NIRS-M-102

Assessment of the Health and Environmental Impact from Radiation Doses due to Released Radionuclides

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the International Workshop at Chiba, January 18 - 20, 1994

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Preface

Since the Chernobyl accident, the time of eight years has passed. During these years, its health consequences have been searched intensively by the countries of previous USSR. Nevertheless, the radiation hazards have never been clearly recognized, because these could also appear by other causes and estimated radiation dose and dose rate are so low. At the same time, valuable experiences on the protection of hazards have been accumulated, although the evaluation of the results are still not fixed.

Considering the above situation, "International Workshop on Assessment of the Health and Environmental Impact from Radiation Doses due to Released Radionuclides" was held at NIRS cooperated by Japan International Sciences and Technology Agency, from Jan. 18 to 20, 1994. Twelve foreign scientists from Belarus, Russia and Ukraine participated in this workshop.

The Main purposes of the workshop was to clarify the estimation of radiation dose, to review the recent situation of health and environmental consequences and to discuss further cooperation among these countries.

Recent health consequences were reported from Russia and Ukraine, which revealed the necessity of unification of diagnostic criteria considering discrepancies among the countries. Concerning the dependences on radiation doses, there are also discrepancies of the viewpoints, which indicate the necessity to confirm dose estimation. Limited to inhabitants, severe influences on health are caused through psychological and neurological disorders by stress in unfavourable change of circumstances.

We have already established the methodology and criteria for searching and evaluation of health consequences at Hiroshima and Nagasaki. The case of Chernobyl accident, however, requires something new development including radioecology and whole-body measurement, because radiation sources, dose rate, irradiation process etc. are quite different from the case of the bombing.

Among radionuclides released in the environment, the most important was Cs-137, but the contributions of Sr-90 and Pu were also pointed out.

As the further cooperation researches, following subjects are proposed :
(1) whole-body counting and data analysis,
(2) thermoluminescence measurement of irradiated materials,
(3) natural radiation dose measurement from Rn, U etc.,

(4) ESR measurement with teeth enamel of decontaminators,
(5) epidemiology and risk estimation,
(6) calibration of measuring devices,
(7)measurement of chromosome aberration,
(8) optimization of hazard protection.
these subjects were agreed to pursue as cooperative works among four countries.

I hope that this proceedings will give a help to deepen scientific assessment of the Chernobyl accident and to promote cooperative researches among these countries.

Yasuo Hirao
Director-General,
National Institute of
Radiological Sciences

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Special Contributions

Opening address

Yasuo Hirao, Director-General
National Institute of Radiological Sciences

Ladies and Gentlemen:

I am very happy to address to such the nice participants here in this International Workshop.

Since the Chernobyl accident which brought about various discussions against the safety of nuclear power plant, eight years have already passed. By this accident, we have had a lot of population exposed at low dose and low dose-rate due to released radionuclides. It has been pointed out strongly that its scientific investigation is quite important in order to clarify the health consequences.

Our NIRS has participated in its various scientific researches since occurrence. In 1988, NIRS started the cooperative work of irradiated dose confirmation with JAERI and PNC, to be followed by the analysis of health consequences. Since then, NIRS has performed the cooperative research of contamination in environment with the Research Center for Radiation Medicine of Academy of Medical Sciences of Ukraine etc., except two years interrupted by the revolution of the USSR. The Radiation Effect Research Foundation, Japan, has also done the cooperative work in the field of health consequences.

In 1990, Japan-USSR Joint Seminar was held to review the Chernobyl accident, in which very important information about health effects and environmental contamination was reported. We have heard that further studies have been continued and valuable data are being accumulated by the previous USSR side.

In this International Workshop, we have eight invited scientists, Drs. Likhtarev, Los, Perevoznikov and Goritskyi from Ukraine, Drs.Ramzaev, Tsyb and Serezhenkov form Russia and Dr. Skryabin from Belarus, who are all the prominent experts in the field of health effects and environmental contamination of radionuclides.

Based on the reports of the latest status from these countries and also the cooperative researches during the last five years from Japanese side, various scientific discussions are expected during this three day meeting.

I hope that this Workshop will be informative and fruitful, and will also stimulate further cooperation among Japan and these countries in the field of health effects due to radionuclides.

RADIATION DOSES AND HEALTH CONSEQUENCES OF THE CHERNOBYL ACCIDENT IN RUSSIA

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1. ABSTRACT. Data (1986-1993) of the Institute of Radiation Hygiene on radiation doses from the Chernobyl accident and their influence on health of Russian population in the most contaminated regions and liquidators are analyzed. Average doses for population of 3667 settlements were reconstructed. In 1991 about 200.000 inhabitants in 494 settlements incurred effective doses of 1 to 5 mSv. The territory of 153 settlements was contaminated in 1986 with ^{137}Cs in the range of 0.6-4.0 TBq/km^2. External irradiation from 1986 fallout according to measurements at 8000 people decreased from 0.4 mSv in 1986 to 0.05 mSv in 1992 per 0,37 TBq of ^{137}Cs (1Ci) in 1992 per 1 km^2. Average ^{137}Cs+^{134}Cs body burden for adults of different settlements(250.000 measurements) was 40-400 kBq in 1986 and decreased 20 times to 1992. The decrease was 5-10 times faster than previously expected. The total average effective dose in 1986-1992 among 112.000 inhabitants on contaminated area 0.6-4.0 TBq/km^2 reached 50 mSv, and thyroid dose from ^{131}I was 0.3-2.0 Gy at 9500 people and 2.0-7.0 Gy at 270 people. Collective effective doses from the accident for Russian population during 70 years will be only 0.3% of the dose from natural and medical sources.

Analysis of health(thyroid cancer, leukemia etc.) in 1986-1992 did not show any dose-related effects upon the inhabitants. Some

increase of endocrine morbidity in population of contaminated regions and observation of cardiac-vascular and neurologic disorders in liquidators could be explained by severe psychological stress..

2. INTRODUCTION. The interest of the world science to study the Chernobyl accident consequence is not falling away with the time. The results of these investigations probably will not be less important than a great contribution to the progress of mankind of Japanese and USA scientists studies on consequences of Hiroshima and Nagasaki atomic bombing. The cases are different in two aspects.

As it has been shown earlier [1], the main harm to population after the Chernobyl accident would be only 300 000 person-years of health loss, approximately 5-7% of the losses in Hiroshima and Nagasaki. Contribution of the Chernobyl accident to the collective effective dose of Russian population presents only 0.3% of the total dose from natural and medical radiation (Table I). As individual doses did not approach to the threshold deterministic levels, the harm to the health from radiation will be determined by the collective dose and by stochastic effects, if they really exist at such small Chernobyl doses. Nevertheless, the above-mentioned considerations are not final at all. Accident at the Chernobyl nuclear plant was not the first, although of the large scale and, probably, will not be the last one in the world, which in accordance with the sober estimation will develop atomic energy and use of ionizing radiation. The point is that main postulates of contemporary radiation protection, particularly based on non-

Table I. **Radiological situation in Russia in 1993.**

Source of radiation	Number of irradiated people	Effective dose: Mean individual in 1993, mSv	Effective dose: Dose for life, mSv	Effective dose: Collective dose for life (70 years), man·Sv
I. All sources:	I50 000 000	4.0	280	42 000 000
natural	I50 000 000	2.9	200	30 000 000
medical [2]	I50 000 000	I.0	70	I0 000 000
others (fallout, accident etc.)	I50 000 000	< 0.I	< I0	< I 500 000
II. Occupational [3]	250 000	7.0	350	87 000
III. Accidents:				
1) Effluents in river Tech [4]	28 000	<1.0	200-300	7 000
	2 000		I000	2 000
2) Accident in Kyshtim [4]	24 000	0.I-0.3		
	I5 000		I5	225
	7 000		40-I20	560
	I 500		500	750
3) Air contamination from "Majak"				
in Chelabinsk-65	80 000		80	6 400
in Chelabinsk region [4]	I I00 000		27	30 000
4) Atomic weapons tests:				
-in Arctic (reindeer herding)	I00 000	0.3	30	3 000
- Altai [5]	270 000	0.0	50-250	4 000
	40 000	0.0	≥ 250	≥ I0 000
5) Chernobyl [6]	I50 000 000	< 0.I	0.8	I20 000
Bryansk region	I00 000	I.5	80	8 000
"Liquidators" [7]	I70 000	0.0	I00	I7 000

threshold dose-effect relationship, the accepted coefficients of stochastic risk used for dose limits and intervention levels, are doubtful till now,possibly, because extrapolation of atomic bomb investigation data to peaceful accidents. Even very simple questions about effective half-life of cleaning of the environment after atomic bomb explosions appeared to be not reliable to the Chernobyl accident case.

Hurricane of doubts has been raised to the available data on dose-effect relationship from recent Belarus publication heartily supported by WHO about very early and very high levels of thyroid radiation cancers among children [8]. The above considerations gave some formulation of questions, which we tried to solve by analysis of investigations carried out in 1986-1993 by the Institute of Radiation Hygiene over the regions of Russia especially suffered from the Chernobyl accident. The studied territory of the regions is contaminated with ^{137}Cs more than 0.04 TBq per km^2(1 Ci/km^2) amounts 55.000 km^2. Two interconnected purposes have been raised for the solution:

- to demonstrate the radiation levels in dynamic to Russian population during last 7 years after the Chernobyl accident. In accordance to decision of the Government, Sanct-Petersburg Insti tute of Radiation Hygiene is the main organization commissioned for research in Radiation Protection in all Russia;
- to analyze the original data from health organizations on possible health consequences for population in the most heavily contaminated areas in Bryansk region and for liquidators livings in St.Petersburg by specialists - radiologists.

3. MATERIALS AND METHODS. Our data on the doses to Russian population from the Chernobyl accident are the result of direct measurements of internal and external radiations. To support such measurements and calculations, we used mathematic models, which interrelate levels of radioactive contaminations of territory or foodstuffs with the absorbed (or effective) doses to the people. External irradiations were measured by thermoluminescent dosimeters of the USA firm Harshow (2000D). Minimal measured dose was 40 microgray. Intercalibrations of our dosimeters with those from Sweden and Norway showed possible error ±5%. The investigation were carried out on the territory contaminated by ^{137}Cs + ^{134}Cs in the range of 0.6-4.0 TBq /km^2 where live about 112 000 inhabitants in settlements , with total area 2 700 km^2. During 1986-1993 there were conducted measurements at 8000 people living in 44 settlements to which belong 90% of control zone population. The ^{137}Cs and ^{134}Cs whole-body burdens were detected by transportable field devices with NAI crystal. The devices were calibrated on volunteers (some of the authors), who had ingested a known amount of Chernobyl mixture of ^{137}Cs and ^{134}Cs. The method was officially approved [9]. About 10% of measurements were fulfilled by more perfect whole-body counters. Altogether there were carried out 250 000 detections including 90 000 in 1986, 70.000 in 1987 and then (1988-1993) 8000-20 000 per year.

Direct measurements of ^{131}I in thyroid were made only at 2500 persons. Due to the obtained results we developed in 1987 a method of dose reconstruction for thyroid using the data on radiation field during the first weeks after the accident, on consumption of milk, relation of ^{137}Cs contents in body measured in August-September 1986 and thyroid dose from ^{131}I measured in May-June 1986. In accordance with the method, there was organized data base for individual thyroid doses at 58.999 persons among 112.000 persons in control zone of Bryansk region.

As initial materials for evaluations of population health in contaminated regions and health of liquidators, we used documents containing results on individual health investigations by hundreds physicians of different specialties. There were analyzed some summary statistical data of state health-service institutions of Bryansk region (on population) and of St.Petersburg (on liquidators). Analyses of chromosome aberrations in lymphocytes of blood, electroencephalograms and cardiography of liquidators were made directly by specialists of our Institute.

4.RESULTS. The latest analysis of the Institute of Radiation Hygiene on the consequences of the Chernobyl accident was published in proceeding of international workshop held in May 1993 in Bryansk [10] and papers issued in USA [11]. Here we are going briefly to present some new data in tables and figures. The information on external and internal irradiations is shown mainly from the zone contaminated higher than 0.6 TBq ^{137}Cs per km^2. For dosimetry forecast, and dose reconstruction on territory without direct measurements, where there are only available data on surface contamination by ^{137}Cs, information is presented in Fig.1. It gives relationship between annual effective dose rate (E in 10^{-6}Sv per kBq of ^{137}Cs per m^2) and time after 1987 by years(t). The exact equation is: $E = 6.0 \cdot \exp.(-0.176t)$.

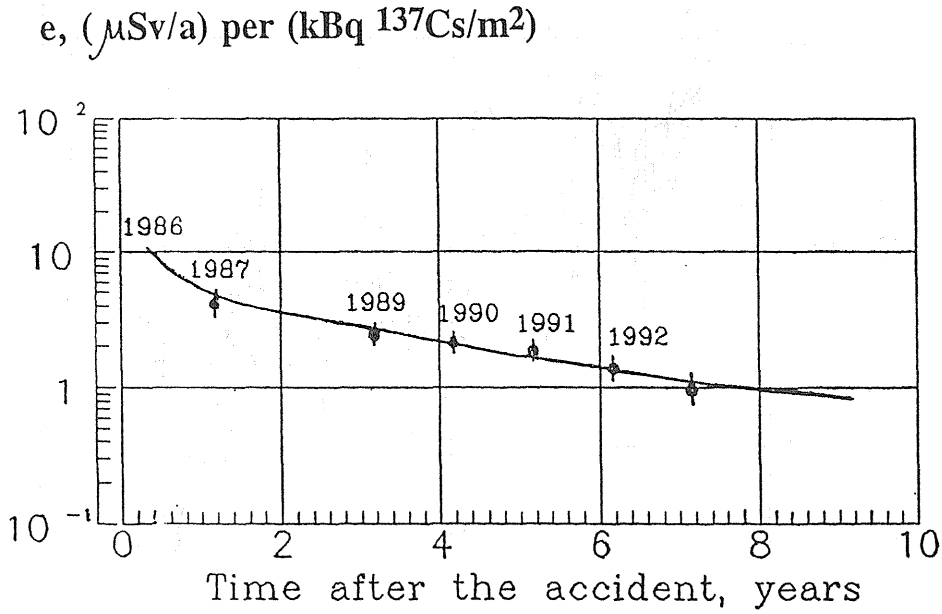

Fig. 1. Time dependence of annual effective dose of external gamma radiation in rurla population of Bryansk region.

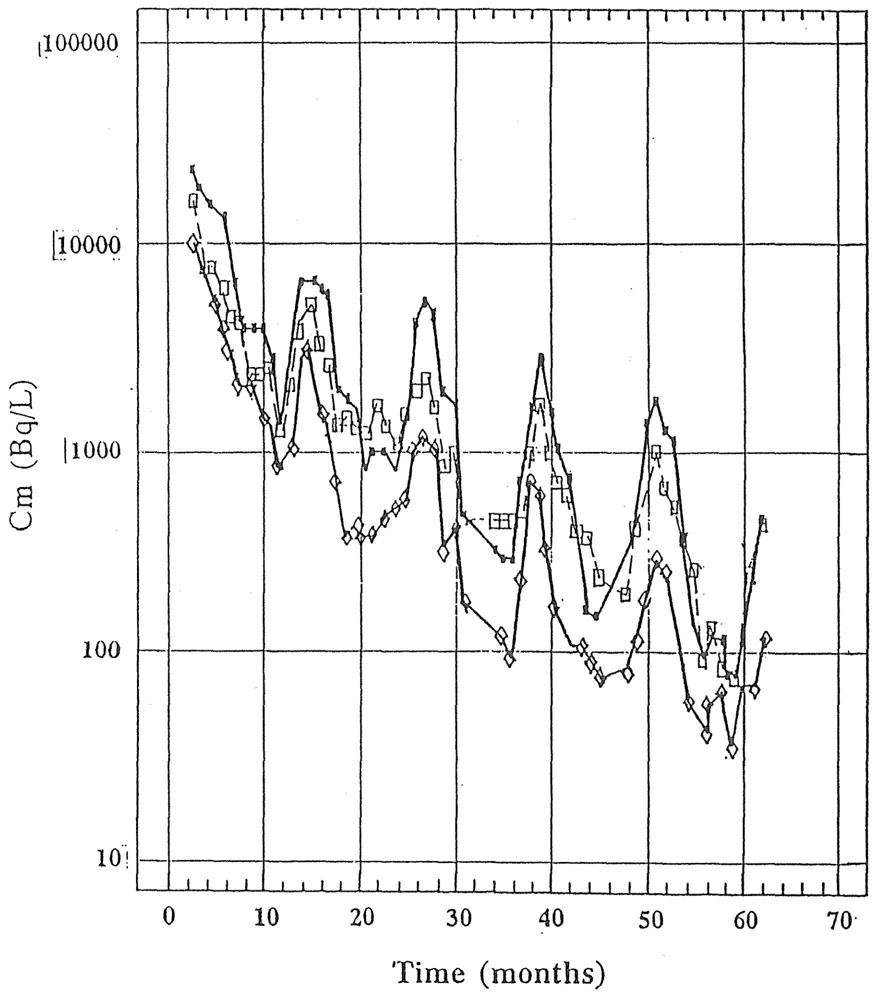

Fig. 2. Average ^{137}Cs concentration in milk C_m from collective farms of the Bryansk region after the Chernobyl accident.

The observed during 7 years dynamics of ^{137}Cs and ^{134}Cs body burden in adults (Table II) and appropriate effective doses (Table III) show only average view of population irradiation in contaminated zone for estimation of collective dose. Real distribution of individual levels follows a log normal law with 10 times bias to the higher levels. As it can be seen from the tables, radiocaesium body burden in urban residents was about 3 times less than in rural ones. Internal radiation in villagers amounts only 25% of total (together with external) dose. Unexpectedly, during 7 years almost the same rate of decrease of external and internal doses (13-14 times) was observed, in accordance with 2 years half-life (from 1986). It is noticed some deceleration in the rate and in time. Decreasing of ^{137}Cs body burden in villagers (20 times) is supported by almost 100 times cleaning of local milk (Fig.2) which has great seasonal fluctuations with the highest levels in summer. Prognosis of milk cleaning and the followed human body burden, made on the "bomb" model, thank goodness, has not been confirmed. It was suggested to be about 10 years, but in reality only 1-4 years. People who live in brick houses incur radiation 1.6 time less than in wooden ones. Because of shielding by buildings only 25% of outside gamma-radiation reach human body. Doses to the people of the most contaminated areas amounted 50 mSv during 7 years did not approach a threshold of deterministic effects. This makes practically useless the striving for general individual dosimetry demanded by special Russian law on the Chernobyl accident [12]. Such dosimetry, which should cover some millions of people, will result in more harm, than benefits, especially for human health. It

Table II. Average ^{134}Cs and ^{137}Cs body burden in adults on regions contaminated more than 0.6 TBq(15 Ci) ^{137}Cs per km^2

Date of measurements	villages		towns	
	kBq	10^{-6}Ci	kBq	10^{-6}Ci
August-September 1986	207	(5.60)	63	(I.70)
February-March I987	89	(2.40)	24	(0.65)
February-March I988	4I	(I.I0)	I4	(0.38)
September-November I988	32	(0.85)	I5	(0.40)
September I989	24	(0.66)	I6	(0.42)
September-November I990	20	(0.54)	6	(0.I6)
All I99I	I5	(0.40)	3	(0.09)
All I992	II	(0.30)	4	(0.I0)

Table III. Average effective doses at villagers in regions contaminated higher than 0.6 TBq $^{137}Cs/km^2$, in mSv

Date	External	Internal	Total
I986	I7.0	6.2	23.2
I987	6.7	2.4	9.I
I988	4.6	I.5	6.I
I989	3.4	I.I	4.5
I990	2.2	0.92	3.I
I99I	I.9	0.65	2.5
I992	I.5	0.45	2.0
Total I986-I992	37	I3	50

Table IV. Thyroid doses from ^{131}I in Bryansk regions contaminated higher than 0.6 TBq $^{137}Cs/km^2$

Date of birth	Numbers of person received doses, Gy			
	< 0.3	0.3-0.75	0.75-2.0	> 2.0
I976-I986	3202 (38%)	3332 (40%)	I563 (I9%)	220 (3%)
I97I-I978	8523 (83%)	I375 (I3%)	338 (3%)	2I (0.2%)
before I97I	3754I (93%)	2404 (6%)	45I (I%)	29 (0.07%
All	49266 (84%)	7III (I2%)	2352 (4%)	270 (0.5%)

increases only feeling of doom, radio phobia, which is high enough even today. As concerning the benefits, such dosimetry is necessary only for absurd scientific ambitions to confirm very rare effects.

The highest thyroid doses from ^{131}I , as expected, observed at children (Table IV). Among 270 person with absorbed thyroid dose more than 2.0 Gy (up to 7.0 Gy) in area with contamination more 0.6 TBq of ^{137}Cs per km^2, 220 persons belonged to age group up to 7 years old. The mean thyroid dose in all Bryansk population was 40 mGy and in control zone - 220 mGy. Probability of deterministic effects here is very small, as to the ICRP[13] hypothyroidism appears due to doses higher than 45 Gy in 1-5%. Levels of expected stochastic effects (Table V) on all Bryansk regions, 120 cases, mean only 3% above spontaneous level (4 700 cases during 70 years), and in the highest contaminated area - 15%. As a spontaneous level, we choose the average morbidity of thyroid cancer for clean Bryansk territory for 1986-1992 (4.5 per 100 000 inhabitants). Radiation risk was taken from USA NCRP report N80 [6], which gives 75 cases per 10 000 man-GY for external irradiation and 3.5 times less from ^{131}I dose. We do not think, it will be possible to prove or to reject such effect on our materials. The facts of thyroid cancer morbidity (Table VI) showed, that an morbidity average for 7 years after the accident appeared to be even 60% ($p<0.05$) higher in contaminated regions than in clean areas. But a simple interpretation of this excess due to ^{131}I would be prematurely. This excess was noticed already during the first 2 years after accident and reached 2.4-3.6 times. Exactly during these years the Ministry of Health had sent additionally hundreds physicians from

Table V. Thyroid collective absorbed doses from ^{131}I and prognosis of thyroid cancer morbidity for 70 years. Sp - spontaneous, R - radiation.

Region	People in million	Doses 10^3man-Gy	Number of cancer		$\frac{R}{Sp}\cdot 100$
			Sp	R	
Bryansk- - all	I.	55	4700	I20	3
Bryansk-contaminated zone	0.II2	22	350	50	I5
Tula	I.9	50	6000	II0	2
Orel	0.9	I5	2800	30	I
Kaluga	I.0	I5	3200	30	I
Total	5.3	I35	I6700	290	2

Table VI. Thyroid cancers per 100 000 inhabitants in Bryansk region in 1986-1992

Regions, number of inhabitants	I986	I987	I988	I989	I990	I99I	I992	Mean± error
All I 460 000	3.3	4.5	4.7	5.0	4.7	5.I	6.7	4.9±0.39
Clean I 205 000	2.7	3.2	4.5	5.I	4.4	5.0	6.6	4.5±0.49
Contaminated 255 000	6.4	II.2	6.4	5.8	6.0	6.0	8.0	7.2±0.79

Table VII. Malignant tumorous of bloodforming and lymphoid tissues,
per 100 000 inhabitants in Bryansk regions in 1986-1992.

Regions, number of inhabitants	I986	I987	I988	I989	I990	I99I	I992	Mean± error
All I 460 000	I0.8	8.7	I2.2	I0.7	I0.5	I2.4	I3.0	II.2±0.6
Clean I 205 000	I0.8	9.3	I3.4	I0.5	I0.9	I3.3	I3.3	II.6±0.6
Contaminated 255 000	II.3	6.3	6.6	II.8	8.6	8.6	I2.I	9.3±0.9

Moscow, Leningrad and other centers for more careful examinations of people in contaminated regions. During next years medical attention fell down but not to initial level. So, the morbidity in contaminated regions fell down 2 times (1988) and stayed on the same level for 4 years. It was 15-40% higher in contaminated regions. The further detailed analysis of dose-effect relationship will be necessary for reliable conclusions. Variations in medical service had no influence on tumorsof blood-forming and lymphoid tissues (Table VII). Here the morbidity staied at the same levels during all 7 years. There were no significant differences between the contaminated and clean regions.

Summary of morbidity on all basic classes of diseases in 1988-1991 is shown in Table VIII. At that period there was no external additional medical service. General (total) morbidity of people living on contaminated territory and in all Bryansk regions appeared the same. Differences were not significant. But it is possible to notice the differences and excess on contaminated regions for endocrine diseases (two times), mental disorders (70%) and cardiac-vascular diseases (50%). At the same time a clear decrease of respiratory diseases (40%) should be mentioned. A review of regional morbidity shows very high variations. So the regional differences among contaminated areas reach up to 70 times for pregnancy and delivery disorders, 6.5 times for mental and 6.0 times for endocrine diseases. It is beyond understanding how to relate these fluctuations with any environmental factors apart from very great differences in levels of diagnostic practice and regional register. It would be vain hope to detect 2-15% of

Table VIII. Mean numbers of adult patients in Bryansk regions per year (1988-1991) per 100 000 inhabitants in thousands by types of diseases (TD): 1-all, 2-infections, 3-tumorous, 4-endocrine, 5-mental, 6-neural, 7-cardiovascular, 8-respiratory, 9-digestive, 10-genital-urinary, 11-diseases of pregnancy

TD	Contaminated region									All Bryansk area
	Klin-ci	Klin cov sky	Novo-zyb-cov	Zlin covs ky	Kras-nogo rsky	Klimov sky	Gorde evs ky	Staro dub sky	Mean regio nal	
I	64.4	46.9	74.I	47.2	35.I	36.0	37.5	3I.6	55.4	56.7
2	2.2	I.3	2.5	I.4	I.I	2.I	0.7	I.3	I.7	I.9
3	I.0	0.8	I.2	0.6	0.8	I.0	0.6	0.7	0.9	0.9
4	0.4	0.7	I.I	I.2	I.7	0.4	I.3	0.3	I.I	0.5
5	I.6	I.7	2.6	0.4	0.7	2.I	I.2	0.4	I.7	I.0
6	5.8	5.4	8.6	2.I	3.6	4.8	4.I	2.3	6.0	6.5
7	2.0	I.5	3.4	I.9	I.9	I.3	2.8	I.6	2.6	I.7
8	26.4	I0.0	22.6	I8.0	5.5	II.I	I0.9	I2.8	I5.8	2I.7
9	2.5	I.6	3.0	I.3	2.0	2.6	I.7	I.3	2.2	2.I
I0	2.I	2.I	3.6	2.7	2.3	I.8	2.2	I.3	2.9	2.5
II	2.8	2.I	2.7	0.03	I.I	0.9	0.I	0.7	I.8	I.2

expected radiation effects on the background of chaos in todays Russian health service. The same picture of high fluctuations (almost 5 times) can be seen in neonatal morbidity (Table IX) on contaminated regions. Of course, it is not diagnostics which should be blamed. Russian physicians did not unlearn to determine death. More reasonable cause here is difficulties in standardization of all conditions for nursing. More reliable data concerning dose-effect relationship obtained on liquidators although among small group (3000 persons) but during more qualified examinations carried out by radiologists from St.Petersburg including the authors of the report. These examinations were conducted in 1990. The liquidators worked at Chernobyl in 1986, 1987 and 1988 and, as a result, received mean doses: 190; 120 and 20 mSv accordingly. The age of the patients was the same (36-38 y at average). Liquidators of 1986 (Lq-86) in comparison with those ones of 1988 suffered significantly from hypertension and functional disorders of neuro and cardiac-vascular systems (TableX). They (Lq-86) also showed more frequent complaints about headache (50%), fatigue and irritability (40%). Level of anxiety determined by method of Spilberger [14] raised up to the high degree (43.3 units) among 30% of Lq-86. Some changes in electroencephalogram (decrease of amplitudes in alpha-waves etc.) should be mentioned which showed influence of psychologic factors. Manifestation of disorders in electrocardiogram at Lq-86 is so quite persuasive (Table XI). Even in 1992-1993 it was possible to see more higher levels of chromosome dicentric aberrations at Lq-86. The observed results were 2.9±0.5 per 100 cells at dose≤100 mSv, 4.0±0.6 at 110-250 mSv

Table IX. **Newborn mortality per 1000 births (for 1 month, stillborn included)**

Region or town	I986	I989	I990	I99I
Contaminated:				
Krasnogorski	20.5	I6.3	I2.4	22.0
Klinci	I4.I	I6.2	I5.4	I6.8
Novosibcov	8.6	II.3	I8.2	22.0
Gordeevski	4.4	I0.2	8.3	4.7
Zlincovski	22.9	23.I	4.0	I8.5
Clean: Zucovski	I7.5	7.9	22.8	22.5
Bryansk area (all)	I7.4	I4.5	I6.6	I7.2

Table X. **Morbidity of "liquidators" in % of examined person.** Asterisk means a confident statistical differences between data of 1988 and others

Diseases	Time of work at Chernobyl; (dose, mSv)		
	I986 (I90 ± 50)	I987 (I20 ± 60)	I988 (20 ± 7)
All cardiac-vascular	I5.3 ± 3.7*	I2.7 ± 4.5	6.2 ± 0.5
Coronary disease	2.0 ± I.0	0.9 ± I.3	0.9 ± I.8
Hypertension	I3.3 ± 3.I*	II.8 ± 4.4*	5.3 ± 4.2
Dynamic neurologic and cardiac-vascular	22.4 ± 4.3*	I5.5 ± 4.9	I3.0 ± 6.3
Respiratory tract	6.4 ± 3.5*	II.4 ± 4.3	6.2 ± 4.5
Gastric-intestinal tract	I7.3 ± 3.9	I5.5 ± 4.9	I5.5 ± 6.8
Diffuse increase of thyroid	5.3 ± 2.3	4.I ± 2.7	3.5 ± 3.4
Osteochondrosis	5.3 ± 2.3	5.0 ± 2.9	2.6 ± 3.0
Cataract	I.3 ± I.2	I.4 ± I.6	0.9 ± I.8
All diseases	82.I ± 9.4*	7I.6 ± II.4	56.I ± I4.0
Total number of patients	375	220	II4

Table XI. Electrocardiograms data of liquidators(Lq) of 1986,1987 and 1988, in % of examined persons. Asterisk-show significant differences from 1988

Indications	Lq-I986 190 mSv	Lq-I987 120 mSv	Lq-I988 20 mSv
I. Rhythm sinusoidal, normal	20.0 *	24.8	3I.7
2. Rhythm disturbance	59.I *	58.3 *	45.6
3. Disturbance of conductivity	43.I *	34.2	26.6
4. Other changes	22.8	I8.6	I7.7

Table XII. Structural changes in blood cells of liquidators (% cells). Examined 300 persons.

Time after irradiation	Tipe of cells	
	Two-nucleus limphocytes	Hypersegment neutrophils
I - IO days	0.8±0.05	I.6±0.09
I - 3 months	0.5±0.0I	I.6±0.07
5 months	0.5±0.0I	I.3±0.03
Control	0.2±0.0I	0.6±0.08

(background 0.11±0.04). Qualitative structural changes in leukocytes in the form of binuclear lymphocytes and hypersegmentic neutrophils can be found 2-3 times more than in control, even 5 month after irradiation (Table XII). The differences were statistically significant ($p<0.05$).

5. DISCUSSION. The precious store knowledge accumulated almost during a half of century by studying of atomic bomb consequences teach us that problem of dose-effect relationship in radiation protection can not be solved hasty. Till now the scientists in Japan are verifying the information even on such questions as doses received by hibakusha. It is quite possible that difficulties in studying of Chernobyl consequences will not be much easier. Lasting of the consequences in generations will determine an appropriate research period of time.

Among endless list of questions for the discussion, which follow from above our confusing results, especially difficult questions are:

1). In spite of hundreds of thousands direct measurements of external and internal irradiation till now there is no satisfaction on reliability of dosimetry data, particularly during early phase (10-20 days) after beginning of the accident. A project of ^{129}I assessment and ceramic dosimetry may be useful.

2). Our thyroid tumor morbidity data do not give the evidence on increase of such cases in contaminated areas which might be related to the effect of radiation. Significant increase (2-3 times) of morbidity during first two years after the accident should be considered as a result of improvement of diagnosis and medical service in general. As thyroid cancers at children in contaminated Bryansk regions were very rare (sporadic) for the last 7 years (5 caces per 1.5 millions residents of all Bryansk area), a phenomenon of sharp raising of the child thyroid cancers reported by Belarus scientists can not be corroborated by our results. It is imaginable that Russian physicians missed some child tumors. At any case, even the high child thyroid tumours (2 cases per 100.000 people) on the background of 8 cases of all age thyroid cancers and about 200 all forms of cancers can not change a level of population health. Current mortality from all thyroid cancers (15 cases for 1.5 millions of inhabitants in all Bryansk area in 1991-1992) gives only 0.1% to this main indication of health.

3). Considering the formula of radiation health detriment we are coming to the necessity of establishment of general measure of health status which we call "health quantity". Indices of mortality and morbidity are not fully reliable for an assessment of "quantity of health". Indeed how the general radiation harm could be assesed (for instance in Table 8), where the level of endocrine morbidity is 600 per 100 000 persons and increased two times, but the level of respiratory diseases decreased by 5900 cases per 100 000 persons (1.4 times). Similar inconsistency could be found in some Russian report [15], when total morbidity in 1 209 000 residents at radioactive contaminated areas increased in 1989-1990 from 49% to 72%, but the next year mortality had decreased from 23 to 15 per thousand. We propose to express health detriment from all diseases in the form of unified index of health quantity loss. This quantity presents some of four socially significant weighted indicators, such as life-span, integral time of whole life working capacity, health-feeling and generations health. The main idea of interpretation of morbidity in health loss quantity and relevant method was developed at our Institute.

4).Our observations underline a very important influence of psychological factors (stress) upon population health under circumstances of low radiation dose. The stress is predetermined by misinforming (sometimes by scientists) about influence of radiation and extremely exaggerated radiation fears of one's life. Very rare and only hypothetical stochastic effects, which can determine only 2% of health (in the form of mortality) even in the most contaminated regions impress and concern ordinary people, even physicians and authorities, who ignore really dangerous factors for health. Much more harm than benefit gives ungrounded resettlement, withdrawal of foodstuffs under lower levels of radiation in Russia than even internationally approved.

Non-professional and not always objective presentation of scientific data and experts opinion by mass media creates an unnecessary fear and psychological stress in population which provokes an increase of stress-related diseases, such as cardiovascular, neurological and endocrin. The experience of Japanese scientists and health authorities dealing with such a situation during many years could be of great value for a joint effort to mitigate the consequences of nuclear and other large scale accidents to prevent health detriment in population.

6.ACKNOWLEDGEMENTS. Many sincerely thanks to hundreds of Bryansk and St.Petersburg physicians who prepared original data for this report. Especially we thank very much the Organization Committee of the workshop and first of all General Director H.Matsudaira and Doctor M.Uchiyama for possibility to present this report.

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Discussion

Dr. Likhtarev, (RCRM): The incidence of thyroid cancer has increased from 1989 in Ukraine. The incidence was $8/10^6$-$16/10^6$ from 1981 to 1988, and it increased dramatically in 1992 and 1993 to $101/10^6$ and $112/10^6$. Dose-relationship is observed as the incidence is higher in contaminated area.

Dr. Nagataki, (Nagasaki Univ.): Why do you think there is a different incidence of thyroid cancer in Russia and Ukraine? Is it because of the difference in radiation quality or quantity between both countries ? Is it because different criterion for thyroid cancer are used in different countries or do other factors unrelated to the accident contribute to the disease?

Dr. Ramzaev, (IRH): It is not caused by the different radiation quality nor dose. I suspect other possibilities. I do not believe that the estimated doses from ^{131}I are high enough to account for such a high incidence.

Dr. Okajima, (Nagasaki Univ.): What do you think is the reason for the quicker half life of ^{137}Cs in Chernobyl accident than that from fallout? Is there any difference in the chemical form?

Dr. Ramzaev, (IRH): The chemical form is the same. In case of fallout, the half lives of ^{137}Cs in the field or in milk were determined under the condition that ^{137}Cs was continuously supplied from air. This must be the reason why we overestimated a half life. In case of the Chernobyl accident, ^{137}Cs that was released settled down within a short period.

Dr. Nakajima, (NIRS): What are you planning to do about the psychological stress caused by the accident?

Dr. Ramzaev, (IRH): We understand the importance of mitigating psychological stress of the inhabitants. The reaction of inhabitants changes greatly according to the attitude of competent authorities, medical doctors and teachers. Sometimes their stress increases when too much information is given. Under present regulations, inhabitants are moved when the dose 5 mSv/ year above the dose limitation. I am proposing at this moment to raise the limit to 50 mSv/ year.

MAIN PROBLEMS IN POST-CHERNOBYL DOSIMETRY

I.Likhtariov, L.Kovgan, O.Bobiliova, I.Los', G.Gulko, V.Repin, O.Perevoznikov, N.Tsigankov, S.Vavilov, E.Kalchenko, R.Gluvchinsky, D.Novak, V.Berkovskiy, V.Chumak, I.Kayro, G.Phedosenko, I.Komarikov, L.Litvinetz, S.Soroka

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For clear understanding of all the dosimetric problems deal with the Chernobyl accident it's rather fruitful to represent the time-space structure as sources of exposure and contingents exposed by these sources as well.

According to classification accepted in [1] four main phases in post-accidental period which are differed by the type of exposure can be determined.

Both the evolution of doses due to the Chernobyl accident sources and subgroups of people affected by different radiation sources at different time are shown in Fig.1.

As it follows from this diagram, all the radiation accident sources we divided on some groups:

- the short-lived sources,
- long-lived sources,
- super long-lived sources.

Follow radiation exposure may be considered as the **short-lived sources:**

- **external irradiation** from radioactive materials present in the cloud and **internal irradiation** as a result of inhalation of radio nuclides during passage of the cloud; average life-time of these types of sources is from some hours to some days;

- **internal irradiation of thyroid** by 131-I as a result of ingestion of radioiodine in foods (milk, fresh vegetables). This exposure is important during the time-interval from few days till two months after deposition.

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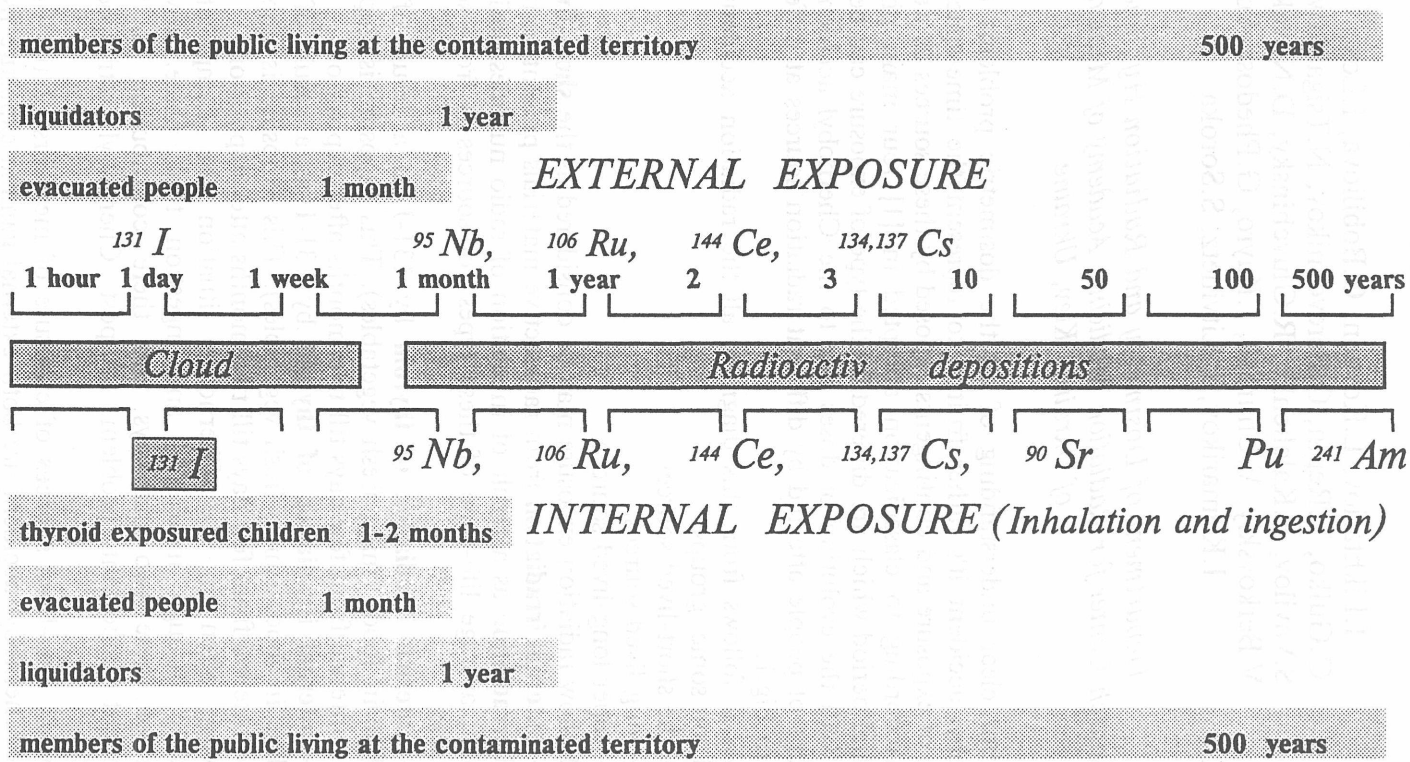
Very often in the Chernobyl situation the complicate intake of radioiodine through inhalation and ingestion took place. Investigation of relation of these two pathways and there contribution to the doses is independent important problem of post Chernobyl retrospective thyroid dosimetry.

Main **long-lived sources** of exposure of members of the public affected after the Chernobyl accident are both external gamma exposure from the decay of radionuclides deposited on surfaces, primary the soil, and internal exposure from the ingestion of radiocesium and radiostrontium with locally produced foodstuffs.

Fig. 1. Chernobyl radiation sources and exposured contingents (time evolution)



The transuranium isotopes (TUI) 238-,239-,240-Pu and 241-Am are the **super long-lived** post Chernobyl sources. These radionuclides aren't important contributors to the total dose during the first 50-100 years after the accident but in future, when the doses from 90-Sr and 137-Cs are reduced practically to zero, the low-levels doses from TUI will play the main role among the Chernobyl radiation factors.

Till now the classification of radioactive sources was based on the factor "time of there life". But when we consider the problem of exposure of clean-up workers ("liquidators"), which participated in one way or another in the clean-up activities at the Chernobyl Nuclear Power Plant (the decontamination of the reactors, nearest territories and other) in 1986 through the first part of 1987 it's important to stress that the dose fields in which those persons worked (and lived!) had extremely complicate configuration. There were some primary pathways of exposure in that time. In particular, the exposure in high level external radiation fields, beta-exposure of opened parts of skin and, probably, the lens of the eye and, also, internal exposure of lung and different parts of gastrointestinal tract through the inhalation of radionuclides that were resuspended.

The inhabitants evacuated from Pripyat-town (27 April) and from the settlements of 30 km radius zone (these people had been evacuated during the first ten days after the accident) form the specific group.

Consider more detail all the sources and contingents mentioned above.

1. External gamma-irradiation on the contaminated territories

Main gamma-emitters of Chernobyl release, and typical radionuclied ration in soil deposition presented in Table 1.

On Fig.2 the contribution and the time-dynamic of gamma-exposure for four main groups of gamma-emitters in Chernobyl deposition at the Ukraine territory are shown.

Irradiation from short-lived emitters 99-Mo, 132-Te, 239-Nb, 131-I, 140-Ba (140-La) were important components of the total external gamma-exposure during the first couple months after deposition. For the first year 95-Zr, 95-Nb, 103-Ru and 141-Ce made contributions, but since than, for some tens of years, only gamma-exposure of 137-Cs[1] (and radionuclides 106-Ru, 144-Ce, 134-Cs) have been of significance.

The exposure of long-term depositions depend on the process of penetration of these radionuclides in soil. This factor of attenuation had been calculated based on the gamma-spectrometric measurements of deep soil profiles selected on the contaminated Ukraine territory. The curves plotted on Fig.2 are the result of the process both the radioactive decay for each radionuclied and accepted attenuation function. Results of these calculations (the curve corresponded the total exposure from all the radionuclides) had been compared with direct daily measurements of EGER made at some reference meteorological areas[2].

---

[1]Actually this is 137mBa.
[2]This work was done together with A.Bouville (National Cancer Institute, USA) and L. Anspaugh (Lawrence Livermore National Laboratory, USA).

Table 1

Radionuclides composition of Chernobyl fallout

Reports			Zr 95	Nb 95	Ru 103	Ru 106	La 140	Ba 140	Ce 141	Ce 144	Np 239	Mo 99	Te 132	I 131	Cs 134	Cs 137	Ru103 / Ru106	Ce141 / Ce144	Nb95 / Zr95	average Ru103 / Ru106	average Ce144 / Ce141	average Nb95 / Zr95
1	SOUTH	2-zone	25	-	7.5	5	-	22.5	27.5	15	-	-	22.5	15	0.38	1	1.5	1.8	-	**2.1**	**1.65**	-
		3-zone	10	-	8	3	-	10	10	6	140	25	13	20	0.3	1	2.7	1.7	-			
	WEST	2-zone	5	-	3.5	2	-	7	4.5	3	45	7	19	15	0.5	1	1.8	1.5	-			
		3-zone	5	-	3.5	1.5	-	8	5.5	3.5	45	7	18	15	0.5	1	2.3	1.6	-			
2	IVANKOVSKIY		10	32	13	3.2	-	-	13	6.7	-	-	-	-	0.5	1	4.1	1.9	3.2	**4.5**	**1.45**	**3.4**
	VICHGORODSKIY		17	54	16	3.9	164	-	23	14	-	-	-	-	0.54	1	4.1	1.6	3.2			
	POLES-KIY	3-zone	6.5	21	9	1.5	-	-	5	4.1	-	-	-	-	0.51	1	6	1.2	3.2			
		2-zone	1.4	5.8	1.1	0.3	1.5	-	1.4	1.3	-	-	-	-	0.56	1	3.7	1.1	4.1			
		all	4.5	15	5.7	1	0.6	-	3.6	3	-	-	-	-	0.53	1	5.7	1.2	3.3			
3	ЛИРГ, 19....		-	-	1.7	-	-	0.9	-	-	-	-	17	10.5	0.54	1	-	-	-			
4	REG1		-	-	1.1	0.2	-	-	-	-	-	-	-	15	0.6	1	5.5	-	-	**4.4**	-	-
	REG2		-	-	1.2	0.2	-	-	-	-	-	-	-	33	0.6	1	6	-	-			
	REG3		-	-	1.3	0.3	-	-	-	-	-	-	-	16	0.5	1	4.3	-	-			
	REG4		-	-	1.0	0.4	-	-	-	-	-	-	-	7.2	0.5	1	3.5	-	-			
	REG 5		-	-	1.1	0.4	-	-	-	-	-	-	-	4.3	0.5	1	2.8	-	-			
5			6	-	6.8	1.5	-	-	12	4.2	-	-	-	-	-	1	4.5	2.9	-			
mean	1		11.2	-	5.6	2.4	-	12	12	7	77	13	18	16	0.42	1	**3.7**	**1.5**	**3.4**			
	2		9	28	10	2.2	-	-	11	6.5	-	-	-	-	0.53	1						
	3		-	-	1.7	-	-	1	-	-	-	-	17	10.5	0.54	1						
	4		-	-	1.2	0.3	-	-	-	-	-	-	-	15	0.54	1						
	5		6	-	7	1.5	-	-	12	4.2	-	-	-	-	-	1						
	1-5		10	28	7	2	-	12	12	7	**77**	**13**	**18**	14	0.5	1						
USED IN MODEL			**2.1**	**7.1**	**1.2**	**0.3**	**4.1**	**4.1**	**3**	**2.5**	**45**	**7**	**18**	**20**	**0.5**	**1**						

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From the other side, the formal analytical approximation of direct EGER measurements is able to give more simple mathematical form describing the change with time the gamma-irradiation which formed the external doses of people.

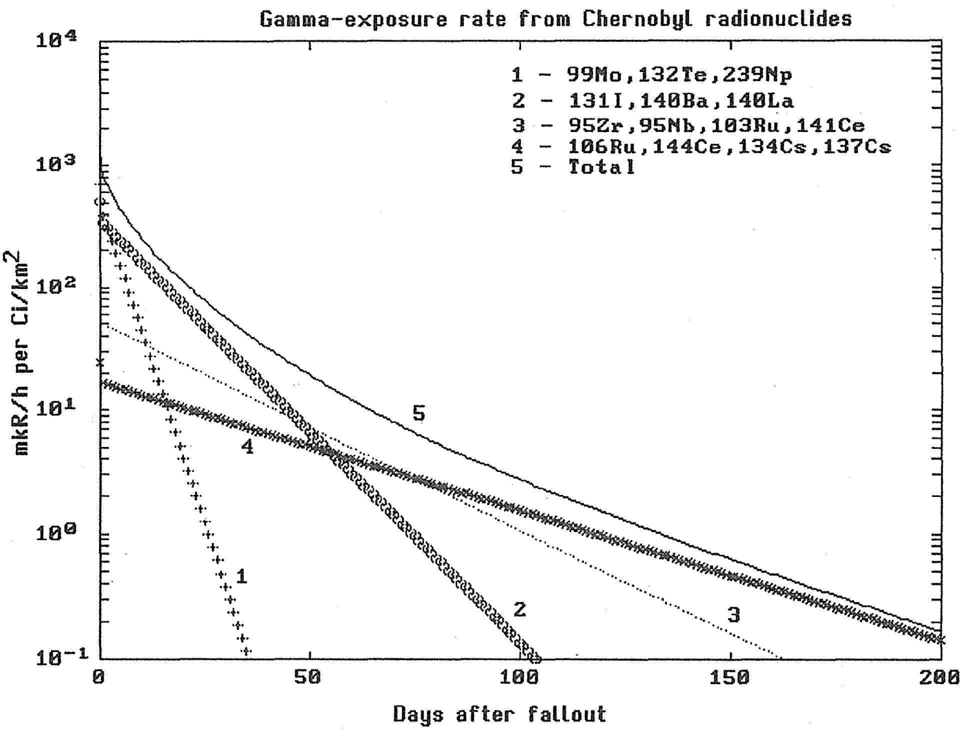


Fig.2. Contribution to the total gamma-exposure of four main groups of deposited radionuclides

On the Fig.3 the fitting function describing the dynamic of EGER ($P_\gamma(t)$) and points corresponding the results of direct EGER measurements normalized on the 137-Cs deposition density are presented.

It was founded [2] that the function $P_\gamma(t)$ could be approximated by the power function (for the time-interval 30-370 days, this part of curve is marked by index II) and two exponential function (for the time-period beyond the first year, this part of curve is marked by index III). These functions with the parameters estimated by the least squares method (non-linear estimation by Nalder-method) are:

$$P_\gamma(t)=\begin{cases} P_\gamma^{II}(t) = 2900 \cdot t^{-0.98} \quad ,30 \le t \le 370 \text{ days}, \\ P_\gamma^{III}(t) = 4.25 \cdot 10^4 \cdot \exp(-2.95 \cdot 10^{-2} \cdot t) + 8.28 \cdot \exp(-7.69 \cdot 10^{-5} \cdot t) \\ \qquad t > 370 \text{ days} \end{cases} ,(1)$$

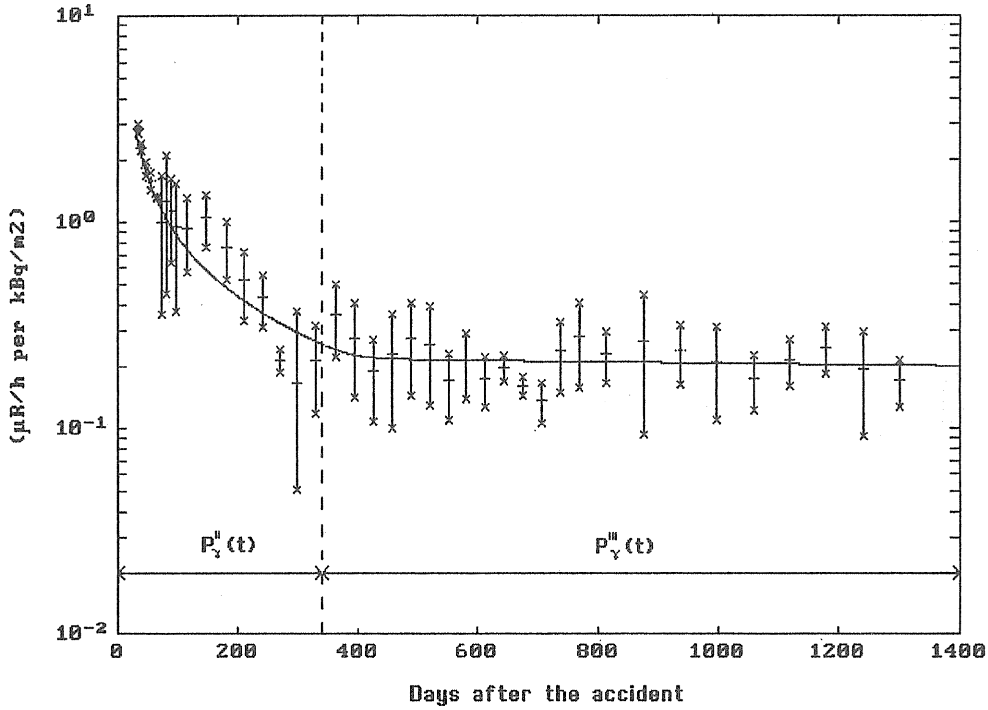


Fig.3. Data-set of direct measurements of EGER and fitting function used for description of time-dynamic of gamma-exposure

For estimation of external exposure D_i for members of some i-th group of people lived on the radioactive contaminated area (settlement) of Ukraine, the mathematical model was developed. In according of this model:

$$D_i\ (t) = K_{bi} \cdot D_{0i}\ (t) \quad , \qquad (2)$$

where D_{0i} is so called "reference settlement dose" corresponded the dose obtained in the case of spending the whole day (24 hours) on some hypothetical reference area. Reference area is characterized by the average level of 137Cs density deposition σ_0 for this settlement. K_{bi} referred as "behavior factor" is ration of dose really absorbed by member of i-th group to dose D_{0i}..

Dose D_{0i} is determined by the equation:

$$D_{0i}(t) = \alpha_i\ \sigma_0 \int P_\gamma(t)\ dt \ , \qquad (3)$$

where α_i - is the age-dependent conversion factor from gamma-exposure rate in air to the effective dose; $P_\gamma(t)$ is determined by eq.(1).

In Table 2 the accepted values of behavior factors for each of five population groups for summer, spring-autumn and winter seasons are presented.

Table 2

Behavior factors for the different groups and different seasons used in the model

i-th group	K_{bi}^{mod}		
	Winter	**Autumn-spring**	**Summer**
Children ≤7	0.11	0.12	0.15
Children 8-17	0.15	0.18	0.20
Employees	0.24	0.26	0.28
Agriculture	0.33	0.37	0.43
Pensioners	0.22	0.25	0.29

Used the values of behavior factors presented in Table 2 and eq.(1)-(3) the external doses for post-accidental period had been calculated.

2.The internal doses from ingestion of foods contaminated by radiociesium

Unlike the traditional models for the estimation of doses from ingestion of radioactive cesium (9-10), the main element in the model developed by the authors (Fig.4) for calculation of dose from ingested radiocesium of the Chernobyl accident is compartment depicted as Q which is "radiociesium body barden". This compartment is determined based on the direct Whole Body Counters (WBC) results.

As it followed from the scheme of Fig.4 two definitions for the intake function are used:

- "reference daily intake" q_r , which would be in the case if the system of countermeasures limited (including self limitations) the intake of locally produced foods is absented;
- "real intake function " q^* which is determined based on the direct WBC information.

Apparently that effectiveness of countermeasures can be estimated by comparison of reference q^* and real q_r intakes.

Because of daily intake is the time-function, the parameters of this function can be obtained by the approximation of WBC-measurements made in different post-accidental period.

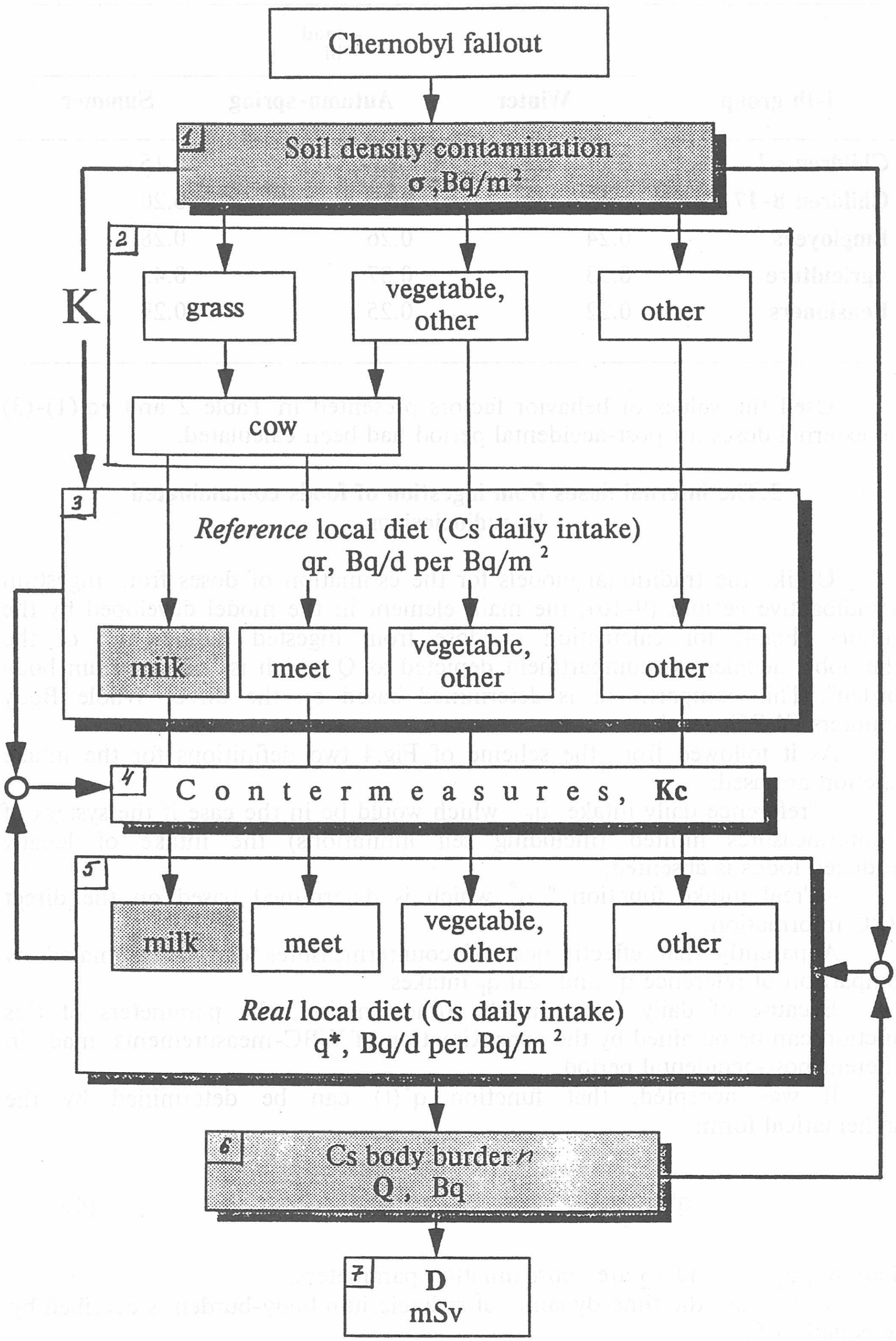
If was accepted, that function $q^*(t)$ can be determined by the mathematical form:

$$q^*(t) = a_1 e^{-\lambda_1 t} + a_2 e^{-\lambda_2 t} , \qquad (4)$$

where a_1, a_2, λ_1 and λ_2 are approximation parameters.

In this case the time-dynamic of radiociesium body-burden is decribed by the equation(5):

Fig. 4. Structure scheme for the estimation of internal dose from Cs−137 ingestion



$$Q(t) = \left(\frac{a_1}{\lambda_b - \lambda_1}\right)\left(e^{-\lambda_1 t} - e^{-\lambda_b t}\right) + \left(\frac{a_2}{\lambda_b - \lambda_2}\right)\left(e^{-\lambda_2 t} - e^{-\lambda_b t}\right), \quad (5)$$

It's obvious that values of parameters of function $q^*(t)$ reflect the rate of decreasing (λ_1 and λ_2) and absolute value (a_1 and a_2) of intake and also depend on the ecological condition (transfer coefficient radiociesium from soil to diet) and the level of countermeasures.

The parameters of function $q^*(t)$ had been obtained by the approximation of WBC-measurements of members of the public living in two large regions (oblast') of Ukraine which are Jitomir and Rovno. The territories of these regions had been very contaminated after the Chernobyl accidental release.

Besides, the territories of these regions are differed both the ecological conditions (type of soil which determine the process of migration radionuclides in soil) and types and quality of countermeasures.

When WBC-measurements were approximated the sub-population groups with people living in the same ecological and economic conditions were formed. Ecological specific of region was taken into account by introducing some general coefficient k_c, which calculated as ration of radiociesium concentration in milk to deposition density at the area where those milk had been produced.

For determination of k_c the large-scale work for selecting and gamma-spectrometric measuring of contaminated milk and soil have been organized. At those time more than 100 thousand samples of milk selected in more than 6000 settlements have been analized. Based on these results the special dosimetric maps for the territories of five regions (oblast) of Ukraine have been made.

It was founded that all the territory of Ukraine can be divided on four areas:

- territories with relatively non dangerous milk-meat production, $k_c \leq 1$ nCi/l per Ci/km^2 ;
- territories where minor risk of milk and meat contamination is existing, 1-5 nCi/l per Ci/km^2;
- territories with high risk of milk and meat contamination, k_c=5-10 nCi/l per Ci/km^2;
- territories with extremely high risk of milk and meat contamination, k_c>10 nCi/l per Ci/km^2.

On Fig.5 schematic maps of two areas with different levels of k_c are demonstrated.

The average and interval values of WBC-measurements results Qi, normalized on the radiociesium density contamination are presented. The fitting function according the eq.(5) is plotted at the same figure.

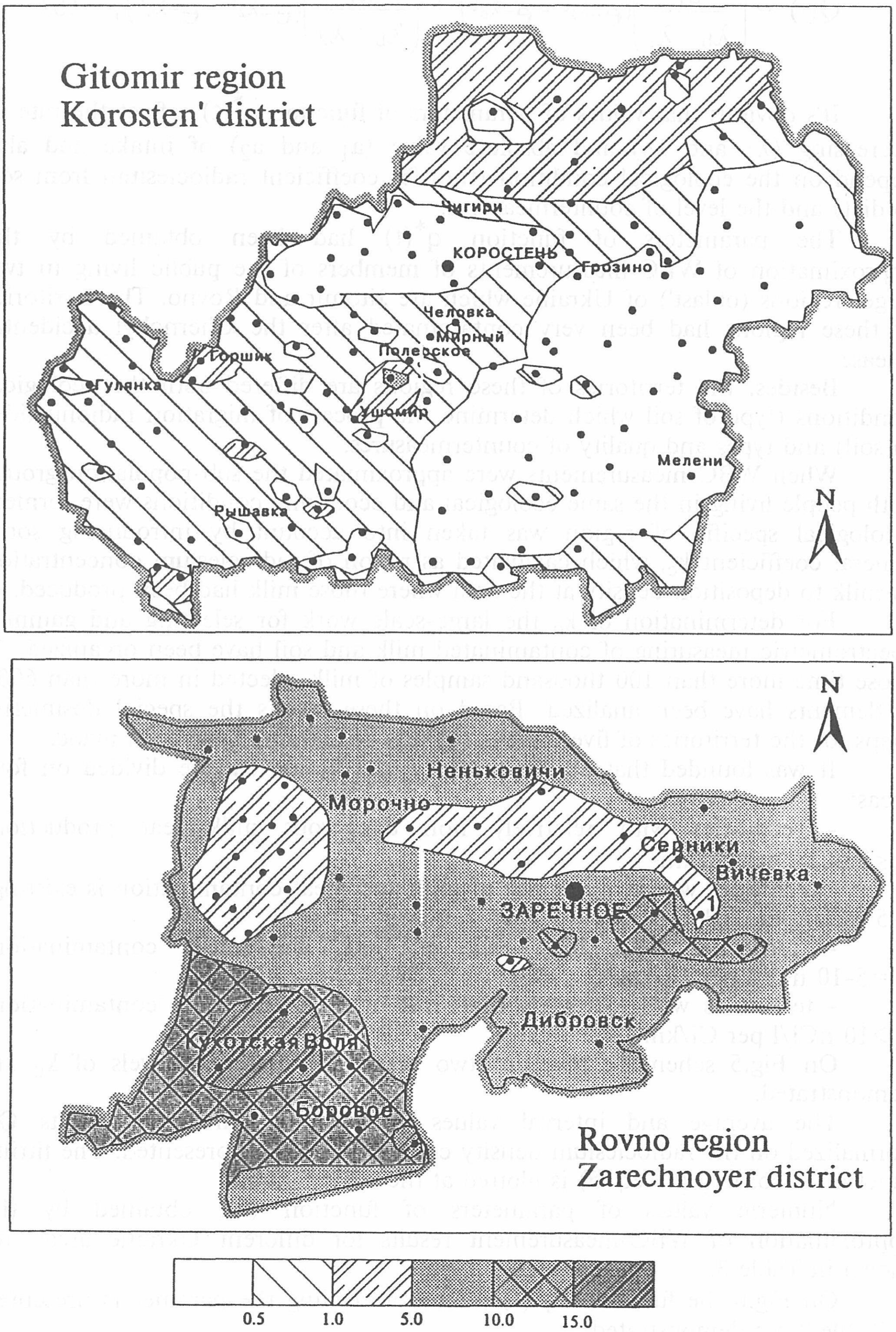
Numeric values of parameters of function (4), obtained by the approximation of WBC-measurement results for different Ukraine areas are shown in Table 3.

On Fig.6 the functions $q^*(t)$ plotted according the parameters presented in Table 3 are demonstrated.

Fig. 5. RATIO Cs-137 CONCENTRATION MILK-SOIL 1991-1992

(transfer coefficient)

nCi/l per Ci/km^2



nCi/l pei Ci/km^2

Table 3

Parameters of intake function

$$q(t) = a_1 \times exp(-\lambda_1 \times t) + a_2 \times exp(-\lambda_2 \times t)$$

obtained by the approximation of direct WBC – measurements

Gitomir region

k nCi/l per Ci/km^2	k–av nCi/l per Ci/km^2	a_1 nCi/day per Ci/km^2	a_2 nCi/day per Ci/km^2	T_1 log(2)/(365*λ_1) years	T_2 log(2)/(365*λ_2) years	λ_1 1/day	λ_2 1/day	N
≤ 1	0.5	0.85	1.0	0.92	6.6	0.002	0.00029	1894
1 – 5	1.9	1.1	1.1	1.0	8.5	0.0019	0.00022	3674

Rovno region

k nCi/l per Ci/km^2	k–av nCi/l per Ci/km^2	a_1 nCi/day per Ci/km^2	a_2 nCi/day per Ci/km^2	T_1 log(2)/(365*λ_1) years	T_2 log(2)/(365*λ_2) years	λ_1 1/day	λ_2 1/day	N
1 – 5	2.8	6.75	3.58	1.3	6.0	0.0015	0.0003	4595
5 – 10	7.4	8.6	5.9	1.2	10.5	0.0016	0.00018	1140
>10	16.8	38	5.6	1.0	8.1	0.0019	0.00023	2766

k – milk – soil transfer coefficient (nCi/l per Ci/km2);
k_av – average value milk – soil transfer coefficient (nCi/l per Ci/km2);
a_1, a_2, λ_1, λ_2 – parameters of intake function q(t);
T_1, T_2 – half – time of diet (environmental) loss, years;
N – number of WBC – measurements;
t – time after the deposition

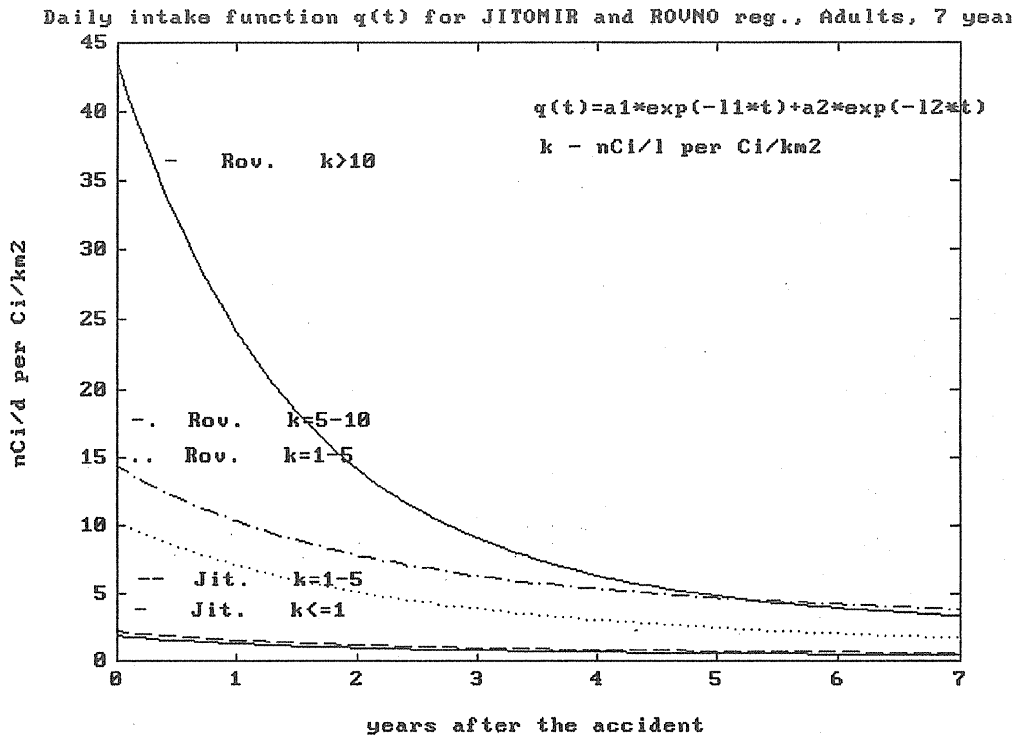


Fig.6. Fitting daily intake function q(t) for different areas of Jitomir (Jit) and Rovno (Rov) regions

The dynamic of radiociesium body burden Q(t) plotted for the cases if the daily intake described by the functions $q^{*}(t)$ with parameters from Table 3 are plotted on Fig.7.

3. Total external and internal (from incorporated radiociesium) irradiation of members of the public living on the contaminated territories

The models and procedures described in parts 1 and 2 give the possibility to create the system for realization the retrospective and prediction dose estimation for members of the public living on the territories contaminated by radiociesium.

Results of this work are presented in Table 4. Because of all the dose estimations in Table 4 are normalized on the radioceasium density deposition, the approach which was realized by authors gave the possibility to use only parameter σ for the retrospection an prediction of exposure of members of the public.

At the end of this part it's important to stress, that both the calculate procedures and obtained parameters can be considered only as the first version of the total exposure model of members of the public.

Table 4

Post-Chernobil expousure of members of the public (Ukraine) from radioactive soil deposition (external expousure) and 137-Cs food ingestion (internal expousure)

cSv per Ci/km^2

Area	k_c, nCi/l per Ci/km^2	Years after the accident								
		1			5			70		
		Ext	Int	Total	Ext	Int	Total	Ext	Int	Total
Kiev, Jitomir, Chernigov regions	≤ 1	0.07	0.03	0.10	0.15	0.10	0.25	0.36	0.21	0.57
	1 - 5	0.07	0.04	0.11	0.15	0.12	0.27	0.36	0.30	0.66
Rovno, Volin' regions	1 - 5	0.07	0.15	0.22	0.15	0.52	0.67	0.36	0.88	1.24
	5 - 10	0.07	0.26	0.33	0.15	0.81	0.96	0.36	2.0	2.36
	> 10	0.07	0.70	0.77	0.15	1.6	1.75	0.36	2.42	2.78

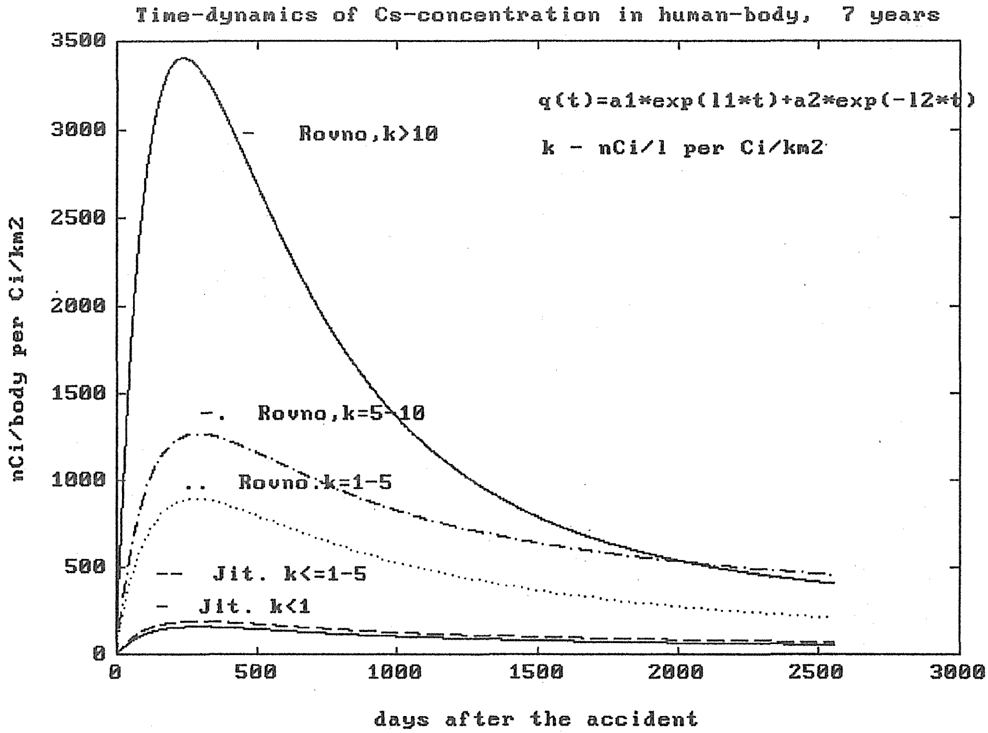


Fig.7. Dynamic of ciesium to-day burden for different areas of Jitomir(Jit.) and Rovno(Rov.) regions

Now in the laboratories of the Department of Dosimetry and Radiation Hygiene the work on modernization and more accurate definition of parameters are conducted. This investigation are carried out by involving new, more correct data and revision of quality of information used early for the creation of model. Important direction which is developed now is introduction new approaches for estimation of uncertainties and sensitivities of parameters of the model.

4. Irradiation of members of the public from ingestion of foods contaminated by 90 Sr

Model developed for estimation of doses from 90-Sr which is ingested with contaminated food is based on the values of age-dependence metabolic parameters for Sr, described in Publication 56 ICRP, both the values of waiting tissue factors and approaches of publication 60 ICRP and, also, default "effective diet of reference Ukraine man". According this "reference diet" 45% of 90-Sr intake with milk, 35% - with vegetables, 15% - with potatoes, 5% - with meat.

Very important area's parameters (as in the case of radiociesium) is transfer coefficient k_s (nCi/l per Ci/km^2). Direct measurements shown that for Rovno region this coefficient is about 6.26, for Jitomir region - 4.35 and for Volin' region higher than 10 nCi/l per Ci/km^2.

If daily intake of milk for "reference" (averaged for all the ages) inhabitants of Ukraine is 340 ml during one year, the annual intake of Sr with diet may be estimated by the relation:

$$\tilde{A} = 750\ k_S \cdot \sigma_S \qquad (6)$$

Apparently that the estimation gives by eq. 6 is very conservative because of the assumption that all the foodstuffs of diet are locally produced.

Real intake is about 2-5 time lower. This is in a very good agreement with the direct measurements of 90-Sr in autopsy materials.

Here we will not describe all the stages of calculation in the model, but final relation between density deposition σ and effective dose for "reference" member of the public in the case of consumption of 90-Sr with foods during 7 years is:

$$E = 150\ k_S \cdot \sigma_S\ ,\ \ \mu Sv \qquad (7)$$

5. Transuranium elements

One of the specific of Chernobyl accident was the high level of trausuranium elements in the accidental release: plutonium isotopes with atomic number 238-242, americium - 241, neptunium-239 and other. The main dose contributors among them are plutonium's alpha-emitters (238, 239, 240) and americium-241.

Main pathway of irradiation deals with those alpha-emitters is inhalation as a result of resuspension of the deposited materials, resuspension and other.

However, it's very important to stress that as long as beta-emitter 241-Pu is decayed, after 70-100 years after the accident, the relative radiation significance his daughter radionuclide 241-Am will achieve the maximum level, this level corespondents approximately 10-times increasing its level in environment compare to the amount released at the time of accident. At that the radioactive activity of americium will be about two time higher than alpha-activity of all the isotopes of plutonium.

Because of both the ecological and metabolic mobility of americium are higher than those for plutonium, the dose significance of 241-Am will be increased with time.

The calculations made in our department under conservative assumptions indicated that 241-Am concentration at the moment of there maximum level will not be higher then $(1\text{-}2)*10^{-4}$ Bq per L in water of Daiper. At that annual doses will not be higher than 1 μSv.

Concerning the pathway of irradiation throw the inhalation of resuspentions and aerosols, this factor, in the case if the wind's raising is 10^{-8} - 10^{-10} m^{-1} will be negligible small contributor in total dose.

However it must be taken into account that the relative dosimetric significance of 241-Am and other transuranium elements as the contributors to dose beyond the 70-100 years will be higher than significance of such main dose contributors of first then years after the accident as 137-Cs and 90-Sr.

6. Thyroid dose estimations after the Chernobyl accident in the Ukraine.

Irradiation of the thyroid gland is one of the most serious problem in the Chernobyl accident. There are some main tasks in this problem:

- continuous revision of the measured in 1986 activities of ^{131}I in the thyroid and individual thyroid doses estimations;
- retrospective thyroid dose reconstruction for the nonmeasured people;
- individualization of the thyroid dose assessments in the groups of population for the epidemiology of the radioindused thyroid cancers.

Table 5: Possible methods for retrospective thyroid dose reconstruction

Methods	Possibilities	Difficulties
Dynamic of air dose rate	Moderate	Moderate
Radionuclides ratios:		
- ^{137}Cs deposition	Moderate	Moderate
- ^{137}Cs in human body	Low	Low
- ^{90}Sr depositiion	Low	High
- ^{239}Pu deposition	Low	High
- ^{129}I deposition	High	High
- ^{129}I in thyroid	High	High
- ^{14}C in trees	High	High
Direct measurements of ^{131}I activity in thyroid (May and June 1986)	High	Moderate
Direct measurements of ^{131}I activity in thyroid engaged of the questionnaries data	High	Moderate

Table 5 shows the potential of various methods of carrying out the dose estimations. The methods are graded according to their feasibility (from the authors' point of view) on a three-step scale: high, moderate or low. In this context, 'feasibility' refers to two main factors: the possibility of constructing a model (system) and the level of technical and fundamental difficulties encountered in the process.

The most accurate and reliable estimations are obtained from direct measurements of ^{131}I activity in the thyroid gland, particularly when use is made of data relating to "real" behaviour patterns.

A further possibility is to use radionuclide ratios (using ^{129}I and ^{14}C is most perspective) or different kinds of interpolation and extrapolation (based on geografical aspects, age groups, or behaviour patterns).

6.1. Thyroid doses on thė basis of instrumental measurements.

All dose estimations are based on over 150 000 instrumental measurements of radioiodine activity in the thyroid which were taken in May-June 1986 [3].

For the thyroid dose calculations based on the direct measurements it is necessary to use the models for the functions of radioiodine intake to the organism. In this case three main types of uncertainties can be identified:

- uncertainties of the results of the direct measurements of ^{131}I activity in the thyroid;
- individual, group or ethnic variability in the anatomy of the thyroid and methabolism of iodine in the organism;
- noncomplete adequacy of the intake model.

Improvement of dose estimations for these contingents of the population are based, mainly, on such problems.

The uncertainties of the direct measurements of ^{131}I activity were estimated by means of a neck phantom [4]. Rather good quality of the measurements results for all types of the devices was confirmed in the modelling of the measurement process [5].

In the same study the influence of the thyroid mass and the thickness of the tissue overlying of the thyroid on the measurements results were investigated. Fig. 8 demonstrates the uncertainties due to the individual variability of the thyroid mass for the different types of the used devices.

Thyroid dose is proportional of the number of the ^{131}I decays in the unit of a gland mass. Therefore it is necessary to know the thyroid mass for individuals or, at least, for the group of population with the fixed age. For this purpose, the age-dependent thyroid mass for the Kiev inhabitants was studied. We can concluded that the age dependence of the thyroid mass for the city of Kiev corresponds to the values recomended in Publication 56 (Fig.9) [6].

A futher critical point for dose estimations is selecting the function describing the intake of ^{131}I into the body. In the first and second stages we used models with both acute and prolonged intake (Fig.10), the former being a typical inhalation model, while the later was an "ecological" one (involving foodstuffs contaminated with radioiodine).

The next stage in the development of a dosimetric calculation model is to use what are called "realistic intake functions". For example, we can use the dynamics of ^{131}I activity in air, milk or water as an intake function (Fig. 11).

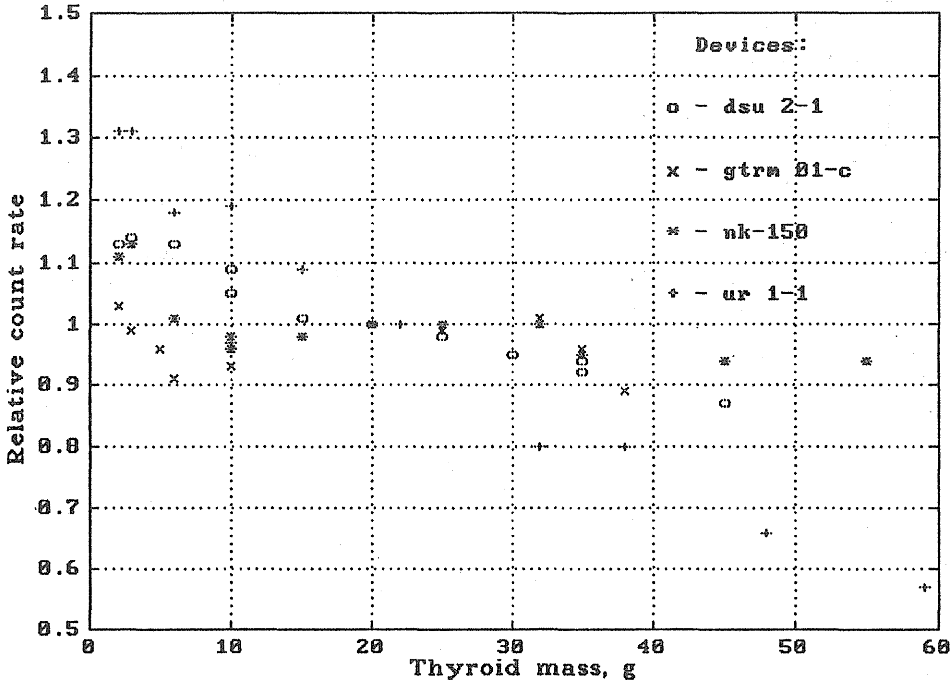


Fig. 8. INFLUENCE OF THYROID MASS ON RESULTS OF MEASURIMENT

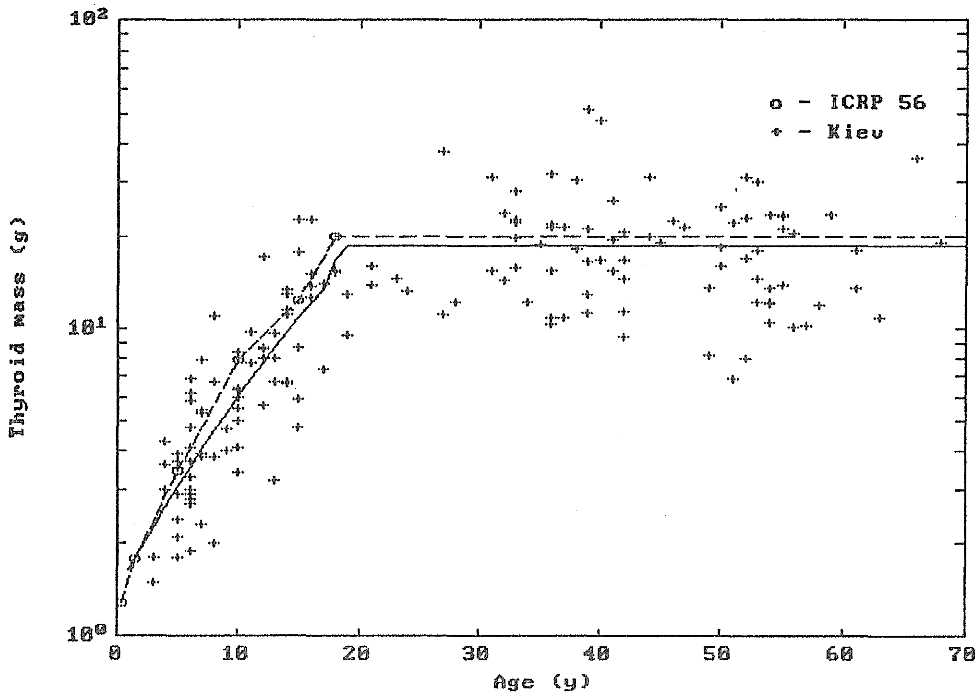
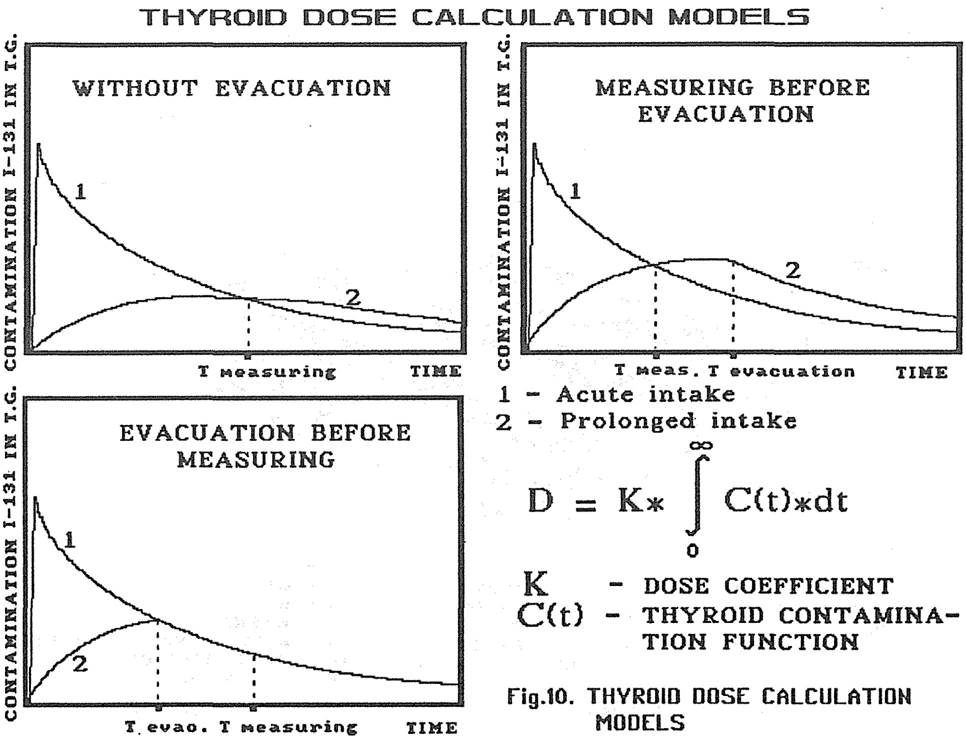


Fig. 9. Age-dependence of the thryroid mass for city Kiev



$$D = K * \int_{0}^{\infty} C(t) * dt$$

K - DOSE COEFFICIENT
C(t) - THYROID CONTAMINATION FUNCTION

Fig.10. THYROID DOSE CALCULATION MODELS

This method was applied to estimate the thyroid doses received by inhabitants of Kiev [7].

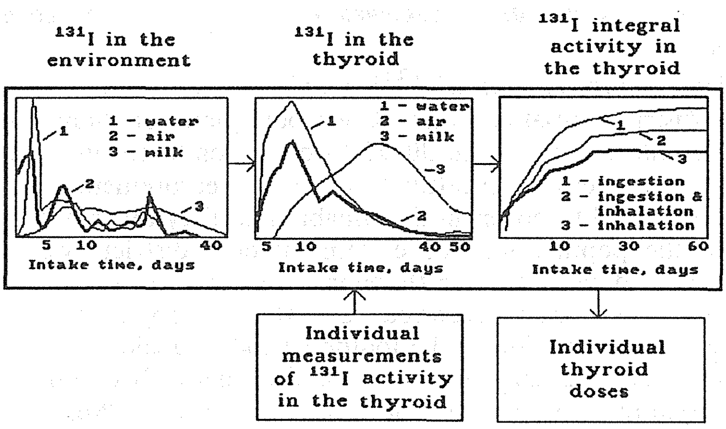
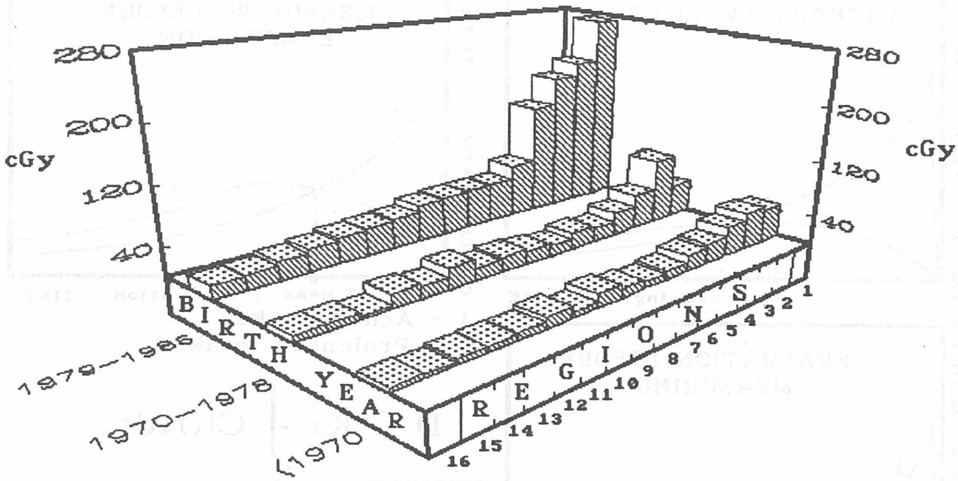


Fig. 11. DOSIMETRIC MODELS FOR THE THYROID DOSE RECONSTRUCTION



REGIONS:

1 - PRIPYAT TOWN
2 - NARODICHSKIE
3 - POLESSKIE
4 - CHERNOBYLSKIE
5 - IVANKOVSKIE
6 - MAKAROVSKIE
7 - BORODYANSKIE
8 - VYSHGORODSKIE
9 - OVRUCHSKIE
10 - KOZELETSKIE
11 - CHERNIGOVSKIE
12 - KOROSTENSKIE
13 - REPKINSKIE
14 - KIEVO-SVYATOSHINSKIE
15 - CHERNIGOV CITY
16 - OLEVSKIE

Fig.12. AVERAGE EXPOSURE'S DOSES OF THYROID GLAND

Based on the direct measurements and in accordence with the represented methods the thyroid doses of the population from the districts situated around the Chernobyl NPP were estimated. Fig. 12 shows average doses for three age groups of the people who lived in this region [3].

6.2. Estimation of the doses received by the groups not covered by direct measurements.

All the direct measurements of ^{131}I activity in the thyroid gland were performed in the districts situated around Chernobyl plant. In May-June 1986 measurements were taken from some 30-90 % of the children and 1-10 % of the adults in these areas. Unfortunately, the measurements in many settlements not only failed to cover all the inhabitants, they did not even cover all age groups of the population. For certain affected districts we have no available measurement data at all. We therefore need to work out a procedure for reconstructing the doses received by those people from whom measurements were not taken during the iodine period of accident.

Such a procedure was developed for the Chernigov, Kiev and Gitomir regions of the Ukraine (situated to the East, South and West from the Chernobyl NPP). It based on the following data:

- direct measurements of ^{131}I activity in the thyroid of 150 000 inhabitants of the Ukraine;
- ^{137}Cs depositions for the all settlements of the three regions;

- spherical co-ordinates of settlements with reference to the Chernobyl plant.

A strictly valid age dependence of the dose emerged for all districts of the territory. The observed values can be approximated by the empirical formula

$$\mathbf{D}(\text{age}) = \mathbf{K}\ \mathbf{a}^{\exp(-\mathbf{b}\ \text{age})},$$

where

D(age) - is the average dose for a given age (cGy);

K - is scale parameter describing radioiodine intake;

a - is a parameter representing thyroid dose in infants (age zero);

b - is a parameter defining the age-dependence of the dose (year^{-1}).

Lognormal distribution of the doses in any age group was assumed since precisely this distribution was found among the persons measured. As an example, Fig. 13 gives the individual doses measured and the estimated mean values in each age group for the inhabitants of one settlement. This figure demonstrates the agreement between the doses calculated on the basis of direct measurements and those obtained on the basis of model calculations of mean values for each age group, and also the possibility of reconstructing doses in age groups for which there are no thyroid activity measurements.

The next step in reconstructing the doses received by the population of districts in the region where no thyroid monitoring was performed is to extrapolate the scale parameter **K** of the age model to settlements in those areas. The extrapolation procedure was carried out using data on ^{137}C deposition and spherical co-ordinates relative to the Chernobyl NPP (radionuclide ratio and geographical extrapolation methods) [8].

The resulting spatial distribution of mean thyroid doses to children (under 6 months) and adults (over 18 years) in the Chernigov region is given in Fig. 14-15.

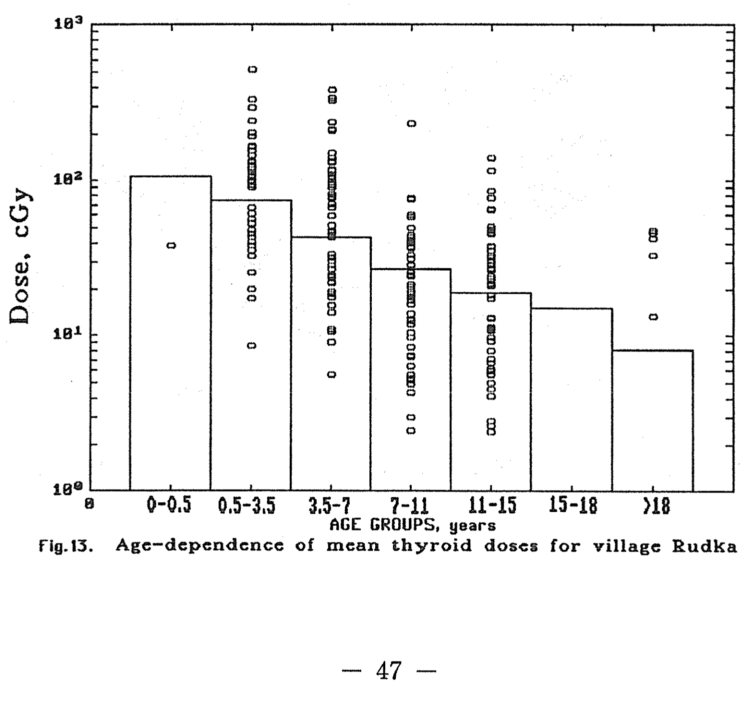


Fig.13. Age-dependence of mean thyroid doses for village Rudka

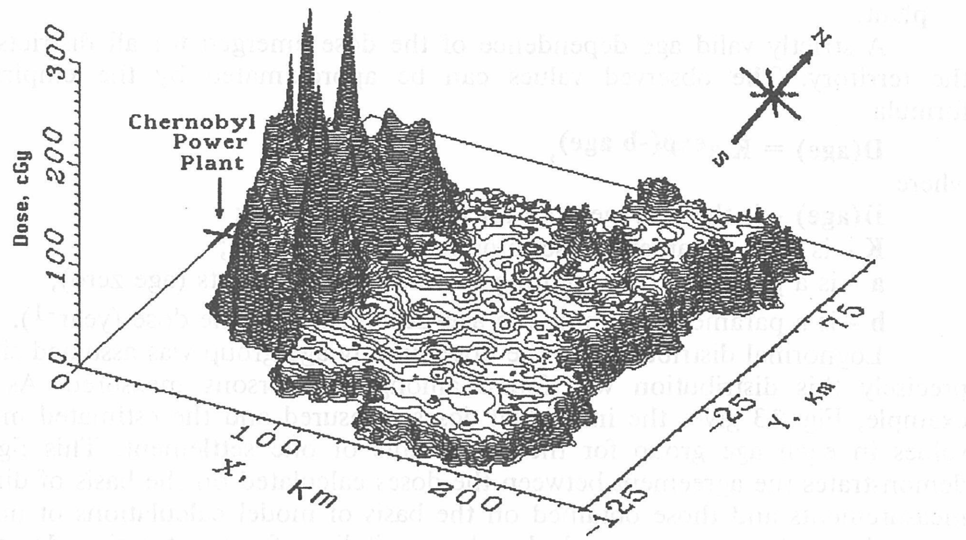


Fig. 14 THYROID DOSE DISTRIBUTION FOR CHERNIGOVSKAYA REGION (CHILDREN 1986 BIRTH YEAR)

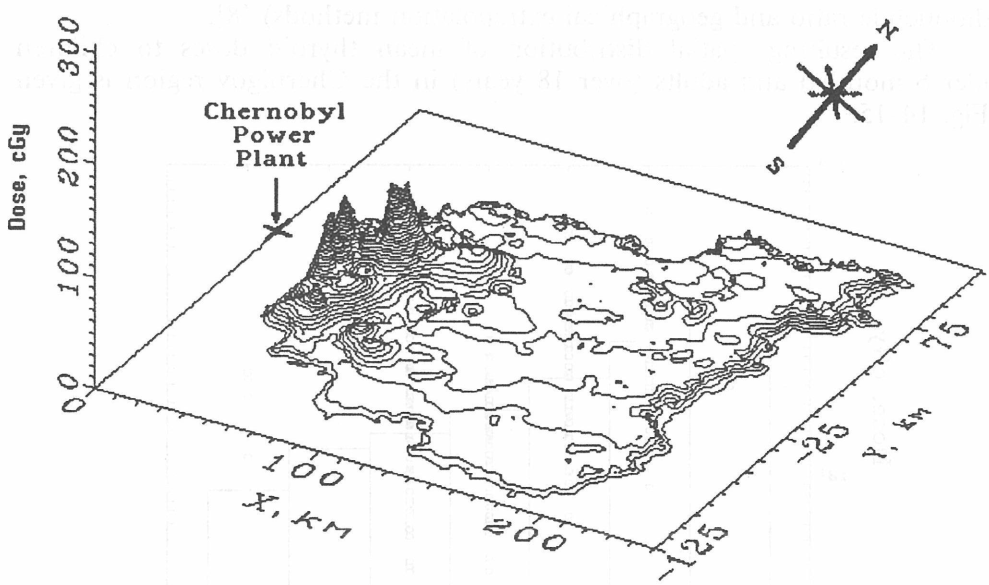


Fig. 15 THYROID DOSE DISTRIBUTION FOR CHERNIGOVSKAYA REGION (ADULTS)

6.3. Individualization of the group estimations

The special problem is to individualized the group estimations of the thyroid doses. This task can be solved by means of analysis of different behaviour factors, taking into account it time dynamic. Such invastigation is performed now based on the inquiry of the population (about 20 000 answers) with the help of special questionairy.

7. Evacuated people

This contingent of people can be devided on two subgroups.

First one includes the inhabitants of Pripyat-town had been evacuated during 36 hours after the first accidental release. Second one is formed from the inhabitants of Chernobyl-town and settlements of 30-km radius zone. Evacuation of these people had been finished only 10 of May 1986.

In both cases all the people were separated on the groups of people with ordinary and not ordinary behaviors.

The ordinary behaviour of person we call such one when this person didn't leave the place of his recidence (settlement, town) during all time before the evacuation. For this group of evacuated people the retrospective estimations of doses have been made based on both the analysis of the special formal questionnaires and direct measurements of external gamma-exposure rate in different points of settlements (town).

It was founded that average dose of inhabitants from Pripyat is about 1.5 sSv, and for the inhabitancies of settlements of 30-km zone about 2 sSv.

The maximum value of doses for the inhabitants of Pripyat arrived 5 sSv, for the inhabitancies of 30-km zone it was about 30 sSv.

According the same estimations the internal irradiation (excluding the thyroid exposure) is about 10% from the external exposure. Even today there are some problems deal with the estimation of doses of evacuated people.

If not ordinary type of behavior took place it was possible the obtaining of high-level doses by inhabitancies (including the children) from Pripyat which spent some time at 26-27 of April 1986 years not far from the 4-th Unit in "red wood" and at the places outside the town, where dose rate could be much more higher then inside the town. According our estimation the number of such persons is about 15% from the wholl amount of evacuated inhabitancies.

Another problem is the problem of dose individualization in different subgroups (these groups may be differed according the ages, professions, areas of living).

Finally the problem of validation of calculated individual doses is independent problem for that we are using some instrumental methods: electron-paramagnetic resonance for spectrometry of teeth enamel termolumiscent dosimetry of the material contained the silisium and other.

8. Liquidators

Liquidators create the group about 130 thousands persons (for Ukraine). The Main dosimetric problem for this contingent is problem of mass-making instrumental reconstruction (and revision) of individual doses. One of most perspective and fruitful method among them is the method of electron-spinresonans of teeth enamel and biodogical dosimetry based on the analyses of reciprocal translocations

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Discussion

Dr. Kumatori, (REA): May I have your evaluation of dose contribution from short- lived radiodine to the thyroid dose?

Dr. Likhatarev, (RCRM): For ^{133}I, it was not more than 30% compared with the dose from ^{131}I. For ^{133}I and ^{135}I, it was less than 2%. The external dose is important to consider, because it is 5 times more effective when compared with internal dose for inducing thyroid cancer.

- : May I have information on the surface contamination of ^{89}Sr in plants and that in milk?

Dr. Likhatarev, (RCRM): I will write it precisely in the proceedings. Radiostrontium has no self-purification mechanism and thus it is different from cesium. We can't be optimistic regarding dose from radiostrontium, because the amount residing in the environment will be the same as ^{137}Cs 20 years from now. We estimated the dose not taking into account the mechanisms of the ecosystems. We may have a different sense to radioeclogists for the movement of radionuclides in the environment.

RADIATION AND THE THYROID: A MODEL OF INVESTIGATION

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Abstract

The thyroid is an ideal organ for the investigation of radiation-induced disease since thyroid glands are sensitive to both internal and external radiation and patients with radiation-induced thyroid disease can survive for a long time. Therefore, the investigation of radiation-induced thyroid disease can be performed on all subjects in a certain cohort at the same time using the same protocol. Principles in the investigation on radiation-induced thyroid disease consists of 1) to make a correct diagnosis in every subjects in a cohort, 2) to determine a correct radiation-dose and 3) to select the most appropriate statistical or epidemiological methods.

According to the principles, a model of the investigation was performed on atomic bomb survivors in Nagasaki more than 45 years after the explosion of atomic bomb. Subjects were cohort members of the Nagasaki Adult Heath Study whose radiation dose had been determined by DS 86. Diagnosis of thyroid disease in every cohort members was made by thyroid experts using ultrasonography and the prevalence of each thyroid disease was analyzed using linear logistic models with sex, age at the time of bombing and DS 86 thyroid dose. The results have shown the clear dose-response in thyroid solid nodule(s) and autoimmune hypothyroidism even 45 years after the atomic bomb explosion.

Questions in the investigation of thyroid disease due to Chernobyl accident are as follows: 1) is diagnosis correct in all subjects in a cohort? 2) is correct radiation dose available in all subjects in a cohort? and 3) is epidemiological analysis performed using reliable data? It is very import to answer to these questions in the thyroid investigation in Chernobyl.

Introduction

The thyroid in an ideal organ for the Investigation on Radiation-induced disease because of reasons shown in Table 1. In the investigation on radiation induced thyroid disease, it is essential 1) to make a correct diagnosis of thyroid disease in all subjects in a cohort, 2) to measure correct thyroid radiation dose in all subjects in a cohort and 3) to employ the most appropriate statistical and epidemiological analysis including the prevalence of each thyroid disease, thyroid radiation dose, age, sex and the other environmental factors.

Table 1 RADIATION AND THE THYROID

1. The thyroid glands take up radioactive iodine released at atomic bomb explosion and nuclear plant accidents (internal radiation).
2. The thyroid glands are sensitive to external radiation at atomic bomb explosions and from radioactive fallout.
3 Patients with radiation-induced thyroid disease can survive for a long time. Therefore, the investigation of radiation-induced thyroid disease can be performed on all subjects in a certain cohort at the same time using the same protocol.
4. The prevalence of thyroid disease in normal controls is higher than that of other radiation-induced disease, which is an advantage for epidemilogical studies.

The Thyroid is An Ideal Organ for the Investigation on Radiation-induced Disease.

This presentation includes two studies; studies with correct thyroid radiation dose and without correct thyroid radiation dose using the results obtained from atomic-bomb survivors in Nagasaki. Then the results of atomic bomb survivors will be compared to those in Chernobyl accident.

Studies on Atomic Bomb Survivors

Subjects were cohort members of the Nagasaki Adult Health Study and thyroid radiation dose of every members in this study was determined according to DS 86 (1).

In order to make a correct diagnosis of every members, methods shown in Table 2 were employed. Procedures to make final diagnosis must be the same in all patients. Therefore, diagnosis with histological examinations was employed only when operation was performed since needle or aspiration biopsies were performed in not all patients. Diagnosis employed in this study is shown in Table 3.

Table 2 METHOD

1. Detailed personal records (radiation dose, family history, past history, living place etc.)
2. Diagnosis of thyroid abnormalities by ultrasonic analysis (quantity and quality). (2)
3. Measurements of T4,fT4, T3, TBG, TSH, as well as thyroid autoantibodies in collected bloods.
4. Medical examination by thyroid specialists.

If some abnormalities are present by the above examinations, and are designated as clear pathological cases, the patients are referred for further medical examinations to Nagasaki University Hospital where they get a final diagnosis.

Table 3 Diagnostic Criteria

1) Nodular lesion
   - Solid nodule
     - histologically determined
       - cancer, adenoma, adenomatous goiter
     - histologically undetermined
   - Cyst

2) Hypothyroidism
   - Spontaneous
     - antibody positive
     - antibody negative
   - Postablative

3) Hyperthyroidism

4) Diffuse non-toxic goiter
   Antibody positive
   Antibody negative

Statistical analysis was performed as follows: The prevalence of each thyroid disease was analyzed using linear logistic models with sex, age at the time of bombing (ATB) and DS 86 organ dose to the thyroid. A quadratic term of the dose was included to examine the linearity in the dose-response, and the terms regarding the interactions between the two factors of sex, age ATB and dose.

The most appropriate model was selected for each thyroid disease by means of deviance; when a model with the interaction of dose with sex was selected, the most appropriate models was selected separately for males and females in the subclass of the models of the similar form. Once the most appropriate model was selected for each thyroid disease, significance tests of parameters in the model were conducted using likelihood ratio statistics.

Dose-response relationship was observed in solid nodule which includes cancer, adenoma and histologically undetermined nodule, and solid nodule was found significantly more in female and prevalence of nodule increased as the age at the time of bombing decreased.

Antibody positive spontaneous hypothyroidism (autoimmune hypothyroidism) also showed a significant dose-response. However, the prevalence of solid nodule showed a monotone dose-response, while that of autoimmune hypothyroidism displayed a concave dose-response relationship reaching a maximum level at 0.7 Sv. A concave dose-response relationship indicates the necessity for further extensive studies on the effects of relatively low dose of radiation.

Studies in Inhabitants in Nishiyama District

The Nishiyama district was protected by a mountain from direct exposure to the atomic bomb but it did receive the radioactive fallout. In 1969 137 Cs radioactivity in the soil was twice that in a non-fallout area and 239Pu in soil and plants was also significantly increased in 1990. (3)

247 people had lived in Nishiyama district for at least 10 years after the explosion and are still living in Nagasaki City. All 247 people were asked to visit the thyroid clinic of the Nagasaki University and 184 (75%) were examined. The controls were 368 age and sex matched individuals living in Nagasaki City. Diagnosis of every subjects were performed according to the method shown in Table 2.

Table 4 shows prevalence of thyroid disease in the fallout area and in the control area (4). Although many patients with thyroid disease were found in the fallout areas, a significant differences was found only in solid nodule, and 5 out of 9 patients with thyroid nodule were younger than 10 years old at the time of explosion.

Table 4 PREVALENCE OF THYROID DISEASE

Diagnosis	Fallout (n=184)	Control (n=368)
Solid nodule	9 *	3
Cyst	8	8
Hyperthyroidism	4	1
Hypothyroidism	4	10
Non-toxic diffuse goitre		
autoantibody negative	5	14
autoantibody positive	4	15
Autoantibody positive without goiter	18	30

* Significantly increased ($p<0.05$)

Questions to Thyroid Investigation in Chernobyl

According to the principles in the investigation of thyroid disease in atomic bomb survivors in Nagasaki, several critical questions could be raised to thyroid investigation in Chernobyl.

Table 5 Is Diagnosis Correct in All Subjects in a Cohort?

1. Procedures of screening and confirmation of diagnosis must be the same in all subjects in a cohort regardless of contamination by radioactive materials.
2. Histological diagnosis must be performed by the same indication regardless of contamination by radioactive materials.

Table 5 shows questions with regards to diagnosis and prevalence of thyroid disease. In order to avoid the bias procedures of screening and indication of histological diagnosis (biopsy or operation) must be the same regardless of contamination by radioactive materials.

The second question is shown in Table 6. In order to determine the dose response relation, radiation dose in all subjects in a cohort is essential. Although many methods have been employed in determining the thyroid radiation dose, there are still critical problems as shown in Table 6. Furthermore, environmental factors which may change the radiation dose and may change the sensitivity to radiation must also be examined very carefully.

Table 6 Is Correct Radiation Dose Available in All Subjects in a Cohort?

1. Reconstruction of thyroid dose in each subject
   - how accurate?
2. Areas of contamination
   - what kind of isotopes; iodine; cesium or etc.?
   - where and when each subject have (had) been living?
3. Eiviromental factors
   - how much dietary iodine intake?
   - when and how much iodine supplementation?
   - other compound?

4. Direct measurement of thyroid ^{131}I

how accurate?
when measured?

The final question is shown in Table 7. After the Chernobyl accident, many children with thyroid cancer were found in Belarus and Ukraine but not in Russia. Although many patients were found in every year since 1989 in Belarus and in Ukraine, it is not clear yet the increase of the number of patients is the real increased incidence in epidemiological investigation. Furthermore, it is not clear yet whether thyroid cancer in children is due to radiation or not, since in the very similar contaminated areas, thyroid cancer was found in Belarus but not in Russia.

Table 7 THYROID CANCER IN CHILDREN

1. 225 cases in Belarus
2. 158 cases in Ukraine
3. 3~5 cases in Russia

Question 1. Is the incidence of thyroid carcinoma increased after the Chernobyl accident?

Question 2. Is the cause of thyroid carcinoma due to radiation by the Chernobyl accident?

It is very important to answer to these questions in studies on thyroid disease in Chernobyl.

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Discussion

Dr. Okajima, (RERF, Nagasaki): Thyroid function is more affected by external radiation. Does it hold in the case of long-term and low exposure?

Dr. Nagataki, (Nagasaki Univ.) : There are 100 to 300 thousand patients to whom I-131 was administered. Any statistically significant increase in thyroid cancer has not yet been reported. In the case of external exposure, some rads exposure can induce statistically more thyroid diseases when compared with controls, as reported in Israel. We have no information on the induction of thyroid diseases when I-131 was administered repeatedly as a treatment for thyroid cancer. The reason is not clear but external exposure is likely to be more detrimental.

Dr. Likhtarev, (RCRM): Twelve cases of radiation induced thyroid cancer was detected in children by epidemiological studies. This implies that thyroid cancer will be induced in 40 cases per 106 individuals. The increase in thyroid cancer cases for children is reasonable when taking into account the population dose to thyroid in the Ukraine.

Dr. Ramzaev, (IRH): According to the ICRP, 70 cases of thyroid cancer per 106 person rem are induced by external expose. From internal exposure to iodine-131, the incidence decreases to one-third to one-forth when compared with the external dose. It is a mystery to us why such an increase has been found in the Ukraine and Belarus. I think there will be less than 10 cases when every case of thyroid cancer is counted and the incidence is expressed per106 individuals. Does the survey by Sasagawa Health Foundation show positive or negative increases in thyroid cancer in the Ukraine? Is there any difference in the diagnosis by doctors between Ukraine and Belarus?

Dr. Nagataki, (Nagasaki, Univ.): We have no conclusive result on a relationship between the incidence of thyroid cancer and dose in the screening tests of about 60 thousand children. We found differences in the incidence of disease among the 5 medical cancers. Statistically many cases of autoimmune diseas have been found. There is little difference in either the level of radio active contamination or the incidence of thyroid abnormally betweenrespective centers. A large incidence of nodularity has been found by Ultrasonic diagnosis by the Sasagawa Health Foundation. No treatment was undertaken. Cooperation with local doctors is required.

Dr. Likhtarev, (RCRM): The ICRP investigation indicated that in Russia there is no incidence of thyroid disease while in Belarus many cases of the disease were found. Which statistic is incorrect?

Dr. Ramzev, (IRH): In Russia we had an increase in morbidity of 60%. We predicted an increase of 2 to 15% based on the risk factor that the ICRP recommended. Diagnosis for children living in the areas not heavily contaminated with radioactivity is important to get conclusive results on this subject. I believe that the difference between 60% and 2 to 15% could be due to errors caused by different diagnosis.

Dr. Matsudaira, (NIRS): The induction of thyroid carcinogenesis is due to occur approximately 10 years after initial exposure.

Dr. Likhtarev, (RCRM): The latent period of thyroid cancer varies with age. We have data for the latent period of 5 years for children, so it is reasonable to have had no incidence of cancer up until 1989. The investigation by Sasagawa Health Foundation is not an epidemiological study. I believe the purpose of their investigation should be changed to epidemiological monitoring so as we can use their data more effectively.

Dr. Nagataki, (Nagasaki Univ.): The Sasagawa Project is a cooperative work based on humanism and does not intend to carry out an epidemiological survey. We too wish that the Foundation will do on epidemiological survey of which results can be more effectively used.

Dr. Suzuki, (NIRS): How do areas deficient in iodine relate to the incidence of thyroid diseases?

Dr. Nagataki, (Nagasaki Univ.): The relationship is not simple. We are now investigating the iodine intake of individuals because it can have an influence on the incidence of thyroid diseases. We have not yet obtained clear results. Both Gomel and Kiev are low iodine areas and intake is various.

Belarus, Russia, Ukraine, Japan
International Workshop on Assessment of the Health and Environmental Impact from Radiation Doses due to Released Radionuclides

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Haematological diseases in the affected areas due to Chernobyl accident

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《Abstract》

The Chernobyl-Sasakawa Medical Cooperation, one of the big international projects, started in Februray 1990 by the request of the government of the former Soviet Union to the Sasakawa Memorial Health Foundation (SMHF), which has an international reputation in the field of medical cooperation.

After the ceremony to donate the mobile units for medical examination in the Red Square in Moscow on April 26, 1991, they started the medical examination in the five regions, one in the Republic of Russia (Klincy), two in the Republic of Belarus (Mogilev and Gomel) and two in the Republic of Ukraine (Kiev and Korosten). Examination points are three, (1) hematological disturbances, (2) thyroid disorders and, (3) radiation dosimetry by whole body counting..

The subjects are children 16 years of age or less, who are most susceptible to radiation effects.

The hematological examination items are white blood cell (WBC) count, red blood cell (RBC) count, platelet count, hemoglobin (Hb), hematocrit (Ht), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC) and leukocyte differenciation.

From May of 1991 to December 1992, a total of 25,000 individuals were examined at five centers in three Republics.

According to accumulated results obtained in the first two years of five-year-project, most of the children who lived in non and high contaminated rayons showed the within normal range in value WBC, Hb level and white blood cell analysis. And there was no special difference against these hematological examinations dsepend on the ^{137}Cs whole body counts, and no cases of hematopoietic disorders or hematopoietic malignancies in the examined children. However, we believe that continued examination will allow us not only to indentify abnormal cases, but also to conduct analysis based on dosimetry and establish a database for long term follow-up.

1. Introduction

To contribute to the humanitarian efforts in supporting and helping the victions of Chernobyl disaster, which worsended the environmented conditions in the three republics affected, Belarus, Ukraine, and Russia; produced great anxiety among the population; and caused serious health hazards, the Chernobyl Sasakawa Health and Medical Cooperation Project commenced the screening activities at each of the five centers; Mogilev, Gomel, Kiev, Korosten, and Klincy.

The course of the examination included the following: (1) collection of disease history, filling in of questionaircs; (2) anthrompometric data ; (3) dosimetric measurement with a whole body counter; (4) ultrasonography of the thyroid; (5) general blood cell count; (6) determination of thyroid hormones in the serum; (7) determination of iodine and creatinine in the urine; and (8) examination by a pediatrician.

In this paper we report the Project activities from May 1991 to December 1992 on the hematological examination to see if any increase in incidence of radiation induced haematopoietic disorders including leukemia among the children.

2. Material and Methods

The study subjects were children born between 26 April 1976 and 26 April 1986 and crrently five to fifteen years old. Untill the end of December 1992, 6496 Children were examined in Gomel, 3764 in Klincy, 3499 in Kiev, 5265 in Korosten, and 6129 in Mogilev (tolal 25153).

Hemotological tests were carried out for the following eight parameters: (1) white blood cell count (WBC); (2) red blood cell count (RBC); (3) hemoglobin concentration (Hb); (4) platelet count (PLT); (5) hematocrit(Ht); (6) mean corpuscular volume (MVC); (7) mean corpuscular hemoglobin concentration (MCHC); (8) mean corpuscular hemoglobin (MCH). Blood testing was conducted with a hemoanalyzer System K-1000 (SYSMEX).

Special EK-0205 vacuum tubes (TERUMO JAPAN) were used for blood sampling. The peripheral blood hemogram (neutrophil, lymphocyte, monocyte, eosinophil and basophil) was analyzed with an Olympus-BH-2 microscope.

3.Results

First, we studied the trend with aging and the normal range of our subjects of the hematological data. On the basis of these studies, we analysed the data related to the radiation dose.

The hematological data by subdistrict (rayon) of the each district (oblast) are analysed by the box-and-whisker plots and examined the relation with Cs-137 contamination levels (Ci/Km^2). In the Eliskii, Kormyaskii, Hoynikskii and Checkerskii rayons of the Gomel oblast, Cs-137 activity was measured >5 Ci/Km^2. But, no statistical evidence was found of difference between the abnormality rate on hemoglobin, WBC, platelet counts, lymphocytes, neurophil counts, and MCV for the rayons with high Cs-137 activity and the data for the control rayons in Gomel[1).

The deviation of hemoglobin level, WBC, platelet counts, MCV, lymphocyte, neutrophil, eosinophil and monocyte counts from normal limits and Cs-137 specific whole body activity are also examined. A hemoglobin level below normal was found in seven boys (0.1%) and seven (0.1%) girls. A hemoglobin level above 160g/L was found in two boyds (0.01%) and seven (0.1%) girls. A decrease in WBC was observed in 16 (0.2%) boys and eight (0.1%) girls while an increase in WBC observed in 178 (2.7%)boys, and 141 (2.2%) girls. A platelet counts below 100 X 10^9/L was found in 24 (0.4%) children, and above 440 X 10^9/L was found in 136 (2.1%) children. An MCV below 80 fl was noticed in 388 (6.0%) children examined subjects. No trend toward a deviation from the normal range when the blood parameters were arranged according to level of radionuclide accumulation was noted.

Concerning the white blood cells, a decrease and increase in lymphocyte counts were noted in 25 (1.3%) and 351 (18.1%) children, respectively. A decrease and increase in neutrophil counts were observed in 23(1.2%) and 71 (3.7%) children, respectively. Eosinophilia was found in 402 (20.7%) children. A decrease and increase in monocyte counts were found in 244 (12.5%) and 46 (2.4%) of the children, respectively.

No relationship related to the whole body Cs-137 count per body weight (Bq/Kg) was also observed.

In the Mogilev region[2], the highest Cs-137 activity, 8.47 Ci/Km^2, was detected in the Krasnopolskii rayon. In the Kiev region[3], many children of the Polesskii, Irankovski, Viskgorodskii rayons, all near Chernobyl, were found to have high body Cs-137 doses of 2200 Bq/Kg. In the Zitomil region[4], the Ovruchskii and Narodichskii rayons showed 2.15 Ci/Km^2 Cs-137 activity, and the Korostenskii rayon showed 5-15 Ci /Km^2. In the Kincy city and Klintsovskii rayon of Bryansk region, the minimum and maximum levels of Cs-137 were 0.95 and 3.15 Ci/Km^2, respectively[5]. But no increase of hematological abnormalities involving leukemia or evidence of a difference between these high-activity areas and control areas was found.

4. Discussion

Through the above-mentioned results, the incidence of hematological abnormality does not appear to always increase in the contaminated area as compared with control area. The data on atomic-bomb survivors in Hiroshima and Nagasaki tells us that, even if the incidence of leukemia increases in the exposed population after the Chernobyl accident, this increase will not appear until ten or more years after the accident[6,7].

The 1991 technical report of the international Chernobyl project conducted by International Atomic Energy Agency (IAEA)[8] stated the incidence of lymphatic and haematopoietic cancers per 100,000 reported were 19 (69 cases in 1987) and 25 (90 cases in 1988) in the Obninsk register, and 12.1 (1982) and 15 (1989) for All UKrSSR, 13.3 (1982) and 17.8 (1989) for Ovruch, Narodichi and Polesskoe (UkrSSR) and 15.8

(1989) for all BSSR. The 1989 data for UkrSSR and BSSR are similar to those reported in eastern Europe (15.8 for the German Democratic Republic, 7.1 for Hungary, 15.4 for the city of Cracow in Poland). Thus, the data that were reviewed do not support contentions that there has been a clear and major increase in the incidence of leukemia in the contaminated regions.

On the other hand, Bebeshka et al[9] reported that a total of 18 patients with acute leukemia (16 cases of them had acute myeloblastic cell leukemia, one had acute lymphocytic leukemia, and another one had acute promyelocytic leukemia) from those exposed to radiation when they had liquidated the consequence of the accident at the Chernobyl Atomic Power Station[9]. Ivanov[10], Osechinsky[11] and Ivanov[12] reported no increase of hematolgoical disorders in chidlren and adults from the hospital surveillances in their respective study areas of the former USSR.

Currently many projects, for example, the International Programme on the Health Effects of the Chernobyl Accident (IPHECA), the Chernobyl Sasakawa Health and Medical Cooperation Project, and the Chernobyl Registry, are underway in the republics of Belasses, Ukranie, and Russia. We believe that the enthusiastic continuous conduct of these projects will surely reveal the future influences on human health of the Chernobyl accident.

Accknowledgement

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Discussion

Don't you think that you need to analyze the morphology of cell nucleus?

Dr. Kuramoto (Hiroshima Univ.): I think it is important. However, at present we are not able to include it as an item in our examinations.

When you examine 25,000 children, statistically you have the possibility of finding an malignant tumor. What do you think about such a situation.

Dr. Kuramoto (Hiroshima Univ.): There is a possibility that the anemia may be its cause. We think detailed examination of the cases with malignant tumors is necessary.

After this presentation, collaborative research between CIS and Japan was proposed for some diagnostic techniques.

Comments by Dr, Kuramoto (Hiroshima Univ.) and Dr. Matsudaira (NIRS)

Dr. Kuramoto, (Hiroshima Univ.): Dr. Ramzaev insisted that improvement in the accuracy of dose measurements and diagnosis and the mitigation of fear of the health consequences are urgently probrems that need to be solved. Dr. Kuramoto has expressed the following comment. It is desirable to establish a relationship between dose and the incidence of disease. Dose must be determined accurately. For this purpose, reconstruction of the dose due to ^{131}I is measurements of ^{129}I. In the presentation by Dr. Likhtarev, dose was estimated taking into account the various conditions of exposure in the Chernobyl accident. Dr. Kuramoto expressed his feelings that the model by Dr. Likhtarev is, from the epidemiological standpoint, an objective one. Dr. Likhtarev was very careful to ask patients precisely then food customs and life patterns. Dr. Kuramoto was interested in developping a model that takes into consideration seasonal changes in food customs and life patterns. He expressed that there is an urgent need to establish the rate at which leukemia is induced due to radiation. As for leukemia in children, there were no cases of limphocytic leukemia among atomic bomb survivors from Hiroshima and Nagasaki. According to the report from Kiev,they observed 16 cases of myelogenous leukemia and 2 cases of limphocytic leukemia. He expressed that improved diagnosis is needed so as to be able to distinguish the various kinds of leukemia accurately. Half of the patients suffered from types of leukemia that can be cured. As for individuals, there is a concern and fear that they will suffer from incurable diseases as a result of the accident. He hopes that through early diagnosis and early medical treatment, relationship between the incidence of cancer and dose will be established and lead to appropriate countermeasures. He also extended that there is a need for the exchanges of information between Japan and CIS countries.

Dr. Matsudaira (NIRS): He has expressed the following comment. His concern is to know the relationship between dose and the occurence of cancer. There is a requirement to carry out an epidemiological study on selected groups of subjects whose pattern of exposure has been established, using agreed upon evaluation methods. As for dose estimation, he evaluated the increase in use of the whole-body counting method, tooth enamel-ESR method, spectrometers and TLD method. He pointed out the difficulty in the reconstruction of the thyroid dose and hoped that young Japanese scientists would join in this specific work. As for biodosimetry up until now only acute exposure has been studied. He proposed that chronic exposure should be now the target of a laboratory study. Further, he pointed out that psychological effects should be quantified biologically.

Discussion

Dr. Matsudaira, (NIRS): I would like to have some information on the patients who had been hospitalized in the sixth hospital in Moscow.

Dr. Likhtarev, (RCRM): Among the patients, 117 individuals are living in Kiev and observed from view of health consequences. I think the occurence of thyroid cancer will precede that of cataract. According to recent data, cataracts will be induced in 25% of the subjects. In the cooperative studies between New York and Colombia and our center in Kiev, it is predicted that half the subjects with an exposure of over 65 rems will be suffer from cataracts.

Dr. Sugawara, (Health Research Foundation): Which populations have been accurately measured and established doses among the many populations reported so far ?

Dr. Likhtarev, (RCRM): First, the population of children in Ukraine. Next, the population of liquidators, although not all of them. The workers who labored within the 30 km area in years 1986 and the first half of 1987 are the third population. In this last case, neoblastoma and cataracts could be among the diseases that occur. The Chernobyl data on cataracts will possibly be submitted to the Committee 1.

Comments:

By Dr. Kumatori (REA):

1. There is considerable difference in the incidence of thyroid tumors among the Republics. Are you making efforts to standardize the criteria of diagnosis?

Drs. Likhtarev and Ramzaev explained that their final diagnoses for thyroid tumors are usually correct. It was also mentioned that there is a possibility that tumors may be overlooked in the primary survey using ultrasonography.

2. Only one occurrence of leukemia, which was acute myeloid leukemia, was found in the case of the Marshall Islands. But as to the thyroid gland, nodules were found that were dose dependent, starting the 9th year after the radiation exposure. The incidence increased in parallel to the increase of the dose, up to a certain dose, and then it decreased. Special attention should be given to exposure in Chernobyl in this regard because the causative effects could be different between the Marshall Islands and Chernobyl.

Additional comment by Dr. Likhtarev.

Considering the average exposure dose, there is less possibility of the discovering hematological disorders. I hope the Chernobyl-Sasakawa Medical Cooperation will work not only from the stand point of humanitarianism but also in that of scientific goals.

Dr. Kuramoto said that they were making efforts to lead their work in a scientific direction.

Radioactivity concentration in environmental samples collected around areas affected due to the Chernobyl accident

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ABSTRACT

Many kinds of environmental samples such as milk, fish, water, total diet samples etc., were collected in the vicinity of Chernobyl, especially around Kiev, Ukraine. Milk, fish (carp), and total diet samples were also collected in Ibaraki, Japan. Radioactivities of ^{137}Cs, ^{134}Cs, ^{40}K, ^{60}Co and ^{54}Mn in the samples, were determined by gamma-ray spectroscopy using a germanium detector. Strontium-90 was determined by low-background beta-spectrometry. Thorium-232 and ^{238}U were determined by inductively coupled plasma mass spectrometry (ICP-MS). Furthermore, stable elements were determined by ICP-MS and inductively coupled plasma atomic emission spectrometry (ICP-AES).

Ratios of radionuclides and/or stable elements were calculated in both countries. Comparison of the levels of radionuclides between the Ukraine and Ibaraki showed the former were several times to a few tens of thousands of times higher than the latter, depending on the samples. Annual dose equivalents for inhabitants of both places were also estimated.

INTRODUCTION

Global contamination of radionuclides was likely induced by the Chernobyl nuclear accident in April 1986. Much information has been accumulated from the viewpoints of radiation protection, radioanalytical chemistry, and social ramifications. In this study many kinds of environmental samples such as milk, fish, water, total diet samples etc., were collected in the vicinity of Chernobyl, especially around Kiev [1,2]. Several kinds of samples were also collected in Ibaraki Prefecture, Japan for comparison with Chernobyl sample levels. After samples were dry-ashed, radioactivities of ^{137}Cs, ^{134}Cs, ^{40}K, ^{60}Co and ^{54}Mn were determined by gamma-ray spectroscopy with a germanium detector. Strontium-90 was determined by low-background beta-spectrometry. Minor and trace elements including ^{232}Th and ^{238}U in the freshwater samples, were determined by both quantitative or semi-quantitative analysis modes of ICP-MS. Furthermore major and minor stable elements were determined by ICP-AES. Ratios of radionuclides and/or stable elements were calculated in both countries. Annual dose equivalents for inhabitants of both places were also estimated by using the methods of ICRP Publication 30 [3].

MATERIALS AND METHODS

Materials Environmental samples (milk, fish, vegetables, total diet samples, and airborne dust) were collected near Chernobyl during 1987-1991 as shown in Table I. A few selected samples,

Table 1. Radioactivities of ^{90}Sr, ^{137}Cs, ^{134}Cs, ^{40}K, ^{60}Co, and ^{54}Mn in environmental samples collected in Ukraine and Ibaraki

Sample	Location	Sampling time	^{90}Sr (Bq)	^{137}Cs (Bq)	^{134}Cs (Bq)	^{40}K (Bq)	^{60}Co (Bq)	^{54}Mn (Bq)
Milk[a]	Ukraine	1990 Sep	–[f]	77.3 ± 0.3[e]	8.33 ± 0.11	28.2 ± 0.86	2.18 ± 0.07	0.505 ± 0.054
Milk	Ukraine	1987 Nov	0.251 ± 0.006	5.87 ± 0.07	1.69 ± 0.07	30.4 ± 0.69	< 0.09	< 0.87
Milk	Ukraine	1987 Dec	0.748 ± 0.006	8.93 ± 0.13	2.66 ± 0.16	55.5 ± 1.48	< 0.21	< 2.0
Milk	Ukraine	1987 Feb	1.18 ± 0.008	21.7 ± 0.2	6.14 ± 0.15	44.0 ± 0.97	< 0.13	< 1.0
Milk	Ibaraki	1988 May	0.025 ± 0.004	< 0.033	< 0.17	47.9 ± 0.5	< 0.07	< 4.0
Carp[b]	Ukraine	1990 Nov	3.88 ± 0.02	45.9 ± 0.3	5.14 ± 0.11	47.9 ± 2	< 0.16	< 0.21
Carp	Ukraine	1990 Nov	74.5 ± 0.1	195 ± 1	22.2 ± 0.41	27.4 ± 3	< 0.40	< 0.58
Carp	Ukraine	1988 Jul	2.98 ± 0.12	2130 ± 60	492 ± 5	197 ± 10	< 1.7	< 12
Carp	Ibaraki	1990 Nov	0.76 ± 0.01	< 0.84	< 0.48	92.1 ± 5.0	< 0.62	< 0.81
Carp	Ibaraki	1990 Nov	–	< 0.79	< 0.44	74.9 ± 4.3	< 0.51	< 0.71
Carp	Ibaraki	1990 Nov	0.76 ± 0.02	< 0.44	< 0.48	69.3 ± 4.4	< 0.56	< 0.76
Carp	Ibaraki	1990 Nov	0.98 ± 0.03	< 0.60	< 0.52	85.9 ± 5.1	< 0.69	< 0.75
Diet (adult)[c]	Ukraine	1991 Jan	0.25 ± 0.01	0.44 ± 0.07	< 0.18	76.5 ± 2.4	< 0.22	< 0.27
Diet (child)	Ukraine	1990 Jun	1.08 ± 0.004	7.29 ± 0.06	0.93 ± 0.03	19.4 ± 0.4	0.21 ± 0.02	< 0.07
Diet (adult)	Ibaraki	1985 Jun	–	0.17 ± 0.02	< 3.2	53.0 ± 0.7	< 0.32	< 0.18
Diet (adult)	Ibaraki	1986 Jul	–	< 0.43	< 4.6	78.9 ± 2.2	< 0.75	< 0.58
Diet (adult)	Ibaraki	1987 Jul	–	0.13 ± 0.03	< 1.1	75.1 ± 1.0	< 0.24	< 0.09
Diet (adult)	Ibaraki	1989 Jun	–	< 0.10	< 0.24	58.2 ± 0.8	< 0.12	< 0.03
Diet (adult)	Ibaraki	1989 Dec	–	< 0.07	< 0.20	75.0 ± 0.9	< 0.11	< 0.02
Airborne dust[d]	Ukraine	1990 Aug	0.063 ± 0.001	0.026 ± 0.001	0.0036 ± 0.0002	< 0.007	0.0037 ± 0.0003	0.0018 ± 0.0003
Water[a]	Ukraine	1988 Mar	0.019 ± 0.001	0.0050 ± 0.0003	< 0.01	< 0.1	< 0.007	< 0.06
Water	Ukraine	1988 Apr	0.021 ± 0.001	0.0048 ± 0.0003	< 0.003	0.066 ± 0.006	< 0.001	< 0.01
Beetroots[b]	Ukraine	1991 Jan	0.58 ± 0.03	< 0.43	< 0.24	98.9 ± 3.2	< 0.35	< 0.37
Potatoes	Ukraine	1987 Oct	2.19 ± 0.02	183 ± 1	55.1 ± 0.6	177 ± 3	< 0.37	< 4.0
Leafy Vegetables	Ukraine	1987 Oct	–	47.6 ± 0.6	13.8 ± 0.7	71.3 ± 3.9	< 0.61	< 7.3
Carrots	Ukraine	1988 Aug	–	55.5 ± 0.4	12.8 ± 0.3	144 ± 3	< 0.34	< 2.1
Mushrooms, cooked	Ukraine	1988 Sep	–	614 ± 2	131 ± 1	73.7 ± 3.5	< 0.60	< 3.6
Dry apples	Ukraine	1987 Oct	1.22 ± 0.02	65.4 ± 0.4	19.2 ± 0.4	184 ± 3	< 0.32	< 3.4
Cheese	Ukraine	1989 Jul	–	57.5 ± 0.5	10.4 ± 0.3	29.9 ± 2.4	< 0.39	< 1.2
Beets	Ukraine	1987 Oct	–	43.0 ± 0.4	12.9 ± 0.4	114 ± 3	< 0.41	< 3.9
Haricots	Ukraine	1987 Oct	–	14.0 ± 0.3	4.62 ± 0.45	398 ± 7	< 0.85	< 7.7
Cucumbers	Ukraine	1988 Aug	–	12.1 ± 0.2	2.68 ± 0.16	96.5 ± 2.3	< 0.25	< 1.5

a) Per liter, b) Per kg-wet weight, c) Per person per day, d) Per m^3, e) Counting error (1σ), f) Not determined.

total diet samples, milk and fish (carp) were collected in Ibaraki Prefecture during 1985-1990. The samples were dry-ashed in a muffle furnace[1].

Freshwater samples were collected mainly from the Ukraine, Russia, and Belorussia in 1990-1991[2]. They were from different sources: tap water, well water, reservoir water, lake water, river water. The samples were stored in 25 ml polyethylene bottles in a refrigerator until measurements were made.

Gamma-ray analyses Approximately 2-10 g ash were analyzed with a Ge-detector (Ortec GEM-30185) coupled to a multichannel analyzer (Seiko EG & G 7800). Counting time was 30,000-80,000 seconds. Gamma-ray peaks for the measurements were 604.7 kev for ^{134}Cs, 662 Kev for ^{137}Cs, 834.8 keV for ^{54}Mn, 1332 keV for ^{60}Co, and 1461 keV for ^{40}K[4].

Analysis of ^{90}Sr Analytical procedures for ^{90}Sr were almost the same as those of the standard method[5]. Approximately 2-4 g ash were treated by fuming nitric acid with added strontium carrier to precipitate strontium in a nitrate form. Determinations of ^{90}Sr in strontium carbonate, were made three times for 100 min each using the Tracerlab Omni/Guard low-background beta-counter.

ICP-AES measurements Analytical procedures employed for stable elements were those described elsewhere[6]; they are summarized below. The aliquots of ash (0.25 g) were digested repeatedly with a mixture of concentrated nitric acid and 61% perchloric acid. The residue was dissolved in dilute hydrochloric acid and demineralized water, and made up to 25 ml to give a final acid concentration of 0.3M. The operating conditions for the ICP-AES measurements using a Shimadzu ICPQ-1012W inductively coupled plasma emission spectrometer were as in the literature[6].

ICP-MS measurements The ICP-MS instrument used was Yokogawa PMS2000 Model. Specifications and operating conditions were summarized previously [2]. A few milliliters of sample solution were sufficient for analysis.

RESULTS AND DISCUSSION

Radioactivities of the environmental samples Concentrations of radioactivity elements are shown in **Table I**. Gamma-ray analyses were made for all ash samples collected, but analyses of ^{90}Sr were done for only selected samples due to the small amounts of samples. Manmade radionuclides (^{137}Cs and ^{134}Cs) and a natural one (^{40}K) were detected in most of the samples, but ^{60}Co and ^{54}Mn were found in only limited samples.

Milk is one of the most important food items, especially for infants and children. Milk from several different producers (total:14 liters) was purchased from markets in Mito City, Ibaraki and mixed to give one sample. Levels of ^{90}Sr in the Ukraine were in the range of 0.251 and 1.18 Bq/l, against 0.025 Bq/l in Ibaraki. Concentrations of ^{137}Cs in the Ukrainian milk samples were in the range of 5.87 to 77.3 Bq/l; the value for Ibaraki was below 0.033 Bq/l(not detected). The level of ^{137}Cs in the Ukrainian milk was 200-2,000 times higher than in the Japanese milk. The concentrations of ^{134}Cs had almost the same trend as ^{137}Cs. For ^{40}K, concentrations in milk from Ukraine and Ibaraki were found to be at the same levels as the natural background and, hence, indicated no relationship to the accident.

Total diet samples for an adult and a child in Kiev, Ukraine were collected in 1990 and 1991. Total diet samples were also collected by a duplicate portion study for an adult male in Mito during 1985-1989. Daily ^{90}Sr intake, calculated from one sample collected in the Ukraine for an adult, was found to be 0.25 Bq per person. The radioactivity of ^{90}Sr in the Ibaraki was not analyzed. According to the literature values[7,8], the average intakes of ^{90}Sr were 0.10 ± 0.03 Bq in Ibaraki and 0.083 ± 0.010 Bq for all Japan during 1985-1990. The ^{137}Cs intake, 0.44 Bq per person per day in the Ukraine, was only a few times higher than that of Ibaraki (0.13 and 0.17 Bq). Average ^{137}Cs intakes, 0.10 $\pm$ 0.05 and 0.13 ± 0.05 Bq/p/d were reported in Ibaraki and all Japan, respectively[7,8]. Concentrations of ^{134}Cs, ^{60}Co, and ^{54}Mn were below the limits of detection without a children diet sample.

Fish (carp) samples, an airborne dust sample, water samples, and miscellaneous food samples, collected near Chernobyl, were analyzed and the results are also shown in **Table 1**. For fish samples, the radioactivity levels of ^{137}Cs, ^{134}Cs and ^{90}Sr at Chernobyl were 10-1,000 times higher. The airborne dust sample equivalent to 400 m^3, collected in Rovnocity, Ukraine, had higher concentrations of ^{90}Sr (0.063 Bq/m^3) and ^{137}Cs (0.026 Bq/m^3) compared to the all Japan literature values of 1.3 ± 0.8 $\mu Bq/m^3$ and 1.3 ± 0.5 $\mu Bq/m^3$, respectively[7,8]. The results for foodstuff samples could not be compared closely, because corresponding samples have not been collected in Japan. But, for both leafy and root vegetables, differences of 10 to 10,000 times have been seen between the two countries[7,8].

Concentrations of stable elements Twelve stable elements (Na, K, Ca, Mg, P, Fe, Zn, Mn, Al, Sr, Cu, and Ba) were determined in the same environmental samples by using ICP-AES. The results are omitted here ; They are available in a previous report[1].

Ratios of nuclide concentrations Ratios of radionuclides and/or stable elements, such as $^{90}Sr/Ca$, $^{137}Cs/K$, $^{134}Cs/K$, $^{40}K/K$ etc., were calculated from the data in **Table 1** and analytical data of stable elements just mentioned above. Those ratios are shown in Table II. The ratios of $^{90}Sr/Ca$ (Bq ^{90}Sr/g Ca) in the Ukraine and Ibaraki were as follows (values in parentheses were found in Ibaraki): milk, 0.37-1.0 (0.024); carp. 0.088-6.1(0.056-0.071); diet, 0.30. The reported average ratio of diets collected in Ibaraki during 1985-1990 was 0.15 $\pm$ 0.03 [7,8]. The ratios of $^{137}Cs/K$ (Bq ^{137}Cs/g K) were as follows: milk, 5.3-89(<0.02); carp, 30-390 (<0.4); diet, 0.18 (0.073). The ratios of $^{90}Sr/Ca$ and $^{137}Cs/K$ in the Ukraine, were 2 to 4,000 times higher than those of Ibaraki, respectively. Ratios of $^{40}K/K$ were found to be in the range of 29 to 37 Bq/g (i.e. 30.3 Bq/g is equivalent to natural abundance, 0.0117% of ^{40}K) except for certain samples (carp, beets, carrots, cucumbers, dry apples, and haricots). Ratios of $^{134}Cs/^{137}Cs$ in the Ukraine samples were in the range of 0.1 to 0.3 depending on the sampling times.

Concentrations of stable elements in freshwater samples The semi-quantitative analysis program already installed in the ICP-MS, was used. Response factors for element numbers 3 to 92, which had already been generated by the manufacturer (Fig. I), Table Ⅱ. Ratios of radionuclides and stable elements in environmental samples collected in Ukraine and Ibaraki

Sample	Location	Sampling time		$^{90}Sr/Ca^{a}$	$^{137}Cs/K^{b}$	$^{134}Cs/K^{c}$	$^{137}Cs/^{40}K^{d}$	$^{134}Cs/^{40}K^{d}$	$^{40}K/K^{e}$	$^{134}Cs/^{137}Cs^{d}$
Milk	Ukraine	1990	Sep	–[f]	89	9.6	2.7	0.30	32.5	0.11
Milk	Ukraine	1987	Nov	0.37	6.1	1.7	0.19	0.056	31.4	0.29
Milk	Ukraine	1987	Dec	0.49	5.3	1.6	0.16	0.048	32.9	0.30
Milk	Ukraine	1987	Feb	1.00	15	4.4	0.49	0.14	31.2	0.28
Milk	Ibaraki	1988	May	0.024	<0.02	<0.1	<0.0007	<0.004	30.3	–
Carp	Ukraine	1990	Nov	0.89	30	3.3	0.96	0.011	30.8	0.11
Carp	Ukraine	1990	Nov	6.1	360	41	0.71	0.81	50.7	0.11
Carp	Ukraine	1988	Jul	0.088	390	90	11	2.5	35.9	0.23
Carp	Ibaraki	1990	Nov	0.070	<0.3	<0.2	<0.009	<0.005	32.9	–
Carp	Ibaraki	1990	Nov	–	<0.4	<0.2	<0.01	<0.006	35.4	–
Carp	Ibaraki	1990	Nov	0.056	<0.2	<0.3	<0.006	<0.007	35.8	–
Carp	Ibaraki	1990	Nov	0.071	<0.3	<0.2	0.0070	<0.006	37.4	–
Diet (adult)	Ukraine	1991	Jan	0.30	0.18	<0.07	0.0057	<0.002	32.0	<0.4
Diet (child)	Ukraine	1990	Jun	4.08	12	1.5	0.38	0.048	31.2	0.13
Diet (adult)	Ibaraki	1985	Jun	–	0.093	<2	0.0032	<0.06	28.6	<20
Diet (adult)	Ibaraki	1986	Jul	–	–	–	<0.005	<0.06	–	<10
Diet (adult)	Ibaraki	1987	Jul	–	0.053	<0.4	0.0017	<0.01	30.8	<8
Diet (adult)	Ibaraki	1989	Jun	–	–	–	<0.002	<0.004	–	–
Diet (adult)	Ibaraki	1989	Dec	–	<0.03	<0.08	<0.0009	<0.002	31.1	–
Airborne dust	Ukraine	1990	Aug	–	–	–	>4	>0.5	–	0.14
Water	Ukraine	1988	Mar	–	–	–	>0.05	–	–	<2
Water	Ukraine	1988	Apr	–	–	–	0.073	<0.04	–	<0.6
Beetroots	Ukraine	1991	Jan	1.6	<0.1	<0.08	<0.004	<0.002	31.2	–
Potatoes	Ukraine	1987	Oct	24	92	28	1.0	0.31	88.6	0.30
Leafy Vegetables	Ukraine	1987	Oct	–	20	5.7	0.67	0.19	29.6	0.29
Carrots	Ukraine	1988	Aug	–	40	9.2	0.38	0.088	104	0.23
Mushrooms, cooked	Ukraine	1988	Sep	–	250	52	8.3	1.8	29.5	0.21
Dry apples	Ukraine	1987	Oct	5.8	36	11	0.35	0.10	103	0.29
Cheese	Ukraine	1989	Jul	–	69	12	1.9	0.35	35.8	0.18
Beets	Ukraine	1987	Oct	–	40	12	0.38	0.11	107	0.30
Haricots	Ukraine	1987	Oct	–	4.0	1.3	0.035	0.012	114	0.33
Cucumbers	Ukraine	1988	Aug	–	11	2.5	0.13	0.028	90.1	0.22

a) Bq ^{90}Sr/g Ca, b) Bq ^{137}Cs/g K, c) Bq ^{134}Cs/g K, d) Bq/Bq, e) Bq/g, f) Not determined.

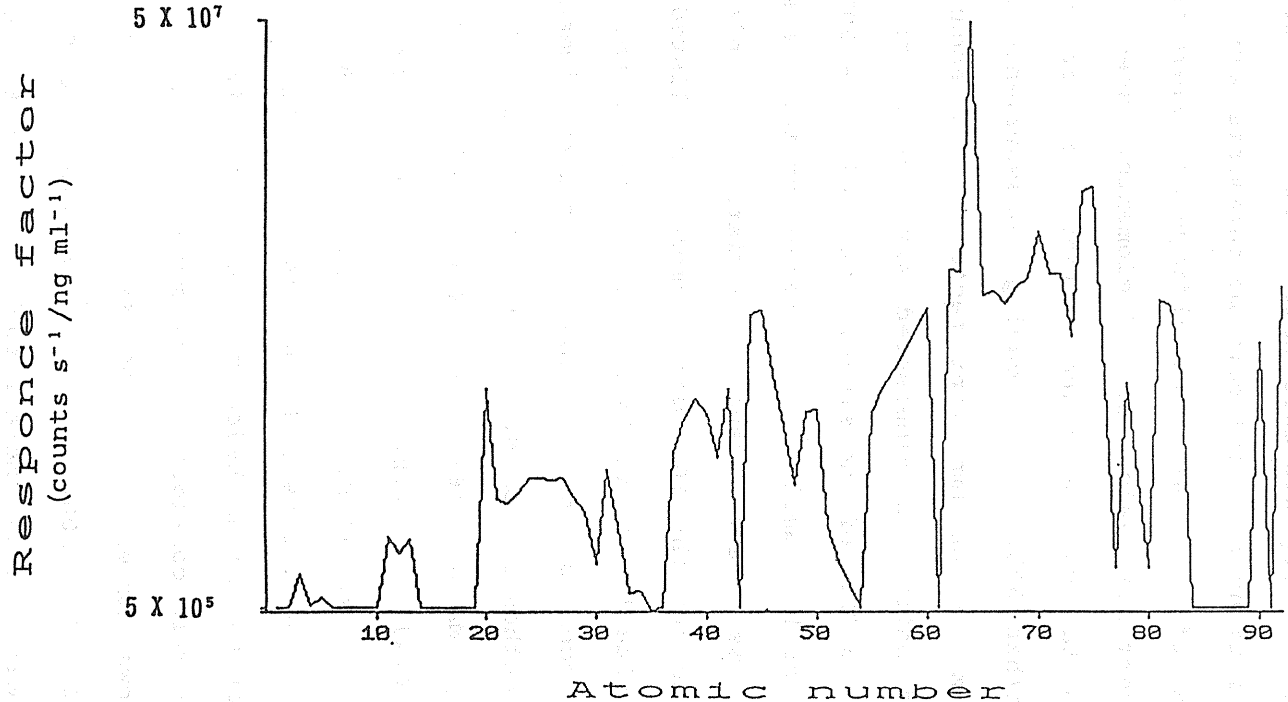

Fig. 1. A curve of the response factors in atomic numbers, 3–92.

were used. Calibration was based on the factors which are shown as counts per second per 1 ug/ml of analyte. Detection limits were close to 0.1 ng/ml. Accuracy and drift in the measurements were checked by using Standard Water, NBS SRM 1643b. Relative standard deviations of triplicate measurements were found to be in the range of 1 to 4% for thirty-four elements detected. There were certified values for 17 elements. Except for Fe, the analytical data and certified values were in fairly good agreement within 30%. Drift during measurements over a long period of time, is an important factor in the accuracy levels. The standard water was remeasured after every ten freshwater samples. The drifts of the elements were within $\pm$ 30% during the measurements of 102 samples over a period of four days.

Median, mean and standard deviation of elemental concentrations for the 102 water samples are listed along with literature values[9,10] in Table III. Median and mean values (ng/ml) of concentrations were found as follows (mean values are shown in parentheses): Be N.D. (6.6), B 53 (130), V 0.95 (1.4), Cr 2.2 (2.9), Mn 0.6 (63), Co 0.4(51), Ni 5.7 (7.3), Cu 3.4 (7.8), Zn 5.0(41), As 1.2(3.6), Se 5.4 (6.7), Sr 590(790), Mo 0.70(2.6), Ag N.D.(N.D.), Cd N.D.(0.07), Ba 60(81), Tl N.D.(0.17), Pb N.D.(0.29), Bi N.D.(N.D.). In processing the data, analytical values below the detection limit, in the 102 water samples were considered to be zero. The results by ICP-AES were as follows (ng/ml): Na 25,000(83,000), Ca 60,000(74,000), Mg 14,000(23,000), K 5,200(12,000), P 380(440), Fe 90(169). The levels of alkaline earth metals such as Sr and Ba were 6-7 times higher than the global mean values of freshwater. Concentrations

Tabl Ⅲ. A comparison of concentrations in freshwater collected in the former USSR for 27 elements between the present and literature values

Element	Present result				Literature values (ng ml^{-1})		
	Concentration(ng ml^{-1})			Number	River water[d]	Freshwater[e]	
	Mean ± S.D	Median	Range	nondetectable[c]	Mean	Median	Range
Na[a]	83k ± 147k	25k	2k - 695k	0	9k	6K	700 - 25k
Ca[a]	74k ± 51k	60k	6.6k - 284k	0	1.5k	15k	2k - 120k
Mg[a]	23K ± 23k	15k	0.4k - 122k	0	4.1k	4k	0.4k - 6k
K[a]	12k ± 22k	5.2k	3 - 133k	0	2.3k	2.2k	0.5k - 10k
P[a]	438 ± 312	383	4 - 1210	0	20	20	1 - 300
Fe[a]	169 ± 364	90	61 - 2570	0	-	500	10 - 1400
Be[b]	6.6 ± 47	N.D.	N.D. - 440	86	< 0.1	0.3	0.01 - 1
B[b]	130 ± 180	53	98 - 960	0	10	15	7 - 500
V[b]	1.4 ± 1.9	0.95	N.D. - 13	1	1	0.5	0.01 - 20
Cr[b]	2.9 ± 1.9	2.2	0.7 - 9.7	0	1	1	0.1 - 6
Mn[b]	63 ± 260	0.60	0.1 - 1900	0	~ 5	8	0.02 - 130
Co[b]	51 ± 260	0.40	N.D. - 2800	6	0.2	0.2	0.04 - 8
Ni[b]	7.3 ± 6.8	5.7	0.3 - 48	0	0.3	0.5	0.02 - 27
Cu[b]	7.8 ± 12	3.4	0.5 - 83	0	5	3	0.2 - 30
Zn[b]	410 ± 2600	5.0	0.4 - 19000	0	10	15	0.2 - 100
As[b]	3.6 ± 14	1.2	N.D. - 130	1	~ 1	0.5	0.2 - 230
Se[b]	6.7 ± 440	5.4	2.1 - 29	0	0.2	0.2	0.02 - 1
Sr[b]	790 ± 630	590	83 - 2500	0	50	70	3 - 1000
Mo[b]	2.6 ± 6.1	0.70	N.D. - 38	11	1	0.5	0.03 - 10
Ag[b]	N.D.	N.D.	N.D.	102	0.3	0.3	0.01 - 3.5
Cd[b]	0.07 ± 0.23	N.D.	N.D. - 1.3	80	-	0.1	0.01 - 3
Ba[b]	81 ± 73	60	1 - 410	0	10	10	<3 - 150
Tl[b]	0.17 ± 1.1	N.D.	N.D. - 11	95	-	-	-
Pb[b]	0.29 ± 1.4	N.D.	N.D. - 13	73	3	3	0.06 - 120
Bi[b]	N.D.	N.D.	N.D.	102	-	0.02?	-
^{232}Th[b]	0.49 ± 4.1	N.D.	N.D. - 40	99	0.1	0.03	0.007 - 0.1
^{238}U[b]	32 ± 140	0.7	N.D. - 1000	24	0.04	0.4	0.002 - 5

a) Determined by ICP-AES;k means 10^3. b) Determined by ICP-MS.
c) Total sample numbers were 102. d) K. Fuwa (1981). e) H.L.M. Bowen (1979).

of major elements (Na, Ca, Mg, K, and P) were also higher than the reported ones. Silver and Pb were lower than literature values. Mean Pb value, 10 $\pm$ 2.4 ng/ml(29 samples) excluding not detectable values from all samples, was too low compared with global means. The remaining elements, Be, V, Cr, Mn, Co, Cu, Zn, As, Mo, Cd, Tl, and Bi had almost their global mean values. For Be, Mn, Co, and Zn, their higher mean values were due to the high values of a few water samples. With regard to the Chernobyl accident, concentrations of Be, Cr, Pb, Cd, and As were not significantly higher in this region compared to the global means.

Concentrations of ^{232}Th and ^{238}U in freshwater samples Mean ^{238}U concentration was found to be 32 $\pm$ 140 ng/ml amd its range was too wide depending on the sampling locations[11]. The median was 0.7 ng/ml, against a median for Japanese freshwater of 0.0071 ng/ml[12]. Isotope ratios of ^{234}U, ^{235}U, and ^{238}U were also measured in limited samples. Ratios of $^{235}U/^{238}U$ were almost the same value, about 7.1 x 10^{-3} in all samples measured. Ratios of $^{234}U/^{238}U$ were divided into two groups, i.e. 10^{-4} and 10^{-5} levels. In most of the samples, concentrations of ^{232}Th were found to be below the detection limits. Only three samples, collected in Krasnodor, had detectable values of 0.3, 9.7, and 40 ng/ml.

Dose estimation It is premature to draw a firm conclusion from this study due to the small number of samples analyzed. However, the levels of radionuclides in the Ukraine, near Chernobyl, were several times to a few tens of thousands of times higher than those in Ibaraki. Annual dose equivalents (ADEs) by ingestion of ^{137}Cs and ^{90}Sr were estimated for Ukrainian and Japanese adults by using the method of the ICRP Publication 30[3]. ADEs of ^{137}Cs for Ukrainian and Japanese adults were 2 x 10^{-6} and 8 x 10^{-7} Sv, respectively. For ^{90}Sr, 3 x 10^{-6} and 1 x 10^{-6} Sv were estimated for Ukrainian and Japanese adults. Dose estimation from milk intake was also done by using the milk consumption rate for Reference Man, i.e, 0.3 liters per person per day[13]. ADEs of ^{137}Cs and ^{90}Sr for an Ukrainian were as follows (values in parentheses were for Japanese): ^{137}Cs 4 x 10^{-5} (8 x 10^{-8}); ^{90}Sr 3 x 10^{-6} (1 x 10^{-7}). The difference in ADEs (30-500 times) between the two habitants, based on milk intakes, was found to be higher than that (3 times) by total diet. It was suggested that internal dose (ADE) would be reduced by the dilution effect due to intakes of many kinds of foodstuffs. Furthermore, ADEs by ingestion of ^{232}Th and ^{238}U in drinking water were estimated. Concentration ranges for ^{232}Th and ^{238}U in freshwater samples were found to be N.D. to 40 (0.0005) ng/ml and N.D.- 1,000 (0.0071) ng/ml. Values in parentheses were found for Naka River from which tap water is supplied to habitants in Mito. ADEs of ^{232}Th and ^{238}U for an Ukrainian were estimated by using maximum concentrations of the radionuclides and volume of drinking water (1.6 liter per person per day)[13]. ADEs of ^{232}Th and ^{238}U were 7 x 10^{-5} and 5 x 10^{-4} Sv/y, respectively. In this case, the contribution of drinking water would be too big an internal dose from oral intake. For a Japanese, the contribution of drinking water was 10^{-2} to 10^{-3} times that of the total diet[14].

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Discussion

Dr.Okano, (REA): The milk and other foods showed ^{60}Co activities. Were these activities obtained also in the old USSR data?

Dr.Shiraishi, (NIRS): The number of samples was limited and I have received comments from Dr.Los that the reasons for the ^{60}Co activity and other radioactivity were not known.

Dr.Los, (RCRM): A milk sample was obtained in 1986 when the ground surface was contaminated by the pass of the radioactive plume. Relatively low ^{137}Cs activity in the sample may be due to losses caused during the sample treatment before gamma spectrometry. The current measurement was requested how accurate the measurements of foods with low-level contamination collected even in highly contaminated areas were. In Kiev, foods were imported from the south but, due to its location, 100 Km from Chernobyl, ^{137}Cs activity in foods is still found, from time to time, higher than in the southern foods.

The water data are precious. A strange $^{234}U/^{238}U$ activity ratio was found in a sample using alpha spectrometry with unresolved peaks in our center. To confirm the result, we requested that measurements be made in Japan using ICP-MS. We are very thankful to Dr. Shiraishi for the reliable data on the ratio of $^{234}U/^{238}U$ for the 102 samples we sent.

IRRADIATION DOSES AS A RESULT OF THE CHERNOBYL NPP ACCIDENT AND FROM OTHER SOURCES

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Since August, 1991 Ukraine became independent state with territory of 604 000 km^2 and population of about 52 million people.

Today the most important thing for Ukraine is establishment of own laws and standards in all the fields, including those in the field of population radiation protection.

At first stage optimization of radiation protection is based on comparative analysis of population irradiation doses from all the irradiation sources. Second stage is substantiation of expediency of implementation of any countermeasures both according to economic and social criteria. In other words, radiation protection should be organized taking into account psycho social aspects of population reaction at any irradiation factor.

In this report quantitative assessments are represented only for population irradiation doses.

On Table 1 and Fig.—4 population irradiation doses are represented both on account of the Chernobyl NPP accident and other sources. On Fig.4 collective doses from accidental releases are calculated taking into account population mortality and birth rate in 1988 assumed that it will not be changed.

Thus, today the basic dose—factor is radon—222 determining about 60 per cent of collective dose. More detailed information about irradiation doses from natural radioactivity sources will be represented at the next report, of Dr. A.V.Goritsky et al.

Practically in all the contaminated places where population lives today doses from the Chernobyl NPP accident are comparable and in most cases are less from irradiation doses on account of other sources of non—accidental origin.

However, until now the "accidental" doses remain the factor about which population is the most anxious. This fact foresees appropriate measures both on diminishing of population anxiety level and irradiation doses.

Analysis of structure of "accidental" irradiation doses (Fig.5) shows that nowadays the basic dose—forming radio nuclide is 137—Cs and the basic dose—forming component of diet is milk produced on contaminated areas. That's why prognosis of 137—Cs behavior in soils will be the basis for countermeasures planning.

On Fig.6 prognosis is represented for dose rate changes in air from 134—Cs and 137—Cs released on soil surface for virgin soils and without taking into account shielding effect of rough character of land and vegetation. But even in such case taking into account deepening and physical decay data obtained on diminishing of dose rate has wide range. Under real condition taking into account all the factors reliability of prognosis represents separate problem.

Diminishing in two times of 137—Cs content in milk is observed in 6.5 years, though earlier analysis of results indicated 2 years (Fig.7). It testifies about that fact that process of milk activity diminishing depends on many changeable factors and does not allow to obtain stable assessments at this time range. In such cases for countermeasures planning it is reasonable to implement data on measurement of current irradiation doses which constitute 5 and more mSv per year for separate towns and villages and groups of individuals. As a rule, these are internal irradiation doses in locations with high 137—Cs transfer coefficients in chain soil—vegetation (food products).

The most effective countermeasures on diminishing of internal irradiation doses are:

— in chain soil—vegetation: ploughing of soils; it gives diminishing in 2—4 times for 137—Cs in grass;

— in chain grass—milk: ferrocine milk filters giving diminishing of cesium in 10 times;

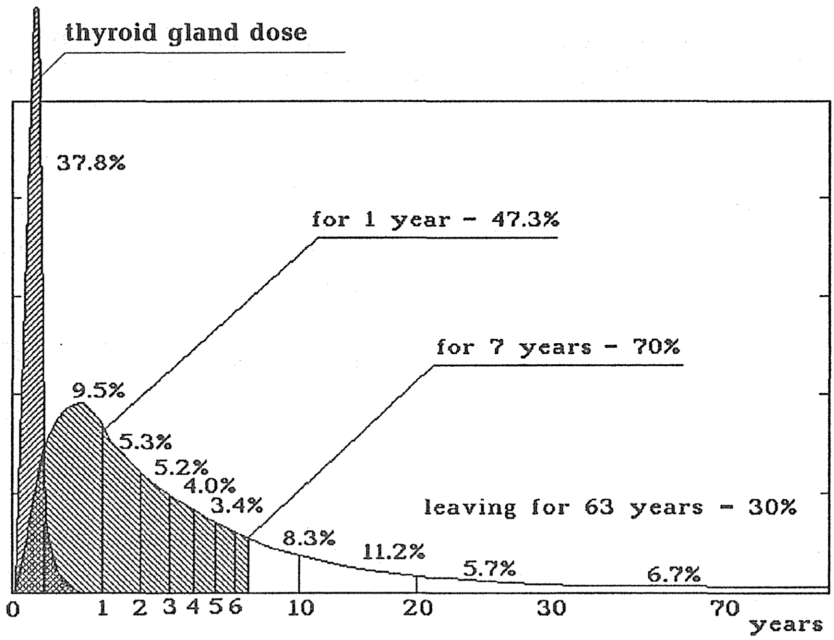
— in chain food products—human being: substitution of contaminated food products by "clean" ones; consumption of food products with ferrocine to diminish suction of cesium into gastrointestinal tract of human being.

There is number of other measures (potassium fertilizers, soils liming etc.), but their implementation can be justified only in separate cases for separate types of soils or conditions of residence of population.

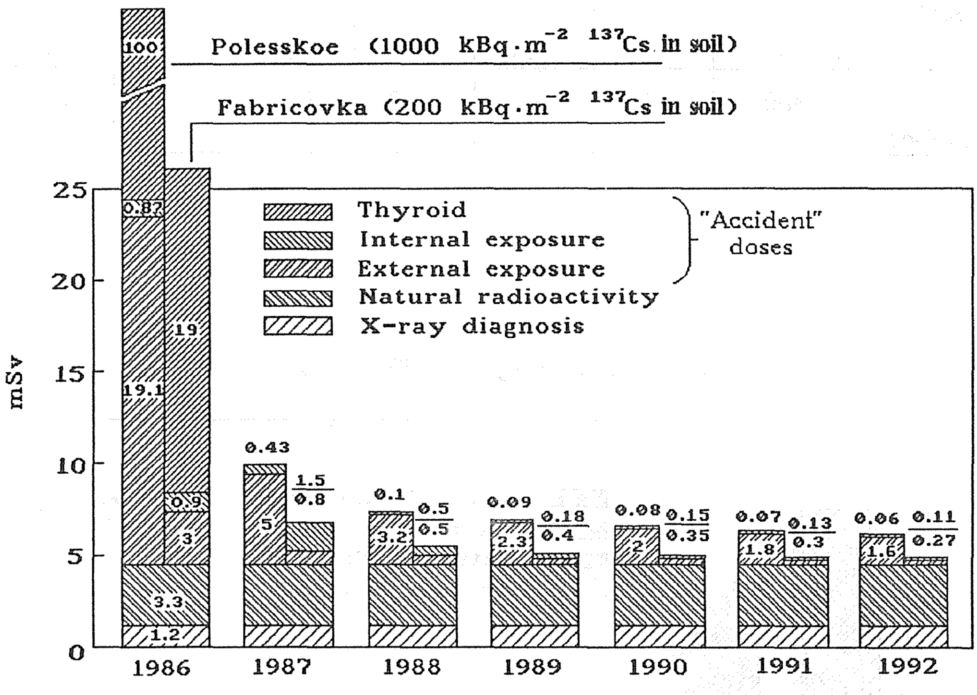
Table 1

Average individual effective doses for population living in different Ukrainian regions due to the Chernobyle Nuclear Power Station's 4-th block nuclere escape for the period 1986 to 1992

REGION, DISTRICT	mSv for 7 years	REGION	mSv for 7 years
Vinnitsa	5.4	**Krym**	1.5
Volyn	2.9	**Lugansk**	5.9
Dnepropetrovsk	1.8	**Lvov**	0.2
Donetsk	5.4	**Nikolayev**	3.6
Zhitomir		**Odessa**	4.8
Narodichi	104	**Poltava**	1.3
Ovruch	44	**Rovno**	8.1
other distr.	22	**Sumy**	3.0
Zakarpatye	4.9	**Ternopol**	2.2
Zaporozhye	1.3	**Harkov**	2.7
Iv.-Frankovsk	3.2	**Herson**	1.9
Kiev		**Hmelnitsky**	2.5
Ivankov	38	**Cherkassyi**	12.7
Polessye	173	**Chernigov**	10.5
other distr.	22	**Chernovtsyi**	7.4
Kirovograd	8.4		

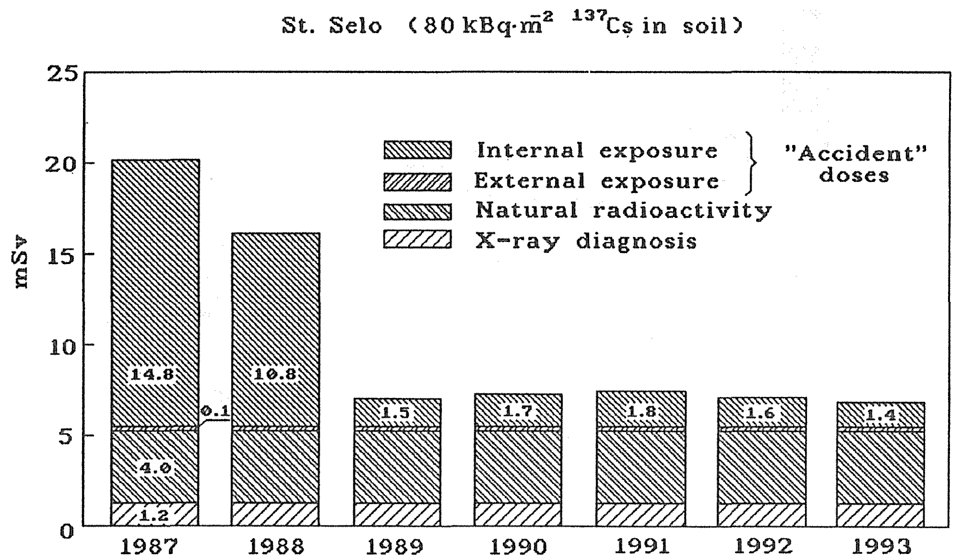


Pic. 1. Realization of "accident" doses of irradiation of the population for the period of 1986 to 2056

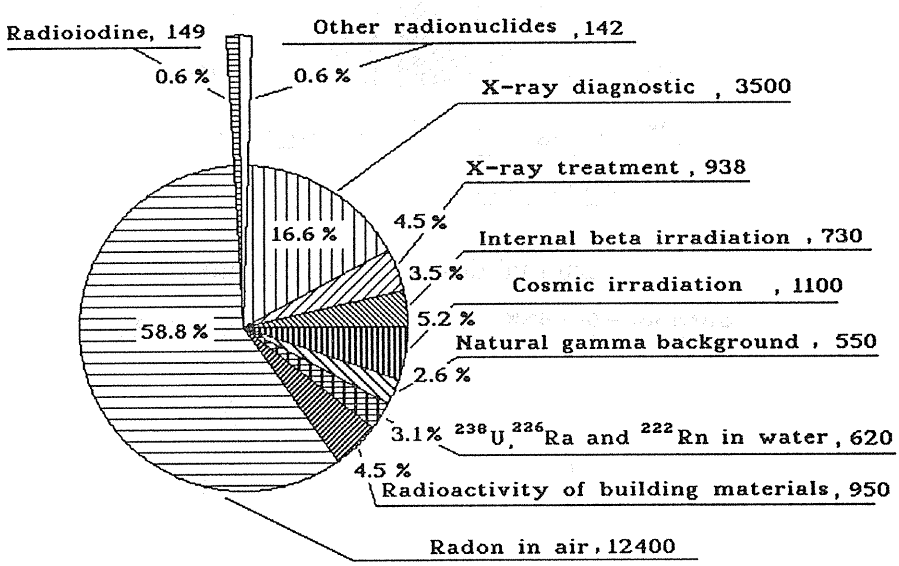


Pic. 2. Dinamic of anual doses due to Chernobyl accident and other sources in Polesskoe and Fabricovka

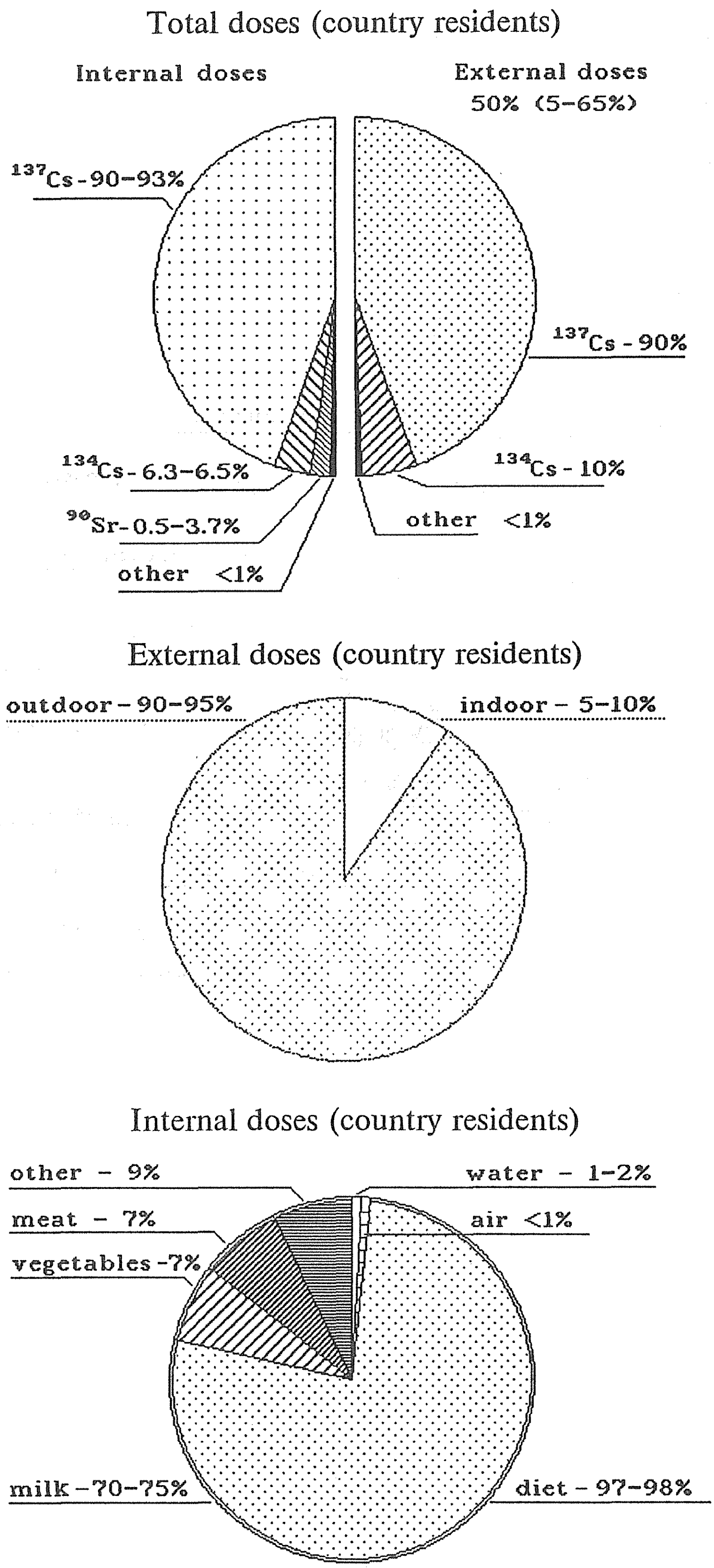
Year	1987	1988	1989	1990	1991	1992	1993
A_{milk}, $kBq \cdot l^{-1}$	3.10	2.20	1.60	1.20	0.86	0.63	0.46
n	27	45	133	236	35	41	16
A_{body}, $kBq \cdot body^{-1}$	360.0	264.0	37.5	42.7	43.1	40.0	34.5



Pic. 3. Structure and dynamic of annual doses due to Chernobyl accident and other sources in St. Selo, Rovno region, where soil-to-milk transfer coefficient of ^{137}Cs is highest

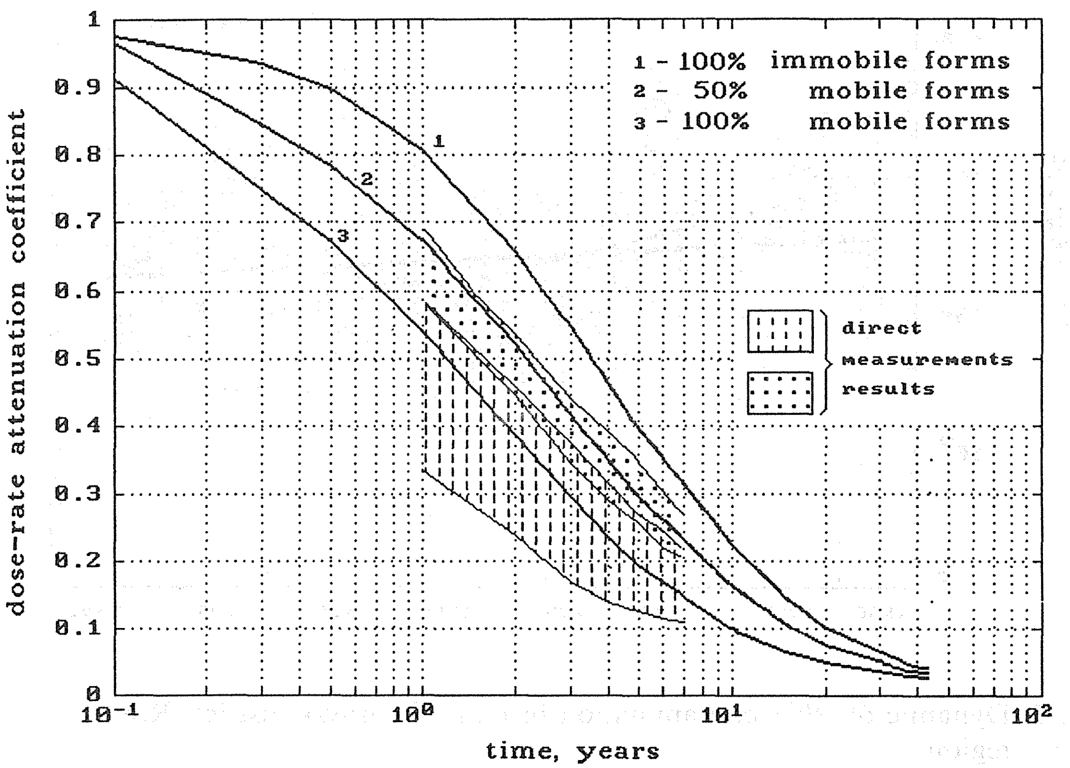


Pic. 4. Lifetime doses due to Chernobyl accident and other sources (thousands man·Sv)



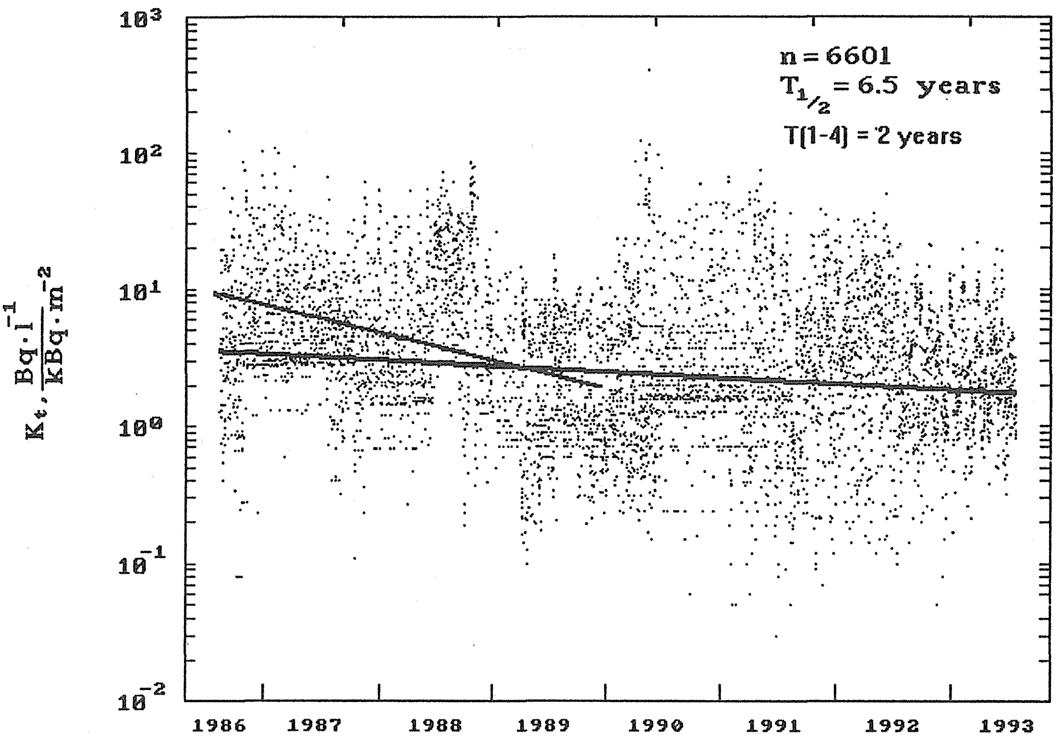
Pic. 5. Structure of doses due to Chernobyl accident in 1993

Conditions	$T_{1/2}$, year	$T_{1/4}$, year
1	1.1	3.8
2	2.1	6.2
3	3.3	9.0



1 - ≈ 5 km around Chernobyl, 2 - ≈ 60 km from NPP, 3 - >200 km from NPP

Pic. 6. Dynamic of air dose-rate from $^{137+134}Cs$ ground surface contamination



Pic. 7. Dynamic of ^{137}Cs contamination in milk, Dubrovsk district, Rovno region.

Discussion

Dr. Minenko, (RMRI): What is the cause of the slight increase in the ^{137}Cs transfer factor for milk in recent year?

Dr. Los, (RCRM): They had bad and rainy weather in Rovno in 1993. There are a lot of forests and swamps in Rovno, which had accumulated the radionuclides accidentally released from the Chernobyl nuclear power plant. It is most likely that those radionuclides flowed with rain water out of the forests and swamps, resulting in the elevation of ^{137}Cs level in the meadows. We had similar results also in 1990 and 1991.

Dr. Honma, (JAERI): The ^{137}Cs level in milk was represented in terms of the transfer factor, i.e. the ^{137}Cs concentration in milk was normalized to that in the soil in the Figure. The transfer factor consists of two variables, i.e. ^{137}Cs concentration in milk and that in soil. The former can vary independently of the latter. If this is so, what is the contribution of each variable to the fluctuation of the transfer factor.

Dr. Los, (RCRM): The values indicated in the figures were all measured or estimated on the basis of measurements. Countermeasure such as the removal of radioactivity effects some of the measurements. The kind of fodder that was given to cattle and the seasonal changes in the climate, effect other measurements. All these measurements in total explain the real situation. It would be interesting idea to investigate the temporal and spatial changes in ^{137}Cs when artificial activities are not carried out on a pasture.

Dr. Uchiyama, (NIRS): I agree with your opinion that consideration should be taken into on the psychological stress to the inhabitants of concern, when a countermeasure is carried out. Do you have any idea to evaluate the stress to the inhabitants quantitatively?

Dr. Los, (RCRM): I think a questionnaire to the inhabitants is one of the traditional methods. However, we meet a difficulty when we reflect the outcome of questionnaire on the countermeasure quantitatively as we have not yet developed a suitable method of evaluation. A recent investigation shows that the dose of ^{137}Cs to the inhabitants in Kiev, which originated from the Dnipr River, is likely to contribute 30% to the total dose due to the accident. In reality, the actual contribution was very small. I think nevertheless, it may be required to take into account the feeling of inhabitants mentioned above when a countermeasure goes into effect. At present, we have no methodology to evaluate the psychological effects of the implementation of countermeasures. I would like to propose that Japanese scientists join us on a cooperative study of this problem.

Dr. Ishiguro, (PNL): You pointed out that the feeling of inhabitants and the uncertainty of projected values must be taken into account when a countermeasure is implemented. May I have your opinion on the relationship between the uncertainty of prediction and the resulting anxiety to the inhabitants?

Dr. Los, (RCRM): The quantity of stress does not depend on the magnitude of dose. We have experienced that there are no differences in the magnitude of stress to inhabitants between living in heavily contaminated areas and to those living in areas of low contamination.

Dr. Kobayashi, (NIRS): Am I correct in understanding that the temporal change in radioactive contamination is, in general, rapid immediately after the beginnings, and decreases later according to your data in relation to the transfer factor for ^{137}Cs from soil to milk and the change in the body burden with time?

Dr. Los, (RCRM): You are right. Care must be taken that the external dose must be considered separately. Migration of radionuclides into soil is a good example. In this case, the penetration into soil progresses in a non-liner way. The temporal change in the external dose becomes different from that of the internal dose.

Dr. Nishimura, (NIRS): May I know what countermeasures were taken for the decontamination of ^{137}Cs in cow milk ?

Dr. Los, (RCRM): The first step was to decrease the transfer from soil to grass.

1) By deep plowing; the expected reduction of ^{137}Cs concentration is 1/2 to 1/5.

2) By liming meadows; the expected reduction is 1/2 to 2/3. There is, however, the possibility that liming will repress the transfer of trace

elements from the soil to grass. This technique is also questionable when taking account the burden to the environment and the resulting adverse affects. The second step was to decrease the transfer from grass to milk.

1) By using feed with less contamination; Also, heavily contaminated milk can be used in processing industries and in the production of feed.

2) By using ferrocyn filters to remove ^{137}Cs from milk. It is possible to reduce ^{137}Cs concentration to 1/10. The third was to reduce the intake of ^{137}Cs by inhabitants. 1) Ferrocyn can be/was administered to individuals as necessary.

Dr. Ramzaev, (IRH): You reported that in the Ukraine, the radiation exposure due to the accident was 50% from the internal dose and 50% from the external dose. For us in Russia, the contribution was 25% from the internal dose. What is the cause of this difference between these two countries?

Dr. Los, (RCRM): The half-time of ^{137}Cs in the environment is dependent on distance from the source. Distance changes the ratio of the internal dose to the external dose. We chose the Rovno distract as our test site, for it was there that transfer factor from soil to milk was the largest in the Ukraine. Rovno is the place we obtained the result that I presented.

External dose assessment by TLD method using construction materials exposed to radiation due to the Chernobyl accident

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Abstract

Potential health effects of low dose-rate radiations on human beings can be provided by the epidemiological study of inhabitants in some sites of relatively high contamination due to the Chernobyl accident. The best dose estimates of the inhabitants are extremely required for the assessment of dose-effects relationships. A prospective study is now in progress for the dose evaluation of the inhabitants using a TLD personnel monitor. In order to support the prospective study, cumulative gamma doses due to radioactive materials distributed on the ground by the Chernobyl accident were determined with the TL techniques of ceramic materials which have been used for the atomic bomb dosimetry in Hiroshima and Nagasaki.

Ceramic samples of brick and tile were collected from buildings in several areas highly contaminated between Kiev to Gomel in 1990-1991. TL measurements were carried out at the National Institute of Radiological Sciences. The background dose for beta rays coming from natural radionuclides in the samples was measured in the laboratory using MSO-TLD powder. The resultant cumulative doses determined by the TL technique significantly correlated with the exposure rate free in air.

INTRODUCTION

Many materials existing on the earth possesses characteristics of thermoluminescence(TL) phenomenon. These may be of geological, archaeological, biological and even extraterrestrial origin and comprise different materials such as rocks, ceramics, slags, bones and meteorites[1].They are exposed to natural radiations from the earth and cosmic rays and may acquire significant levels of natural TL. By measuring TL, one can determine the radiation doses that these materials have received during the past. Since the natural radiation doses steadily accumulates with time, the total dose is directly related to the radiation exposures. The principle of TL dating is that the firing of pottery by ancient man resets the TL clock to zero and that during the subsequent centuries, the trapped electron population builds up a uniform rate due to the weak radiation fields provided by natural radioactive materials in the clay itself and in soil in which the pottery was buried after the archaeological site fell into disuse[2]. In the TL dating, fired natural quartz in samples of pottery has been used as a long term TL dosemeter. Various TL dating techniques has been improved and developed to successfully use in the recent archaeological period with samples of pottery and brick. Several techniques of them can be applied for environmental dosimetry. Maruyama et al[3] have reevaluated external gamma doses from the atomic bombs in Hiroshima and Nagasaki using pre-dose and high temperature techniques. The accident in Unit 4 of the Chernobyl Nuclear Power Plant, in which large amounts of radioactive materials were released into the environment, occurred on 26 April 1986. The radiation levels from the released radioactive materials were highest in the immediate vicinity of the reactor. These materials then mainly affected the western part of the USSR and northern and eastern Europe. Extensive measurements have been made in these regions, allowing the radiation doses to the affected populations to be evaluated in some detail. Because the released materials became further dispersed throughout the northern hemisphere, estimates of exposures to populations in other countries have also been made.

At some sites of relatively high contamination, an assessment of the health effects on inhabitants is being made .In addition, potential health effects from radiation exposure or otherwise attributable to the accident are to be assessed. Dose assessment of inhabitants is very necessary for analysis of dose-health effect relationships. A study is now in progress to evaluate the external dose from materials radioactively contaminated by the Chernobyl accident.

Samples of brick and tile for TL measurements were collected from buildings in several areas highly contaminated between Chernobyl and Gomel on Oct.14,1990.Bricks and tiles were carefully cut with a diamond cutter, and pieces at a depth of 0.5 to 1.5cm from the outer surface was used for the TL measurements. The pieces were gently crushed in a mortar. TL measurements were made with a TL readout system. The background dose for beta rays coming from natural radionuclides in the samples was measured in the laboratory using MSO-TLD powder ($Mg_2 SiO_4$). Fig.3 shows preliminary results of cumulative gamma-ray doses from radionuclides released from the Chernobyl accident as a function of exposure rates in terms of "mR/h" measured with a survey meter at the sites from which sample were collected. The cumulative dose determined by the TL measurements correlated significantly with the exposure rate free in air. This suggested that the TL measurements of bricks and tiles can be used for the dose evaluation of humans from the Chernobyl accident.

DATING TECHNIQUES

1)Quartz inclusion technique:The quartz inclusion technique was developed for the large quartz grains in pottery. The quartz grains free radioactivity are separated from the crushed pottery and their a dose shell is etched away with hydrofluoric acid. The remaining cores of the quartz grains which is used for TL measurement have only received the beta and gamma contribution of dose from the matrix. Since the beta dose is also to some degree attenuated in coarse quartz grains, a correction must be applied. Ichikawa and Nagatomo[5] have evaluated the gamma doses from the atomic bombs in Hiroshima and Nagasaki, using the quartz inclusion technique.

2) Pre-dose dating technique

Glow curves of quartz show a large peak in the 110°C region. The peak height for a given test dose depends strongly on the pre-dose that the quartzes have received before heating to about 500°C. This sensitization behavior is the basis for the pre-dose technique for quartz. The sensitization from the annual pre-dose is compared to that induced by a known ceramics laboratory dose. This technique is especially suited for young,quartz-bearing ceramics. Owing to saturation it is restricted to roughly the last thousand years.

3) Fine-grain technique

The fine-grain technique use only the matrix of the pottery below 10 mm grain size. This fraction received the full alpha, beta and gamma contributions of natural dose rate. For artificial irradiation, one need both alpha and beta sources. Because the fine-grain matrix from archaeological ceramic commonly contains feldspars, the TL of fine-grain fractions is susceptible to anomalous fading.

PRINCIPLE OF DOSE ESTIMATION

The TL dating technique used in archaeology has been applied to the dose estimation of gamma rays from the atomic bombs in Hiroshima and Nagasaki. Bricks and tiles cumulate TL energy due to radiations from natural radioactive materials at a constant rate after kiln firing. In addition to the background TL due to natural radioactivities, the bricks and tiles received instantaneously a significant amount of TL energy from the atomic bomb radiation in 1945. After the detonation of atomic bombs. the bricks and tiles continuously cumulated the background TL in them. In the case of Chernobyl accident, the TL energy due to radiations released from radioactive materials deposited mostly on the ground is continuously accumulated in the bricks and tiles with the elapse after the accident as shown in Fig.1.

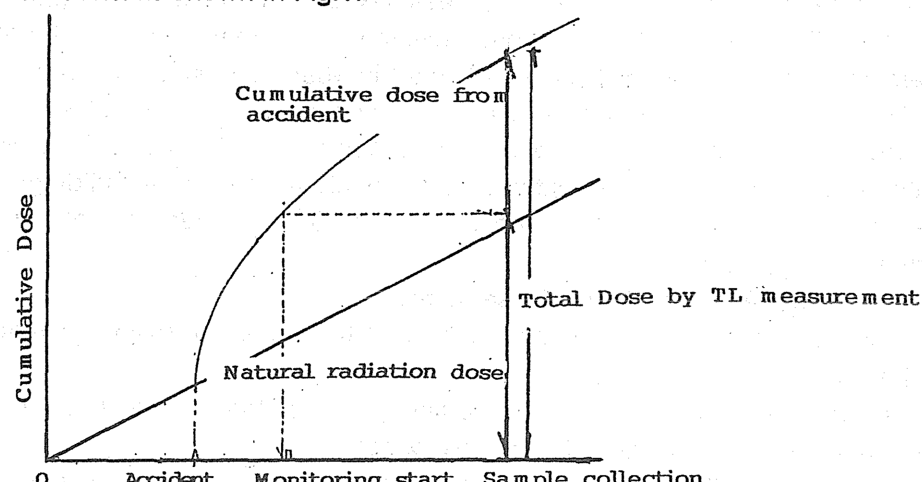


Fig.1. Schematic drawing of cumulative dose evaluation by TL measurements.

The radiation dose to quartz grains in bricks and tiles, D, arising from the radioactive materials is determined using the following equation:

$$D = D_L - D_B T \qquad (1)$$

where,

D_L:Accrued dose to quartz grains evaluated by TL measurement

D_B:Annual background dose from natural radiations

T: Age of brick and tile samples after firing.

The standard error of the dose estimates was derived using the following equation;

$$\sigma_D = [\sigma_L^2 + (\sigma_T)^2 (D_B)^2 + T^2(\sigma_\beta^2 + \sigma_\gamma^2)]^{1/2} \qquad (2)$$

where,

σ_D:standard error in the dose estimates of interest;

σ_L:standard error in total dose estimate from the TL measurement

σ_T:standard error in age estimates of ceramic samples

σ_b:standard error in annual beta dose rate

σ_g ;standard error in annual gamma dose rate

For the estimation of the total error, additional requirements include knowledge of orientation of the samples, irradiation and heating history, degree of shielding, density and elemental composition. Given the difference in the energy response of quartz relative to that of tissue at low photon energies, a knowledge of the energy spectrum of the radiations is also required. The techniques used for measuring background dose, for preparation of samples and for TL measurements themselves are derived largely from archaeological TL dating practices and are detailed below.

MATERIALS AND METHODS

1)Sampling

In order to evaluate radiation doses due to radioactive materials released from the Chernobyl accident using TL measurement techniques , samples of brick and tile were collected from buildings in several areas highly contaminated between Chernobyl and Gomel in 1990. The sampling of brick and tile is primarily important for the dose evaluation. The samples were collected not only from the surface of a building directly exposed to the radiations, but also from various sites such as inside or rear of the buildings In the sampling of bricks and tiles, the samples which satisfied the following conditions were collected .

Conditions required for brick and tile samples:

(a)The samples of bricks and tiles have been attached to the buildings since the Chernobyl accident.

(b)Fires have not occurred in the buildings and they have not been reconstructed since the original firing of the pottery.

(c)The age of the buildings from which the samples were collected is known or

can be estimated.
(d)There has been no man-made radiation source around the buildings of interest.
(e)The geometry, incident angle of radiation, and location and composition of nearby structures and large objects was known.
(f) Gamma dosimetry of natural background could be carried out at the sample location.

Fortunately, in the case of Chernobyl accident, a number of ceramic samples are still available.The most useful samples were bricks from the outside and inside walls of private houses and apartment houses.Table 1 gives locations of brick and tile samples preliminarily collected in and around Chernobyl.

Table 1. Location of brick and tile samples

Sample Number	City	Type of building	Sampling site	Materials	Exposure rate (μR/h)
1	Pripyat	Appartment house	Veranda	Brick	180 - 200
2	Pripyat	Hospital(Entrance)	Ceiling	Brick	380 - 400
3	Pripyat	Hospital(Inside)	Shower room	Tile	50 - 60
4	Pripyat	Private house	Fence	Brick	170 - 220
5	Pripyat	Private house	Inside wall	Brick	10 - 20
6	Chernobyl	Private house	Entrance	Brick	210 - 250
7	Capote	Private house	Window	Brick	350 - 400
8	Capote	Private house	Wall	Brick	10 - 30
9	Spelitje	Private house	Wall	Brick	230 - 270

In Table 1, exposure rates free in air at the locations of brick and tile samples were measured with a survey meter(manufactured by Victoreen Co.Ltd.) calibrated in unit of μR/hr.

2)Energy dependence of TL response

The thickness of brick and tile samples was mostly more than 5cm and 2cm, respectively. The energy dependency of TL response in brick and tile samples to a given dose was determined for X-rays in the effective energies of 40, 75 and 100 kev, ^{60}Co gamma rays and 10 MV X-rays. Fig.2 shows an example of the results for a brick sample. Normalizing the response of ^{60}Co gamma rays to unity, the response of 40kev X-rays was about three at a depth of 0.5 cm in the brick sample.

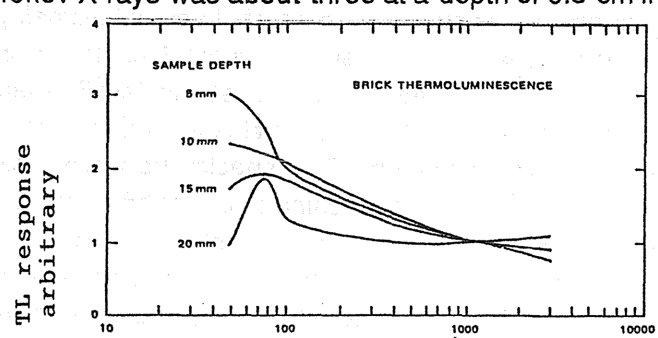


Fig.2. Energy dependence of TL response at various depths in a brick sample.

3)Contamination of samples with radionuclides with long half lives:

The buildings were expected to be contaminated with radioactive materials released from the Chernobyl accident. The distribution of radioactivities at various depths in the brick sample was measured with a Ge semiconductor spectrometer, using samples in a thickness of 2 mm quarried with a diamond cutter. Fig.3 shows an example of results of measurements.The specific activities of ^{137}Cs and ^{134}Cs were decreased with increasing of a depth in the sample.

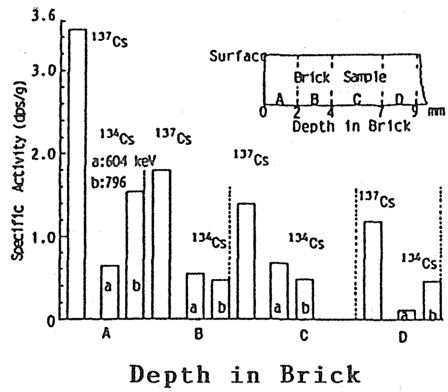


Fig.3. Specific activity of Cs radioisotopes Vs depth in sample

4)Preparation of Specimen for TL measurements

Procedures for preparing the samples for TL measurement are as follows:

(a)Brick and tile samples from a depth of 0.5 to 1.5 cm from the surface exposed to radiations.

(b)Weighting the samples

(c)Crushing the samples in a mortar

(d)Passing the crushed samples through the mesh of a 210mm and a 105mm sieve

(e)Washing with water and acetone in an ultrasonic cleaner

(f)Cleaning away unwanted clay matrix materials by a magnetic separator

(g)Observing with a microscope to confirm the sample contain the quartz materials.

Brick and tile samples were carefully cut into small peaces with a diamond cutter, and a peace of brick at a depth of 0.5 cm to 1.5 cm from the outer surface of the building was prepared as a specimen for TL measurement. For the tiles, the whole portion about 1.5 cm thick after removal of the ornamental part was used for TL measurements.The specimens were weighted and were gently crushed in a mortar after pressing in a V-shaped metal holder supported in the jaws of vice. Passing through a mesh of a 210 μm and a 105 μm sieve, unwanted materials of more than 210 μm and less than 105 μm was sifted out. The remaining specimen with a grain size from 105 μm to 210 μm was washed with water and acetone in an ultrasonic cleaner. The dried specimen was cleaned of unwanted clay matrix materials by a magnetic separator. Finally, the existence of quartz in the specimen was used for the TL measurements.

3. TL Measurements

All the measurements of TL yield from the specimens were carried out with a TL readout system(a multipurpose Type 2000, manufactured by Harshow Chemical Co., Ltd.)

1)High temperature technique

In the pre-dose technique, linear relationships between TL response and gamma dose are not obtained for the high dose region above about 1.5Gy for brick and tile samples, although the linear dose-response range was slightly different from sample to sample. Fig.5 shows glow curves of brick and tile specimens at high temperature, which were mostly used for the high gamma doses. In the quartz inclusion technique, the glow curves at high temperature were used.In present measurement the hydrofluoric acid was not used.Present technique was different from the quartz inclusion technique and was called "high temperature technique".The stability of TL signal storage was checked with the plateau test as shown in Fig 4. The ratio a/(b-a) was calculated for each temperature, where a and b represent a TL output obtained from the glow curves A and B, respectively. The area under the glow curves from 275 to 310 C was used for the determination of gamma dose.

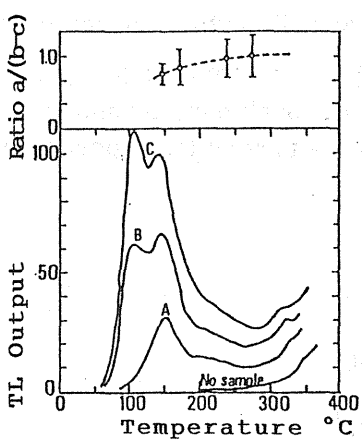


Fig.4. Typical glow curves and plateau test. The glow curves were measured for the ceramic samples irradiated with ^{60}Co γ doses of 10Gy(curve B) and 20Gy(curve C). Curve A shows natural TL output. The "no sample" curve shows a red-hot glow of a TL heater.

(2) Additive Pre-dose technique:

For the determinations of gamma dose less than about 2 Gy, the pre-dose technique was applied. According to the model of Zimmerman the essential mechanism is thermal transfer from a reservoir hole-trapping to a luminescent hole-trapping center. The 110°C peak in quartz for the pre-dose effect is not present in natural thermoluminescence as its half-life is only about two hours.

However, it is a highly sensitive peak, and exposure to the test dose around 10-100 mGy is usually sufficient to incidence an accurately measurable TL signal. The increase in sensitivity consequent to briefly heating the sample to 400 - 500 °C is proportional to the total radiation dose that the sample has received after its firing in antiquity.In the original pre-dose,a β-ray source with high level radioactivity is required for providing a laboratory dose. Since, however, it was not allowed to use a strong radiation source in a normal laboratory room from the national regulation of radiation protection ,an improved pre-dose technique was applied for the TL measurement of samples from the Chernobyl. Fig.5 shows schematically the improved pre-dose technique. In this technique, several specimens were prepared from the sample. One specimen was used for the determination of the ratio of S_N/S_0,, where S represents the area of the 110°C peak from 85 to 125°C,S_0 is the peak area measured prior to any pre-dose application, and S_N is the peak area measured after 500°C heating.by procedures from 1 to 3 in Fig.5. Other specimens were irradiated with various values of γ dose using a ^{60}Co therapy unit.The ratios of $S_{N+\gamma}/S_0$ for these irradiated specimens were determined by procedures from 4 to 6 in Fig.5. Usually a β dose of 12 mGy from a ^{90}Sr source was used as the test dose. The γ exposure was measured in Roentgen unit with an ionization chamber calibrated with the National Standard Dosimeter at the Electrotechnical Laboratory in Tsukuba. Powdered samples of bricks and tiles were irradiated with ^{60}Co gamma rays under secondary electron equilibrium by using a 1-cm-thick brick plate as shown in Fig 6.The absorbed dose in air was determined by multiplying the exposure by a conversion factor of 0.95.

Procedures of Pre-dose Technique:
(a) Give test dose and measure TL output S_0
(b)Heat to 500°C,
(c)Give test dose and measure TL output:S_N
Other samples irradiated with ^{60}Co gamma doses;
(d)Give test dose and measure TL output :S_0
(e)Heat to 500°C,
(f)Give test dose and measure TL output $S_{N+\gamma}$

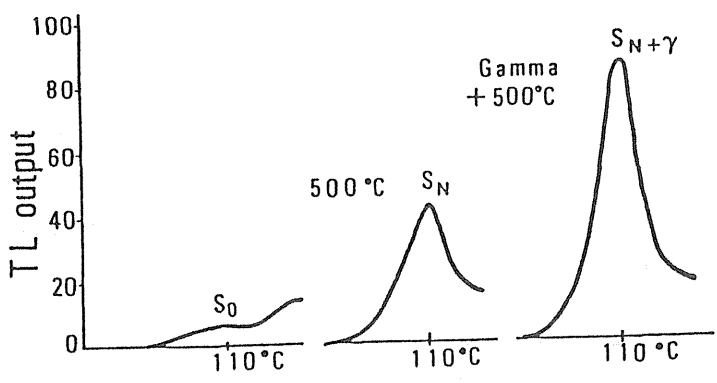


Fig.5. Conceptual diagram of present pre-dose technique(additive pre-dose technique). TL output S_0,S_N and S_{N+g} were determined from the area under the 110°C glow peak from 85 °C to 125°C.

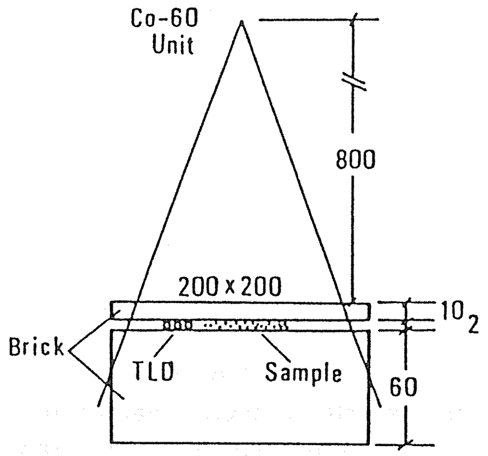
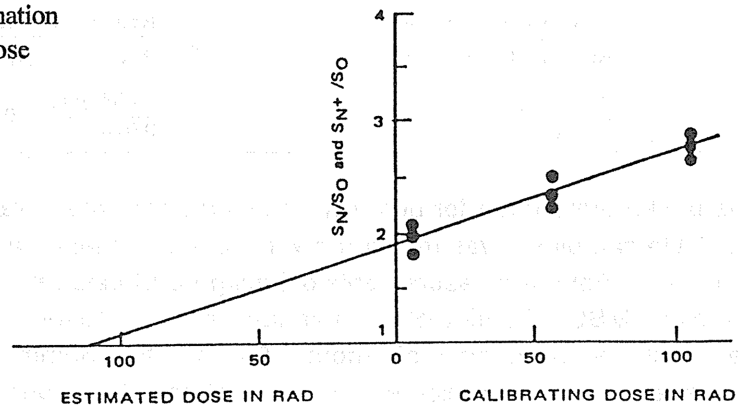


Fig.6 Geometrical arrangement of irradiation for additive dose (length or thicknesses in mm) The TLD detector consists of Mg_2SiO_4 powder contained in a glass tube 2 mm in diameter and 12 mm long.Powdered ceramic samples were put into a black polyethylene bag.The TLD detector was used as a monitor.

By plotting the ratios S_N/S_0 and $S_{N+\gamma}/S_0$ vs. the test dose and calibrating γ doses, the estimated doses were determined, including the background with an extrapolation of the curves using least squares method as shown in Fig.7.

Fig.7 Determination of estimated dose



4.Background Measurements

Bricks and tiles contains various natural radioactive nuclides such as the uranium and thorium decay series. In order to study the abundance of natural radionuclides in brick samples, preliminary gamma spectrometer with a Ge semiconductor detector was tried. Table 2 gives the results of spectroscopy for the typical brick and tile samples. These results suggest that brick and tile samples may not contain so large amount of alpha emitters from the uranium and thorium series.

Table 2 Relative activity of natural radioactive nuclides in percentage of ^{40}K activity for typical ceramic samples in Japan.

Sample	^{235}U	^{228}Ac	$^{212}Pb, ^{212}Bi$	^{208}Tl	^{214}Pb	^{214}Bi	^{40}K
Hiroshima (tile)	0.8	7.4	7.3	7.3	4.9	6.4	100
Hiroshima (tile)	0.1	7.6	8.5	9.3	5.4	7.6	100
Nagasaki (brick)	0.5	6.8	8.2	7.3	3.0	5.9	100
Nagasaki (brick)	0.7	5.3	6.2	6.2	4.4	5.8	100

Irradiating with alpha rays from ^{241} Am and beta rays from ^{90}Sr, the TL response of quartz in brick and tile samples to these charged particles was measured with the high temperature and pre-dose techniques. Table 3 gives an example of resultant response for a brick sample. It was found that , in the pre-dose technique, the response of brick to alpha rays was considerably reduced as compared with the response to beta rays.

Table 3. Response of TL yield in brick sample to charged particles.

In the high temperature technique:	In the pre-dose technique:
$k = \frac{\text{Response to } \alpha\text{-ray dose}}{\text{Response to } \beta\text{-ray dose}}$	$k = \frac{\text{Response to } \alpha\text{-ray dose}}{\text{Response to } \beta\text{-ray dose}}$
$= \frac{0.34/\text{rad}}{2.8/\text{rad}} = 0.12$	$= \frac{0.0082/\text{rad}}{0.024/\text{rad}} = 0.034$

The background dose for beta rays coming from natural radionuclides in brick and tile samples , was measured with an experimental arrangement as shown in Fig.8. For the measurements of background beta rays from brick and tile samples, MSO -TLD(Mg_2SiO_4 ;manufactured by Kasei Optoniks,Japan) powder with a grain size of about 100 mm to 150mm was used. A polyethylene foil 100 mm thick was used to absorb the alpha rays from the brick and tile samples. The gamma ray background was measured with the MSO-TL powder placed on a 15 mm thick plastic absorber to cut beta rays from the brick and tile samples as shown in Fig. 8. These dosimetric assemblies for the background measurement were put in a lead shield container of 150 mm thickness for about 6 months.

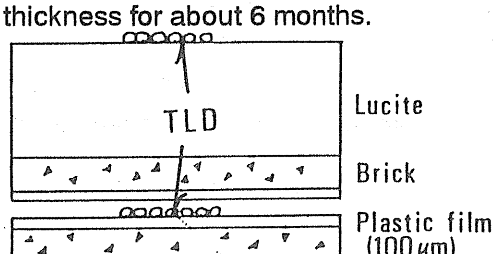


Fig.8. Experimental arrangement for beta background dose measurement. beta dose were determined with TLD powder(Mg_2SiO_4).

Table 4 gives the annual beta ray background dose determined.with the measurements described above, assuming that a correction factor of 0.7 for the absorption of beta particles in the polyethylene foil .For the determination of the correction factor, it was assumed that potassium 40 contributes about 80 % of the annual dose of beta rays while the uranium and thorium series provide about 10%. These percentages were taken from the TL dating techniques [7] .As given in Table 4, the annual beta-ray background doses were significantly different among the ceramic samples from the Chernobyl. The beta-ray dose rate of No.2 sample was extremely high. This high value may be due to the self-contamination with Cs radioisotopes from the Chernobyl accident..

In Hiroshima and Nagasaki, the annual background gamma-ray doses from environmental radiations and from wall materials of the building at which brick and tile samples were collected have been measured with a MSO-TL detectors[1]. In the Chernobyl, however, in situ background measurements were not performed yet. The annual background γ doses were estimated to be about 1 mGy/year on the basis of personnel doses determined with a microdose pocket dosemeter(manufactured by Aloka Co.,Ltd.) at a street in Kiev and Gomel Cities.

Table 4. gives annual background β dose rates of brick and tile samples from the Chernobyl.

Sample Number	Samples	Annual β dose rate(mGy/year)
1	Brick	1.91
2	Brick	14.74
3	Tile	1.65
4	Brick	4,87
5	Brick	1.13
6	Brick	1.91
7	Brick	0.51
8	Brick	3.55
9	Brick	0.70

RESULTS AND DISCUSSION

According to the TL dating in the archaeology, the annual alpha ray dose from the natural radioactive material in the brick and tiles will be ranged from a few mGy to a few cGy. However, in terms of the TL yield induced, the contribution by the alpha ray dose is much less than this even for the high temperature technique, because alpha rays are less effective in producing TL yield than are beta and gamma rays. In the pre-dose technique, the response of TL yield to alpha rays was very small as given in Table 5.

It is difficult know a time zero point at the original firing for each brick and tile samples.The construction of the Chernobyl nuclear power station was carried out in three stages ; the first stage(Units 1 and 2) was constructed between 1970 and 1977, and the second stage(Units 3 and 4) was constructed in 1983.

Most of the buildings in and around Chernobyl and Pripyat were constructed as apartment houses and offices for the nuclear station.Bricks and tiles were most likely manufactured about one year before the construction of buildings. The age of the brick and tile samples was preliminarily estimated to be about 15 years(from 1975 to 1990).Total background doses of brick and tile samples up to the time of TL measurements were estimated using the age of buildings and total annual background dose rates as given in Table 5.

Table 5. Preliminary results of radiation doses estimated with TL measurements of brick and tile samples from radioactive materials distributed on the ground by the Chernobyl accident.

Number	Total TL dose	Total β dose	Total γ dose	Estimated dose
1	1.31 Gy	29mGy	45mGy	1.24 Gy
2	0.42	220	45	0.16
3	0.24	24	45	0.17
4	1.48	73	45	1.36
5	0.06	17	15	0.03
6	0.91	29	15	0.87
7	0.45	7.7	15	0.43
8	0.21	53	15	0.14
9	0.15	10	15	0.13

Note:

Samples 1 - 4: High temperature technique

Samples 5 - 9 :Pre-dose technique

In the high temperature technique, a ray background was estimated to be 2 mGy. Age of brick and tile samples were estimated to be about 15 years old.

Fig 9 shows preliminary results of cumulative gamma ray doses from radionuclides released from the Chernobyl accident as a function of exposure rates in unit of mR/hr measured with a survey meter at the site from which the brick and tile sample was collected on October 15, 1990.The cumulative dose determined by the TL measurements of brick and tile samples was significantly correlated with the exposure rate. This suggests that the TL measurements of brick and tile samples can be used for the dose determinations of inhabitants from the Chernobyl accident.

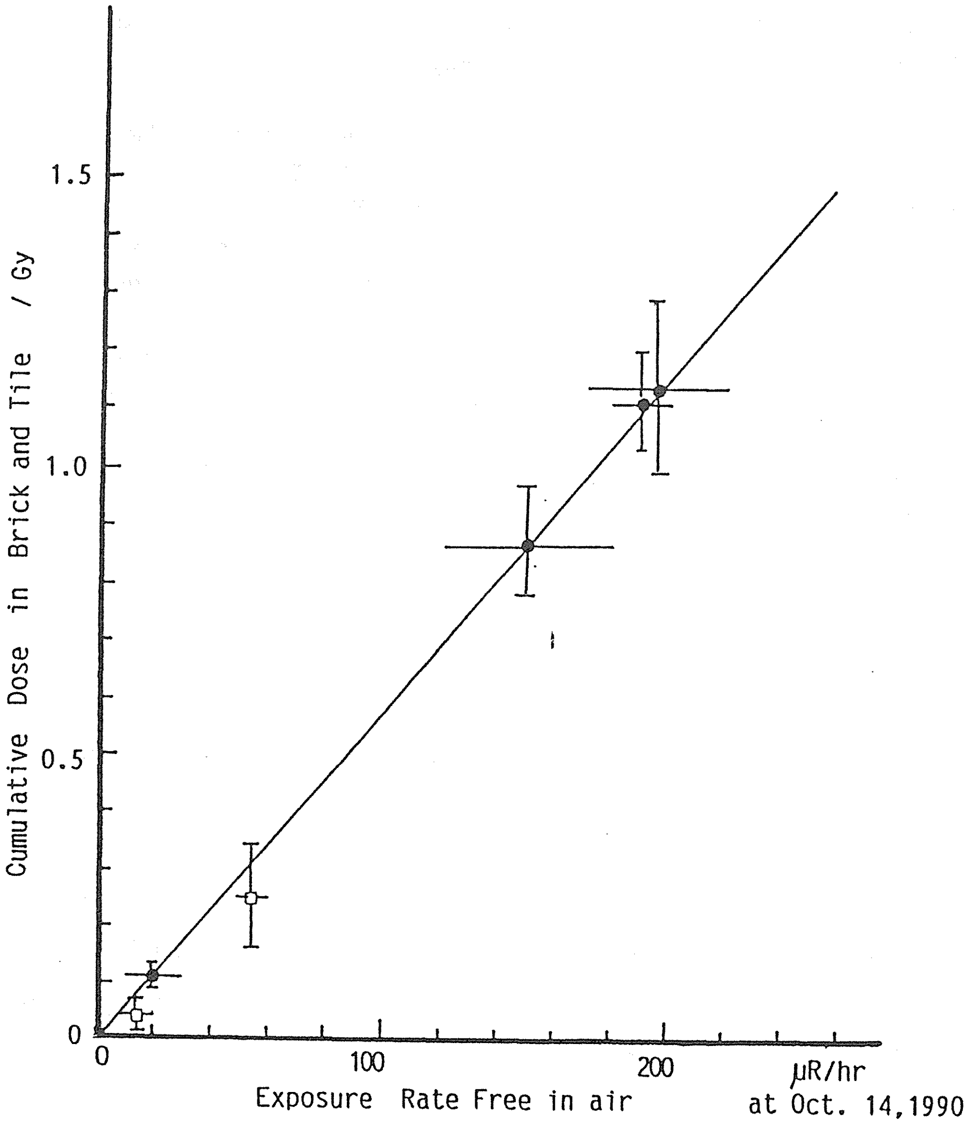


Fig.9. Preliminary results: Correlation of cumulative radiation doses determined by the TL measurements of brick and tile samples with exposure rates free in air determined by a ionization chamber type survey meter.

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Discussion

Dr. Okajima, (RERF, Nagasaki): If the fall-out adhered to the sample, the measured dose may be higher than the actual dose. What was the level of contamination?

Dr.Maruyama, (NIRS): We obtained samples from within the material and measured the activity distribution at different depths. Very small amount of radioactive contamination was found, but we concluded that the estimated dose was not influenced by the contamination. We agree that contamination must be checked.

NATURAL RADIOACTIVITY: IRRADIATION DOSES FOR UKRAINIAN POPULATION AND BASIC DIRECTIONS OF THEIR DECREASE

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Programme of studies of natural radioactivity was based on the following facts. First, about 30 per cent of territory of Ukraine is located on crystalline massive with enhanced content of natural radionuclides in geological structures and in soil (Fig.1). Second, these are those areas where population density is high; it establishes high collective doses. Third, optimisation of actions both in problems of radiation protection and location of objects of nuclear fuel cycle requires knowledge of population irradiation doses values from all the ionising irradiation sources in separate areas and on the whole territory of Ukraine.

On Fig.2 results of these studies are represented. Average annual individual effective dose on account of natural radioactivity sources weighted by structure of residential fund, water consumption etc. is 5,3 mSv. Non–controlled part of this dose (dose from cosmic irradiation, external irradiation from soil and internal beta–irradiation) is 12,7 per cent.

From controlled part of dose the highest contribution is on account of ^{222}Rn in air of residential premises (79 per cent, more than 6000 measurements with one–month exposition using nitro–cellulose film). Value of equivalent equilibrium concentration of radon in air of premises fits to common regularities (Fig. 3, 4): higher in one storey houses and in winter time etc.

Radioactivity of mineral construction raw materials determines only 5 per cent of effective average annual weighted dose. It is understandable that for urban conditions this dose is higher and can be (for example, in Kiev) from 0.4 for brick houses to 1,0 mSv per year for panel buildings.

On Fig.5 frequency distribution is given for total specific effective activity of mineral construction materials in one oblast (region), where about 15 per cent of these raw materials exceed content of natural radionuclides acceptable for residential building construction.

Contribution of natural radioactivity of potable water from drilled wells and wells is 3,3 per cent into weighted average effective annual dose. However, only 22 per cent of population consumes water from 5000 drilled wells, 11 per cent of population –from wells. In separate cases average individual effective doses for inhabitants of separate towns and villages on account of water are 10 mSv per year. Maximum concentrations of natural radionuclides detected on territory of Ukraine in potable water: for ^{226}Ra – 5 $Bq \cdot l^{-1}$, for natural uranium – 21 $Bq \cdot l^{-1}$.

In general outlook average effective doses for the Ukrainian population are typical ones for the European countries (Fig.6), though in separate locations and towns and villages their values are comparable with acceptable irradiation doses for professional groups. That's why problem of diminishing of population irradiation doses from natural radioactivity sources is actual for Ukraine.

Besides, by economic criteria in many cases it is reasonable to conduct diminishing of summary irradiation doses from all the ionising irradiation sources by diminishing doses from natural radioactivity.

Basic stages of this process are:

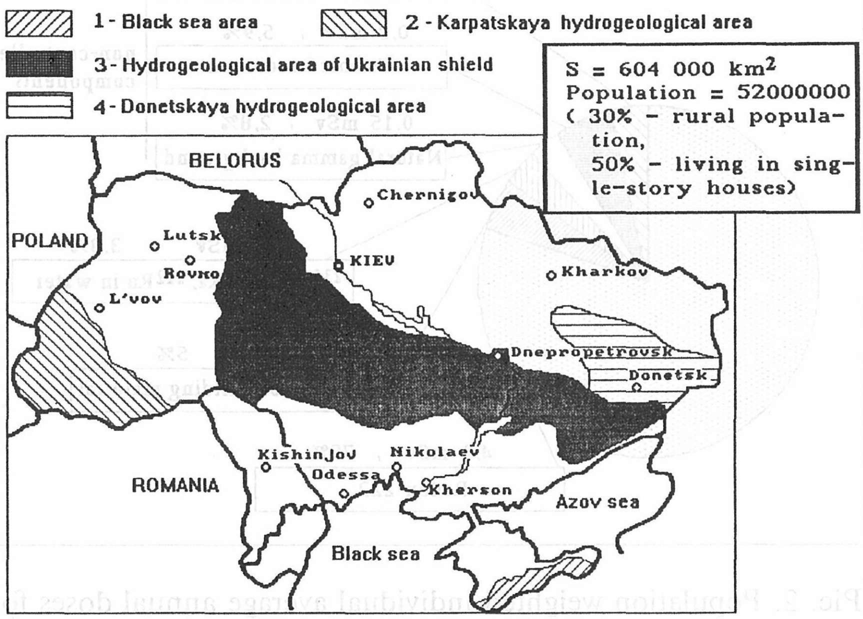
— substantiation of standards and recommendations;

— organization of radiation control;

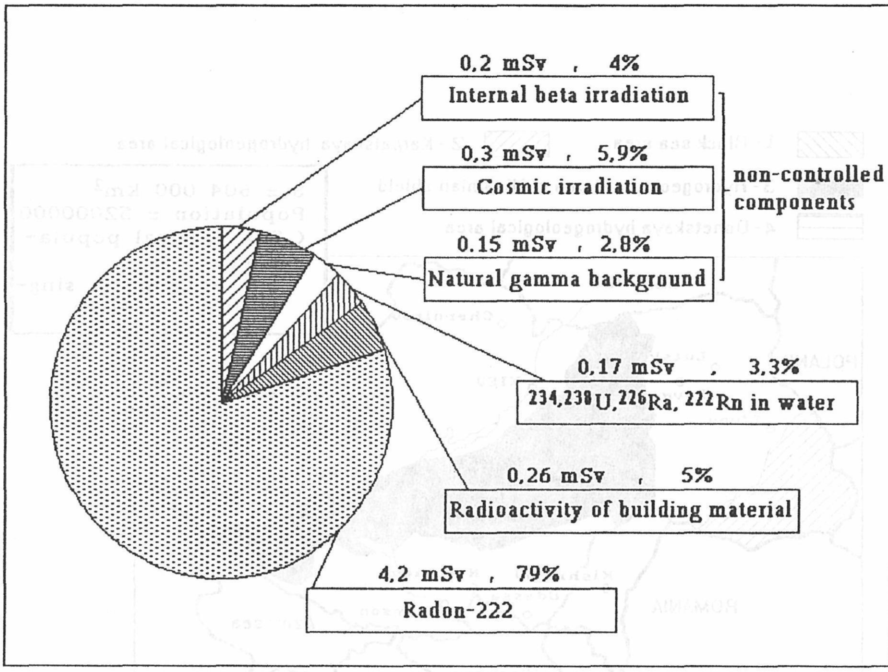
— substantiation and realisation of countermeasures.

On Table 1 Basic standards in the field of natural radioactivity established by the Health Ministry of Ukraine are represented. Radiation control structure is represented on Table 2. Peculiarity of radiation control is single methodological rules for all the organizations.

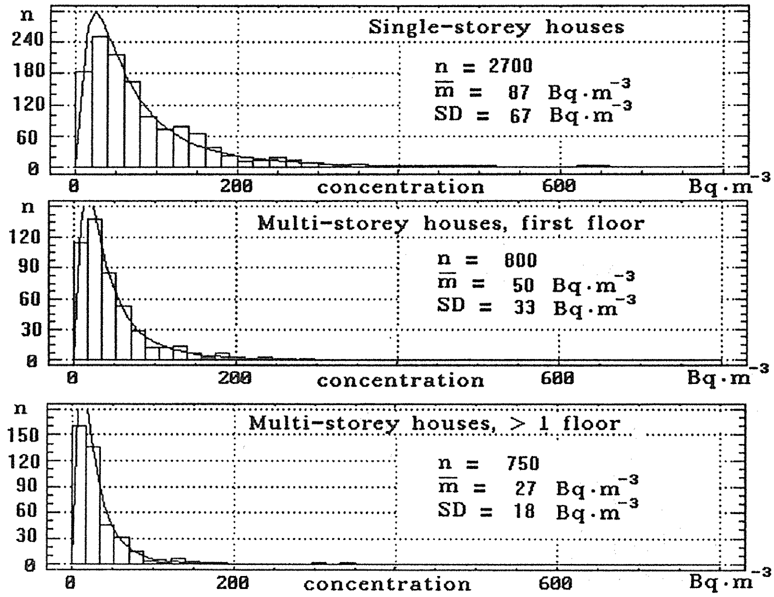
As for countermeasures, in this field they are commonly known. But the important point is that in Ukraine during two years already a rule exists under which all new buildings should have a document about fitness to standards given in Table 1. In case of non—fitness either additional works are conducted on diminishing of radon, for instance, in air of premises, or designation of a building is changed, if there is no possibility to diminish external irradiation dose rate, for instance. In this case a residential building is reconstructed to be a hotel or an office. There are some such cases already.



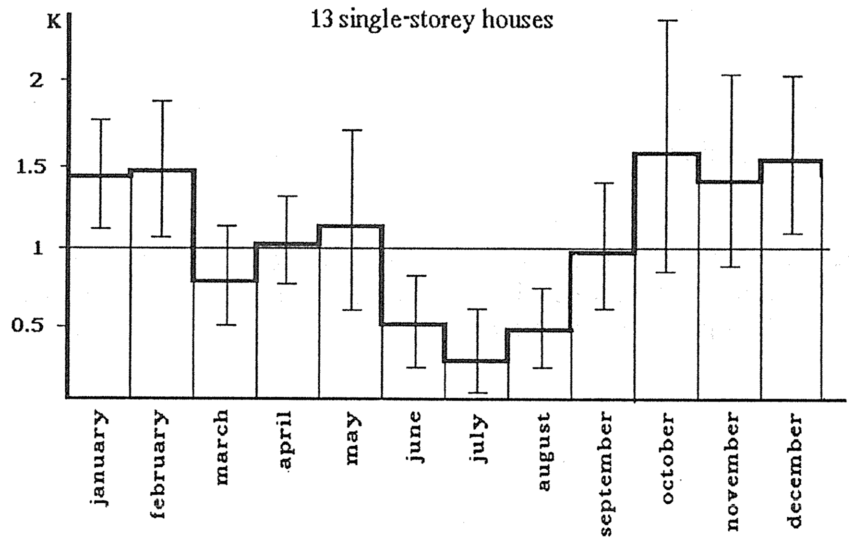
Pic. 1. Hydrogeological area of the Ukraine



Pic. 2. Population weighted individual average annual doses for Ukrainian residents from natural sources

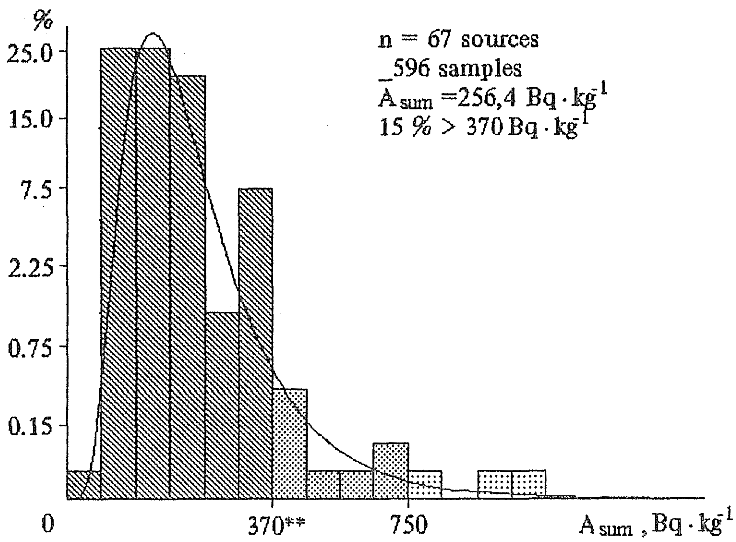


Pic. 3. Frequency distribution of indoor radon EEC's under types of houses in Ukraine
n - number of buildungs, m - average concentration, SD - standard deviation



Pic. 4. Monthly averaged radon concentrations in dwellings of single-storey houses

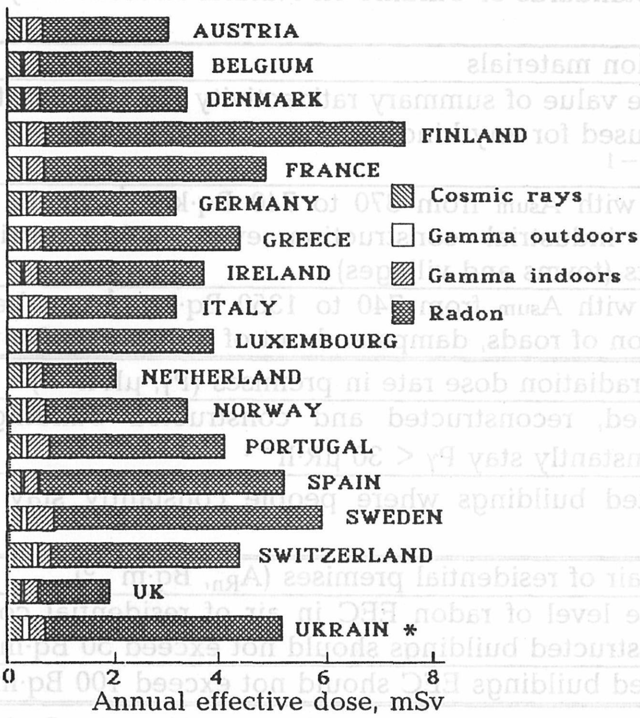
$$A_{sum} = A_{Ra^*} + 1{,}31 A_{Th^*} + 0{,}085 A_{K^*}$$



* - ^{226}Ra, ^{232}Th, ^{40}K;

** - acceptable Asum for residential construction

Pic. 5. Frequency distribution of total effective activity - Asum of natural radionuclides in mineral construction materials in Dnepropetrovsk region



* — own results

Pic. 6. Average effective doses from natural radiation source (From: B. M.R. Green, J.S. Hughes, P.R. Lomas. Radiation Atlas: Natural Sourses of Ionising Radiaton in Europe. NRPB, Chilton, Didcot, Oxon, OX11 ORQ, UK. — 1991, p.9.)

Table 1

Basic Standards of Ukraine on Natural Radioactivity

1.	Construction materials
1.1.	Acceptable value of summary ratioactivity A_{sum} in construction materials used for any kinds of construction should not exceed 370 $Bq \cdot kg^{-1}$
1.2.	Materials with A_{sum} from 370 to 740 $Bq \cdot kg^{-1}$ can be used for road and industrial construction even within territories of settlements (towns and villages)
1.3.	Materials with A_{sum} from 740 to 1350 $Bq \cdot kg^{-1}$ can be used in construction of roads, damps and out of territories of settlements
2.	Gamma irradiation dose rate in premises ($P\gamma$, $\mu R \cdot h^{-1}$)
2.1.	In designed, reconstructed and constructed buildings where people constantly stay $P\gamma < 30\ \mu R \cdot h^{-1}$
2.2.	In exploited buildings where people constantly stay $P\gamma < 50\ \mu R \cdot h^{-1}$
3.	Radon in air of residential premises (A_{Rn}, $Bq \cdot m^{-3}$)
3.1.	Acceptable level of radon EEC in air of residential constructed and reconstructed buildings should not exceed 50 $Bq \cdot m^{-3}$
3.2.	In exploited buildings EEC should not exceed 100 $Bq \cdot m^{-3}$
4.	^{226}Ra – natural uranium in potable water (A_{Ra}, A_u, $Bq \cdot l^{-1}$)*
4.1.	Acceptable content in drinking water: $A_{Ra} \leq 2\ Bq \cdot l^{-1}$ $U \leq 44\ Bq \cdot l^{-1}$

* nowadays is revised and will be diminished.

Table 2

Radiation Control Structure

Control Type	Implementing Organization	Goal of activities
Establishmental control	Building Construction Ministry (A_{sum} of construction materials, A_{Rn} in air of residential premises, $P\gamma$ in premises); Ministry of Water Husbandry (Ra, U in water); Geology Ministry (A_{sum} of construction materials, Ra, U in water)	Certification of products, dwellings
Out – establishmental control	Health Ministry	Fitness of products and dwellings to standards
Scientific and methodological support for control	Center for Radiation Medicine, "Rosa" Scientifc and Industrial Firm, other scientific organizations	Substantiation of standards, methodologies, recommendations (countermeasures); quality control for measurements (intercomparison of measurements results)

Discussion

Dr. Kobayashi, (NIRS): Are the current regulatory concentrations for construction materials the same in the former USSR?

Dr. Ramzaev, (IRH): The current limits are different from those of Russia.The regulatory limits have been revised in the last ten years and will be revised again in the future.

Dr. Goritskyi, (RCRM): There are 200 institutions making measurements in Ukraine. Buildings are not to be constructed without examinations of the parent radionuclides of Rn in the materials.

Dr. Kobayashi, (NIRS): I feel that the limit of 50 Bq/m3 for radon in houses is very restrictive.

Dr. Ramzaev, (IRH): It's now 120 for newly built houses in Russia.

Dr. - : In Sweden it is 35 for newly built houses and 75 for existing houses.

Dr. Matsudaira, NIRS: Were the values of radon concentration multiplied with an equilibrium coefficient of 0.4?

Dr. Goritskyi, (RCRM): These are values multiplied with an equilibrium coefficient of 0.5.

Dr. Okano, (RIKEN): Is Intervention carried out if the value is known to exceed the set limits?

Dr. Goritskyi, (RCRM): The value is not used for intervention but only as indicators for individuals to make personal choices.

EXPERIENCE, PROBLEMS AND RESULTS OF MASS IMPLEMENTATION OF WHOLE – BODY COUNTERS AT POST CHERNOBYL PERIOD

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ACTUALITY

In this report data is represented concerning methodology, technique and discussion of basic results on assessment of population individual doses of internal irradiation conditioned by radio caesium intake with food products.

Assessment of contribution of different radio nuclides into internal irradiation dose since 1987 shows that 95 – 97 per cent of annual dose is determined by radio caesium and only several percent are determined by 90 – Sr and other radio nuclides. Thus, in postchernobyl problem factor of irradiation by radioisotopes of 137 – Cs and 134 – Cs is the most long – time one and since end of 1986 and beginning of 1987 it determines population dose loading.

In this connection one of the most important tasks of elimination of consequences of the accident since its first days became establishment of radiation monitoring system for internal irradiation doses by direct methods for hundreds thousand people residing on vast territories affected by radiation contamination.

Solution was complicated by number of problems connected with lack of sufficient number of whole—body counters (WBC), methodological and metrological support, information collection and processing systems.

INSTRUMENTS AND METHODS

Lack of mobile radiation and dosimetric laboratories in 1986—1988 conditioned necessity of wide implementation of portable energoselective WBC for express determination of summary 137—Cs and 134—Cs content in human organism under condition of expedition and operational assessment of internal irradiation levels for large population groups.

Implementation of single—channel pulse analysers with NaI(Tl)—detectors allowed to establish relatively cheap measuring installations providing high—quality dosimetric information under condition of expedition measurements.

Implementation of Marinelli geometry in portable WBC is substantiated experimentally, by the way of measurement of characteristics of time dynamics of radio caesium distribution after one—time intake in organisms of volunteers by WBC of scanning type.

So, in five hours after one—time radio caesium intake into human organism deviations of measurement results from real values of activity in Marinelli geometry constitute about 30 per cent, and in one day measurement errors become insignificant.

In parallel stationary BC have been implemented. Studies of technical and dosimetric characteristics of WBC with different measurement geometries allowed to modernise number of stationary instruments which have high sensitivity due to implementation of geometry with location of a detector closely to a human body and thus such instruments allow to obtain reliable data under high capacity. Such WBC were used as expert and calibration systems.

In methodological aspect during implementation of portable WBC in Marinelli geometry problem appeared on registration of shielding effects during measurements without implementation of means of protection against background irradiation in contaminated areas. Shielding coefficient (K e) depends on constitution of a human body and energetic characteristics of gamma—field.

Values of shielding coefficients are approximated satisfactorily by expression with using of weight only

$$Ke = 0.5 + \exp(-0.25 \cdot \sqrt{m}) \qquad (1)$$

Here content of radio caesium in human organism was determined:

$$Q = (Ns - No \cdot Ke(m) \cdot Kp) \cdot Kg(m) \cdot m \cdot t^{-1} \qquad (2)$$

Under non—stationary condition of measurements it appeared convenient to implement set of canisters filled with water solution of potassium as a background phantom.

Under existing scale of the accident for implementation of complex radiation control a mobile radiation and dosimetric laboratory has been worked out and is implemented now on basis of a powerful diesel passenger bus of increased cross—country ability. The basic technical parameters of the laboratory(Table 1):

Table 1

Basic technical parameters of MRDL

Weight of lead protection, tones	1.2
Reserve of travel capacity, km	800
Divisibility of weakening of protection on Cs−137+Cs−137	5.0
MDA WBC−1 on Cs−137, t=3min, Bq/organism	185
NaI(Tl) detectors size	75x75mm
Capability for 12 hours, men	400
Measurement time for two people, not more than min	3
Crew, men	4

Characteristics of WBC in RCRM

Table 2

Instrument type	Capacity men/hour	MDA, Bq (t=180 s) on 137−Cs	Size NaI(Tl) detector mm	Pulse analyser
Positronika	30	100	140x210x70	ORTEC
Super−Gemini	40	280	75x75	ORTEC
MRDL	50	160−185	75x75	SIMCAS
Portable	30	600	75x75	NC−482

Table 3

Physical and dosimetric characteristics of fillers of phantoms.

Date of measurement	29, January, 1992
137−Cs concentration, $Bq.kg^{-1}$	571±1.5%
134−Cs concentration, $Bq.kg^{-1}$	46±3.8%
40−K concentration, $Bq.kg^{-1}$	355±4.9%
137−Cs and 134−Cs ratio	12.4
Ratio density, $g.dm^{-3}$	885

For provision of high–quality measurements without decrease of capacity two–seats WBC is installed in the bus with shadow protection providing high sensitivity for two measurement geometries (protection arm–chair and "marinelli").

Characteristics of WBC exploited are represented in Table 2.

CALIBRATION

Under situation appeared after the Chernobyl NPP accident problem of metrological support of internal irradiation dosimetry became the most complex one. It is conditioned by dramatic increase of number and types of WBC for wide implementation. In many cases lack of standardised methodologies for implementation of measurements and means of calibration for equipment used (checked human body phantoms and graduation sources) led to sufficient methodological errors of measurement results.

For calibration of WBC human body phantoms have been developed with poured radioactive filler (dried peace). Design of a poured phantom is protected by a patent (1993). Totally six such phantoms were made modelling human body of different age groups.

Physical and dosimetric characteristics of a filler of phantoms are represented in Table 3.

For assessment of quality of phantoms and their metrological characteristics number of intercomparisons was conducted.

Long–time exploitation of assembled human body phantoms with poured radioactive filler has revealed high efficiency of the method implemented:

— the phantom adequately models shape of human body for different age groups and all geometry of measurements;

— complete assembling of the whole set requires not more than 30 minutes;

— the phantom is safe for transportation and storage;

— ratio of caesium radioisotopes fits to "chernobyl" ratio;

RESULTS

Development of equipment, methodological and metrological support allowed to implement population mass monitoring with possibility of provision of reliable information for operative decision making, long-time prognosis and recommendations, study of regularities of individual internal irradiation doses formation.

Since 1986 210 000 measurements have been made. Measurements were made mostly in "reper" towns and villages with maximum involvement of all the population groups on professional, sex and age indices during provision of representative samples.

Analysis of dynamics (Fig.1) allowed to study regularities of internal irradiation doses formation depending on radiation factor, sex, age and profession. So, average dose values varied within the range of 0.9-0.02 cSv per year at log-normal character of distribution (Fig.2). Ratio of average values to medians is 2-4. Doses at men are 1.1-1.6 times higher in comparison with women depending on age. At initial stage of the accident doses at children were 1.1-1.5 times higher than at adults and, as a rule, lower at later stage of the accident.

Fig.1

Equivalent internal irradiation doses for inhabitants of Ukraine (median values, adults)

A — Ivankov, B — Polesskoye, C — Narodichi, D — 30-km zone around the Chernobyl NPP, E — Ovruch, F — Rokitne

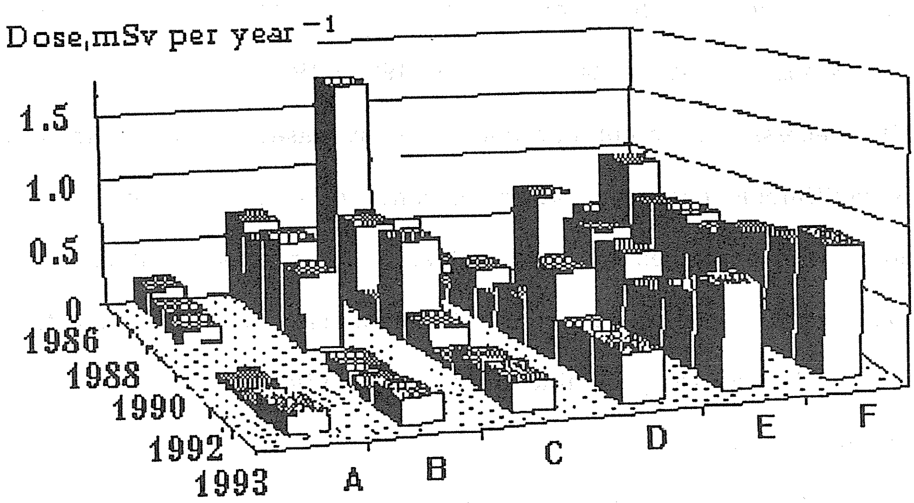
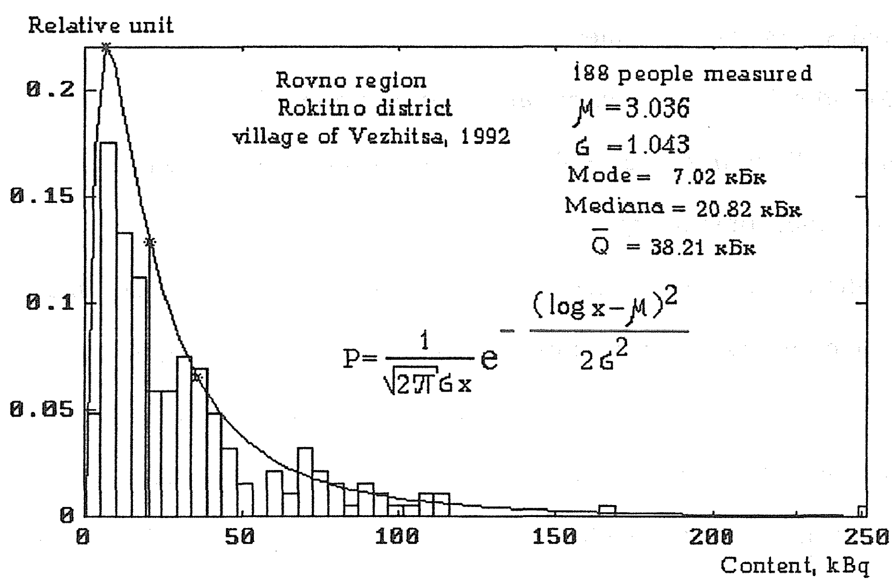


Fig.2.

Example of distribution density function for summary content of 137-Cs and 134-Cs radioisotopes



Children and agricultural workers, forestry workers first of all, were included into critical groups.

As it follows from dynamics analysis, both in towns and villages, where constant decrease of radio caesium content was observed, and in towns and villages with abnormally high transfer coefficients increase of radio caesium content was observed at 30−80 per cent in 1992−1993.

It's necessary to point out that in many cases activity distributions acquire multimodal character, where presence of modes is conditioned by age index. It is explained by lower values of radio caesium at children at later stages of the accident as a result of metabolism peculiarities and thanks to complex of measures providing decrease of radio caesium concentration in their nutrition ration.

Dependence of internal irradiation levels from radioactive fallouts density on spot represents factor of assessment of mechanism of population irradiation doses formation. On Fig.3 such dependence is represented on example of towns and villages in Narodichi district. Median values of 137−Cs content in human organism and 137−Cs fallout densities on spot are considered as depending values.

Considerable dispersion of values testifies about low level of reliability of correlation links ($r = 0.2 - 0.7$) between values considered, the latter is related with their time dynamics.

It allows to make conclusion about that fact that establishment of different models for reliable internal irradiation doses prognosis is very complex, and in many cases non−soluted, task. Real picture of population dose loadings formation could be obtained only on basis of wide implementation of instrumental dosimetry methods using WBC. Only in

Table 4

Relative errors of 137 – Cs content measurements in an adult man body phantom implemented in leading world institutes

Name of an organisation	Δp
ARC(Austria)	1.18
IAEA	0.85
NIRS(Japan)	1.03
JAERI(Japan)	1.03
URCRM	1.00

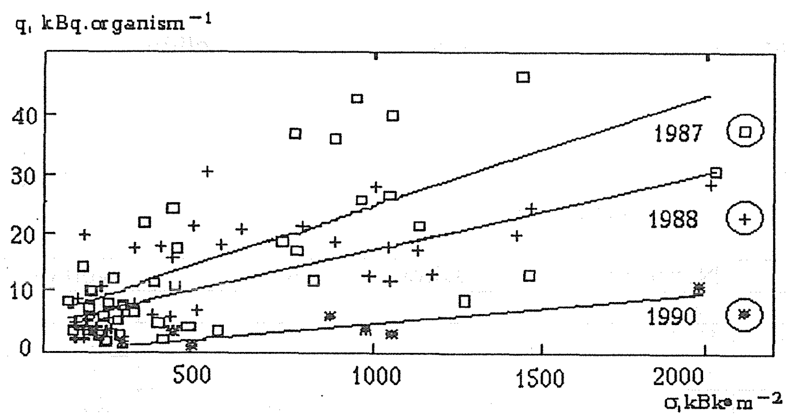
Table 5.

Information about amount of WBC measurements in URCRM for 1986 – 1993 in Ukraine

Regions	Number of towns and villages	Number of measurements in thousands
Kiev	66	53.2
Zhitomir	104	92.7
Rovno	62	31.7
30 – km zone	7	4.3
city of Kiev	1	18.4
others	468	9.0
TOTAL	708	209.3

Fig.3.

Dependence of average values of 137 – Cs content in human organism from its fallouts density on spot (Narodichi district).



number of areas with standard types of soils and efficiently conducted countermeasures it was possible to observe systematic decrease of radiocaesium contence.

In number of towns and villages dynamics of doses decrease can be represented by function reflecting change of average values in time and has exponential character with period of half−purification of T0.5=1.8 years (Table 6).

CONCLUSION

Based on huge factual material and experience of WBC implementation the three−level concept (Prof. I.A.Likhtarev et al) has been developed for population internal irradiation doses assessment system.. It allowed to install network of stationary WBC in Ukraine (40 systems) with single methodological, metrological and software support.

As time showed, establishment of monitoring system is actual nowadays, because in 1992−1993 we managed to track excess of incorporated radio caesium levels at 30−80 per cent in connection with interruption of countermeasures because of economic decay and also possible changes in degree of accessibility of radio nuclides.

Table 6.

Dynamics of doses decrease

	Narodichi	Polesskoe	Ovruch	average
N_{places}	12	6	9	27
N_{msr} 10^{-3}	13.3	2.4	5.5	21.3
r	−0.91	−0.89	−0.95	−0.84
$T_{0.5}$	1.39	2.89	1.63	1.82
◆	0.23	0.67	0.73	1.02

Discussion

Dr. Ramzaev, (IRH): What do you think was the cause for incorporated Cs-137 levels in 1992-1993 to increase?

Dr. Perevoznikov, (RCRM): I think it was because of the curtailment of counter-measures due to economic necessity and the possible changes in the degree of radionuclide transfer into vegetation.

Dr. Ramzaev, (IRH): The same trend in the increase was also observed in Russia. The incorporated Cs-137 level didn't vary much by season, but Cs-137 in cow's milk varied in a range from 1 to 10 times. It may be because cow's food is different in summer and winter and because a cow's biological half-time is short, about 20 days.

Calibration Study of Whole-body Counters for ^{137}Cs in the Body using Different Phantoms carried out by the Cooperation Program between Japan and Ukraine

– Interim Summary of the Study in 1989-1993 –

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I. Abstract

A plenty of whole-body counting has been carried out to determine the ^{137}Cs content of the public affected by Chernobyl accident in Ukraine and Belarus. The results provide the basic data for estimating individual internal dose which is necessary for the investigation of health effect of the public, and also be effective to reduce the fears of people. The practical application of whole-body counting primarily requires the establishment of its reliability, and the calibration of the counter by appropriate phantom is necessary.

The inter-calibration study of whole-body counter is the one of the main subject of the cooperation program in the field of radiation medicine started in 1989 between Japan and USSR, in which Ukrainian Research Center for Radiation Medicine (RCRM), former name is All Union Scientific Center of Radiation Medicine, is the institute in Ukrainian side and National Institute of Radiological Sciences (NIRS), Japan Atomic Energy Research Institute (JAERI) and Power Reactor and Nuclear Fuel Development Corporation (PNC) are the institutes of Japan side. Scientific Research Institute of Radiation Medicine (SRIRM) in Gomel is also the cooperative institute of the program. Anthropometric phantoms prepared by Japanese side and Green peas phantoms prepared by Ukrainian side were used for the calibration study.

The result of measurements of anthropometric phantoms by

whole-body counters in Japan shows that the efficiencies of the counters have dependency of body size and the large variation observed for small body size. The ratio of measured radioactivity of ^{137}Cs to filled radioactivity of the anthropometric phantoms resulted the range of 0.8-1.2 for the counters in Ukrain and this shows the calibration being generally well established. And the range of 0.7 - 1.5 for the counters in Belarus shows somewhat inappropriate calibrations is presumed and suggests the need of another appropriate calibration values set up.

II. Introduction

The standardization of the calibration of the whole-body counter has not been established inside Japan and also world wide scale. Each institute uses their own phantoms as standard for the calibration, and intercomparison of the calibration study has not been implemented. And this calibration of the counter of each institute may not be resulted any problem if the measurement is carried out isolated from other institutes for the purpose of individual monitoring unless standardization is not required in national level or international level.

The traceability of the calibration using standardized phantoms is necessary for the comparison of whole-body counting data in national or international level, and it may also necessary in Ukraine and in Belarus to establish the basic standard to evaluate the body activity or internal dose of the public affected by Chernobyl accident.

The standardization of the calibration provides the unified interpretation of the whole-body counting results and their intercomparison between institutes. The cooperation on calibration of whole-body counter and intercomparison of whole-body counting technique was started in such circumstances.

Lots of whole-body counting has been carried out to determine the ^{137}Cs content of the public affected by Chernobyl accident in Ukraine and Belarus. The results provide the basic data for estimating individual internal dose which is necessary for the investigation of health effect of the public. And the whole-body counting is also effective to reduce the fears of radiation detriment of people. The reliability establishment of whole-body counting is essentially required for its practical application, and then the calibration by appropriate phantom is necessary.

The inter-calibration study of whole-body counter is the one of the main subject of the cooperation program in the field of radiation medicine started in 1989 between Japan and USSR, in which Ukrainian Research Center for Radiation Medicine, former name is All Union Scientific Center of Radiation Medicine, is the institute in Ukrainian side and National Institute of Radiological Sciences, Japan Atomic Energy Research Institute and Power Reactor and Nuclear Fuel Development Corporation are the institutes of Japan side.

Anthropometric phantoms of 3 years, 11 years and adult sizes were used for the calibration study which were prepared by Japan side. Green pea phantoms were also used which are prepared by Ukrainian side. The cooperation was initiated by the whole-body measurement of body activity in green peas phantoms and scientists of RCRM when they visited Japan for this study in 1989. The inter-calibration of whole-body counter using above anthropometric phantoms were implemented in Japan, Ukraine and Belarus. Precise whole-body counters with shielded room were used in Japanese institutes and simple chair type ones in Ukraine and Belarus.

The biological half times of cesium were measured for three Ukrainian and six Japanese scientists by following up measurement. The biological half time is proportional to internal exposure dose and is one of the important parameters to evaluate internal dose of individuals. Therefore, retention of radionuclide for individuals should be taken into account for the estimation of individual internal exposure.

In the followings, whole-body counters and phantoms used in the cooperation study, and the results of calibration are described .

III. Whole-body counters and phantoms

III-1 Whole-body counters

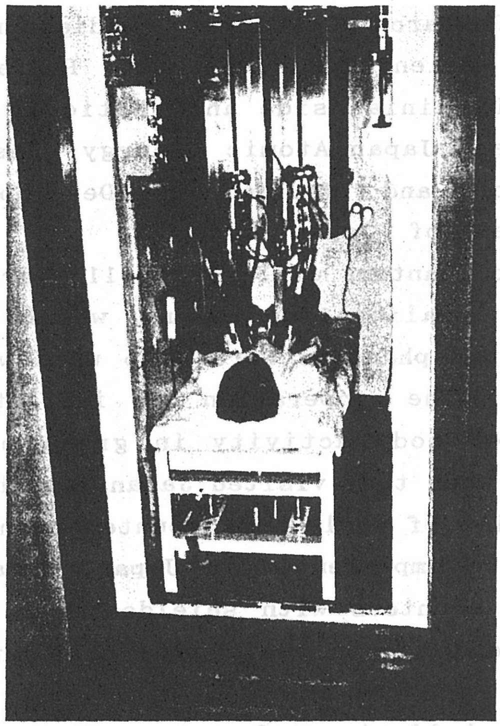


Photo.1 Inside of the shielding room of precise whole-body counter in JAERI

All of the whole-body counters in Japan, Ukraine and Belarus applied to the calibration study are used NaI detectors. NaI detectors of 20 cm diameter and 10 cm thickness are used in Japanese side whole-body counters. JAERI and PNC adopt multi-detector geometry and NIRS adopts scanning geometry, which field of view are most of the whole-body. Photo. 1 shows the precise whole-body counter in JAERI. While chair type whole-body counters in Ukraine and Belarus use single NaI detector of 6.3 to 10 cm diameter with lead collimator. Photo.2 shows chair type whole-body counter at polyclinic in Betka town in Belarus which has view field from neck to thigh of the body. Another simple body monitors, whose detector being nearly contact to body, are also used in Ukraine ; e.g. "Positorinica" whose detector contacts to back of body, and "Super Gemini" whose detector contacts to front abdomen. Photo.3 shows this Super Gemini whole-body counter measuring adult green peas phantom. The counters in Ukraine and Belarus is light weight and small size and are transportable. The detection limit of them is in order of several hundreds Bq, while that of precise counters in Japan is in order of several tens Bq ; e.g. 16 Bq of ^{137}Cs for JAERI whole-body counter in 1000 sec. measurement.

III-2 Phantoms used for the calibration study

The purpose of the cooperative calibration study is to calibrate the whole-body counters in Japan, Ukraine and Belarus by means of anthropomorphic phantoms as standard to establish the proper calibration results. Followings describe the outline of the phantoms used in this calibration study.

a) Anthropometric phantom

Anthropometric phantom is designed and manufactured faithful to the anthropometric data and then has enough reliability. Three anthropometric phantoms of different size, 3 years old, 11 years old and adult, are prepared for this study by Japanese side. The phantom is made of acrylic acid resin of 4mm thickness. As a example the outline of the 3 years old phantom is shown in Fig. 1. The height and weight of these three phantoms and their radioactivity filled for the calibration study are in Table 1. The radioactivities filled in the phantoms for the calibration study are determined taking account the sensitivity of the whole-body

Photo.2 Chair type whole-body counter in Betka District Polyclinic in Belarus

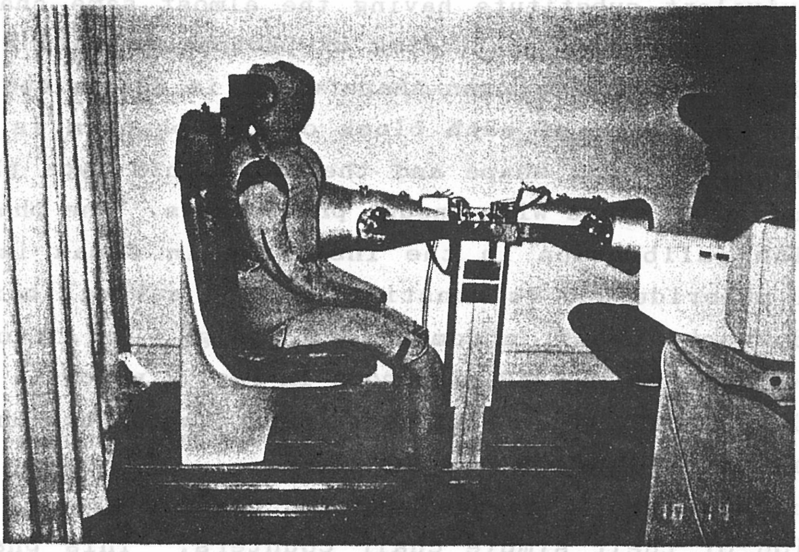


Photo.3 Super Gemini whole-body counter in RCRM in Ukraine

counter used and the statistical error of measurement, such as about 3 to 10 kBq for the experiment in Japan and about 20 to 40 kBq for the experiment in Ukraine and Belarus. Homogeneous solution of ^{137}Cs with CsCl carrier and hydrochloric acid is filled in each part of the phantom in which PH of the solution is adjusted to about 3.

b) Block water phantom

Anthropomorphic phantom is generally applied for the calibration of the most of whole-body counters. This phantom is made of tissue equivalent substitute having the almost same characteristics for absorption and scattering of photons as soft human tissue, and have simplified human shape which is determined by human data. But the shape of each block of the phantom is too much simplified such as box shape and therefore this type phantom do not express human shape with enough preciseness. The phantom used for routine calibration in the institute in Japan is made of polyvinyl chloride and is constituted with several box blocks, e.g. head, neck, chest, abdomen, arm, thigh, leg, foot. The adult block phantom in JAERI is shown in Fig. 2 which is almost as same as that in PNC, while NIRS uses round shape block phantom.

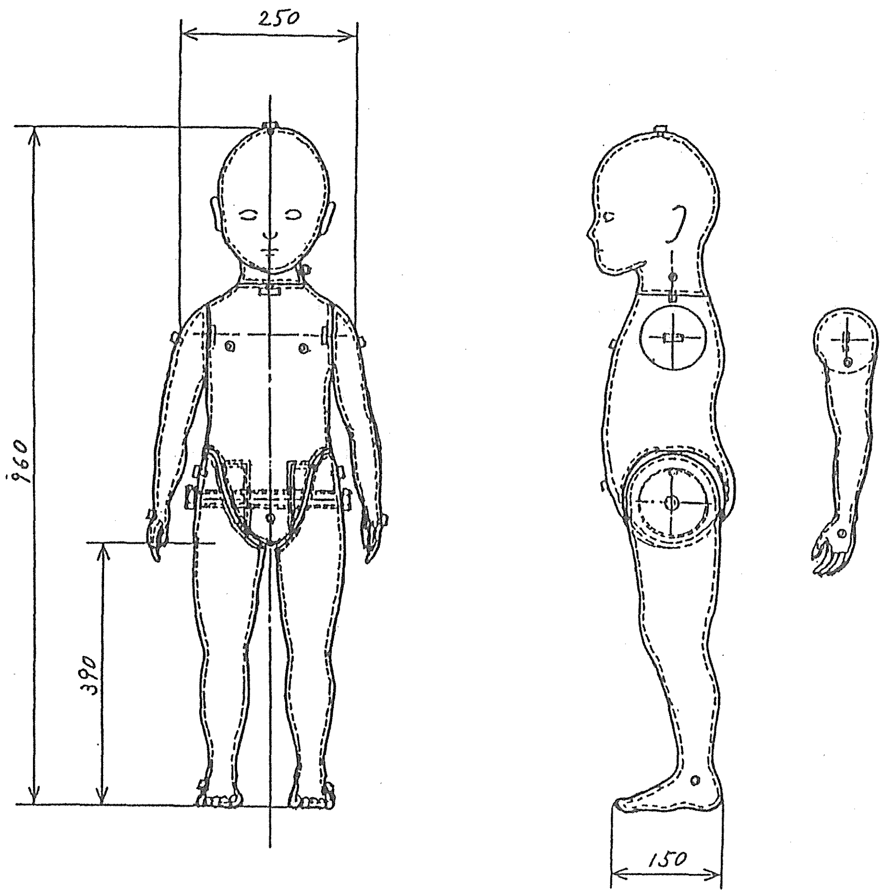
c) Phantoms in Ukraine and Belarus

Green peas phantom is designed and used in Ukraine for the calibration of their simple chair counters. This phantom has human shape and made of cloth filled with green peas contained ^{137}Cs(^{134}Cs). Photo. 3 shows this phantom of adult size in measurement position by Super Gemini whole-body counter in RCRM. Green peas phantom is well designed and manufactured as shown in photo.3, but has some problems such as change shape or size are brought by its flexibility. And another problem is the tissue equivalent material of dried green peas which density is about 0.8 and is not close to the soft tissue density of 1.06.

Brick phantom is used in Belarus which is made of polysterol and is used by inserting stick sources in each brick. The problems are the insufficient expression of body shape and inhomogeneity of sources.

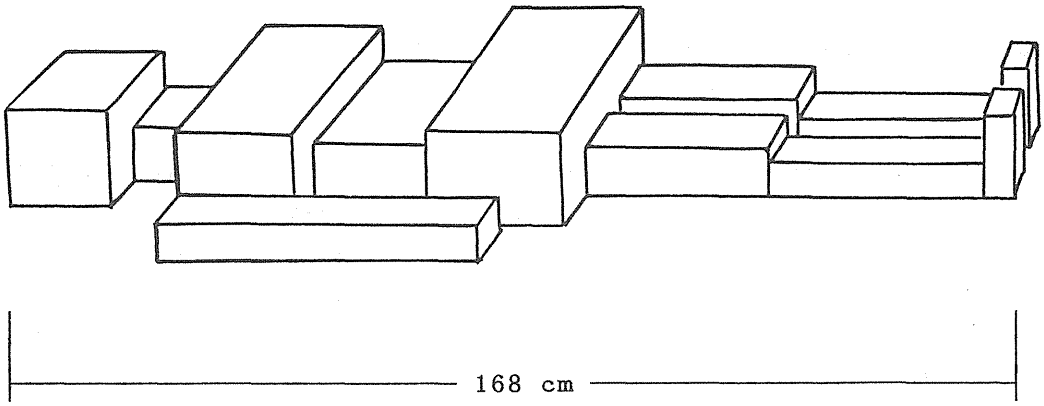
able 1 Size of anthropometric phantoms and activity of ^{137}Cs filled in the experiment in Ukraine and in Japan

Anthropometric phantom	Height (cm)	Weight (kg)	Volume ($x10^3 cm^3$)	Activity of ^{137}Csfilled in Ukraine [in Japan] (kBq)
3 years old	96	16	12.4	20 [9.67]
11 years old	143	37	26.2	20 [3.23]
Adult	173	64.3	48.3	37.6 [5.96]



Height	96cm
Head circumference	50cm
Chest circumference	52cm
Abdomen circumference	48cm
Width of the shoulder	25cm
Height of the crotch	39cm
Length of the foot	15cm
Body weight	14.6kg

Fig.1 Outline of anthropometric phantom of 3 years old



Dimensions of each units

	unit	Dimension (cm) W x L x H
1	Head	13.3 x 18.0 x 16.7
2	Neck	7.8 x 8.5 x 8.7
3	Chest	29.1 x 20.3 x 19.4
4	Abdomen	25.0 x 20.3 x 16.1
5	Pelvis	28.2 x 23.6 x 18.8
6	Arm	6.6 x 51 x 7.4
7	Thigh	11.4 x 33.0 x 12.7
8	Leg	7.7 x 37.7 x 8.6
9	Foot	8.4 x 6.6 x 16.8

Fig.2 JAERI block phantom of adult size of 168 cm body height and 58 kg weight consisted by 13 box units made of polyvinyl chloride of 5mm thickness which are filled with radioactive solution

IV. Results

Calibration studies initiated 1989 in Japan using RCRM green peas phantom followed by measurements using anthropometric phantom of adult size in Japan, Ukraine and Belarus in 1990. The another calibration study using anthropometric phantoms of 3 years old and 11 years old were carried out in 1993.

IV-1 Calibration experiment in Japan using anthropometric phantom

Calibrations of whole-body counter were made in JAERI, NIRS and PNC using three anthropometric phantoms of 3 years old, 11 years old and adult. Table 2 shows the results where the body size dependency of the efficiency was observed in every whole-body counter. The efficiency result by JAERI whole-body counter plotted against reciprocal of body weight is shown in Fig. 3. The variation of the efficiency per kg is estimated about 0.3 % at 64 kg body weight and about 3 % at 16 kg body weight. It shows the necessity of correction of efficiency especially for the small size human body. The efficiency obtained for the RCRM green peas phantom are indicated by the symbol of triangle and show relatively high efficiency compared with those for anthropometric phantom.

IV-2 Calibration experiment in Ukraine and Belarus using anthropometric phantom

Calibration experiments of whole-body counters in Ukraine and Belarus using adult anthropometric phantom were carried out in 1990 with RCRM adult green peas phantom. The measurements were made by one whole-body counter in Ukraine and three whole-body counters in Belarus and the results are shown in Table 3. The expression AP denotes anthropometric phantom and GP denotes Green peas phantom. The difference of measured activity with filled activity is expressed by percent. The difference is in the range between -7 and +11 % which suggests the calibrations of whole-body counter in Ukraine and Belarus were well performed for adult.

Calibration study using 3 years old and 11 years old anthropometric phantoms were carried out in 1993 in Ukraine and Belarus. Photo. 4 shows the measurement for the 3 years old phantom in RCRM. Measurements for these anthropometric phantoms were made by four whole-body counters in Ukraine and four whole-body counters

Table 2 Results of whole-body counting of three anthropometric phantoms (adult 11 years old and 3 years old size), which contained ^{137}Cs solution homogeneously, carried out in three institutes in Japan

Institute	Detecting system*1	Detection efficiency*2 for anthropometric adult phantom	Detection efficiency*2 for anthropometric 11 years old phantom	Detection efficiency*2 for anthropometric 3 years old phantom
JAERI	fixed 5 detectors	1.09 cpm/Bq	1.20 cpm/Bq	1.48 cpm/Bq
NIRS	scanning 2 detectors	0.35 cpm/Bq	0.46 cpm/Bq	0.67 cpm/Bq
PNC	fixed 2 detectors	0.49 cpm/Bq	0.70 cpm/Bq	0.96 cpm/Bq

*1 Detectors used in each institute are all NaI(Tl) detectors of 20 cm diameter and 10 cm thickness
*2 Detection efficiencies are for photo peak of 662 keV gamma ray of ^{137}Cs

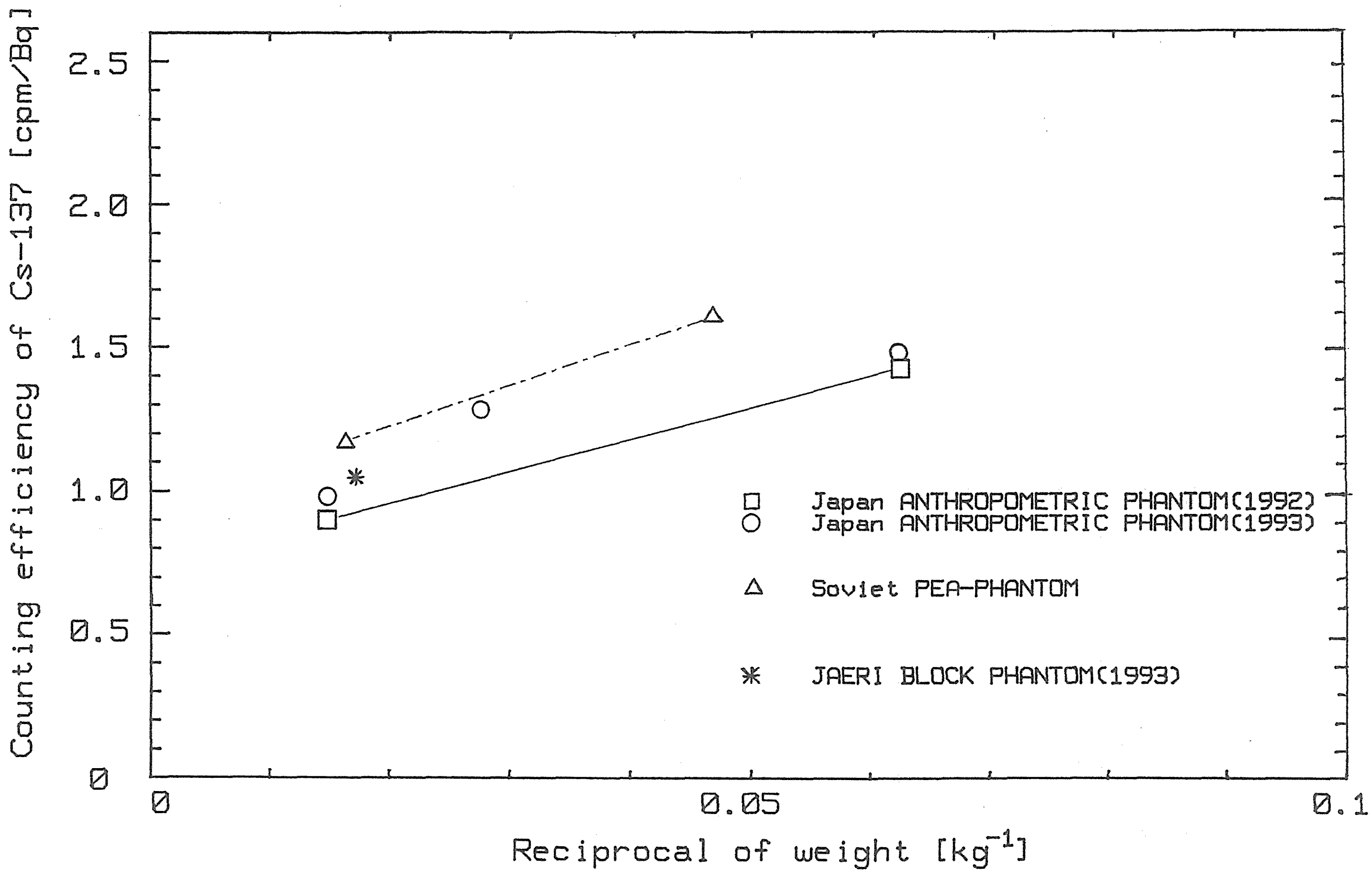


Fig.3 Weight dependency of counting efficiency of ^{137}Cs in phantoms observed at JAERI precise whole-body counter for three different type phantoms; antropometric, RCRM green peas and JAERI block phantoms

Table 3 Results of Whole-body Counting of green peas phantom(GP)*1 containing ^{137}Cs and ^{134}Cs, and anthropometric phantom(AP) containing ^{137}Cs, both phantom are of male adult size, carried out in Ukraine and Belarus

Place*2 (facility)	Phantom [name of nuclide estimated its activity]	Filled activity [A]	Estimated activity from measurement [B]	Difference (B-A)/A (%)
Kiev (RCRM)	GP[^{137}Cs] AP[^{137}Cs]	28,300 Bq 37,600	27,200 Bq 35,100	-4 -7
Gomel (hospital)	GP[^{137}Cs+^{134}Cs] AP[^{137}Cs]	31,700 Bq 37,600	33,000 Bq 38,900	+4 +3
Vetka (hospital)	GP[^{137}Cs+^{134}Cs] AP[137Cs]	31,700 Bq 37,600	37,400 Bq 38,000	+18 +1
Khoyniki (hospital)	GP[^{137}Cs+^{134}Cs] AP[137Cs]	31,700 Bq 37,600	38,900 Bq 41,800	+23 +11

*1 Green peas phantom, which is possessed by RCRM in Kiev, has contained both ^{137}Cs and ^{134}Cs (activity ratio of ^{134}Cs to ^{137}Cs is 1/8) while anthropometric phantom has been filled with ^{137}Cs solution.

*2 Gomel, Vetka and Khoyniki are the names of town located in southern part of Belarus in Belarus and the results are shown in Table 4. The results for the whole-body counters in Ukraine shows that the calibration has been made adequately except the counter in mobile bus which has large error of -35% for the 3 years old phantom because the counter is applied for adult only and the calibration was made for adult size. On the other hand, the results in Belarus show relatively large error, mostly over estimate, which suggests the need of another proper calibration values set up.

V. ^{137}Cs retentions observed

Retentions of ^{137}Cs were measured for 9 scientists in addition to the calibration study of whole-body counters. The biological half times estimated for 3 RCRM scientists and 6 Japanese scientists are in Table 5. The RCRM scientists incorporated small amount ^{137}Cs about 140 kBq for the calibration purpose of the whole-body counter and Japanese scientists ingested slight amount of ^{137}Cs of several hundreds Bq from food when they visited Ukraine and Belarus for the research cooperation. The results for Ukrainian scientists are estimated by the combination of data in RCRM and in Japan. All of the measurements for Japanese scientists were made in Japan. The half times for RCRM scientist may include the effect of repeated ingestion of ^{137}Cs from food while living in Ukraine.

Half times observed are the range of 50 to 137 days and then it is said that the half time value of 110 days ICRP suggested in ICRP Pub. 30 seems conservative. Individual biological half time should be taken into account to estimate individual internal exposure because of the large individual difference of biological half time.

VI. Discussions

It is impossible nor practicable to prepare phantoms for whole-body counting suit to all of the persons of different physique. Evaluation of the efficiency for a given physique by interpolation or extrapolation of the several calibrated points obtained using appropriate standardized phantoms is necessary at

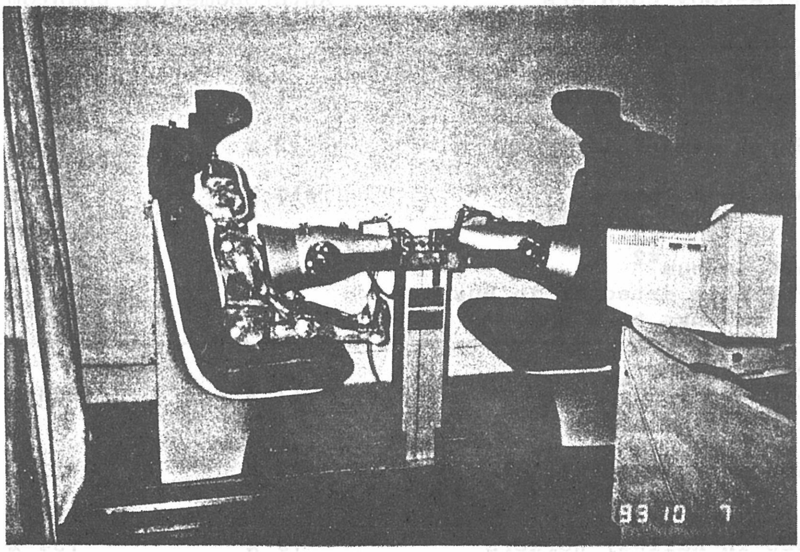


Photo.4 Measurement of anthropometric phantom of 3 years old by Super Gemini whole-body counter in RCRM in Ukraine

Table 4 Results of intercalibration study of whole-body counter using anthropometric phantoms, 11 years old and 3 years old size prepared by Japan side, carried out in Ukraine and Beralus, where their estimations of the activities in the phantoms are expressed by the percentage error from the exact filled activities of 20kBq

Whole-body counters	Anthropometric phantom 3 years old	Anthropometric phantom 11 years old
UKRAINE		
Positronika in RCRM*1	-1 %	+13 %
Super gemini in RCRM	+2 %	-9 %
WBC in mother & child polyclinic	+16 %	+1 %
WBC in bus*2	-35 %	-4 %
Portable detector in Bus belongs to RCRM	+4 %	+1 %
BERALUS		
WBC in SRIRM*3	+17 %	+23 %
WBC in Gomel District Polyclinic	+29 %	+11 %
WBC in Railway Workers Polyclinic	+5 %	+34 %
WBC in Vetka District Polyclinic	+44 %	+39 %

*1 Ukranian Research Center for Radiation Medicine
*2 This counter is applied for adult only and then calibrated for adult size
*3 Scientific Research Institute of Radiation Medicine in Gomel Belarus

Table 5 Biological Half-time of cesium obtained for 3 Ukrainian and 6 Japanese through the calibration study of whole-body counter in 1989 and 1990

Race /Country	Subject	Age	Height (cm)	Weight (kg)	Biological half-time (days)
Ukraine	1	54	137	94	178
	2	50	173	71	113
	3	43	174	75	104
Japan	4	52	174	50	50
	4'	53	173	50	60
	5	55	162	52	64
	6	53	158	62	102
	7	40	170	74	110
	8	52	162	58	90
	9	43	170	60	74
	9'	44	170	64	115

* Subject 4 and 9 have two values of Biological half-time obtained after two times visit to Ukraine in 1989 and 1990

present and also in future. There is not enough experimental endorsement for the calibration results using conventional phantoms of anthropomorphic phantom such as block water phantom and this is one of the major problems for whole-body counting. The realization of inter-calibration study using different phantoms between institutes concerned in Japan and with RCRM and SRIRM was due to the efforts of the persons concerned. This study brought enough useful results giving endorsement of the validity of present calibration of whole-body counter and traceability through the measurement of anthropometric phantoms.

Further studies will be necessary to establish the more suitable method for inter- and extrapolating the calibration data points, and multi-level standardization system of calibration of whole-body counter using phantoms with different metrological levels.

Acknowledgement

The authors deeply appreciate the efforts of the persons concerned to this cooperative study and express sincere thanks to staff of institutes concerned for their valuable contribution for arrange and measurement of phantoms.

Discussion

Dr. Perevoznikov, (RCRM): There are two types of the mobile counters in Ukraine. One size is for adults and another size is for children.

There was a large measurement error when the 3 years old phantom was used as a phantom for adults.

Dr. Mizushita, (JAERI): The difference between the measured and the filled radioactivity ^{137}Cs for the phantoms probably resulted from the difference between phantoms and the calibration method. This suggests standardization of phantoms and calibration methods are necessary. Anthropometric phantoms may be appropriate for the standardization of whole-body counters. The calibration of whole-body counters using an appropriate phantom is necessary and is one of the main subjects of the cooperation program.

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Estimation of Absorbed Dose to Evacuees at Pripyat-City using ESR Measurements of Sugar and Exposure Rate Calculations

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The external absorbed doses in Pripyat-city resulting from the Chernobyl nuclear power plant accident have been evaluated from eight ordinary granulated sugar samples using the electron spin resonance method. The indoor and outdoor external doses to the people evacuated from Pripyat-city at about 36 h after the Chernobyl accident have been estimated using both data from the eight household sugar samples present in Pripyat-city prior to and during the accident and information on the type of buildings and survey-meter measurements of the exposure rates there. The absorbed dose to the evacuated people, as estimated from the exposure rates calculated in combination with the sugar dosimetry data, agree approximately with the reported average effective dose equivalent to such people, which was derived from both calculations and exposure-rate surveys. If each person in Pripyat-city could remember exactly the proportion of time spent indoors before being evacuated after the accident, the absorbed dose could roughly be estimated from the relationship between the documented external dose outdoors during the period between the accident and evacuation and the length of the period spent indoors by each individual prior to evacuation. It is suggested that as little as 1 g of sugar would be one of the most useful emergency dosimeters for people inside their dwellings, at least for absorbed doses greater than about 0.02 Gy.

1. Introduction

At about 1:24 a.m. on 26 April 1986, an accident occurred at the Chernobyl nuclear power plant in the U.S.S.R. and many people were exposed internally and externally to ionizing radiation. It is considered important to know the dose to the exposed persons for both medical treatment in the case of accidents in the future and research into the health of such persons for epidemiological studies. Unfortunately, a method of evaluating the external dose to the actual victims had not been established at the time of or immediately following the Chernobyl accident. On the other hand, many technical publications on the Chernobyl accident have since been reported by investigators throughout the world. (Devell *et al.*, 1986; Fry *et al.*, 1986; Webb *et al.*, 1986; Lange *et al.*, 1988; Holmberg *et al.*, 1988; Schuller *et al.*, 1988; Yesin and Cakir, 1989; Strand *et al.*, 1989). However, comprehensive estimation of absorbed dose values, or an average effective dose equivalent to the people in the U.S.S.R., have not yet been reported, except for some official estimates in the U.S.S.R. and in a US Department of Energy report (DOE/ER, 1987).

According to a private communication on the external dose in the Chernobyl accident (Pyatak, 1988), the exposure or absorbed dose of the evacuated people in Pripyat-city has been estimated with both data based on the exposure rate by survey-meter and data based on the period of time spent by evacuated people outdoors. The approximate average effective dose equivalent to the exposed people has been reported from these data (DOE/ER, 1987). Such data have not, however, been corroborated or certified by other researchers.

An ESR dosimeter has previously been proposed as one possible retrospective dosimetric system for the people exposed to the external radiation (Nakajima and Watanabe, 1974). The ESR method, using sugar, has more recently been proposed by the present author (Nakajima, 1989; Nakajima and Otsuki, 1990) to estimate the external absorbed dose to those exposed indoors at the Chernobyl accident.

Some household sugars that were present indoors at the time of the accident were collected from two apartments at Pripyat-city near the power plant where the accident occurred, and the tentative doses for different times inside the apartments were estimated using the ESR method (Nakajima *et al.*, 1991). The relationship between the dose outside the apartments from which the sugar samples were taken, and the average effective dose equivalent to the people in Pripyat-city who were evacuated 36 h or more after the occurrence of the accident, have not yet been reported. Information on the apartment wall materials and thicknesses, and the exposure-rate just after the occurrence of the accident was recently disclosed privately by a Ukrainian investigator (Likhtariov, 1990).

The external dose outside the sampling houses, the maximum external dose to the evacuated people at Pripyat-city, and the average effective dose equivalent to the people spending a specified post-accident time in the city will all be discussed in the present study in terms of the absorbed dose obtained from the sugar analyzed by ESR spectrometry and the exposure rates measured during that time by survey meter.

Recently, six additional sugar samples present during the accident were collected and the doses inside the apartments were estimated again using the ESR method. In the present paper, the external doses to the evacuees at Pripyat-city are estimated from both the data on the eight original sugar-ESR dosimeters and on the survey-meter exposure rates. The U.S.S.R. data reported in 1987 to International Atomic Energy Agency (DOE/ER, 1987) are also discussed in connection with the present results. Furthermore, from the viewpoint of possible emergency dosimeters for the public, the practical usefulness of sugar as an emergency dosimeter is considered.

2. Methods of Dose Estimation

The ESR absorptions of the eight sugar samples collected at Pripyat-city and the control sugar obtained from the Aeroflot Airline were observed with an ESR spectrometer, which was operated at room temperature in the X band, a microwave power level of 2 mW, a modulation width of 1.6 mT and with a signal averaging system of the ESR signal from the sample. In this work, the number of an accumulated scans was from 20 to 30.

Figure 1 shows the ESR first-derivative absorption spectra of a sugar sample collected in Pripyat-city and the control sugar from Aeroflot, and the Mn^{2+} standard sample observed under the above conditions. In Fig. 1, curve A is the ESR spectrum of the control sugar, curve B is one of the unknown the sample sugars from Pripyat-city, and curve C is an unknown sample sugar irradiated with an additive gamma-ray dose of 0.64 Gy. Furthermore, Mn in Fig. 1 presents the absorption peaks from the Mn^{2+} standard sample.

As shown in Fig. 1, the ESR absorption peaks of the free radicals from the unirradited control sugar, the unknown sample and the post-irradiated sample sugars were observed in a magnetic field range between the third and fourth peaks of the Mn^{2+} standard sample. Five replicate aliquots of 500 mg taken from each of the eight sugar samples and the control sugar sample were used to obtain the ESR data.

In Fig. 2, the ESR response of the irradiated sugar as a function of the absorbed dose is presented. As can be seen in Fig. 2, a good proportionality between the ESR response of sugar and the absorbed dose has been obtained. The absorbed doses as measured by six of the eight sugar samples were determined with both a linear regression and a gradient between the measuring points obtained with the additive-dose method (Aitken, 1981).

Figure 3 shows the linearity between the ESR response of the sugar sample and, the accidental dose and the additive doses. As shown in Fig. 3, good proportionality between the latter and those in Fig. 2 was obtained. Moreover, as listed in Table 1, the correlation-coefficient for proportionality between the ESR absorption intensity and the absorbed dose is about 0.999 and the ESR sensitivity (which is defined in this work as the ESR absorption intensity per unit dose) of sugar is effectively independent of the batch of sugar. Namely, the mean net ESR sensitivity (ESR signal intensity per Gy) of six in the eight sugar samples was 0.376 ± 0.029. Each sensitivity value for a given six sugar samples was obtained with both the regression linear function and the gradient between the measuring points with the additive-dose method. The results show that, under identical conditions of ESR measurement, the ESR sensitivity of sugar can be applied to the dose evaluation of all sugar samples. In fact, the ESR sensitivity has been applied to the dose evaluation of two (sample Nos 12 and 13) of the eight sugar samples

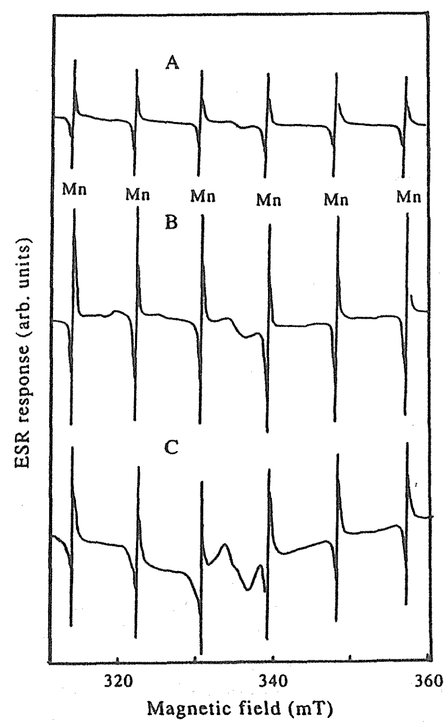

Fig. 1. ESR spectra of the unirradiated control (curve A) and unknown Pripyat-city sample (curve B) sugars and the sample sugar irradiated with the additive dose of 0.64 Gy (curve C). Mn in Fig. 1 represents the reference signal of bivalent manganese ions.

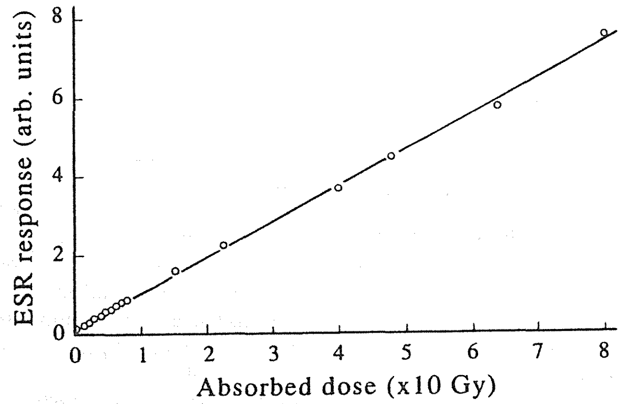

Fig. 2. Linearity of ESR response of as a function of the absorbed dose administered to the irradiated sugar. Sample weight was 600 mg and gamma-rays from a ^{60}Co source were used for the irradiations.

(see Table 1). A laboratory source for establishing the ESR absorption intensity of the sample was a calibrated ^{60}Co source supplying gamma radiation.

According to a recent private communication (Likhtariov, 1990), the thickness of the brick walls in the apartment houses is *ca* 50 cm, and the different estimated exposure rates in the sampling regions of Pripyat-city at 12:00 p.m. on 27 April 1986 were classified into two groups, as can be seen in Fig. 5. For one of these, which was referred to as the first region (A), the survey-meter value was from 1.03×10^{-4} C kg^{-1} h^{-1} (400 mR/h) to 1.29×10^{-4} C kg^{-1} h^{-1} (500 mR/h) and for the other referred to as the second region (B), it was from 1.55×10^{-4} C kg^{-1} h^{-1} (600 mR/h) to 1.81×10^{-4} kg^{-1} h^{-1} (700 mR/h). It has been reported that the main radionuclides discharged at the time of the accident were ^{131}I, ^{132}Te, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{141}Ce, ^{144}Ce and ^{103}Ru (DOE/ER, 1987). In the present work, it is assumed that ^{131}I is typical of the radionuclides with a short half-life (8.02 days) and ^{137}Cs is typical of those with a long half-life (30.0 years) and may be considered the most important radionuclides released, in terms of external dose to evacuees.

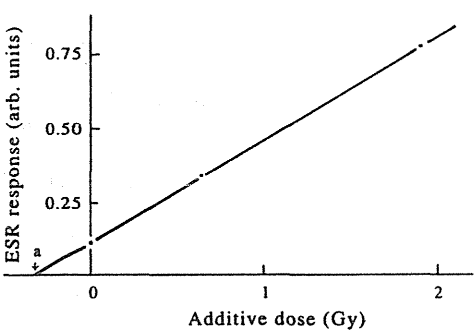

Fig. 3. Typical relationship between additive doses and ESR response of sugar sample. The value of each point corresponds to the external dose to sugar at 1264 days after the accident.

The external dose to the people evacuated from Pripyat-city after the Chernobyl accident has been estimated using a combination of the various dosimetry data from the sugar, computational information derived from the shielding effects of buildings, and the survey-meter exposure rates registered outdoors. The routine procedure for the dose estimation suffered by the evacuated people in Pripyat-city is shown by the flow chart in Fig. 4.

3. Results and Discussion

3.1. Estimation of indoor dose from sugar

The external doses inside eight different apartment rooms at the sampling sites in Pripyat-city were estimated from sugar samples which were exposed with two different exposure rates in the first and second city regions at 12:00 p.m. on 27 April 1986. The period between the accident and sampling date, when the sugar samples were collected, was 1264 d.

Table 2 gives the absorbed doses in the period of 1264 d as measured by sugar in eight of the indoor sampling sites, using the ESR spectrometer. The standard deviations of the evaluated dose in Table 2 are also listed for each dose estimate.

As can be seen in Table 2, the mean of the indoor values of dose over 1264 days, evaluated from the samples in the first and second regions, were 0.077 ± 0.032 and 0.118 ± 0.048 Gy, respectively. It

Table 1. Correlation-coefficient (C.C) between ESR intensity and the absorbed dose of six sugar samples, coefficient of variation (C.V) of the ESR measurement, 1 and ESR sensitivity (a relative ESR intensity per unit absorbed dose). The random uncertainty about the mean is estimated at 1σ

Sample No.	C.C	C.V (%)	ESR signal/Gy
02	0.9984	2.3	0.353
03	0.9999	1.4	0.424
11	0.9938	5.3	0.397
14	0.9998	8.4	0.376
15	0.9999	6.1	0.356
16	1.0000	2.8	0.351
Mean	0.9986 ± 0.0024		0.376 ± 0.029

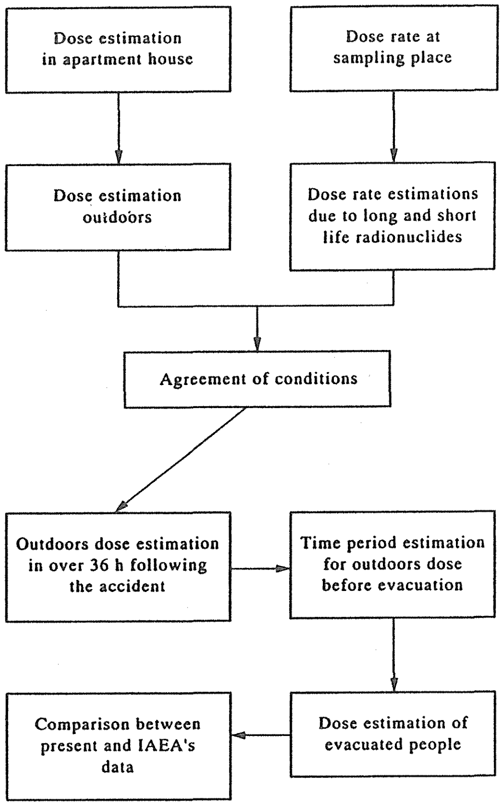

Fig. 4. Procedural flow chart for the dose estimation for evacuated people with sugar-ESR dosimeter and other data.

seems that these values depend on both the exposure rate on 27 April 1986 after the accident and the shielding effect of the sampling site walls, and a large contribution to the standard deviation in the same region derives from differences in the shielding conditions between individual sugar samples. In fact, obtaining information on the shielding effect due to the wall materials and thickness is a difficult problem and an important limiting factor in reporting these estimated doses.

3.2. External dose outdoors in Pripyat-city

If detailed data on the apartment wall materials and their thicknesses, and comprehensive shielding

Table 2. Sugar absorbed dose at each sampling point in Pryipat-city for 1264 days which is the period between the accident and the sampling data. The exposure rate in the first and second regions on 27 April 1986 was from 1.03×10^{-4} to 1.29×10^{-4} C kg^{-1} h^{-1} and from 1.55×10^{-4} to 1.81×10^{-4} C kg^{-1} h^{-1}, respectively. The random uncertainty about the mean is estimated at 1σ

	Sugar dose (Gy)		
Sample No.	First region	Sample No.	Second region
02	0.068 ± 0.006	13	0.146 ± 0.024
03	0.055 ± 0.002	14	0.164 ± 0.036
11	0.045 ± 0.008	15	0.057 ± 0.004
12	0.138 ± 0.013	16	0.104 ± 0.015
Mean	0.077 ± 0.042		0.118 ± 0.048

information for the individual sugar samples could be collected, the external dose could be estimated roughly by a simple gamma-ray shielding calculation.

The material and thickness information of the walls of the building could only be obtained from a previous private communication (Likhtariov, 1990). Any correlation of locations and dimensions among the wall, window material and thickness, as well as locating sugar samples in the rooms, was very complicated. In fact, it was difficult to obtain information on the exact shielding conditions for each sugar sample. Therefore, in this paper, a general shielding effect has been considered in terms of a brick wall of 50 cm thickness (Likhtariov, 1990).

The density of brick in Pripyat-city could not be measured and information on the density was not available. Therefore, the density of brick exposed by the atomic bomb at Hiroshima and Nagasaki in Japan typically ranging from 1.5–2.0 g/cm^3 (William and Maruyama, 1983), were used. It is assumed to be 1.8 g/cm^3 in this work. When the transmission of the gamma-rays is calculated with the simplest equation, $I/I_0 = \exp(-\mu l)$, where I_0 and I are the doses of gamma-rays before and after the transmission, respectively, μ(cm^{-1}) being the linear attenuation coefficient for the brick and l(cm) the thickness of the brick wall, the calculated values of transmission I/I_0 for the gamma-rays from ^{131}I and ^{137}Cs sources at perpendicular trajectory through the 50 cm brick wall are 2.460×10^{-4} and 2.805×10^{-3}, respectively.

As mentioned above, the period between the accident and 12 October 1989, when the sugar samples were collected, was 1264 d. For the period of 1264 d, the sugar dose in the sampling houses can be assumed to be exposed mainly by ^{137}Cs sources, because the half-life of ^{131}I is very much shorter than that of ^{137}Cs. The calculated mean of the integrated external dose for that period in the first and second regions was 27.3 ± 1.3 and 42.1 ± 14.7 Gy, respectively, outside the sampled houses from the sugar data.

3.3 Estimated initial dose from the exo-U.S.S.R. data

The outdoor exposure rate in the first region on 27 April 1986, as measured by survey meters, was between 1.03×10^{-4} C kg^{-1} h^{-1} and 1.29×10^{-4} C kg^{-1} h^{-1} (see Section 2). On the other hand, the exposure rate in Pripyat-city on 29 May 1986 had readings reported from 1.29×10^{-5} C kg^{-1} h^{-1} (50 mR/h) to 2.57×10^{-5} C kg^{-1} h^{-1} (100 mR/h) (DOE/ER, 1987). Figure 4 shows a map of Pripyat-city where the exposure-rate sampling was made at the different sites on 27 April 1986.

For simplicity, if it is assumed that the external radiation due to the radionuclides released by the accident consisted mainly of gamma-rays from both short-lived radionuclides, such as ^{131}I (half life: 8.02 d) and ^{132}Te (78.2), and long-lived radionuclides such as ^{134}Cs (2.065 y) and ^{137}Cs (30.0 y), the dose-rate from

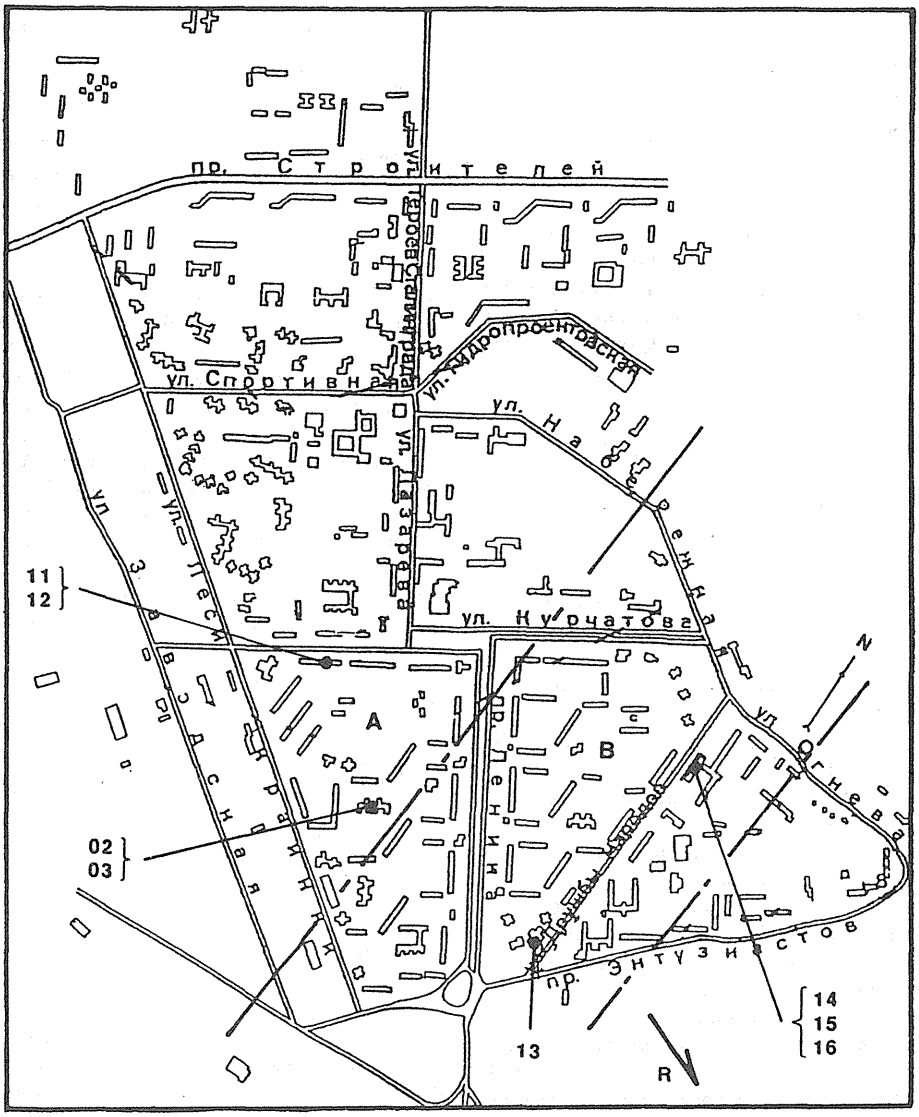

Fig. 5. Map of Pripyat-city and sugar sampling sites. Sample Nos 02, 03, 11 and 12 sampling sites were retrieved from the first region, A, in which the exposure rate on 27 April 1968 ranged from 1.03×10^{-4} to 1.03×10^{-4} C kg^{-1} h^{-1}. Sample Nos 13, 14, 15 and 16 were from the second region, B, where the exposure rate ranged from 1.55×10^{-4} to 1.81×10^{-4} C kg^{-1} h^{-1}. R in the map indicated the direction of the Chernobyl reactor power plants.

each of these radionuclides could typically be evaluated using a simple simultaneous equation as follows:

$$\dot{D}_{\mathrm{I}} + \dot{D}_{\mathrm{Cs}} = \dot{D}_{\mathrm{a}}$$

and

$$\dot{D}_{\mathrm{I}} \exp(-\lambda t_{\mathrm{I}}) + \dot{D}_{\mathrm{Cs}} \exp(-\lambda t_{\mathrm{Cs}}) = \dot{D}_{\mathrm{b}},$$

where $\dot{D}_{\mathrm{I}}$ and $\dot{D}_{\mathrm{Cs}}$ are the initial external dose rate values from the short-lived (^{131}I) and the long-lived (^{137}Cs) radionuclides at Pripyat-city, $\exp(-\lambda t_{\mathrm{I}})$ and $\exp(-\lambda t_{\mathrm{Cs}})$ are the decays of those radionuclides, respectively $\dot{D}_{\mathrm{a}}$ and $\dot{D}_{\mathrm{b}}$ the dose rates at Pripyat-city on 27 April 1986 and 29 May 1986, respectively (an interval of 32 days).

If it is assumed that ^{131}I and ^{137}Cs were the principal radionuclides released (DOE/ER, 1987), the values of $\exp(-\lambda t_{\mathrm{I}})$ and $\exp(-\lambda t_{\mathrm{Cs}})$ would be 0.0625 and 1.0, respectively, at 32 days after the occurrence of the accident.

The exposure rates at the sampling sites of the sugar were not measured at any time during the first years after the accident but they were checked in the first region on 27 April 1986 as can be seen in Fig. 5. The exposure rates given above for the sampling sites in the first region may be estimated to be between the

Table 3. Four different combinations of the exposure rates ($\times 10^{-4}$ C kg^{-1} h^{-1}), on 27 April and 29 May 1986 at outdoor sites near the first region in Pripyat-city

Case No.	1	2	3	4
27 April 1986	1.032	1.29	1.032	1.29
29 May 1986	0.129	0.129	0.258	0.258

maximum and minimum exposure rates. Thus, four combinations of the exposure-rates, as given in Table 3, as well as dose rates (in Gy per day) for ^{131}I and ^{137}Cs gamma-rays, as given in Table 4, can be estimated from the maximum and minimum values of two exposure rates observed at nearly the same area on different dates. The exposure rates around the sampling sites in the first region were estimated from the approximate agreement of both groups of data obtained from the exposure rates on different monitoring dates and from the sugar measurements, as follows.

3.4. External dose indoors and outdoors

An integral external dose indoors and outdoors at Pripyat-city was estimated for the 1264-day delay period, using both the survey-meter exposure rates in the first region at a different monitoring date and the data obtained from the sugar ESR measurements. Since the half-life of ^{131}I is very much shorter than that of ^{137}Cs, the component of ^{131}I source in the integrated external dose for 1264 days may be of minor significance.

Table 5 lists the integral external doses from ^{137}Cs gamma-rays inside and outside the sugar sampling apartments in the first region of Pripyat-city. These values were obtained from both the case of No. 3 in the four combinations of the exposure rates on the different monitoring dates and the average of the sugar ESR dosimeter reading in the first region. As given in Table 5, the integrated external doses indoors and outdoors, obtained from the case No. 3 in the four combinations of exposure rates in the first region, agree closely with the mean of the values for the four sugar samples in the first region.

This suggests that the combination of the exposure rates of 1.03×10^{-4} C kg^{-1} h^{-1} (0.137 Gy/36 h), on 27 April 1986 and 2.58×10^{-5} C kg^{-1} h^{-1} on 29 May 1986, outside the sampling houses at Pripyat-city, are the most accurate results. On this basis, the initial dose rates due to the short-, $\dot{D}_I$, and long-half-life $\dot{D}_{Cs}$ radionuclides in the first region on 27 April 1986 were estimated to be 0.11 Gy/36 h (or 0.073 Gy/24 h), and

Table 4. Four different combinations of the estimated initial dose rates $\dot{D}_I$ and $\dot{D}_{Cs}$ ($\times 10^{-3}$ Gy d^{-1}) on April 27 1986 for the released ^{131}I and ^{137}Cs radioactivities, respectively, at outdoor sites near the first region in Pripyat-city

Combination Case No.	1	2	3	4
$\dot{D}_I$	85	109	73	97
$\dot{D}_{Cs}$	6.1	4.6	18	17

Table 5. Comparison of estimated integral doses of external radiation indoors and outdoors for 1264 days using the sugar ESR dosimeter (sugar-ESR), and the case No. 3 in the four different combinations of the exposure rates, (FDCER), on 27 April and 29 May 1986 at outdoor sites near the first region. The random uncertainty limits are estimated at 1σ for the sugar data

Dose estimation method	Indoors (Gy)	Outdoors (Gy)
Sugar-ESR	0.077 ± 0.004	27 ± 1.3
FDCER	0.065	23

0.027 Gy/36 h (or 0.018 Gy/24 h), respectively, as given by the case No. 3 in Table 4, and the total initial outdoor dose in the first region over a 36-h period before the evacuation was 0.137 Gy. In this case, a conversion factor from the exposure to the absorbed dose was 36.8 Gy/C kg^{-1}.

Correspondingly, if the ratio between the initial exposure rate due to radionuclides with short and long half-lives in the first region is assumed to apply to the second region, in which the exposure rate was from 1.55×10^{-4} to 1.81×10^{-4} C kg^{-1} h^{-1} on 27 April 1986, in Pripyat-city, the exposure rates due to the short- and long-half-life radionuclides in the second region are, respectively, 1.24×10^{-4} and 3.10×10^{-5} C kg^{-1} h^{-1}, or 1.45×10^{-4} and 3.61×10^{-5} C kg^{-1} h^{-1}. When the conversion factor 36.8 Gy/C kg^{-1} is used and the component of ^{131}I source irradiation in the integrated external dose for 1264 d is neglected, the integrated external dose outdoors in the second region due to the ^{137}Cs radionuclides is 40.3 Gy over a 1264-day period, which agrees approximately with the mean dose, 41.9 ± 13.5 Gy as registered by four sugar samples in the second region.

Accordingly, the exposure rate of 1.81×10^{-4} C kg^{-1} h^{-1} on 27 April 1986 outside the sampling houses at Pripyat-city appears to be the most accurate result. Therefore, the estimated initial outdoor doses in the second region was estimated to be 0.239 Gy during the first 36 h immediately after the accident.

3.5. Estimation of external dose for evacuees

The estimated dose obtained from the most reasonable combination of the exposure rates, as mentioned above, was used for comparison with the published dose data (DOE/ER, 1987).

It is stated that the people in Pripyat-city were evacuated about 36 h after the occurrence of the accident. If the people are assumed to have stayed outdoors for that entire 36-h period, they would have been exposed to the maximum estimated external dose of 0.14 Gy in the first region and 0.24 Gy in the second region. However, the evacuated people would likely have been indoors for at least some of the time for sleeping, eating and so on, before the evacuation. Therefore, their dose estimation would be diminished accordingly. Furthermore, the dose contribution from the released gamma-ray-emitting radionuclides such as ^{131}I or ^{137}Cs transmitted through the 50 cm-

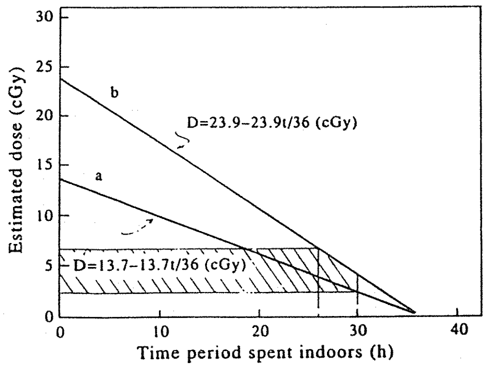

Fig. 6. Changes in estimated the external dose outdoors for the evacuated people during 36 h in Pripyat-city as a function of time spent indoors. Curve a is for the first region, A, and curve b for the second region, B.

wall was so small that it can be neglected. The integral external dose to the evacuated people can be approximately represented as a simple linearly decreasing function of time spent indoors (over a relatively short period).

Figure 6 shows the decreases in the estimated external dose to the evacuated people in Pripyat-city as a function of the time period spent indoors in the two regions. In this case, the external dose indoors has been neglected, because, as mentioned above, the indoor dose is greatly decreased by the shielding effect of the brick wall of 50 cm.

There are no survey data on domestic time use and leisure activities at Pripyat-city. Thus, in this work, typical data for Japanese activities have been used. According to survey data on such time use and leisure activities in Japan (SBMCA, 1988), Japanese people at 15-y age and over spend about 21 h per day indoors, on Saturdays and Sundays, for sleeping, personal care, meals, house-keeping, child care, indoor shopping, etc. The accident occurred at about 1:30 a.m. on 26 April 1986 (Saturday). Therefore, it may be expected (assuming similar practices) that the evacuated people in Pripyat-city would have stayed indoors for a period of from 26–30 h before the evacuation. In such circumstances, the integral external dose to the evacuated people in the first and second regions of the city may be estimated to be about 0.023 to 0.038 Gy, and 0.040 to 0.066 Gy, respectively, as shown in Fig. 6 and the mean dose to all citizens was estimated to be 0.042 ± 0.018 Gy from the integral external dose data on the evacuated people in the first and second regions.

On the other hand, according to the U.S.S.R. report (DOE/ER, 1987), the average effective dose equivalent of external radiation to the people in Pripyat-city was 0.033 Sv per person. When a significance test of the difference between the estimated external dose in this work and the reported average effective dose equivalent was carried out, no significant difference between could be found.

If the people who were evacuated from Pripyat-city could report correctly the length of time they spent indoors in the period from the accident until their own evacuation, their absorbed doses could be estimated. This would contribute to a rational reconstruction of the estimated effective dose equivalent to the individual evacuees. The results also show that if sugar samples could be collected from many houses in the city and measured, and if there were documented data on the exposure-rate at the time of, or just after, the accident, the effective dose equivalent to the individual evacuees in Pripyat-city would be more faithfully estimated, and the assigned dose values could contribute to a reconstruction of the dose equivalent to the evacuees.

3.6 Estimated ratio of doses between indoor and outdoor exposure

The timing of the evacuation is an important parameter in determining individual exposure. The ratio between doses received indoors and outdoors is another important item of information.

Table 6 gives the ratio of doses received inside and outside a brick building with a wall thickness of 50 cm. In the case of the Chernobyl accident, the dose contribution from ^{131}I gamma-rays was of major importance at an early stage. Therefore, the shielding effect of a building on the collective dose will be greatly increased by a longer stay indoors, depending, of course, on the materials used in the construction of the building, as given in Table 6.

Table 6. Estimated external doses indoors and outdoors in a period (36 h) from the accident until evacuation, and their ratio

Indoor dose (Gy)	Outdoor dose (Gy)	Indoor/outdoor ratio
77×10^{-6}	0.14	5.5×10^{-4}

4. Conclusion

The external doses at the sampling sites and to the evacuated people in the Chernobyl accident have been estimated roughly from both ESR measurements of the sugar and the survey measurement and computational data on the exposure rates and estimated dose equivalent.

It is concluded that, if the people in Pripyat-city evacuated at 36 h had stayed indoors for a period of time ranging from 26–30 h after the accident, the reported mean effective dose equivalent of 0.033 Sv to those people would agree approximately with the absorbed dose of 0.042 ± 0.018 Gy estimated from both the sugar data and the exposure rates based on survey-meter readings.

It is suggested that sugar can be a useful emergency dosimeter for estimating indoor doses. In a radiation emergency, about 1 g of crystalline sugar, such as household granulated sugar, is sufficient to provide a rough estimate of absorbed doses in the range from 2×10^{-2} to 10^3 Gy.

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Discussion

Dr. Toyoda, (Osaka Univ.): Your paper was very interesting. How did you evaluate the errors that are indicated in the graphs for the relationship between the ESR signal and dose?

Dr. Nakajima, (NIRS): I measured five samples to obtain the data. The errors are the standard deviation for the five samples.

Dr. Novak, (RCRM): Why did you use the value of 3 as the shielding factor to derive the outdoor dose from the indoor doses?

Dr. Nakajima, (NIRS): I did not use the value of 3. I used the appropriate value for a 50 cm thick wall. This value was derived from experience in Hiroshima and Nagasaki.

Dr. Likhtarev, (RCRM): I also investigated the behaviour of the 18,000 inhabitants at Pripyat-City for the two days after the accident. I was very surprised to hear your report because our investigated result was very close to yours. I have one question on your method of using ESR.With your method of sugar-ESR, you are able to get a very high sensitivity when compared with the method for tooth enamel-ESR. I would like to know the reason. Which ESR signal from free radicals do you mean?

Dr. Nakajima, (NIRS): The situation is entirely different with these two methods. The sugar-ESR signal can be considered to be caused by the free radicals that were generated with the cutting the sugar molecules by radiation. The energy required to cut a molecule is the essential requirement that determines the detection limit of 500 mg, Furthermore, in the case of sugar, it is very easy to get samples of 500 mg, but this is not the case with tooth enamel.

ESTIMATION OF RADIATION DOSES USING ESR SPECTROMETRY OF TOOTH ENAMEL AND THE APPLICATION OF THE METHOD TO DOSE ASSESSMENT FOR RESIDENTS OF THE AREAS AFFECTED BY THE CHERNOBYL ACCIDENT.

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Abstract

To evaluate the validity of electron spin resonance (ESR) spectrometry of dental enamel as a method of biological dosimetry for monitoring the regions affected by radioactive pollution we investigated enamel of deciduous and permanent teeth. There was no significant difference in radiation incused ESR signals between samples of enamel from back wall, front wall, and occlusal surfaces as well as from permanent and from deciduous teeth irradiated in vitro. It was found that admixture of dentin decreased the dose estimation unproportionally: a sample with 50% of dentin gave the amplitude of ESR signal 3.2 times less than a sample of the pure enamel of the same mass. We compared doses estimated by ESR analysis of dental enamel and by the cytogenetic method for residents of the Gomel region and the Bryansk region (1991-1992) and the Bryansk region (1993).

Introduction

Recently, at the time of the uncontrolled testing of nuclear weapons, of environment pollution by the wastes of radiochemical industries, of accidents on the nuclear power plants, the problem of evaluation of radiation doses is espe-cially significant. The analysis of the radiation dose for people at the cases of accidents is often impossible because people have no individual dosimeters. Design and introduction of the methods of individual "biological" dosimetry can give reliable and objective data about the radiation situation in the region.

It is known that the tooth enamel can store an information about the radiation influence in the form of stable radicals CO^{3-}_{3} [1,2,3,4,5]. This information can be revealed by the electron spin resonance (ESR) spectrometry. There are two methods of evaluation of a radiation dose from the tooth enamel. The first one is based on the additional irradiation of the enamel sample. The second one is based on the analysis of the total ESR signal of the enamel when radiation induced ESR signal is picked out of the total signal and its intensity is estimated [6,7,8]. In this entry, the results of the development of the second method and its practical applications in the regions of Russia are presented.

Methods.

The surface of the enamel of the permanent and deciduous teeth was cleaned properly [9]. Dentin was removed completely and enamel chips not more than 1 mm in size were prepared. The ESR measurements were taken three days later. Enamel chips arranged in a single layer were irradiated. Co-60 was used as the source of gamma rays. The effective photon energy of the X-ray was about 0.1 MeV (equipment RUP-200, voltage 190 kV, current 15 mA, and filtration thickness 0.5 mm Cu + 1 mm Al). ESR measurements were taken at room temperature using Radiopan spectrometer connected with MP1092 computer (Radiopan, Poland) and using ESR spectrometer ECS-106 (Bruker, Germany).

The method of cytogenetic dosimetry was described earlier [10,11]. Doses were determined from the dose response curve for lymphocytes aberrations, dicentrics plus rings, $y = 0.013 + 9.8 D$, obtained by irradiating blood samples in vitro with Co-60 gamma rays over the range 0 - 0.5 Gy .

Results

The dependence of the ESR signal of inner standard (Mn) from the enamel sample weight for the ESR spectrometer "Radiopan" is described as:

$K(m) = - 0.0026m + 1.065$ for $m < 25$ mg and

$K(m) = 0.37 + 90.55/(m + 119.71)$ for $m > 25$ mg.

The amount of the radiation induced centers (Fig.1) per unit of enamel mass (I, relative units) was described by the equation:

$$I = A/m\ K(m) \quad /1/$$

A - an amplitude of the radiation signal (R).

The dose of radiation was calculated from a dose-response curve using /1/ when Radiopan was used [8]. The characteristics of ECS-106 cavity give us a possibility not to use K(m).

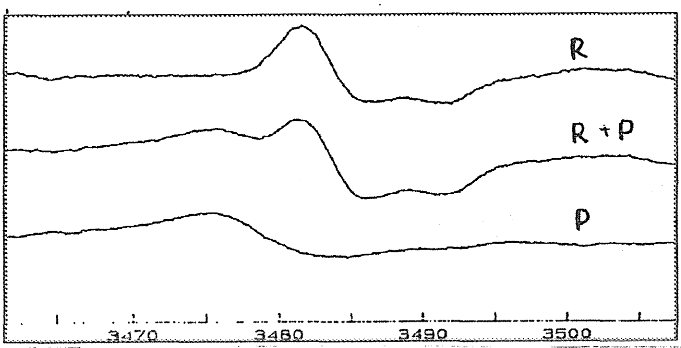


Fig.1 ESR signal of enamel chips irradiated in vitro with a dose 2,5 Gy of Co-60 gamma rays.
(P+R) the whole recorded signal, (P) background signal, and (R) radiation induces signal. Modulation amplitude 0.5 G, microwave power 20 mW, T - 293 K, ESR spectrometer ECS-106.

It was shown [12] that the dependence of the ESR signal of the paramagnetic centers on the power of microwave is described as:

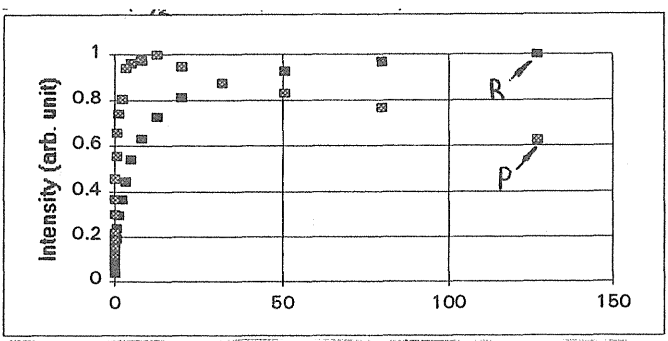
$$A(p) = k\sqrt{P}\,/(1 + P/P_{1/2})^{b/2} \qquad /2/$$

where b - parameters of nonhomogeneity

P - effective factor of saturation

k - coefficient, determined by the amount of centers and the conditions of the measurement.

Our experimental curves A(p) for the radiation signal and background signal of permanent teeth, are approximated well by equation /2/ (Fig.2). The radiation center is characterised by the nonhomogeneous broadening of the ESR signal ($b = 1.02 \pm 0.05$) and by the effective factor of saturation $P_{1/2} = 17 \pm 1$ mW. The background has no nonhomogeneous broadening of ESR signal ($b = 1.5 \pm 0.1$) and by the effective factor of saturation $P_{1/2} = 3.6 + 0.3$ mW.



Power (mW)

Fig.2 Dependence of the intensity of the radiation signal (R) and background signal (P) of the enamel of permanent teeth on the power of microwave. Modulation amplitude 0.5 G, T - 293 K, ESR spectrometer ECS-106.

The samples of enamel of permanent and deciduous teeth taken from the front wall, the back wall and the occlusal surface of each tooth were irradiated by x-rays with dose 50 cGy, radiation

ESR signal of every sample was estimated and accumulated dose was assessed. For the front wall, back wall, and occlusal surface of the deciduous tooth the estimated doses were 51 cGy, 56 cGy, and 55 cGy and for these parts of the permanent tooth they were 53 cGy, 50 cGy, and 58 cGy. Several additional dose of radiation were given to enamel of permanent and deciduous teeth and the intensity of the ESR signals are presented in Fig.3.

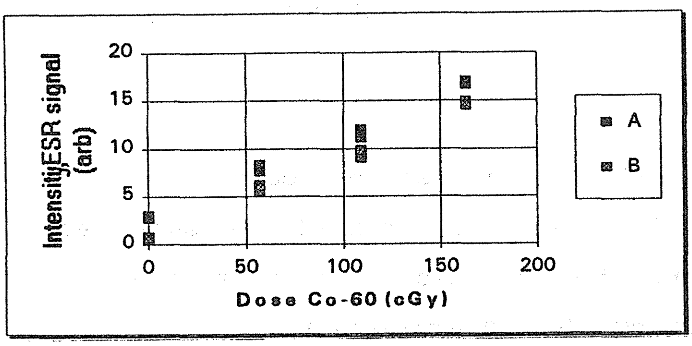


Fig.3 The relationship between the doses of irradiation and the intensity of ESR signal: (A) - deciduous teeth, (B) - permanent teeth.

The dependence of estimated dose of radiation on the content of dentin in a sample (from 0 to 60 % dentin admixture) is shown at Fig.4. The pure enamel (m = 150 mg) was radiated by X-rays with the dose 250 cGy and then gradually dentin was added, ESR signal was measured, and the dose per a unit of mass of the sample was calculated. Admixture of dentin decreased the radiation ESR signal unproportionally: the sample with 50% of dentin revealed the radiation signal 3.2 times less than the sample of the pure enamel.

Kcorr = -0.94091

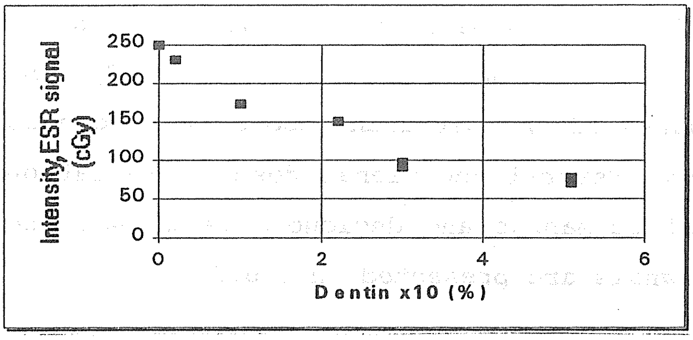


Fig.4 The relationship between the intensity of ESR signal and admixture of dentin.

During our investigations, in eleven cases we had a possibility to analyze two identical teeth of the same person (Fig.5). The coefficient of correlation is equal to 0.989 over the dose ranges 0 to 200 cGy (Co-60 equivalent).

Kcorr = 0.98933

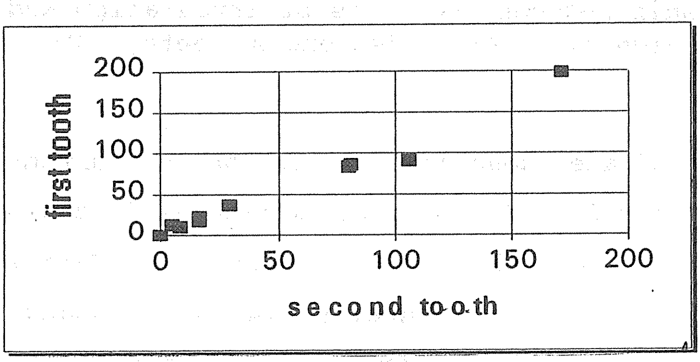
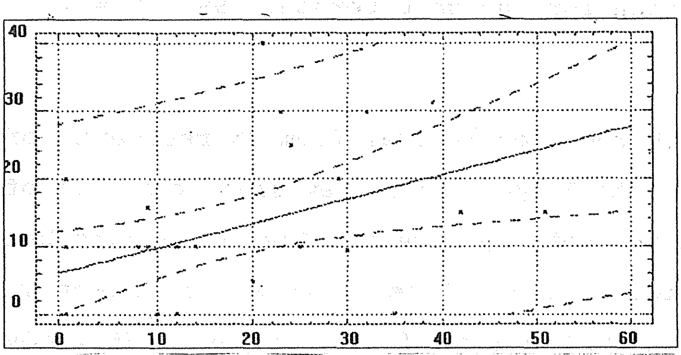


Fig.5 Relationship between the doses estimated by ESR analysis of enamel from two teeth of the same person.

In 1991 the doses of radiation accumulated by eight residents of the Gomel region (Belorussia) were estimated by the ESR analysis of dental enamel and by the cytogenetic method. The coefficient of correlation between doses estimated by two methods was rather high (k1 = 0.58). From the linear dependence model, the dose estimated by cytogenetics was ca. 63 % of the dose revealed by ESR.

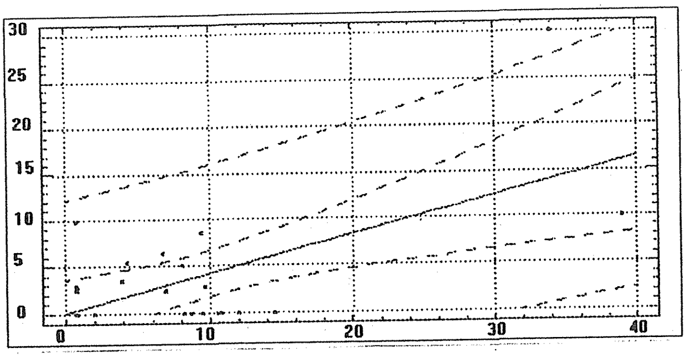
In 1992 the doses of radiation were estimated by these two methods in 24 persons of the Bryansk region (Russia) and 3 persons of the Gomel region. The coefficient of correlation between the dose estimates received by the two methods was not high (k2 = 0.46), but significant ($p < 0.01$). From the linear dependence model (fig. 6), the dose estimated by cytogenetics was ca. 66 % of the dose revealed by ESR.



X = ESR dose (cGy), Y = cytogenetic dose (cGy)

Fig.6 Regression line of the ESR dose estimation on cytogenetic dose estimation for the same person. 1992. n = 27.

In 1993, the doses of radiation were estimated by these two methods in 23 persons of the Bryansk region. The coefficient of correlation between the dose estimates received by the two methods was rather high (k3 = 0.59) and significant ($p < 0.01$). From the linear dependence model (fig. 7), the dose estimated by cytogenetics was ca. 41 % of the dose revealed by ESR.



X= ESR dose (cGy), Y= cytogenetic dose (cGy)

Fig.7 Regression line of the ESR dose estimation on cytogenetic dose estimation for the same person. 1993. n = 23.

ESR analysis of teeth received in 1992 from 85 residents of the Bryansk region, from 7 to 76 years old, revealed, that 76% of donors had not received any notable dose and 24% of donors had received the dose higher than "the natural radioactive background" including 7% with the doses from 13.5 cGy to 65.0 cGy and one person with the dose 139.5 cGy. 15 people of the first group and 7 people of the second group had been exposed to diagnostic X rays of the abdomen, the stomach or the thorax.

Discussion.

According to our results, individual radiosensitivity of the tooth enamel [13], sensitivity of enamel of different parts of a tooth, of enamel of two teeth of the same person, and of enamel of permanent and deciduous teeth does not exceed the error of the ESR method of dose estimation. One of the roots of such result can be found in our calibration curve (dose-response curve) every point of which was obtained using enamel of several different teeth of different persons [8]. Being irradiated in vitro with the same dose enamel of teeth of different people revealed nearly equal amplitudes of radiation ESR signals.

Admixture of dentin in a sample of enamel decreased the dose estimate unproportionally indicating some other influence in addition to a simple "dilution" of enamel with a mass without radiation induced signals. Such a decreasing is perhaps associated with the sufficient quantity of water in dentin which leads to lowering of the solidity of the cavity. In our case the sensitivity of ESR "Radiopan" declined. This result emphases the necessity of proper purification of the enamel sample.

It was found previously [8, 14] that contribution to the enamel dose assessment due to normal in Russia dental x-rays was negligible. Here we found no detectable influence of diagnostic x-rays of abdomen and thorax on radiation signal of enamel. Hence, this influence can be ignored unless we keep ± 20% as the error of ESR dose estimation [14, 15]. This statement is valid for diagnostic irradiation abut not for medical treatment with x-rays or gamma-rays.

Our comparison of the doses estimated by ESR analysis of enamel and by cytogenetic method (chromosomal aberrations in lymphocytes) revealed rather constant pattern: cytogenetic dose was lower than ESR dose making 63-66% in 1991-92 and 41% in 1993. This result can attributed to the probable underestimation of the doses by the cytogenetic method. Although the residents of polluted areas have continued to be irradiated since the Chernobyl accident, most of their total dose would be "old" one. It does not matter in the case of enamel but does in the case of cytogenetic method since the rate of replacement of irradiated lymphocytes by newly formed cells is probable variable [14]. Comparison of ESR dose distributions of 1992 and of 1993 by Kolmogorov-Smirnov two-sample test reveals the identity in the distributions (DN = 0.39 p> 0.05). The same test reveals statistically significant difference between cytogenetic dose distributions of 1992 and of 1993 (DN = 0.49 p<0.01). Hence, the increase of discrepancy between two methods from 63-66% to 41% could not arise by chance alone. This can indicate the rapid elimination of irradiated lymphocytes during last year in all the population as well as the higher quota of people with rapid rate of elimination in the sample of 1993.

There is a source of possible overestimation of the dose by ESR method which . ESR analysis of enamel evaluate the dose of radiation in equivalent of gamma-rays of Co-60. If an vivo irradiation included sufficient part of particles with energy less than 80 - 100 KeV, ESR dose estimates could be overestimated [16]. However, this can not contribute to the disagreement of the two methods, because cytogenetic method uses the same equivalent of Co-60 gamma-rays. nI spite ESR method of radiation dosimetry from tooth enamel has its own weak points it can be treated as valid method for evaluation of accumulated radiation dose for populations affected by the accident on the Chernobyl Power Station.

Acknowledgement

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Discussion

Dr. Nakajima (NIRS): I am deeply impressed with your level of skill in getting the enamel samples from deciduous teeth. What is the reason, do you think, for there being not such a good correlation between the two methods.

Dr. Serezhenkov (ICP): The main reason of the discrepancy is that the blood sample was not homogeneous.

Dr. Okajima (Nagasaki University): I was engaged in the dosimetry for people in Hiroshima and Nagasaki and radiation workers. I have been using tooth enamel ESR for long time. The most important point with this method is the influence of tooth dental X-rays on the teeth. In Japan, dental X-ray are frequently given to patients. Furthermore, the sensitivity of the ESR signal in teeth is very high at that X-ray energy region. Did you consider these points in your research?

Dr. Serezhenkov(ICP): Yes, of course, I considered them because I know that they were discussed for a long time. The dose level by dental X-ray is 40 to 100mGy per photograph according to our investigation. When I had taken three photographs of the same teeth sample in vitro, the response was within the BG signal change. I think, therefore, one of our results 20cGy, was not caused by the dental X-rays. In Russia, dental X-rays are not so common compared with Japan. We also checked the patients care records before doing our measurements.

Dr. Likhtarev (RCRM): The sensitivity of the teeth-ESR is very dependent on the energy of the radiation, especially in the dental X-ray energy region. In this research, I think, this point has not been well considered. It is meaningless to discuss the value of assessed dose and compare it with the results of chromosomal aberrations.

Chairman: It would be better to discuss these items later, after the next presentation.

Separation of CO_2^- signal from a spectrum of irradiated tooth enamel in ESR dosimetry

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ABSTRACT

A new mathematical method using matrices is proposed to extract an ESR signal component due to CO_2^- radical from an ESR spectrum. A theoretical ESR signal due to CO_2^- was obtained by numerical simulation of powder spectrum while a Lorenzian line was obtained as that of interfering organic radical by fitting to the signal observed in dentin. The intensity of CO_2^- signal obtained by this method was enhanced by artificial irradiation. Re-estimations of radiation doses were made for teeth extracted by dentists in Braginsikij, Gomeliskoi, Belarus. The minimum detectable radiation dose by this method is obtained as the error in the estimation of signal intensity of CO_2^- radical.

INTRODUCTION

Some lattice defects trap unpaired electrons created by ionizing radiation to be paramagnetic centers. ESR (electron spin resonance) evaluates the amount of centers to determine accumulated radiation dose. Tooth enamel is one of the most adequate materials for dosimeter. It has an advantage that an accumulated radiation dose can be obtained for any person. Tooth enamel was successfully used for re-estimation of radiation doses exposed to atomic bomb survivors [1-4] and for estimation of accidental radiation at the Chernobyl reactor accident [5].

A radical due to radiation effect, which is sensitive to radiation dose, has been assigned to CO_3^{3-} radical [1]. However, recently, it was re-assigned to CO_2^- radical with hindered rotation [6] by comparing g factors with those observed in irradiated synthetic hydroxyapatite [7].

One of the problems in ESR dosimetry of tooth enamel is how to remove the dose given by dental X ray because estimated radiation dose includes this effect as well as natural radiation dose and the one at radiation accidents. It was proposed to obtain doses separately from both buccal and lingual sides of a tooth [8]. X ray produces more radical in buccal side, when X ray is irradiated from buccal side, than in lingual side, because the mass absorption coefficient of X ray is large. On the other hand, γ ray produces uniformly in tooth enamel. A typical example was obtained by the image of radical distribution using a scanning ESR microscope [9,10]

Another problem has been how to extract the signal component due to CO_2^- from mixture of CO_2^- and organic radical components, that is, an observed ESR spectrum. A scheme was proposed according to the following equation [11],

$$I_{p-p} = 0.63\ I_0 + I_1 + I_2$$

I_{p-p} : Corrected peak to peak intensity of CO_2^- radical

I_0 : Peak to base height at $g = 2.0055$

I_1 : Peak to base height at $g = 2.003^*$

I_2 : Peak to base height at $g = 1.997$

*This value is not described in the original paper [11].

In another paper [12], a theoretical signal with a Lorenzian line shape was subtracted from observed spectrum. The part of build up in lower magnetic field was fitted to by a Lorenzian line manually. The peak to peak height in the spectrum after subtraction was taken as the intensity. This method was applied to estimate radiation dose given to teeth extracted by dentists in Braginsikij, Gomeliskoi, Belarus.

The signal component due to CO_2^- radical was extracted from a spectrum observed in a piece of leg bone irradiated at a radiation accident [13]. A computer program, EPRDAP (U.S.EPR) was used assuming that signal due to organic radical is negligible in bone irradiated at 50 kGy.

In this paper, a new scheme is proposed to separate ESR signal due to CO_2^- from that of organic radical using matrices (Equation 3). Peak to peak intensity has been measured as an ESR intensity in previous studies, where recorded data in the part other than peaks have been abandoned. In contrast, all data recorded as a function of magnetic field are used in this scheme to determine the intensities of signal components. Therefore, accuracy and detection limit of radiation dose should be better than previous studies. Such an attempt was once made to obtain accumulated doses as a function of magnetic field in ESR dating [14].

The conditions of ESR measurement are the following in order to detect weak signals effectively [6].

Incident microwave power	: 5 mW
Field modulation width	: 0.2 mT
Field modulation frequency	: 100 kHz
Scan speed	: 10 mT / 128 minutes
Time constant	: 10 seconds

THEORY

ESR signals are recorded as a function of magnetic field. When several ESR signals are overlapping, the spectrum is a linear combination of the signals as denoted by,

$$F(H) = x_1 A(H) + x_2 B(H) + x_3 C(H) \cdots \quad (1)$$

where H is magnetic field, F is recorded ESR spectrum, and A, B, C, ··· are spectra for the components. x1, x2, x3 ··· are the intensities of the components, A, B, C, ···, respectively. ESR spectrum can be recorded as digitized data by ESR spectrometers with a computer, recently. Several thousands of digitized data are obtained in one scan of measurement. When f_i is i-th data of the spectrum with two components, f_i is expressed as,

$$f_i = x_1 a_i + x_2 b_i \qquad (2)$$

where a_i and b_i are i-th data of spectra due to CO_2^- radical and to organic radical, respectively. x_1 and x_2 are respective intensities. Equation (2) can be rewritten using matrices as the following,

$$\vec{y} = P\,\vec{x} \qquad (3)$$

where

$$\vec{y} = \begin{pmatrix} f_1 \\ f_2 \\ : \\ : \\ f_n \end{pmatrix} \quad P = \begin{pmatrix} a_1 & b_1 \\ a_2 & b_2 \\ : & : \\ : & : \\ a_n & b_n \end{pmatrix} \quad \vec{x} = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$$

If we know elements of P, that is, spectra of CO_2^- and of organic radical without any other components, **x** can be obtained by the least squares method.

The least square solution, expressed as,

$$\vec{x}' = \begin{pmatrix} x_1' \\ x_2' \end{pmatrix}$$

where x'_1 and x'_2 are the best estimate of the parameters, is given by the following equation [15],

$$\vec{x}' = (P^tP)^{-1}P^t\vec{y} \tag{4}$$

where P^t is a transposed matrix of P. The equation (4) should be solved by the QR decomposition method rather than by obtaining its inverse matrix in order to get accurate solution [15].

Errors of the best estimate of the parameters are obtained by the following equations [15],

$$\Sigma_{\vec{x}'} = (P^t\Sigma^{-1}P)^{-1} \tag{5}$$

$$\Sigma_{\vec{x}'} = \begin{pmatrix} \sigma_{x1}^2 & \rho\sigma_{x1}\sigma_{x2} \\ \rho\sigma_{x1}\sigma_{x2} & \sigma_{x2}^2 \end{pmatrix}$$

$$\Sigma = \begin{pmatrix} \sigma_1^2 & 0 & & \\ 0 & \sigma_2^2 & & \\ & & \ddots & \\ & & & \sigma_n^2 \end{pmatrix}$$

where σ_{x1} and σ_{x2} are errors of the best estimates of parameters, x'_1 and x'_2, respectively, ρ is the correlation coefficient between errors of x'_1 and x'_2, and σ_i is the error for the spectrum data, f_i. In the present case, the error for the spectrum data is unknown. However, it can be estimated by the residuals in the following equation as σ.

$$\sigma^2 = \frac{\sum_{i=1}^{n}(f_i'-f_i)^2}{(n-2)} \tag{6}$$

where f'_i is the estimate of the data as denoted by,

$$f_i' = x_1'a_i + x_2'b_i$$

Therefore, equation (5) is rewritten as,

$$\Sigma_{\vec{x}'} = \sigma^2\ (P^tP)^{-1} \tag{7}$$

Theoretical ESR signals

A candidate for the spectrum for CO_2^- without any overlapping signals is that of tooth enamel with large amount of irradiation. However, a small signal of organic radical is still overlapping as shown in Fig.3a. The signal intensity of organic radical may be also enhanced by irradiation. A theoretical ESR signal with numerical simulation of powder pattern with axial symmetry was made with the following parameters, using a computer program, IER-PRIT-SIM1 made by JEOL Ltd., attached to ES-PRIT 425 data system (HP9000) of an ESR spectrometer, RE-2X, JEOL.

$$\begin{aligned} &L/G = 70 / 30 \\ &g_{\perp} = 2.0031 \qquad \Delta H_{\perp} = 0.295 \text{ (mT)} \\ &g_{//} = 1.9976 \qquad \Delta H_{//} = 0.225 \text{ (mT)} \end{aligned} \tag{8}$$

where L/G is the ratio of Lorenzian to Gaussian components. ΔH is peak to peak line width of the derivative ESR line (maximum slope width of absorbed line). The conditions were searched manually so that the calculated line shape is fitted best to the CO_2^- signal in the spectrum of tooth enamel irradiated at 10 kGy (Fig.1a). The simulated spectrum is also shown in Fig.2.

The other component, the signal due to organic radical, was obtained using the ESR spectrum observed for dentin without enamel (Fig.1b). A Lorenzian line with a linear baseline was fitted to the observed spectrum to obtain the parameters as the following,

$$\begin{aligned} &g = 2.0046 \\ &\Delta H = 0.725 \text{ (mT)} \end{aligned} \tag{9}$$

The obtained spectrum is shown in Fig.2b where linear baseline was subtracted.

SAMPLES AND PROCEDURE FOR CALCULATION

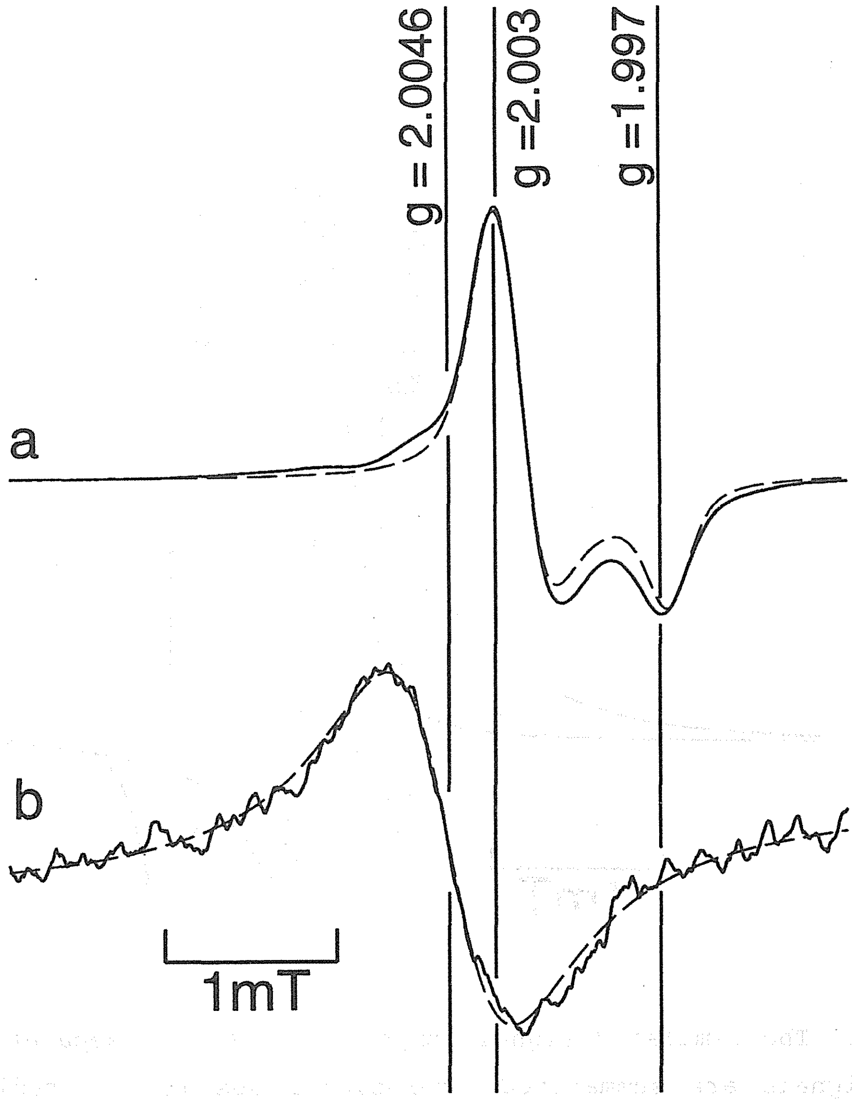

Fig. 1 Solid lines denote ESR spectra observed (a) in tooth enamel irradiated at 10 kGy and (b) in dentin without enamel. A simulated ESR spectrum for CO_2^- radical was obtained by fitting the spectrum best to the observed spectrum (a) of the part due to CO_2^- radical, as indicated by the broken line in (a). The parameters used for the simulated spectrum is indicated by equations (8) in text. A Lorenzian curve with a linear baseline was obtained, as the signal due to organic radical, by fitting to the observed spectrum (b) as denoted by the broken line in (b). The parameters are indicated by equations (9).

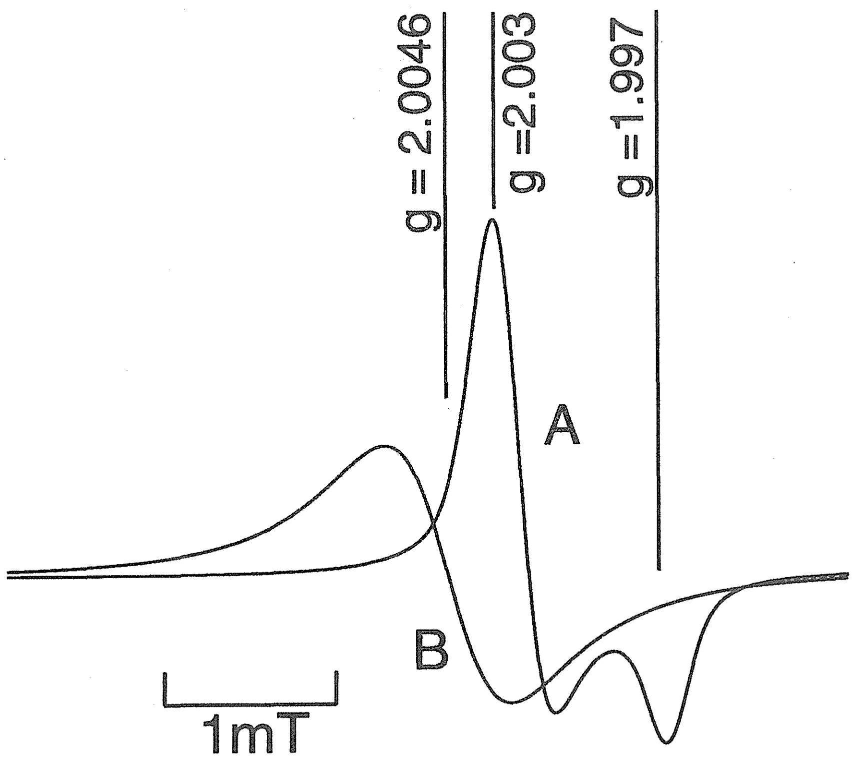

Fig. 2 The simulated signal components used for separating ESR signals are summarized. The signal due to CO_2^- radical is indicated by A, and that due to organic radical by B.

Table I An example of output of calculation for signal separation.

```
------- CYCLE 1
Mean of square residuals:      0.0309837
                INTENSITY           ERROR
COMPONENT 1 0.5669495E-04   0.1828367E-04   :CO2- radical
COMPONENT 2 0.2561398E+00   0.1885009E+00   :organic radical
COMPONENT 3 0.1185551E+00   0.5626618E-02   :slope of baseline
COMPONENT 4 0.3926881E-01   0.1761126E+00   :intercept of baseline
```

Table II Enhancement of the signal component due to CO_2^- by artificial γ ray irradiation.

γ ray dose (mGy)	Intensity (arb. units, $\times 10^{-4}$)	Error (arb. units, $\times 10^{-4}$)
#7		
0	0.57	0.18
240	3.9	0.26
480	6.8	0.36
720	11.7	0.42
#8		
0	0.26	0.11
240	3.3	0.25
480	6.3	0.33
720	9.6	0.41

Tooth enamel was separated from human teeth, which were extracted by dentists in Braginskij, Gomeliskoi, Belarus. Four ESR spectra were obtained for each sample with no irradiation and after three steps of artificial ^{60}Co γ ray irradiation made at the Institute of Industry Science, Osaka University. Radiation doses given to 5 teeth were re-estimated using the present method. These teeth are of 8 ones, which were once examined by ESR to obtain radiation dose [12]. The digitized spectra obtained previously were used again in the present study.

ESR spectra were recorded as digitized data with 12 bit. The number of data points was 8190 per one measurement. The scan width of magnetic field was 10 mT. Data of 4000 points from g = 2.0200 of the spectrum were used, where each four data were averaged to obtain 1000 data points in order to reduce the load to the computer. A component of linear baseline was also considered in the present calculation for signal separation. Therefore, the matrix, P, had 4 columns and 1000 rows. A software package, ASL/SX, NEC, was used in the calculation with matrices, i.e., equations (4) and (7).

RESULTS

An example of output of calculation for signal separation is shown in Table I where intensities and their errors of the components are listed. The simulated spectrum was obtained using intensities in the results and theoretical ESR spectra. Fig.3 shows the examples of simulated spectra with observed ones. The present method simulates spectrum around g = 2.003 well while some differences are around g = 1.997. It may indicate the need for improvement in the theoretical ESR signal due to CO_2^-.

The signal component due to CO_2^- was enhanced by γ ray irradiation as an example shown in Table II. The radiation dose was obtained as the one equivalent to ^{60}Co γ ray irradiation dose (D_E) by extrapolating the linear enhancement to the zero ordinate as examples shown in Fig.4. The regression line was obtained by the

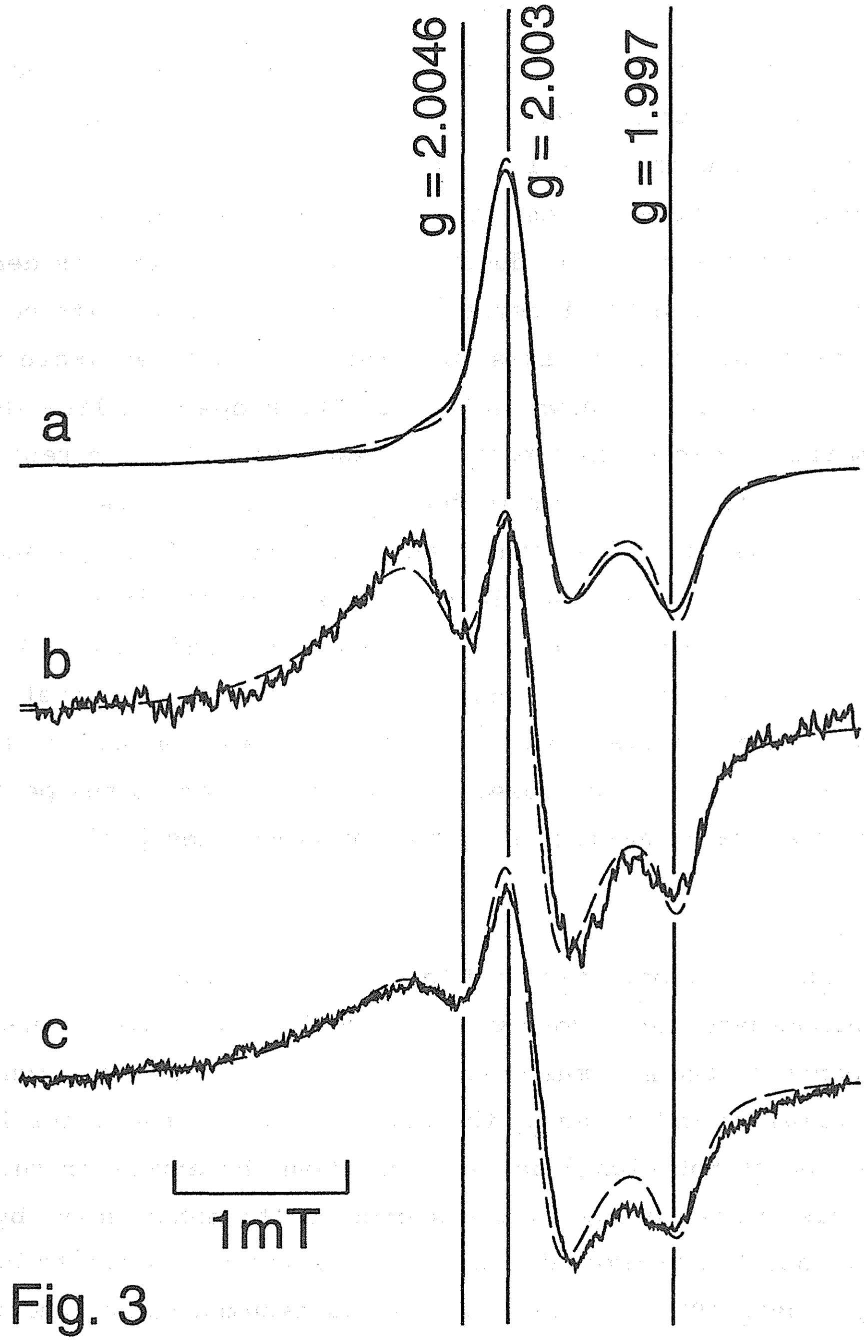

Fig. 3 Examples of the results of numerical separation of ESR signals, the method of which is proposed in the present paper. Solid lines indicate observed spectra by summing the signals shown in Fig. 2 with obtained signal intensities. ESR signals were observed (a) in tooth enamel irradiated at 10 kGy, **(b)** in tooth enamel irradiated at 240 mGy, and (c) in human bone irradiated at about 10 Gy.

least square method using a software package, SALS [16] where errors in the slope and the intercept of the line and correlation coefficient between the errors were obtained. The errors in D_E was estimated with these values. When slope of the line (in Fig.4), i.e., the efficiency of producing CO_2^- by irradiation, is denoted as horizontal axis and the intercept, signal intensity with no irradiation, as vertical axis, parameters of best estimate are plotted at a point as shown in Fig. 5. The slope of a line in Fig. 5, from the origin to that point corresponds to D_E. The region of parameters within 1 σ error is denoted as the inner region of the ellipse because correlation between the errors of the parameters is considered. Therefore, the slopes of the tangent lines to the ellipse from the origin correspond to maximum and minimum D_E's within 1 σ error. Radiation doses (D_E) estimated for 5 teeth by the above method are summarized in Table III. These values are again within natural radiation doses potentially given to the persons, and systematically smaller than the previous ones [12].

DISCUSSION

Minimum radiation dose detectable with tooth enamel

Minimum detectable dose with ESR dosimetry of tooth enamel corresponds to the minimum detectable intensity of CO_2^- signal. The latter value is indicated by the errors of the intensities in Table II obtained by the signal separation. When the errors in the signal intensities were divided by the slopes of the enhancement by γ ray irradiation, the minimum detectable dose was estimated to be within 100 mGy, where 100 mg of tooth enamel is assumed to be used in the ESR measurement. The detection limit would be larger if one uses lager amount of sample. It is noteworthy that the minimum detectable dose described here should be on the ground of statistics and should depend on experimental conditions, such as signal to noise ratio of the ESR spectrometer, the amount of contaminating dentin in enamel and so on. It should also depend on

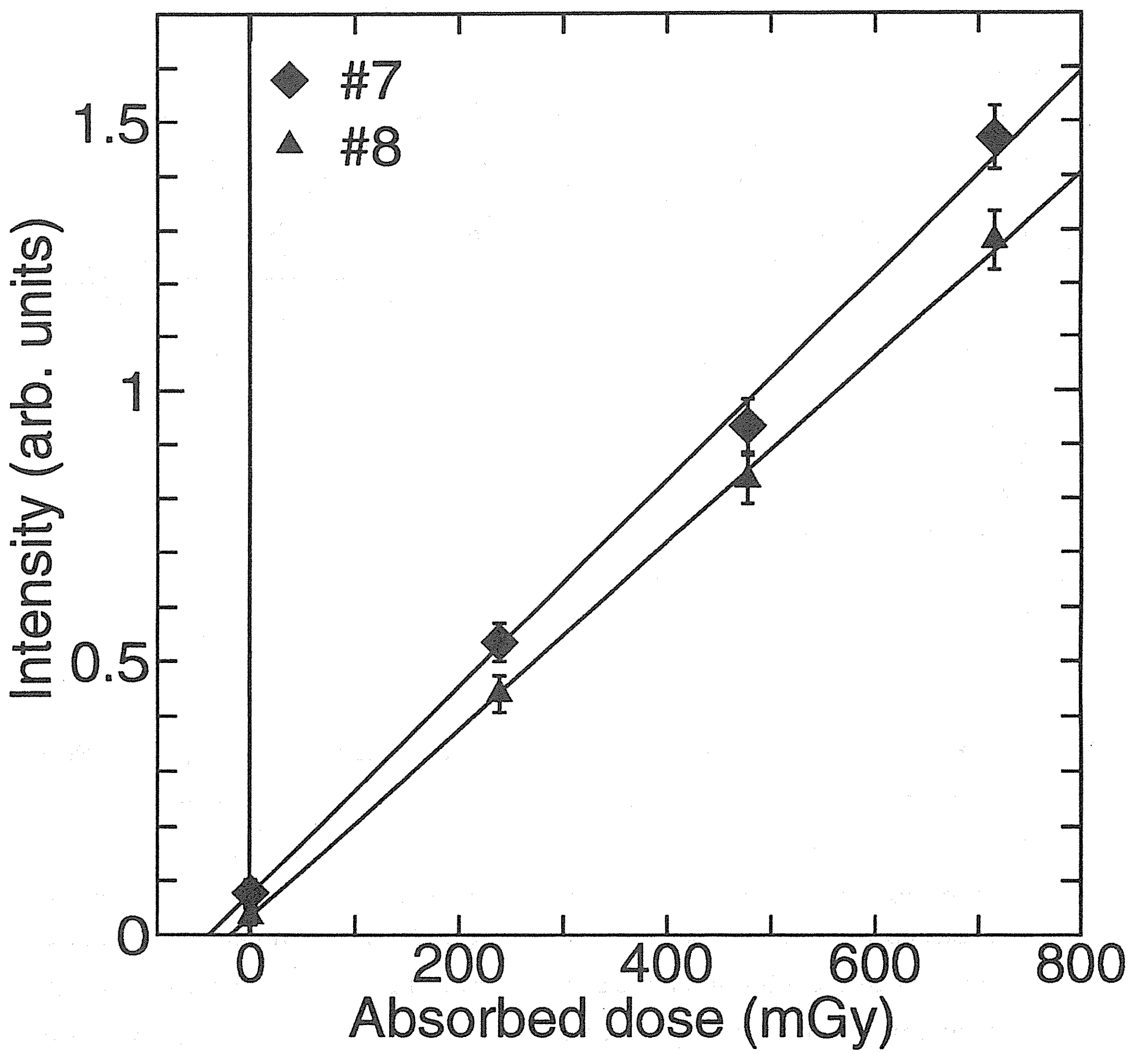

Fig. 4 Examples of the enhancement of signal intensities due to CO_2^- radical by artificial γ ray irradiation. The radiation dose (D_E) is obtained by extrapolating the line to the zero ordinate.

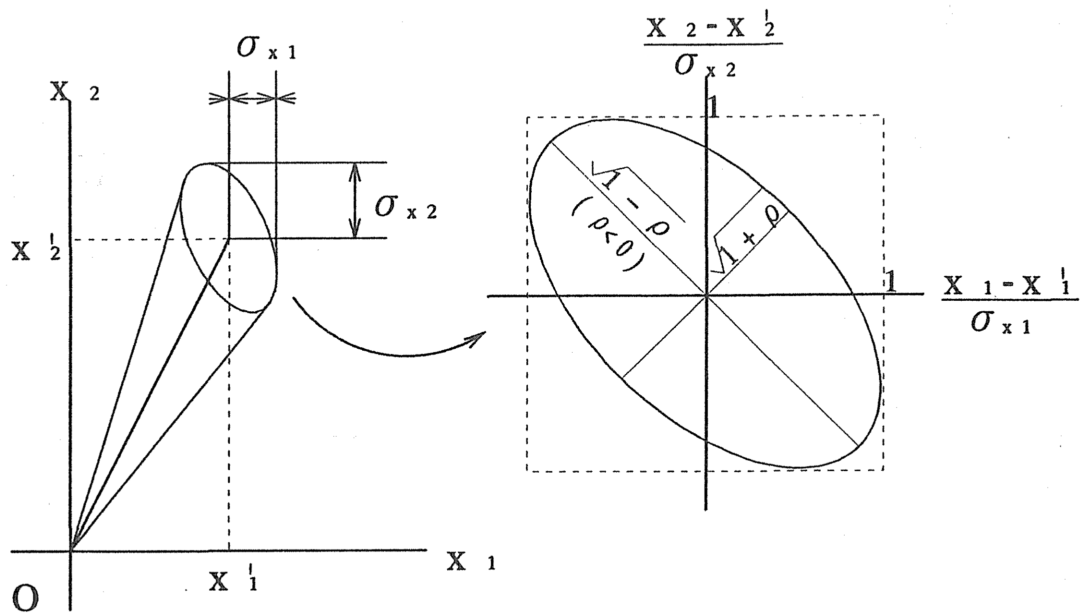

Fig. 5 Estimation of the error in radiation dose (D_E). The horizontal axis denotes x_1 which is the slope of the line in Fig. 4, the formation **efficiency** of CO_2^- radical. The vertical axis denotes x_2 which is intercept of the line. The set of best estimates of the parameters, x_1' and x_2', is plotted at a point in this figure where the slope of the line from the origin to the point corresponds to estimated radiation dose (D_E). The region of the parameters within 1 σ error is denoted as the inner region of the ellipse because of the correlation between the errors of the parameters. The slopes of the tangent lines to the ellipse from the origin correspond to maximum and minimum D_E's within 1 σ error.

Table III Estimated radiation dose (D_E) for teeth from Braginsikij, Gomeliskoi, Belarus.

Sample	Birth Year	Radiation dose (mGy)
#2	1920	10±6
#5	1940	0*
#7	1920	40^{+14}_{-13}
#8	1923	20±9
#10	1984	5±10

* Obtained dose is negative.

the propriety of the theoretical ESR signal in parameters (8).

Problems

As indicated in the previous section, the present method assumes that the theoretical ESR signal can simulate the observed signal perfectly. However, there seems systematic difference between them as shown in Fig.3. Although parameters are proposed as of ideal ESR signal due to CO_2^- radical in (8), efforts would be still needed to clarify them.

It should also be noted that the radiation dose obtained in the present method includes the dose given by dental X ray effect as well as the one due to accidental radiation. It would be needed to obtain radiation dose for samples take both from buccal and lingual sides in order to estimate dental X ray effect as previously proposed [8].

A tooth piece must be extracted to estimate radiation dose in the conventional ESR dosimetry. An attempts has been made to develop an equipment for *in vivo* ESR dosimetry of teeth [17,18]. It is expected that such a system has sensitivity high enough for practical dosimetry in the future.

SUMMARY

A new scheme using matrices was proposed to separate ESR signal due to CO_2^- radical from the one due to organic radical. When appropriate parameters for theoretical signal are chosen, it would be possible to reduce highly the minimum dose detectable with ESR measurement of tooth enamel, because the method uses whole spectrum to determine the intensity of CO_2^- signal. The method was practically applied to 5 teeth from Braginskij, Gomeliskoi, Russia. Estimated radiation doses were smaller than those previously estimated [12].

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We would like to express our gratitude to Dr. A. M. Skryabin (Gomel Branch Office, Scientific Research Institute of Radiation Medicine, Belarus) for offering us tooth samples and to Dr. M. Okano (Radiation Effects Association, Japan) for the arrangement of the present research. We thank Dr. N. Kimura (Institute of Industry Science, Osaka University) for ^{60}Co γ ray irradiation. We also thank Dr. M. Uchiyama and Dr. T. Nakajima (National Institute of Radiological Sciences, Japan) for inviting the present paper to the International Workshop on Assessment of the Health and Environmental Impact from Radiation Doses due to Released Radionuclides.

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Discussion

Dr. Serezhenkov, (ICP): Have you tried any chemical methods to decrease the background signal?

Dr. Toyoda, (Osaka Univ.): We have no experience on chemical methods. However, we did hear that there is such a method.

Dr. Serezhekov, (ICP): If the exposure dose is at the same level as the ESR signal the background level and ESR signal due to radiation may become equal. Have you ever observed this?

Dr. Toyoda, (Osaka Univ.): In our validation test, mass was standardized. According to our experience, background level and ESR signal always differ, though slightly.

Dr. Serezhenkov, (ICP): What is the method you use to extract the component of the radiation signal of 250 mGy from the ESR spectrum?

Dr. Toyoda, (Osaka Univ.): It's a mathematical method using a matrix.

Dr. Likhtarev, (RCRM): It is surprising that a mathematical method accomplishes such a detection level. How do you treat energy information in the matrix?

Dr. Toyoda, (Osaka Univ.): We used a calibration source of ^{60}Co. The dose can be assumed to be standardized by ^{60}Co.

Dr. Likhtarev (RCRM): Considering the energy difference between ^{60}Co and the average environmental radiation level, the dose level may differ three times. You would have to consider energy dependence in your matrix, wouldn't you?

Dr. Toyoda, (Osaka Univ.): We do not have to consider energy dependence, because the data have been standardized.

Overview from Belarus of the health and environmental consequences due to the Chernobyl accident

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ABSTRACT

Belarus has turned to be the zone with the greatest radiation impact due to the Chernobyl accident. The area with radioactive contamination was approximately 1/4 of its territory. About 2 million people inhabit this area now and the collective dose due to all the Chernobyl related sources is estimated to be about 1200 man Sv for 1993. Apart from radionuclides from Cs which are the main dose formation factors, body burdens of Sr-90 and Pu (Pu-238 and Pu-240) were studied. The dose from these radionuclides did not exceed 10% of the total dose received by population. Retainment of radionuclides from Cs in the food chain is significantly dependent on soil type and the environmental characteristics of the regions as well as on time. The greatest migration mobility was observed in the vast and forested area in Polesiye, Belarus, where there are predominately light sandy and boggy soils. As for the internal dose formation, the importance of the "forest" factor in rural populations was demonstrated. It competes with the "milk" factor and governs the internal dose formation of some population groups, of which the daily intake mainly consists of forest produce. Internal dose distribution significantly depends on personal food consumption habits and the countermeasures applied. Observance of countermeasures leads to a 20-30% reduction of dose.

INTRODUCTION

Eight years have passed since the Chernobyl accident and as yet not all the social and economic problems resulting from the destruction of normal living conditions for the affected population have been solved. Among the three former USSR republics, Belarus appeared to be the most affected following the accident at the Chernobyl nuclear power plant: more than 23% of its territory was radioactively contaminated whereas only 4% in the Ukraine and about 0.5% in Russia. More than 100,000 inhabitants in the most affected regions were relocated for different periods of time. About 1.8 million people, i.e. every sixth Belarussian, inhabit territory with a 1 Ci/sq.km level of contamination.

To assess the radiological consequences, it is necessary to state that the conservative estimation of the current collective dose for the population living in the affected areas in Belarus results in 1200 man Sv/year (with the average individual doses in the most contaminated settlements to be 2-3 mSv/year). According to our assessments, 50-55% of the lifetime dose (for 20 years) has already been realized at the present time. The current radiological situation is stable, and dose intake rates have been significantly reduced by 2-3%/year. Cs isotopes (Cs-134 and Cs-137) are the main dose formation factors (more than 95%). The role of Sr-90 and transuranium elements dose not seem to be very important, although direct measurements of their body content in the Chernobyl zone have not been sufficient. Therefore we carried out a special study which allowed us to estimate the content and dose which were experienced by the population of the affected regions. Full-scale radiation safety for the population has been achieved. There is no settlement where the critical dose of 5 mSv/year is exceeded. None the less, further minimization of radiation by the reduction of the collective dose is still considered to be very important. The effectiveness and adequateness of the countermeasures can be provided only when their choice is based on the knowledge of the factors influencing the dose.

Other things being equal, these factors can be defined by individuals themselves, for example occupation, age, food consumption habits, etc. This gives the possibility to differentiate the approach and choice of countermeasures for a definite region, population group or a settlement. Natural factors such as soil-ecological characteristics and time factors should also be taken into account. Unfortunately these problems have not been properly studied. The present paper presents the results of our investigations which partially highlight the above problems.

MATERIALS AND METHODS

All the investigations, the results of which are presented below, were carried out in Gomel region, Belarus. To detect Sr-90 and Pu isotopes (Pu-238 and Pu-240) content, we studied autopsied materials taken from former residents of the Gomel region. For Sr-90 detection we took two ribs, the 5th and the 6th, and for Pu we used the lung, lymph nodes, the liver, and bones (skull, ribs, vertebrae sawed off). After turning samples into ashes, an ordinary radiochemical analysis was made to excrete Sr-90, and counting was made for yttrium-90 on the residue using a low background detection device. The excreted compound of Pu isotopes (Pu-238 and Pu-240) was counted by alpharadiometry. (Ratio of the activity of Pu-238/Pu (Pu-238 and Pu-240), defined by spectrometry on 10% of all samples was equal to 0.32) We also detected stable calcium concentration in bone tissues (in ash) using the flame-photometrical method.

To study the possible role of soil-ecological peculiarities of the region the whole territory was divided into four zones: southern, western, north-western and central. All possible information on Cs in private milk from the above zones for 1988-1992 was collected. Milk was sampled in each different settlement from not less than 10 cows. The study was carried out with the help of gamma-spectrometry. Cs-137 including Cs-134 body content was measured on WB counters with about 370 Bq/body as the lower limit of detection. Calculation of doses on the results of measurements was based on the procedures adopted in the CIS standard methodology. The coefficient of correlation between Cs-137 content and the dose for an adult in 1992 was equal to 1.2 mSv/year/37 kBq/body.

To estimate the contribution of the "forest" factor we chose settlements which formed 3 groups by their location, i.e., 1) in the forest 2) in a forestless area and 3)an intermediate position. To further provide detailed analysis of dose formation factors, four settlements were chosen to be representative of their social and environmental conditions. Apart from WB measurements, surveys and questionnairing were carried out in the above settlements, aimed at determining the age-occupational grouping of each resident, main food consumption (food consumption habits), and the link with the forest. The processed data permitted us to split the population of the settlements into five main groups based on food consumption habits and two professional-age groups. These data were then subjected to statistical analysis.

RESULTS

1. Body burden of Pu (Pu-238 and Pu-240) and Sr-90

Table.1 presents the results of measurements of body burden for Pu (Pu-238 and Pu-240)

Table 1. Body burden of Pu in the population of Gomel region (1990-1992)

	specific activity, mBq/kg				whole body content, mBq
	lung	limph nodes	liver	skeleton	
Gomel reg. City of Gomel and 15 districts of the region	23.5±9.5 (32)*	181±75 (9)*	45±31 (126)*	28.3±10.5 (34)*	412±185
Western Europe (1975-1985)	1-3	2-21	20-28	3-9	70-125

* number of cadavers from which the autopsied samples were taken.

The greatest concentration of plutonium was in the lymph nodes of the lung, the smallest in the skeleton and the lung. However, with respect to all the organs, the basic amount of plutonium (>60%) was deposited in the skeleton, about 20% in the liver and about 10% in the lung.

It can be viewed from the table that the body burden of plutonium in the population of the Gomel region affected by the Chernobyl accident is 3 times higher than that in the population of European countries due to global fallout 10 years ago. The dose which is realized from this amount of plutonium in EDE units is estimated as about 24 mSv/year. Sr-90 data for the same period are presented in Table 2.

Table 2. Man bone tissue Sr-90 concentration

Units of measurement	Concentration	
Bq/g.ash	0.035±0.009	(832)*
pCi/g.Ca (strontium unit)	2.6 (1.4-3.9)	

* number of cadavers from which the autopsied samples were taken.

The detected amount of strontium-90 in the population of the Gomel region is about 3 times higher than the pre-accident global level for the then USSR. The calculated effective dose equivalent for the detected amount of strontium-90 is equal to about 14 mSv/year.

2. Regional peculiarities of radiocesium migration along the food chain.

As stated above, ratio of the Cs-137 concentration in milk to the density of soil Cs-137 contamination was used as the index of cesium migration ability along the food chain (Bq/l : kBq/sq.m.) or the so called TF from soil to milk.

Table 3 presents the calculated TF values for 4 geographical zones of Gomel region for the period of 1988-1992.

In order to calculate TF dependence on the density of contamination, the southern and north-eastern zones were divided into 3 sub-zones according to the density of contamination: 1-5, 5-15 and more than 15 Ci/sq.km.

By analyzing the data in Table 3, we came to the following conclusions:

- the western zone stands out among the 4 zones where the TF value is 2-3 times higher than the corresponding values for the other zones;
- and the difference between the other three zones is not so sharp;
- TF value decreases with time (especially in 1990), from 3 to 10 times within the whole period under consideration;
- the difference between zones (apart from the western) becomes smaller with time;
- the inversely proportional dependence of the TF value on the density of contamination is apparent, which is characteristic to all the zones within the whole period of study.

Graphs in Figures 1 and 2 which present normal probability plots (cumulative probabilities) of TF in logarithmic scale for the zones, for the 1988 and 1992 years of study, illustrate the above information.

We can see that not only absolute TF value decrease with time but, and it is significant, dispersion decreases (the tangent of the angle of the slope of the curves has become larger).

Table 3. Temporal changes in the Transfer factor from soil to milk in Belarus from 1988 to 1992 (Bq/L / KBq/m^2).

Geographic Zone	Deposition density	Calendar year 1988	1989	1990	1991	1992
1.South	1-5	2.1±0.27	1.25±0.23	0.44±0.05	0.39±0.07	0.64±0.11
	5-15	0.99±0.17	0.54±0.10	0.16±0.03	0.16±0.04	0.30±0.03
	>15	0.73±0.17	0.50±0.29	0.09±0.08	0.06±0.02	0.14±0.03
2.Northeast	1-5	1.64±0.2	1.37±0.24	0.71±0.08	0.40±0.05	0.32±0.04
	5-15	1.13±0.09	0.72±0.09	0.38±0.07	0.23±0.03	0.22±0.02
	>15	0.73±0.12	0.58±0.10	0.22±0.20	0.32±0.03	0.1±0.01
3.West	1-5	6.1±0.7	5.4±0.4	1.9±0.77	1.87±0.30	1.21±0.16
4.Middle	1-5	3.1±0.6	2.1±0.3	0.26±0.12	0.29±0.05	0.43±0.05

Table 4. Main characteristics with regard to dose assessment at the Belarussian settlements investigated.

Properties Contamination Level Ci/km^2	Kirov 25	Haltch 15	Grebeny 7	Kovizhev 7
Population in 1993	547	1595	289	50
Soil Type	Sand (I)	Sand/Loam (I)	Sand (I)	Sand/Peat (H)
Distance to District Centre km	40	2	15	20
Distance to forest	Close	Far	Close	Close
The number of individual using a cow	15 (I)	21 (H)	14 (I)	3 (L)

Note (L),(I) and (H) indicate low , intermediate and high factors

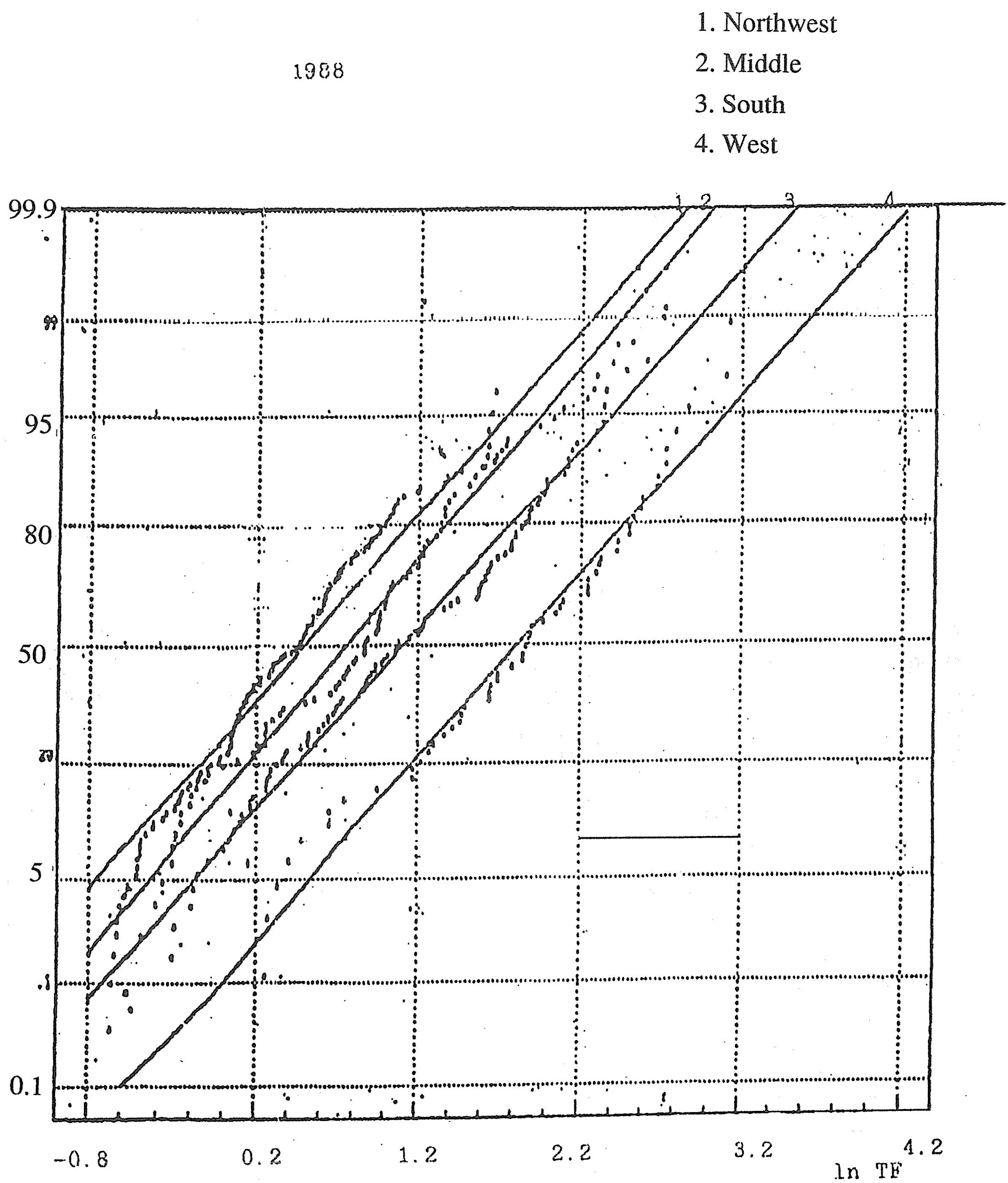


Figure 1. Cumulative percent of the logarithmic transfer factor from soil to milk at different areas in the year 1988

Note: Every point on the plots is the average TF for a single settlement

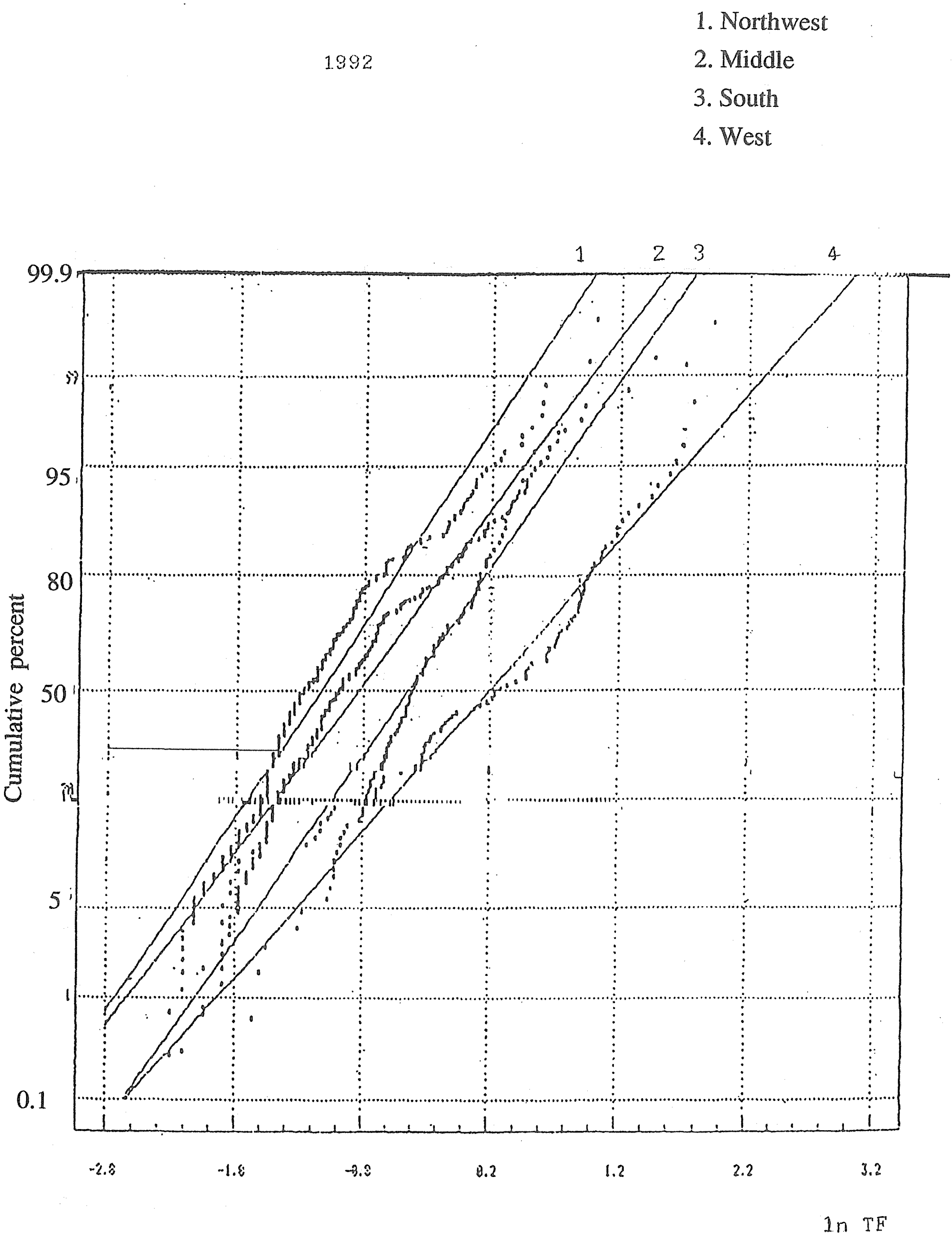


Figure 2. Cumulative percent of the logarithmic transfer factor from soil to milk at different areas in the year 1992

Note: Every point on the plots is the average TF for a single settlement

3.Factors influencing internal dose experienced by the rural population

3.1 Forest factor

In order to evaluate the influence of the forest factor on internal dose, three groups of settlements were chosen representative for their proximity to the forest. The first group comprised of settlements located in the forest zone. The second group included settlements without forests in the vicinity. The third group represented the intermediate position of the settlements, with the forest about 3-5 kilometers away. The number of settlements constituting each group was 9, 10 and 4 respectively. TLD and whole body content measurements were carried out on the greater part of the above settlements inhabitants to provide data on internal and external doses experienced. D internal/D total ratio was used as the criterion for the forest factor influencing the internal dose. We consider that the larger the ratio the greater the importance of the forest factor. Distribution of the internal and external doses contribution to the total dose for the three groups of settlements is graphically indicated in the figure 3. It proved our suggestion that forest is an important factor of dose formation. Thus, in the forest zone the largest ratio of D internal/D total was observed, i.e., 50-80%. Internal exposure predominates in its population. And for the settlements without forests in the vicinity, the external exposure predominates with the internal share equal to 10%. D internal/D total ratio for the settlements of the third group is equal to 20-35%. Apropos, more than half of all the rural population of the region inhabit the settlements of the third group.

3.2 Dietary habits.

Apart from environmental factors we considered that personal lifestyles and occupation most likely affect the level of dose received. We intended to determine in particular whether dietary habits as well as profession and age influence the dose. As indicated earlier, four representative settlements were selected to as a basis for our study. The main characteristics of the settlements under consideration are presented in Table 4. It is impossible to avoid

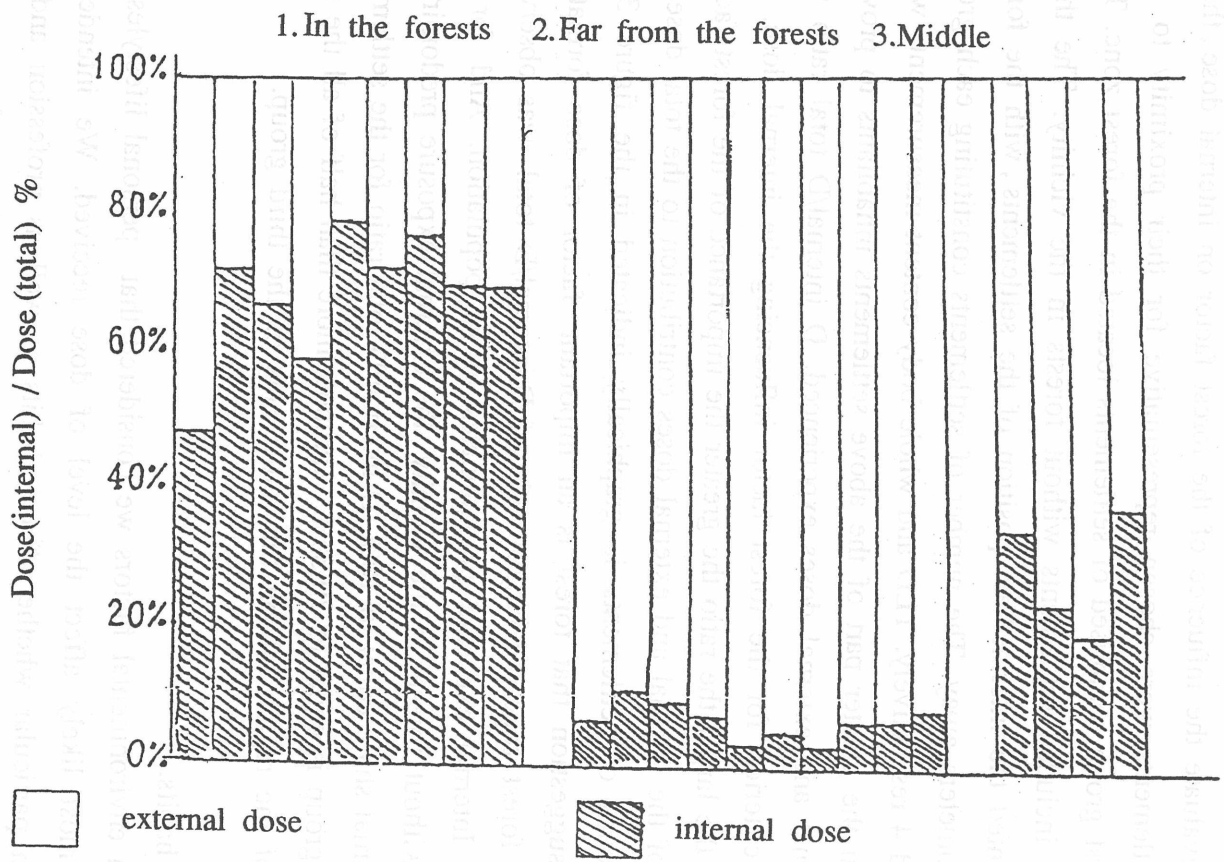


Figure 3. Ralative importance between external and internal doses to groups of settlements in the forest , near the forests and far from the forests.

population surveys while studying the dietary habits. Public questionnaires resulted in the five following population groups that differ in dietary habits: (Ⅰ) those avoiding private milk consumption as well as forest produce (mushrooms, berries and game); (Ⅱ) those consuming private milk and avoiding forest produce; (Ⅲ) those avoiding private milk but consuming forest produce; (Ⅳ) those consuming private milk and forest produce but not game (hunted wild animals and birds); (Ⅴ) those consuming the whole scope of "critical" foods: private milk, forest produce and game.

The aim of this study was to determine whether the above differences influence the doses received. Figure 4 presents the results of the WB burden measurements of the survey participants, in this case, the population of Kirov. It is representative in number of the statistically relevant groups. The results of body burden measurements are graphically presented in the form of "boxes with whiskers". The height of a "box" is a number of persons in a group, the middle vertical line is a median value, left-hand and right-hand sides are 25 and 75% quartiles. Distribution of body radiocaesium within the corresponding groups is presented quantitatively and very explicitly. Figures under the boxes present median values, kBq/body.

If we analyze the data presented in Figure 4, we can conclude that:

- groups Ⅰ and Ⅴ differ greatly in consumption not only in median values (7 times) but in dispersion (10 times difference in extreme), which is very illustratively demonstrated in Figure 5.
- the significance of locally produced milk and "forest" produce factors is comparatively the same, which is proved by the fact that the accumulation is practically equal for Ⅱ and Ⅲ groups, though dispersion in those who consume "forest" produce is significantly higher. We cannot explain why accumulation in group Ⅳ is somewhat higher than in groups Ⅱ and Ⅲ taken together although Ⅱ + Ⅲ must have been equal to Ⅳ.

We should stress the importance of the game consumption factor in comparison with other "critical" foods. If we divide the median value of the group Ⅴ median value by the corresponding value of group Ⅳ (Ⅱ + Ⅲ), the consumption of game only results in the same body burden as the consumption of milk

Figure 4. Distribution of Cs-137 body burdens and its relationship between living conditions and/or dietary habits in population groups at Kirov, Belarus, 1993　Estimates are based on questionnaires and whole-body counting.

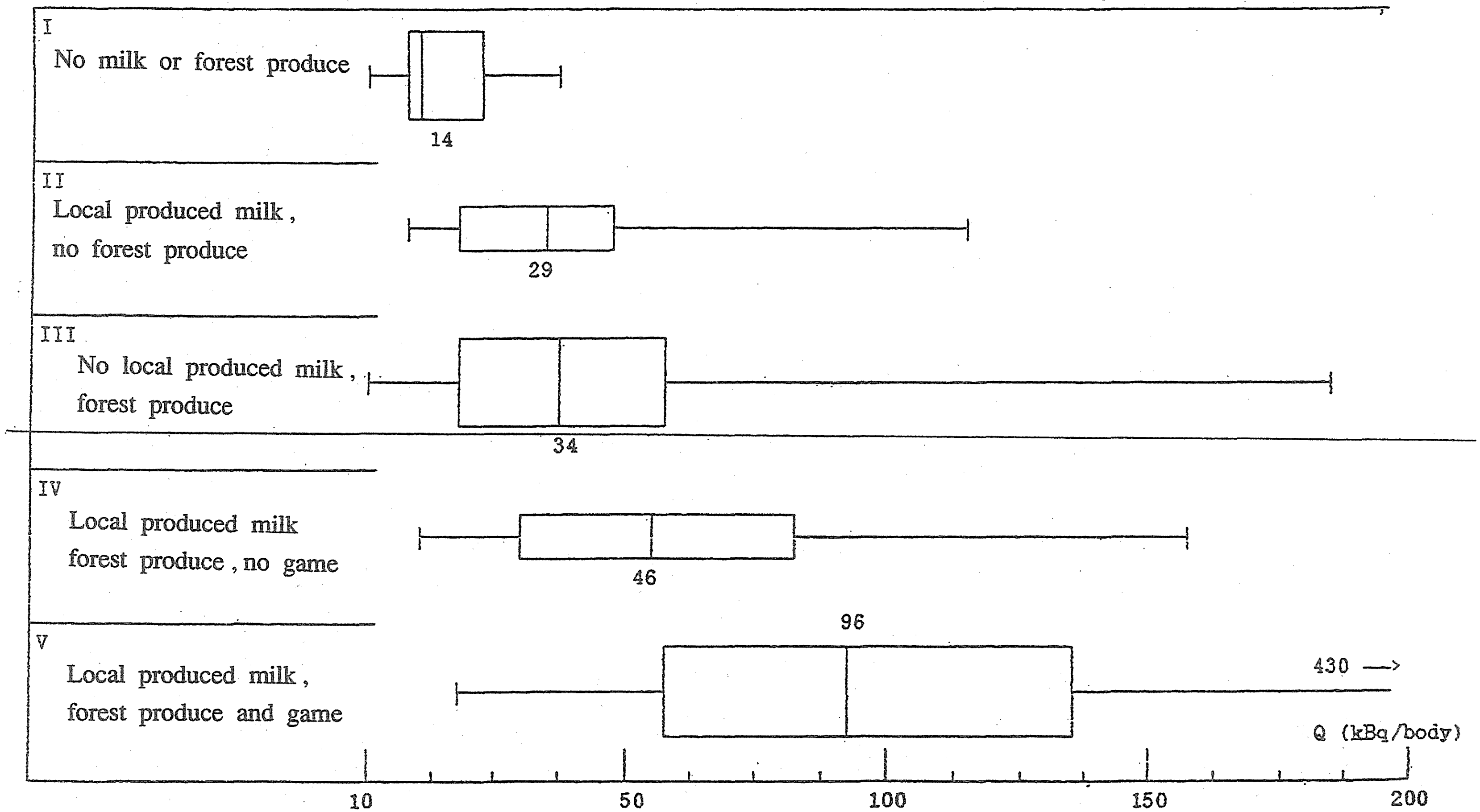
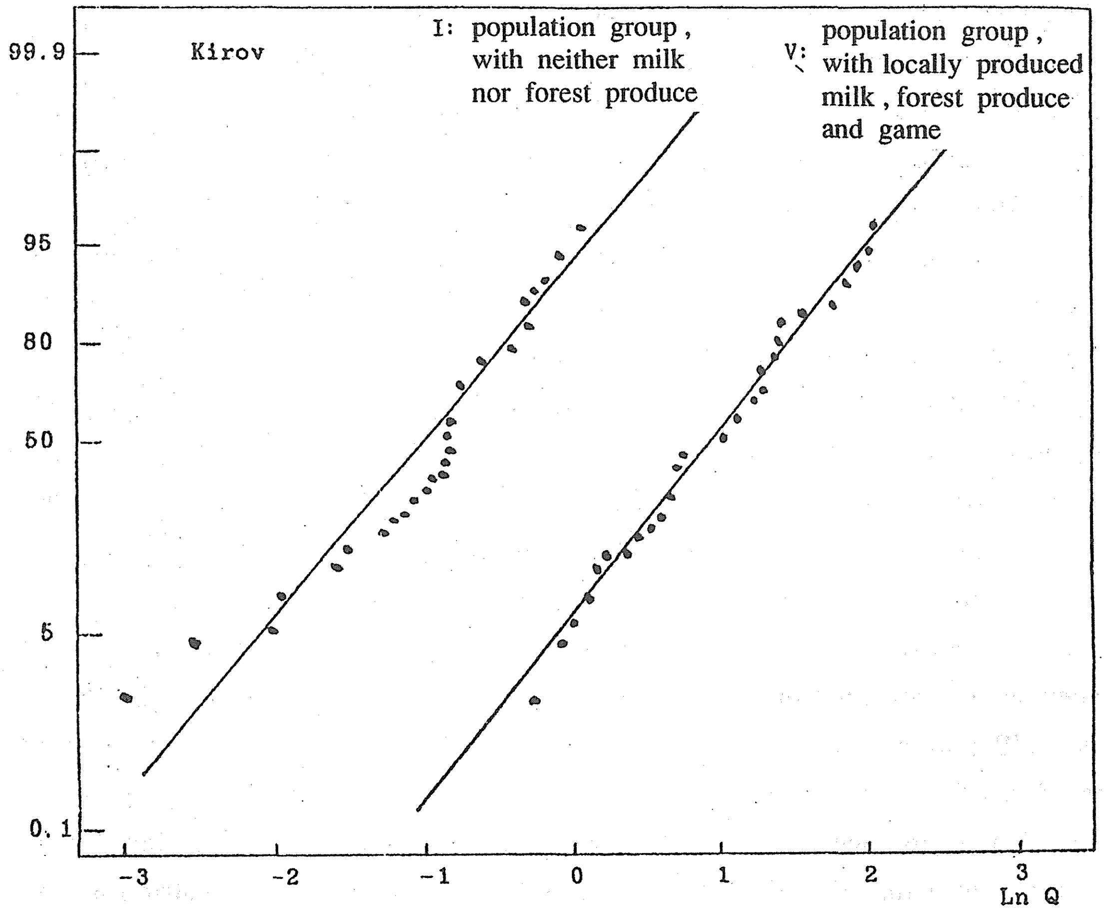


Figure 5. Distribution of Cs-137 body burdens in population groups different in social conditions and dietary habits



and forest produce all together. The distribution of inhabitants of a certain settlement in these groups vs. dietary habits and body burden should then be analyzed with the knowledge of each group's contribution to the collective dose. Figures 6 and 7 give the answer to the above question. Groups Ⅰ and Ⅴ are equal with regard to the number of participants but differ greatly with regard to their contribution to the collective dose. Group Ⅰ makes only about 6% , while group Ⅴ contributes practically half of the collective dose. It seems likely that this population group can be considered the "critical" one. It should be mentioned that the calculation method is the one which is adopted and most widely used for the assessment of radionuclides with foods intake. The method is based on the use of average statistical data of daily intake and the specific activity concentration in food data. Figure 6 demonstrates the state of adequateness of this method as compared with the method using actual consumption data. Three groups of comparisons are presented in the figure. (Ⅰ) - calculation of body caesium intake based on the adopted method of statistical consumption, (Ⅱ) - calculation based on public questionnaire data when actual consumption of "critical" foods is taken into account. The group Ⅲ -- WB burden measurements data. It is clear that assessment of accumulation based on the real consumption (Ⅱ) and real measurements data (Ⅲ) are in close agreement , while the adopted calculation method is absolutely inadequate in the real situation. Firstly: there is no correlation for the distribution in relation to the groups of consumers; secondly, when we use the statistic method for the integral of the content for all the three groups , it is 4 times lower than in the actual situation.

3.3. Professional-age factor

While analyzing the information on WB burden with the help of actual analysis , the population of the settlements was broken into two professional-age groups (PAG Ⅰ and Ⅱ). Then as indicated earlier , analysis was carried out on the distribution of internal dose composition taking into account the dietary habits of the groups. The results of this analysis are presented in Figure 8. We can conclude that PAG Ⅱ dose distribution characteristics are more unfavourable

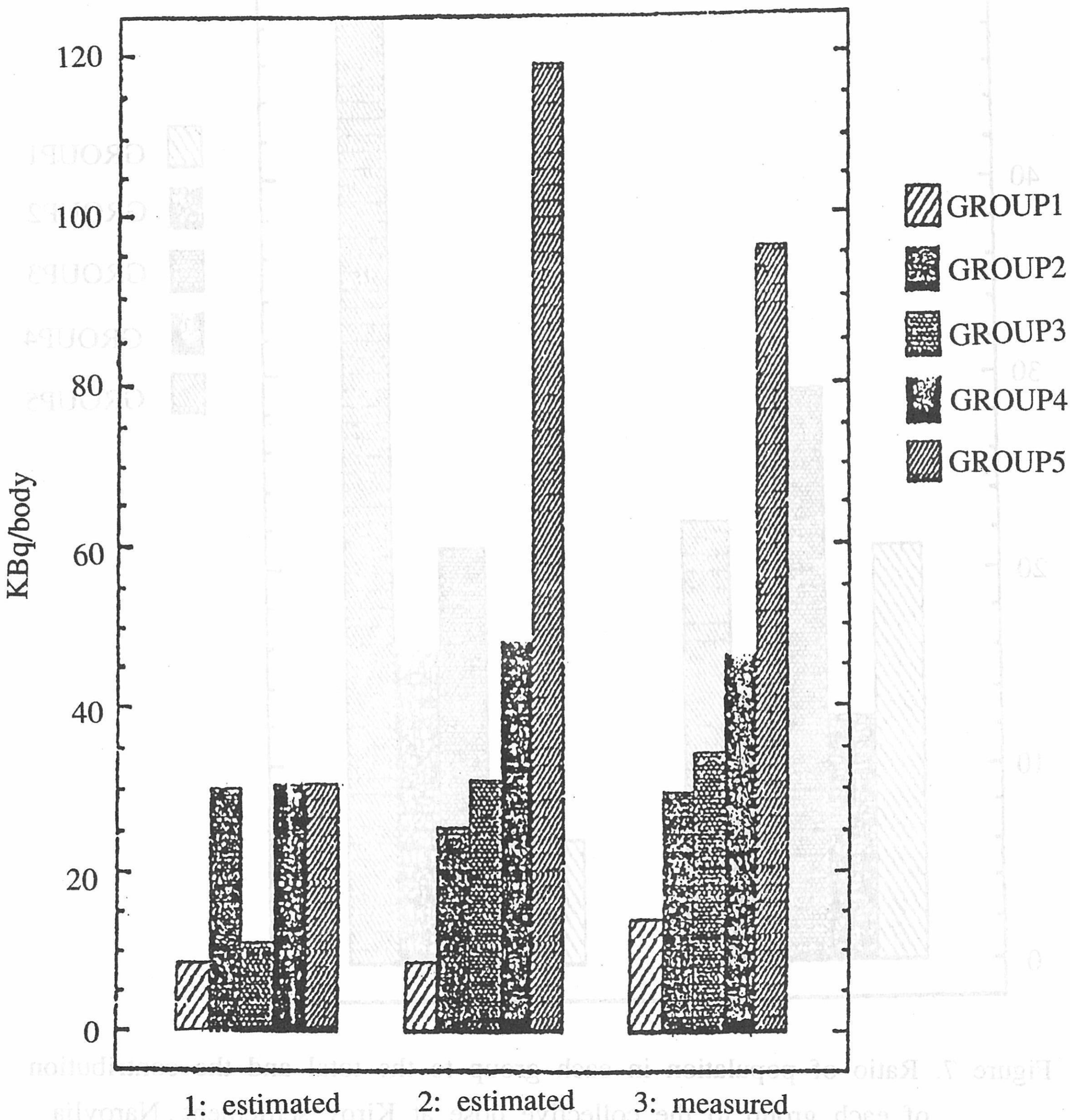


Figure 6. Two estimated Cs-137 body burdens compared with actual measurements for 5 population groups using different dietary habits at the Kirov settlement , Narovlja area in 1993

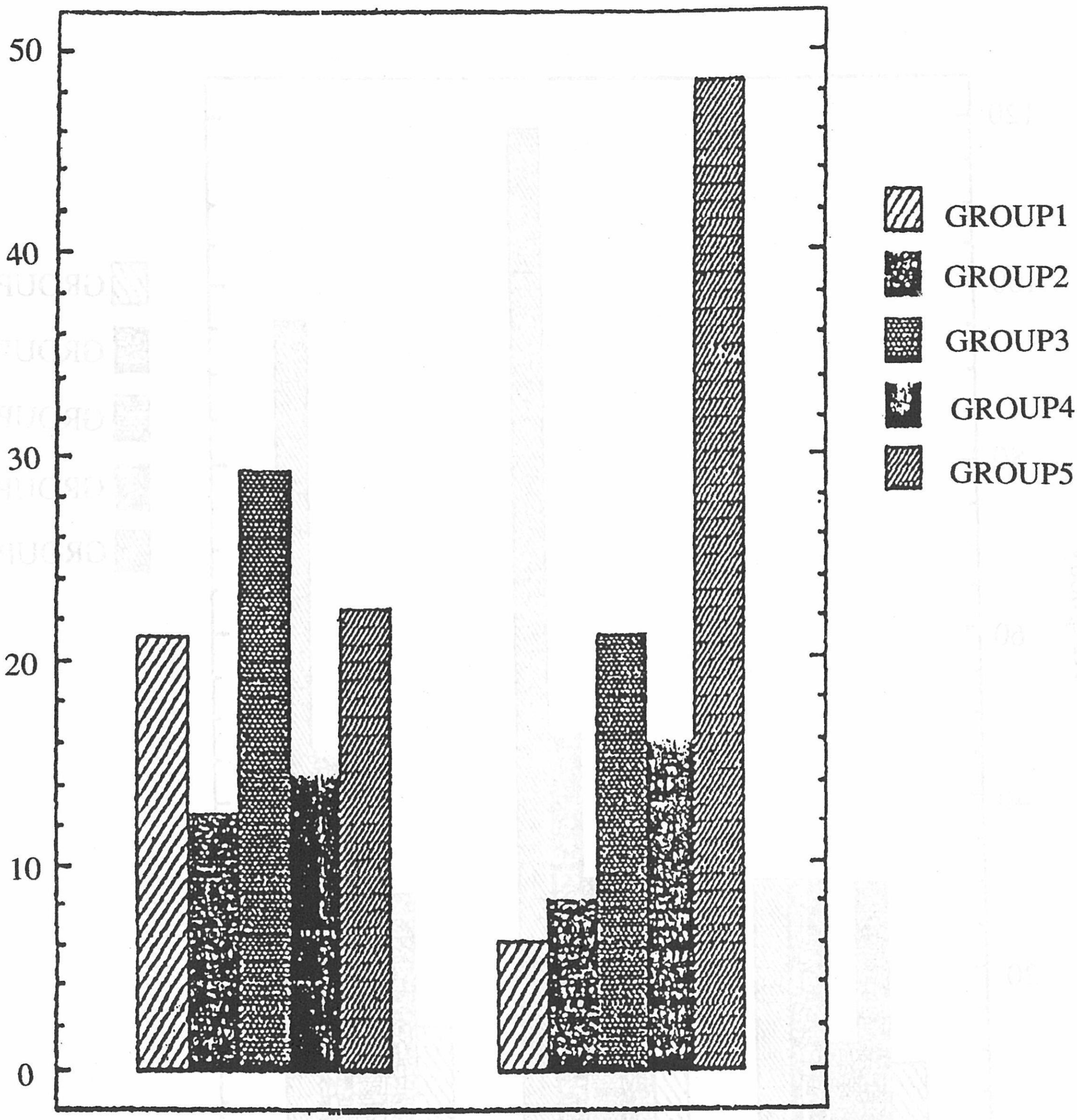


Figure 7. Ratio of population in each group to the total and the contribution of each group to the collective dose at Kirov settlement , Narovlja area in 1993

1. Ratio of population in groups 1 to 5 to the total population
2. Ratio of dose contribution in groups 1 to 5 to the total dose

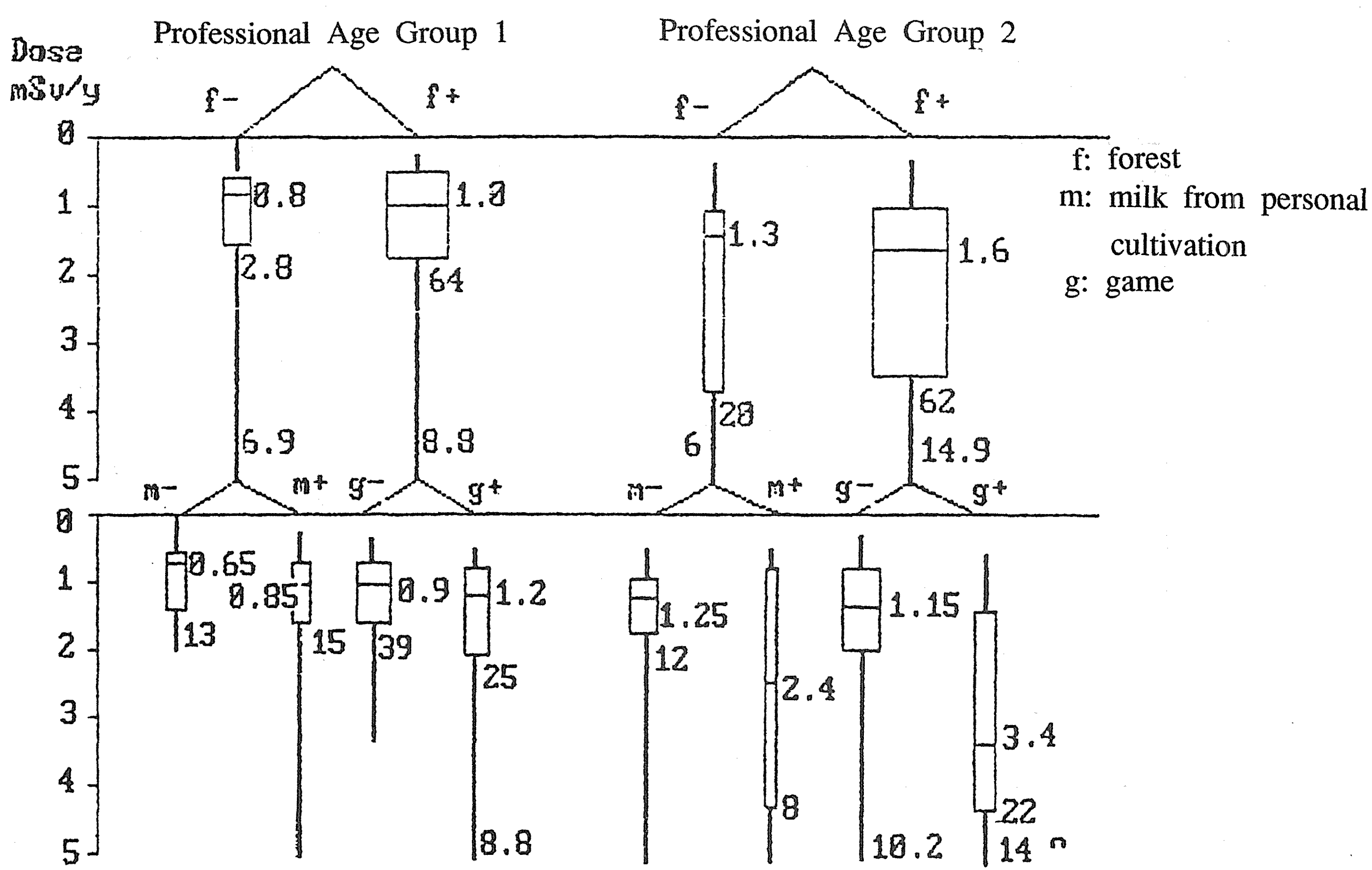


Figure 8. Analysis of internal dose from Cs-137 related to social factors and living conditions for 2 different population groups at the Kirov settlement , Narovlja area in 1993

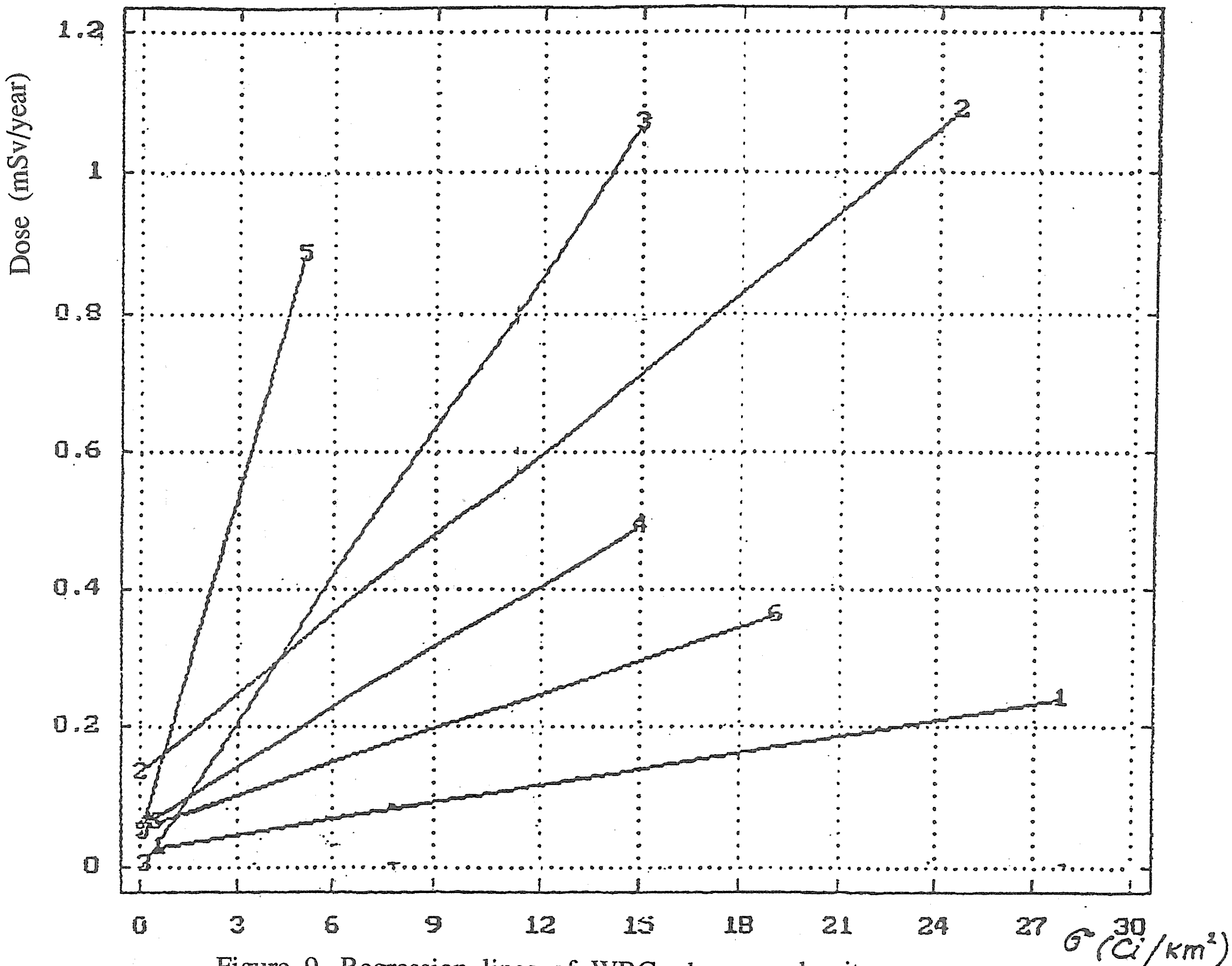


Figure 9. Regression lines of WBC - dose on density soil contamination for 6 settlement classes

than PAG I for median values and dispersion. Thus for the forest produce consumers constituting PAG II, median value of the dose is 3 and the dispersion is 2 times higher than in PAG I constituants. For PAG II private milk drinkers, the corresponding median value of dose and the dispersion is 2 and 4 times higher than for PAG I respectively. As the result, we can consider that profession and the age influence the distribution and magnitude of internal dose in rural populations significantly.

4.Evaluation of the applied countermeasures

Out of all the countermeasures which were timely applied, we shall consider only the two which are still in use. These are restrictions on a) locally produced milk and b) forest produce consumption. Evaluation was based on the four settlements mentioned above. "Quantity of saved dose" was used as the criterion of the effectiveness countermeasures expressed as

D estim. / D real (%)

D estim.-- the value of dose the population could have experienced if the countermeasures had not been applied or totally ignored.

D real -- actual dose value based on information on TLD and WB measurement

The results of the evaluation are presented in Table 5. Vertical columns include dose due to the consumption of milk and forest produce (mSv/y) and the relative dose saved, as a result of the application of countermeasures, in %. We can see that the dose saved by "forest" restrictions is a little bit higher than that by the "milk" restrictions.

Table 5. Dose reduction due to different restrictions.

Settlements	Countermeasure: Milk from local production		Countermeasure: Forest produce		Dose reduction to total
	Dose mSv/year	Dose reduction	Dose mSv/year	Dose reduction	
Kirov	2.35	16.8	2.57	23.0	39.8
Grebeny	1.11	6.3	1.14	8.8	15.1
Haltch	0.12	12.5	not available		12.5
Kovizhev	1.81	8.3	not available		8.3

5. Discussion

The post Chernobyl situation in Belarus is now at the restoration stage. The main content of the restoration is to facilitate a return to normal living conditions in the affected territory and to minimize current doses experienced by the population at the affected areas , which vary in magnitude when compared with background radiation. The dose formation due to strontium-90 and transuranium elements when compared with Cs-137 , is not significant. Until now dose reduction has been connected with countermeasures. However the effectiveness of countermeasures is very low now due to the population returning to a habitual lifestyle. The number of privately owned cows has returned to normal and people have begun consuming forest produce again. The countermeasures thus become ineffective as a result of the adverse economic situation. This has ultimately led to an increase in dose. Radionuclides are fixed in the soil and their transfer to the food chain is decreasing in magnitude. We should mention the successful application of agricultural countermeasures. External dose reduction due to countermeasures with respect to radiation factors should be optimized because the dose from radon in many areas can be higher than that from Chernobyl. The countermeasures should be chosen according to the classes of the settlements and other groups in the affected population. Priority should be given to the settlements of classes 2,3 and 5 , as well as those comprising of the "risk or critical" groups (PAG Ⅱ, forest produce consumers especially). The scientific value of the present study is that we tried to develop a methodology for the optimization of the internal dose , by correcting for a variety of conditions (including population factors) that influence the internal dose. The method needs perfecting so as to take time evolution into account. The same method can be created for external dose assessment , as well as the sum of external and internal dose distribution for separate settlements. The aim is to establish adequate methods of dose assessment and prediction as well as risk pathways and risk population group identification , in order to develop adequate countermeasures. Such studies are currently in progress.

RADIATION AND EPIDEMIOLOGICAL ANALYSIS OF MEDICAL AND DOSIMETRIC INFORMATION ON THE CHERNOBYL ACCIDENT EMERGENCY WORKERS.

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ABSTRACT.

This paper presents a brief characteristic of the cohort of Chernobyl accident emergency workers (EW) residing in Russia. The results of statistical analysis of medico-dosimetric data on health status of EWs are considered in order to reveal possible dose-morbidity rates dependence for general classes of diseases.

Statistically significant increase in relative risk for malignant neoplasms, mental disorders and some other diseases depending on external radiation dose is demonstrated for the first time.

INTRODUCTION

A vast amount of papers concerning Chernobyl accident issues has been published recently. However, they fail to give full account of the problems of radiation and epidemiological analysis of the EW health status.

This situation results from the necessity to take on tremendous work of collection and processing of medico-dosimetric information on EW in order to conduct research of this kind. The Russian National Medical and Dosimetric Registry (RNMDR) is involved in this work.

RNMDR was created in the beginning of 1992 in the Medical Radiological Research Centre of Russian Academy of Medical Science in the city of Obninsk. It was based on the All-Union Distributed Registry of persons exposed to radiation due to Chernobyl accident that was organized in 1986.

The disintegration of the USSR in 1991 led to the formation of National Registries based on the All-Union Distributed Registry. At present such Registries exist in Belorus, Russia, the Ukraine and in the Baltic states. RNMDR was created to provide long-term automated personal registration of various population and EW groups exposed to radiation resulting from the Chernobyl accident, and their progeny; of radiation doses, health status and its changes.

By now the database of RNMDR contains information on 235888 persons including 144762 EWs.

Estimates of dose dependence of EW relative risk for general classes of diseases are shown in the paper. The data were accumulated in RNMDR in 1986-1992.

MATERIALS AND METHODS

Cohort and radiation doses

For 99475 out of 144762 EWs presently registered in Russia the external radiation dose is officially verified. For 131 persons among that number no information about any medical checkup after the cleanup in the 30-km zone around Chernobyl NPP started is available. Thus the size of the cohort under study is 99344 persons. Men constitute the majority of EWs (more than 99%), 90% of which are in the age group of 18-40 yrs. The age distribution of EWs is shown in fig.1. The average age of EWs is 33.7 yrs. The majority of EWs (82%) were engaged in cleanup work in 1986-87. Fig.2 shows the distribution of EWs by date of arrival to the 30km zone. The average period of work in the affected zone is 2.6 months, while the average dose for EWs from Russia

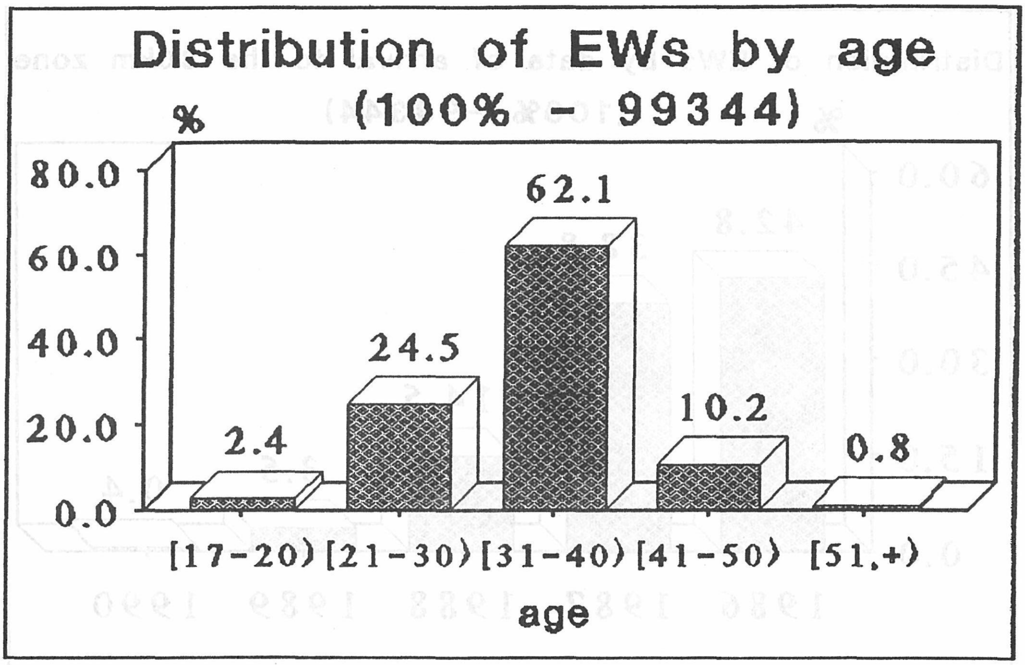

Fig. 1. The age distribution of EW_s.

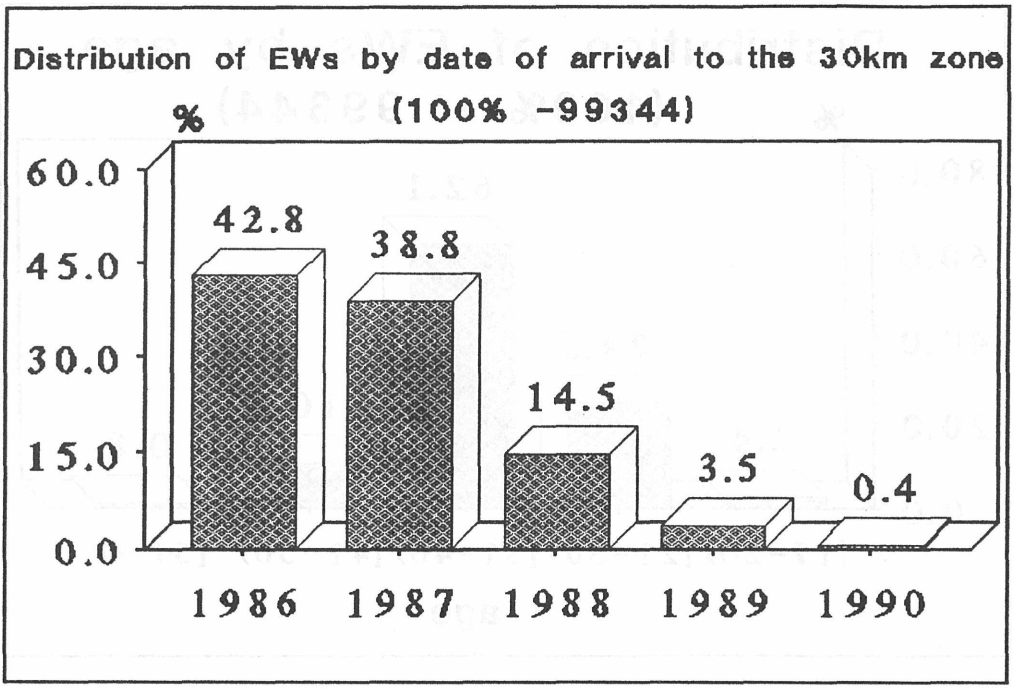

Fig. 2. The distribution of EW_s by data of arrival to the 30km zone.

is 11 cGy. The distribution of EWs by the time of work in the 30km zone is presented in fig.3 and the distribution of EWs by external dose is shown in fig.4.

The term "dose" here implies a documentary verified amount of external radiation received by each EW.

The data were obtained via individual TLD-dosimetry, group assessment (only one member of the group having a dosimeter) and methods of simulation modeling using the information on EW activities (itinerary papers) (1-2).

Data collection

The acquisition of data in RNMDR is performed in the following way. Special Registry record papers (1) containing the information about radiation doses and health status of the person under examination are filled in on the basis of unified medical protocols during regular medical checkups in central district hospitals. The papers thus filled in are verified and passed on to the province level. On this level the data are transferred to magnetic media (floppy disks), checked and passed on to the Regional Center. RNMDR encompasses 15 Regional Centers collecting information throughout Russia.

Regional Centers pass the information on to Obninsk (National level), where it is subjected to logical control and processed. As a result, the RNMDR database contains personal medico-dosimetric information encompassing:

- general data on EW: name, surname, date of birth, address, etc.;
- data on EW's participation in Chernobyl cleanup: arrival date, period of time spent in the 30-km zone, external radiation dose, etc.;
- data on EW's health status: codes (ICD-9 (3)) of diseases revealed after the Chernobyl accident, as well as when and where the diagnosis was made.

RNMDR database is updated annually with information from Regional Centers and from specialized Registries of the Defense Ministry of Russia, Ministry of Home Affairs, Ministry of Security, Ministry of Transport and Ministry of Atomic Power Engineering and Industry of Russia. The EW cohort studied in this paper conforms to the data contained in the RNMDR database as of the beginning of 1993.

Statistical methods

The term "case of disease" is used here to denote the registration of a diagnosis of a particular class of diseases by a health institution. The

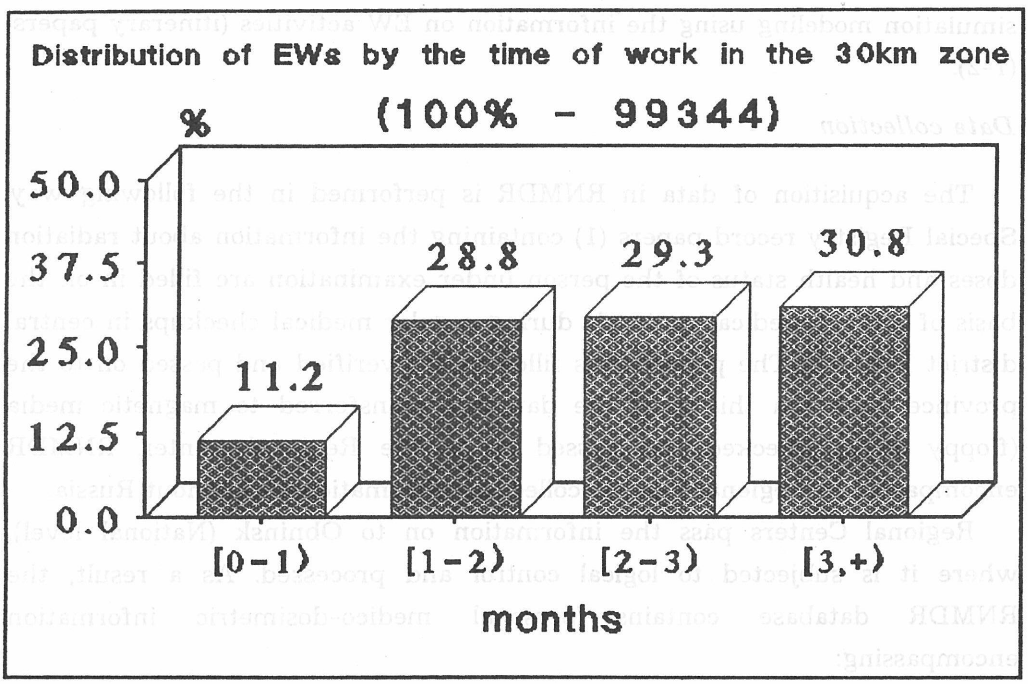

Fig. 3. The distribution of EW_s by the time of work in the 30km zone.

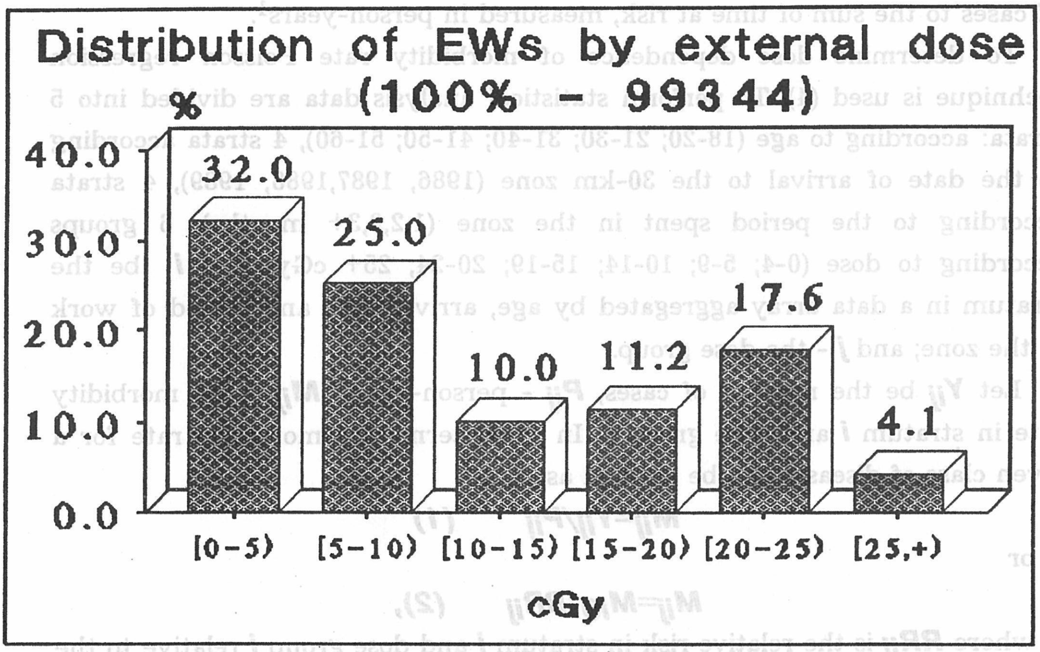

Fig. 4. The distribution of EW_s by external dose.

diagnosis for EW implied here is the first one after his/her arrival to the 30-km zone. No recurrent diagnosis of the same disease is discussed in this work.

In case of chronic diseases EWs having the same diagnosis before and after the accident were not included in the analysis. Thus the time at risk to develop a disease of a particular class for each person is calculated as the difference between the date of registration of the primary diagnosis for this class of diseases and the date of arrival to the 30-km zone. Therefore, the term "morbidity rate" used below is determined as the ratio of the total sum of cases to the sum of time at risk, measured in person-years[1].

To determine dose dependence of morbidity rate Poisson regression technique is used (4). To perform statistical analysis data are divided into 5 strata: according to age (18-20; 21-30; 31-40; 41-50; 51-60), 4 strata according to the date of arrival to the 30-km zone (1986, 1987,1988, 1989), 4 strata according to the period spent in the zone (1,2,3,3+ months), 6 groups according to dose (0-4; 5-9; 10-14; 15-19; 20-24; 25+ cGy). Let i be the stratum in a data array aggregated by age, arrival date and period of work in the zone; and j - the dose group.

Let Y_{ij} be the number of cases, P_{ij} - person-years, M_{ij} - the morbidity rate in stratum i and dose group j. In these terms the morbidity rate for a given class of diseases can be defined as:

$$M_{ij}=Y_{ij}/P_{ij} \qquad (1)$$

or

$$M_{ij}=M_{i0}*RR_{ij} \qquad (2),$$

where RR_{ij} is the relative risk in stratum i and dose group j relative to the dose group [0-5) cGy with the background morbidity rate adjusted by age, arrival date and period spent in the zone.

Risk coefficients are calculated assuming RR=const for each dose group and linear RR function (in dose), i.e.

$$RR_{ij}=R_j \qquad (3),$$

$$RR_{ij}=1+b*D_{ij} \qquad (4),$$

where D_{ij} is the average dose in ij-stratum, R_j and b - the unknown parameters.

Model parameters and their 95% confidence intervals were assessed via the method of maximum likelihood using the ***AMFIT*** program (5). Y_{ij} were assumed to be independent Poisson random values with mean value $E(Y_{ij})=P_{ij}*M_{ij}$ where P_{ij} is viewed as constant.

Table I.
Number of subjects, Diseases and Person-Years by dose

	dose (cGy)						
	total	[0-5)	[5-10)	[10-15)	[15-25)	[20-25)	[25+)
Number of subjects	99344	31821	24845	9933	11165	17497	4083
Infectious and Parasitic Diseases (001.0-139.9)[a]	2180 (401056)	500 (113192)	505 (95658)	237 (41484)	329 (49827)	521 (81650)	88 (19246)
Neoplasms (140.0-239.9)	1646 (403943)	537 (113444)	338 (96365)	167 (41768)	188 (50486)	332 (82611)	84 (19269)
Malignant Neoplasms (140.0-209.9)	491 (405933)	121 (114096)	111 (96719)	56 (41956)	72 (50659)	101 (83049)	30 (19455)
Endocrine, Nutritional and Metabolic Diseases and Immune Disorders (240.0-279.9)	8913 (390557)	2513 (110397)	2166 (93511)	786 (40646)	1098 (48725)	1980 (78683)	370 (18595)
Diseases of the Blood and Blood-Forming Organs (280.0-289.9)	916 (404721)	231 (113913)	198 (96509)	93 (41874)	122 (50503)	225 (82755)	47 (19166)
Mental Disorders (290.0-319.9)	14175 (378373)	3630 (107854)	3572 (90342)	1312 (39150)	1990 (46784)	3042 (76139)	629 (18104)
Diseases of the Nervous System and Sensory Organs (320.0-389.9)	15827 (369841)	4371 (104058)	3910 (88704)	1573 (38412)	2057 (45914)	3214 (75050)	702 (17703)
Diseases of the Circulatory System (390.0-459.9)	9791 (383658)	2564 (108136)	2388 (91883)	1027 (39652)	1218 (47912)	2102 (78099)	492 (17976)
Diseases of the Respiratory System (460.0-519.9)	26691 (353390)	8305 (99278)	6148 (85470)	2525 (36734)	3163 (44011)	5296 (71176)	1254 (16721)
Diseases of the Digestive System (520.0-579.9)	11618 (376277)	3325 (105586)	2844 (90063)	1176 (38890)	1443 (46921)	2300 (76886)	530 (17931)
Diseases of the Genitourinary System (580.0-629.9)	2361 (401165)	722 (112484)	553 (95794)	239 (41483)	307 (50043)	432 (82219)	108 (19142)
Diseases of the Skin and Subcutaneous Tissue (680.0-700.9)	2903 (400574)	940 (112459)	663 (95577)	256 (41476)	338 (50031)	586 (81807)	120 (19226)

[a]*Codes of diseases (ICD-9)*

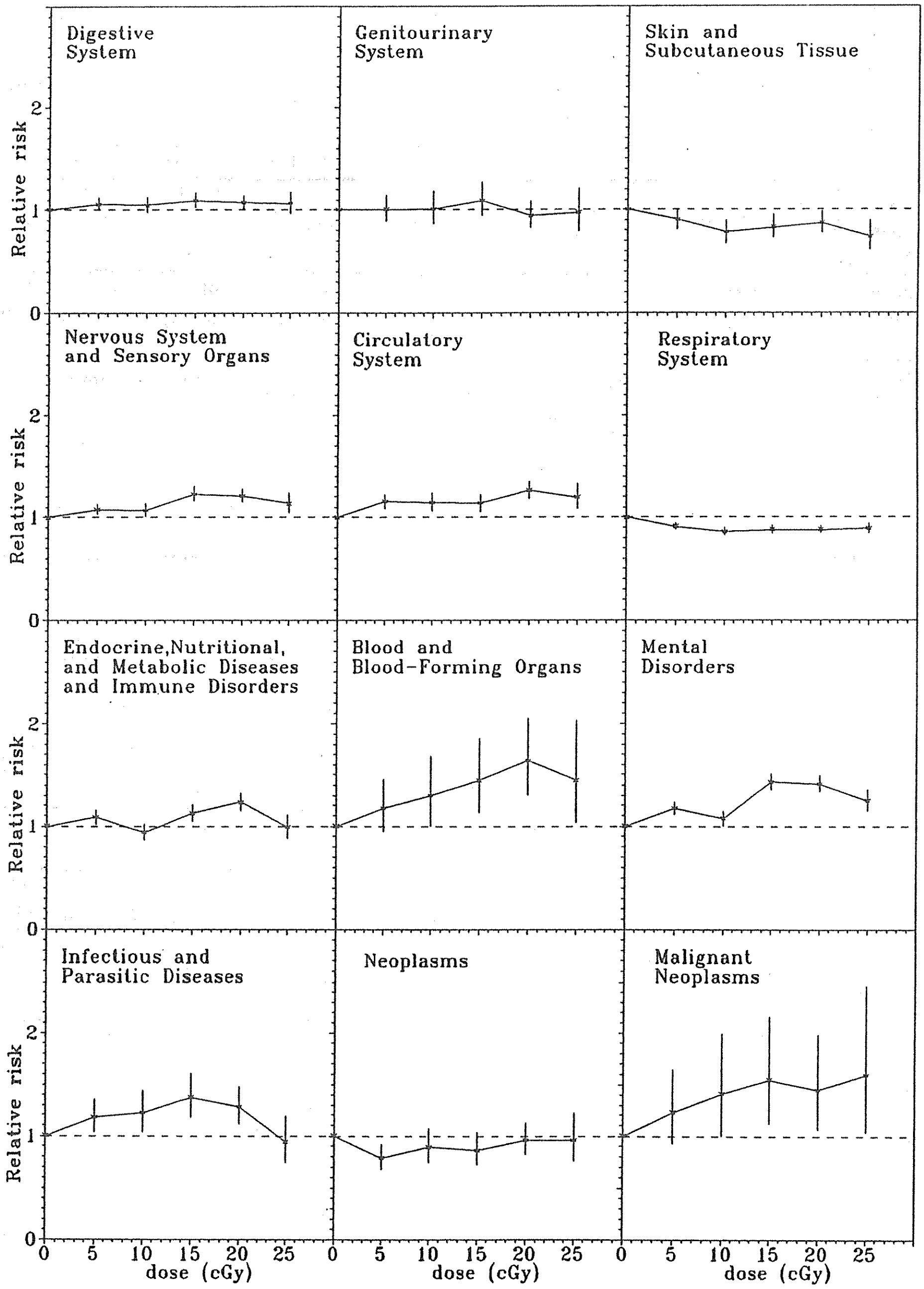

Fig. 5. Dose–dependence of relative risk for general classes of diseases.

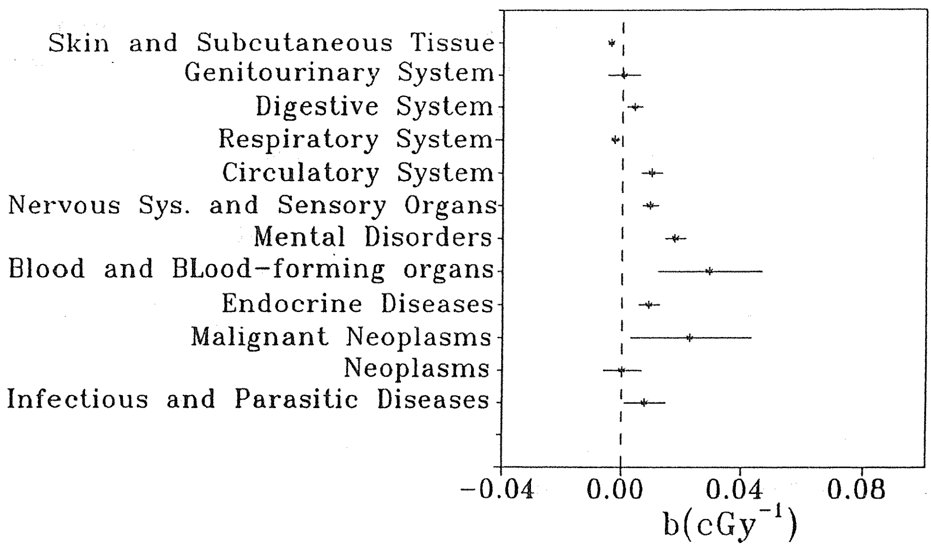

Fig. 6. Estimation of excess relative risk per 1cGy for various classes of diseases.

RESULTS AND DISCUSSION

Parameters of relative risk R_j (relative risk for a definite dose group (Eq.3)) and b (excess relative risk per 1cGy (Eq.4)) were calculated for 12 general classes of diseases selected according to ICD-9.

The distribution of the number of EWs, cases of diseases and person-years for these classes according to the dose of external exposure for the cohort under study is shown in table I.

Diseases of the Respiratory System (39,8%), Nervous System and Sensory Organs (23,6%), Mental Disorders (21,1%) and diseases of the Digestive System (17,3%) were the most often found ones. Relative risk coefficients R_j are shown in fig.1 for each dose group and each class of disease with 95% confidence interval. The estimates of the excess relative risk per 1cGy (Eq.4)- in fig.2 with the 95% confidence interval.

Statistically significant ($P<0.01$) linear increase of relative risk values depending on the dose is registered for Malignant Neoplasms, diseases of Blood and Blood-Forming Organs, Endocrine Diseases, Mental Disorders, diseases of Nervous System and Sensory Organs, diseases of the Circulatory System. A significant ($P<0.05$) positive trend $RR(D)$ (Eq.4) is also observed for diseases of the Digestive System and Infectious and Parasitic Diseases.

Statistically significant dose-dependence of relative risk coefficients is not a demonstrative proof of "causality" of increase in morbidity rates of the above classes of diseases. In fact, EWs exposed to relatively high doses of external radiation participated in emergency work in the first year after the accident. At that time a lot of unfavorable factors affected the health of EWs, stress and psycho-emotional factors among them.

However, preliminary results presented in this paper necessitate further study of the EW cohort. Of great importance is to redetermine the radiation doses obtained using modern techniques of biological dosimetry.

Accumulation of new medico-dosimetric information and verification of the already obtained data will lead to more precise and reliable assessment of dose dependence of morbidity rate during the first 10 years after the Chernobyl accident.

Footnotes:

[1]In case of chronic diseases this term coincides with the term "incidence rate"

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General Discussion and Conclusion on the future cooperative study

A special session was held to discuss future cooperative studies on 20th January 1994 at NIRS, Chiba. Dr.Likhtarev.I.A., RCRM of Ukraine, chairman and a moderator of the CIS delegates, opened the session and prescribed the following four subjects as a basis of the collaboration:

(1)Optimization of protection measures.

(2)Dose measurements which include internal and external exposures, predictions, retrospective measurements, standardization, methodology, and instrumentations.

(3)Radiation protection responding to ICRP Pub.60 recommendations.

(4)Subjects which are indirectly related to the Chernobyl accident such as natural radiations including radon.

He also invited alternative plans from the floor, but asked the participants to give each subject order of priority.

Dr. Uchiyama, M., chairman and moderator of the NIRS party, set out his opinion that it is essentially important to make clear the possible range of the collaboration, both scientifically; and financially, and to find out avid counterparts. Subsequently, Dr. Kobayashi, S., NIRS, outlined the history of prior USSR/Japan coordination previously implemented. Calibrations as well as fabrications of phantorms for the whole-body radioactivity measurement, retrospective dose measurements and natural radiation measurements had been carried out, he said, but the biomedical effects of chronic exposure, hormesis, the combined effects with other diseases and immunity at low doses have not been studied in relationship to each other.

Dr. Ramzaev, P.V., IRH of Russia, proposed the organization of another meeting in one the involved three CIS states in February or March in 1994, in which the Japanese delegates would attend to make the final agreement. He also proposed concentrating the collaboration research on (1) Dose measurements in which external and internal exposures and the transport of radioactive materials are studied taking into account the local differences among the three CIS states. (2) Health effects of radiation including natural radiations, in which studies are done on the rate of decrease, low dose effects to the workers engaged in decontamination of the Chernobyl site, and development of proper indices of the health effects, and (3) Exploitation and evaluation of protective measures, in which an optimization study of evacuation and/or relocation will be given the first priority.

Dr. Likhtarev, however, opposed Dr. Ramzaev's proposal on the next meeting and maintained that it is essential to obtain conclusions without delay. Consequently the possibility of an additional meeting was dismissed.

Dr. Minenko, V.F., RMRI of Belarus, agreed basically with proposals on subjects raised by Ukraine and Russia, but insisted that the reconstruction of the iodine dose in Belarus in the early phase of the Chernobyl accident should be given the priority. He pointed out that the external dose in the early phase of the accident remained vague, and hoped to start the study immediately. With respect to the health effects, he suggested that the study of diseases from psychological as well as physical viewpoints are as important as radiological studies of thyroid cancer while taking into account local differences among the three CIS states. He also suggested the importance of the optimization study, mentioring that the public were complaining about the authority's action on evacuation.

Dr. Likhtarev, however, referring to his experiences in collaboration with Japan, said that it would be best to limit the range of studies. He also suggested that studies born in the collaboration should be published as common properties.

Dr. Matsudaira, H., ex-DG of NIRS, explained the background of the ex-USSR/Japan agreement which was arranged when former USSR President Gorbachev visited Japan. In terms of the agreement, Dr. Matsudaira explained, NIRS would not directly participate in studies of the health effects but would contribute mainly with dose measurements. Comments which Dr. Matsudaira added were that (1) studies of natural radiation would contribute to the study on the Chernobyl contamination, and (2) an automatic analyzer for chromosomal mutation had been developed in NIRS. Dr. Likhtarev announced that he is ready to give first priority to the mutation study if a proper program is set up. Dr. Shigematsu, I., Radiation Effects Research

Foundation, assured that he would support the study through NIRS. Dr. Hayata, I., NIRS, briefed us on the status of the mutation study at NIRS and raised key reasons why collaboration is necessary. Dr. Hayata also pledged to offer instructions and manuals to prepare samples for the automatic analyzer to possible CIS counterparts.

Japanese status was summarized as follows:

(1)Dr.uchiyama, M., NIRS, will continue collaboration in the whole-body countings of internal radionuclides and its data analyses, Dr.Mizushita, S., JAERI, is also available to continue collaboration within the present framework.

(2)Dr.Maruyama, T., NIRS, will participate in the thermoluminescence measurements of bricks provided proper calibrations and technical trainings are available.

(3)Dr.Kobayashi, S.,NIRS, will continue radon measurements. Dr. Shiraishi, K., NIRS, commented that the studies on natural radiation other than radon are also necessary, and his proposal was approved.

(4)Dr.Nakajima, T., NIRS, will check the ESR measurement for teeth , provided proper cross check measurements and background measurements are supplied. And Prof.Toyoda, S.,Osaka University, assured us that he would support the program and help cope with possible difficulties, and as Dr.Likhtarev responded that his colleagues would also make efforts to overcome problems, it was decided that the ESR measurements would continue in collaboration.

(5)Dr.Kobayashi, S., NIRS,will take part in the epidemiological studies and related risk estimation in collaboration with Shigematsu. Dr. Kobayashi, S., hoped that the CIS counterparts would contribute to develop computer programs for analyses.

(6)Calibration of instruments should be implemented in every individual subject.

(7)Dr.Hayata, I., NIRS, will contribute to the measurement of chromosomal mutations. Dr.Shigematsu will be able to help in the case of thyroid measurements.

Lastly, active discussions were held on the remaining subject "optimization of protection measures", of which significance was stressed by all the CIS delegates. Although Dr. Kobayashi, S., suggested contributions by JAERI and PNC, assurance was not obtained. Dr. Likhtarev proposed this study be started when adequate collaborators are found, and Dr. Matsudaira, H., proposed to categorize this study with the other miscellaneous subjects. NIRS and delegates of the involved CIS states agreed with this.

Conclusion

As a consequence of all the discussions, an agreement was obtained between the NIRS and the delegates of the involved three CIS states that future collaboration would continue in the following areas:

(1)Whole-body countings of internal radionuclides and its data analyses.

(2)Retrospective dose measurements including thrmoluminescence measurements of bricks.

(3)Measurements of natural radiations which cover

1)radon

2)others

(4)ESR measurements of teeth of the workers engaged in the decontamination of the accident.

(5)Epidemiological studies and related risk estimation.

(6)Calibration of instruments.

(7)Measurements of chromosomal mutations.

(8)Others.

Subsequently, the session was adjourned.

(by K. Fujitaka Ph.D.,
M. Furukawa Ph.D. and Y. Inoue)

Closing Address

Dr. Sadayoshi Kobayashi
Director, Safety Analysis Unit, NIRS

Mr. Chairman, distinguished delegates from Republic of Belarus (Belarus), Russia Federation (Russia) and Ukraine (Ukraine), invited lecturers and discussion leaders from various research institutions in Japan, ladies and gentlemen, I wish to deliver a few words of thanks in closing the meeting on behalf of the sponsor and organizer of the Workshop, i.e., Science and Technology Agency and the National Institute of Radiological Sciences.

First of all, I would like to thank the delegates from Belarus, Ukraine and Russia for your kind participation in this meeting who had overcome all the difficulties in preparation of their travel, difficulties in communication, in acquiring visas , air-tickets, and permits from relevant national authorities to come abroad and so forth. Such difficulties in one case forced a participant to arrive in Japan just this morning, and in another case a complete cancellation of participation despite of all his efforts he made during the past several months. Your arrival in Japan was the prerequisite to the success of this meeting, or we might as well say, the objective of the meeting. As Confucius says, it is the utmost pleasure in our life to receive friends who have come from far away.

The unfortunate incidence of Chernobyl accident made us to become friends beyond political and geological boundaries. I believe that more than half of the objective of the present meeting has been attained by the simple fact that friends have been able to get together during the past three days. Thanks to your ardent and eager participation during these three days, we have been able to lead very much condensed and scientifically fruitful discussions. We all present in this room have shared a pleasant process of experience where we followed a tread through the woods of science starting from opposing views to an consensus and a conclusion.

We have been successful, to our great pleasure, in identifying 8 subject items of common scientific concerns as possible subjects of future cooperative study, and agreed upon our willingness and wishes to start implementation of joint efforts on these subjects as they become feasible.

From the Japanese side, we wish to mention that we will try our best efforts in formulating the ways and means to enable initiation of such studies as soon as possible through consultation with responsible governmental offices concerned. In this regard, we would like to ask for the kind cooperation from the research institutions and universities within Japan in implementation of such studies.

I wish to thank again all the friends from abroad, discussion leaders and participants, all the staff who laboriously worked behind the curtain in operating the meeting. Last but not least, we should especially like to thank two interpreters, Ms. Yonehara and Ms. Shibata for their excellent job, without which the meeting could not have attained such a successful result.

Let us now hope for the bright future in this joint enedour by Japan, Beralus, Russia and Ukraine in radiation effects research, and may I now declare the meeting adjourned. Thank you.

APPENDIX

International Workshop on Assessment of the Health and Environmental Impact from Radiation Doses due to Released Radionuclides

PROGRAM

Tuesday, January 18

Opening Address 9:25-9:30
Dr. Hirao, Y. (Director-General, NIRS)

Overview Session 1 9:30-12:50
Chairmen : *Dr. Likhtarev, I. A. (RCRM) and*
Dr. Akanuma, A. (NIRS)

1801. Radiation Doses and Health Consequences of the Chernobyl Accident in Russia.
Dr. Ramzaev, P. V. (IRH) 9:30-10:30

1802. Overview of Recent Health and Environmental Consequences due to the Chernobyl Accident from Russia.
Dr. Tsyb, A. F. (MRRC RAMS) 10:30-11:30
Comment
Dr. Kuramoto, A. (Hiroshima Univ.) 11:30-11:50

1803. Overview from Belarus of Health and Environmental Consequences due to the Chernobyl Accident.
Dr. Skryabin, A. M. (SRIRM) 11:50-12:50

Lunch 12:50-14:00

Overview Session 2 14:00-17:40
Chairmen : *Dr. Ramzaev, P. V. (IRH) and*
Dr. Aoki, Y. (Univ. of Tokyo)

1804. Main Problems in Post-Chernobyl Dosimetry.
Dr. Likhtarev, I. A. (RCRM) 14:00-15:00
Comment
Dr. Matsudaira, H. (NIRS) 15:00-15:20

1805. Radiation and Thyroid: A Model of Investigation.
Dr. Nagataki, S. (Nagasaki Univ.) 15:20-16:20

1806. Haematological Diseases in the Affected Areas due to the Chernobyl Accident.
Dr. Kuramoto, A. (Hiroshima Univ.) 16:20-17:20
Comment
Dr. Kumatori, T. (REA) 17:20-17:40

Reception (Birdie Hotel, Chiba) 19 : 00 -

Wednesday, January 19

Technical Session 1 9:30-12:30

Chairmen : *Dr. Los, I. P. (RCRM) and*
Dr. Ishiguro, S. (PNC)

1901. Radioactivity Concentrations in the Environmental Samples Collected around the Affected Areas due to the Chernobyl Accident.
Dr. Shiraishi, K. (NIRS) 9:30-10:30

1902. Doses to Inhabitants from Chernobyl and Other Sources.
Dr. Los, I. P. (RCRM) 10:30-11:30

1903. External Dose Assessment by TLD Method Using Construction Materials Exposed to Radiation due to the Chernobyl Accident.
Dr. Maruyama, T. (NIRS) 11:30-12:30

Lunch 12:30-13:30

Technical Session 2 13:30-16:30

Chairmen : *Dr. Perevoznikov, O. (RCRM) and*
Dr. Hoshi, M. (Hiroshima Univ.)

1904. Monitoring System, Dosimetry and Standardization of Dose from Natural Radioactivity in Population.
Dr. Goritskyi, A. V. (RCRM) 13:30-14:30

1905. Experience, Problems and Results of Body Counter's Usage in Ukraine Population Monitoring after the Chernobyl Accident.
Dr. Perevoznikov, O. (RCRM) 14:30-15:30

1906. Calibration Study of Whole-body Counters for Cesium-137 in the Body Using Different Phantoms, Carried out by the Cooperation Program Between Japan and Ukraine. Interim Summary of the Study in 1989 - 1993 from Japan Side.
Dr. Mizushita, S. (JAERI) 15:30-16:30

ICP	:	Institute of Chemical Physics, Russian Academy of Sciences, Russia.
IRH	:	Institute of Radiation Hygiene, Russia.
REA	:	Radiation Effects Association, Japan.
JAERI	:	Japan Atomic Energy Research Institute.
PNC	:	Power Reactor and Nuclear Fuel Development Corporation, Japan.
RERF	:	Radiation Effect Research Foundation, Japan.
NIRS	:	National Institute of Radiological Sciences, Japan.

Thursday, January 20

Technical Session 3 9:30 - 12:30

Chairmen : *Dr. Serezhenkov, V. A. (ICP) and*
Dr. Bingo, K. (JAERI)

2001. Dose Assessment for the Inhabitants in Prypiat Using Sugar ESR.
Dr. Nakajima, T. (NIRS) 9:30-10:30

2002. Dose Estimate Using ESR from Teeth Enamels and Its Application to Dose Assessment for Inhabitants in Affected Areas by the Chernobyl Accident.
Dr. Serezhenkov, V. A. (ICP) 10:30-11:30

2003. Separation of an ESR Signal due to CO_2^- from Organic Radicals in Tooth Enamel. Dose Response of the Signal and Minimum Detectable Dose.
Dr. Toyoda, S. (Osaka Univ.) 11:30-12:30

Lunch 12:30-13:30

Technical Session 4 13:30-16:30

Chairmen : *Dr. Likhtarev, I. A. (RCRM) and*
Dr. Uchiyama, M. (NIRS)

Discussion for Future Cooperative Study 13:30-16:30

Closing Address 16:30
Dr. Kobayashi, S. (NIRS)

Farewell Party (Birdie Hotel, Chiba) 19:30-

RCRM :	Research Center for Radiation Medicine of Academy of Medical Sciences of Ukraine.
SRIRM :	Gomel Branch Office, Scientific Research Institute of Radiation Medicine, Belarus.
MRRC :	Russian Academy of Medical Radiation Research Center.
RAMS :	Russian Academy of Medical Sciences.

SUMMARY BY RAPPORTEURS

List of Rapporteurs

Title No.	Rapporteurs
1801	Drs. G. Suzuki* and S. Akashi*
1804	Drs. N. Nohara* and N. Ishigure*
1805	Drs. I. Hayata* and T. Ogyu*
1806	Drs. I. Hayata* and T. Ogyu*
1901	Mr. T. Watabe* and Mr. H. Kawamura*
1902	Mr. T. Watabe* and Mr. H. Kawamura*
1904	Drs. Y. Kumamoto* and A. Shiragai*
1905	Dr. S. Mizushita (JAERI) and Mr. T. Ishikawa*
1906	Dr. S. Mizushita (JAERI) and Mr. T. Ishikawa*
2001	Drs. K. Ninomiya (PNC) and T. Asano (PNC)
2002	Drs. K. Ninomiya (PNC) and T. Asano (PNC)
2003	Drs. K. Ninomiya (PNC) and T. Asano (PNC)

*(NIRS)

1801. RADIATION DOSES AND HEALTH CONSEQUENCES OF THE CHERNOBYL ACCIDENT IN RUSSIA

Ramzaev P.V., Balonov M.I., Kacevich A.I., Karlin N.E., Karpov V.B., Komarov E.I., Konstantionov V. O., Lebedev O.V., Libernman A.N., Ramzaev V.P.
(Institute of Radiation Hygiene, St. Petersburg, Russia)

I would like to present data of the radiation doses and health consequences of the Chernobyl accident in Russia, using the 11 Tables and 1 Figure. Table 1 shows the collective effective doses for life of Russian people from different radiation sources. As you can see natural irradiation contributes to the dose by 71% and medical irradiation does by 24%. The effective dose from the radioactive nuclides that were released by the Chernobyl accident is 0.8 mSv/person for all Russian people, 80mSv for Bryansk residents and 100 mSv for the "Liquidators" the Collective effective life time dose by the nuclides from the accident is only 0.3% of the collective effective dose for life by all sources.
Figure 1 depicts the levels of external gamma radiation in rural population of Bryansk region after the accident. Levels of gamma radiation decreased by a half life of 2 years for the first 2 years after the accident, and by a further half-life 4 years thereafter. One can estimate the external doses of residents from this data in combination with the contamination map in Russia.
Table 2 shows the mean ^{134} Cs and ^{137} Cs burden in adult. The mean burden was 207 kBq/person in rural areas in Aug./Sept., 1986. It decreased to 1/20 in 1992. The rate of decrease was 5 to 10 times faster than expected. The amount of ^{137}Cs in milk also decreased from 1/20 to 1/100 of the original for the same time. The rate of decrease was faster than the expected value that was obtained from the data on ^{137}Cs in fallout. Table 3 shows the cumulative dose that was deduced from these data. The dose of the most irradiated man is 50 mSv from 1986 to 1992.
Table 4 shows the thyroid doses from ^{131}I released due to the accident. Doses of 0.3 to 2.0 Sv and 2.0 to 7.0 Sv were received by 8,500 and 270 people, respectively. According to the ICRP risk model, one can estimate the number of thyroid cancer incidences in Bryansk from the accident. This estimate is shown in Table 5. The incidence of thyroid cancer will increase

by 3% in Bryansk (population size of 1 million) and by 15% in the highly contaminated area in Bryansk (population size of 112,000). Table 6 demonstrates the actual thyroid cancer incidence per 1 million person in Bryansk from 1986 to 1992. Bryansk people are divided into 3 groups, two groups in the clean area (population sizes of 460,000 and 205,000) and one group in the contaminated area (population size of 255,000). Incidences of thyroid cancer/ million person are 2.7-6.6 in clean areas. In contrast, incidences in the contaminated area increased markedly in 1986 and 1987 to 6.4 and 11.2 respectively, but decreased to 5.0-8.0 after 1988. The sharp increase in 1986 and 1987 was due to the extensive health survey by physicians, which ceased in 1988. Children are thought to be more susceptible to radiation induced thyroid cancer than adults. Therefore, we have surveyed to the number of thyroid cancer cases for children (<15y). From 1986 to 1992, only 5 children suffered from the disease. These data show that there is no increase in thyroid cancer at the moment related to the irradiation from the accident in Russia.
Figures 7 and 8 depict the incidences of hemato-lymphatic malignancies and other diseases. There are no statistical differences between the incidences of hemato-lymphatic malignancies in clean and contaminated areas. However, incidences of endocrine disorders and psychiatric disorders increased in contaminated areas. The dose-incidence relationship is not clear for these diseases. Moreover, the incidences differ from town to town even in the contaminated area, indicating that the diagnostic criteria of the disorders could be different from regional doctor to doctor. The mortality rate of the newborn is not significantly different between contaminated and clean areas (Table 9). The rate fluctuates from town to town, indicating that the difference in hygienes from town to town is a dominant factor.
Tables 10 and 11 show the data for liquidators. The radiation doses for the liquidators in 1986 and 1987 are 190 ±50 and 120 ±60 mSv, respectively. The doses of the liquidators after 1988 are less than 20mSv. It is noteworthy that the incidences of cardiovascular disorders and psychiatric disorders were high among liquidators in 1986 and 1987, which could be explained by the severe psychological stress in these people.

1804. Main Problem in Post-Chernobyl Dosimetry
Dr. Likhtarev, I. A. (RCRM)

The authors consider the Chernobyl accident to be catastrophic accident. The reasons are 1) the complex spatial-temporal structures of sources and doses, 2) the large-scale evacuation of several million people and 3) the massive commitment of the 260 thousand liquidators.

The exposed populations were categorized into four groups: 1) children whose thyroids were heavily contaminated, 2) general public, 3) evacuated people and 4) liquidators.

The doses to one fifth of the liquidators had been fixed (the authors call it "the administrative dose"). The authors reviewed the doses and presumed that a small percentage of them received doses exceeding 30 rem. The authors evaluated the actual doses of the individuals using ESR from teeth enamel and in future have a plan to apply cytogenetical approach to individual dose assessment.

The authors used two approaches to estimate the external gamma dose: 1)radiochemical analysis of fall-out and 2) direct measurement of gamma-rays.

Since the external dose depends on the behavioral regime of the public, the authors determined the behavior-related dose-modifying factors for the following groups, 1) preschool children, 2) school children, 3) employees 4) farmers and 5) pensioners by each season. A fivefold difference was found in the factors between the groups.

The "Ecosystem" model is sometimes used to evaluate internal dose by Cs-137. The authors, however, considered the model not applicable to the present circumstances, because countermeasures to reduce doses were introduced and because the inhabitants consumed food from foreign areas. The authors have data on the Cs-137 content of fifty thousands of inhabitants measured with whole body counters. The authors emphasized the validity of direct measurement to evaluate internal dose. The authors measured ten thousand of samples of milk and soil to assess the risk to farming.

Assuming that the evacuated people would behave as usual, the average dose was estimated to be 2 rem with a maximum of 30 rem. However, they behaved unusually. The dose to the individuals should be evaluated by biodosimetrical approach or by the ESR method.

As a whole, the authors emphasized the validity of direct measurements of activity and doses of individuals.

1805. Radiation and the Thyroid: A Model of Investigation

Dr. Nagataki, S. (Nagasaki Univ.)

Principles in the investigation on radiation-induced thyroid disease consist of 1) making a correct diagnosis of every subject in a cohort, 2) determining the correct radiation-dose and 3) selecting the most appropriate statistical or epidemiological methods.

According to the principles mentioned-above, a model of the investigation was performed on atomic bomb survivors in Nagasaki more than 45 years after the explosion of atomic bomb. Subjects were cohort members of the Nagasaki Adult Health Study whose radiation doses had been determined by DS 86. Diagnosis of thyroid disease in every cohort member was made by thyroid experts using ultrasonography. Criteria for the diagnosis are shown in the slide; briefly, nodular lesions including solid and cystic lesions, hypothyroidism, and hyperthyroidism. The prevalence of each thyroid disease was analyzed using linear logistic models for sex and age at the time of bombing and the DS 86 thyroid dose. Solid nodule increased proportionally with the thyroid radiation dose in women, and risk was higher in younger person. Unconfirmed thyroid lesions and thyroid cancer increased with radiation dose, and autoimmune hypothyroidism increased with doses in the lower dose region and decreased with doses at higher dose ranges with a peak at 0.7 Sv.

People in Nishiyama area of Nagasaki City were not irradiated directly but exposed to fallout of the A-bomb. A significant increase of the thyroid nodule was observed. It was considered that these thyroid nodules were caused by fallout.

Questions in the investigation of thyroid disease to Chernobyl accident are as follows: 1) Is the diagnosis correct in all subjects in a cohort? 2) is the correct radiation dose available for all subjects in a cohort? And 3) is the epidemiological analysis performed using reliable data? In addition, it is important that the diagnosis should be similarly performed in not only the exposed cohort but also with controls. When radiation doses are estimated, attention should be paid to 1) reconstruction of thyroid dose, 2) reliability of iodine dose estimated by the cesium dose, 3) personal history, and 4) iodine intake and its route, and other chemicals that affect thyroid function. It is also important to decide the further monitoring method of cohorts with estimated doses.

The incidence of thyroid disease in Belarus and Ukraine is different from that in Russia. The cause of the difference should be made clear. More detailed scientific bases are required to verify the reason for the increase in thyroid disease.

1806. Haematological Diseases in the Affected Areas due to the Chernobyl Accident

Kuramoato, A. (Hiroshima Univ.)

Centers for the medical examination were established in Klincy (Russia Fedelation), Mogilev and Gomel (Republic of Belarus), and Kiev and Korosten (Ukraine). Subjects were 5-15 years old. They were selected by the Ministry of Health in each rayon. With the help of special buses equipped for medical examination, 20-40 children were examined per day. Items for hematological examination were white blood cell (WBC) count, red blood cell (RBC) count, platelet count. Hemoglobin (Hb), hematocrit (Ht), mean corpuscular volume (MCV), mean corpuscular hemogiobin (MCH), mean corpuscular hemoglobin concentration (MCHC) and leukocyte differentiation. From May of 1991 to December 1992, a total of 24,923 children (11,929 boys and 12,994 girls) had the examination. Most of the children who lived in both non and highly contaminated rayons showed the normal ranges for WBC, Hb level and white blood cell analysis. There was no special relation between the results of these hematological examinations and ^{137}Cs whole body counts. Hematopoietic disorders and hematopoietic malignancies were not found in those children.

To date, about 50,000 children have been examined. We hope to investigate as many children as possible. In the future, it will be necessary to organize a network system for the follow-up study, to add more items of examination such as immunological markers and to establish the normal range of hematological values for children.

1901. Radioactivity Concentrations in Environmental Samples Collected around the Areas Affected by the Chernobyl Accident

Dr. Kunio Shiraishi
Division of Radioecology
National Institute of Radiological Sciences
Nakaminato, Japan

In relation to the environmental transfer of radionuclides accidentally released and their impacts on human health, he believes it is important to determine and utilise the most suitable techniques for chemical analysis and measurement of radioactivity especially when there is a great variety samples such as food and water collected and used, as the vicinity of Chernobyl, particularly Kiev, Ukraine.

Group 1 samples included milk, fish, diet, vegetables, tap water, etc., all ashed and sent from the research Centre for Radiation Medicine. For comparison food and other environmental samples of similar type were also collected from the Mito area, Ibaraki Prefecture, Japan. Group 2 samples consisted of water samples collected from wells, lakes and rivers in several districts in Ukraine.

Radioactivity of ^{137}Cs, ^{134}Cs, ^{40}K, ^{60}Co and ^{54}Mn was measured using gamma spectrometry with a Ge detector. ^{90}Sr was determined by beta spectrometry after chemical separation using fuming nitric acid. Natural radionuclides, i.e. ^{232}Th and U isotopes were evaluated using ICP mass spectrometry (ICP-MS). Non-radioactive elements, i.e. Na, K, Ca, Mg and P were measured with ICP emission spectrometry and other trace elements, i.e. Cr, Cd, Pb, As, etc. by ICP-MS.

Four milk samples from Kiev, collected during the period 1987-1990 showed 10-50 and 200-2000 times larger activities for ^{90}Sr and ^{137}Cs respectively, than those from Mito collected during 1985-1990. Radioactivities of ^{90}Sr and ^{137}Cs in the diet from Kiev were a few times to one order of magnitude higher than in those from the Mito area. ^{60}Co and ^{54}Mn activities in the diet were also detected although their origin is not known. Other foods e.g. beet, carrot, cheese, mushroom, leaf vegetables, fruits, etc. from Kiev were shown to have one to four orders of magnitude of higher activity for ^{90}Sr and ^{137}Cs than in Mito. As for stable elements, unusual elements compounds were found from time to time but it is not known if these compounds were present at the sampling sites or if they were introduced later.

The radioactivity-to-stable element concentration ratios (Bq/g) is important with respect to the environmental behavior of radionuclides. The $^{90}Sr/Ca$, $^{137}Cs/K$ and $^{134}Cs/K$ ratios in the milk from Kiev were one order of magnitude larger than those from Mito, and a similar one order of magnitude larger in the carp sample.

Dose equivalents relating to annual intakes of ^{90}Sr and ^{137}Cs in the diet were estimated for adult males using the dose conversion factors of ICRP Publication 30 as 3 and 2 uSv respectively, being three times higher than in Mito. For milk consumption, 3 and 40 uSv were estimated for ^{90}Sr and ^{137}Cs respectively, being 30 and 500 times the doses found in Mito, respectively.

Water samples, 102 in all, were first analyzed by ICP-MS by using the semi-quantitative mode for 4 days under quality control using NIST SRM 1643b: accuracy and sensitivity drift being both within 30%. Isotope ratios of ^{234}U, ^{235}U and ^{238}U were estimated using the quantitative mode for well water from Russia and other samples. The $^{235}U/^{238}U$ showed values close to the natural abundance ratio while the $^{234}U/^{238}U$ ratios were classified into two groups with levels of 10^{-4} and 10^{-5}. The data of the former group being tentatively attributed to Szilard-Chalmer's reaction to ^{234}Th. The U isotope results did not show any relation to the accident. Further studies may be considered. Alkaline earth elements in these water samples excluding Be were a few times to one order of magnitude higher than global literature concentrations; this being attributable to the soil type. The other heavy metals and trade elements, studied in relation to the fire-fighting activities of the accident and local diseases, showed comparable concentrations with world-wide data all being consistent with the IAEA's results. Relative ingestion intakes through potable water and diet were 70:1 and 5:1 for ^{232}Th and ^{238}U, respectively, being three orders of magnitude or more larger than those in Japan.

In conclusion, the above results show the feasibile use of the most recent analytical instruments and indicate a further need for the planned sampling and measurement.

1902. Irradiation Doses of the Ukrainian Population as a Result of the Chernobyl NPP Accident and from Other Sources

Dr. Ivan P. Los (RCRM)

The implementation of radiation protection for the Ukrainian population needs information on the radiation doses to the population delivered from all radiation sources, taking into account the psychosociological aspect, that is, the perception of risk.

The accident at the Chernobyl nuclear power plant brought radiation doses to the population of the Ukraine corresponding to 0.2 to 173 mSv in terms of individual effective dose equivalent for seven years from 1986 to 1992. The assessment of the life-time dose showed that the contribution of the first year dose to the total was equivalent to 37.8% for thyroid glands and nearly 50% for the whole body. Seventy % of the total would be delivered in the first 7 years. The radiation dose to the population in the areas highly affected by the accidental release of radioactivity that was reduced to similar levels found in the areas of less contamination by the execution of countermeasures such as the transportation of foodstuff from the non-contaminated areas and so on. The radioactivity surveys no longer show remarkable differences in the levels of ^{137}Cs both in milk and in the human body, even in the region where highest concentrations of ^{137}Cs had been reported.

The exposure to radon and its progeny in indoor air and the medical exposure to diagnostic X-rays are still important radiation sources for the population, regardless of the extent of radioactive contamination in the environment following the accident. The contribution of radon and its progeny to the life-time dose was estimated to be 60%, whereas that of diagnostic X-rays 16-17%, assuming that the population and the composition by age groups in Ukraine remain unchanged until the year of 2056. Radioactivity accidentally released would play a role as a radiation source of less importance, as its contribution corresponds to less than 2% of the total. No matter how small the radiation doses caused by radioactivity due to the accident might be, however, they are recognized to be unfavourable or unacceptable by the general public, when compared with other sources. Not only the risks related to the radiation doses, but also the public's perception of unavoidable radiation sources could be the grounds for the implementation of the radiation protection, particularly in the case of optimization analysis.

Radioactivity accidentally released delivered externally and/or internally the radiation doses to the population and the contribution of each mode of irradiation was found to be equal in Rovno, Ukraine. The contribution of ^{137}Cs to the total external dose corresponded to 90% of the dose delivered by a wide spectrum of radionuclides, and the contribution of the dose due to outdoor irradiation was 90-95% of the total external dose. On the other hand, the internal doses were mainly caused by the intake of contaminated foodstuffs, which accounted for 97-98% of the total, and the remainder was brought about by the intake of water and the inhalation of air. Milk produced in the region heavily affected by released radionuclides was the most important contributor among foodstuffs and was estimated to yield 70-75% of the internal dose. The radiological situation as mentioned would reveal the most efficient countermeasures to be executed for reducing the radiation dose of the population, that is, the reduction of the ^{137}Cs level in milk.

The level of radiation is expressed on the horizontal axis from year to year and on the vertical axis, the transfer factors of radioactivity from soil to milk. A relatively fast decline was observed for a few years immediately after the accident. Prediction of ^{137}Cs levels in milk as announced in 1989, based on this above mentioned result. The tendency has slowed down and a 2nd prediction was announced again in 1993. The temporal change of ^{137}Cs has been the same as that in body burdens. The prediction of temporal change in levels of contamination is very difficult. This must be the cause of difficulty for choosing appropriate countermeasure for radiation protection.

1903. External Dose Assessment by TLD Method Using Construction Materials Exposed to Radiation due to the Chelnobyl Accident

Dr. Maruyama, T. (NIRS)

Dr. Maruyama reported on the estimation of external doses using the thermoluminescence method with tiles and bricks obtained from around Chernobyl. He pointed out that the common standardized method should be used in the dose estimation. The capability of the TL method in dose estimation in an accident was shown by describing the history and results of the dose estimation in the atomic bomb incident. The TL material which works well for measurement is the quartz contained in bricks and tiles. The method has also been used for dating in archaeology. The TL method was used when the 1965 atomic bomb dose (T65D) was established, but the apparatus has not been developed enough to give doses for samples obtained at more than 1 km from the epicenter. In the course of the development of the 1986 dosimetry system (DS86), the measurements were carried out with samples collected by the Radiation Effects Research Foundation. Estimated doses agreed between theoretical and experimental methods.

Bricks and tiles around Chelnobyl were collected only from walls 1.5 m above from the earth. Sun dried bricks are not suitable to obtain samples to be measured. The sampling date was 14, 10, 1990. The samples, A 5 m surface layer 5 mm in thickness was removed and discarded. We took samples at consecutive depths, crushed into powder and washed and dried. The samples were investigated so as to establish calibration information. The measurements were made. In natural background doses, the beta doses were measured by holding commercial TL powder between the layers of the sample for several months in a 10 cm lead shield. The gamma doses measured were average values obtained until now. The correlation between the estimated doses and the doses measured with a survey-meter was shown to be good. The dose obtained with the TL method gives the possible highest dose. If both the time-course changes in the air and the behavior of each person were known, it would be possible to estimate the dose received by each person. The alpha dose doesn't have influence on the dose estimated with the TL method, because the pre-dose method was used. He proposed that there would be an intercomparison between the institutes in the future.

1904. Monitoring Systems, Dosimetry and the Standardization of Dose from Natural Radioactivity in the Population

Dr. Goritskyi, A.V. (RCRM)

Thirty per cent of the territories of Ukraine are covered with silicate rock rich in natural radionuclides. More than 40 per cent of the Ukrainian population lives in these territories.

The average annual effective dose per caput for the Ukrainian populationdue to natural radiations is 5.3 mSv. The exposure from internal sources and cosmic rays can not be controlled, but the exposure from radon and its decay products in the air (80 %), construction materials(5 %), and radionuclides in water and so on, may be controlled.The annual average equilibrium Rn concentration in houses is 87 Bq/m^3 in single story, and in two story houses 50 in the ground floor and, in average, 27 above on the first floor. These values vary monthly and maximum values are measured in January and February in the farm-houses of Dnepropetrovsk. There are territories where the average concentration in all construction materials is over 370 Bq/m^3. About 22 per cent of the Ukrainian population consumes water from drilled water wells. Natural radioactivity in water contributes 3.3 percent to the average annual effective dose per caput in the population. There are territories where the average annual effective dose per person is more than 10 mSv. The average annual effective dose per caput in Ukraine is not always large compared with those of other countries in Europe.However, there are territories where the average annual effective dose per person from natural radioactivity exceeds the dose limits for occupational exposure. Also, there are territories where the effective dose from natural radioactivitiy is more than that due to the Chernobyl accident.

It may be justifiable from these facts and, in addition, from an economic standpoint that includes the cost of evacuation from a contaminated area, that basic efforts to diminish total exposure doses should be directed toward reducing exposure to natural radioactivity. For this purpose, it is important that (1) reliable standards of control be set and be recommended, (2) environmental monitoring be carried out and (3) adequate measures be taken.

In Ukraine the following control standards have been adopted since 1990.

Construction Materials			Drinking water		
1. ≦	370 Bq/kg	all	Ra-226	≦	2 Bq/1
2. ≦	740	road, industrial construction	U	≦	44
3. ≦	1350	road, dam (outside of living territories)			

In Houses	γ -ray	Rn and its Decay Products
newly built	< 30 μR/hr	≦ 50 Bq/m^3
existing	< 50 μR/hr	≦ 100

These regulations will become more restrictive in future.

1905. Experience, Problems and Results of Mass Implementation of Whole-Body Counters in the Post-Chernobyl Period

Dr. Perevoznikov, O. (RCRM)

About 3500 km^2 of Ukranian territory was contaminated with Cs-137 deposition at 180 kBq/km^2. According to the investigations that started from 1987, the internal dose by Cs-137 was 95 to 97% of the total internal dose. In regards to the necessity of mass population monitoring, we had to solve problems that included an insufficient number of whole-body counters, metrology and methodology. These problems were solved as follows:

From 1986 to 1988 we used portable whole-body monitors because of the absence of mobile whole-body counters. Stationary counters can measure low level dose by setting the detector close to a subject. These counters have been used for special investigations and metrological purposes. Some mobile whole-body counters (MDA=160-180 kBq/3min) have two seats. The internal dose for most people in the monitoring area was higher than the value of MDA, so this type of counter was sufficient for the monitoring of people in the area. The calibration of whole-body counters was conducted using six green pea phantoms of different body size.

From 1986, 21000 measurements were carried out. Average dose values varied within the range of 0.9-0.02 cSv per year with log-normal distribution; doses for men were 1.1 to 1.6 times higher than doses for women and doses for children were 1.1 to 1.5 times higher than doses for adults. The recent establishment of a linked monitoring system in the Ukraine has made it possible to observe the increased incorporation of Cs-137 in 1992-1993.

1906. Calibration Study of Whole-body Counters for Cs-137 in the Body Using Different Phantoms, Carried out by the Cooperation Program between Japan and Ukraine

Dr. Mizushita, S. (JAERI)

A lot of whole-body counting has been carried out to determine the Cs-137 content of the public in Ukraine, Belarus and Japan. The practical application of whole-body counting primarily requires the establishment of its reliability. An inter-calibration study of whole-body counters started in 1989 between Japan and the USSR. The calibration of whole-body counters has been conducted with their own phantoms, without inter-calibration. Calibration of counters with standard phantoms was necessary.

Three anthropometric phantoms, 3 years old, 11 years old and adult size, prepared by the Japanese side were used for the calibration study in Ukraine and Belarus. Whole-body counters at JAERI, NIRS and PNC have several NaI detectors. The counters at JAERI and PNC are stationary types and the counter at NIRS is a scanning type. In Ukraine and Belarus a chair type whole-body counter is used and it has one NaI detector. In Ukraine whole-body counters where a detector is set close to the subject are also used. The MDA is several tens Bq for WBC in Japan and several hundreds of Bq for WBC in Ukraine and Belarus. The ratio of radioactivity for Cs-137 measured to filled adult anthropometric phantoms ranged 0.9 to 1.11 for the counters in Ukraine and Belarus and this shows the calibration being generally well established. And the ratio of counting efficiency for 3 year to 11 year phantoms was less than 20% for the counters in Ukraine. An error in the range of 0.7-1.5 was formed for the counters in Belarus.This shows somewhat inappropriate calibrations were presumed and suggests the need for another proper calibration.

2001. Dose Assessment for the Inhabitants at Pripyat-City Using Sugar-ESR

Measurement and Exposure Rate Calculations

Toshiyuki Nakajima

The aims of this presentation are 1) to assess the exposure dose of the inhabitants who evacuated from Pripyat-City, and 2) to confirm the availability of sugar as a radiation monitors of the dose measurement for general populations in the case of a radiation emergency. I will present the results of the dose assessment for the inhabitants at Pripyat-City within 36 hours after the Chernobyl accident.

First, I want to mention about the characteristics of Sugar-ESR for radiation. The linearity of the ESR signal for radiation had been confirmed using 600 mg of sugar, in the range of 0.03 to 2 cGy and 0 to 80 Gy. As for fading, it was confirmed that there was no significant change in the signals for 11 weeks at room temperature and 100 minutes at 100 ℃. Therefore, it is expected that the free radicals in sugar caused by radiation could be kept stable at least for 100 years. The minimum detectable dose is estimated as 20 mGy under conditions of 500 mg sugar samples, 100 cumulated signals and 5 mW microwave strength, assuming the safety factor as 40. Eight sugar samples had been collected from Pripyat-City, and the dose was measured by "cumulated signal method ". The measured doses were 7.65 cGy and 11.8 cGy at points A and B at Pripyat-City, respectively as the cumulated dose for 1.264 days. Considering the attenuation factor of the radiation for a 50 cm wall thickness, the outdoor doses at points A and B are evaluated as 27.3 cGy and 41.9 cGy. Further, considering the results of the dose rate measurement, the outdoor doses during the first 36 hours after the accident were estimated to be 13.7 cGy and 23.9 cGy at points A and B, respectively.

We have to consider the time the inhabitants stayed in their houses at Pripyat-City during the 36 hours after the accident. The accident occurred on the 26th of April Saturday midnight, and the next day was Sunday. Many people tended to stay in their house a long time. By using from Japanese statistical data from "A Report of Fundamental Social Life (1986)", we may assume that people were stayed in their houses for 26 to 30 hours during the first 36 hours. Therefore, the exposure dose of the inhabitants at Pripyat-City was assessed to range 2.3 to 6.6 cGy, with 42 +/- 18 mGy in average. This value shows fairly good agreement with the value, 33 mSv, which was reported to the IAEA from the former Soviet Union, and with the value, 20 to 50 mSv, which was reported by Dr. Likhtarev the day before yesterday.

The conclusion of my presentation is as follows:

1) The assessed dose of the inhabitants at Pripyat-City by sugar-ESR method shows fairly agreement with the value that was reported to the IAEA from former Soviet Union, and with the one that was reported by Dr. Likhtarev the day before yesterday.
2) Sugar can be a good radiation monitor for the general public in the case of radiation emergencies.
3) For a nuclear accident such as Chernobyl, it is necessary to investigate appropriate programs for the early evacuation of the inhabitants considering the conditions of the country.

2002. Dose Estimate Using ESR from Teeth Enamels and its Application to Dose Assessment for Inhabitants in Affected Areas by the Chernobyl Accident

Serezhenkov, V.A. (ICP)

It is known that the ESR from teeth enamels is very stable and is able to keep radiation information for a long time. There are two methods used to evaluate the radiation dose using ESR from teeth enamels; 1)cumulative signal method and 2) Spectrum analysis method. We applied the second one.

I will mention 1) The individual sensitivity differences of the ESR signal for the radiation, 2)Mechanically induced signals 3)Spectrum dependence of the ESR signal, 4)Comparison of the evaluated dose measured by ESR and chromosomal aberrations.

The minimum detectable dose is 1 to 2 rad using 100mg of tooth enamel sample. It was found the admixture of dentine decreases the dose estimation.

We compared the doses estimated by ESR analysis for dental enamel and the chromosomal aberrations in lymphocyte cultures from a sample of residents from the Gomel region and the Bryansk region. The ages of the residents ranged between 7 to 76 years old. The correlation between them was not so good.

2003. Separation of an ESR signal due to CO_2^- from organic radicals in tooth enamel: Dose response of the signal and minimum detectable dose

Shin TOYODA (Osaka University)

Tooth enamel has been used to reconstruct the radiation dose due to accidental exposure, such as in the case of the atomic bomb survivors in Hiroshima and Nagasaki, though not in so many cases. An ESR signal due to the CO_2^- radical is observed in irradiated tooth enamel with an overlapping signal due to an organic radical. A new method to extract the CO_2^- signal from the observed signal has been developed. To validate the new method, tooth samples irradiated in the Chernobyl accident from Bragin and Gomel were used. In the validation test, (1) the extraction method for the CO_2^- signal from the ESR spectrum was used, (2) no significant increase due to the Chernobyl accident was observed for 5 teeth, and (3) The detection limit was 9 to 15 mGy. Measurement of tooth enamel necessitates the extraction of the tooth, so another method which does not require the tooth to be extracted is under development. Presently the detection limit of the new method is 2Gy, so the improvement of the detection limit will be stressed.

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POSTSCRIPT

The most important purpose of this publication is to, without delay, inform concerned scientists from around the world of the present accurate facts on the health and environmental consequences resulting from the Chernobuyl accident. Due to the limited time available, we did not make any major grammatical and typographical corrections on the submitted manuscripts. The Japanese rapporteurs also did not have sufficient time to check their own manuscripts. Some English versions of the manuscripts were not submitted in complete form or not submitted at all. Accordingly, the editorial office had to prepare them from the Japanese manuscripts in a very short time. In these cases, the editorial office asked Mr. Damien Andrews, C.S.I.Ltd., to edit the English of these manuscripts. The editorial office would like to express its heartfelt gratitude to him for his devoted endeavor.

An unexpected happiness for us all was the contribution to these proceedings by two scientists from Gomel, Belarus and Obninsk, Russia who could attend for only half a day or missed the chance to join the Workshop at all. We are thankful for their cooperation as this publication was greatly improved by their contribution.

We are also very grateful to Ms. M.Takabayashi and Ms. N.Ogiu of Safety Analysis Unit, and Ms. K.Tanabe of Division of Environmental Health, National Institute of Radiological Sciences, for their help in typing some of the revised manuscripts.

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