm depth averaged over four samples from three locations in Dolon' village (background dose is subtracted).

RLD method of dose estimation*)	dose in the brick at 10 mm depth, mGy**)	references
TL	249±42	[16]
Tl/OSL	204±15	[14,15,18] ***)
OSL	210±120	[17]

*) TL – thermo stimulated luminescence; OSL – optical stimulated luminscence.

**)In order to estimate accumulated dose in the air multiply to 2.0±0.2.

***)Averaged over 4 Labs.

Evaluation of potential of RLD.

Figure 8 shows example of results of measurements of accumulated dose in air VS ^{137}Cs soil contamination density in different locations of Bryansk oblast, Russia [1,2, 19].

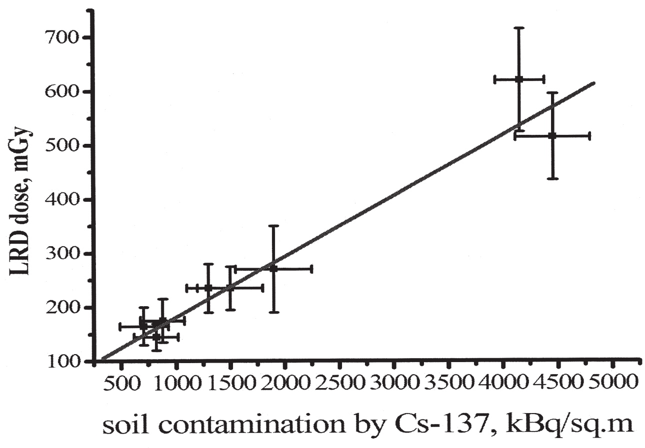

Fig. 8. Example [1,2,19]. Results of measurements of accumulated dose in the air VS ^{137}Cs soil contamination density in different locations of Bryansk oblast, Russia. Dose estimations were performed in 1998 year (R=0.97).

Figure 9 shows an example of comparison of RLD dose in the air (external irradiation) with calculated dose for several locations in St. Vishkov village, Bryansk oblast, Russia [1,2,19].

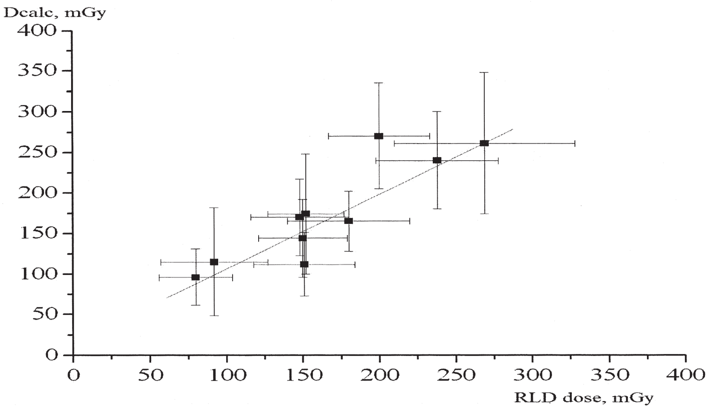

Fig. 9. Example [1,2,19] of comparison of RLD dose with calculated dose for locations in St. Vishkov village, Bryansk oblast, Russia (R=0.86).

Results of RLD dose estimations (dose in air) for settlements in the vicinity of the trace of 1st former USSR nuclear test (1949 year) are presented in Table 3 [3].

Table 3. Example of RLD dose estimation for some settlements in the vicinity of the trace of 1st former USSR nuclear test (1949 year) [3].

Territory	RLD dose (in the air), mGy
Kazakhstan: Dolon'	475±110
Kanonerka	225±60, 250±60
Akkol'	less than 20 mGy
B. Vladimirovka	less than 20 mGy
Izvestka	less than 20 mGy
Altai Krai, Russia: Topolinskiy	230±60

It should be noted that LRD dose for Dolon' village is in a good agreement with the results of computed dose: LRD dose is equal to 475±110 mGy [3] and computed dose is equal to 645±70 mGy [18]. According to [20,21] the computed dose is equal to ≈ 500 mGy.

Retrospective ESR dosimetry with human tooth enamel.

Tooth enamel mainly consists from nonorganic crystal fraction of hydrooxiapatite. As a result of irradiation the stable paramagnetic centers are forming in the crystal fraction. The concentration of these centers is determined by ESR method [22-25].

The international intercomparison of ESR tooth enamel dosimetry method was performed among 20 Labs. The irradiation of tooth samples by unknown nominal doses was performed by IAEA. SD between nominal doses and ESR doses determined by MRRC is equal to 32 mGy (Figure 10).

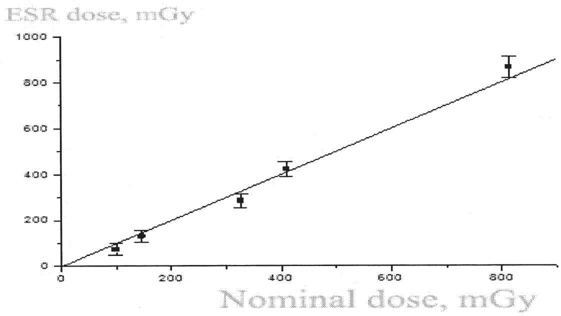

Fig.10. Retrospective ESR tooth enamel dosimetry: international intercomparison: result of MRRC participation are presented.

ESR dosimetry: evaluation of potential.

Figure 11 shows the correlation between individual doses determined by ESR method and calculated doses for Zaborie village (Bryansk region, Russia) contaminated after the Chernobyl accident [19].

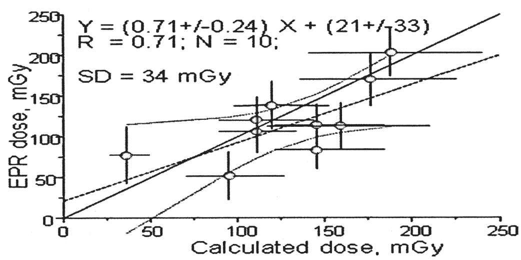

Fig. 11. Example [19]. Accumulated individual doses determined by ESR method VS calculated individual doses for inhabitants of Zaborie village (Bryansk oblast, Russia). SD between two methods is equal to 34 mGy.

ESR doses in Dolon' village near Semipalatinsk nuclear test site are presented in Table 4.

Table 4. Example. Accumulated doses (from 1949 year till 2000 year) among inhabitants of Dolon' village near Semipalatinsk nuclear test site determined by ESR tooth enamel method are presented. Background dose is subtracted.

ESR dose, mGy	number of samples	references
165±22	11	[22]
177±33	3	[23]
45	2	[24]
ESR dose overall average: 156±37 mGy (n=16)		

Current results.

Three independend methods of dose reconstruction (computational modeling, RLD, ESR) were overwieved. Instrumental mehods are in good agreement with computational modeling.

Sensitivity of RLD and ESR methods is about 20-30 mGy of accumulated dose. It is possible to reconstruct accumulated dose at least 50 years after irradiation.

Possible future implementation of potential of retrospective dosimetry methods:

To establish international collaboration and Nonformal International Virtual Laboratory of Retrospective Dosimetry for a cases of possible large scale radiation accidents.

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THE KAINAR SYNDROME: HISTORY AND MODERN UNDERSTANDING

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Introduction: More than 60 years has passed since the first nuclear test was made at the Semipalatinsk Nuclear Test Site (SNTS) in the former Soviet Union, and several hundreds of other explosions, both of atomic and hydrogenic types were made in this area from 1949 to 1989 [1,2]. Due to these explosions several hundred thousand people in our country were exposed to various doses of ionizing radiation. As exposure continued for 40-years period, and 23 years has passed after the last nuclear test, three generations of exposed people are now available for epidemiological and clinical studies at the present time. Even now thousands of people are battling diseases, both somatic and psychological, caused by radiation [3,4].

Brief history: Generally speaking, two periods of nuclear tests were made in the Semipalatinsk region. According to modern data, compiled mainly from former classified military sources, in the technical area III of the SNTS 26 above ground and 87 atmospheric nuclear explosions were conducted during the period from 29 August 1949 to 30 December 1962. One of these tests occurred on 24 September 1951, and mainly affected the Kainar village, located in the area [5].

During the period from 11th October 1961 to 10th October 1989, 223 underground nuclear explosions were conducted at the technical area "G" of the SNTS, and during the period from 19th June 1968 to 19th October 1989 an additional 123 underground nuclear explosions were conducted at the technical area "B". The total number of these explosions and the peculiarities of radiation dose formation are shown in the table 1.

Table 1.Radiation explosions number and the peculiarities of radiation dose formation (in comparison with atomic bombs, exploded in Hiroshima and Nagasaki)

	Semipalatinsk, and it's vicinity	Hiroshima	Nagasaki
Number of explosions	1st period: Atmospheric and on-the-ground tests: 1949-1963 (125 tests, among them 26-on-the-ground, 91 – in the air, 8 – from the plane); 2nd period: Underground tests: 1963-1989 (343 explosions);	1	1
Exposure duration	Chronic type, 40 years	Acute type	Acute type
Type of exposure	External and internal (X-rays, +α, + β particles)	Mainly external (X-rays + neutron)	Mainly external (X-rays, and only partly neutron)

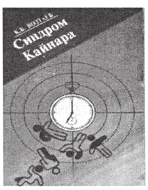
On August 5th, 1963 the Limited Test Ban Treaty was signed by the United States, Great Britain, and the Soviet Union. After Senate approval, the treaty came into effect on October 10th, 1963 banning nuclear weapon testing in the atmosphere, in outer space, and under water [6, 7].

Several years after the tests had been started, the authorities received several letters from local residents complaining for some strange symptoms, that were unknown in this area before [8]. The letters were passed to President of Kazakhstan's Science Academy Professor Kuanish Satpaev. In 1958 he ordered to send a group of medical researchers to check the reason of "strange conditions". The group was guided by Professor Bahiya Atshabar, who was at that time the Director of the Research Institute for Local Pathology. The task was very dangerous: only 5 years passed since 1953, when hundreds of physicians were shot or sent into prisons in "Physicians Affair", as Stalin suspected them in lack of loyalty [9, 10].

As a result of the studies, the group described patients with symptoms like increased bleeding, hair loss, fainting and fatigue. In the blood tests the main finding was leucopenia. As it was impossible to attribute the findings to nuclear tests, the way was found. These symptoms were combined in "Kainar syndrome" as the group provided their studies in nearby villages, but most patients were exactly from Kainar village itself. Brucellosis, local infectious disease from sheep, combined with lack of vitamins, was named as the reason of newly described condition.

Authorities didn't believe to the results of this study, so another group was send to the area in 1959, but they returned with the same results. So, the secret Dispensary N4, which was opened in Semipalatinsk in 1957, was renamed into "Antibrucellosis Dispensary" and had the task to study health condition of those affected by nuclear tests. Nowadays this is our Research Institute for Radiation Medicine and Ecology (renamed in 1991). Unfortunately, in 1965, according to Order from USSR Health Ministry, the studies in Semipalatinsk itself were strictly forbidden [3].

The story of "Kainar syndrome" became popular again in the early 90-s, when the former communist leader, Chief of Semipalatinsk area Mr. Boztayev, published a book "The Kainar Syndrome", describing this story [8].



The book from the library of the Research Institute for Radiation Medicine and Ecology, Semipalatinsk.

As it is written in the book, "...Clinical medical detachment conducted health examination of Abay region, Dolon village of Beskaragay and Barshatas region residents. Most frequent symptoms were bleedings from the nose, mucous membranes of upper respiratory tract, mouth; stomach bleeding; vomiting; colon, gums and genital bleeding, dystrophic changes in the skin of the open areas, weakness.

As a rule, all these symptoms were present at the same patient. These symptoms were called "The Kainar syndrome" in the name of the village, where this symptoms were diagnosed for the first time.

The history and modern understanding of Kainar Dosimetry:

In the first reports, that were presented to Semipalatinsk region authorities by military officials the dose from all nuclear tests was interpreted as low, and in average equal to 0,3 cSv. It was said that it was as low as one month background exposure and it's better to neglect them [11].

Shortly after that, in 1992 the government of independent by that time Kazakhstan Republic requested the data about the total radiation, including radiation doses for the whole 40-years period of explosions from the authorities of the Semipalatinsk Nuclear Test Site.

These data allowed distinguishing the four different zones of radiation exposure, so-called "radiation risk zones" in the Semipalatinsk region [3].

The first zone is an extreme radiation risk zone, where the dose equivalent to the population exceeded 100 cSv, for example 12.1cSv in Chagan.

The second is the maximal radiation risk zone, comprising populated areas within the most exposed places of the Semipalatinsk vicinity, namely the Abaisky and some other districts. The estimated dose equivalent to population was in range from 35 to 100cSv. It was named as high as 94,5cSv in Zulkarash village of Abaisky district, 87.7cSv in Karaul and 68.1 cSv in Kainar. These are the exact villages, where the group of Prof. Atchabarov provided their studies.

The third - is the zone of increased radiation risk, comprising the population of 6 districts in the Semipalatinsk vicinity and the city itself. The radiation doses of these areas population ranged from 7 to 34.9cSV.

The fourth zone of minimal radiation risk - comprising five most distant districts of the Semipalatinsk region, including Makanchinsky, Urdjarsky, Taskeskensky, Kokpektinsky and Aksuatsky districts. The dose equivalent to the population of this radiation risk zone was less than 6.9cSv.

To be sure, the distinguishing of all these zones was rather conventional. It was difficult to set any clear territorial borders for specific doses of external or internal radiation exposure. The "behavior" of radionuclides within the radioactive cloud is unknown. Also it's not fully understood , why radioactive fallout occurred in the territories, which are hundreds kilometers away from the hypocenter [12]. The total number of exposed in Kainar is shown in table 2.

Table 2. Population of Kainar village, exposed to external radiation doses (Number of people)

Population study group	**External radiation dose, cSv**				
	<1	**1 - 5**	**5 - 10**	**10 - 15**	**15 - 20**
Children	**1729**	**86**	**1003**	**214**	**-**
Adults	**2079**	**90**	**513**	**293**	**480***

According to the newly unclassified in 1995 archival data, the effective equivalent and absorbed doses to thyroid gland of some residents were recalculated. The results are shown in table 3.

After 1994, when the famous Japanese physicist Professor M. Hoshi was approved as the principal researcher in the field of Semipalatinsk Dosimetry, the new era began. The determination of external dose to teeth of inhabitants of settlements near the SNTS was made by many methods. One of the most reliable today is the EPR dosimetry. In the studies made after 1994, tooth doses have been reconstructed for dosens of persons with teeth having been formed before the first nuclear test in 1949. In brief, the mean external gamma doses for residents of most studied settlements were in the range from a few tens of mGy to approximately 100 mGy.

Table 3. Calculated effective equivalent and absorbed doses to the thyroid gland of some residents of Abay region in1965 (mSv, mGy)

Villages	Effective equivalent dose, mSv	The absorbed dose to the thyroid gland, mGr	
		Adults	Children
Kainar	**558,6**	**1 399,5**	**11491,6**
Karaul	**451,8**	**1 326,8**	**10 326,8**
Sarzhal	**665,4**	**1 472,3**	**12 656,3**
Arhat	**234,8**	**896,5**	**9 836,1**
Kaskabulak	**445,2**	**1 024,7**	**10 124,5**
Kokbay	**312,6**	**810,6**	**9 126,3**
Medeu	**318,8**	**924,3**	**9 472,1**
Kyzyltu	**288,4**	**1 126,8**	**12 276,8**
Orda	**302,6**	**836,2**	**9 423,5**
Kundyzdy	**225,2**	**1 226,5**	**13 226,4**
Average-weighted dose	**361,1**	**1071,3**	**10 718,7**

The Kainar problem discussion

The threshold levels of radiation exposure for determining radiation effects are well known [13,14] and shown in table 4.

Table 4. The threshold levels of radiation exposure

Radiation effects	Threshold dose (mSv)	Kainar dose (mSv), external and internal
Bleeding	1000	Below 700
Hair loss	2000	Below 700
Dystrophic changes of skin and mucous membranes	2000	Below 700
Asthenia, weakness	1000	Below 700
Leucopenia	500	Below 700

But the results of independent studies of 2 researcher groups in the Karaul area in late 50's of the last century clearly described such effects as mucous bleeding, hair loss, fatigue, dystrophic changes of the skin and mucous membrane.

What was the possible reason of these discrepancies? To our understanding, it could be due to the following causes. Firstly, it was quite possible for some of the exposed to have higher doses, as they probably several times crossed the radioactive tracks with heavily exposed spots (Prof. Stepanenko V.F., personal opinion, 25th January, 2012). Secondly, according to the data of the Kazakh National Institute of Nutrition, the list of following peculiarities of the exposed in Kainar area people diet was named:

a) the invariable diet with lack of essential vitamins, especially vitamins C, B, A;

b) lack of Iodine intake with average consumption was 68.9 mkg/day and daily requirement in our area more than 160 mkg/day;

c) lack of other essential microelements, especially iron consumption.

All these diet peculiarities were combined with high level of infectious diseases among the exposed people due to poor hygienic traditions [15].

Our previous studies provided at the heavily exposed zones in the Semipalatinsk vicinity showed that with the increased level of exposure the increased incidence of respiratory allergy was registered, including bronchial asthma, hay fever and allergic rhinitis [16].

We also found the peculiarities of hay fever among the exposed to ionizing radiation, including its early formation (in many cases even infancy, which is quite uncommon in the non exposed population) more common concomitant asthma increased sensitization structure. It was impossible to explain these peculiarities simply by dose as the threshold for deterministic effects is generally higher than 1000 cSv and in the most cases less than 100mSv. So, we proposed that in many cases radiation exposure was aggravated by psychological stress.

As allergic diseases are more likely to be formed in patients who underwent stress factor influence, we proposed that damaged psychology was one of the mostly underestimated factors in the Semipalatinsk area. Many modern researchers think in the same way. Thus, in his short report from the Chernobyl area V.Stephan emphasized that poverty and stress were much bigger threat to public health than radiation itself [17]. Recent studies of the psychological consequences of Chernobyl accident concluded that mental health effects were the most significant public health consequences of this disaster.

Another study of Chernobyl liquidators, who were in reality the most exposed clean-up workers, reported that among them the rates of depression and posttraumatic stress disorders remain elevated even two decades later. But the findings on prenatally exposed remain inconsistent. Thus, recent studies in Kiew, Norway and Finland point to specific neuropsychological and psychological impairments associated with radiation exposure, but other studies found no significant effects. General population studies report increased rates of poor self-rated health as well as clinical and subclinical depression, anxiety and posttraumatic stress disorder [18].

A new wave of interest came after Fukushima power plant accident in March, 2011 [19]. This disaster further heightened scientific interest for hazards, associated with radiation. For example, S. Takahashi described the challenge of a 36 weeks pregnant lady-physician specialist in obstetrics-gynecology who felt herself powerless because she had a responsibility to warn patients of the risks, but had no clear way to quantify them [20].

In conclusion, we want to stress, that it is difficult to explain the clinical signs, that were seen in some of the Kainar area residents. Some explanation may come from better understanding of Dosimetry, and another one – from damaged psychology of the exposed.

Our data concerning "the Kainar syndrome" in some of the exposed may be used in possible future studies. We propose the need of experimental studies, where the known threshold levels of various effects of chronic radiation exposure would be compared in 2 groups, one with good diet and another one with experimental hypovitaminosis. This data may be important in interpretation of radiation incidents among the population of developing countries with similar to ours experience of poor diet and bad hygiene.

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ABSTRACT

Several years after the tests at the SNTS had been started, the authorities received several letters from local residents complaining for some strange symptoms, that were unknown in this area before. The letters were passed to President of Kazakhstan's Science Academy Professor Kuanish Satpaev. In 1958 he ordered to send a group of medical researchers to check the reason of "strange conditions". As a result of the studies, the group described patients with symptoms like increased bleeding, hair loss, fainting and fatigue. In the blood tests the main finding was leucopenia. As it was impossible to attribute the findings to nuclear tests, the way was found. These symptoms were combined in "Kainar syndrome" as the group provided their studies in nearby villages, but most patients were exactly from Kainar village itself. Brucellosis, local infectious disease from sheep, combined with lack of vitamins, was named as the reason of newly described condition. Authorities didn't believe to the results of this study, so another group was send to the area in 1959, but they returned with the same results. So, the secret Dispensary N4, which was opened in Semipalatinsk in 1957, was renamed into "Antibrucellosis Dispensary" and had the task to study health condition of those affected by nuclear tests. Nowadays this is our Research Institute for Radiation Medicine and Ecology (renamed in 1991). It is difficult to explain the clinical signs, that were seen in some of the Kainar area residents. Some explanation may come from better understanding of Dosimetry, and another one – from damaged psychology of the exposed.

The scientific basis for the organization of health screening radiation-exposed population of Kazakhstan, the results of the analysis, design prenosological prevention and rehabilitation

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Introduction

Health effects of the Semipalatinsk nuclear test site are not limited to the purely radiological. Experience of the elimination of the Chernobyl disaster, the Ural region of Semipalatinsk Nuclear Test Site (SNTS) suggests that minimizing the effects of radiation exposure for the population depends on the organization and effective work of agencies and health institutions.

In this regard, one of the major tasks of medical care is still a timely organization of clinical and epidemiological surveillance of the health of people living in the disadvantagedly radioecological areas. Thus obtained and strictly verified operational information from the medical and scientific research institutions of the country about the health of the population, who had been exposed to ionizing radiation is the main criterion for the mobilization of additional forces and resources for healthcare assistance to victims of disasters and radioecological consequences of the development of radiation protection measures.

Priority actions in the health care of this population are in the competence of the government. These actions demand for the creation of a national system of control measures in health care.

In this regard, the priority development of activities of practical public healthcare in affected areas as well as medical health care of affected people remains long-term goal of the state.

Materials and Methods

From the list of representatives of the population of Borodulikha, Beskaragai and Kokpekty areas of East-Kazakhstan District included in database as of 2006 -2010 years, were formed by two representative groups for the study of epidemiological and statistical analysis of the prevalence of morbidity - the main group is the primary medical records – 3,130 people and a control group (Kokpekty District) – 1,988 people.

In assessing the dynamics of the level of disease prevalence rate PR is calculated by the formula:

$PR = n \times 10^{3} / N$,

where n - number of persons suffering from this disease at a certain time (at the time of the survey), N-size of the cohort during the inspection, 10^3- the standard number of surveys.

To characterize the prevalence of diseases were calculated by the intensive parameters. To eliminate the influence of demographic differences we performed subsequent standardization of these indicators in direct way by conventional methods in medical statistics.

As an indicator on the differences in prevalence among groups selected areas as a whole, separate age-sex groups, using the value of the indicator "relative comparison" - the relative risk [11].

RR=PR of the main group / PR control group A statistically significant increase in relative risk was confirmed by constructing 95% confidence intervals. Statistical significance was assessed using the RR criterion χ 2, percentage points of distribution are given in tabular form in handbooks on statistics. To investigate the relationship between the discrete qualitative characteristics were analyzed by two-dimensional contingency tables with calculation of the values of Pearson χ 2 and the values of the association ϕ - index of the coupling strength for the qualitative dichotomous variables [12].

Results and discussion

Table 1 presents data on average annual values of the levels of prevalence of diseases with a significant difference between study and control groups. The average level of general morbidity among men and women made up the core group – 2,620.9cases per 1000 population in the control group – 1,631,0 (RR = 1,59, p <0.05).

It has been established that the highest relative risks in the study group were recorded on diseases of blood and hematopoietic system, endocrine system diseases, mental disorders, diseases of the digestive system, and inborn malformations. Average annual rates of cancer in the study group were - 260, 0 cases per 100 000 population, in the control group - 170. 0 cases (RR = 1, 53, p <0.05). Approximately the same relative risks reported for diseases of the circulatory system (1.54) and diseases of the respiratory system (1.55). The average levels of blood diseases and blood-forming tissue in the study group were - 161.4 per 1,000 population, in the control group - 78.3 cases (RR = 2, 06, p <0.01). Average annual rates of diseases of the endocrine system (the average proportion of thyroid diseases - 74.2%) in the study group was - 278.4 per 1,000 population in the control group - 126.8 cases (RR = 2, 37, p <0, 05). The highest average levels of illness in the study group reported on diseases of the circulatory system (CVD) and respiratory system. Thus, the average level of CVD in the study group was -690.2 per 1,000 population, in the control group - 467, 3 (RR = 1, 54, p <0.05). The average relative risk of diseases of the respiratory system in the study group was - 1.55.

These results testified to the sound methodological approach to the organization of screening in populations living in disadvantaged radioecological areas. First of all, it is relate to the careful selection of representative groups of research before the actual screening.

The proposed system of surveys of screening radiation risk groups in areas adjacent to SNTS is a complex joint actions of Institute of Radiation Medicine and Ecology of the city of Semey and Family and health facilities explored regions taking into account the forming of study groups (with confirmation of legal residence in a particular locality), forecasting, early diagnosis and preventive treatment of radiation-induced diseases.

As the analysis of domestic, foreign literature and research results among the liquidators of the Chernobyl accident and those living in the contaminated areas shows that there is an increased dosoindependent incidence of cardiovascular and cerebrovascular pathology.

In large-scale epidemiological studies conducted on populations exposed to radiation in different radioecological situations, significant differences are not found in the dynamics of morbidity among individuals with different dose rates compared with expected. They did not register "dose-effect" as well.

Therefore, we must recognize that only a standardized screening methods based on the formation of groups of radiation risk, taking into account the objective dose rates, will provide data on the prevalence and nature of somatic pathology of the decreed population, to assess the needs in the location of specialized medical care that can improve the quality of life of people affected due to the testing of nuclear weapons.

We believe the most effective study of markers indicating radiation damage and elucidation of the pathogenetic mechanisms of radiation-induced somatic pathology not only in a hospital survey, but also in the results of primary screening of the health of the affected population from nuclear weapons tests in the SNTS.

Experience of Clinical Research departments of Radiation Medicine and Ecology in the last 10 years including studying and assessing the health of the irradiated population of Kazakhstan, allowed to formulate the main stages of screening.

The First step: the creation of the office-based medical statistics of regional medical hospitals of the database of the State Scientific-aided medical register affected by the Semipalatinsk nuclear test site (SNTS).

The tasks of database sector:

-monitoring of decreed population movement in the group;

-monitoring of health status decreed by the group;

-verification and ranking the causes affecting the health of the population of the decreed group;

-the formation of groups at risk the implementation of long-term effects of radiation;

-formation of the limited volume of care of the decreed population;

The second stage – the organization of medical assistance to affected populations

Objectives of the second stage:

Planning and allocation amounts of medical services between partners required to meet the challenges of early diagnosis and in-depth survey of the decreed population;

-negotiation and approval of schedules of joint activities for the conducting routine inspections of the decreed population;

-organization of joint preventive examinations of the decreed population;

-organization of in-depth survey using consultative and diagnostic department of Institute of Radiation Medicine and Ecology;

-organization of treatment of identified patients in the hospital of the Research Institute of Radiation Medicine and Ecology, and regional hospitals.

The third phase – the development of risk criteria and methods of radiation-induced diseases, treatment and prevention of long-term effects of radiation.

Objectives:

-analysis of information on the movement of people and the main statistical indicators of the health of radiation-exposed population and their descendants;

-study of pathogenetic mechanisms of inheritance and implementation of long-term effects of irradiation descendants of persons born to parents exposed to radiation;

-the introduction of methods of early diagnosis, treatment and prevention of radiation-induced diseases.

Currently, the Institute of Radiation Medicine and Ecology widely uses epidemiological methods of calculation of phenotypic correlations ("parent-child") of individual nosological forms of diseases, established in individuals exposed to direct radiation and their possible inheritance when radiation-induced modification of the genome of their offsprings.

The Institute's specialists developed an algorithm for the possible pathogenetic mechanisms of indirect effects of radiation exposure in high-risk groups, represented by the descendants of those born to exposed parents, early diagnosis prenosological states, monitoring of risk factors for primary prevention (Figure 1).

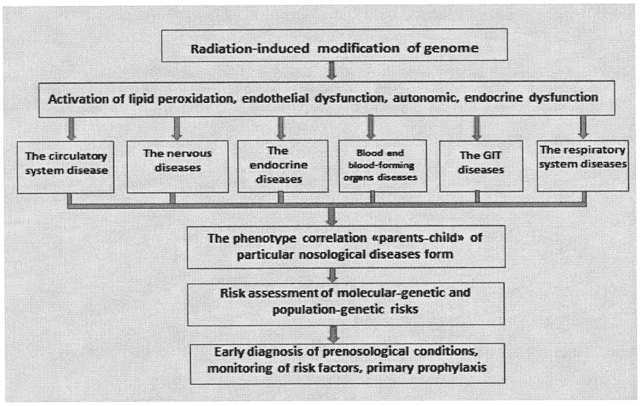

Figure 1 - The system of forecasting, early detection, prevention and treatment of radiation risk in groups of children born to exposed parents

Modern cytogenetic and molecular genetic studies of radiation risk groups of the participants in the elimination of the Chernobyl accident, and also decreed population led to the "breakthrough" in science conclusions about the pathogenic mechanisms of radiation-induced modification of the human genome, are realized in the form of genomic instability (clinical interpretation), followed by inheritance of individual deterministic effects of ionizing radiation.

Radiogenic modification of the genome associated with activation of lipid peroxidation, endothelial disfunction, impaired autonomic regulation and hormonal imbalance homeostat. These targets form the radiation exposure of individual clinical features of the current nosological forms of diseases associated with the earlier they start, malignant course, the frequency of complications and their outcomes. These pathological substrates in radiogenic modification of the genome are inherited and recorded.

The presented scheme of development and implementation of the pathogenetic mechanisms of radiation-induced modification of the genome requires amolecular-genetic objectivization with subsequent calculation of risk. We believe that only the early diagnosis prenosological forms of disease in groups of children born to parents exposed to radiation, monitoring of risk factors, as well as primary prevention, may confirm or refute the possibility of inheritance of determinate ionizing radiation parents of their children.

Overall Image of Nuclear Tests among Inhabitants in the Semipalatinsk Area

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Abstract

The present paper is an attempt at describing overall image of nuclear tests for the residents at Semipalatinsk, Kazakhstan. Our research team conducted the survey by interview from 2002 to collect testimonies of inhabitants. We analyzed testimonies using the hierarchical clustering method and the multi-dimensional scaling method. The result showed that there are two different types of appeal in residents' mind. One is the complaint for the present condition – especially about the health of one's family and one's own. The other is the memory at the testing time.

Our results suggest that the most impressive memories for the inhabitants are "mushroom cloud", "flash light", "waving of the ground" and "Evacuation to the outside". The experiences of "waving of the ground" and "evacuation to the outside" are peculiar to the Semipalatinsk residents. For the residents near the SNTS the greatest concern at present is their health problems. They still struggle with their diseases, family's death even though 20 years has passed since the last nuclear test.

INTRODUCTION

From 1949 to 1989, over the four hundred times of nuclear tests had conducted at Semipalatinsk Nuclear Test Site (SNTS)[1],[2] - that is one of the negative legacy of the former Soviet Union. It is said that several hundred thousand people have been affected by radiation exposure around this area[3]. There is a possibility that most residents still have trouble with many kinds of symptoms[4].

Our research team began interviewing the inhabitants of villages near the SNTS in 2002 to investigate their health status, their experiences of the nuclear explosions, psychological effects caused by those experiences, and the routes of exposure[5],[6]. The present research focuses upon the inhabitants themselves, that is, we tried to clarify the realities of Semipalatinsk by listening to first-hand accounts from the victims. With the information about the victims' personal experiences, we expected to be able to provide a more complete picture of the radiation effects in and around Semipalatinsk.

MATERIALS AND METHODS

For this research, we use the data from 2002 to 2007 surveys. In those years we have conducted surveys on six occasions covering 26 villages near the SNTS (see Figure 1). The study subjects comprise persons who experienced the nuclear tests on the ground between 1949 and 1962 in each village and persons who currently reside there. We selected the subjects at random.

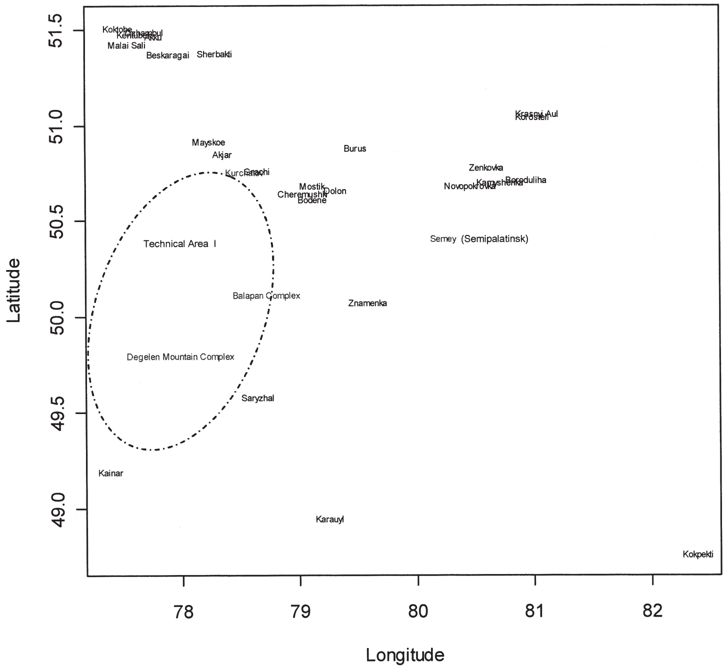

Figure 1. Semipalatinsk Nuclear Test Site (SNTS) and the target villages (except Semey and Kurchatov)

All testimonies were translated into Japanese. As an exception, the survey in 2006 there are 88 testimonies in Kazakh language which haven't been translated into Japanese. So we excluded them from our analysis.

First, we selected the words of high frequency from testimonies. Then we analyzed those words using the hierarchical clustering method and the multi-dimensional scaling method[7],[8].

The open-ended survey question about experience and testimonies concerning nuclear test is as follows;

> "Please write about anything concerning the nuclear tests that cannot be forgotten, that still haunts you, that you regret, or any opinions about nuclear test in detail in the space provided below. You may write about your experiences, or that of your family or your close neighbors."

RESULTS AND DISCUSSIONS

Table 1 shows the number of respondents. There were 395 males and 549 females. The total number of testimonies was 944. Average age of the subjects was 64.88 ± 8.97 years old.

Table 2 shows the words which are used more than 50 times in testimonies. We selected all nouns, adverbs, adjectives and the verbs relating to the experiences of nuclear tests[9],[10]. We analyzed testimonies in Japanese then translated into English for this paper. The words - “explosion”, “see”, “house”, “test”, “polygon” and “mushroom cloud”- are the highest frequency.

Table 1. The number of respondents classified by sex in each village

Year of survey	Village	Male	Female	Total
2002	Dolon	6	13	19
	Kainar	29	19	48
	Kokpekti	7	16	23
	Saryzhal	29	19	48
2003	Dolon	4	5	9
	Kainar	1	5	6
	Karauyl	13	18	31
	Kokpekti	3	6	9
	Saryzhal	13	6	19
	Znamenka	7	6	13
2004	Bodene	24	21	45
	Burus	14	26	40
	Cheremushki	20	21	41
	Grachi	9	19	28
	Mostik	23	22	45
	Znamenka	15	20	35
	Institute*	0	3	3
2005	Boroduliha	8	21	29
	Kamyshenka	8	9	17
	Korosteli	4	9	13
	Krasnyi	11	13	24
	Novopokrovka	16	18	34
	Zenkovka	8	15	23
2006	Akku	19	27	46
	Beskaragai	17	32	49
	Dzhambul	20	26	46
	Sherbakti	19	30	49
2007	Akjar	6	20	26
	Kentubek	10	24	34
	Koktobe	10	11	21
	Malai	12	21	33
	Mayskoe	10	28	38
Total		395	549	944

*In 2004 we interviewed the 3 patients at the hospital of Kazakh Scientific Research Institute of Radiation Medicine and Ecology.

Table 2. 60 words of high frequency used in testimonies (50 times or more)

Order	Word	Frequency in total	Order	Word	Frequency in total
1	explosion	868	31	ravine	97
2	see	600	32	give	96
3	house	445	33	go up	93
4	test	436	34	close	90
5	polygon	346	35	cloud	89
6	mushroom cloud	312	36	lie down	81
7	nuclear	260	37	school	80
8	window	260	38	strong	79
9	remember	253	39	get (sick)	78
10	disease	251	40	die	77
11	child	234	41	resident	73
12	outside	208	42	many	72
13	influence	201	43	now	71
14	soldier	197	44	at that time	69
15	village	171	45	door	67
16	shake	167	46	break	66
17	everyone	163	47	cancer	62
18	die	144	48	shake	62
19	be taken to	137	49	husband	61
20	sky	132	50	parent	61
21	feel	130	51	district	60
22	person	130	52	blast wave	58
23	glass	128	53	bright	57
24	ground	121	54	be born	57
25	health	116	55	invalid	57
26	now	115	56	blow (off, away)	55
27	people	113	57	son	54
28	first	110	58	dish	53
29	all	109	59	receive (pension)	52
30	light	102	60	pension	51

Some verbs have various meanings, we provided the objects or adverbs in ( ) due to understand clearly.

Next we calculated the distances of each word based on the frequency of appearance simultaneously in the same testimonies of one person. Then we classified those 60 words through the hierarchical clustering method (see Figure 2) .It means that if the distance is closer, the possibility of using these words simultaneously will be greater. The following testimony is one of examples, which includes the words of "die", "cancer" and "husband" together;

Test site took millions of people's lives, mortality is very high. Almost all my relatives died. Husband died of cancer as well as my son. Many people died in my house and all of them died of cancer. We need peace, quite life, welfare. We spend a lot for medicine. Free medical service is needed. (Female, 76 years old, Borodulicha)

The result shows that the testimonies of inhabitants are divided into two groups. In the upper group, we can see the words of "health", "die", "invalid", "disease" and "cancer" and so on. These words are related to their health condition. The words like "child", "son", "parent" and "husband" indicate the family experience of shaking of the ground. (5)The words of “ravine”, “outside” and “lie down” suggest the experience of evacuation to the outside.

Figure 3 described the distances among the words more visually by using multi-dimensional scaling method. This figure also shows the same result as figure 2. The words can be divided into two groups. One is the complaint for the present condition .The other is the memory at the testing time. Some remarkable samples of testimonies are in the Appendix.

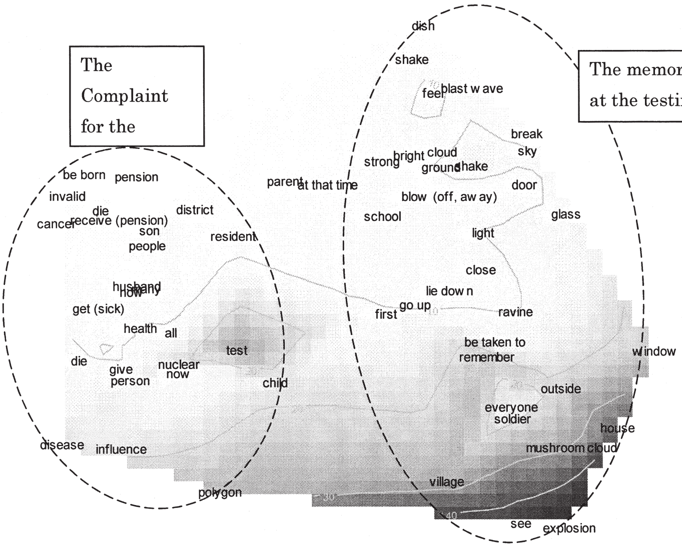

Figure 3. Result of the multi-dimentional scaling method

CONCLUSION

As a result of the statistical analysis, testimonies were divided into two main components. One is the memory at the testing time. The most impressive memories for the inhabitants are (1) mushroom cloud, (2) blast wave, (3) flash light, (4) waving of the ground, (5) evacuation to the outside. Especially, the experiences of “waving of the ground” and “evacuation to the outside” are unique to Semipalatinsk inhabitants.

The other is the complaint for the present condition. Particularly, residents near the SNTS suffered from some kinds of diseases. Their family also struggle with their diseases and have the fear of death. The experiences of nuclear tests at Semipalatinsk still have an influence upon the inhabitants’ health, life and mind even though more than 20 years has passed since the last nuclear test.

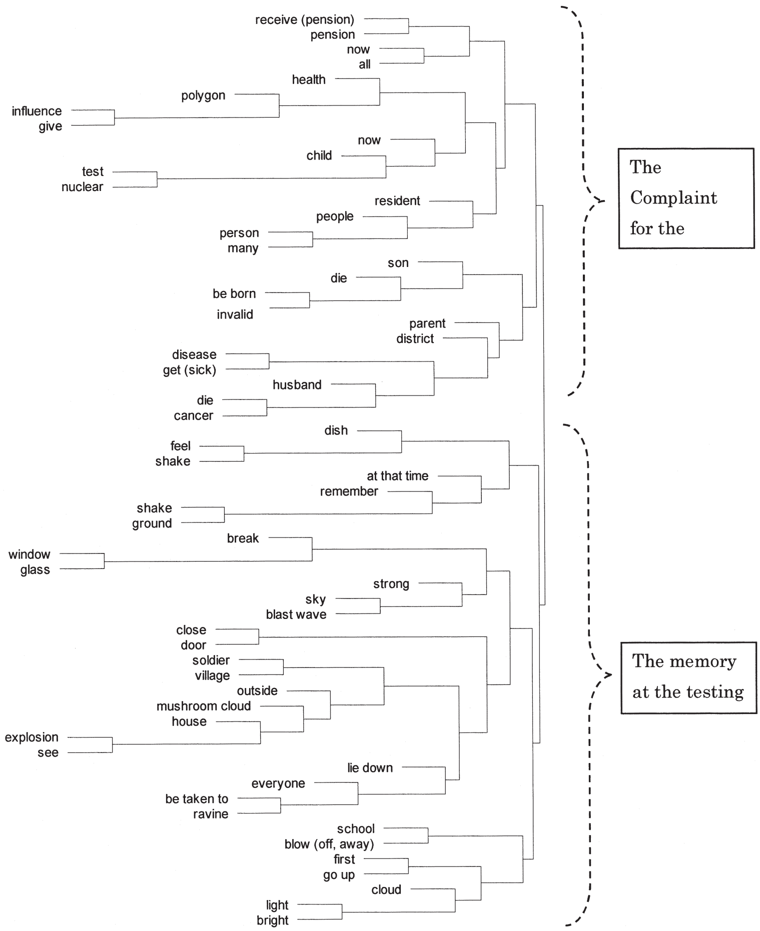

Figure 2. Result of the hierarchical chrustering method

members. These facts show that this group indicates residents' mind of the complaint for the present condition, especially about the health of one's family and one's own.

The other group includes the words of "shake", "ground", "blast wave", "mushroom cloud", "ravine", "light", and "bright" and so on. These words indicate the memory at the testing time of residents'. Five kinds of experiences are suggested by those words. (1)The words of "mushroom cloud", "cloud", "go up" and "sky" suggest the experience of seeing mushroom cloud. (2)The words of "blast wave", "blow off" "blow away" suggest the experience of blast wave. (3)The words of "light", "bright" suggest the experience of flash light. (4)The words of "shake", "ground", "break", "glass" and "window" suggest the

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Appendix. Examples of the testimonies including the high frequency words

The complaint for the present condition

- All my life I never suspected that the nuclear tests could do so much damage to people's health. Now I experience the consequences of nuclear tests myself. My parents died from cancer, one of my grandchildren is a cripple from birth, and I myself have acute leukemia, which is a death sentence. I feel fear for the future of my children, as these consequences will never leave them. ----(F 1935 Saryzhal)

The memory at the testing time

(1) Mushroom cloud

- ----There was something in the shape of a mushroom in the sky, the dark cloud rose into the sky. For us children it was interesting, and we watched the sky. ----(M 1942 Kainar)
- In the fall of 1955 I saw the burning fire and a mushroom cloud. The clay rained from our wooden house, the fire from the stove dropped on the floor, and the windows were smashed.----(F 1927 Dolon)

(2) Blast wave

- ----First, there was thunder and then blast wave went through. It was like a very strong wind howling in the forest. Some houses had their windows broken and the stoves' shuts opened.----(M 1929 Mostik)
- ---- I felt underground jerks, blast-wave. Furniture was shaking in houses.---- (M 1959 Dzhambul)

(3) Flash light

- ---- We were grazing cattle when a glint flashed as bright as the sun, then the blast wave came, smut erupted out of the stove.----(M 1927 Dolon)
- ----But I remember that I saw the bright flashes, the rumble, like a thunder, the earth trembled and the windowpanes were smashed.----(M 1941 Kainar)

(4) Shaking of the ground

- I remember that when I was about 10 years old, dishes, panes, windows in our house were shaking and clinking. I thought that it was an earthquake. (F 1941 Zenkovka)
- I haven't seen explosions themselves but I felt when the ground was shaking. We all knew that that were explosions.(F 1924 Novopokrovka)

(5) Evacuation to the outside

- ----When we were children, it was announced that we all must go outside, we had been hiding in a ravine; for us, children, that was very interesting. ----(M 1946 Dolon)

Note: ( ) indicates Male or Female/ birth year/ village. ---- indicates omission of sentences.

Can we diminish the psychosomatic effects of exposure to nuclear fallout?

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ABSTRACT

Radiation in large doses has bad effects on human tissues. The effects have been traced by organisations such as RERF for many decades, and will be further traced following the Fukushima incidents. Those exposed to much smaller amounts, may enter a profoundly negative downwards psychological spiral, and attribute all their problems to such exposure. We propose these effects could be diminished by (1) Indirect education about radiation effects (2) education about the repair mechanisms in the human body (3) that for most man-made exposure, including radiation, the body is able to deal with amounts much higher than encountered in the course of evolution (examples will be given) (4) that radionuclides are not in a uniquely toxic category (5) participation in a hyper-optimistic philosophy as found in some organisations usually selling goods and training their members (6) willingness of scientists to expose themselves publicly to these agents, in safe amounts (7) administration of a placebo e.g. Prozac (8) slow disappearance of symptoms with time (9) psychotherapy, including Acceptance and Commitment Therapy. A New Zealand example of navy personnel exposed during WWII is reviewed.

INTRODUCTION

Exposure to unfamiliar agents such as large amounts of man-made radiation can cause strong psychological effects in a minority of exposees alongside the physiological effects. This also applies to exposure to industrial chemicals, such as the dioxin contamination in Seveso, Italy, (1979) and the Bhopal isocyanate explosion (1984). Recently in New Zealand negative psychological effects have emerged as the result of deliberate exposure of 500 navy personnel to nuclear tests at the Malden and Christmas Islands in the central Pacific, during 1957-1958. This paper explores some ways of possibly helping such people, but the review at this stage is theoretical only.

TECHNOLOGICAL FEAR.

New materials are constantly introduced to the environment by technological change. Very specialised skill has been used to create these, and often even fellow scientists will not immediately understand all the details. The general public understands much less, and if such material has been involved even once in an accident causing death or chronic illness, some become fearful, and almost paranoid. This is hard to change because they no longer trust either the substance or the experts who produced it.

Lifton [15] recorded the psychological aftermath of Hiroshima/Nagasaki, and his book is aptly entitled "Death in Life". The psychological effects in some people are a kind of psychological death. In further work Vyner [28] studied 11 US exposed veterans and called the psychological effects the Radiation

Response Syndrome. He found undiagnosable symptoms, preoccupation with health and radiation, identity conflict, lack of employment and loss of social relationships. According to Jourdain [12] many such people have "no psychological rest from the possibilities of illness", and citing Lifton "a precarious inner balance between the need for symptoms and the anxious association of these symptoms with death and dying. "

Further study, this time of some Chernobyl victims, was reported [7]. However this group had been very heavily exposed, and a more common feature of those we are discussing is doubtful exposure and because of no clear scientific/medical response, a feeling of psychological invisibility in the victims.

Those who have studied this condition generally differentiate it from Post Traumatic Stress Disorder, because the original exposure was sometimes not a traumatic event, and may have been invisible. However PSTD is obviously a possible issue for Hiroshima/Nagasaki survivors. The group of 50 NZ Veterans and 50 controls, studied by Jourdain [12] are an example where PTSD does not apply. The veteran group of about 500 was exposed deliberately in 1957-58 to nuclear fusion tests near Christmas/Malden Islands (Central Pacific) at distances from 20 to 150 nautical miles. At the time the exposure was not traumatic, and fears only started to emerge about 20 years later.

When a review of these people's health was undertaken in 1997 [21] there was evidence when calculating relative risk that some hematological cancer and leukemia may have been associated with the radiation, but that most illness was probably not. No other cancer type was associated with the exposure. Chromosomal analysis showed translocations about 3x normal, probably corresponding to radiation which was a significant fraction of 1 Gy of exposure.[29].

"The veterans showed rates of illness that were slightly higher than the control group, but the control group had *lower* rates of illness than the population as a whole while the veterans had rates that were about the same. Neither of these results has a clear explanation." [this summary from Wikipedia] However a healthy worker explanation could be the reason.

The uncertainties in these studies made the veterans more uneasy and they launched a political campaign for compensation. Victims assume the worst applies to them and scientific studies are not very likely to convince them.

A study by Jourdain [12] on these veterans showed anxiety, depression, and stress, though not quite reaching a formal clinical level of depression. What could alleviate these? Scientists might tend to hand this problem entirely to clinical psychologists and therapists, but this paper suggests there is still a minor part for scientists to play.

DEMOGRAPHICS

The study by Yamada & Izumi from RERF[30] showed for the Hiroshima/Nagasaki exposees (1) those showing anxiety and somatoform disorders (body symptoms attributed to the exposure) were in the minority (2) The prevalence for anxiety peaked in middle age then declined (3) the somatoform condition prevalence decreased with age for men but increased for women. In other words overall there is decrease of symptoms with age, and time is generally on the side of these people. The increased prevalence for women is not easy to explain, but may have been somehow conflated with general effects of menopause. As in other studies, resilience predominates: prevalence for anxiety and somatoform conditions were approximately 30% and 3% respectively. Most people are not lastingly affected. The minority affected still need lots of help.

THERAPY

Cognitive Therapy has not shown much effect on this condition [12]. So Jourdain used ACT (Acceptance and Committal Therapy). She was able to interact for therapy with 5 of the exposed. Only one actually underwent therapy, which was ACT. He showed improvement but so did two others who declined the therapy. Two others showed little change. However this showed change is possible for some.

Acceptance and Committal Therapy basically accepts a situation as it is, and commits to enduring and not letting it affect one psychologically. It uses the Buddhist idea of Mindfulness, i.e. full awareness but detachment. It could possibly be fruitful among the Fukushima exposees in Japan.

THERAPEUTICS

In Jourdain's study a selective serotonin reuptake inhibitor (SSRI) was prescribed because this class of drugs has been shown to have some use. The drug used is well-known Prozac, or fluoxetine, which usually reduces anxiety, though in some patients it actually has the opposite effect, so results must be monitored. This is one example of a widely available drug which is worth considering making available free in the wake of a disaster such as Fukushima.

It should also be pointed out that there is a strong placebo effect involved here. Almost any substance would have some positive effect[11,10]. The placebo effect is even seen if you tell a person that the pill is a placebo! It is in the useful category of doing *something* rather than nothing.

EDUCATION

Education is one way of making the feared, familiar. In the West we have the proverb "Familiarity breeds contempt". So is education useful? The answer is, perhaps, with care. But this would most profitably come from others than scientists, perhaps clinicians. So any useful material should be passed on to them.

For psychological reasons education is not always successful. The first author in the nuclear debate in New Zealand in 1975 gave a public lecture to demystify radiation, because many people were deeply suspicious of it, and had rather wild ideas, which scientifically could be outright dismissed. However a questionnaire after the meeting revealed that many were more suspicious of radiation than before!! This has also been reported by others, and it seems education may make people focus on the subject and worry more about it. However there are a few areas, as follows, where indirect special education might be useful.

SPECIAL EDUCATION

Technological fear sometimes extends to a distrust of any material or substance which is "man-made". The general principle behind such distrust is that people have had at least millennia to get accustomed to what is common in the environment, but may very likely not be able to deal with novel artificial compounds or agents. The artificial substance may overwhelm whatever defences are in the human body. However contrary to that idea the following three principles are scientifically supported and could be usefully taught:

1. There is a large bodily reserve capacity against bad effects of most technological substances
2. Artificial substances are on average no more lethal than natural ones
3. Attacks on health are generally followed by a "bounce back" to at least temporarily better health than before the exposure.

In this paper "reserve capacity" is the difference between normal environmental levels and those technologically enhanced, or naturally extreme.

1. Reserve Capacity

In the case of radiation, those reading this will be aware that an annual radiation dose is about 2 mSv, but also aware that humans recover from a dose of about 1 Sv, so the reserve capacity is about 500x times the natural level. This capacity does not arise from previous evolutionary exposure. According to Karam [14] astronomical events like gamma-ray bursters and supernovae would give a sea-level dose on earth of about 1 Gy every five million years and 0.2 Gy every million years. It is doubtful this is enough dose to be the origin of human radiation resistance, because it is not sufficiently lethal or frequent. Nor is it possible for altered genes from human exposure in the rare natural high radiation areas to have spread universally.

This reserve capacity is not unique to radiation, nor to humans. The data for other agents, in the following examples, are mostly from Wikipedia sources.

pH. Skin can tolerate pH 3 but is normally at pH 7. That is a factor of 10,000 for the reserve capacity.

O_2: Humans have never encountered significantly higher oxygen concentrations than currently exist, but can tolerate amounts 50% higher and recover (and oxygen is a poison: it creates severe oxidative damage).

DDT: 100mg/Kg causes symptoms in dogs, but the natural concentration is vanishingly low, and the reserve capacity is enormous.

1080: (fluoroacetate) (a common poison for predators in New Zealand) 2-10mg/Kg is fatal for humans but natural concentrations are vanishingly low. There is a very large reserve capacity.

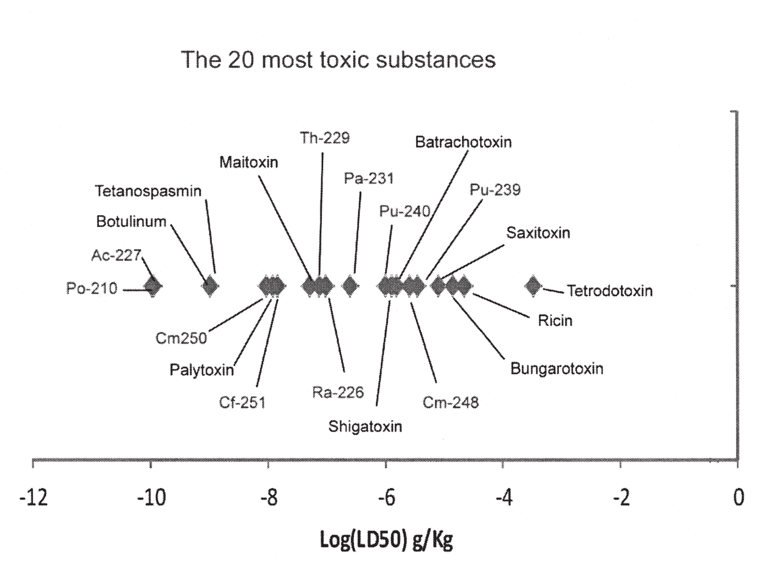
Hg. This has an LD50 of 14-57mg/Kg, but normal amounts in the environment are microgram/Kg. There is a reserve capacity of at least 1000 times.

The basic reason why such good reserve capacity exists is that bodily enzymes are frequently general and non-specific in action. Some are "mixed function oxidases" with very broad functions. Enzymes can break virtually any chemical bond, even including the highly resistant C-F bond [6] though the latter enzyme is not yet known in the human body.

Genes producing enzymes which degrade completely artificial antibiotics already exist in bacteria in nature, as another example of "reserve capacity"

2. Toxicity – unusually bad for artificial sources?

The following diagram gives toxicity comparisons on a weight basis, for the 20 most toxic substances known.



Criteria for the above graph: The substance must be able to be produced in a quantity sufficient to produce death. For the isotopes, ICRP levels for Sv/Bq were used, [4] the most toxic effect chosen where there was a choice, and a level of 4 Sv for 50% lethality. Data for natural toxins are due to Helmenstine [9] and details checked in Wikipedia sources.

A statistical runs test gives p=0.82, so no difference between toxins and radionuclides is demonstrated. The treatment above is quite approximate, but because of the large spread of toxicities, even different assumptions would result in no change to the following conclusion: *radionuclides are about as toxic as natural substances and are not in a class apart*. Incidentally the most toxic nerve gas known is not in the top 20.

3. Health challenge provokes hyper-repair.

Living beings contain defence systems which usually lie dormant but when activated (induced) they repair damage, sometimes even damage from before the time of activation. There are three classes of repair enzymes that repair DNA damage, (see Wikipedia). The same is more simply seen in the body's repair of a broken bone – the join is actually stronger than the original structure.

Similarly with a bacterial or viral infection, such a concentration of antibodies is produced by the body that the protection against the original agent is thousands of times better than it was, and this immunity is long-lasting, though variably so.

Similarly Gamma globulin – a general protection against infection, is increased during infection, so that general ill health from infections is less likely for some time. (One exception: pneumonia is *more* common after influenza).

Studies of recovery after blood donation and using slight extrapolation, suggest that for many people the final haemoglobin concentration after recovery of a few months will be slightly higher than at donation, staying that way for perhaps 1-2 weeks [22] at least for many individuals.

There are apparently 3000 studies suggesting that low levels of radiation to a certain low dose may be stimulatory or even beneficial, which is generally known as hormesis [16]. However following what is known as the precautionary principle, radiation regulatory bodies assume all radiation will be harmful. What should those inadvertently exposed, like the Fukushima victims be told?

It is a fair summary that most examinations of health effects of low-level exposures are consistent with a linear hypothesis, particularly the work of RERF, but the large literature where beneficial actions have been shown for doses of less than 100mSv, means that it is reasonable to say to people: there is some scientific uncertainty at the dose levels you have received and it is a slightly different type of exposure, and *this exposure may well be good for you.* This is justified to counteract the negative ideas about radiation that people have internalised.

There is a known psychological overestimation of low risks which is hard to counter in exposees except by much familiarisation. The results of calculating actual linear risks for radiation are generally not accepted by exposees, who think the results for them are far worse, and it may be necessary to present the "possibly good for you" message to counteract this. This message could be very unwelcome to some who find themselves victims. However it is still important to monitor the health of Fukushima exposees over the next several decades, because ingested fallout effects may, for reasons we cannot at present appreciate be different from what we expect.

Why do these large reserve capacities for response exist? In the environment there is a constant state of competition (for example bacteria versus large animals) and to exist as a species, an animal must have defences against a very wide and general range of threats, and also be able to invade and dominate new and somewhat hostile ecological niches. Such a capacity is almost a prerequisite for a successful species.

Although the above is only a first step, a case can be made that the body is constantly trying to heal itself and on average (1) the enormous reserve capacity of the body can deal with most things it encounters (2) artificial substances are only about as harmful than natural ones, and (3) a health challenge will often lead to better health than existed initially. Perhaps knowing this would help remove even the Radiation Response Syndrome.

EFFECTS OF NEGATIVE THINKING AMONG VICTIMS ON RERF RESULTS?

It is generally known that both control and exposed group in the RERF Hiroshima/Nagasaki cohorts have better health than the general population, generally ascribed to the two-yearly medical checkups. A comparison of the exposed and control groups has given rise (along with other world-wide studies) to the valuable dose-response data we all use so much. However the question does arise whether .the negative frame of mind of the exposees has had a significant effect in these studies.

There is a small literature [1,26, 23] which generally finds lower cancer recurrence rates with optimism, and higher ones with pessimism. According to work by the Mayo Clinic on U.S. citizens (unrelated to radiation exposure) [17] pessimists showed a 19% worse survival rate. These effects may mean that the RERF work itself may be slightly influenced because the victims have a very pessimistic outlook. There could also be higher stroke prevalence with pessimism[19]) (RERF finds some excess of strokes among the exposed). It is likely that if such effects exist, they will be a minor part of the whole dose response rather than dominant.

SENSE-EXPERIENCE OF RADIATION

Because radiation is invisible, one must use an instrument to measure it. In contrast, something directly sensed becomes familiar and psychologically discounted. A possible solution to the invisible nature of radiation exposure is make radiation measuring equipment much more widely available. Such detectors are available (e.g. Berkeley Nucleonics Corporation) as key ring attachments and within specialist wrist-watches, but are several hundred dollars each.

It is even possible to make a very cheap radiation detection device oneself [3]. It is an electroscope with leaves of kitchen Aluminium foil, in a kitchen container dried with desiccated wall board, and charged electrostatically with rapid peeling of Scotch adhesive tape. Radiation makes the leaves collapse and the effective radiation measuring range is 0.03-0.43 Rad/h with an error of ±25%. It was designed and described by scientists in the US. Oak Ridge National Laboratory, at the height of the Cold War, during fears of civil defence emergencies. It was designed to be assembled by an average family in only a few hours. Science classes in schools could profitably make these.

Constant use of this or an electronic device, in a suspect radiation environment, would rapidly remove much fear. Jourdain cites Price-Embury: (1992) "Increased understanding in whatever form this takes for an individual may allow the necessary habituation required to cope with ongoing conditions of uncertainty."

SCIENTIFIC ETHICAL EXAMPLE

Jesus of Nazareth, the founder of Christianity, condemned a class of religious leaders called Pharisees who "lay on men burdens [i.e. observing the Mosaic Law] grievous to be borne, and will not lift a finger to help". But are scientists any better? They develop many techniques and substances, and let others take them and use them but may do little to lessen harms which result.

One of the most effective ways to show a substance one has developed is safe, is to expose one's self to it. Thus early medical pioneers vaccinated themselves to show vaccine safety[2]. Some scientists as an ethical and practical example should be prepared to go and live in some chosen area near Fukushima which they find is safe enough.

If scientists think radiation is safe enough, they should be prepared to live in it with their families. It is now impossible to do this for Hiroshima victims, but the example might be reassuring and life-changing for some victims at Fukushima. It would need to be well publicised.

Judging by reported dosimeter results[18,5] doses In Fukushima City of which at most have approximately doubled background and the average dose for three months from September was 0.26mSv would be within the natural variation of background levels. Fukushima City appears safe to live in, and this will also be true of some areas nearer the reactors themselves.

As published elsewhere [24] drawing on RERF work, risks even up to a risk level of about 100 mSv a year give rise to only a few percent risk increase compared with background. The risks are overshadowed ten times by smoking risk, or air pollution risks (e.g. in Tokyo). If Tokyo inhabitants moved to the exclusion zone, or a smoker moved to the exclusion zone and stopped smoking, their risks would actually decrease. We also know [27,20, 25] that this level or levels near it are experienced naturally and permanently in several parts of the world, such as Niue Island, Southern India, Ramsar (Iran), China, and no health effects have been able to be found in spite of good epidemiological studies. The total dose for those countries in a lifetime is about 1Sv. The first author of this paper is of the opinion that he would be happy to expose himself permanently to such radiation levels if it would act as an example to others, to avoid excessive fear of risk.

HYPER-OPTIMISM

The opposite of the negative downwards spiral in which many exposees find themselves, is a kind of hyper-optimism, which is well known in some parts of the West.

It is commonly claimed that studies show pessimists are actually more realistic than optimists. This rule of thumb however is based only on the "planning fallacy"[13] (Kahneman & Tversky 1979) in which when asked for project date completion, the pessimists are always more realistic. However another study suggests that the underestimates of project time may only be to please superiors. There is no good reason to think pessimists are universally more realistic than optimists.

A pessimist probably does not think it worth doing anything – an optimist possibly wrongly does, but if he remains active, trying many rather improbable things, a few will work even by a placebo effect, and he may end up better off than the pessimistic person who does nothing. The few successes keep him going, as they do a gambler.

At one time in the West one of these exponents of extreme positive thinking had a slogan "Every day in every way, I'm getting better and better"[8]. He recommended 20 repetitions of his slogan at each end of the day and many during it. This seems ridiculous but probably some hyper-optimism is needed to counteract hyper-pessimism. Perhaps only a minority would accept this, however? This thinking could be particularly difficult in Japan, in which the various Buddhist philosophies are not inherently hyper-optimistic.

Some of the most positive thinking people are businessmen in sales, and some business organisations make this an explicit part of their principles. They have mentors to encourage new recruits, and guide them, conferences to raise the enthusiasm level, and many incentives. Although there is quite a large drop-out rate in such organisations, some of the principles could also benefit exposees. These organisations can easily be found, indeed they actively recruit new members.

CONCLUSIONS

There is possible help for exposees:

1. Time
2. Therapy, perhaps of the ACT variety
3. Therapeutics such as Prozac
4. Education, particularly that showing the immense resilience of the human body
5. Measuring devices being available

6. Scientific ethical example
7. Strong positive thinking.

But what can you personally do to help?

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THE NCI STUDIES ON RADIATION DOSES AND CANCER RISKS IN THE MARSHALL ISLANDS ASSOCIATED WITH EXPOSURE TO RADIOACTIVE FALLOUT

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Abstract

The U.S. National Cancer Institute (NCI, National Institutes of Health) was requested by the U.S. Congress in 2004 to assess the number of radiation-related illnesses to be expected among the people of the Marshall Islands from nuclear tests conducted there during 1946-1958. A thorough analysis conducted by the NCI concluded that 20 of the 66 nuclear devices tested in or near the Marshall Islands resulted in measurable fallout deposition on one or more of the inhabited atolls of the Marshall Islands; all other tests deposited their fallout on the test site atolls and in the open ocean. In this work, the deposition densities (kBq m^{-2}) of the 63 radionuclides that are responsible for 98% of the doses received were estimated at each of the 32 atolls and separate reef islands of the Marshall Islands for each test. Those data along with reported measurements of exposure rates and bioassay results were used to estimate radiation absorbed doses to the red bone marrow, thyroid gland, stomach wall, and colon wall of atoll residents from both external and internal exposure. Annual doses were estimated for six age groups ranging from newborns to adults. The geographic pattern for total deposition of ^{137}Cs, external doses, internal organ doses, and cancer risks were similar with the large population of the southern atolls receiving the lowest doses and populations of atolls nearest the test sites that had not be relocated prior to testing receiving the highest doses. The annual doses and the population sizes at each atoll in each year were used to develop estimates of cancer risks for the permanent residents of all atolls that were inhabited during the testing period as well as for the Marshallese population groups that were relocated prior. About 170 excess cancers (radiation-related cases) are projected to occur among more than 25,000 Marshallese, half of whom were born before 1948. All but about 65 of those cancers are estimated to have already been expressed. The 170 excess cancers are in comparison to about 10,600 cancers that would spontaneously arise, unrelated to radioactive fallout, among the same cohort of Marshallese people. This paper summarizes the methods and results that are presented in a series of papers published in Health Physics in 2010 [1].

INTRODUCTION

From 1946 through 1958, 65 nuclear weapons tests, in seven series, were carried out by the U.S. at Bikini and Enewetak Atolls located at the northwestern end of the archipelago that makes up the Marshall Islands and one additional test was carried out 100 km to the west of Bikini. The total explosive yield of the 66 tests was approximately 100 Mt (equivalent to 100 million tons of trinitrotoluene or TNT) [2, 3, 4], about 100 times the total yield of the atmospheric tests conducted at the Nevada Test Site. Radioactive debris from the detonations that was dispersed in the atmosphere was generally blown by the predominantly easterly winds towards the open ocean west of the Marshall Islands, though various historical reports [5, 6] indicate that radioactive debris from a number of tests traveled in other directions.

Of special significance was the largest test conducted in the Marshall Islands, code-named Castle BRAVO, a 15-Mt thermonuclear device tested on 1 March, 1954. As a result of unexpected wind shear conditions, heavy fallout of debris from BRAVO on atolls east of the Bikini atoll test site resulted in high radiation doses to the populations of nearby atoll populations that had not prior relocated prior to the testing.

In the month after the BRAVO test, ^{131}I, an important radionuclide in fallout, was measured in urine collected about two weeks after the Bravo event from adults exposed on Rongelap, Ailinginae, and Rongerik [7, 8]. Those measurement data are the first known measurements of ^{131}I in urine after fallout and have provided the basis for estimating internal doses.

This report summarizes extensive efforts at the U.S. National Cancer Institute (NCI) to reconstruct radiation exposures and organ doses from exposure to radioactive fallout and to project cancer risks to the Marshall Islands population. Detailed information on the technical aspects of this work and on the results of all parts of the study have been published in Health Physics [1] and should be consulted for details:

- the estimation of the amounts of fallout that were deposited on the ground over each atoll and separate reef island of the Republic of the Marshall Islands [9];
- the estimation of doses from external irradiation [10];
- the estimation of the doses from internal irradiation [11];
- the estimation of the cancer risks [12];
- summary of all findings [13].

METHODS AND FINDINGS

A brief overview of methods of the NCI study and a summary of the findings is presented here.

The estimated total radiation absorbed doses include three components: (1) external exposure resulting from fallout deposited on the ground; (2) internal exposure from acute radionuclide intakes immediately or soon after fallout after each test; and (3) internal exposure from chronic (i.e., protracted) intakes of radionuclides resulting from the continuous presence of long-lived radionuclides in the environment. Sixty-three radionuclides were considered in the estimation of internal doses from acute intakes of fallout radionuclides from each test. Based on screening estimates, these 63 radionuclides were estimated to account for over 98% of the internal dose to any organ from acute intakes. In addition, five long-lived radionuclides (^{55}Fe, ^{60}Co, ^{65}Zn, ^{90}Sr, and ^{137}Cs) were considered for the estimation of the internal doses from chronic intakes, including two radionuclides, ^{60}Co and ^{65}Zn, that were not considered in the calculation of the doses from acute intakes. Doses from acute and chronic intakes from cumulative deposition of $^{239+240}Pu$ were also estimated.

Fallout Activity Deposited on the Ground

As discussed in [9], a thorough review of various historical and contemporary deposition-related data, some available only government laboratory reports and internal agency and laboratory memoranda, was used to make judgments on which tests deposited fallout in the Marshall Islands and to estimate fallout deposition density and fallout transit times, known as times-of-arrival (TOA). In some instances, it was necessary to use the results of a well-established model of atmospheric transport and deposition [14] to check our initial assumptions on the occurrence of fallout on particular atolls after certain tests.

For each atoll, fallout TOAs and the estimated fractionation of fallout were used to estimate deposition density for 63 activation and fission products from each nuclear test, plus the cumulative deposition over all tests of $^{239+240}Pu$. Estimation of deposition densities relied on factors provided by Hicks [18, 19]. Examples of deposition densities of 24 of these radionuclides are presented in [9].

The estimated total ^{137}Cs activities deposited by all tests from this analysis, after appropriate decay to account for the effective decay rate (radiological plus weathering effects) and a correction for global fallout from non-Marshall Islands tests, were compared [9] with contemporary measurements (1978-1993) of the total ^{137}Cs activities remaining [15, 16, 17]. Comparisons indicated excellent agreement.

Our estimates for the ^{137}Cs deposition density and for the corresponding TOA at each atoll and for each of 20 individual tests are presented in [9]. As expected, the cumulative ^{137}Cs deposition densities were found to be much greater on northern atolls (e.g., Rongelap and Rongerik) than on mid-latitude atolls (e.g., Kwajalein) or southern atolls (e.g., Majuro).

Radiation Doses

Doses received by Marshallese came from three sources of exposure: (1) external irradiation from fallout deposited on the ground; (2) internal irradiation from acute radionuclide intakes immediately or soon after deposition of fallout from each test; and (3) internal irradiation from chronic intakes of radionuclides resulting from the continuous presence of long-lived radionuclides in the environment.

External doses. Doses from external irradiation arose from gamma rays emitted during radioactive decay of the fallout radionuclides during the passage of the radioactive cloud or after deposition on the ground. Exposure during cloud passage was implicitly included by integration of the exposure rate from the initial time of fallout arrival rather than from the time when the exposure rate was at its peak.

The doses from external irradiation were estimated in three basic steps [10]:

1) estimation of the outdoor exposure rates at 12 h after each test and of the variation in the exposure rates with time at each atoll after each test;
2) estimation of the annual exposure from 1948 through 1970 and of the total exposure from TOA to infinity, obtained by integrating the estimated exposure rates over time, and,
3) estimation of the annual and cumulative absorbed doses to tissues and organs of the body by applying conversion factors from free-in-air (outdoor) exposure to tissue absorbed dose and by assuming continuous residence on the atoll (with corrections for temporarily resettled populations).

Annual and cumulative exposures were estimated [10] using the variation with time of the exposure rate calculated by Hicks [18, 19] modified to take fractionation into account as well as the "weathering effect" which reflects the gradual decrease of the exposure rate caused by the migration of the deposited activity into deeper layers of soil.

The conversion factors from free-in-air (outdoor) exposure to tissue absorbed dose depend on the energy distribution of the gamma-rays that are incident on the body and on the organ for which the dose is being estimated. For most of the fission and activation products that are created during a nuclear explosion, the gamma-ray energies resulting in external exposure are a few hundred keV or more and the variation in photon energy results in at most a few percent difference in dose per unit incident fluence for the various organs considered in this study [20]. Thus, energy and organ dependence in dose conversion factors were not taken into consideration; a single conversion factor, 6.6 x 10^{-3} mGy per mR, was used for all organs in adults. Because the conversion factor depends on body size and shape (usually a function of age), our calculated doses for adults from external irradiation were increased by 30% for children less than 3 years of age and by 20% for children 3 years of age through 14 years [20]. Building shielding was estimated not to be important since houses at that time, made primarily out of palm tree fronds, did not provide any substantial reduction of gamma ray intensity.

Annual absorbed doses from external irradiation from all important tests were estimated for the time period from 1948 through 1970; that is, until the annual doses had decreased to very low levels in comparison to the peak values observed in 1954.

Internal doses from acute intakes of radionuclides. The internal radiation doses resulting from acute intakes, defined as those that occurred during or soon after fallout deposition, were assumed to be primarily a consequence of ingesting radionuclides in, or on, debris particles that contaminated food surfaces, plates and eating utensils, the hands and face, and, to a lesser degree, drinking water [11, 21].

The methods used in this study for estimating acute intakes of fallout radionuclides and resulting doses are based on: (1) the estimates of test-, atoll-, and radionuclide-specific deposition densities discussed in [9], (2) historical measurements of ^{131}I in pooled samples of urine collected from adults about two weeks after the Bravo test [7, 8]; and (3) assessment of appropriate values of gastrointestinal uptake for the radionuclides present in fallout particles [22]. The assessment of internal doses relied on the following six steps: (1) estimation of the intake of ^{131}I by populations on Rongelap, Ailinginae, and Rongerik following the Bravo test using historical bioassay data, (2) estimation of the intake of ^{137}Cs at the same three atolls based on the ratios of ^{137}Cs to ^{131}I [18, 19] but corrected for fractionation, (3) estimation of the deposition density of ^{137}Cs following each of 20 tests on all inhabited atolls, (4) estimation of the intake of ^{137}Cs at all inhabited atolls assuming that the ratio of intake to deposition was the same at all atolls, (5) estimation of intakes of all radionuclides considered at all inhabited atolls following each nuclear test, and (6) estimation of annual and cumulative radiation absorbed doses to four organs (red bone marrow, thyroid, stomach, colon) of representative persons for all relevant birth years.

Detailed information on the acute intakes and resulting doses, as well as the estimated uncertainty in these dose estimates, is presented in [11].

Internal doses to the thyroid gland were much found to be much greater than those to the other organs and tissues, and were much greater for the Marshallese who resided on Rongelap and Utrik atolls at the time of the BRAVO test than for the residents of any other atoll [11]. The southern atolls, where about 73% of the population resided during the testing years, received the lowest organ doses from internal irradiation. The population of mid-latitude atolls, home to about 23% of the total Marshall Islands population during the testing years, received organ doses that were about three times greater than at the southern atolls. The population of Utrik received internal doses intermediate in magnitude between the mid-latitude atolls and Rongelap, with thyroid doses about 35 times greater than the southern atolls [11]. The Rongelap Island community received the highest doses with thyroid doses about 350- to 400-times greater than those received in the southern atolls.

Internal doses from chronic intakes of radionuclides. Following the deposition of radionuclides on the ground, chronic (i.e., protracted) intakes took place at rates much lower than the acute intakes that followed the tests. While both types of intake were primarily a result of ingestion, the environmental transport processes leading to chronic intakes were substantially different from those that gave rise to acute intakes. Chronic intakes primarily resulted from consumption of seafood and of locally grown terrestrial foodstuffs internally contaminated with long-lived radionuclides via root uptake and, to a lesser degree, inadvertent consumption of soil [11]. A previous assessment [23] showed that five radionuclides account for essentially all the internal dose from chronic intake: ^{55}Fe, ^{60}Co, ^{65}Zn, ^{90}Sr, and ^{137}Cs.

Available historical whole-body counting and bioassay measurements were used as a basis to estimate the chronic intakes since a complete dietary model does not exist that covers the many years after the tests when lifestyles became more westernized. Those whole-body and bioassay measurements were made on the Rongelap and Utrik evacuees for years after they returned to their respective home atolls [23] following their evacuation about two days after the BRAVO test. During the first few weeks after their return and until the 1980s, a Brookhaven National Laboratory team regularly conducted measurements of whole-body activity of ^{137}Cs, ^{60}Co and ^{65}Zn, as well as urinary concentrations of ^{90}Sr. Measurements of ^{55}Fe in blood were also performed, but only once [23].

The steps used to estimate the doses from chronic intakes of radionuclides were: (1) estimation of the chronic intakes by Rongelap and Utrik adult evacuees due to the BRAVO test, (2) estimation of the chronic intakes resulting from the BRAVO test by adults of all other atolls, based on the relative ^{137}Cs deposition, (3) estimation of the chronic intakes by adults resulting from tests other than BRAVO, again based on relative ^{137}Cs deposition, (4) estimation of the chronic intakes by children, and (5) estimation of the doses from chronic intakes from all tests and all population groups using ICRP recommended dose coefficients.

Detailed information on the estimation of chronic intakes and resulting doses is presented in [11]. The doses from chronic intakes show the same geographical pattern as the doses resulting from acute intakes and ^{137}Cs deposition. However, because of the absence of short-lived iodine isotopes which dominated the thyroid dose from the acute intakes, the thyroid doses from chronic intakes were not much greater than the doses to other organs and tissues. Similar to the situation for acute intakes, only a few radionuclides contributed most of the organ absorbed dose. For all organs and for all four of the atoll and population groups discussed, ^{137}Cs was either the first or second most important contributor to internal dose from chronic intakes. For the evacuated Rongelap Island community, ^{137}Cs was the most important contributor to the chronic dose, whereas ^{65}Zn was the largest contributor to dose for the residents of all other atolls [11].

Summary of doses. Residents of the southern atolls who were of adult age at the beginning of the testing period received external doses ranging from 5 to 12 mGy on average; the external doses to adults at the mid-latitude atolls ranged from 22 to 60 mGy on average, while the residents of the northern atolls received external doses in the hundreds to over 1000 mGy. Except for internal doses to the thyroid gland, external exposure was generally the major contributor to organ doses.

Internal doses to the stomach wall and red bone marrow were similar in magnitude, about 1 mGy to 7 mGy for permanent residents of the southern and mid-latitude atolls. However, adult residents of Utrik and

Rongelap Island, which are part of the northern atolls, received much higher internal doses because of intakes of short-lived radionuclides leading to doses from 20 mGy to more than 500 mGy to red bone marrow and stomach wall. In general, internal doses to the colon wall were four to ten times greater than those to the red bone marrow and internal doses to the thyroid gland were 20 to 30 times greater than to the red bone marrow. Adult internal thyroid doses for the Utrik community and for the Rongelap Island community were about 760 mGy and 7,600 mGy, respectively.

We found that our estimated total doses at each atoll were relatively comparable within each of the four population groups: residents of southern atolls, residents of mid-latitude atolls, the Utrik community, and the Rongelap Island/ Ailinginae / Rongerik evacuees. Adults in mid-latitude atolls received cumulative organ doses approximately four times as great as adults in the most southern atolls. Similarly, adults of the Utrik community received cumulative organ doses four to seven times as great as adults from the mid-latitude atolls. Adults among the Rongelap Island /Ailinginae / Rongerik evacuees received the largest cumulative doses, 6 to 8 times as great as adults from Utrik.

We found that our estimates of total organ radiation absorbed doses (sum of external and internal) varied by year of birth. Persons who were adults at the beginning of the testing period (born in 1930 or earlier) received relatively low thyroid doses from the large tests in 1954 compared to those who were very young at the time of those tests. Among the 4 representative population groups, cumulative thyroid doses ranged from 33 mGy for adults who lived on Majuro (southern atoll) at the time of testing to as high as 23,000 mGy for infants on Rongelap Island at the time of the BRAVO test.

For purposes of cancer risk projection [12], the annual organ doses were estimated. Children born in 1953 would have received the largest doses of any birth cohort.

Projected Cancer Risks

The annual doses from external irradiation and from internal irradiation were estimated for 25 Marshallese population groups according to birth year. Those estimates were combined with the population sizes and with age-dependent organ-specific risk coefficients to derive the corresponding cancer risk projections presented in [12]. Risk estimates were presented in terms of the number of cancers by organ site, projected to occur among Marshallese as a consequence of exposure to fallout from regional nuclear tests. The cancer risks were based on an estimated population of 12,175 residents of the Marshall Islands born before 1948 and another 12,608 born in the years 1948 through 1970, giving a total potentially exposed population of 24,783.

The projected number of baseline (non-radiation related) cancers among the 24,783 Marshallese in all organs totals 10,600, while the projected number of excess (radiation-related) cancers is 170 including 65 that are projected to occur after 2009 [12]. When the entire population of the Marshall Islands is considered, the estimated fraction of cancers that has occurred or will occur and that can be attributed to exposure to radioactive fallout, expressed as a percentage, is about 20% for thyroid and about 5% for leukemia. These percentages can be compared to all other cancers, for which the attributable fractions are on the order of 1%.

CONCLUSIONS

The assessment conducted by the NCI on radiation doses and cancer risks to Marshallese from nuclear testing is the most comprehensive evaluation ever conducted for that population. A number of important lessons can be derived from that analysis. Here, it has been confirmed that exposure to radioactive fallout, particularly soon after detonation of a large device, can result in high exposures and substantial increases in cancer risk. At distances of more than a few hundred kilometers from the test site, however, exposures and related cancer risks are likely to be highly diminished due to dilution of the radioactive debris in the atmosphere (depending on the meteorological conditions) and radioactive decay during transit. Lifestyles that are dependent on storing and preparing food outdoors are particularly susceptible to transmitting radioactive contamination to man.

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Reconstruction of the Individual Cumulative Doses of Radiation Exposure in Cases of Infant Leukemia Registered within the Early Period after Chernobyl Accident

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Abstract

Individual cumulative doses in all cases of infant leukemia developed after Chernobyl accident within the years 1986 and 1987 in residents of Belarus have been reconstructed. Totally, 20 children were included into this population-based study. The median cumulative dose was 0.21mSv.

Introduction

Infant leukemia in children exposed *in utero* due to Chernobyl accident has been assessed as possible effect of radiation [1, 2]. Some attempt were made within a few ecological and one case-control study to establish the dose relationship in children on the contaminated areas in Belarus, Russia, Ukraine, Germany, Greece, Romania, etc., however, without any significant results [3-7]. However, reconstruction of individual doses has been never performed.

Aim of this study was a reconstruction of cumulative doses in all Belarusian children with infant leukemia which were born in 1986-1987 and were affected during the Chernobyl accident in utero and/or within first year of life. Tasks of the study were as following: to reconstruct individual cumulative doses; to assess cumulative doses absorbed of embryo and fetus exposing in utero; to assess the time-related role of dose forming factors; to calculate the coefficient of child/mother dose; to compare the calculated doses with possible leukemogeneic threshold.

Patients and Methods

All children with infant leukemia, residents of Belarus, which were in utero and/or were at their first year of life at Chernobyl accident supposed to be eligible for this population-based study. Totally, 20 cases which were born from August 22, 1986 to December 25, 1987 (during 4–20 months of early post-Chernobyl period) have been included for the dose reconstruction.

Leukemia was established as infant if age of a child was less than 1 year. Data for every case of infant leukemia were provided by population-based Childhood Cancer Sub Registry of Belarus run at Belarusian Research Center for Pediatric Oncology and Hematology (Minsk, Belarus).

Data for doses assessment included subject's date and place (toponim) of birth, radiological characteristics of toponim (Table 1). As shown in the Table 1, cases with infant leukemia were registered in 5 of 6 oblasts excepting Grodno oblast. 13 toponims (2/3) were located in oblasts of Gomel and Mogilev. Toponims were revealed in almost all radiological zones (9 of 10) excepting Zone 1 (South part of Gomel oblast) that has been mostly contaminated after Chernobyl accident. Density of σ_{137Cs} toponim's area contamination was very low with median ~15 kBq/m^2 or about 0.40 Ci/km^2 (~93 kBq/m^2 as maximum).

Table 1. Subject's address and radiologic characteristics of toponim.

Subjects[a]	Date of Birth	Address [b] (Toponim[c])	Radiological Characteristics of Toponim	
			σ_{137Cs}, kBq/m^2 [d]	Zone Index[e]
1	22.08.1986	grp. Bereza (Brest obl.) [f]	6.512	9
2	17.11.1986	d. Mayskoye, Zhlobin region, (Gomel obl)	93.28	5
3	06.12.1986	pgt Rossony (Vitebsk obl)	2.59	10
4	30.12.1986	gop. Krichev (Mogilev obl)	18.17	5
5	01.02.1987	Minsk city	4.181	8
6	04.02.1987	Minsk city	4.181	8
7	16.02.1987	Gomel city	80.77	4
8	02.03.1987	Mogilev city	24.79	6
9	03.03.1987	Minsk city	4.181	8
10	13.03.1987	d. Ostashkovichi, Svetlogorsk region, (Gomel obl)	32.08	5
11	26.03.1987	d. Zaprosie, Luninetsky region (Brest obl)	47.25	7
12	26.04.1987	gop. Kalinkovichi (Gomel obl)	43.81	2
13	01.06.1987	d. Zhgun, Dobrush region (Gomel obl)	30.86	3
14	05.06.1987	d. Kurenec, Vileisky region (Minsk obl)	1.591	9
15	03.07.1987	gop Bobruisk (Mogilev obl	8.029	5
16	06.08.1987	gop Zhlobin (Gomel obl)	49.69	5
17	16.09.1987	d. Dvorec, Luninetsky region (Brest)	68.89	7
18	15.10.1987	d. Porech'e, Octyabrsky region (Gomel obl)	11.8	5
19	22.12.1987	gop. Bobruisk (Mogilev obl)	8.029	5
20	25.12.1987	pgt. Uzda, Uzdensky region (Minsk obl)	1.887	9

Notes:
[a] subjects are placed in chronological order according to the date of birth;
[b] questionnaire data of mother's migration during the pregnancy and after delivery are included;
[c] toponim is an address of a child's birth being the same as a place of mother's living during her pregnancy;
[d] surface fallout density activity by^{137}Cs;
[e] zones of radioactive fallouts;
[f] type of settlement (grp –city of raion level, pgt – village city-type, gop –city of oblast level, d – village)

Duration of antenatal and postnatal periods has been used for cumulative doses calculation of subject (Table 2).

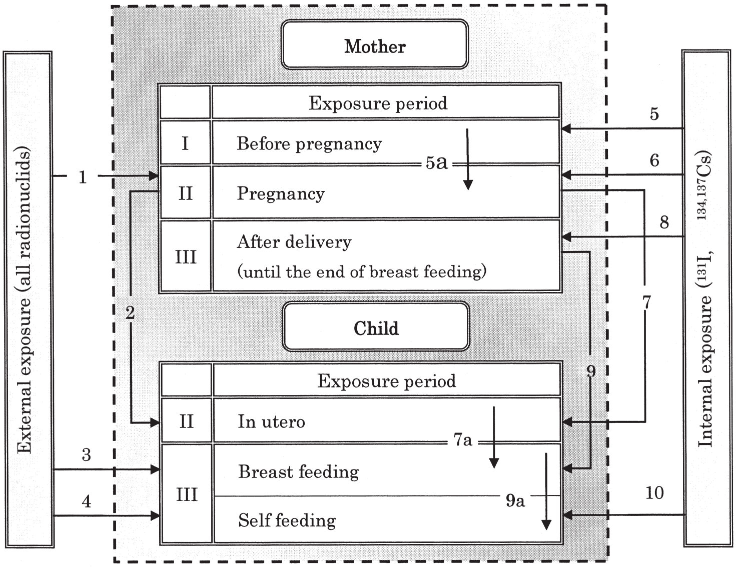
Table 2. Estimated duration of subject's exposure during the antenatal and postnatal phases.

Subjects	Period I, *in utero*, in days	Period II, postnatal [a], in days
1	118	119
2	205	0[b]
3	224	20
4	248	0
5-20	274	Subjects 16 and 17 – 0, Median ~ 95, Max – 342.

Notes: [a] period from the date of birth to date of infant leukemia diagnosis; [b] infant leukemia was diagnosed at birth

Dose Estimation

We assumed that subject's dose depends on the mother's dose exposure (Picture 1).



Picture1. Pathways and sources of dose formation within a system "Mother – Child".

Description.

External exposure:

1. (II) during a pregnancy;
2. (II) an embryo and a fetus (*in utero*);
3. (III) a child during breast feeding;
4. (III) a child after breast feeding.

Internal exposure:

5. (I) a mother before conception;

5a. residual dose of mother after Period I;

6. (II) a mother during pregnancy;
7. (II) an embryo and a fetus *in utero*;

7a residual dose of the newborn child;

8. (III) a mother after delivery (until the end of breast feeding);
9. (III) breast feeding of the newborn child;

9a. residual dose of a newborn child after breast feeding;

10. (III) a newborn child after the end of breast feeding.

Thus, according to the Picture 1, a total cumulative effective dose of subject consists of the following parts:

- an external dose of a child *in utero* and in postnatal period;
- an internal equivalent dose of ^{134,137}Cs *in utero* and effective dose of ^{131}I due to their prolong ingress into mother's body before and after pregnancy;
- a residual effective dose of radionuclides *in utero* until the moment of a child birth: the total period up to disease diagnostics;
- a lactation dose of ^{131}I, ^{134,137}Cs due to intake of breast milk;

– a residual lactation dose of a child after stop of breast feeding;
– a dose of non-breast feeding due to radionuclide intake during the period from the end of breast feeding up to diagnostics of leukemia.

Results and discussion

Cumulative dose

Cumulative doses of subjects according to the periods of exposure are presented in the Table 3.

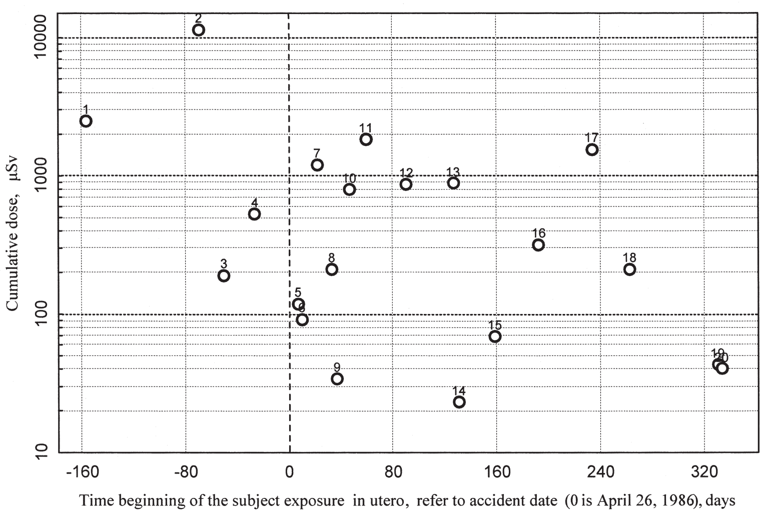
Table 3. Cumulative dose of subject according to the periods of exposure.

Subjects	Exposure **Periods**	
	Period I, *in utero*, μSv	**Period II, postnatal,** μSv
1	2436	45
2	11448	0
3	188	3
4	528	0
5	100	19
6	83	9
7	979	225
8	178	33
9	33	1
10	757	37
11	974	853
12	364	503
13	419	461
14	20	3
15	48	21
16	319	0
17	1562	0
18	145	67
19	38	5
20	16	24

As shown in the Tables 1 and 3, doses correlated with radiological characteristics of toponims. For example, the highest doses were observed in toponims with the highest σ_{137Cs} level and the lowest number of zone index. Median cumulative dose in our study was 210 μSv. Additionally, the dominated role of *in utero* exposure over the total dose has been established in our study: median ratio of subjects doses (I/I+II) was 0.88. As a result, dose in utero was 185 μSv.

Dose forming factors

Two main factors were assessed in the study: a toponim factor (radiological) and a subject's factor related to the time of beginning of exposure *in utero*. It seems that joint effect of both factors caused the very broad variability of cumulative doses (Picture 2). As shown on the Picture 2, the determining factor for the dose forming was a 'toponim factor'. So, the dose in subjects with similar beginning of exposure time (№№ 8, 9 and №№ 13, 14) differed due to various radiological factors. However, almost similar doses were revealed in subjects with analogous radiological factors despite the differences in the beginning of exposure time (№№ 3, 18 and №№ 9, 19, 20).



Picture 2. Time-depending changes of the cumulative dose-distribution.

Trend of dose

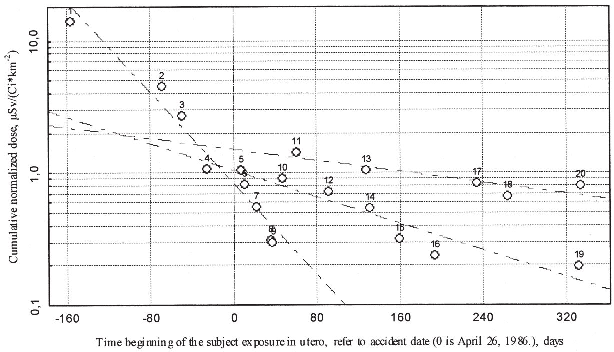
Normalizing of D/σ_{137Cs} performed in this study allowed to observe a relationship between cumulative dose and time more clearly (Picture 3). Three groups of subjects (or toponims) were established by the descent rate of dose (exponential approximation) with $T_{1/2}$ of 35 (iodine dose decrease), 119 and 289 days, relatively. Differs between second and third groups can be explained by unequal ratio of external and internal doses. Analysis of time-depending changes of radionuclides and their exposure pathways (Picture 4) confirmed this assumption. In the beginning, the total dose is formed mostly by radioiodine; however, its impact is dramatically decreased with a relative raise in dose-forming of radiocesium. Since the middle of the summer 1986 the dose has been completely formed by these radionuclides with a little changes during the time and a prevalence of external exposure pathways (median ratio $d_{ext}/d_{(ext+int)} \approx 75\%$).

"Subject/mother" ratio.

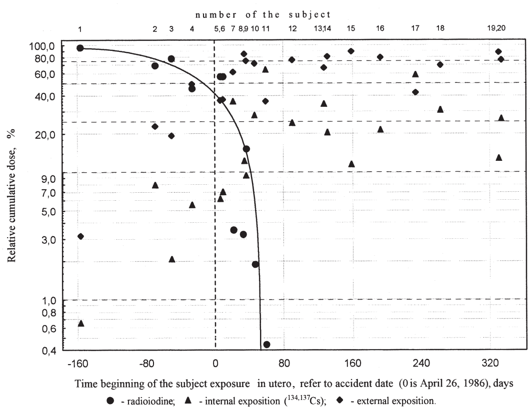
Arithmetic average ratio of cumulative doses subject/mothers (210 µSv and 170 µSv, respectively) was ~0.45. However, the assessment by median ratio revealed that coefficient of a child's defense is 0.75.

Dose comparing to the leukemogeneic threshold.

According to the conservative approaches, the lowest level of leukemogeneic threshold for *in utero* exposure is 20 mSv [7]. The median dose in our study is 0.185 mSv with maximum dose of ~11mSv in only one case. Has the possibility to achieve the leukemogeneic threshold existed after Chernobyl radioactive fallout? Yes, if the radioactive density of 15 kBq/m^2 (0.4 Ci/km^2) forms a dose of 0.21mSv, the border density of area ^{137}Cs contamination will be about 1430 kBq/m^2 (~40 Ci/km^2). As known, a population which lived on such kind of areas in Belarus and received the highest doses was resettled at different times. Therefore, a high probability of additional infant leukemia cases existed.



Picture 3. Time-depending changes of the normalized cumulative dose-distribution.



Picture 4. Time-depending changes of the relative radionuclides doses and their dose-formings pathways.

In general, our retrospective population-based study analyzed data of 20 children with infant leukemia for individual cumulative dose reconstruction for the period included antenatal/postnatal exposure with relation to the radiological characteristics of toponims and date of birth.

By our results, a median cumulative dose in the total group of infant leukemia cases was rather low (0,21 mSv), and 88% of this dose was received in utero. Ratio of the median total doses of a child and his mother was ~0.75.

A decreased trend of a cumulative dose was caused by changes in radiological environment which mostly depended on radioiodine and short-living radionuclides ($T_{1/2}$ 35 days) in the early period after Chernobyl accident and cesium radioisotopes later, from the middle of the summer. At that time, external exposure dominated over internal (0.75/0.25).

Doses reconstructed in our study are too small accounting ~1/100 of the presumable leukemogeneic threshold of irradiation dose *in utero*. That is why we cannot insist that cases of infant leukemia in Belarus are related to the Chernobyl radioactive fallout despite the fact that most of them were registered on the radiologically unfavorable toponims.

Moreover, it is unclear why all the cases were only registered on the territories with low level of contamination and no cases on highly contaminated areas. By the literature, leukemogeneic density of fallout by ^{137}Cs is about ~40 Ci/km^2 (1480 kBq/m^2). In Belarus, 135 000 of inhabitants lived on this area before the evacuation have received middle leukemogeneic doses, and nobody had an infant leukemia in 1986-1987. By our opinion, this fact can be related to high numbers of abortion which were advised within the early years after Chernobyl accident to the woman from highly contaminated areas. However, this matter will required study.

Acknowledgements

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Forecasting of the remote radiobiological effects of lens pathology of people taken part in the liquidation of the effects of Chernobol nuclear power station

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ABSTRACT

The research itself reflects the condition of immunological reactivity at lens patology of people taken part in the liquidation of the effects of Chernobol nuclear power station.

INTRODUCTION

The phenomenon of immune privileges of an eye and its response to damaging action of various factors draws attention of present-day researchers [1,2,3,4].

At ionizing radiation influence the most evident changes occur in the lens as according to many authors it is the most radiosensitive in an organ of vision [5], and also is a classical example of a natural autoantigen [6].

The lens is held away from immune system by blood-ocular barrier (BOB) which operates as an immunologic barrier and interferes with migration of fabric antigens from the eye and to entering of immunocompetent cells into the eye [6].

In case of abnormality of BOB there is formation of autoantibodies to protein of a lens and further development of specific reaction with possible formation of the autoimmune response over 10-14 years [4,7,8].

For formation of the systemic autoimmune response the damage of blood-ocular barrier is not enough. The previous condition of immune system has significant importance.

On this basis the main objective of our work was studying of separate links of immunologic responsiveness of the liquidators of disaster at the Chernobyl Atomic Power Station, with the lens pathology, in the remote period.

MATERIALS AND METHODS

The basic group consisted of 60 men, the liquidators of consequences of the Chernobyl APS (ChAPS), at the age from 40 till 60 years, with a cataract, depending on a year of entrance to a zone of emergency works and the received average radial dose (established by the Medical radiological research center of the Russian Academy of Medical Science, city of Obninsk, on the basis of Russian state medical radiation-measuring register) have been divided into subgroups: I - 1986 – 32 persons, the received dose of radiation – 18.2±0.58 cGy., II - 1987 - 18 persons, the received dose of radiation – 8.43± 0.60 cGy and

III-1988 - 1989, the received dose of radiation – 12 persons - 3.27±0.31 cGy. Duration of staying in the zone of heightened radiation hazard is from 5-30 days.

For estimation of contribution of the radiation factor in development of changes of immunologic indicators of the investigated category of persons, the exclusion of influence of a somatic pathology on studied characteristics of leukogram was assumed as necessary. In this connection the control group was formed, in which 60 men were included, of identical age, with a cataract, but not exposed to ionizing radiation influence in the anamnesis. During the investigation done which included estimation of anamnestic, clinical and laboratory data, the immunodepressive diseases connected with effect of radiation or other agents, of persons from control group were not detected.

The healthy group consisted of 60 men of the above-stated age, without lens pathology. In the anamnesis there is no link with ionizing radiation.

Use of mathematical integrated indicators, part from which changes already in the pre-nosological period or at the earliest stages of disease, allows estimating of condition of various links of immune system in dynamics not using special methods of research (4,9). On the basis of results of a peripheral blood we have made mathematical calculation of 6 integrated indicators owing to which we have indirectly estimated condition of various links of immune system of the patients with cataract: Leukocyte Index (LI), Leukocyte Index of Intoxication (LII), Index of Leukocytes Ratio and ESR (ILRESR), Lymphocytic-Granulocytic Index (LGI), Index of Ratio of Neutrophils and Lymphocytes (IRNL), Index of Ratio of Neutrophils and Monocytes (IRNM).

At the bottom of somatic remote consequences (the example: radiation cataract) of post-radiation reduction the inferiority of many regenerative processes was noted, especially it was brightly shown in tissues with low level of physiological regeneration. Exactly the cells of these tissues in consequence of weakly proceeding processes of reparation as though remember radiation influence that happened earlier, owing to what they are easily revealed in experiment [10, 11].

In this connection, we spend studying of stimulated leukocyte agglomeration by antigens of lens in vitro, allowing to estimate the lens condition, in the remote period of influence of ionizing radiation.

Material for research was the lens extract withdrawn during operation of phacoemulsification.

All results are processed statistically by using the program Statistica 6.0.

RESUITS OF THE STUDIES

As is obvious from the data presented in table 1, the Leukocyte Index (LI) reflecting mutual relation of humoral and cellular links of immune system, of the patients from control group was in the range of healthy persons. At the same time, concerning the participants of liquidation on the Chernobyl APS (table 2), the results of the basic group exceeded indicators of control group and healthy persons. The received results give evidence of dysfunction of immune system which is most expressed at the persons who have received doses of ionizing radiation equal to 18,2±0,58 cGy.

At calculation of Leukocyte Index of Intoxication (LII) in both investigated groups its increase has been established. In all subgroups of the basic group, LII exceeded the referential limit that is possibly caused by rising of level of an endogenous intoxication.

Index of Leukocytes Ratio and ESR (ILRESR) of the patients with cataract was higher by 42 %

(p<0,001) than the results of healthy persons. As to patients with cataract of radiation genesis in the basic group the highest indicators of ILRESR in 1 and 2 subgroups were observed, that allows assuming presence of an autoimmune component in cataract formation.

Table 1. Integral hematological indicators of the persons with cataract (M±m)

Indicator	Groups	
	Healthy (n=60)	Control (n=60)
LI	0,43±0,02	0,51±0,09
LII	0,83±0,07	1,13±0,11*
ILRESR	1,65±0,24	2,84±0,21*
LGI	4,01±0,18	2,55±0,12*
IRNL	2,54±0,11	1,98±0,38
IRNM	17,3±3,42	45,08±3,14*
Note: *- reliability of indicators' difference p<0,05.		

Though, when calculating Lymphocytic and Granulocytic Index (LGI) permitting differentiate autointoxication there was determined its reduction only in the control group for 36,4% (p<0,001) in comparison with the results of healthy persons. In the basic group the LGI indicator was within normal limits regardless of the dose of ionizing radiation.

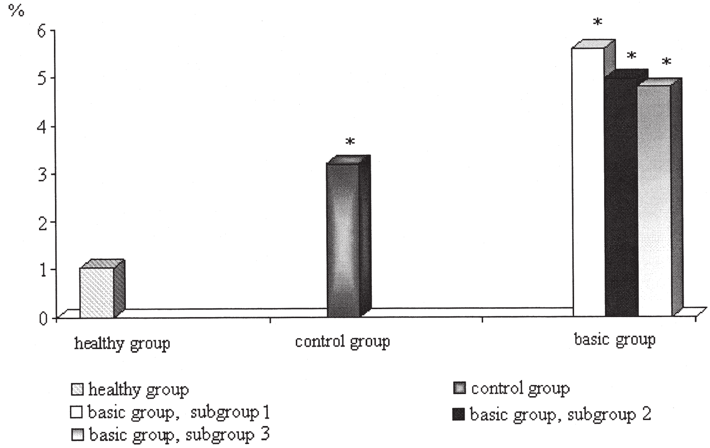
Neutrophil and Lymphocyte Index (NLI) among cataract patients in both groups tended to reduce which is caused by dysfunction of nonspecific resistibility factors. This fact is proved also by results of calculation of Lymphocyte and Monocyte Index (LMI).

Table 2. Integral hematological indicators of cataract patients depending on the dose of ionizing radiation (M±m)

Indicator	Healthy (n=60)	Basic group		
		Group 1 (n=32)	Group 2 (n=18)	Group 3 (n=12)
LI	0,43±0,02	1,28±0,09*	0,58±0,04*	0,56±0,06*
LII	0,83±0,07	1,49±0,09*	1,47±0,11*	1,34±0,08*
ILRESR	1,65±0,24	4,28±0,05*	3,94±0,21*	3,26±0,76*
LGI	4,01±0,18	4,03±0,06	4,19±0,12	3,97±0,22
NLI	2,54±0,11	1,99±0,77	1,74±0,35	1,83±0,41
IRNM	17,3±3,42	47,95±2,1*	49,53±3,15*	48,84±2,18*
Note: *- reliability of indicators' difference p<0,05.				

Further we estimated dose-related stimulated leukocyte agglomeration by lens antigens.

As it seen from the data presented at Figure 1 the stimulation of leukocyte agglomeration by lens antigens was about 1,03±0,05% among almost healthy people. After statistical analysis it was determined that the indicator exceeding 1,05% is an evidence of increase of adhesion properties of leucocytes to the corresponding stimulator.



* - reliability of differences in regard to healthy group is p>0,001

Fig 1. Leukocyte agglomeration stimulated (%) by lens extract in vitro at cataract

In the control group leukocyte agglomeration indicator was 3,19±0,52% which is 3,1 times more (p<0,001) than that of healthy group. At the same time there was a clear dependence of leukocyte agglomeration increase from the dose of ionizing radiation among patients with radiation genesis cataract. In this case in subgroup 1 with the dose of ionizing radiation of 18,2±0,58 cGy there was determined the highest indicators of stimulated leukocyte agglomeration of 5,59±1,52% which exceeds the reference limits in 5,4 times (p<0,001). In group 2 this rate was 4,96±0,73% which is 4,8 times more than that of healthy group (p<0,001). In case of radiation exposure of 3,27±0,31 cGy there was determined the least rate of leukocyte agglomeration of 4,79±0,51%. Although these results exceeded the results of healthy group in 4,7 times (p<0,001).

Increase of this indicator is an evidence of increase of adhesive properties of leukocytes to the lens antigens which is expressed clearly in case of cataract among patients who had received different doses of ionizing radiation ranging from 18,2±0,58 cGy to 3,27±0,31 cGy.

Thus, calculation of integral hematological indicators permitted to determine that regardless of the type of cataract and of the dose of ionizing radiation there forms dysfunction of immune system which leads to decrease of function and metabolic and phagocytic activity of micro- and macrophages, signs of autoimmune component and quality changes of leukocytes in particular increase of their adhesive properties at this nosology;

It was determined that in case of stimulation of leukocytes with lens extract the indicators of 1,03±0,05% are referential. Increase of this indicator is a result of increase of adhesive properties of leukocytes.

Leukocyte agglomeration stimulated by lens antigens indicates the level of autosensibilization which is well expressed among patients who had received ionizing radiation of the dose of 18,2±0,58 cGy and 3,27±0,31cGy which may be a criterion of dose-related effect for forecasting cataract of radiation genesis.

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A 24-year follow-up of malignancies in Sweden after the Chernobyl nuclear power plant accident in 1986

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Abstract: A 24-year follow-up of total malignancies in Sweden after the Chernobyl nuclear power plant accident in 1986 shows a small increase in the incidence of malignancies when the average deposition of caesium-137 for each parish was used to classify the exposure.

Background: The accident at the Chernobyl nuclear power plant in Ukraine, USSR occurred on 26 April, 1986. Five percent out of the total 85 PBq released caesium-137 from the Chernobyl reactor was deposited in Sweden during the ensuing days, especially during the heavy rainfall on April 28-29, with an unequal distribution in the eastern coastal regions from Stockholm in the south to Umeå in the north [1]. The main contributors to the dose rate in the first weeks were short-lived nuclides replaced by the long-lived caesium-134 and caesium-137 [2]. Two studies in Sweden have shown a slight increase in total malignancies related to caesium-137 deposition after the Chernobyl accident. In the initial study the inhabitants in the 450 parishes in 7 counties in Northern Sweden were classified using an analogous map on the deposition of caesium-137 in these parishes, the excess relative risk (ERR) was calculated to 0.11 per 100 kBq/m^2 (95% Confidence Interval 0.03-0.20) [3]. In the second study a digital map was used instead to match each person's dwelling coordinate to the exposure of caesium-137 with a similar result of ERR 0.10 per 100 kBq/m^2 (95% CI 0.00-0.23) [4].

Methods: The population in nine out of Sweden's 21 counties was included in this 24-year follow-up study: Norrbotten, Västerbotten, Jämtland, Västernorrland, Gävleborg, Dalarna, Västmanland, Uppsala and Södermanland. These counties had the highest fallout of radionuclides in Sweden after the Chernobyl accident, but had also areas with no fallout. The total population was annually retrieved from the National Archives 1986-1992. Each individual was classified annually with their address to the parish. In all, 612 parishes and 2,183,212 individuals were included in the study. The average deposition of caesium-137 for each parish was given by the Swedish Radiation Safety Authority from the lowest average of 1 to the highest of 85 kBq/m^2 in May 1986. By assignment with the Swedish Radiation Safety Authority, the Geological Survey of Sweden had performed aerial gamma measurements over the whole of Sweden creating a grid of 200*200 meter of caesium-137 deposition. This digital map was used by the Swedish Radiation Safety Authority to calculate the parish average.

Using the annual address for the individuals each person could be followed over time. Taking into account both the half-life of caesium-137 of 30 years and if a person changed address a cumulative exposure estimate could be created in $kBq{*}years/m^2$ for 1986-1992. Cases of malignancies and deaths with date of diagnosis were retrieved from the Swedish Cancer Registry for April, 28 1986 to December, 31 2009. If there was more than one malignant neoplasm registered for a person, we considered only the first one. Individuals with a malignancy before 28 April 1986 were excluded from the analyses. Incidence of malignancies was also calculated for the period January, 1 1980 to April, 27 1986, using the same classification of parishes and methods in order to investigate if there was a regional difference in the incidence already prior to the Chernobyl accident. All malignancies were coded according to the International Classification of Diseases (ICD), version 7, as continuously used by the Swedish Cancer Registry. A total of 201,201 incident cases of malignancies were observed during 49,155,576 person-years.

A Poisson regression model was applied, including total cases of malignancies, taking age as a continuous variable and sex as potential confounding factors. Exposure expressed as kBq*years/m^2 (see Figure below) was used as a continuous variable to study the exposure response relationship. All continuous variables were modeled using restricted cubic splines to account for potential non-linear relationships. The statistical model included age, cumulative exposure and sex together with sex*age and sex*cumulative exposure interaction terms to allow for different exposure-response relationships across different ages and sexes. All statistical analyses were performed using R version 2.13.0.

Results: The median exposure for caesium-137 was 226 kBq*years/m^2. Incidence of malignancies for men showed an average increase of about one case and for women about 0.5 case per 1,000 person-years between 5^{th} to 95^{th} percentile (table 1). The incidence of malignancies for men was partly influenced by a weak positive pre-Chernobyl trend over the parishes.

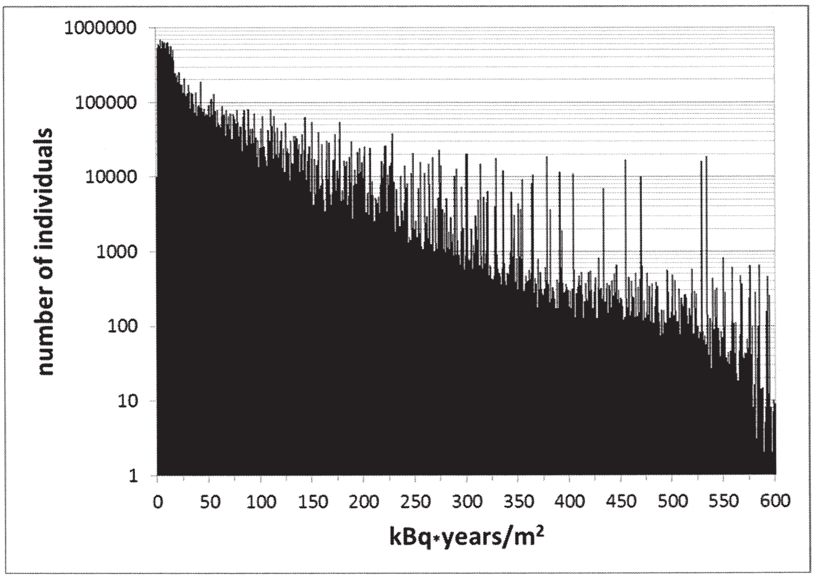

Table 1 Total malignancies April, 28 1986 to December, 31 2009

	percentile	Cs-137 kBq*years/m^2	Incidence per 1,000 person-years	95% confidence interval
Men	5th	21	3.31	3.28-3.35
	95th	524	4.43	4.26-4.61
Women	5th	21	2.58	2.55-2.61
	95th	524	3.10	2.97-3.24

Conclusion: Preliminary results from a 24-year follow-up study in Sweden after the Chernobyl nuclear power plant accident could indicate a slight overall increased incidence of total malignancies for cumulative exposure. Further analyses will focus on the exposure response relationship after improved dosimetry and separate analyses will be performed on sites with a known relationship to ionizing radiation e.g. leukaemia.

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Radiation doses to Swedish nuclear workers and cancer incidence in a nuclear power plant

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Introduction, the Swedish nuclear energy program

There are about 2000 nuclear facilities in Sweden licensed by the Swedish radiation safety authority (1). Thirty are nuclear technical plants and three are nuclear power plants with 10 now running reactors. The Swedish nuclear program started in early 50ies with the first nuclear reactor at the Royal Technical Institute of Stockholm reaching criticality in 1954 (table 1). National self-sufficiency was stressed in the beginning of the nuclear program stressing the possibility to both produce energy and create strategic atomic weapons. Sweden has relatively large uranium findings and heavy water could be obtained from the Rjukan facility in Norway. The first commercially energy producing plant started in 1964 in Stockholm, a heavy water reactor for both district heat and electricity. Out of totally 16 Swedish reactors built, presently there are 10 reactors in use (table 1). The two reactors in the Barsebäck nuclear power plant were stopped in 1999 and 2005. Recently the Swedish state enterprise Vattenfall has acquired shares in three German nuclear reactors with 67% shareholding in Brunsbüttel, 50% in Krümmel and 20% in Brokdorf.

Table 1. Table of nuclear reactors located in Sweden or run by a Swedish company abroad.

Site	Type	Electric effect Brutto/Netto (MW)	Thermic effect (MWh)	In operation
Stockholm R1	HWR	n.d.	Up to 1	1954-1970
Studsvik R2 (and R2a*)	Swimming pool LWR	n.d.	30-50	1960-2005
Stockholm R3	PHWR	12/10	80	1964-1974
Norrköping R4	B/PLWR	n.d.	n.d.	Planned 1964*
Barsebäck 1	BLWR	615/600	1800	1975-1999
Barsebäck 2	BLWR	615/600	1800	1977-2005
Oskarshamn 1	BLWR	487/467	1375	1972-
Oskarshamn 2	BLWR	627/602	1800	1975-
Oskarshamn 3	BLWR	1194/1160	3300	1985-
Ringhals 1	BLWR	870/830	2500	1976-
Ringhals 2	PLWR	910/870	2652	1975-
Ringhals 3	PLWR	960/920	2775	1981-
Ringhals 4	PLWR	970/915	2775	1983-

Forsmark 1	BLWR	999/961	2928	1980-
Forsmark 2	BLWR	997/956	2928	1981-
Forsmark 3	BLWR	1227/1185	3300	1985-
Brunsbüttel**	BLWR	806/771	2292	1976-2007
Krümmel**	BLWR	1401/1346	3690	1983-2009
Brokdorf**	PLWR	1480/1410	3900	1986-
Marcoule***	ASTRID	n.d.	n.d.	Planned for 2014?

n.d.= not defined, *Never finished, **Germany, ***France
HWR= Heavy water reactor
LWR= Light water reactor
PHWR= Pressure heavy water reactor
BLWR= Boiling light water reactor
PLWR= Pressure light water reactor
ASTRID= Advanced Sodium Technological Reactor for Industrial Demonstration

Presently only Brokdorf is running, because of the 2011 German governmental decision for a planned termination of nuclear energy production. Instead an agreement between the Swedish and French governments has been signed in 2011 to develop a sodium cooled fast neutron reactor prototype (ASTRID, Advanced Sodium Technological Reactor for Industrial Demonstration) in French Marcoule.

Radiation doses to Swedish nuclear workers

Out of presently ten running reactors four were built in the seventies and have therefore been extensively renovated, to increase both power, safety and life expectancy. Therefore an extensive renovation program was launched to modernize existing reactors. These renovations of existing reactors were performed mainly during the 90ies causing both an increase in the number of exposed workers and their doses (fig 1).

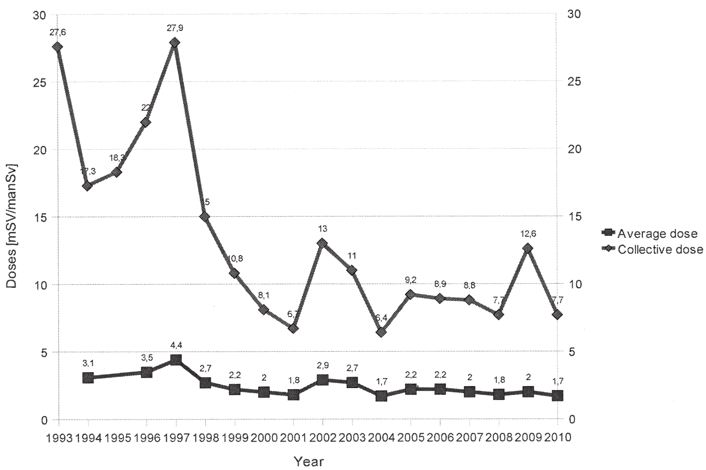

Figure 1. Average effective doses [mSv] and collective doses [manSv] for Swedish nuclear workers reported to the National dose registry from 1993 to 2010.

The average dose among the nuclear workers reached a maximum level in 1997 with an average received external dose of 4,5 mSv to 6500 nuclear workers (table 2) (1). Received average doses for the workers have been roughly constant during the last ten years with annual average received external doses ranging between 1,7 and 2,7 mSv (table 2). Among totally 4 400 nuclear workers, with registered doses, the collective dose during 2010 was 7.7 manSv. The average dose was 1.7 mSv during 2010 compared to 2.0 mSv to 6400 workers during 2009. The Swedish radiation safety authority is also focusing on special sources of radiation doses. Increasing doses have been observed for the turbine hall workers, probably due to higher levels of dampness from boiling water reactors (1). The average received doses are approximately 50% higher in Swedish boiling water reactor plants than for pressure water plants. Also chronic inhalation of uranium dust is an occupational problem with internal radiation doses close to present safety limits. Therefore all nuclear power stations participate in a project measuring whole body radiation of the nuclear workers in order to screen for possible internal contamination. Another major source of received radiation dose is radiographic work when the reactor construction is checked with mobile X-ray equipment (1).

Table 2. Reported external and internal doses for Swedish nuclear workers (only power stations) to the Swedish national dose register from 1993 to 2010

Year→	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Number of nuclear workers	n.d.	n.d.	n.d.	n.d.	6341	5433	4801	3988	3639	n.d.	4074	3664	4195	4238	4348	4290	6403	4462
Average dose (mSv)	n.d	3,1	n.d.	3,5	4,4	2,7	2,2	2,0	1,8	2,9	2,7	1,7	2,2	2,2	2,0	1,8	2,0	1,7
Collective dose (manSv)	27,6	17,3	18,3	22,0	27,9	15,0	10,8	8,1	6,7	13,0	11,0	6,4	9,2	8,9	8,8	7,7	12,6	7,7
Maximal dose (mSv)	n.d.	31,7	n.d.	n.d.	45,4	33,0	25,0	20,7	19,6	n.d.	26,7	19,5	23,6	19,7	18,2	18,6	22,8	16,9
External dose >20 mSv	216	47	26	n.d.	258	15	6	1	0	n.d.	8	0	n.d.	0	0	0	n.d.	0
Internal dose**	0	0	0	0	0	0	0	0	0	n.d.	1	2	2	0	2	0	0	0

n.d.=not defined/no data
** Number of nuclear workers receiving an external dose exceeding 20 mSv.*
*** Number of nuclear workers receiving an internal dose exceeding the current safety limit (5 mSv to 1999, 1 mSv 2000-2002, 0,25 mSv from 2003)*

Cancer incidence at the Forsmark nuclear power plant, background

There has been concern among the personnel at the Forsmark nuclear power plant about a supposedly increased number of cases of cancer among the nuclear workers, and the department of Occupational medicine at Uppsala university hospital was asked to investigate this.

Method

Medical records for the nuclear workers during 6 years were retrieved from the local occupational health clinic to verify the occurrence of neoplastic disease. Smoking habits were also recorded. The Forsmark nuclear power plant has 1050 employees. The expected number of neoplastic diseases were calculated according to age- and gender standardized data from the Swedish cancer registry. The standardized incidence rate (SIR) was calculated as the ratio between the number of observed and expected cases. A Chi-square significance testing of the supposedly poisson distributed cases was made. Accumulated individual effective doses were retrieved from the Swedish dose registry.

Results

Retrospectively during a period of 6 years 20 cases with malignant disease could be verified (table 3). For comparison 14.7 cases were expected among the work force according to age- and gender-standardized data from the Swedish cancer registry. SIR, the standardized incidence rate was 1.4 with confidence interval 0.8-2.1. The average cumulative effective dose registered by the national dose registry was 4,5 mSv for the 20 subjects with malignant disease (table 3). This cumulative dose is about twice the average yearly dose for all Swedish nuclear workers (table 1). A clear dose-response pattern could not be found from registered doses. The mean age during the study period increased from 39 to 43 years and the proportion of female employees were constant (18 %). Information about smoking habits in all personnel was not available, but among the cases 63 % had been smokers.

Table 3. Cumulative doses and smoking habits among 20 cases with neoplastic disease.

Type of cancer	Age	Cumulative dose [mSv]	Ever smoker*
Lung	52	2,1	+
Lung	52	-	-
Lung	53	1,4	+
Lung	53	8,9	+
Lung	66	0,9	+
Breast	40	-	-
Breast	47	-	-
Breast	49	44,9	?
Colon	54	2,9	-
Colon	55	-	+
Brain	49	-	?
Brain	39	0,1	?
Germinalcell	41	6,1	+
Thyroid	58	-	+
Hodgkin	52	12,7	+
CLL*	50	2,1	+
Stomach	55	-	+
Prostate	62	6,7	+
Uterus	52	1,5	+
Cervix	54	-	+

*Chronic lymphatic leucemia

Discussion

According to the Swedish dose registry the average mean dose to Swedish nuclear workers has been relatively stable during the last ten years, ranging between 1,7 to 2,7 mSv (table 2). It is about the same level as the mean yearly natural background radiation dose of 2,4 mSv to the Swedish population (2). Due to extensive renovation jobs higher doses were received during the 90ies with mean received yearly doses up to 4,4 mSv. In the Forsmark nuclear plant, where there had been an alarm about increased occurrence of cancer among the nuclear workers the average doses have been lower than the national average doses (1). A significantly increased incidence of malignancies could not be verified by a crude comparison between the number of observed and expected cases.

There has been a debate whether nuclear workers have an increased risk of cancer or not. Rosalie Bertell claimed already in the seventies that they are at risk of having malignant diseases (3). The largest study on cancer incidence among nuclear workers, the 15 countries collaboratory study comprising 407 391 personnel, found an increased risk for total cancer incidence (RR=1,1 at a nominal accumulated dose of 100 mSv) (4). The Swedish sub-cohort of this study showed on the contrary a lower risk for Swedish nuclear workers. This could probably be explained by a "healthy-worker effect" which was observed in most participating countries (5). It is also well-known that smoking is an effect-modifier of cancer induction together with ionizing radiation, for example increasing the risk of lung cancer with concomitant radon exposure (6). Since a majority of the workers in the present study were smokers, as compared to less than 20% in the general Swedish population, the attribution of smoking to the cases of lung cancer, which were 25 % of total cases of cancer, would be significant. Furthermore the individual mean accumulated dose over several years of employment among the cases was less than 5 mSv. Therefore ionizing radiation at work as a causative factor behind the 40% increase in observed cases of cancer in the present study could not be distinguished from the influence of chance or life-style factors.

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Prevalence and risks of chronic internal diseases among workers of Uranium Processing Enterprise

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Abstract

Risks of somatic diseases among personnel of Uranium Processing Enterprise in Kazakhstan

The prevalence and relative risks of somatic pathology were studied in 912 workers of uranium processing plant. Excessive rough and standardized relative risks for arterial hypertension, chronic obstructive pulmonary disease were obtained.

The intensive development of the global economy does not allow for the foreseeable future to eliminate the use of atomic energy. The Republic of Kazakhstan takes one of the leading places in the world on reserves of uranium ore. In 2009, Kazakhstan moved into first place for the extraction of uranium in the world – the extraction of natural uranium was 13 500 tons [1]. Due to productive expansion, a large number of "professionals" and population are involved into impact area of radiation factor; therefore, the assessment of ionization radiation (IR) impact in low doses (LD) on the health of the nuclear fuel complex personnel becomes more acute [2]. Medical and biological effects of chronic exposure to low doses (LD) to the present time are not fully clear, although it is known that the extrapolation of data obtained for high doses of ionization radiation (IR) for the LD is not justified [3, 4]. At this stage, all effects of LD are considered as stochastic, realizing in the form of cancer or genetic disorders. However, as data of the literature give evidence, this is not all manifestations of the low level radiation exposure. These also include the effects of early aging, various metabolic disorders, respiratory diseases - plutonium pneumofibrosis, bronchitis, etc. [5, 6]. According to a number of authors, IR in LD can contribute to a number of somatic diseases. In this case the radiation factor may not play a decisive role, and act as an agent, potentiating impact of traditional risk factors for major somatic diseases [2, 7]. Existing in the available literature data on the prevalence of chronic noninfectious diseases among workers of the nuclear industry are small, fragmented and, in some cases, contradictory [2, 3, 8].

Aim of this study was to investigate the prevalence and relative rough and standardized risks of chronic somatic diseases among personnel of uranium processing enterprise who are exposed to the long-term radiation-toxic effects during their professional activity.

Materials and Methods. The prevalence and relative risks of somatic diseases were studied in 912 workers of primary production (personnel of group "A") of Hydrometallurgical Plant (HMP), which is one of the largest in Central Asia and Kazakhstan enterprise on production of commercial suboxide-oxide of uranium, molybdenum-acid ammonium and affined gold.

Men reached 809 persons (88.7%), women - 103 (11.3%) persons. The average age of personnel of HMP was 43,2 ± 10,3 years. Work experience in contact with sources of IR was 13,9 ± 12,7 years.

According to the service of radiation safety of HMP, the recorded radiation exposure to personnel in a number of years was uniform. Thus, the average individual radiation dose for 2010 was 6.76 mSv/y (maximum - 9.86 mSv/y, minimum - 0.064 mSv/y). Excess of MPL in concentration of natron, ammonia, sulfur dioxide, cinder dust, sulfuric acid vapor was not observed.

As a comparison group was studied the prevalence of somatic diseases among 788 (696 men and 92 women) workers of the production shop at the Stepnogorsk Bearing Plant (SBP), located at a distance of 10 km from HMP.

The one-stage continuous cross-sectional survey was conducted. The prevalence of somatic diseases was assessed according to results of in-depth medical examination, which covered 96.3% of HMP workers and 98.5% of SBP workers of main production plants.

As an integral indicator of health status, moment prevalence (Pr) was assessed, rough relative risks (RR) of somatic diseases were calculated. Stratification of studied groups was performed and standardized relative risks (SRR) corrected according to gender, age, duration of labor experience and significant risk factors for major somatic diseases were identified. To calculate corrected values, Mantel-Hanzela procedure was used, 95% confidence limit (CL) was calculated by the method of Woolf [9].

For comparison of independent samples on the binary feature (prevalence), an analysis of fourfold table of contingency using criterion χ^2 was carried out. When checking the statistical hypotheses, the critical level of significance was taken as 0.05. The achieved level of significance when checking the statistical hypotheses was designated as «p <...» in the text. Statistical analysis was performed using the software package «Statistica 6.0» and «SPSS 13.0».

Results and discussion. Analysis of the values of moment prevalence of somatic diseases (Table 1) revealed a high prevalence of endocrine diseases among workers of HMP and SBP.

Table 1. Prevalence (Pr., ‰) of somatic diseases

Diseases	HMP			SBP		
	N	Pr., ‰	95% CL	N	Pr., ‰	95% CL
Endocrine diseases, total	**318**	**348,7**	**317,8-379,6**	**251**	**318,5**	**288,0-351,1**
Among them						
Hyperplasia of the thyroid gland	176	193,0	167,4-218,6	150	194,0	162,9-217,8
Obesity	92	100,9	81,4-120,4	77	97,7	77,0-118,4
Chronic autoimmune thyroiditis	43	47,1	33,4-60,8	16	20,3	10,5-30,2
Nodular goiter	14	15,4	7,4-23,4	7	8,9	2,3-15,4
Diabetes mellitus, type 2	9	9,9	3,5-16,3	7	8,9	2,3-15,4
Diseases of the circulatory system, total	**306**	**335,5**	**304,9-366,1**	**163**	**206,9**	**178,6-235,1**
Among them						

Diseases	HMP			SBP		
	N	Pr., ‰	95% CL	N	Pr., ‰	95% CL
Arterial hypertension	225	246,7	218,7-274,7	81	102,8	81,6-124,0
Chronic forms of ischemic heart disease	52	57,0	42,0-72,0	45	57,1	40,9-73,3
Neurocirculatory dystonia	32	35,1	23,2-47,0	24	30,5	18,5-42,5
Symptomatic arterial hypertensions	26	28,5	17,7-39,3	23	29,2	17,4-40,9
Diseases of the digestive system, total	**291**	**319,1**	**288,8-349,4**	**144**	**182,7**	**155,8-209,7**
Among them						
Chronic gastritis	159	174,3	149,7-198,9	64	81,2	62,1-100,3
Chronic cholecystitis	36	39,5	26,9-52,1	32	40,6	26,8-54,4
Gastro-oesophageal reflux disease	43	47,1	33,4-60,8	31	39,3	25,8-52,9
Chronic pancreatitis	28	30,7	19,5-41,9	20	25,4	14,4-36,4
Peptic ulcer disease	33	36,2	24,1-48,3	18	22,8	12,4-33,3
Diseases of the respiratory system, total	**190**	**208,3**	**181,9-234,7**	**79**	**100,3**	**79,3-121,2**
Among them						
Chronic obstructive pulmonary disease	176	193	167,4-218,6	77	97,7	77,0-118,4
Bronchial asthma	14	15,4	7,4-23,4	2	2,5	1,0-6,1
Diseases of the urinary system, total	**66**	**72,4**	**55,6-89,2**	**68**	**86,3**	**66,7-105,9**
Among them						
Chronic pyelonephritis	49	53,7	39,1-68,3	44	55,8	39,8-71,9
Nephrolithiasis	20	21,9	12,4-31,4	18	22,8	12,4-33,3
Diseases of the osteoarticular system, total	**59**	**64,7**	**48,7-80,7**	**48**	**60,9**	**44,2-77,6**
Among them						
Osteoarthritis	52	57,0	42,0-72,0	40	50,8	35,4-66,1
Diseases of the blood system, total	**23**	**25,2**	**15,0-35,4**	**21**	**26,6**	**15,4-37,9**
Among them						
Iron deficiency anemia	20	21,9	12,4-31,4	21	26,6	15,4-37,9

With that as it can be seen from Table 2, only chronic autoimmune thyroiditis and nodular goiter had an excessive RR (more than 1). Not less high prevalence of cardiovascular diseases among workers of

HMP was caused by considerable damage of personnel by arterial hypertension (AH), relative risk of which in the exposed group was increased (RR = 2,4; 95% CL 1,9-3,0). Excessive prevalence among workers of HMP had been also when chronic gastritis (CG)-RR=2,1; 95% CL 1,6-2,7 and chronic obstructive pulmonary disease (COPD) - RR=2,0; 95% CL 1,6 -2.6.

Table 2. Rough relative risks of somatic diseases

Diseases	**RR**	**95% CL**	χ^2	**p**
Endocrine diseases, total	1,1	0,97-1,25	1,59	0,207
Among them				
Hyperplasia of the thyroid gland	1,0	0,82-1,21	0,01	0,939
Obesity	1,0	0,75-1,32	0,02	0,892
Chronic autoimmune thyroiditis	2,3	1,31-4,04	8,31	0,004
Nodular goiter	1,7	0,69-4,18	0,97	0,325
Diabetes mellitus, type 2	1,1	0,41-2,93	0,00003	0,967
Diseases of the circulatory system, total	1,6	1,36-1,87	34,4	<0,0001
Among them				
Arterial hypertension	2,4	1,91-3,01	58,35	<0,0001
Chronic forms of ischemic heart disease	1,0	0,68-1,46	0,01	0,923
Neurocirculatory dystonia	1,2	0,71-2,01	0,16	0,691
Symptomatic arterial hypertensions	1,0	0,57-1,73	0,01	0,934
Diseases of the digestive system, total	1,7	1,43-2,00	40,56	<0,0001
Among them				
Chronic gastritis	2,1	1,60-2,74	31,35	<0,0001
Chronic cholecystitis	1,0	0,62-1,58	0,01	0,912
Gastro-oesophageal reflux disease	1,2	0,76-1,87	0,45	0,504
Chronic pancreatitis	1,2	0,68-2,11	0,26	0,608
Peptic ulcer disease	1,6	0,91-2,81	2,15	0,143
Diseases of the respiratory system, total	2,1	1,65-2,66	36,27	<0,0001
Among them				
Chronic obstructive pulmonary disease	2,0	1,56-2,55	29,54	<0,0001
Bronchial asthma	6,2	1,41-27,16	6,13	0,013
Diseases of the urinary system, total	0,8	0,58-1,10	0,95	0,331

Diseases	RR	95% CL	χ^2	p
Among them				
Chronic pyelonephritis	1,0	0,67-1,48	0,01	0,933
Nephrolithiasis	1,0	0,53-1,87	0,02	0,899
Diseases of the osteoarticular system, total	1,1	0,76-1,58	0,05	0,826
Among them				
Osteoarthritis	1,1	0,73-1,63	0,21	0,645
Diseases of the blood system, total	0,9	0,50-1,61	0,03	0,853
Among them				
Iron deficiency anemia	0,8	0,43-1,46	0,4	0,527

Obtained excessive values of relative risks for major somatic diseases in personnel of HMP, were "crude" because they reflect only the quantitative characteristics, in our study - the prevalence of somatic diseases. "Crude" RRs do not give an answer on the causes of differences in the incidence of prevalence of a disease among the exposed on IR and non-exposed groups. Meanwhile, differences in prevalence between the compared enterprises may be not only in the impact of IR in the LD or lack of it, but also in the impact of other "disturbing" factors (confounding - factors). To eliminate the impact of confounding - factors, we performed a stratification of HMP personnel according to gender, age, duration of labor experience and the most significant risk factors (RF) for the progression of major somatic diseases.

To analyze the impact of AH predictors on prevalence of this disease, we has consistently studied the prevalence and relative risk of the following predictors of AH among the personnel of HMP and SBP: genetic heredity, obesity, metabolic syndrome, alcohol and table salt abuse, low physical activity, psychosocial stress. Results of the study revealed a significant prevalence of personal anxiety (PA) of high degree among workers of HMP (58.2% (95% CL: 54,8-61,6)), which exceeded the same prevalence among workers of SBP by 21.6 times ($p < 0, 0001$). It is known that work in hazardous conditions is accompanied by great emotional stress associated with the risk sensory uncertainty and prediction subjective uncertainty, meanwhile it was found that long-term chronic stress leads to the development of AH [10]. The prevalence of other predictors of AH at the compared enterprises was comparable.

As a result of conducted study we calculated SRR of AH, which was 2.91 (95% CL 2,1-3,8; χ^2=51,5; p<0,001).

To date no one has any doubts in the important role of Helicobacter pylori (HP) infection in the progression of CG, and it is confirmed by the results of controlled clinical and epidemiological studies [11]. In chronic atrophic (CAG) and non-atrophic gastritis (CNG) at the compared enterprises, the prevalence of HP colonization of gastric mucosa (GM) and its degree of severity were comparable. SRRs of CNG and CAG of HMP vs SBP were calculated. Stratification was carried out according to the degree of HP colonization of GM and age. SRR of HMP vs SBP for CNG was 2.1 (95% CL 1,4-2,7; χ^2=12,1; p=0.0007); for CAG - 3.9 (95% CL 1,9-7,0; χ^2=19,1; p<0.0001).

Smoking is a major proved predictor of CB. The prevalence of smoking at the compared enterprises ranged from 67% to 72.3%, and the RR of smoking at HMP vs SBP=1.1 (was not excessive), what give evidence about the comparability of the prevalence of smoking in the enterprises. Stratification was carried out with regard to age, labor experience, pack-years index. SRR CB was 2,8 (RR = 2,4); SRR for chronic nonobstructive bronchitis (CNB) was 1,6 (RR=1,3); for COPD - 5,0 (RR=4,6).

As the impact of confounding factors in the process of stratification was excluded, the increase in SRR of major somatic diseases showed the influence of the aggressive factors of production, in particular the IR in LD, serving as an additional risk factor for the development and progression of primary somatic pathology in workers of uranium processing industry.

Conclusion

- Among personnel of uranium processing enterprise, the most common somatic diseases were arterial hypertension (Pr=247 ‰), CG (Pr=174 ‰) and COPD (Pr=193 ‰).
- Personnel undergoing long-term radiation-toxic effects had a greater risk for AH progression – by 2.4 times; CG – by 2.1 times and COPD - by 2.0 times in comparison with workers of non-exposed enterprise.
- Standardized (according to gender, age, labor experience, significant risk factors) relative risks of a major somatic diseases among personnel of uranium processing enterprise versus personnel of non-uranium hazardous production were higher than rough risk and were for AH - 2.91; CNG - 2.1; CAG - 3.9 and COPD- 5,0.

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Radiation Exposure Caused by Nuclear Power Plant Accident and Thyroid Cancer

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I. Introduction

Twenty-five years has been passed since the Chernobyl accident, and last year in 2011 in Japan, Fukushima Nuclear Power Plant Accident (NPPA) has occurred. Increased incidence of thyroid cancer following the accident in the youth (under age 18, especially in children) in Chernobyl was reported in "UNSCEAR Report in 2008".

We have already showed the first oncology models (hypothesis) of thyroid cancer development in Hiroshima (after the A−bomb) and in Chernobyl. Then newly summarized hypothesis of thyroid cancer development in Chernobyl in children (youth) will be explained from the points of the (A) initiating factor, (B) thyroid injuries caused by I-131, (C) small cancer foci (microcancer), (D) promoting factors, and (E) characteristics of clinical cancers.

Then after showing the reports and comments related to thyroid cancer in the "UNSCEAR Report in 2008", our comments will be added from our datas and experiences. And the possibilities if thyroid cancer in children develop or not develop in the future in Fukushima will be explained from the unfavorable faces and profitable faces compared with the results in Chernobyl. Related papers and books are listed in the References at the end of this paper.

II. New concology model, hypothesis of thyroid cancer development in children in Chernobyl.

New oncology model is shown in Figure 1. Explanations below (from ①−㉔) will follow the same numbers in this Figure.

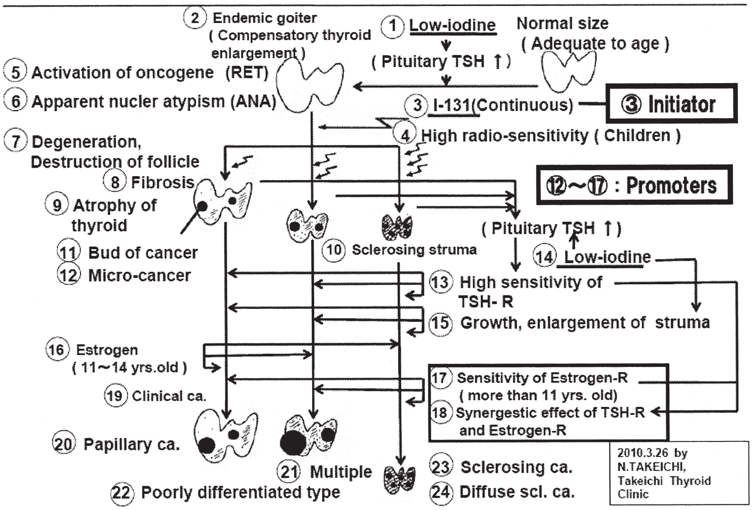
(A) Initiating factor

Conditions in the affected areas of natural iodine, struma and I-131 were as follows (①−③). ① The affected area in Chernobyl was low natural iodine region. ② Therefore the cases of compensatory thyroid enlargement (endemic goiter) were common in these affected areas. ③ Following the NPPA, a large continuous uptake of radioactive iodine (I-131) into the thyroid occurred. This I-131 is thought as a initator of thyroid cancer after NPPA.

(B) Thyroid injuries by I-131

Following ④−⑩ were estimated as a result of thyroid injuries caused by I-131. ④ Due to the high radiosensitivity of children's thyroid cells, ⑤ oncogene (such as RET) in the nuclei of follicular cells were activated, ⑥ and apparent nuclear atypism (ANA) revealed in these follicular cells. ⑦

Fig. 1. New Hypothesis of the Process of Thyroid Cancer Development in Radiation Exposed Children after the Chernobyl Nuclear Power Plant Accident.



Degeneration and destruction of follicle cells, subsequent variation in follicle size including follicular atrophy, lymphocytic infiltration occurred, ⑧ and fibrosis advanced. This degree of fibrosis corresponded to I-131 contamination levels. ⑨ Atrophy of thyroid (atrophic struma) revealed and advanced, ⑩ and the struma showing strong interstitial fibrosis with hard consistency was so-called sclerosing struma.

(C) Small cancer foci (microcancer)

In these degenerated, destructed, fibrotic, atrophic thyroid, small cancer foci revealed. ⑪ Bud of cancer, that is the smallest cancer lesion, appeared in these injured thyroid, ⑫ and enlarged to microcancer (usually smaller than 1.0 cm in adults, but smaller than 0.3～0.5 cm in cases of children).

(D) Promoting factors

Then why did such microcancers rapidly grew within 4－5 years after the Chernobyl accident, and became clinical cancers ? The possibilities of this promotoing factors, (promoters) are listed in the following ⑬－⑰. ⑬ The first possibilities is the high sensitivity of TSH-receptor of children's thyroid. ⑭ Second possible reason is that the low-iodine condition continued for a long time after the accident, and this condition stimulated normal thyroid cells to proliferate and compensate the decreased thyroid function, and also at the same time stimulated thyroid cancer cells to proliferate. ⑮ Third is the remarkable natural growth and enlargement of thyroid struma in children and the youth (under 18 yrs. old). ⑯ Fourth is estrogenic stimulus in female of 11～18 yrs. old. ⑰ Fifth is the sensitivity of estrogen-receptor (estrogen－R) in young female. ⑱ And sixth is the synergestic effect of sensitivities of TSH－R and estrogen－R. ⑲ With the combination of these above mentioned six promoting factors, it is suspected that microcancer of children rapidly grew to clinical cancer in Chernobyl.

(E) Characteristics of clinical thyroid cancer

These clinical cancers following the Chernobyl accident had the characteristics as follows (⑳－㉔). ⑳ High frequency of papillary cancer (histo-pathologically), ㉑ multiple cancer foci in thyroid (struma), ㉒ including the high rate of poorly differentiated type (different from real poorly differentiated papillary cancer), ㉓ sclerotic thyroid cancer (sclerosing cancer) which was characterized by rich of fibrosis in cancer lesion, ㉔ and, diffuse sclerosing cancer which was a diffuse sclerosing variant of papillary cancer showing mixture of cancer tissue and remarkable fibrosis. This sclerosing cancer was a typical characteristic of thyroid cancer developed in the I-131 heavily exposed children.

III. UNSCEAR report in 2008

In the UNSCEAR (United Nations) Report in 2008, following results and comments related to thyroid cancer in Chernobyl were contained. ① Thyroid cancer cases of 6,848 were reported among those under 18 years old in 1986, between 1991 and 2005, and 5,127 cases of them were in children (0－14 yrs. old). ② The increase began to appear 5 years after the accident, and persisted up until 2005. ③ And excess increased incidence of thyroid cancer is related to the estimated individual doses due primary to the radioiodine released during the accident. ④ Substantial portion could be attributed to drinking milk in 1986 contaminated by iodine-131. ⑤ Evidence has also emerged since the UNSCEAR 2000 Report indicating that iodine deficiency might have influenced the risk of thyroid cancer resulting from exposure to the radioactive isotopes of iodine, reliesed during the accident. ⑥ The estimation of radiation risk from these studies remain somewhat uncertain however. And may have been influenced by variations in the use of ultrasonography and mass screening after the accident. ⑦ Although thyroid cancer incidence continues to increase for this group, up to 2005 only 15 cases had proved fatal.

IV. Comments on the UNSCEAR Report.

I like to give some comments on the items of above-mentioned ②－⑦ from our data, and the events in Fukushima NPPA.

② The period of this UNSCEAR Report of thyroid cancer was 1991－2005, so that the data in 1986－1990 was not included. Our survey and datas in Belarus and Ukraine indicated that the increased incidence of thyroid cancer in children began to appear in 1990, 4 years after the Chernobyl accident.

③ From the UNSCEAR Report, thyroid doses of iodine-131 ranged up to several grays within a few weeks after the accident. Unfortunately in Fukushima, individual absorbed doses of I-131 in thyroid in adequate groups or adequate numbers of children were not measured.

④ In UNSCEAR Report, the contamination of fresh milk with iodine-131 and the lack of prompt countermeasures led to high thyroid doses, particularly among children in the former Soviet Union, is written. In Fukushima area it is said that I-131 contaminated cow's milk was not circulated from the early stage after the NPP accident, and the level of radiation dose of cow's milk in Japan (upper standard value,

Fig. 2. Changes of urinary iodine after eating 20 sheets of table flavoured laver, among the healthy ladies of 21-29 yrs. old, Sept. 13, 2002 .

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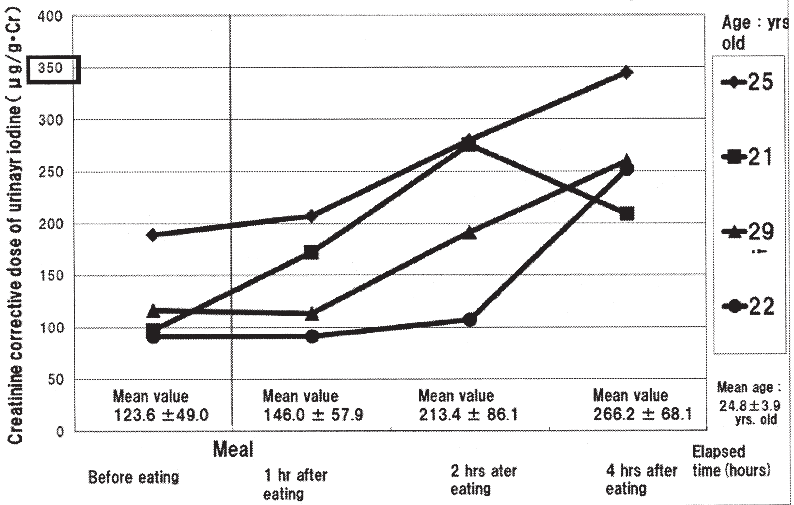

regulated radiation dose by The Nuclear Safety Commission) was strict 100 Bq/L for children and 300 Bq/L for adult. The maximum I-131 dose measured in Fukushima (40 km from NPP) was 5,300 Bq/L, in cow's milk in March 11～April, 2011.

⑤ As shown in UNSCEAR Report, iodine deficiency might have influenced thyroid cancer caused by I-131. I-131 was easily uptaken in thyroid in the low iodine regions such as the affected areas of Chernobyl. However residents in Fukushima area commonly taking natural iodine enriched food, such as seaweeds species. We have reported the comparison of urinary iodine levels in children between Chernobyl and Hiroshima in (1993～2002). Approximate creatinine corrective dose of iodine in urine (µg / g・Cr) was about 50 in Chernobyl and about 300 in Hiroshima. Both cities of Hiroshima and Fukushima faces to the sea and residents were thought to eat natural iodine rich food. Here we have new data shown in Figure.2. Changes of urinary iodine after eating 20 sheets of table flavoured laver (seasoned laver) among the healthy four ladies of 21−29 years old, who were working at Takeichi Thyroid Clinic, were shown. All of other 8 ladies who showed more than 300µg / g・Cr of urinary iodine before eating this flavaured laver were not included here. Average level of 266.2 after 4 hours after eating was almost 2.2 times higher than the level of 123.6. This 266.2 was almost same level (about 300) of general Japanese people. So that I-131 uptake in thyroid will be prevented by taking this 20 sheets of table flavoured laver, soon after the accident.

⑥ This explanation of UNSCEAR Report about the risk factors of radiation effect on thyroid cancer is agreeable. Small thyroid nodules are found more easily using advanced and precise ultrasonography. So that the real epidemiological results should be based on cancer size, measured by same type or same

Table 1 Estimated Conditions of Thyroid after Fukushima Daiichi Nuclear Power Plant Accident

Unfavorable faces		Profitable faces
1. I-131 leakage occurred.	→	People within 20 km zone went out in early stage after the accident.
2. I-131 is easily uptaken in thyroid in low iodine regions. 3. Potassium iodine was not delivered soon after the accident.	→	Residents in Fukushima are commonly taking diet of rich iodine, such as seaweeds species, because they live seaside.
4. Thyroid of children is sensitive to I-131 effect, and is destructed easily.	→	Apparent regenerative activity is seen in thyroid follicles even in the strongly destructed thyroid in children, and this activity compensate the thyroid function.
5. Thyroid cancers were induced in children by I-131.	→	But half-life of I-131 is short 8 days, and vanish in almost 3 months.
6. Four furnaces of NPP had accident in Fukushima, and I-131 leakage has been lasted for a long time. Estimatod released dose was about 110,000 TBq.	→	Released I-131 dose in Fukushima was estimated as one sixteenth (1/ 16) of thst in Chernobyl (1,800,000 TBq).
7. Residents have fear for the possibilities of thyroid cancer development.	→	Eealy detection of thyroid cancer is possible with periodical thyroid examinations. Even if thyroid cancer occurred, prognosis of this cancer is usually better compared with other cancers .
8. Thyroid cancer is surgically operated, basically.	→	Many cases of microcancer ($\leqq$ 1.0 cm) are stable and have long prognosis throughout the life.
9. Sugical operation is the final method for the large clinical thyroid cancers.	→	Enlargement of the tumor was controlable with taking continuous thyroid medicine (T4).
10. Operation scar remains in the foreneck, and children have mental burden.	→	Recurrence and metastasis are well controlable with post-operative administration of thyroid medicine (T4).
11. There is a possibilities of transformation from well differatiated cancer to the poorly differentiated and or anaplastic cancer of poor prognosis.	→	With the early detection and early operation, transformation to the poor prognosis of cancer will be prevented.
12. I-131 contaminated cow's milk was drunk in Chernobyl. And maximam approbal dose in cow's milk for children was 1,000 Bq / L and 2,000 Bq / L for adults	→	In Fukushima, it was strict 100 Bq / L for children, and 300 Bq / L for adults. I-131 contaminated milk was not cirulated, from the early stage after the NPP accident.

thorough ultrasonography. And also doctor's skill and ability to find the cancer might be considered in this sence.

⑦ UNSCEAR Report says only 15 cases were fatal in 6,848 thyroid cancer, between 1991 and 2005, amongst those under age 18 years in 1986. However the age at death of those fatal cases were all less than 37 years old (until 2005). Fatal cases of thyroid cancer who died under age 37 years are very very rare (almost none) in the field of thyroid surgery. So that I think we have to be careful for the prognosis of thyroid cancer cases caused by I-131 contamination while in childhood.

V. Estimated conditions of thyroid after Fukushima Daiichi NPPA from the aspects of unfavorable faces and profitable faces.

From these conditions in Fukushima in this Table 1 and also experiences and knowledges obtained in Chernobyl, it is suspected that the incidence of thyroid cancer in children (youth) following Fukushima NPPA will not so increase as in Chernobyl. Even though, why Nation or responsible persons in Japan did not order children to escape from the 20−30km zone from NPP, and also why iodine−K (potassium) was not delivered to the residents in peripheral area of NPP (within 30km from NPP) soon after the accident. If these two were enforced, risk of thyroid cancer development in the youth, who were exposed to I-131 while they were childhood in 2011, might not increase apparently in the future in Fukushima.

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Frequencies of Dicentric Chromosome and Translocation in Lymphocytes from Residents in Radio-contaminated Villages near Semipalatinsk Nuclear Explosion Test Sites

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Abstract

More than 400 above-ground and underground nuclear explosion tests were conducted at Semipalatinsk nuclear explosion test site (SNETS). The significant radioactive substances was released and radioactive plumes moved on villages at the time of explosion test, then residents in villages near SNETS are considered to be exposed internally and externally. In order to assess the biological effects on residents, frequencies of chromosome aberrations in peripheral blood lymphocytes were observed in 116 residents living in 3 villages near SNETS and 46 residents in a non-contaminated village by conventional Giemsa staining method and fluorescent *in situ* hybridization (FISH). Frequencies of dicentric and ring chromosomes in residents from the 3 villages were 1.5-2.55 per 1,000 cells, comparing to 0.78 in control area. Residents in contaminated areas had more complex chromosome aberrations. Frequencies of stable-type chromosome aberrations such as translocation were detected in 0.1% and 0.07% in 2 contaminated villages, while 0.02% in control area. More sensitive FISH analysis of chromosome subset revealed higher frequency of translocation (2.17%) in a resident. Multiple chromosome aberrations (MCA) involving more than 10 abnormal chromosomes were found in 0.12-0.42 % of observed cells among all villages, irrespective of radio-contamination. These results indicate that residents living adjacent SNETS were exposed internally and externally, but their estimated external doses were less than previously estimated 140-440 mGy, though how internal exposure was contributed to the higher incidence of chromosome aberrations is unclear.

Introduction

The Semipalatinsk nuclear explosion test sites (SNETS) is a highly contaminated area with radioactive fallout that is due to more than 456 substantial nuclear explosions, including atomosphelic and underground tests over period of 40 years from 1949 to 1989 by the former Union of Soviet Socialistic Republics in Semipalatinsk, Kazakhstan Republic. Significance remaining long lived radionuclides of ^{239,240}Pu, ^{137}Cs and ^{90}Sr has been reported in SNETS areas [1]. Residents were repeatedly exposed to radioactive plumes passed over villages during nuclear explosion tests. Then, residents were considered to be continuously exposed to both external and internal exposures for a long time. Epidemiological studies showed a higher incidence of cancer in the esophagus, stomach, liver and lung among residents [2,3].

Unstable-type chromosome aberrations (Cu) such as dicentric chromosome and ring chromosome will be sensitive and more reliable indicator for radiation exposure, even at low dose and low-dose-rate. Frequencies of dicentric chromosome in lymphocyte has been observed in chronically exposed individuals and populations such as clean-up workers of Chernobyl nuclear accident, residents in radio-contaminated apartment houses in Taiwan and nuclear facility workers and medical technologists [4-8]. In contrast, cell with stable-type of chromosome aberrations (Cs) such as translocation can persist for a longer term after irradiation, then translocation might be superior to dicentric chromosomes to estimate accumulated dose in chronic exposure as well as exposure dose at the time of past acute exposure. In present study, we analyzed frequencies of dicentric chromosome and translocation and the spectrum of the chromosome aberrations in 116 residents living three villages adjacent to the SNETS.

Materials and Methods

1) Subjects and blood culture method

Subjects were 162 healthy adults with their informed consent from 1998 to 2002. Out of them, 116 subjects (84 females and 32 males) had been living continuously in the area since between 1948 and 1965 when the atomospheric nuclear tests were performed. The residents were from three different radio-contaminated villages in the vicinity of SNETS (Dolon, Sarjar, and Kaynar,) and 46 control residents (35 female and 11 male) from non-contaminated area, Kokpekty, where locates about 700 km away east from SNETS. Three more contaminated villages, Dolon, Sarjar and Kaynar are about 100 km away east or south from the center of SNETS. All subjects ranged in age from 45 to 73 years at the time of sampling. Residents who were born in 1939-1949 in these villages were 0-10 years old at the time of the first nuclear explosion test in 1949. For example, the 55-year-old resident was 5 years old at the time of the first nuclear tests. Cases with chronic thyroiditis who showed high anti-thyrogloblin anti-body values (TgAb $\geq$ 0.4 U/ml) were excluded from present study.

The 10 or 20 ml whole blood drawn from 162 healthy subjects was immediately mixed with 20 ml RPMI 1640 medium containing 20 ml fetal bovine serum(FBC) and 1 % phytohemaggulutinin (PHA) in 50 ml sterilized conical tube and stored at 4℃. These samples were transferred to Japan. The blood transportation method is presently modified to be more suitable for chromosome analysis [9, 10]. Four 10 ml culture flasks were set up and their blood were cultured for 52h using fresh RPMI1640 medium plus 20% FBS. Colcemide was added for the last 2h before harvesting. Cells were treated with hypotonic solution and fixing solution according to standard protocol. Chromosome metaphases were prepared by air dry method and stained in Giemsa solution. Unstable-type aberrations (dicentric, ring chromosomes and fragments) were observed under microscope in about 200-500 well-spread metaphases from each subject. All of the abnormal metaphases were photographed. Translocation, inversion and deletion were analyzed on the photos.

2) *Fluorescence in situ hybridization (FISH) method of chromosome subsets*

Peripheral blood lymphocytes from a 60 year old man, who stays in Sarjar without movement since 1940 when he was born, was used for FISH analysis. Whole chromosome specific painting (WCP) probe (Vysis, Naperville, IL, USA) were used for metaphase FISH. We applied two-colors painting of chromosomal subsets using different chromosomes, as WCP probes for chromosomes 1, 2 and 4 were shown as rhodamine derivative spectral orange and WCP probes for chromosomes 6, 7 and 9 were FITC derivative green. These two kinds of probes were mixed and hybridized. Our FISH protocol has been published previously [11]. Painted chromosome aberrations with these WCP probes were classified according to the protocol for aberration identification [12]. Furthermore, we calculated the expected frequencies of translocation in 23 pairs of chromosome from observed translocation frequencies using Lucas's formula [13]: Frg = 2.05[fr(1-fr)+fg(1-fr)-frfg]Fg, where Frg and Fg are observed and calculated frequency translocation, respectively, and fr and fg are the percentages of the genome stained in red and green, 0.224 and 0.157 in 6 pairs of chromosomes,1, 2, 4, 6, 7 and 9 contains 38.2% of the whole genome [14].

Results

1. Frequencies of dicentric chromosome aberration

Results on chromosome aberrations in 116 residents from 3 villages (Dolon, Sarjar and Kaynar) near SNETS and 46 residents from control village, Kokpekty, are summarized in Table 1. Each village had similar age distribution(58.5±5.18 in Dolon; 56.9±5.36 in Sarjar; 56.9±4.84; 52.1±3.34 in Kokpekty) . Numbers of dicentric chromosome (Dic) in lymphocytes of residents of Dolon, Sarjar and Kaynar were 1.74, 1.17 and 1.2 per 1,000 cells, respectively, which were 2-3 times higher than 0.6 in control residents. Frequencies of dicentric and ring chromosomes (Dic+Rc) in 3 villages were 1.55-2.55 per 1,000 cells, comparing to 0.78 in control area. Also, the numbers of cell with both dicentric chromosome and fragment (Dic+ F) in a metaphase of residents of Dolon, Sarjar and Kaynar were 0.92, 0.44 and 0.69 per 1,000 cells, compared to control area (0.42). Residents in most contaminated area, Dolon, had about two times higher aberration(Dic+F) than control area. Numbers of chromosome per abnormal cell were 1.71, 1.88 and 1.7, compared with 0.8 of the control residents, which indicating that more complex chromosome aberrations were found in the residents of the three contaminated villages. Interestingly, metaphases with multiple complex chromosome aberrations(MCA), which contain more than 10 abnormal chromosomes including tricenric, dicentric, ring chromosomes, fragments and double minute chromosome in a metaphase, were observed in 0.34 % of analyzed metaphases in a contaminated village, Dolon, compared to 0.1, 0.05 in two contaminated area, Sarjar and Kaynar, and 0.03 control area, Kokpekty (Table 1). Representative metaphases with MCA are shown in Fig.1. Metaphases with MCA were excluded from scoring dicentric and ring chromosomes, because it is considered not to be radiation-induced.

2. Frequencies of trasnlocation

As shown in Table 2(a), Cs cells also observed higher incidences in residents living in the contaminated areas. Out of total 162 residents, 63 residents (28 from Dolon, 17 from Sarjar, and 18 from control area, Kokpekty) who were analyzed in 2001-2002, were used for present translocation analysis using conventional Giemsa staining method. Cs cells with either or both translocation, inversion or deletion（t + inv + del） were identified on the photos. The frequencies of residents from Dolon and Sarjar were 0.1% and 0.07%, respectively, which were higher than 0.02% in control area, Kokpekty. Frequencies of each chromosome aberration of translocation, inversion and deletion were 0.6%, 0.2 % and 0.4 % in Dolon, and were 0.4%, 0.2% and 0.4 %in Sarjar, whereas 0, 0 and 0.2 % in control area, Kokpekty. FISH analysis of chromosome subset with two colors is more sensitive than conventional Giemsa staining method, then we applied the method to a subject of the 17 residents in Sarjar to detect precise frequency of translocation in lymphocytes. Ten metaphases (0.99%) were detected to have translocation in 1,008 observed metaphases [Table 2(b)]. Expected frequency of translocation in the man was obtained as 2.17 % by calculation with the Lucas's formula, which was higher than those obtained by conventional Giemsa staining method.

Table 1. Frequencies of chromosome aberrations in lymphocytes from residents in three contaminated villages, detected by conventional Giemsa staining method

Villages	subjects	Obs. cells	Ab. cells (%)	Dic (per 1,000 cels)	Rc	Dic+Rc (per 1,000 cells)	Dic+F (per 1,000 cells)	Comlexity (No. chr. ab. per ab. cell)	MCA cells (%)
Dolon	35	9,794	62(0.63)	17 (1.74)	8	25(2.55)	9(0.92)	1.71	33(0.34)
Sarjar	48	13,642	141(1.03)	16 (1.17)	7	23(1.69)	6(0.44)	1.88	13(0.1)
Kaynar	33	11,650	40 (0.34)	14 (1.2)	4	18(1.55)	8(0.69)	1.7	6(0.05)
Kokpekty	46	14,192	66 (0.47)	9 (0.6)	2	11(0.78)	6(0.42)	0.8	4(0.03)

Obs: observed, Ab: abnormal, Chr.: chromosome, Dic: dicentric chromosomes, Rc: centric ring, F: fragment

Table 2 (a) Frequencies of translocation in lymphocytes from residents in two contaminated villages, detected by conventional Giemsa staining method

Villages	Subjects	Obs. cells	Ab. cells(%)	Total (t+inv+del) (%)	Trans (%)	Inv	Del
Dolon	28	9,000	78 (0.87)	11 (1.2)	5(0.6)	2(0.2)	4(0.4)
Sarjar	17	5,150	20 (0.39)	5 (1.0)	2(0.4)	1(0.2)	2(0.4)
Kokpekty	18	6,600	7 (0.11)	1 (0.2)	0	0	1(0.2)

Obs: observed, Ab: abnormal, Trans: translocation, Inv: inversion, Del: deletion

(b). Frequency of translocation in lymphocytes from a resident in contaminated area, Sarjar, detected by FISH

Village	Subject	Obs. cells	Ab. cells (%)	Obs. trans	Calculated trans (%)*	Rc	Ace. ring
Sarjar	1	1,008	12 (1.19)	10 (0.99)	(2.17)	2	2

*Number of translocations in whole genomes equivalent was calculated using Lucas's formula. Obs: observed, Ab: abnormal, trans: translocation, Rc: centric ring, Ace ring: acentric ring

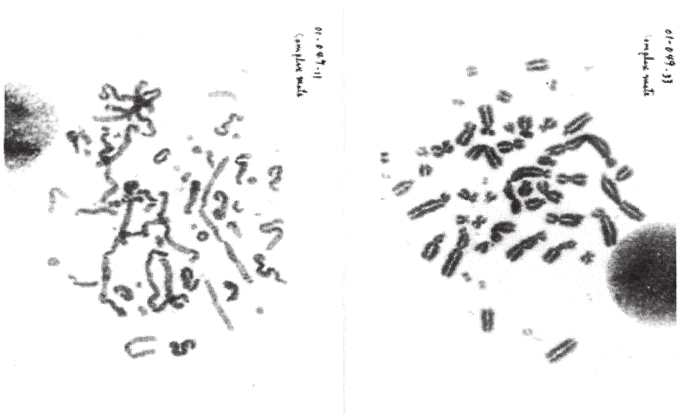

Figure 1 Representative two metaphases with MCA from independent subjects. Multiple abnormal chromosomes such as tricentric, dicentric, ring chromosomes and fragments are shown in a metaphase.

Discussion

Testa et al. obtained quite similar result on frequencies of dicentric and ring chromosome (Dic+Rc) to ours (2.55 in 1,000 cells), in which 21 subjects in Dolon village had 2.6 in 1,000 cells [15]. Another two reports on the observation in 80-100 subjects showed that mean numbers of dicentric and ring chromosome were 2.3 and 4.4 in 1,000 cells [16, 17]. These Dic +Rc values of 2.3 and 2.6 in residents near SNETS were approximately 2.9 and 4.4 times higher than background values (0.85 and 0.56 per 1,000 cells) observed in large number of non-exposed UK and Japanese persons, respectively [6,18]. A metaphase with both dicentiric chromosome and fragment (shown as Dic+F in Table 1) is considered not to have entered any cell division after exposure. The lymphocyte with such chromosome aberration is presumed to come from memory cells preserved long-term in stem cells, or to be just after exposure. The incidence of Dic+F in residents of most contaminated area, Dolon was approximately two times higher than that of control area, These cytogenetic results are indicating that residents living near SNETS have been more exposed externally or internally. Another possibility will be taken into consideration for the reason why higher incidences of unstable-type (Cu) aberrations such as dicentric and ring chromosomes (Dic+Rc), dicentric chromosomes (Dic) and dicentric chromosomes with fragment (Dic+F) was observed in residents of contaminated areas near SNETS. Cu cells harboring dicentric chromosome might be eliminated slower in chronic irradiation at low-dose-rate than previously observed in acute irradiation at high-dose-rate. Our recent experiment revealed that mice exposed to gamma-rays for 400 days at the low-dose-rate [20 mGy/22h/day(0.45 mGy/h)] had slower elimination of dicentric chromosome than expected, which was also much different from that of acute irradiation (unpublished result). Also, the reason why chronically exposed persons at low-dose-rate such as nuclear facility workers, radio-medical technologists, clean-up workers of Chernobyl accident and so on have always higher incidences of dicentric chromosome than non-exposed persons [6,18] could be explained by same reason. Higher incidence of micronuclei, which mostly developed by radiation-induced chromosome break, found in residents in SNETS would be caused from same reason [19].

Lymphocytes with MCA are called as "rogue cells"[20]. The percentages of MCA in residents of SNETS were 0.05-0.34%, which were higher than the values of Chernobyl regions [21]. It is unlikely that MCA found in residents of SNETS region caused from direct radiation-induced damage. MCA has been etiologically discussed that it would be occurred by endemic virus because it is found worldwide even in non-exposed persons at a small incidence [22].

Chromosome aberrations is sensitive indicator for biodosimetry, specifically at low dose or low-dose-rate range, but they occur spontaneously and frequencies of translocation dramatically increase with age [23, 24]. Thus, translocation will be less sensitive indicator for biodosimetry for chronic exposure than dicentric chromosome. In present study, frequencies of translocations and Cs cells (t+ inv+del) in a resident near SNETS was 2.17 % by FISH and 0.6-0.8% by conventional Giemsa method and these values were higher than residents of non-contaminated area. Frequencies of translocations in residents near SNETS have been observed by three authors using FISH method of chromosome subset with single color [25-27], but their obtained results were discrepant. A report showed a significant result that frequency of translocation in 10 residents of Dolon was 1.6 %, comparing to 0.6% of control area [25], but other two reports had no significant results between contaminated and non-contaminated areas [26, 27]. These values detected by FISH method are within the range of elder control persons [24]. Confounding factors such as smoking, medical exposure, habitation, drinking and life style must be influenced with the frequencies of translocation in the evaluation of health effects of low-dose or low-dose-rate radiation.

Dicentric chromosomes increased in linear with dose increment in mice long-term irradiated at low-dose-rates [20 mGy/22h/day(0.91 mGy/h) and 1 mGy/22h/day(0.045 mGy/h)][28], which suggesting that dicentric chromosome will be a useful biodosimetor in chronic exposed peoples. Chromosome analysis in residents of high background radiation area in China showed a similar result [29].Then, frequencies of chromosome aberrations detected in residents of Dolon (2.55×10^{-3} for dicentric and ring chromosomes; 1.74×10^{-3} for dicentric chromosomes) in present study were used for calculation of external dose using chromosome aberration rate and dose response curves of *in vitro* acute or chronic ^{137}Cs gamma ray irradiation with lymphocytes [30], where the value of 8.5×10^{-4} was used for constant (*c)* as background value [18]. We estimated external doses in residents of Dolon as 37.4 and 33.8 mGy of gamma-ray equivalent, which were less than previously estimated as around 140-440 mGy at Dolon by physical methods such as luminescence dosimetry in brick, calculations using soil contamination, frequencies of translocation and electron spin resonance (ESR) [25, 31-35]. However, our present results suggest that estimated external doses of the residents were less than the physically estimated dose range. Our present results did not support the previously estimated external exposure dose, although it is remained to be resolved that the validity of chromosome analyses using dicentric chromosome or translocation for evaluating biological dose in chronic low-dose external or internal exposure is uncertain.

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Modern Biomedical and Environmental Research in Kazakhstan: Challenges and Opportunities

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Environmental research is very important issue in Kazakhstan to be properly addressed and effectively solved. Economic growth, industrialization, and the grave consequences of nuclear weapons testing, uranium mining, pollution are causing heavy environmental and health problems. Economic growth that will benefit present and future generations and establishment of both healthy economics and a healthy environment are of great public concern in Kazakhstan. The ecological disasters that face Kazakhstan mean that environmental and health research is a very large priority for its people. Kazakhstan is poised to become one of the most important 21st century laboratories for studying and solving large scale Environmental &Health problems that face it and the rest of the world.

Previously some of our researchers conducted several joint International project related to Environmental research. For example, in partnership with the Radiation Epidemiology Branch (REB) of the U.S. National Cancer Institute (NCI) they conducted an epidemiologic study titled "Thyroid Abnormalities in Northeastern Kazakhstan" among the population living near the Semipalatinsk Nuclear Test Site (SNTS) in Kazakhstan at the time when nuclear weapons tests were detonated in the atmosphere (between 1949 and 1962). In August, 1998 they jointly with American research team conducted a field study in Kazakhstan. Additional information has been identified that is needed to refine estimates of internal and external radiation dose in the study population. This included data on residential history, records from Regional Archives related to the time of the nuclear weapons tests. Currently, the dosimetric basis for the study is being refined using new information on lifestyle factors, including diet, obtained in September 2007 from focus group interviews in the affected villages. This new information was used to correct current estimates of radiation dose from both external and internal radiation sources in fallout, all of which ultimately depend upon residential history. Results of this study have the potential to improve considerably earlier dose estimates for the cohort members. Based on the focus groups and key informants, several assumptions used in previous dose assessment were modified. In this study new information on food consumption pattern for women during pregnancy and breastfeeding; agricultural practice; evacuation of 1953 H-bomb; and preparation of milk products was collected. Previous dose assessment used data which were based on rather general assumptions regarding these important parameters. Collected data are the first detailed information obtained from the population on several key aspects of daily life in rural villages in Kazakhstan. This data was using to improved thyroid dose estimates in the epidemiological study. New information collected allowed to estimate the uncertainties related to shared and unshared errors in dosimetry model. Information obtained from the focus groups and key informants is being used to define the village-, ethnicity-, age-, and gender-specific (where appropriate) probability density distributions of important behaviour and food consumption parameters of dosimetry models used to reconstruct external and internal doses. These data, combined with physical dosimetry data related to fallout deposition, are used to stochastically generate multiple sets of individual dose estimates for the persons exposed during childhood to radioactive fallout from nuclear weapons tests conducted at the SNTS between 1949 and 1962.

Our researchers published many papers related to health issues around the Semipalatinsk Nuclear Weapons testing Site. Health issues are really complex and we have realized the necessity to develop state- of –the-art diagnostic and treatment modalities to improve the quality of health condition of the population in Kazakhstan. As global medical trends shift from a curative to a preemptive paradigm, the Life Sciences Center strives to contribute to this transformation. This will be through its research efforts in regenerative medicine, genomics, clinical trials and other areas and will be a central theme underpinning Center's research and development programs. Many of the environmental problems can benefit from the application of state-of-the-art research techniques that have recently been developed or can be developed in the course of working on these challenging problems.

As part of its modernization program, Kazakhstan has singled out institutional reforms in higher education and science as a priority to foster a new generation of world-class scientists, engineers and social workers. The government of Kazakhstan wants to diversify the economy and develop high-value added goods and services. Recently, Kazakhstan has adopted a new law on science that is expected to radically change the research environment in Kazakhstan.

The new law prioritizes the following research areas: (1) Energy; (2) Innovative technologies in processing of raw materials; (3) Information and telecommunication; (4) Life Sciences; (5) Basic research in humanities and the other fields. The new law establishes national research councils in the relevant priority areas as well as three streams of funding: (1) Basic funding to support scientific infrastructure, property and salaries; (2) Grant funding to support research programs, and (3) Program-target funding to resolve strategic challenges. In addition, the new law establishes a system for peer review of research grant applications.

Within this new framework Nazarbayev University's priority is to develop research infrastructure and to train world-class researchers. Our goal is to establish research environment that encompasses basic science, technological application, coordinated programs, and consulting and analytical services in high-priority development fields. The intention is to attract top-level scientists regardless of nationality by offering the opportunity to conduct advanced research in cutting-edge facilities. As the research university we recognize the challenges of: selecting priorities for research; funding issues; internal peer review process; infrastructure development; and building a competence.

The NU Center for Life Sciences (CLS) strives to transform medicine and healthcare in Kazakhstan through innovative scientific research, rapid translation of breakthrough discoveries, educating future clinical and scientific leaders, advocating and practicing evidence based medicine, and pursuing research in personalized and predictive medicine. The underlying goal of all these activities is to improve health and quality of life.

The main priorities of the Center are as follows:

- Scientific and innovative approaches in the development of tissue bioengineering, cell therapy, genomic medicine and artificial organs.
- Development of translational medicine, rapid and appropriate transfer of the latest discoveries from

the laboratory to the clinic.

- Development of the scientific basis of healthy aging
- Realization of personalized medicine into clinical practice
- Transform medicine and health from a Curative to a Preemptive paradigm

The CLS is the key member of Nazarbayev University Integrated Healthcare System and promotes aligned research and strong integration, this system also includes the National Medical Holding and School of Medicine (in the near future).

The CLS will establish four laboratories in which the following fields of biomedicine will be developed and implemented: Laboratory of Genomics and Personalized Medicine; Laboratory of Regenerative Medicine and Artificial Organs; Laboratory of Tissue Bioengineering, Innovative Cell Technology and Transplantation Medicine; Laboratory of Translational Research, Clinical Trials and Healthy Aging.

Mission and Vision

Mission: To develop fundamental science and discover new knowledge about the nature and behavior of living organisms, as well as application of that knowledge to improve quality of life and longevity, reducing the burden of disease in humans.

Vision:

To improve the quality of life, health and longevity through the practical implementation of modern advances in biomedical science to clinical practice, as well as the establishment of sustainable scientific and legal structures for a competitive biomedical industry, with a subsequent contribution to the diversification of the Kazakhstan economy

Main areas of research

The main research priorities of the Center are: 1) Genomics and Personalized Medicine; 2) Regenerative Medicine and Artificial Organs; 3) Tissue Bioengineering, Innovative Cell Technology and Transplantation Medicine; 4) Translational Research, Clinical Trials and Healthy Aging; and 5) Global Health

A stepwise plan of development for the Center will unfold in three phases.

Phase 1(2011-2013) – establishment of research infrastructure and development of research personnel, integration with the university hospitals and fostering of international partnerships

Phase 2 (2014-2016) – development of intellectual potential, infrastructure development, development of research projects, increasing capacity and contribution to international scientific knowledge, begin integrating CLS with School of Medicine, become actively involved with doctoral programs

Phase 3 (2017-2020) – create a basis to develop venture capital financing of research projects with commercial potential, continued international research contributions

As global medical trends shift from a curative to a preemptive paradigm, the CLS will strive to contribute to this transformation. This will be through its research efforts in regenerative medicine, genomics, clinical trials and other areas and will be a central theme underpinning CLS's research and development programs.

Development Stages

2011 – 2013 yy. Foundation of scientific innovative infrastructure and human resource potential	2014-2016 yy. Formation of intellectual potential, improvement of infrastructure and scientific environment	2017-2020 yy. Commercialization of Biomedicine and Venture Capital Financing of branch
Construction of 1st phase of the scientific research complex. Training of staff in research centers of foreign partners. Transfer of scientific technologies Determination of innovative research priorities	Design and construction of 2d phase of the scientific research building. Development of staff and researchers. Achieve international patents and scientific publications in high-rated journals. Active participation in international programs. Foundation of scientific research institutes	Completion of construction of second scientific research complex. Commercialization of scientific developments, formation and venture capital financing of biomedical branch

Priorities

Scientific priority	Scientific directions	Strategic goal	Strategic objectives
Human health	- Personalized medicine and genomics - Regenerative medicine, bioengineering and artificial organs - Translational medicine and healthy aging - Tissue bioengineering, transplantation medicine and innovative cell technology	Increase of life expectancy of the Kazakhstani population and reduction of the disease burden through scientific innovation and development in the field of healthy aging, reducing infant mortality and morbidity	- Early detection of disease based on genetic and molecular tests Pharmacological and molecular approaches to disease prevention Research cellular and genetic mechanisms for the effective treatment of diseases Healthy aging, healthy diet and behaviour

Laboratories

- Genomics and Personalized Medicine
- Regenerative Medicine and Artificial Organs

- Tissue Bioengineering, Innovative Cell Technology and Transplantation Medicine
- Translational Medicine, Clinical Research and Healthy Aging
- Global Health

2 GENOMICS AND PERSONALIZED MEDICINE

The Center for Life Sciences believes in transforming medicine from a curative to a preemptive paradigm and would like to contribute to leveraging knowledge of an individual's genetic makeup to create a more personalized approach to healthcare.

Genomic medicine uses genotyping to improve the quality of life. It includes identification of an individual's predisposition to acquiring disease. In a broader sense, personalized medicine represents an integrated medicine which includes the development of personalized means of treatment based on genomics, testing to predisposition to illnesses. Personalized medicine has the potential to eliminate unnecessary treatments, reduce the incidence of adverse reactions to drugs, increase the efficacy of treatments and ultimately, improve health outcomes.

At the Center for Life Sciences researchers plan to study the impact of genetic polymorphisms on heart failure prognosis among patients of Kazakh ethnicity. We are also interested in the role of genetic polymorphisms in multi-drug resistant tuberculosis and the other diseases prevalent in Kazakhstan.

We plan performing whole-genome sequencing to determine risk of developing certain conditions. The results will be compared to databases of disease-related gene variants to identify genes and mutations with known links to disease.

3 REGENERATIVE MEDICINE AND ARTIFICIAL ORGANS

Center for Life Sciences sets the following priorities in the field of regenerative medicine :

- Contribution to international scientific development and the role of regenerative medicine in furthering human well-being
- Training scientific, technical and administration staff with specific skills in biomedical research and regenerative medicine
- Creating a regenerative medicine translational research laboratory
- Fostering collaborations with elite universities and companies worldwide
- Incubating new companies and new technologies

The Center for Life Sciences plans the following joint research projects with University of Pittsburgh McGowan Institute of Regenerative Medicine:

- Adipose Stem Cell/Bioreactor Technology
- Pediatric Cardiopulmonary Mechanical Support and Tissue Engineering
- Development of a Cancer Stem Cell Program
- Development of Advanced Technology for Donor Organ Perfusion Utilizing Blood Soluble Drag-Reducing Polymers
- Advanced technology in blood transfusion
- Biopolymers and stem cells in tissue regeneration

4 TRANSLATIONAL MEDICINE, CLINICAL RESEARCH AND HEALTHY AGING

Center for Life Sciences provides infrastructure support to sponsors and investigators who are testing new drug candidates and other cutting-edge therapies and seeking to identify and validate novel biomarkers.

Early-phase, proof-of-concept clinical trials

- Test new drug candidates and other cutting-edge therapies
- Identify and validate new biomarkers

A dedicated clinical unit located at the National Medical Holding

In addition to providing a full range of clinical research services, Center for Life Sciences is dedicated to:

- Providing scientific leadership in the conduct of clinical research
- Disseminating new knowledge throughout the medical community in Kazakhstan and the former Soviet Union
- Advancing clinical research methodology
- Educating future generations of clinical researchers

The goal of the Center's longevity research program is to address critical issues regarding the general biology of aging, age-associated diseases and disabilities and development of gerontotechnology and gerontoengineering

The specific areas of research interest in biology of aging are as follows:

1. Epidemiological studies in Kazakhstan
2. Identify and validate new biomarkers of processes of aging and healthy aging
3. Research on geroprotectors, gerontotechnology and gerontoengineering
4. Study of desease features, early diagnosis and effective treatment of cardiovascular and cancer diseases, diabetes, Parkinson's disease, Alzheimer's, etc.
5. Study and development of technologies of healthy aging
6. Identification of genetic polymorphisms of aging
7. Study of DNA damage and repair mechanisms
8. Identification of genetic polymorphisms related to different states of pathological aging

5 GLOBAL HEALTH

Center for Life Sciences is working on initiatives of the further development of global health. The Centre has established a partnership with Columbia University, to study the social, biological and genetic aspects of tuberculosis and drug-resistant forms of tuberculosis in different regions of Kazakhstan.

References

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3. Zhumadilov, Zh., Land, C., Hoshi, M., Kimura, A., Kamiya, K. 2000. Fallout exposure in the Semipalatinsk Nuclear Test Site area and the Induction of thyroid Nodules diseases. Radiation and Homeostasis. Proceedings of the International Symposium. Elsevier.
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5. Zhumadilov, Zh., Hoshi, M., Kimura, A., Gusev, B., Takeichi, N., Zhigitaev, T., Asahara, T., Kamiya, K. Thyroid cancer in the Semipalatinsk Region of Kazakhstan. J.Hiroshima Med. Ass., 55(3), 196-197, 2002.
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17th Hiroshima International Symposium

Lessons from unhappy events in the history of nuclear power development

January 25th – 26th, 2012

Kojin-Kaikan, Kasumi campus of Hiroshima University

January 25th, Wednesday

9:00- Greeting from Ohtaki M.

Chair: Ohtaki M. & Cullings H.

1 9:10- Heat, water and black carbon flux in Hiroshima in Aug. 1945, a result of HiSoF (Hiroshima Study Group on Re-construction of Local Fallout)
Aoyama M

2 9:30- Initial process of the nuclear explosion and mushroom cloud formation by the Hiroshima atomic bomb
Imanaka T

3 9:50- Activation analysis for soils of Hiroshima city and estimation of gamma-ray dose rate due to neutron induced activated soil by Hiroshima atom bomb
Endo S, Taguchi Y, Imanaka T, Fukutani S, Granovskaya E, Hoshi M, Shizuma K

4 10:10- Preliminary results on in soil core samples collected from the under-floors of houses built within 1-4 years after the Hiroshima Atomic Bomb
Sakaguchi A, Chiga H, Steier P, Shizuma K, Hoshi M, Takahashi Y, Yamamoto M

<Coffee break>

Chair: Endo S. & Stepanenko V.

5 10:50- What is the origin of ^{137}Cs detected in soil samples under houses built 1-3 years after the Hiroshima atomic bomb ?
Yamamoto M, Sakaguchi A, Hoshi M, Imanaka T, Miyamoto Y

6 11:10- Reported Occurrence of Severe Epilation vs. Location among the Life Span Study Cohort of Atomic Bomb Survivors
Cullings H

7 11:30- Investigation on circular asymmetry of geographical distribution of mortality risk in Hiroshima atomic bomb survivors
Tonda T, Satoh K, Otani K, Sato Y, Maruyama H, Kawakami H, Tashiro S, Hoshi M, Ohtaki M

8 11:50- An assessment of low-dose health effects of A-bomb radiation by neural networks theorem
Sasaki MS

<Lunch>

Chair: Imanaka T. & Zhumadilov Z.

9 13:30- External and internal radiation doses among residents living around 37 km north-west from the Fukushima Daiichi nuclear power plant
Kamada N, Saito O, Endo S, Kimura A, Shizuma K

10 13:50- Radioacitivity of the aerosol collected in Nagasaki City due to the Fukushima Daiichi Nuclear Power Plant Accident
Takatsuji T, Yuan J, Zeng Z

11 14:10- Time trend of air dose rate of radiation in eastern Japan from the Fukushima Daiichi Nuclear Power Plants accident
Otani K, Ohtaki M, Tonda T, Satoh K

12 14:30- The experience of individual dose reconstruction after uncontrolled large-scale irradiation of population
Stepanenko V, Ivannikov A, Skvortsov V, Tsyb A, Zhumadilov K, Hoshi M

<Coffee break>

Chair: Hoshi M. & Shinkarev S.

13 15:10- Modern Biomedical and Environmental Research in Kazakhstan: Challenges and Opportunities
Zhumadilov Z

14 15:30- Neuroendocrine Breast Cancer in the Semipalatinsk Region of Kazakhstan
Orynbayeva N, Baymurinova S, Bolsinbekova

15 15:50- Radiation exposure caused by Nuclear Power Plant Accident and thyroid cancer
Takeichi N, Hoshi M

16 16:10- Accelerator-based boron neutron capture therapy for many types of cancers
Imahori Y, Zhumadilov Z, Itami J, Kayama T, Hoshi M

<Coffee break>

Chair: Shizuma K.

17 16:50- 17:40 Our radiation dosimetry study in Hiroshima
Hoshi M

<18:30- Banquet at Ark Hotel Hiroshima>

January 26th, Thursday

Chair: Sakaguchi A. & Whitehead N.

18 9:00- Study into epilation among residents and "black rain" fallout in the Manose district of Nagasaki City following dropping of the atomic bomb
Honda K

19 9:20- Nuclide identification of alpha-emitters by autoradiography in specimen of atomic victims at Nagasaki
Shichijo K, Takatsuji T, Yamamoto M

20 9:40- A 24-year follow-up of malignancies in Sweden after the Chernobyl nuclear power accident in 1986
Tondel M, Wålinder R, Lampa E

21 10:00- Radiation doses to Swedish nuclear workers and cancer incidence in a nuclear power plant
Wålinder R

<Coffee break>

Chair: Yamamoto M. & Ivannikov A.

22 10:40- Radiation Doses and Cancer Risks to Marshallese Associated with Exposure to Local and Regional Radioactive Fallout from Bikini and Enewetak Nuclear Weapons Tests
Simon SL, Bouville A, Melo D, Beck HL, Moroz B, Weinstock RM

23 11:00- Epidemiology of Infant Leukemia and Reconstruction of Individualized Cumulative Doses of Ionising Radiation Exposure in Cases Registered within the Early Period after Chernobyl Accident
Savva NN, Skrjabin AM, Belsky YuA, Mataras AN

24 11:20- Prediction of long-term radiation effects lens
Yeltokova M, Zharlyganova D, Bahtin M, Kazymbet P, Hoshi M

25 11:40- Prevalence and risk of chronic diseases of internal organs among workers in uranium processing industry in Kazakhstan
Kazymbet P, Bekenova F, Zhakenova A, Altaeva N, Bahtin M., Primatov Y

<Lunch>

Chair: Toyoda S. & Kazymbeț P.

26 13:20- How it may be possible to diminish the psychosomatic effects of exposure to man-made substances such as fallout
Whitehead NE, Hoshi M

27 13:40- Reconstruction of individual doses to the Semipalatinsk historical cohort subjects: methods and input parameters
Shinkarev SM, Granovskaya EO, Katayama H, Apsalikov KN, Hoshi M

28 14:00- Reconstruction of individual doses to the Semipalatinsk historical cohort subjects: preliminary

results
Granovskaya EO, Shinkarev SM, Katayama H, Apsalikov KN, Hoshi M

29 14:20- Data of ESR dosimetry study of population in the vicinity of Semipalatinsk Nuclear Test Site
Zhumadilov K, Ivannikov A, Stepanenko V, Zharlyganova D, Zhumadilov Zh, Apsalikov K, Toyoda S, Zhumadilova A, Endo S, Tanaka K, Miyazawa C, Yamamoto M, Okamoto T, Hoshi M

<Coffee break>

Chair: Kawano N. & Simon S.

30 15:00- ^{90}Sr in teeth of mammals in Semipalatinsk Test Site observed by imaging plates
Toyoda S, Pivovarov S, Hoshi M

31 15:20- Results and perspectives of using the EPR dosimetry at radiation accidents
Ivannikov A, Skvortsov V, Stepanenko V, Zhumadilov K, Hoshi M

32 15:40- The Kainar Syndrome: History and Modern Understanding
Rozenson RI, Apsalikov KN

33 16:00- Scientific foundations of screening organization of the state of health of Kazakhstanean population subjected to radiation, analyses of the results, development prenozological preventive measures and rehabilitation
Muldagaliev T, Hoshi M, Apsalikov K, Kawano N, Belihina T

34 16:20- Overall Image of Nuclear Tests among Inhabitants in the Semipalatinsk Area
Hirabayashi K, Satoh K, Muldagaliev T, Apsalikov K, Kawano N

<Coffee break>

Chair: Imanaka T. & Shinkarev S.

17:00- General Discussion

18:00- Ending remark from Hoshi M

18:10 **End of symposium**