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Establishment of a Cohort for the Long-term Clinical Follow-up with Dose Reconstruction under the Joint Medical Research Project Conducted by Sasakawa Memorial Health Foundation (Japan) and the Research Institute of Radiation Hygiene (Russia)

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INTRODUCTION

Health effects of exposure to radiation is a key point in the scientific grounds of radiation protection policy. Radioactive contamination of large areas following the Chernobyl nuclear plant accident and additional radiation exposure of population in the affected territories stimulated the undertaking of epidemiological studies of possible health effects of low radiation doses. One of the most important tasks in radiation epidemiology studies is the evaluation of individual radiation doses to the members of population samples under consideration. The Joint Medical Research Project on Dosimetry Associated with the Chernobyl Accident conducted by Sasakawa Memorial Health Foundation (SMHF, Japan) and the Research Institute of Radiation Hygiene (RIRH, Russia) was launched to assign individual doses to the children in the Russian Federation born between April 26, 1976 and April 26, 1986 (0-10 years old at the time of the accident) who were subjected to health screening in the Chernobyl Sasakawa Health and Medical Cooperation Project (CSHMCP) in the period from May 1991 to April 1996 (1). It has been agreed to establish a cohort of about 1000 subjects selected in line with individual dose distribution adequate to the goal to investigate possible late effects by long-term clinical follow-up.

In view of the main findings of studies in CSHMCP were thyroid abnormalities (2), selection of cohort members was conducted on the basis of the credible estimates of thyroid dose. Preference for subjects to be included into cohort was defined by the availability of radiometry, environmental and social data that may prove useful for reconstruction of individual dose. The paper describes dosimetry data analyzed for selection of cohort members and presents preliminary estimates of distribution of subjects among thyroid dose intervals.

PRIMARY DATA ON INDIVIDUAL DOSIMETRY

In the Russian Federation territories most affected by radioactive contamination following the Chernobyl accident are the western districts of the Bryansk Region. At the time of the accident 112,000 residents happened to live in so called "strict control zone" (SCZ) with caesium-137 contamination in excess of 0.55 MBq m^{-2} . For this population the main components of radiological consequences of the Chernobyl accident are thyroid dose from incorporated radioiodine and external radiation and whole body dose from incorporated caesium radionuclides and external radiation. Contribution of other radionuclides to internal dose seems to be negligible or of minor importance as compared to that from iodine and cesium radionuclides. The most valuable for assessments of radiation doses are the data from individual examinations of people on radionucides content in the body and on exposure to external radiation. Individual measurements data used for selection of cohort members among the subject of CSHMCP residing in SCZ and in adjacent territory are reviewed here below.

Direct thyroid measurements

The most part of timely and qualified thyroid measurements in Russia following the Chernobyl accident were made by the Institute of Medical Radiology (now the Medical Radiological Research Center of the Russian Academy of Medical Sciences) in Kaluga Region where the level of radioactive contamination was not so high as in the western districts of the Bryansk Region (3). What about the Bryansk Region, most measurements were carried out by inexperienced (in dosimetry) personnel from the local health service. These measurements are in use for thyroid dose reconstruction studies with laborious work to verify data in view of incomplete records and/or problems of retrospective calibration of measuring devices (4,5). For the consideration in our joint project, we use only reliable data from measurements made by the staff of RIRH in May-June 1986.

There were two types of RIRH thyroid radiometry data according to methods and devices used: measurements by stationary whole body counter (WBC) and measurements by non-specific gamma radiometry devices.

WBC designed in RIRH consisted of a gamma radiation spectrometer and shield. The spectrometer shield was made from 14 cm thick cast-iron lined on the inside with 4 mm of lead and 3 mm of copper. The lead and copper reduced the background from low-energy photons. The detector consisted of a 15 cm diameter by

10 cm thick NaI(Tl) crystal having an energy resolution of approximately 11%. The detector signals were recorded over 200 channels in a multi-channel analyzer.

Most of RIRH measurements were made with portable or transportable devices: gamma and X-radiation dose rate meter DRGZ-02 (Russia) with scintillation plastic detector containing dispersed luminophor ZnS(Ag); geological exploration gamma radiometer SRP-68-01 (Russia) with scintillation crystal NaI(Tl) of a 30 mm diameter by 25 mm thick; and one-channel scintillation spectrometry radiometer VA-M-141 (RFT, East Germany). The most widely used, especially in field conditions, was radiometer SRP-68-01 in view of its accessibility, compactness and portability. VA-M-141 was the most sensitive device among transportable radiometers (minimum detectable activity MDA=0.5 kBq for ^{131} in the thyroid), but stationary WBC certainly provided the lowest MDA (less than 50 Bq) and the most reliable data because of gamma radiation energy resolution.

Calibration of all devices was performed by means of thyroid phantom with known metrologically attested activity of ^{131}I. The paraffin phantom of the human neck contained a plastic ball filled with the standardized water solution of ^{131}I. Applying to non-spectrometric devices, calculation of ^{131}I activity in the thyroid from measurement data was carried out taking account for contribution of incorporated radiocesium into registered gamma radiation from the neck. To evaluate this contribution and to derive correction factors, special research was performed by analysis of WBC spectrometry data for 253 persons of various age on the body content of incorporated radionuclides, including ^{131}I, ^{134}Cs and ^{137}Cs. The persons under investigation moved to Leningrad from contaminated areas of Russia, Belarus and Ukraine at various dates after the accident. The values of correction factor were derived for various ages of individuals and for various time of measurement, from May 16 to June 15.

There are two sets of measurements taken into consideration in this study: examination of people arrived in Leningrad (St.Petersburg) from contaminated areas and examination of local population in the settlement situated in the Bryansk Region.

Soon after the Chernobyl accident the Research Institute of Radiation Hygiene (RIRH), local administration and health services organized a special sanitary unit to check the surface and internal radioactive contamination of people (as well as to perform personal decontamination procedures, when necessary), who were arriving in Leningrad from the regions of Russia, Belarus and Ukraine affected by exposure to radiation following the accident. The unit was put in function at May 7, 1986, although the first arriving persons were examined and submerged to decontamination starting from April 28, 1986. 25 thousand persons were examined during May and June 1986 for surface contamination, and 5400 of them were measured for internal radioactivity. Most of these people arrived from Belarus and Ukraine. For the aims of the joint project, 310 residents of seven most contaminated districts of the Bryansk Region were found who were measured for ^{131}I content in the thyroid from May 17 to June 15, among them 146 children 0-10 years old. Data from later measurements are not taken into consideration because of their insignificance in view of radioactive decay of ^{131}I and excretion of rarioiodine from the body. The contents of ^{131}I in the thyroid of children of different age derived from the measurements of 146 subjects are shown in Figure 1. The presented data are calculated with account for radiocesium contribution into measurement results and extrapolated to a common date (May 22) for comparability of data derived from measurements performed at different days. The extrapolation was made by exponential factor accounting for age dependent half-time of ^{131}I in the thyroid.

During the radiological monitoring of the most contaminated territory of the Bryansk Region carried out by RIRH, residents of the settlement Mirny (^{137}Cs contamination level of 1.1 MBq m^{-2}) were examined on the content of radioiodine in the thyroid. Measurements were made at May 22, 1986 with portable radiometer SRP-68-01. Measurement data corrected for contribution of radiocesium are presented in Figure 2 for 283 children who were residing in Mirny. It is seen in Figure 2 that even in a single settlement the distribution of individual thyroid burdens of ^{131}I measured at the same time and in the same age group is very wide. Sources of variability in the measured values of ^{131}I activity in the thyroid are not related to instrumental errors but to environmental and lifestyle factors. This variability , first of all, is resulted from individual dietary differences including food habits and the perception that a person or family has with respect to radiation risk and recommended countermeasures. Locally produced milk from cows grazing on contaminated pastures usually provided the main contribution into ^{131}I intake via food. The concentration levels of ^{131}1 in milk were in excess of temporary permissible level established by the State Sanitary Authorities, and a ban on local milk consumption in the contaminated territories was launched. However, people stopped consumption of locally produced milk from private farms at various time. Questionnaire investigation carried our by RIRH showed that many persons stopped local milk consumption at the last decade of June, when the countermeasures became much more stronger and withdrawal of milk producing cattle from private farms started. The concentration levels of ^{131}I in milk fluctuated at the same time and the same settlement as a result of non-uniform deposition of ^{131}I on pastures, the variability in the consumption rate of grass by different cows, the use of cultivated pastures and uncontaminated stored forage by some farmers and other factors. Therefore, the degree of uncertainty should be realized in ascribing some averaged level of ^{131}I in the thyroid to non-examined persons.

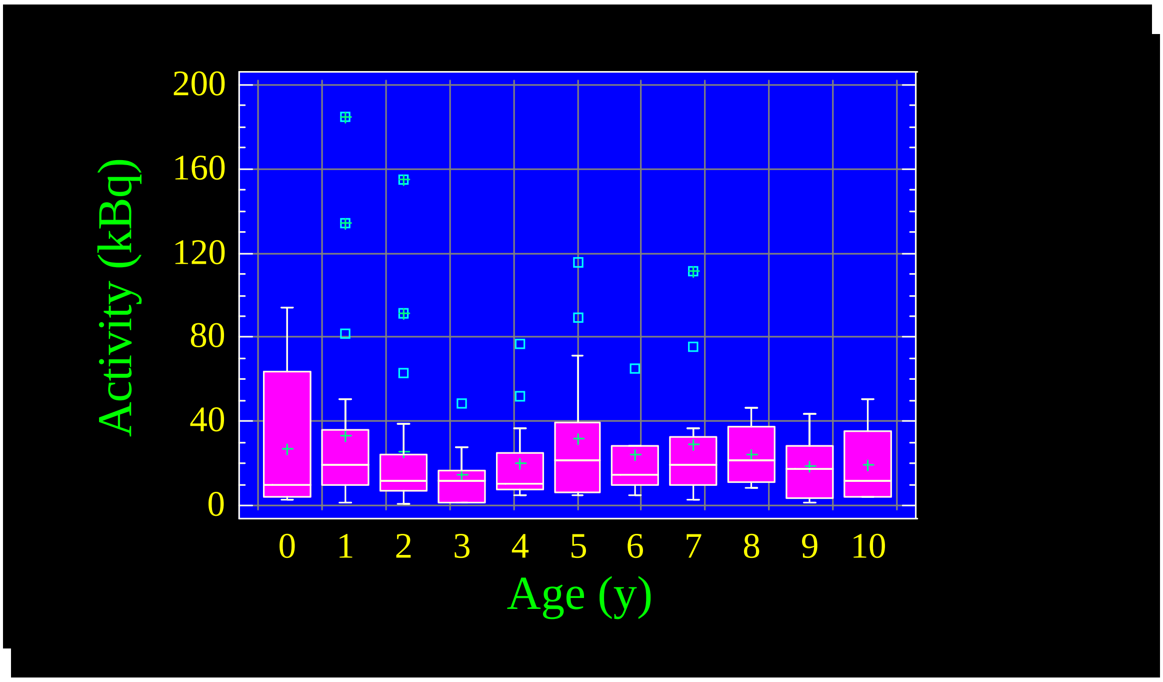

Figure 1. The box-and-whisker plots of ^{131}I activity in the thyroid of children from the Bryansk Region measured in Leningrad (St.Petersburg) from May 17 to June 15, 1986. Measurement data are reduced to May 22. The bottom and top of each box represents 25% and 75% of the data. The line through the middle is the median, while the plus signs indicate the sample mean. The points outside whiskers (small squares)are those which lie more than 1.5 times the interquartile range.

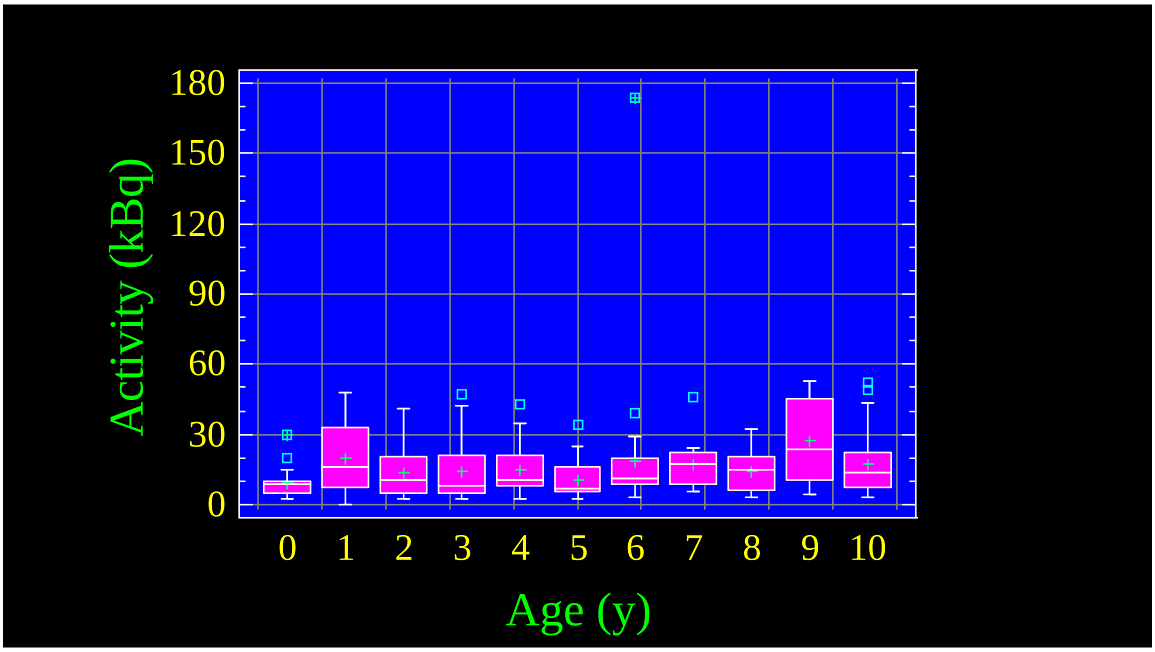

Figure 2. The box-and-whisker plots of measured activity of ^{131}I in the thyroid of children in Mirny (Bryansk Region), May 22, 1986. See Figure 1 for details.

Individual dosimetry of the whole body exposure to radiation

Although radiation exposure of whole body due to incorporated radiocesium and environmental contamination is persisting for long term, about a half of dose to whole body from Chernobyl accident accumulated up to now was realized in the Bryansk Region at the first year after the accident. Therefore, the measurement data for the first months after the accident are of primary importance.

A radiometric examination of the population to determine the body content of cesium radionuclides (^{134}Cs and ^{137}Cs) was undertaken in 1986 by RIRH in the western districts of the Bryansk Region (6). More than 90 thousand people were examined during the first year after the Chernobyl accident. The most intensive examination was carried out during one month between 18 August and 18 September 1986. At that time 78333 inhabitants of the strict control zone were measured by means of portable radiometer SRP-68-01, among them 13985 children 0-10 years old.

An example of measurement data is shown in Figure 3 for the settlement Vyshkov (^{137}Cs contamination level of 0.99 MBq m^{-2}), where 352 children under 10 y were examined from August 25 to September 10, 1986. The wide variation of ^{134,137}Cs body burden for children of the same age are resulted from individual differences in dietary habits including violation of diet by countermeasures, as well as from uneven environmental factors, i.e. the same reasons that were considered applying to ^{131}I in the thyroid in Figure 2. Besides, the rise of mean values of radiocesium body burden with increasing age is obsedrved. It might be explained by the fact that the predominant fraction of radionuclides intake via foods occurred in May-June 1986 and then the daily intake sharply decreased due to natural and social factors: a natural decontamination of plant cover during the first vegetation season after the accident, agrotechnical measures directed to the reduction of cesium intake by agricultural food products, and especially actions to exclude from the human diet foodstuffs contaminated above the regulated permissible levels. Radiocesium in the body accumulated with the predominant early intake was appreciably excreted to August-September 1986. Excretion rate of cesium is essentially age dependent. Half-time of cesium in the body decreases from 50 days for 10 y children to 13 days for 1 y infant (7). Therefore, the content of ^{134,137}Cs in the body of younger children decreased more rapidly. Far outside points at the top of Figure 3 seem to be not related to instrumental errors but to dietary habits. Questionnaire data evidence that even several months after the accident some people, including children did not obey the restrictions established regarding the consumption of contaminated foodstuffs. Moreover, while the average daily consumption of fresh cow's milk by children in this region is 0.7 L, some persons consumed this main contributor of radionuclides into daily food ration more than 2 L per day.

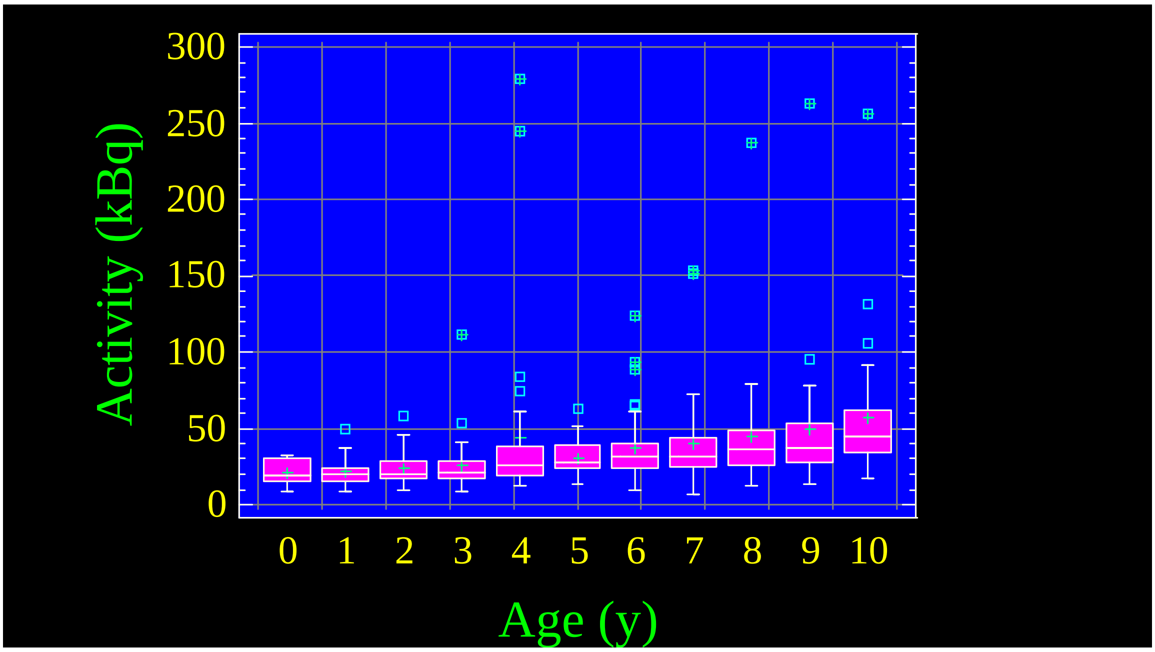

Figure 3. The box-and-whisker plots of radiocesium content in the body of children in Vyshkov (Bryansk Region), August 25-September 10, 1986. See Figure 1 for details.

In view of wide variation of measurement data we should realize a high degree of uncertainty in application of some mean value to particulate person, even in the case if the mean value is averaged for a settlement and age group corresponding to the person under consideration.

Restrictions in consumption of contaminated food averted essential fraction of the projected ingestion dose and resulted in predominant contribution of external radiation into the total effective dose to the whole body. Over 5 thousand individual measurements of exposure to external gamma radiation were made by thermoluminescence dosimeters in the strict control zone and in some settlements in adjacent territory, mainly in the years 1987-1994. Exposure to gamma radiation at the first days and months after the accident was reconstructed by analysis of data on dose rates on the contaminated territory and data on radionuclide composition of Chernobyl fallouts. The personal external dose is dependent upon occupational activity with those individuals who spend more time outdoors receiving higher dose (8). The variation of individual external dose among residents of a single settlements including children is not so wide as for internal contamination with radionuclides, and a personal dose deviates by a factor of not more than 2 from the averaged value for the settlement.

CALCULATION OF THYROID DOSE

Internal dose to the thyroid from ^{131}I a product of age-dependent dose factor to the time integral of radionuclide activity incorporated in the thyroid. There is an inevitable uncertainty in calculation of the individual thyroid dose from a single measurement at some time point, because we have to know the dynamics of ^{131}I intake before and after a measurement. To generalize the uncertainty in dose-activity factor, an analytical research was carried out to obtain a range of uncertainty in the case when the measured ^{131}I activity in the thyroid, the date of measurement and the age of examined person is known. Three modes of intake of ^{131}I into human organism are considered: inhalation, consumption of green vegetables and consumption of milk. One-exponent model of ^{131}I concentration in greens after their surface contamination and two-exponent model of ^{131}I concentration in cow's milk following deposition of radionuclide on pasture are considered with the wide variation of numerical values of parameters derived from published data and revues (9,10). A single contamination of air and deposition of ^{131}I on the territory is considered, as well as continuous contamination and deposition of radionuclide. For different combinations of intake modes, models and parameters, as well as taking account for the effect of countermeasures (e.g. discontinuation of consumption of contaminated food or iodine prophylaxis), the ratio between absorbed dose in the thyroid and the unit of ^{131}I activity in the thyroid (dose/activity factor) is calculated as a function of age of human subject and the time of measurement after the start of contamination.

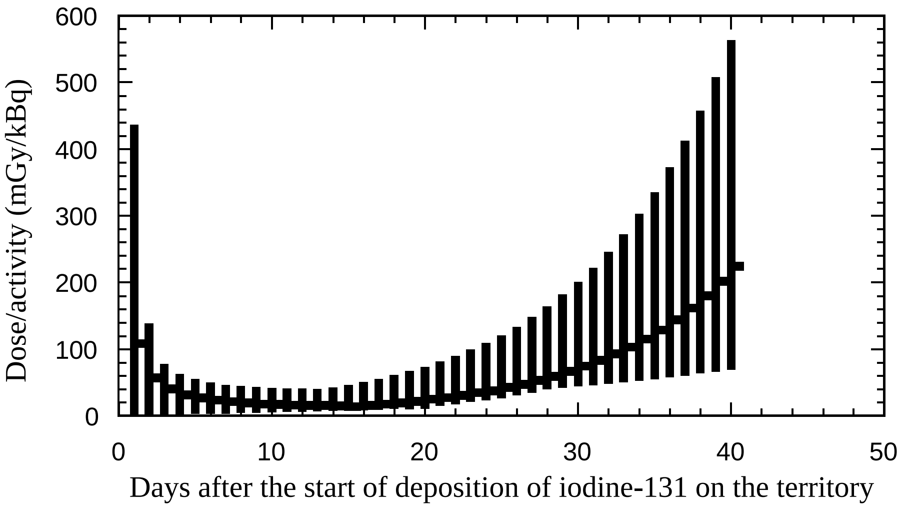

Figure 4. Ratio of absorbed thyroid dose to the measured ^{131}I content in the thyroid of 3 year old infant

The details of this analytical research will be published elsewhere. The results of calculations are shown in Figure 4 applying to a 3 y infant. The columns presented for each day of measurement extend from the lowest to highest value of dose/activity factor ($d_{a,t}$). The height of columns represent uncertainty in dose calculation. This uncertainty varies with day of measurement (t) counted from the date when deposition of ^{131}I on the territory was started. It is the lowest at t=11-15 days and increases at the earlier and later measurements. If we suggest that the dose/activity factor is a geometric mean between minimum and maximum $d_{a,t}$, the calculated individual thyroid dose deviates from the actual personal dose by a factor of not more than 2 at t=5-30 days and this deviation increases to a factor of 3 for t=43 days.

Two comments should be noted concerning the data shown in Figure 4. The first one is that the uncertainty in dose/activity factor decreases with increasing age, i.e. it is relatively higher for younger children and the lowest for adults. The second, the most important is that the calculated wide range of d_t in Figure 4 is related to the case when we have no information besides the value of ^{131}I in the thyroid, date of measurement and age of examinee. The uncertainty might be essentially reduced when information is available about environmental factors (e.g. time course of radioactive fallout and/or concentration of ^{131}I in cow's milk and green vegetables) and individual characteristics (dietary behaviour after the accident, iodine prophylaxis).

For those persons who were not examined by direct measurement of ^{131}I in the thyroid, the methods of thyroid dose reconstruction were developed using data on individual consumption of locally produced milk and on the early measurements of radiocesium contents in the body (11). Due to results obtained from a limited set of direct measurements of ^{131}I in the thyroid and questioning examined persons about consumption of locally produced milk, a correlation was found between thyroid dose and the daily intake of milk from private farms. A linear relationship between thyroid dose and mean ^{131}I concentration in milk was assumed in evaluating the average dose for a settlement and age group, and then the individual dose is assessed from the average dose in specific age group and the ratio between individual rate of milk consumption and the average daily consumption of milk. To employ this method, information on individual dietary behaviour after the accident is needed including date of the discontinuation of milk consumption.

Another correlation was found between thyroid dose and radiocesium content in the body measured later, e.g. in August-September 1986, at least for children over 3 y and adults, who essentially ceased the consumption of local produce in May 1986 and kept this restriction during the summer.

Methods of thyroid dose reconstruction in the absence of direct measurement data were employed in 1987 for distribution of population of the Bryansk Region to the medical examination groups, because thyroid dose as well as the total body dose were among the criteria to assign individuals to a certain category of health service for the people affected by the Chernobyl accident. The distribution of thyroid dose was derived for children 0-14 y at the time of the accident, i.e. born between 1971and 1986. (Subdivision up to 14 y is defined by Russian health statistics with regard to children's age). The distribution was characterized by the following statistical parameters for 16881 children who were residing in the strict control zone (with ^{137}Cs contamination over 0.55 MBq m^{-2}): mean dose 0.34 Gy, median value 0.18 Gy, 5th and 95th sample percentiles 0.04 Gy and 1.1 Gy respectively (12).

SELECTION OF COHORT MEMBERS

Selection of the cohort consisted mainly of two procedures:

- identification of those subjects who were examined both in the Chernobyl Sasakawa Project (CSP) in 1991-1996 and in RIRH studies in 1986 and
- systemization and analysis of available information on radiometric and questionnaire data that may prove useful for individual dose reconstruction.

It should be noted that only a small fraction of children examined in the CSP in 1991-1996 and by RIRH in 1986 are identified as the subjects common for both studies. It is caused by two reasons. At first, CSP examination covered the children residing in the territory with large range of post-Chernobyl radioactive contamination, from ^{137}Cs contamination of w=0.03 MBq m^{-2}, while RIRH monitoring in 1986 was focused mainly on the territories with w>15 Ci.km^{-2} (0.55 kBq m^{-2}) assigned to so called "Strict Control Zone" where radiation protection measures were seemed to be most justified. E.g., about half of examinees in CSP were residents of Klincy-city (w=0.15 KBq m^{-2}) that was not under RIRH investigation in 1986. The second, there is a problem of assured personal identification of subjects in the early RIRH measurements because of some incompleteness and/or incorrectness of the records in primary working documents (e.g. abbreviated first name and patronymic of examinee, incorrect spelling of family name). This problem was partly solved by procedures of verification of primary information in the process of data input (into computer data bases) and analysis.

Kinds of information analyzed for cohort selection are shown in Figure 5 and considered below.

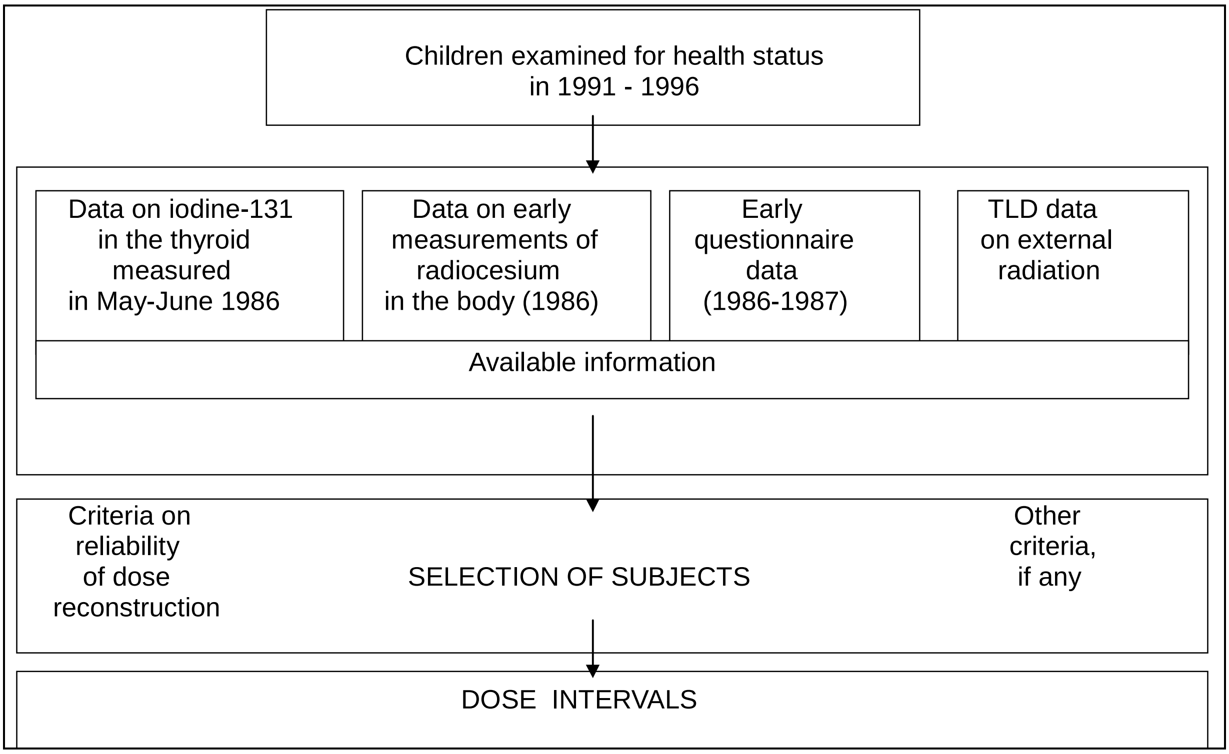

Figure 5.Scheme of selection of cohort subjects on the basis of available data for the reconstruction of individual doses

Individual measurement data are of primary importance for estimates of individual doses. However, only a small percentage of children examined in CSP have direct measurements of radioiodine in the gland made properly and in due time). Moreover, there is a large uncertainty in calculation of thyroid dose from measured content of iodine-131 (see Figure 4). To reduce this uncertainty, data or suggestions about dynamics of intake of radioiodine into human body are needed. For people who lived in contaminated area at least a week after the accident, intake via inhalation is supposed to be of minor importance as compared to intake via consumption of locally produced foodstuffs. Therefore questionnaire data on food habits, mainly on consumption of milk in May 1986 are useful both to interpret measurement data and to ascribe dose value to those subjects that were not measured on iodine-131 in the thyroid. During February-April 1987, a survey questionnaire was administered to inhabitants of the Bryansk Region with respect to their life style and diet at the early post-accident period. Questions were asked on consumption of local food products, daily average quantity and sources of consumed milk, date of taking advice to stop consumption of locally produced milk, dates of temporal relocation in 1986. The questionnaire also contained questions intended to ascertain the individual dose from external gamma radiation: time spent daily outdoors, in wooden houses, stone houses at various seasons of a year.

Data on whole body measurements of $^{134,137}Cs$ serve to verify or support questionnaire information on consumption of contaminated food, to evaluate internal dose to whole body and to derive the contribution of incorporated cesium radionuclides to external dose to the thyroid. For low dose range an account for exposure of the thyroid to external irradiation from the environment and from radiocesium in the body would result in some increase of individual thyroid dose. Furthermore, in interpretation of thyroid dose it should be noted that there are evidences on essentially higher biological effect of external gamma radiation to thyroid as compared to that of internal exposure of the gland from iodine-131. For carcinogenic effect factor of 3 is usually applied (13). After all, taking account for the persistng human exposure to external and internal radiation from long-lived ^{137}Cs , possible health effects from the dose to whole body of cohort subjects should not be neglected contrary to special interest to thyroid diseases.

At the stage of cohort formation criteria on reliability of dose reconstruction include mainly procedures to assess availability and quality of radiation measurements and questionnaire data for particulate subjects as well as radiological, environmental and social data for the settlement of residence and for the population of this settlement.

For the needs of this study, a large massive of primary information on early radiometry and questionnaire examinations of individuals from contaminated areas were searched and analyzed. The primary information included working records on individual dosimetry measurements performed in Leningrad

(St.Petersburg) and in contaminated territory of the Bryansk Region. The individual records were dispersed among various working paper documents, while officially presented documentation was limited mainly by compressed summaries of data for settlements or other units related to averaging results for large samples of people. At the initial period after the Chernobyl accident the main task was evaluation of current radiological situation in the affected territories, a forecast of further exposure to radiation with the aim to justify and optimize protective measures. At the early stage after the accident there was no aim to compile a data bank of individual dosimetry, and many useful records were not organized to meet the needs of our joint project. Therefore, efforts were made to systemize the available archive information on radiometric and questionnaire data that may prove useful for individual dose reconstruction and to input necessary primary records (on paper documents) to the computer data base. Specific software was developed to provide data input and analysis procedures dealing with incorrect and/or incomplete primary records: to verify input into PC data bases, to find duplicate records related to the same subject in a date base, to identify common subjects in the records from various sets of dosimetry and questionnaire examinations, to perform a logical and numerical check of records.

As a result of these procedures and analyses, a cohort of 1210 subjects 0-10 years old at the moment of the accident was selected on the basis of consideration of 424 measurements of ^{131}I in the thyroid, 13985 measurements of radiocesium in the body and 24051 records from questionnaire examinations. In the analysis of questionnaire records, a predominant attention was paid to the data on milk consumption in May 1986. A new questionnaire survey is started to obtain the individual information for those members of cohort who were not questioned at the early period after the accident. Questionnaire format includes fields for information related to subjects identification, their residence, life style, food habits and protective measures in May 1986. It should be noted that the initial number of cohort subjects may decrease in course of a follow-up in view of migration of population.

Estimation of individual thyroid dose was made for cohort subjects. For the subjects who were examined on ^{131}I content in the thyroid, calculation was performed using the most credible assumptions related to the averaged dynamics of radioiodine intake into the human body of children residing in the Bryansk Region after the Chernobyl accident. Corresponding values of dose/activity factor for a 3 year old infant are designated in Figure 4 by pointed curve, i.e. by points at the columns related to days between date of measurement and the date when deposition of radioiodine on the territory started. Correction of dose/activity factor for particulate subjects will be considered after more detailed analysis and verification of individual questionnaire information, both previously obtained and newly derived.

For those subjects who were not examined by direct measurement of ^{131}I in the thyroid, the methods of thyroid dose reconstruction were employed using data on individual consumption of locally produced milk and on the early measurements of radiocesium contents in the body, as it was noted above in this paper. Reconstructed individual dose calculated by these methods may deviate from the actual personal thyroid dose by a factor up to 3. This degree of uncertainty might be considered acceptable for the purposes of epidemiological investigation, where the distribution of cohort subjects among sufficiently wide dose intervals is needed rather than ascribing of precise numerical value of dose to each member of cohort.

Distribution of subjects among the intervals of individual thyroid dose (preliminary estimates) is shown in Figure 6. Laying out the dose intervals was proposed by the Sasakawa Memorial Health Foundation. It should be noted that at the moment the thyroid doses are calculated as caused by internal exposure from incorporated ^{131}I. In further development, contribution of external exposure of thyroid from environmental gamma radiation (above the natural background level) and radiocesium in the body should be taken into account. The further correction of dose estimates is under consideration including some reassessment of models used in dose calculations and more thorough validation of both questionnaire data from 1986-1987 examination and data from retrospective questionnaire study among cohort members that is now in progress. These further developments may result in redistribution of subjects among dose intervals, i.e. some subjects preliminary assigned to any dose interval would be shifted to another interval.

CONCLUSION

As a result of analysis of available radiometry and supplementary data for residents of the western districts of the Bryansk Region in Russia, the initial cohort was composed of 1210 subjects who were 0- 10 years old at the time of the Chernobyl accident. Most of cohort members were examined on their health status in 1991-1996 within the framework of the Chernobyl Sasakawa Project.

Various procedures of individual dose reconstruction were considered and applied to estimates of thyroid dose for the members of the cohort. The preliminary distribution of internal radiation doses to the thyroid among subjects of the cohort is derived. The further stage of dose reconstruction for a cohort study, that is now in progress, consists of reduction of uncertainties in estimates of individual doses by using additional questionnaire information, as well as by taking into account the contribution of external radiation to

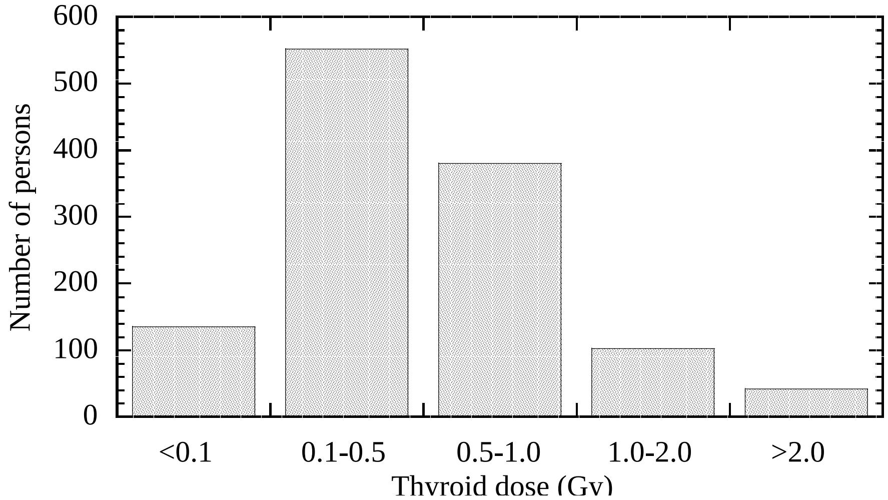

Figure 6. Distribution of selected subjects among the intervals of thyroid dose (preliminary approximation)

thyroid dose and updating analytical procedures to interpret primary data. Finally, the distribution of subjects into several thyroid dose ranges, from <100 mGy to >2 Gy, would be an acceptable approximation for the purposes of radiation epidemiology in a trial to access the radiation risk of developing thyroid diseases and/or other health effects of low radiation doses.

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