RADIOLOGICAL INVESTIGATIONS IN RONGELAP ISLAND 1999

THE FIRST REPORT

Prepared for
The People of Rongelap
As a Humanitarian Support

October 2000

Jun Takada, PhD
International Radiation Information Center
Research Institute for Radiation Biology and Medicine
Hiroshima University

Jun Takada, PhD
International Radiation Information Center
Research Institute for Radiation Biology and Medicine
Hiroshima University

Kasumi 1-2-3, Minami-ku, Hiroshima 734-8553, Japan

E-mail; jtakada@ipc.hiroshima-u.ac.jp

RADIOLOGICAL INVESTIGATIONS IN RONGELAP ISLAND 1999

THE FIRST REPORT

Prepared for

The People of Rongelap

As a Humanitarian Support

Issuance Date: October 2000

This repot may be quoted as:
J. Takada. Radiological Investigations in Rongelap Island 1999: The First Report, Prepared for The People of Rongelap as a Humanitarian Support, October 2000. International Radiation Information Center, Research Institute for Radiation Biology and Medicine, Hiroshima University

Collaboration

Mrs. Taniko Shimizu, Mr. Yukishige Watanabe and Mr. Kosei Shimada
Bumbum Project
for field mission

Dr. Masayoshi Yamamoto
Low Level Radioactivity Laboratory, Kanazawa University
for plutonium analysis

Acknowledgments

The author would like to express his gratitude to Clues of Limanman from Mejatto, and Mr. Noel Bigler of Pacific International Inc. for their assistance and guide in Marshall Islands. He also would like to thank Mr. Nelson, John and George Anjains for providing useful information on Rongelap Island.

The Ministry of Education, Science, Sports, and Culture, Japan
for grants-in-aid for Scientific Research (10558088)

Letter to the People of Rongelap

October 1 2000

Jun Takada PhD, Associate Professor
International Radiation Information Center
Research Institute for Radiation Biology and Medicine
Hiroshima University

Dear my friends in Mejatto and Ebeye Islands

Stays in Rongelap and Mejatto on July 1999 were unforgettable memory in my life. The beautiful inner sea, powerful Pacific Ocean, clear stars in the night sky, tropical fruits, coconuts-crab, turtle and beautiful songs from ladies in Mejatto. Thank you very much for your kindness and collaboration in Rongelap Island. I had a chance to visit this historical place to do radiological investigations from Hiroshima. The year of my birth 1954 was the tragic year for clues of the fifth Fukuryu-maru and the people of Rongelap Island. When I was child, I heard the wards: "houshanou" (radioactivity in Japanese) and Bikini but did not understand the meaning. Twenty years later, I studied the meaning of the words in Science School of Hiroshima University. Now I am a specialist for the radiation dosimetry.

I have done dosimetry studies in over the world such as Semipalatinsk (Kazakhstan the former Soviet Union Nuclear Tests), Sakha Republic (Under ground nuclear explosions for industrial use), contaminated territories due to the Chernobyl accident, Chelyabinsk Russia (Pollution from Plutonium production facility) and Hiroshima (USA atomic bomb) with not only scientific but also humanitarian purposes. The people suffered from radiological hazard want eagerly to know the real facts for radiation dose for themselves since they know a terrible story of atomic bombs in Hiroshima and Nagasaki 1945. 140 and 70 thousand people were died by atomic bombs. Moreover late effects on health such as leukemia and cancers began to appear from 1946. However people should know good news on recovery of both cities. The present environment is very clean on radioactivity. Population in Hiroshima is more than a million. The past was very sad, but the future will be normal or good. They have a chance to get some bright future.

It is great pleasure for me to provide this scientific report to the people of Rongelap. The results will be good news for you. The scientific detail, which is described in this report, may be difficult to understand. In the future I will visit your island and explain it. However I tell you here that radiation due to the radioactive fallout from USA nuclear explosion on March 1 1954 becomes very weak now at least in the main island of Rongelap Atoll. However radiation in Kaballe Island was still high. Although we have not been to other northern islands in Rongelap Atoll, you should be careful to take foods in these islands. The future radiological investigation will be needed to confirm this. I understand that you reevacuated from Rongelap Island in May 1985 by your own will as a result of fear of the radioactive contamination described in the 1982 DOE report of the northern Marshall Islands radiological survey. Surprisingly radiation in the main island of Rongelap Atoll 2000 is five times less than that in 1985. The present values of radiation in the main island is close to the values in Tokyo. Therefore if Rongelap Island is my home island, I will return there right now with my family. I hope that you will get a good future.

Best wishes

Jun Takada

高田純

List of Photo

List of Table

List of Figure

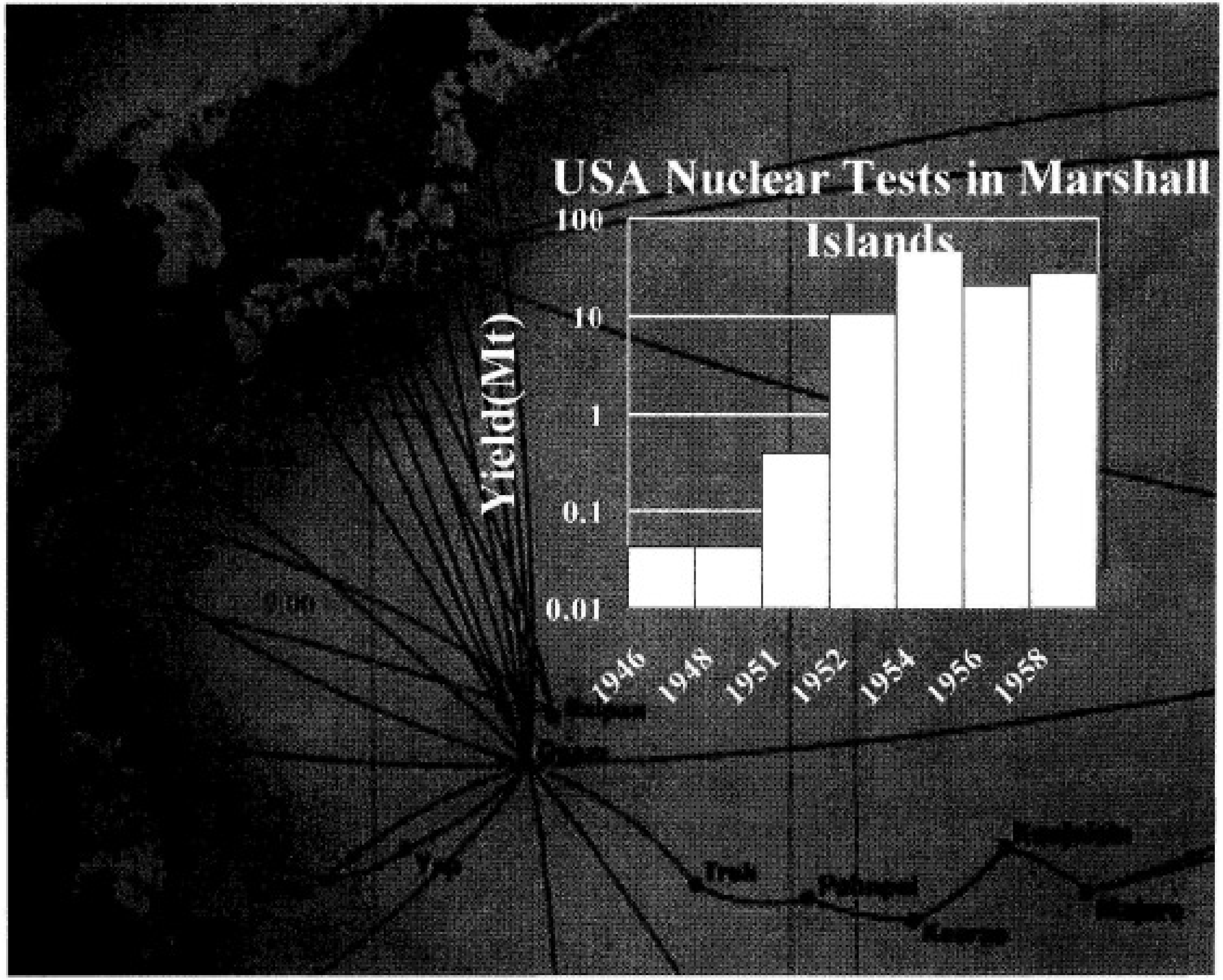
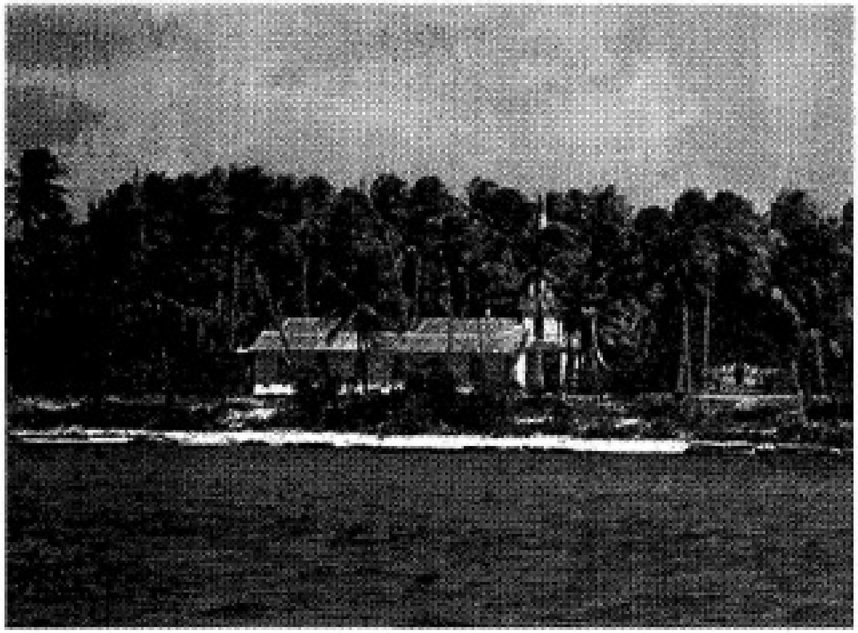
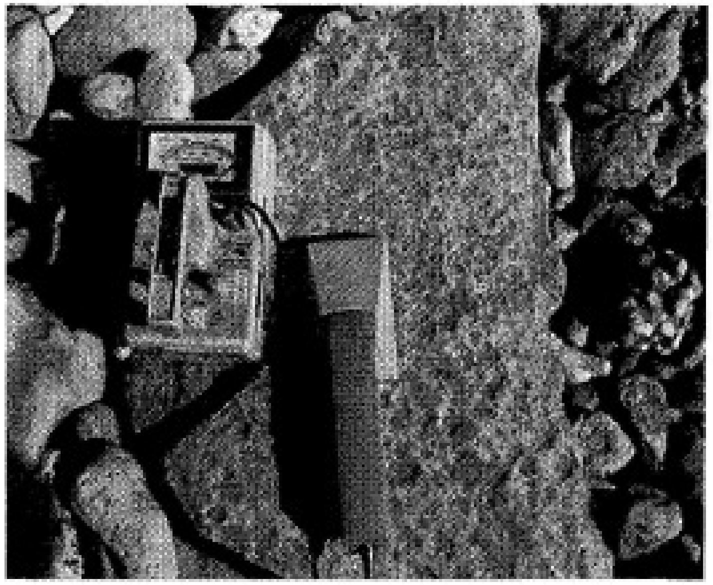


Fig.1 USA Nuclear Tests in Marshall Islands.





Beta counting

Photo 1. Rongelap Island 1999.

Cs-137 whole-body counting

Cs-137 measurement on the beach

Photo 2.

Coconuts crab

Photo 3. Kaballe Island 1999.

K. Shimada

Photo 4. Rongelap Island 1988.

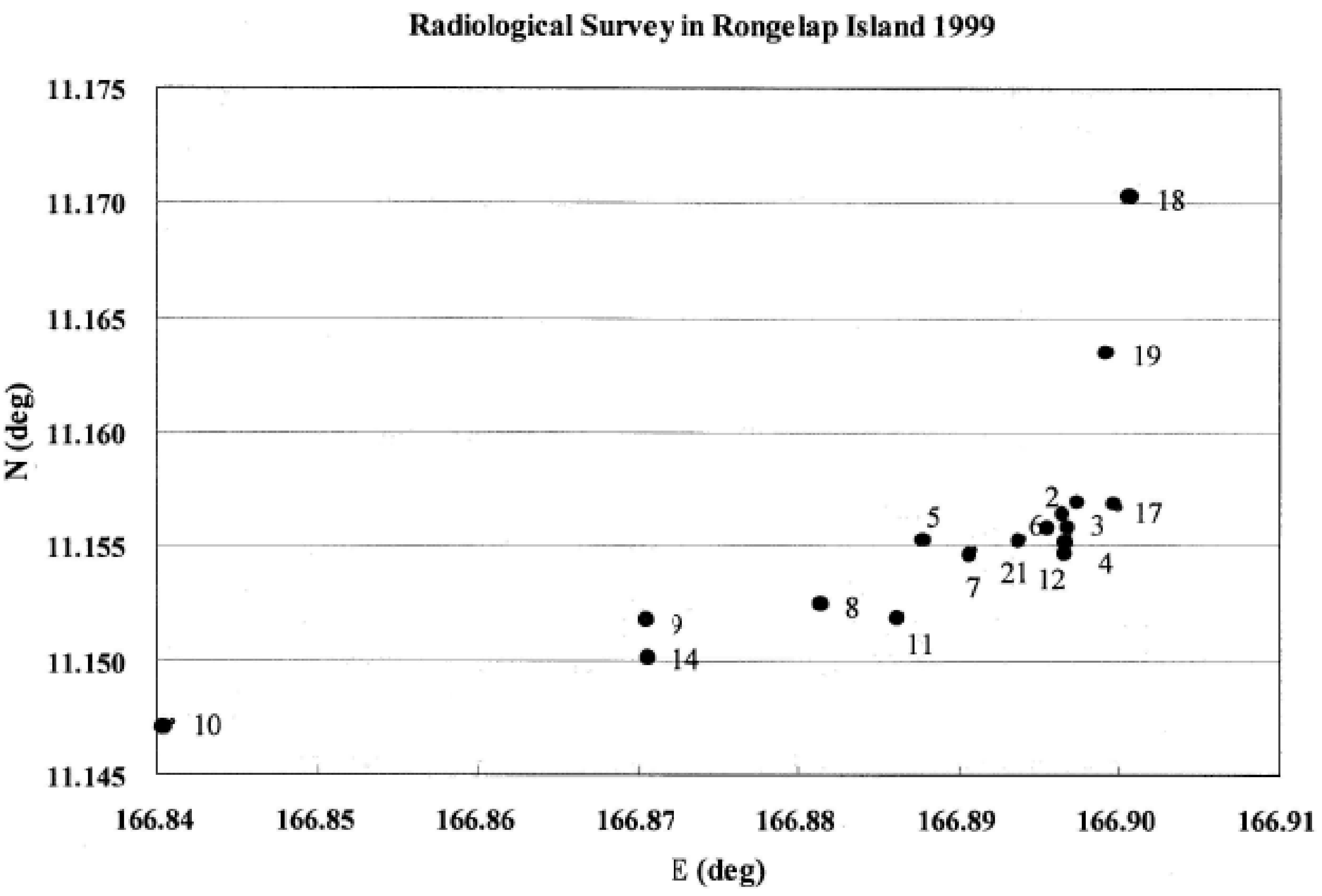


Fig. 2. Measurement Site Map.

TABLE OF CONTENS

ABSTRUCT OF RADIOLOGICAL INVESTIGATION IN 1999

A radiological survey and whole body counting of Cs-137 were carried out in Rongelap Island (main island) of Rongelap Atoll July 1999. The maximum values of Cs-137 contamination and of γ-ray dose rate were 39 kBq/m^2 and 0.033 μSv/h respectively. The maximum α and β gross counting rates on the surface of ground were 1 cpm and 182 cpm respectively. Depth profile of beta ray showed normal sate in a hole with 150cm depth at the center of Rongelap Island. Moreover no Cs-137 was detected in the hole. Activity of Pu-239, 240 for soil was 93 Bq/kg as the top 5cm and 3.9 kBq/m^2 in Rongelap Island 1999. The body burden of Cs-137 was observed to be 2.0 $\pm$ 0.7 kBq for 6 of 15 workers.

Evaluation of external and internal effective annual doses (0.1 and 0.07 mSv/y) indicates there is no large risk on Rongelap Island as of 1999 for radiological point of view. The radiological states in Rongelap Island where severely contaminated by radiological fallout in 1954, have been recovered year by year as shown in Cs-137 decrease on the ground. The effective halftime of Cs-137 decrease on the ground, which is estimated to be 6.6 y is much shorter than physical half-life of Cs-137.

We investigated Kaballe Island where was located in northeast 25 km far Rongelap Island. Radioactive contamination on the island was still high in 1999. One site nearby beach was highly contaminated as Cs-137 of 3.4 MBq/m^2, α-ray of 2 cpm, β-ray of 1205 cpm and γ-ray of 0.73 μSv/h as the maximum. Activity of Pu-239, 240 in soil (n=1) was 341 Bq/kg (top 5 cm) and 12.9 kBq/m^2. The radiological information in the whole atoll will be needed for people of Rongelap after their return to the home island. Continuos supply of imported food for people of Rongelap will play an important role to reduce internal exposure in the near future since the northern islands are their farms.

INTRODUCTION

Resettlement Program of Rongelap Island in Rongelap Atoll of Marshall Islands has been started since July 1998.[1)] Radiological investigation and it's information will be urgently important for people of Rongelap. The Rongelap Atoll was severely contaminated by radiological fallout due to the USA nuclear test of 15Mt March 1 1954. The 64 persons who were evacuated by plane and boat from the island March 3, got 1.9 Gy for whole body[2)]. The Atomic Energy Committee of USA approved the return of the people of Rongelap to their atoll in February 1957. Two hundred and fifty people were returned to Rongelap Island on 29 June of the year. However in May 1985 they were reevacuated by their own will as a result of their fear of the radioactive contamination of Rongelap described in the 1982 DOE report of the northern Marshall Islands radiological survey [3)]. Under the circumstance Rongelap island in the atoll were investigated July 6-12 1999 with assistance of the Bumbum project [4)]. Radiation surveys and in-situ spectroscopy were carried out. Portable whole-body counting (WBC) of Cs-137 was also carried out for workers in Rongelap Island who may take radioactivities by food-chain or by inhalation. The present investigation find that large risk dose not exist in Rongelap Island from the radiation protection point of view 1999 and radioactivity on the coral island has been rapidly decreasing in the Pacific Ocean .

MATERIALS AND METHODS OF INVESTIGATION

The gamma ray dose rate was measured in the present study by using a pocket survey meter (Aloka PDR-101) in which a CsI (Tl) (20x25x15mm) detector is installed. The range is 0.001 ~ 19.99 μSv/h. With this meter, the environmental dose rate was measured with an error of 15%. Beta and alpha countings were done by using ZnS (Ag) plastic sintilator (Aloka TCS-352, active area of 72 cm^2). The in-situ measurement of gamma ray spectra was carried out to detect of Cs-137 for the ground surface and for whole body counting on workers by using a portable NaI spectrometer (Hamamatsu C-3475) which has an NaI scintillator (2.5cmϕ x 5.1cm) and a multi-channel analyzer with 128 channels. This spectrometer has been calibrated for both purposes[5]. The surface density of Cs-137 activity on the ground was calculated with a converting constant from the counting rate to surface density of Cs-137, which was calibrated to contaminated territory near Chernobyl. The Cs-137 bias of the portable WBC was less than 10 % as results of intercomparison in Russia and Japan.

Core soil was sampled for Plutonium analysis by using a stainless steel pipe with inner diameter of 47 mm to a depth of about 300 mm. Determination of Plutonium isotopes was conducted by using radiochemical separation. Activity of Pu-239, 240 was measured by α-ray spectroscopy. The detail procedure has been already described[6].

Table 1. List of Measurements

On the ground

Physical Quantity		Equipment
Position	GPS	Magellan GPS3000
Distance	m	Lytespeed 400
Radiological Survey	μSv/h	Aloka PDR-101 Hamamatsu C-3475
Dose	μSv	Aloka PDM-101
α・β Survey	cps	Aloka TCS-352
α		Nagase Pit film
Cs-137	Bq/m^2	Hamamatsu C-3475
Depth Profile		Hamamatsu C-3475 Aloka TCS-352 Nagase Pit film
Pu-239/240		Soil Sampling, α-ray spectroscopy

Foodstuff

Physical Quantity		Equipment
Weight	g	Yamato Portable mini
Cs-137	Bq/ g	Hamamatsu C-3475
α・β	cpm	Aloka TCS-352 Nagase Pit film
Pu-239/240		Nagase Pit film

Human

Cs-137	Bq/k g	Portable Whole-body Counter Hamamatsu C-3475

Others

Physical Quantity	Equipment
Picture	Sony DCR-PC10
Voice	Sony M-527
Computing	Sony Vaio PCG-808

RADIOLOGICAL STATES AND DOSE ASSESSMENT IN 1999

Radiological abnormal value was not recognized at all 17 sites including beach where we investigated in Rongelap Island. The residual radioactivity in the island was quite low in 1999. Indeed the maximum Cs-137 contamination was 39 kBq/m^2. This values which is ten times higher than values in Japan due to the global fallout of world wide nuclear tests is much lower than values in highly contaminated territory due to the Chernobyl accident[5, 7]. The value in Zaboric village where is the most contaminated territory in Russia due to the Chernobyl accident, was to be 6.3 MBq/m^2 at the maximum in 1997[5].

The maximum value (0.033 μSv/h) of γ-ray dose rate in Rongelap Island was lower than values (~ 0.1 μSv/h) in radiologicaly clean area of Japan and resident area near Semipalatinsk nuclear test site [7]. The mean annual external dose for whole-body due to Cs-137 was estimated to be 0.096 mSv/y where natural background dose rate was assumed to be 0.012 μSv/h as shown in Fig. 3.

The maximum α and β counting rates on the surface of ground were 1 cpm and 182 cpm respectively. These were not higher than Hiroshima bay area.

We found relatively low radiation and activity in the clean up area where the surface soil up to 30 cm depth was removed in the central island. According to the Resettlement Program of Rongelap Island in Rongelap atoll, the surface soil will be removed for each residence [1]. Radiological states in Rongelap Island in 1999 are summarized in Table 2.

Although the foods for workers were imported, some of them often eat local foods such pig, chicken, and fish and tropical fruits in Rongelap Island. Moreover they get radionuclides through inhalation during constructions of road, airport and clean up of the ground. The whole-body counting of Cs-137 for them indicated mean value of 27 ± 11 Bq/kg (2.0 ± 0.7 kBq) for 6 of 15 workers in Rongelap Island. This value is three orders of magnitudes less than annual limit of intake of Cs-137 according to ICRP Publication 30 on occupational exposure [8]. Internal dose rate can be estimated by the following equation [9]:

Internal effective dose rate (mS/y) = 2.55 X 1.4E-2 (mSv/kBq) X Body content (kBq)

Annual internal dose is estimated to be value of 0.071 $\pm$ 0.025 mSv/y for workers in Rongelap Island in 1999. This value is less than 0.26 $\pm$ 0.08 mSv/y which is calculated from data of whole body measurements for Rongelap people between 1977 and 1984 by the Brookhaven National Laboratory[10]. Therefore the internal dose seems to be decreasing with decrease in environmental radioactivity.

Activity of Pu-239, 240 at two sites in Rongelap Island was measured to be 3.6 and 4.2 kBq/m^2. The activity more than 90% was kept between 0 and 10 cm in depth of the ground surface.

Table 2. Data of radiological survey in Rongelap Island 1999

Site[a]	GPS Cordinates (deg) E	N	Cs-137 (kBq/m^2)	γ (μSv/h)	β (cmp)	α (cmp)
99RLI01	166.897	11.157	7.8	0.017	143	0
99RLI02	166.897	11.157	5.2	0.015	109	0
99RLI03	166.897	11.156	1.3	0.012	88	0
		Max.	7.8	0.017	143	0
		Av.	6.5	0.015	126	0
		Min.	1.3	0.012	88	0
99RLI04	166.897	11.156	22.2	0.024	111	0
99RLI05	166.888	11.155	30.1	0.025	120	0
99RLI06	166.897	11.155	21.3	0.028	127	1
99RLI07	166.891	11.155	32.2	0.030	182	1
99RLI08	166.882	11.153	32.8	0.027	134	1
99RLI09	166.871	11.152	39.3	0.033	128	1
99RLI10	166.841	11.147	2.08	0.010	83	0
99RLI11	166.887	11.152	nm[b]	nm	90	1
99RLI12	166.896	11.156	nm	nm	72	nm
99RLI14	166.871	11.150	nm	nm	85	nm
99RLI17	166.900	11.157	nm	nm	69	nm
99RLI18	166.901	11.170	nm	nm	88	nm
99RLI19	166.900	11.164	29.6	0.031	114	0
99RLI21	166.894	11.155	21.8	0.024	133	nm
		Max.	39.3	0.033	182	1
		Av.	25.7	0.026	110	0.56
		Min.	2.1	0.010	69	0

[a] Sites 99RLI01-3 were in clean up area.

[b] nm = not measured.

Cs-137: one measurement at one site

γ, β: average value of data taken at the each corner of triangle with side 5m long.

α: maximum value of data taken at the each corner of triangle with side 5m long.

α and β: active area is 72 cm^2 for the counting

Table 3. Data of radiological survey in Kaballe and Bokoen Islands in 1999

	GPS Cordinates (deg)		Cs-137	γ	β	α
Site	E	N	(kBq/m^2)	(μSv/h)	(cmp)	(cmp)
99KAB01	167.0127	11.362	3400	0.727	1205	2
99KAB02	167.0123	11.363	96.5	0.064	247	1
99KAB03	167.0115	11.364	120	0.074	211	2
99BOK01	167.0125	11.366	3.2	0.007	255	0

Cs-137: one measurement at one site

γ, β: average value of data taken at the each corner of triangle with side 5m long.

α: maximum value of data taken at the each corner of triangle with side 5m long.

α and β: active area is 72 cm^2 for the counting

Table 4. Concentration of Pu-239, 240 in soil samples

Sample No.	Depth (cm)	^{239,240}Pu concentration (Bq/kg)		(Bq/m^2)
RLC21-0	0-5	82.82 ±	3.47	2192.1
RLC21-5	5-10	30.84 ±	0.97	1201.8
RLC21-10	10-15	5.06 ±	0.27	166.2
RLC21-15	15-20	0.67 ±	0.05	18.7
RLC21-20	20-27	0.19 ±	0.02	11.5
	Total			3590.3
RLC4-0	0-5	102.10 ±	2.54	2660.2
RLC4-5	5-10	42.29 ±	1.47	1212.8
RLC4-10	10-15	4.27 ±	0.25	128.6
RLC4-15	15-20	2.46 ±	0.13	114.9
RLC4-20	20-30	1.79 ±	0.11	118.9
	Total			4235.5
KBC3-0	0-5	340.59 ±	18.98	12890.5
KBC3-5	5-10	133.31 ±	7.97	4617.3
KBC3-10	10-15	18.04 ±	0.64	809.7
KBC3-15	15-22	10.13 ±	0.41	810.9
	Total			19128.4

From Dr. M. Yamamoto

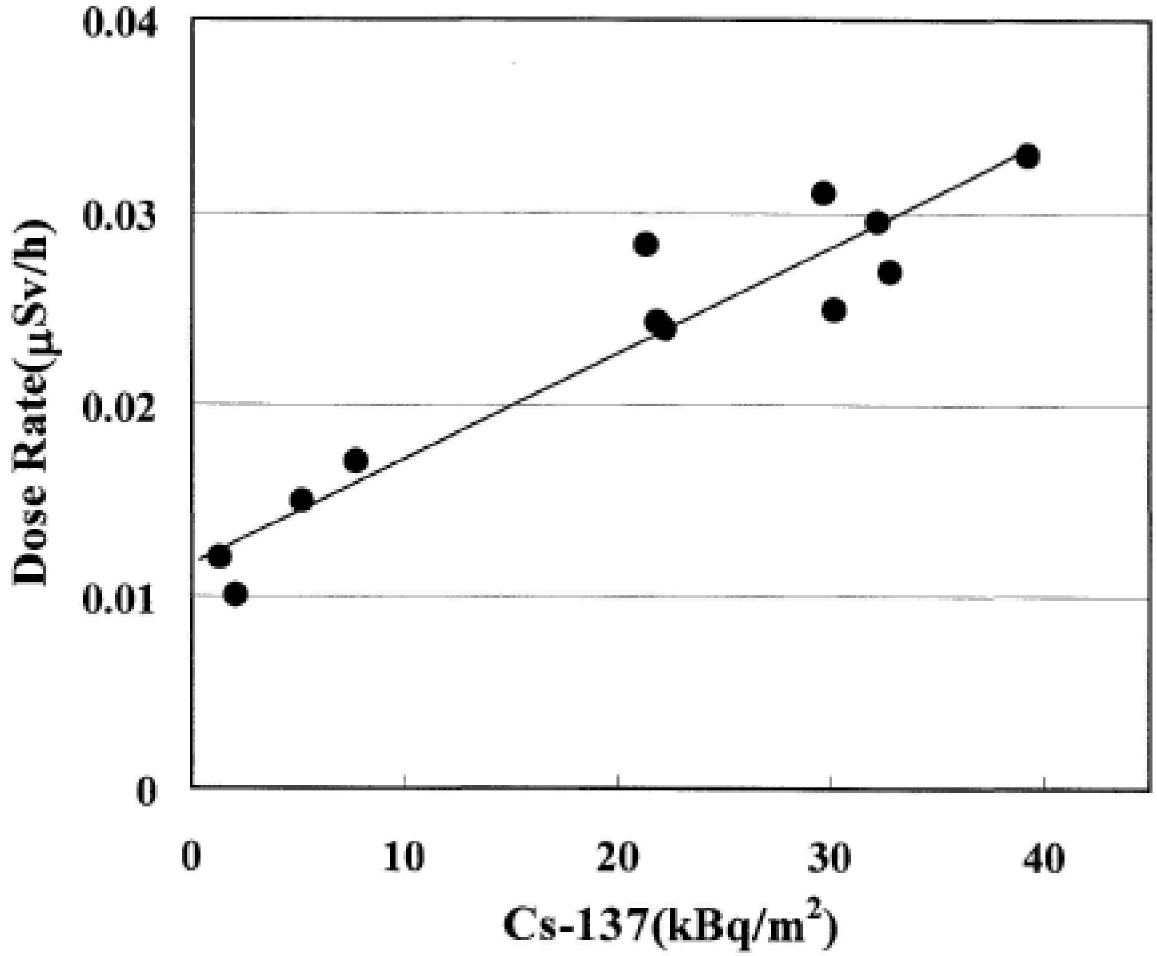


Fig. 3 Gamma dose rates and Cs-137 contamination at several sites on Rongelap Island 1999.

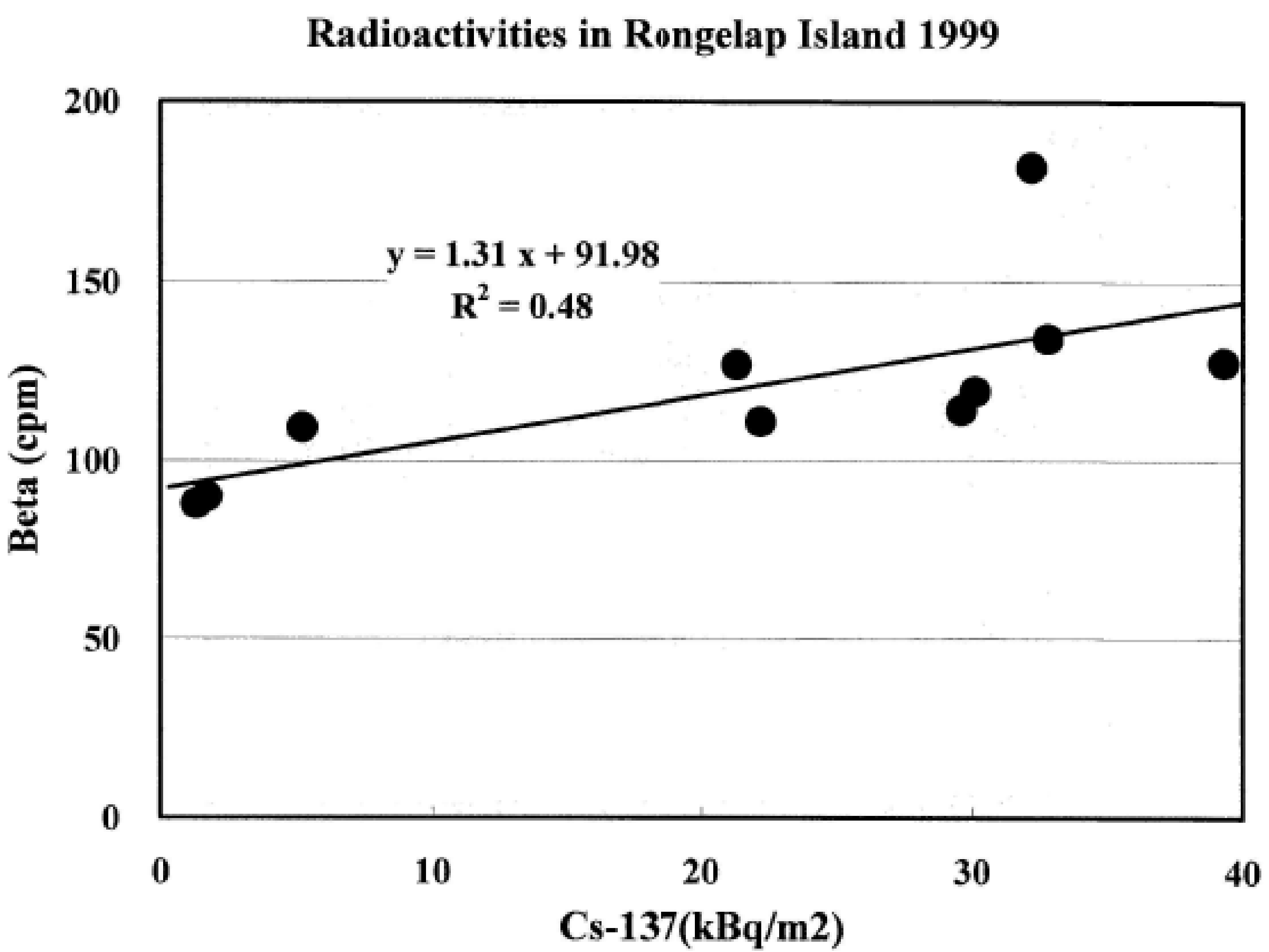


Fig. 4. Beta counts and Cs-137 contamination at several sites on Rongelap Island 1999.

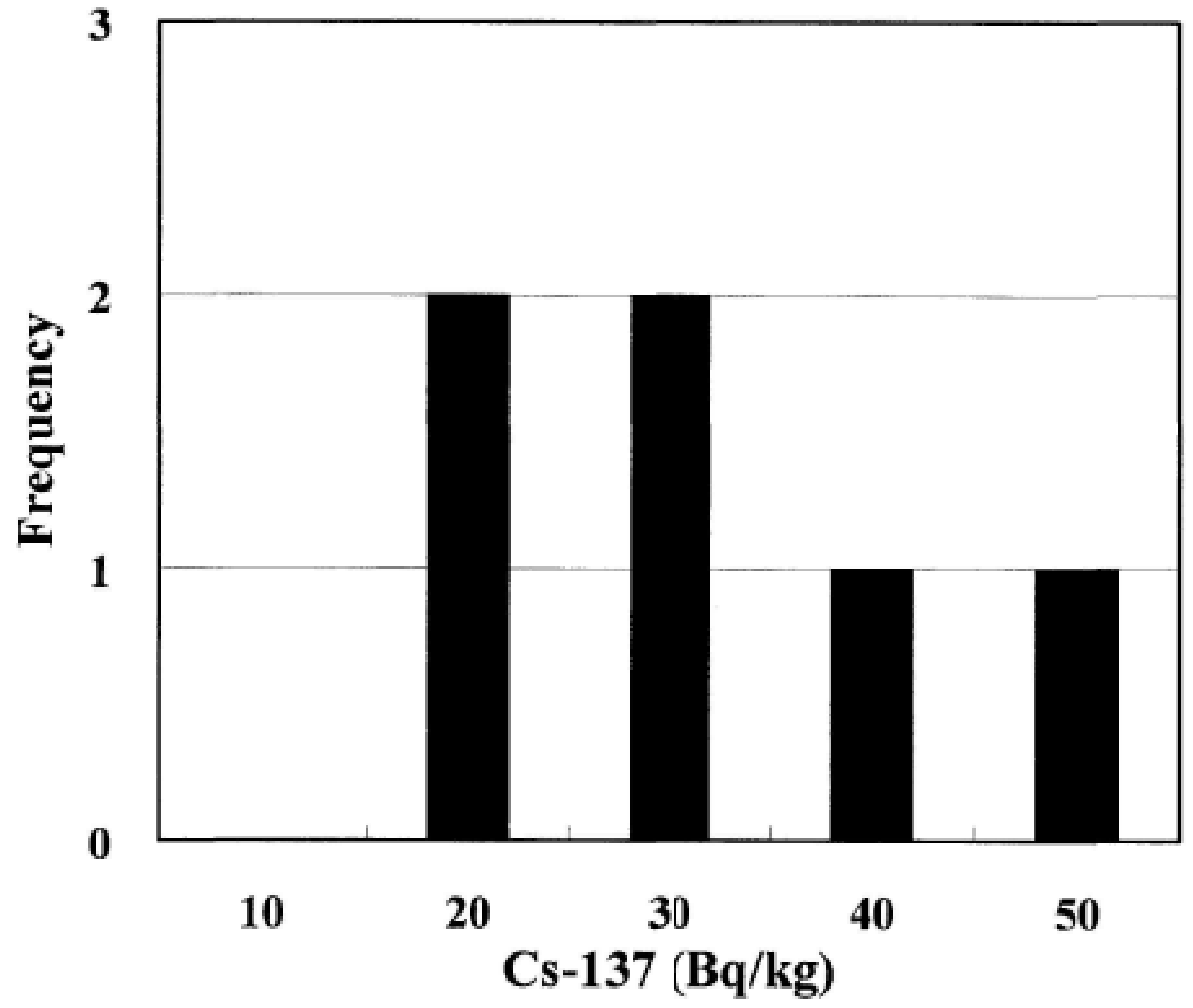


Fig. 5. Whole body counting for workers.

CHANGE OF RADIOACTIVITY AND NORTHERN ISLANDS

The radiological states in Rongelap Island where severely contaminated by radiological fallout in 1954, have been recovered year by year as shown in Fig. 4 where the data on land contamination in 1974 and 1994, and on human body between 1977 and 1984 are from Walker (1997) [11], Simon (1997) [3] and Robinson (1997) [10] respectively. The effective half time of Cs-137 decrease on the ground, which is estimated to be 6.1 y is much shorter than physical half-life of Cs-137 (30y).

This causes decreasing of body burden of Cs-137 as shown in the same figure. The radioactivities on coral island whose sea level is only 1.5 ~ 2.0 m, may have been swept by big waves of the Pacific Ocean. Effective transfer constant (ratio between body-burden (kBq/kg) and land contamination (kBq/m^2) of Cs-137 is estimated to be 0.77 $\pm$ 0.33 (10^{-3}m^2/kg) in Rongelap Island by using data set and fitting function of Fig.6. This effective factor between human and environment includes not only natural components but also social components. The case in Rongelap Island has factors on imported food and food from northern islands where are more radioactively contaminated.

Total effective dose which is estimate to be 0.17 mSv/y due to Cs-137 for residents on Rongelap Island in 1999, is much less than 1 mSv/y for dose limit on public exposure in 1990 Recommendations of the International Commission on Radiological Protection[12].

We noticed that activity for soil (93 Bq/kg as the top 5cm and 3.9 kBq/m^2, n=2) of Pu-239, 240 in Rongelap Island 1999 was smaller than the previous values. The activities for soil sampled in 1978 and in near 1994 (Robinson et al and Simon et al) were 117 and 133 Bq/kg respectively. Plutonium may decrease more slowly than Cs-137 in the environment of island.

The radiological information in the whole atoll will be needed for people of Rongelap after their return to the home island since the northern islands are their farms. We investigated 3 sites in Kaballe Island where was located in northeast 25 km far Rongelap Island. Radioactive contamination on the island was still high in 1999. One site nearby beach was highly contaminated as Cs-137 of 3.4 MBq/m^2, α-ray of 2 cpm, β-ray of 1205 cpm and γ-ray of 0.73 μSv/h as the maximum. The external dose rate in

Kaballe was 22 times higher than that in Rongelap Island. Activity of Pu-239, 240 in soil (n=1) was 341 Bq/kg (top 5 cm) and 19 kBq/m^2.

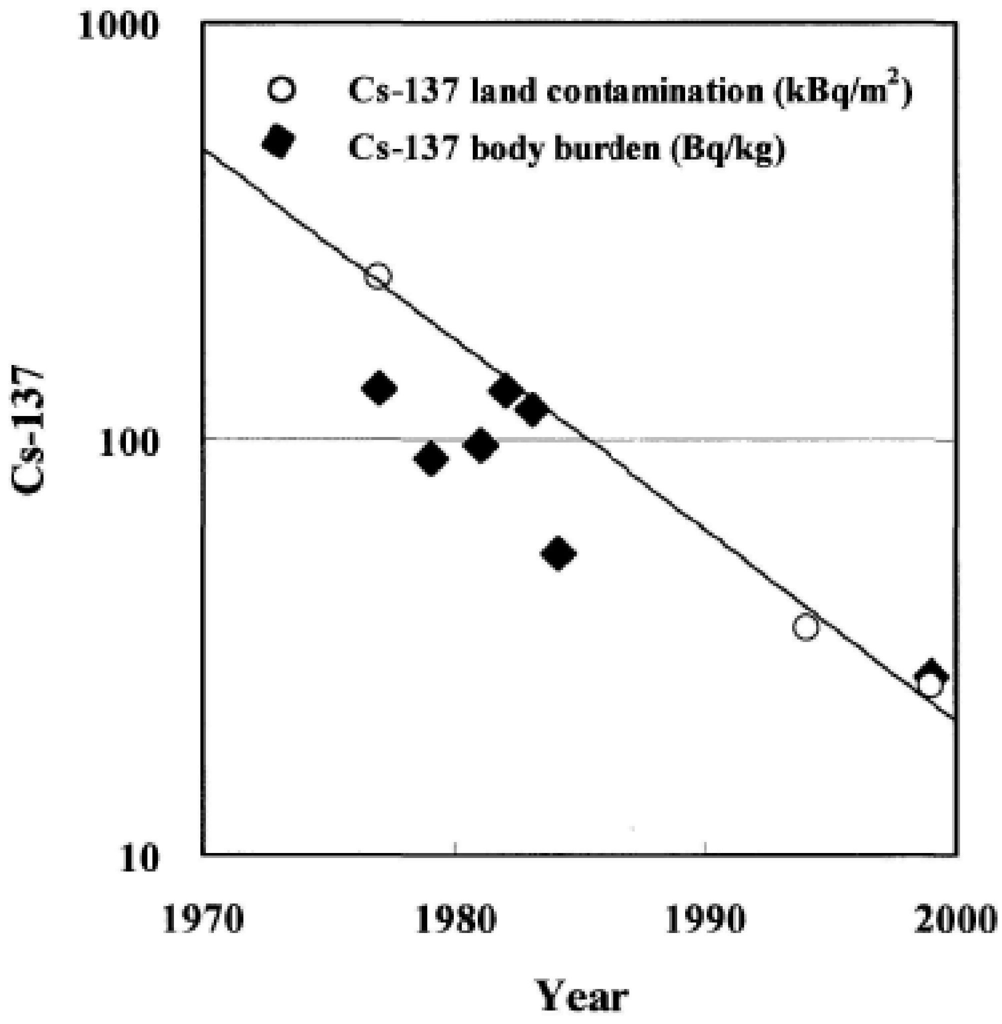


Fig. 6. Cs-137 as a function of year.

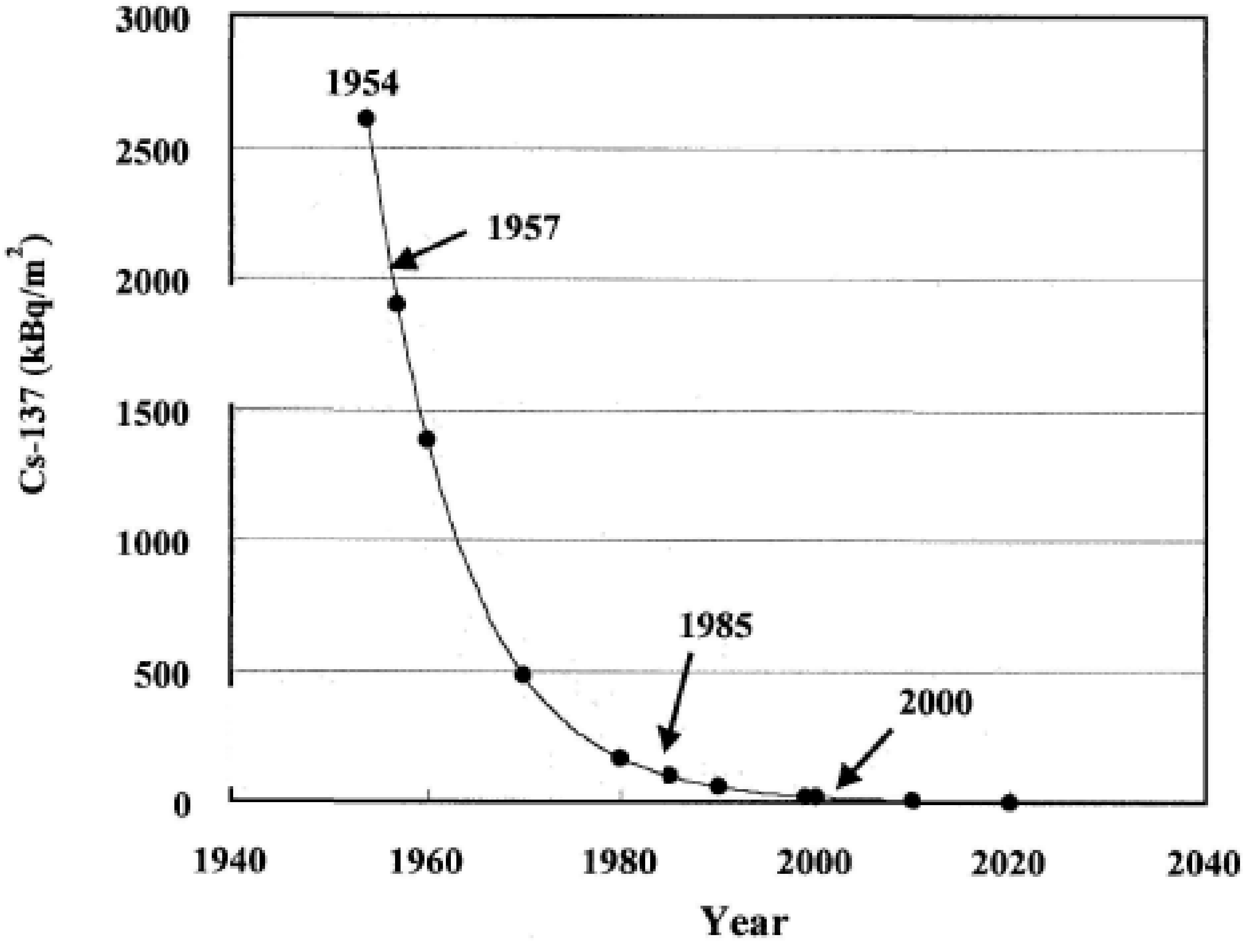


Fig. 7. Estimated Change of Radio Cesium in Rongelap Island.

Table 5. Radiological States in the World

Settlement		Nuclear Hazard	Measurement Year	Cs-137 (kBq/m^2)	γ (μSv/h)	β (cmp)	α (cmp)
Ueno Tokyo	n=4	None	2000	nm[a]	0.04	155	1.3
Hiroshima	n=4	USA A-bomb 1945	1997	4	0.10	241	1.7
Rongelap Island	n=17	USA Nuclear Test 1954	1999	26	0.03	110	0.6
Clean up	n=3		1999	7	0.01	126	0
Zaborie	n=4	Chernobyl Accident 1986	1997	3500	3.00	nm	nm
Dvorische	n=4	Chernobyl Accident 1986	1999	590	0.65	1069	3.8

[a] nm = not measured.

Cs-137: one measurement at one site

γ, β: average value of data taken at three corners of triangle with side 5m long in a site

α: maximum value of data taken at the each corner of triangle with side 5m long.

α and β: active area is 72 cm^2 for the counting

n the number of measurement site

SUMMARY

It was difficult to find that large risk exists in Rongelap Island (the main island of Rongelap Atoll) in 1999 from the radiation protection point of view. However radiological states in a northern island Kaballe was still somewhat high. The radiological information in the whole atoll will be needed for people of Rongelap after their return to the home island since the northern islands will be their farms. Continuos supply of imported food for people of Rongelap will play an important role to reduce internal exposure in the near future.

The summary of the first report of our investigation is as follows.

1. Radiological investigations were carried out by Japanese scientists in collaboration with a non governmental organization mainly in Rongelap Island July 1999.
2. The first report has been prepared for the people of Rongelap as a humanitarian support.
3. The scientific report will be presented in Eighth International Conference on "Low-level measurements of Actinides and Long-lived Radionuclides in Biological and Environmental Samples" Oarai Japan October 16 –20, 2000.
4. Constructions of infrastructure and radiological cleanup have been carried out as reestablishment project of Rongelap Island in Rongelap Atoll of Marshall Islands since July 1998. The results of this investigation will be an urgent and important information for the people of Rongelap Island who consider their return to the island.
5. Alpha, beta and gamma surveys and in-situ spectroscopy were carried out. Pit film technique was applied to samples of coconuts and soil for detecting Plutonium.
6. Portable whole-body counting of Cs-137 was carried out for workers in Rongelap Island who may take radioactivities by food-chain or by inhalation.
7. Radiologically abnormal value was not recognized in all 17 sites including beach where we investigated in Rongelap Island.
8. Depth profile of beta ray showed normal state in a hole with 150 cm depth at center of Rongelap island. Moreover no Cs-137 was detected in the hole.

9. Contamination level of Cs-137 was less than 40kBq/m^2 at all the 17 site. The value was enough low for residents. The value is much less than that in the contaminated territory due to Chernobyl accident.

10. The effective half time of Cs-137 decrease on the ground, which is estimated to be 6.1 y is much shorter than physical half-life of Cs-137 (30y).

11. Radiation in Rongelap Island 2000 is estimated to be five times less than that in 1985. This radiation level is close to the values in Tokyo.

12. Whole-body counting of Cs-137 was done for 6 in 15 workers. They take US imported food and sometimes local foods such as coconut, pig, chicken, coconut crab and fish. The results, which showed the maximum, average and minimum values were of 46, 27 and 17 Bq/kg respectively, were acceptable level.

13. Annual external and internal doses which were estimated to be 0.10 and 0.07 mSv/y as in Rongelap Island 1999, were pretty low.

14. Activity of Pu-239, 240 for soil was 93 Bq/kg as the top 5cm and 3.9 kBq/m^2 in Rongelap Island 1999.

15. Pit films have not been analyzed yet.

16. The plutonium analysis for local foods will be a future work.

17. The present results show us that radiological states in Rongelap Island contaminated USA nuclear test of Bravo 1954 have been recovered till 1999.

18. We investigated 3 sites in Kaballe Island where was located 25 km far from Rongelap island in northeast direction. One site is relatively high contaminated, Cs-137 of 3.4 MBq/m^2 and beta ray of 1200 cpm. The other islands were not investigated.

19. It was difficult to find that large risk exists in Rongelap Island from the radiation protection point of view.

20. Continuos supply of imported food for people of Rongelap will play an important role to reduce internal exposure in the near future since the northern islands are their farms.

Reference

1. Rongelap Atoll Resettlement Plan Phase I, Rongelap Atoll local government Rongelap local distribution authority (1998).
2. S. L. Simon, Health Phys. **73**, 5 (1997).
3. S. L. Simon et al., Health Phys. **73**, 133 (1997).
4. Bumbum Project, which is a non-governmental organization for helping local society of Rongelap people, was established in 1996. http://www.erix.com/bumbum/
5. J. Takada et al. Applied Radiation and Isotopes 52, 1165 (2000).
6. M. Yamamoto et al. J. Radioanalytical and Nuclear Chemistry. 242, 63(1999).
7. J. Takada et al., Health Phys., **73**, 524 (1997).
8. ICRP Publication 30, Part 1, Limits of Intakes of Radionuclides by Workers, Pergamon Press, Oxford. (1978).
9. L.C. Sun, J.H. Clinton, E. Kaplan, C.B. Meinhold. Health Phys. **73**, 86 (1997).
10. W.L. Robinson, C. Sun, Health Phys. **73**, 152 (1997).
11. R. B. Walker, S. P. Gessel and E.E. Held. Health Phys 73, 223 (1997).
12. ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection. Pergamon Press (1991).