EFFECTS OF PRENATAL IRRADIATION ON THE BRAIN AS A RESULT OF THE CHERNOBYL CATASTROPHE (UKRAINE STUDY).

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ABSTRACT

The developing human brain is very sensitive to ionizing radiation. However, the minimal dose level, which induces such pathology, remains to be determined**.** We present research study results of health consequences of the children exposed in utero, who were born just after the Chernobyl accident (between April 26th, 1986 and February 26th, 1987). The children were under investigation for three stages: in 1990-1992; 1994-1996; 2002-2004. Were estimated the data on somatic and psychological health state, IQ level tests against of individual dose reconstruction data.

During the first stage(1990-1992) it was examined 147 five-year-old children exposed in utero and 101 children as a control group. The fetal dose on that period were established within the bounds of 7-13 mSv, thyroid – 0,1-1,2 Sv. The results showed much more somatic diseases and neurovegetative mental disorders. At the same time it was clearly recognized the decrease of immunity (hypo immunoglobulin level and increase of T-lymphocytes, T-helpers). Integral estimation of health showed statistical distinction towards augmentation of chronic diseases. The level of psychological health was significant lower in children who were irradiated in the first trimester of pregnancy(77%), in the second trimester-69% and in third- 45%. It was also established in this cohort that starting with the 0.3 Sv threshold dose thyroid-stimulating hormone (TSH) level grew along with fetal thyroid dose increase. Thereupon the radiation-induced malfunction of the thyroid-pituitary system on this stage was suggested as important biological mechanism in the genesis of health risk assessment and mental disorders of prenatally irradiated children.

At the second stage(1994-1996) the epidemiological WHO project "Brain Damage in Utero" (IPHECA) was implemented. As a result of the WHO IPHECA «Brain Damage in Utero» in Ukraine we examined 544 prenatally irradiated children, 115(21%) of them were evacuated from 30-km zone and 759 children of control group. The examination of prenatally exposed children from the contaminated territories (555 kBk/m2 and more) resulted in increased frequency of moderate mental retardation, emotional and behavioral disorders. Increasing of borderline nervous diseases and psychological disorders of parents from the main group was higher than from the control group. However, it was rather hard to treat these results because individual dosimetric data were not available.

At the third stage (2002-2004) it was examined a cohort of 154 children born between April 26th 1986 and February 26th 1987 to mothers who had been evacuated from Chernobyl exclusion zone to Kiev and 143 classmates from Kiev. In the third stage reconstruction of individual doses of children born to mothers evacuated from the Chernobyl exclusion zone was carried out at taking internal and external exposure. It was established that fetal dose (M±SD) was 65.4±33.9 mSv for the exposed group and 1.2±0.3 mSv – for the control consisted of Kiev residents. Prenatal brain doses were 19.2±11.3 mSv and 0.8±0.2 mSv for the exposed group and control group, respectively. Thyroid doses *in utero* were 760.4±631.8.1 mSv and 44.5±43.3 mSv for the exposed group and control group, correspondingly. The children with whole body prenatal dose more than 100 mSv made up 13,2% and those having thyroid exposure dose *in utero* more than 1 Sv – 33,8%.

It is worth mentioning that the frequency of somatic, neuropsychiatric and thyroid diseases was increasing in all the stages of the study. The third stage clearly demonstrates that the prenatally exposed children had significantly more nervous diseases and mental disorders in compliance

with ICD-10. Children and their mothers were also examined with special psychological tests (WISC, the Achenbach and Rutter A(2), WAIS, SDS, PTSD, GHQ-28 and others). Was revealed significant differences in intelligence, emotional and behavioral disorders of exposed children comparing to the control. The exposed children showed decreasing full-scale IQ along with decreasing verbal IQ. Although the frequency of performance/verbal intelligence discrepancies increased. Intelligence of the acutely prenatally irradiated children is deteriorated due to reduction of full scale and verbal IQ, as well as WISC performance/verbal discrepancies, with verbal decrements. In spite of the children's intelligence is multifactorial, the contribution of prenatal irradiation was revealed. This study suggested that prenatal exposure to ionizing radiation at fetal dose 11–92 mSv and thyroid fetal dose 0.2–2 Gy could result in detectable brain damage, especially if exposure occurred at 16–25 weeks after fertilization. No mental retardation was revealed. The mothers showed no differences of verbal abilities, but evacuated mothers had experienced much more real stress events. So they demonstrated more depression, PTSD, somatoform disorders, anxiety/insomnia, and social dysfunction.
Thus the neuromental health of the acutely prenatally irradiated children at the Chernobyl exclusion zone is deteriorated in comparison with the non-evacuee children living in Kiev. Obviously, their neuromental health disorders are etiologically heterogeneous including psycho-social and economic factors, medical problems in their families.
Overall, with regard to radiological protection, the results obtained through the clinical and psychological work show that during the period of development of cortical structures the brain is highly sensitive to radiation. Deterministic effects prevail during the initial phase of damage which may subsequently be modified by compensation within the brain trough team teaching. The results of this investigation consider the necessary of large-scale epidemiological cohorts analysis for elucidation health risk assessment for people acute and chronic irradiated during prenatally development after Chernobyl accident.
Keywords: Chernobyl accident, brain damage in utero, dosimetry, psychometry, neurophsychiatric and psychological disorders.

INTRODUCTION

Considerable progress has been made in the last years concerning knowledge and understanding of the effects of ionizing radiation on the developing brain. Epidemiological studies on individuals who survived the atomic bombing of Hiroshima and Nagasaki and were exposed *in utero* confirm the vulnerability of the developing fetal brain to radiation injury. Severe mental retardation, lowering of intelligence quotient (IQ) and worsening of school performance, as well as occurrence of microcephalia and seizures, especially after exposure at 8–15 and 16–25 weeks after fertilization were measured (Otake & Schull 1984, 1998; ICRP Publication 49 1986; Schull & Otake 1999; Schull et al 1988). A reanalysis of the dosimetry data indicated that the dose threshold for the development of mental retardation after intrauterine irradiation at gestation terms of 8–15 weeks is 0.06–0.31 Gy. At the gestation term of 16–25 weeks, it is 0.28–0.87 Gy (Otake et al 1996).

Extrapolation of the Japanese data to the situation after the Chernobyl accident is difficult, however. Thus, the Chernobyl accident caused significantly lower fetal doses, but high doses on the fetal thyroid by the incorporation of radioiodine released by the burning reactor. Whereas after the Chernobyl accident the population was continuously exposed to radionuclides, mainly ^{137}Cs, the Japanese population was acutely irradiated by γ-rays and neutrons. There was no separate ^{131}I exposure of the thyroid in Japan. The doses to the fetal thyroid after the Chernobyl accident are partly considerably higher than the threshold doses established by Otake for mental retardation. Because of the different radiobiological situations, it is not easy to predict the radiobiological effect of the Chernobyl accident from results of the Japanese studies.

The present study was designed as the continuation of the WHO Pilot Project «Brain Damage *in Utero*» of the International Program on the Health Effects of the Chernobyl Accident (IPHECA). Preliminary analysis of the results in the three affected countries has shown a tendency to mild mental retardation and some behavioral disorders in the prenatally exposed children in comparison to a control group, and prevalence of borderline nervous and psychological disorders in the parents (Souchkevitch & Tsyb (Eds) 1996; Nyagu et al 1996, 1998; Kozlova et al 1999). The definition of an exposed and unexposed child was based only on the contamination level of the soil of the rayons of residence, without reference to individual doses.
Recently related studies have been published concerning the mental health of *in utero* exposed children after the Chernobyl accident. The authors investigated *in utero* exposed children in Belarus (Igumnov 1996, Kolominsky et al 1999) and in the Ukraine (Bromet et al 2000, Litcher et al 2000). The exposed children in Belarus manifest a relative increase in psychological impairment and a lower IQ in comparison to the control children, but these effects could not be related to the received fetal thyroid doses. The Ukrainian exposed children show only non significant differences in the applied tests in comparison to the control group. It was for both countries concluded that unfavorable psychosocial factors, such as broken social contacts, adaptation difficulties and relocation explained the differences between the exposed and non-exposed groups.

Another study from Belarus reported a reduction of intelligence by thyroid doses exceeding 0.5 Sv for children exposed *in utero* and until the age of 1.5 years (Bazyltchik et al 2001). Also Igumnov and Drozdovich (2000) found a reduction of the IQ in highly *in utero* exposed children. Other studies on prenatally irradiated children demonstrate a possible correlation between radiation and psychosocial factors (Gayduk et al 1994; Ermolina et al 1996, Nyagu et al 2002), or radiation exposure and the level of thyroid-stimulating hormone (TSH) (Nyagu et al 1993, 1998).

On account of the contradictory results of the mental health assessments of the *in utero* exposed children and the etiology of the observed neuropsychiatric disorders in the literature a thorough study of the potential radiation effects on the mental health of the *in utero* exposed children was performed within the framework of the Project 3 «Health Effects on the Chernobyl Accident» of the French-German Initiative for Chernobyl. The reconstruction of individual doses for the prenatally irradiated children and the comparison group was one of the main parts of the work. The fact, that in this study only a cohort of *in utero* exposed children were investigated, whose mothers had been evacuated from Pripyat – the city which is totally uninhabitable – make this cohort more comparable to studies on Japanese victims, because it suffered rather more of an acute exposure when compared to children who live permanently on contaminated territories.
To summarize, although much h as been learned about the effects of prenatal exposure to ionizing radiation on the developing human embryo and fetus, even more remains to be learned. Studies that attempt to disclose the cellular and molecular mechanisms associated with this damage are important not only for the insights they could provide on the hazards of ionizing radiation, but for the contributions they could make to a fuller understanding of normal developmental processes

MATERIALS AND METHODS

DOSIMETRY

Individual reconstruction of total fetal doses, fetal thyroid doses and fetal doses on the brain has been carried out using 2 methods: 1) fetal thyroid dose is assumed to be equal to the thyroid dose of the mother, and 2) according to the model by ICRP Publication 88 (2001). The doses were reconstructed for the exposed children from Pripyat and also for the control group in Kiev.

The main irradiation sources of the pregnant women were: 1) external γ-irradiation of the whole body; 2) irradiation of thyroid by radioactive iodine isotopes; 3) internal irradiation by inhaled radionuclides; 4) internal irradiation by ingestion of radioactively contaminated food.

The estimation of individual doses was carried out by the methods of retrospective dosimetry, which is based on measurements of the gamma dose rate (DR) in the settlements, direct measurements of radioactive iodine content in 10,000 evacuees and ^{137}Cs deposition density at the place of intermediate evacuation (Likhtarev et al 1994, Repin 1996). The doses depended on the settlement, the exact location of the living quarters there, the date and route of evacuation (analysis of 30,000 «route sheets»), and the places of intermediate and final evacuation.

Before the ICRP Publication 88 (2001) there were no internationally accepted models for calculation of the fetal thyroid dose, which can vary by a factor of 1 to 10 of the mother's thyroid dose. If the coefficient of transplacentar transfer of iodine is 1 and iodine concentrations in maternal and fetal tissues are equal, then maternal and fetal thyroid doses are equal and independent of not depending on the prenatal age (Nyagu et al 2002).

In the first method of calculation, the reconstruction of fetal doses was based on the calculation of the doses to the pregnant women. The fetal thyroid dose is supposed to be equivalent to the mother's thyroid dose. The shielding properties of mother's body were taken into account when calculating the external dose. The influencing factors of buildings in towns were assumed to be 10, in rural settlements 3. The behavioral factor for pregnant women was taken to be 0.4 in cases of absence of questionnaire data (Repin 1996).
The total external dose on the whole fetus was assumed to be equal to the dose of the pregnant woman. A tissue-equivalent human phantom was exposed to real Chernobyl fall-outs in order to calculate the dose on the fetal brain. At the places of fetal organs in the phantom LiF detectors with a sensitivity of 0.01 mSv were disposed. The transfer coefficient from DR to equivalent dose on the fetal brain ($K_{braindose} = 5.7 \cdot 10^{-3}$ Sv•R^{-1}) was thus experimentally obtained and does not depend on the prenatal age due to shielding of the fetal head by mother's pelvic bones (Repin et al 1996). Finally, the dose on the fetal brain was calculated as the total dose of mother's external irradiation multiplied by $K_{braindose}$.

In the earliest period after the Chernobyl accident (April 26th till June, 1986) internal irradiation by radioactive iodine accounted for the greatest dose fraction of the population. Radioiodine transfer from pregnant woman to fetus is rapid. The rate of transfer increases by a hundred times with the increasing term of pregnancy (Instruction of the Ministry of Public Health of the USSR, 1986).

Fetal thyroid doses were calculated on the basis of direct measurements of radioiodine contents in the thyroid of the adult population taking into account age and correction factors, the ratio of radioactive iodine isotopes released from the reactor, wind speed and direction. The mean standardized thyroid dose of the adult population of Pripyat was calculated as 0.605 Gy (Repin 1996). The protective effect of stable iodine was estimated to be 0.75.

Dose calculation after the model of ICRP Publication 88

The assessment of the whole radiation dose of pregnant women from all dose-forming factors and the methods for calculation of the dose on the embryo and fetus by external and internal exposure of the pregnant woman are presented. The scheme of dosimetric reconstruction is shown in Figure 1.

Shielding by the mothers body was taken into account for assessment of the brain dose of the embryo or fetus by external exposure of the mother. For assessment of the brain dose by maternal inhalation of radionuclides coefficients from ICRP Publication 88 (2001) were used. Internal doses of the mother by incorporation of radionuclides were assessed by expert judgment, since there is no satisfactory information either from questionnaires or from any other sources. The nutritional habits of the cohort members cannot be fully reconstructed from questionnaire information.

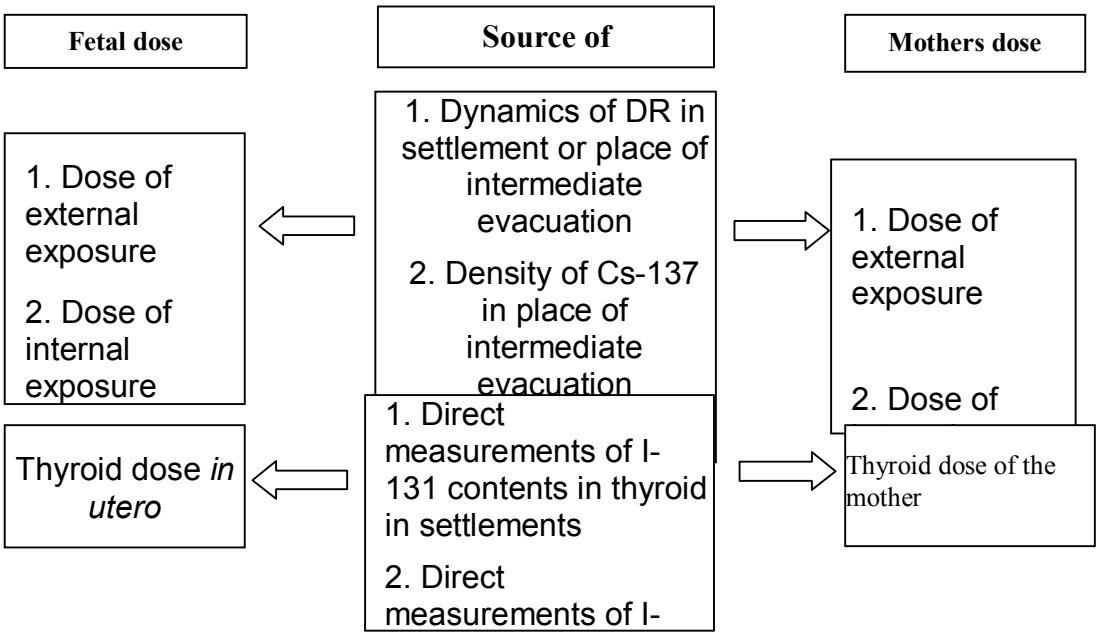

Fig 1. The scheme of dosimetric reconstruction

Effective fetal dose

Calculation of fetal doses was carried out on the basis of the dosimetric history of the mother according to our questionnaire, elaborated for the aims of the study (Table 1). The questionnaire contains additional information for calculation of the coefficient of the behavioral regime of the mother (if the mother could remember this information).

Table 1. Example of a questionnaire with the dosimetric history of a mother

Surname, Name and Patronymic name of a child	*P. Ye. V.*	Dose, mSv
Surname, Name and Patronymic name of a mother	*P. N. S.*	
Date of birth of a child(mm/dd/yy)	*06.06.86*	
Gestation time at the moment of the accident (weeks)	*34*	
Home address in Pripyat	*Lesi Ukrainki Street*	
Data and time of evacuation	*04.27.84*	
Time since April 26th 1986 (at 1 AM) until evacuation	*47*	35.84

(hours)		
The evacuation route (route code)	*Special (5)*	12
Additional dose	*Tolsty Les_ 8 days*	108.98

Information from the questionnaire allows the calculation of the most probable individual doses of external exposure of the evacuated pregnant women, the dose to the embryo and fetus and the brain *in utero*. Contamination of the 30-km zone and particularly Pripyat is very non-uniform and this is the reason for taking the place of residence for calculation of external exposure doses in Pripyat into consideration. The map of Pripyat with sectors related to actually measured DR was therefore necessary during the interviewing of the mothers. A copy of this map is shown in Figure 2.

The DR per hour from the accident until evacuation is shown for the different sectors of Pripyat in figure 2.. For other settlements of the 30-km zone the actual DR of the settlement was used taking into account the migration behavior of the inhabitants around the settlement (Likhtarev et al 1994).

An overview of the levels of external exposure is presented in Figure 2. The distribution of the settlements of the 30-km zone by total external exposure doses in air from the accident until evacuation of the inhabitants is shown.

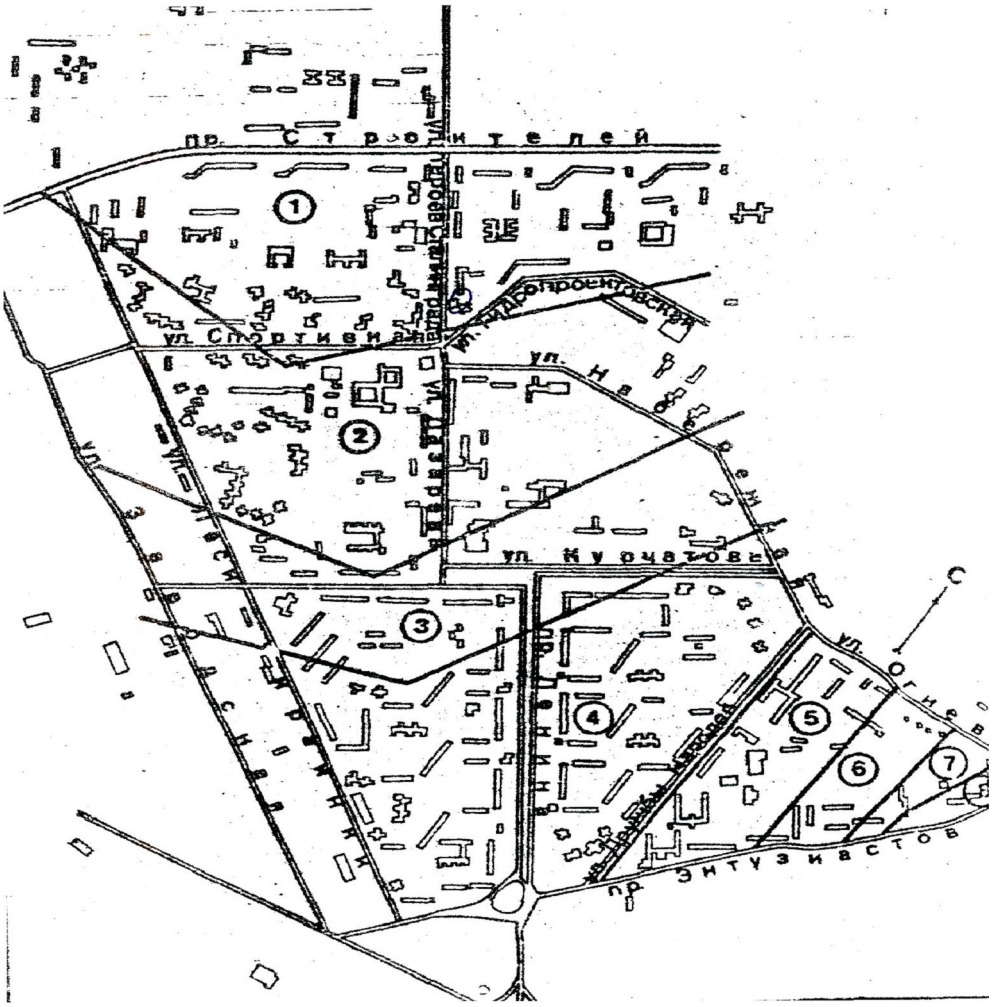

Fig.2. The map of Pripyat with sectors related to actually measured gamma dose rate (DR)

The external dose of a pregnant woman is composed of the dose received in the place of permanent residence, from the time of the accident until evacuation, the dose at the evacuation route and the additional dose received in the places of intermediate evacuation.

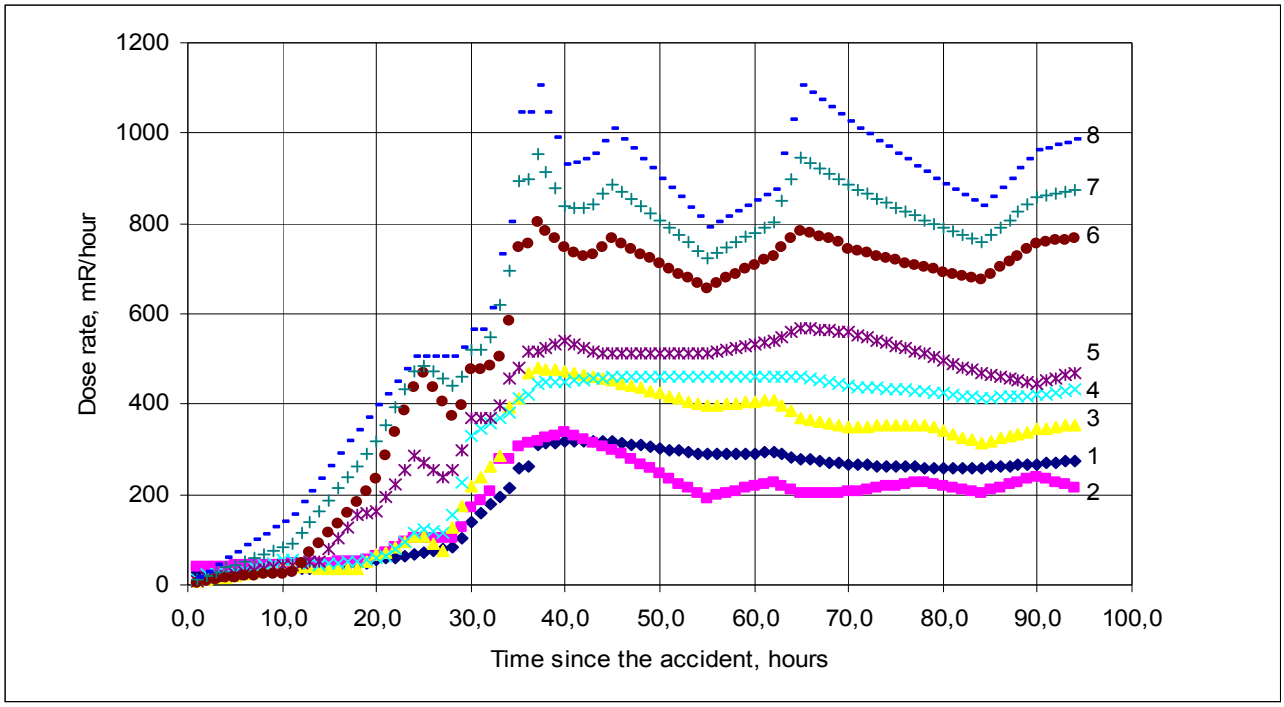

Fig. 3. DR dynamics per hour from the time of the accident untill evacuationin different sectors of Pripyat (Chumak & Korobejnikov 1991)

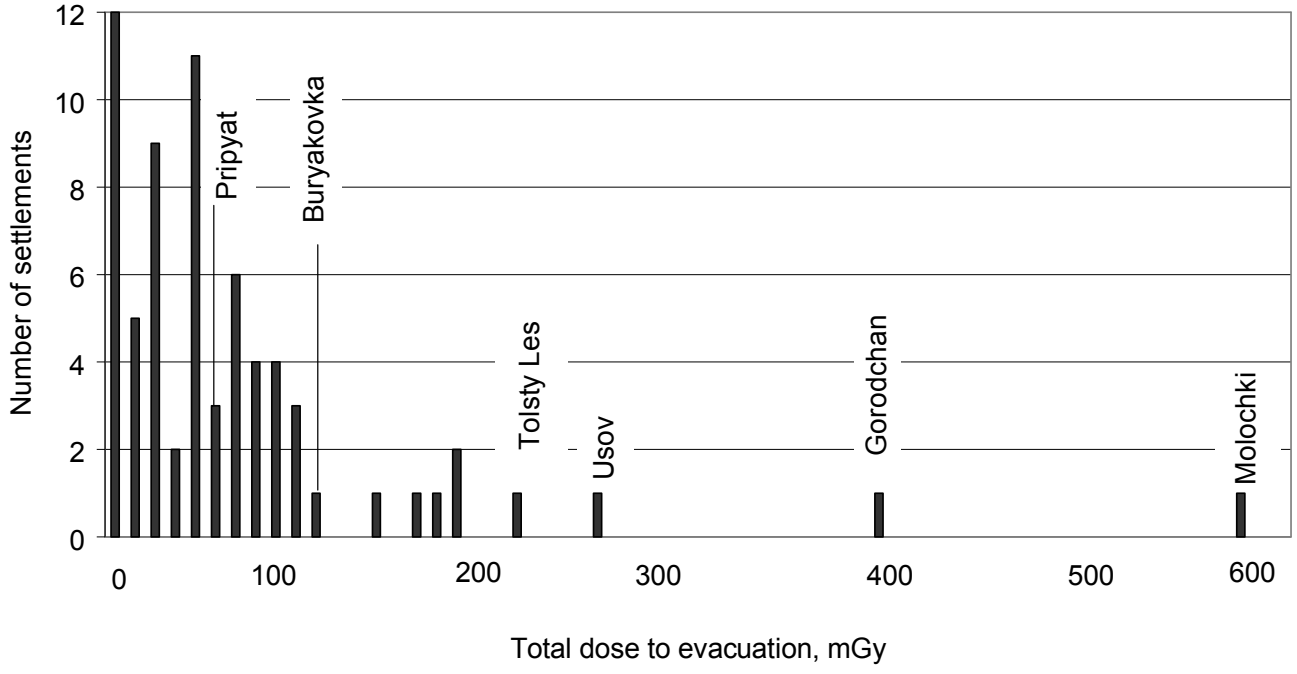

Fig .4 Distribution of the settlements of the 30-km zone on total dose of external exposure in air from the time of the accident until evacuation

The dose of external γ-irradiation D_γ, accumulated in the time t in some points of open area is associated with DR in the following way:

$$D_\gamma = K_d \cdot K_R \cdot \int_0^t P_\gamma(t)dt \tag{1}$$

where K_d — conversion factor of exposure dose towards effective dose;
K_R — behavioral factor, characterizing the fraction of time spent outdoors and building protective properties
P_γ — dose rate (DR)

A general procedure of calculating the external dose is described below:

$$D_\gamma = \sum_i \left[\sum_n P_i(t_n)\Delta t_n + K_p \cdot \sum_m P_i(t_m)\Delta t_m \right] = D_o + K_p \cdot D_b \tag{2}$$

where t_n and t_m is a fixed time for DR measurement;
D_o and D_b are dose values, accumulated in open air at point i during the time outdoors and inside buildings;
K_p is the protection factor of buildings and equals the ratio of DR values inside and outdoors.
The results of such dose reconstruction are presented in detail in papers from the SCRM, Kiev (Likhtarev et al 1994, Repin 1996). In the present study we interviewed the mothers with a questionnaire but also used the average data by Repin (1996) for the amount of time spent outdoors for women of fertile age, since there are in some cases contradictory answers in the questionnaire, the behavioral factor for a pregnant women was then assumed to be 0.4.

For calculation of the external exposure dose the type of settlement was taken into account. Thus the protection factor of buildings for urban settlements was assumed to be 10, for rural settlements 3.
According to Repin (1996) the doses received at evacuation routes are 0.42–19 mSv. For example, evacuation on the Polessky route (used for more than 40% of the evacuated population) contributed 11 mSv, the Kiev route (27% of evacuees) contributed 16 mSv, the Belorussian route contributed 19 mSv and the Chernigov route contributed 0.42 mSv, where all quoted contributions are to the integral dose. If mothers had been evacuated on other routes, the available data about DR on these special routes were used. In the case of ineffective interviewing the dose on that evacuation route was assumed to be 12 mSv (uncertain route). There were 6 official routes.
Two methods were used for assessment of the external exposure dose at the places of intermediate evacuation depending on availability of dosimetric information of DR in a settlement.
The first method is based on the data of DR measurements in a settlement shortly after the accident (as a rule in settlements of the 30-km zone).

The second method for calculation of external exposure doses was used for places of intermediate evacuation outside the 30-km zone. In these places, as a rule, no DR measurements over time have been carried out. The external exposure dose was then calculated using the DR dynamics which are dependent on ^{137}Cs deposition.

The mathematical description of the model for the second method is:

$$P_\gamma(t) = \begin{cases} 1030 \cdot t^{-0.7} & when \quad t \geq 5\ days \\ 67 \cdot t & when \quad t < 5\ days \end{cases} \qquad (3)$$

where $P_y(t)$ is the ^{137}Cs DR in its dependence on time and activity per unit area (μR/h)/(Ci/km^2), and t is the time since the accident (days).
The total effective dose to the embryo and fetus was assumed to be equal to the dose to the pregnant woman, calculated according the equations (1–3).

Calculations of doses of external exposure for pregnant women living in Kiev and fetal doses were done by applying the following equation:

$$P_\gamma(t) = \begin{cases} 1,1\ mR \cdot h^{-1} & t \geq 15\ days \\ 0,85 \cdot t^{-0,87} & t < 15\ days \end{cases} \qquad (4)$$

where t is the number of days since the accident and$_\gamma$(t) is the since the accident and P_γ(t) is the gamma dose rate, mR/h.

Equivalent prenatal brain dose

A number of phantom assays with tissue-equivalent human phantoms exposed to actual Chernobyl fallout have been performed for the calculation of the potential dose to the fetal brain. The brain dose is calculated by $D_{brain} = D_\gamma / K_d * K_{braindose}$(5). D_γ is the dose of external γ-irradiation accumulated by a pregnant women in the place of residence, on evacuation routes and in places of intermediated evacuation; K_{braind} is the dose coefficient of transition from DR in air to equivalent dose on the fetal brain; K_d is the dose coefficient of conversion from exposure dose to effective dose.

Equivalent fetal thyroid dose

The results of direct measurements of radioiodine content in the thyroid of adults from Pripyat and the 30-km zone form the basis for the calculation of the fetal thyroid dose.
There are 9,6250 available measurements on children and 1,065 measurements of adult thyroid glands from the 30-km zone. Additionally 64 children and adults from Pripyat who had been evacuated to Leningrad and examined in Military Medical Academy were measured. Dose calculations for the thyroid of adults after single intake were calculated using equation 6:

$$D_{th} = d(\theta) \cdot C(\tau, t) Q(t) \qquad (6)$$

D_{th} is the accumulated dose from intake till complete disintegration of radioactive iodine (cGy);
$Q(t)$ is the amount of radioiodine in the thyroid at the moment of measurement (μCi);
$d(\theta)$ is the age-related dose coefficient for dose calculation from the moment of measurement (cGy/μCi); $C(\tau,t)$ is the correction coefficient for calculation of total dose from the beginning of intake. The coefficient $C(\tau,t)$ takes into account clearance and disintegration of iodine from intake until the measurement of its activity in the thyroid. The coefficient was calculated for each single person.

The rate of release of iodine isotopes from the destroyed reactor as well as changes of wind direction and speed were taken into account for calculation of the adult thyroid dose. This resulted in different severity of iodine attack on different sectors of the zone. The 30 km zone is divided into 12 sectors which go radially from the center (Chernobyl) at an angle of 30^o. Table 2.2 shows calculated thyroid doses for adults in dependence on the day of evacuation.

Table 2. Average thyroid doses of adults from settlements and sectors of the 30-km zone depending on the date of evacuation

Date of evacuation	Settlement (sector)	Adults	
		Dose (mGy)	*>2 Gy (%)*
27.04.86	Pripyat	799	6.6
03.05.86	(1, 2, 3)	545	—
03.05.86	(6, 7, 8)	615	3.8
05.05.86	Chernobyl (2)	509	—
07.05.86	(1, 2)	792	8.3

Due to a significant variability of the sample sizes in different sectors - there are only single or no measurements in the 1st, 9th and 11th sectors – an average standardized thyroid dose for an adult is used for assessment of the thyroid dose *in utero*. The results of direct measurement of thyroid dose of inhabitants of Pripyat and the 30-km zone are integrated (Repin 1996). In our calculation the average standardized thyroid dose for the adult population of Pripyat was assumed to be 605 mGy before evacuation (geometric deviation 308). Protection factor by intake of stable iodine is 0.75 (for a single intake on the first day of the accident) and was taken into account for calculation of the thyroid doses for evacuees (mothers).

According to the ICRP 88 model the *in utero* thyroid dose is calculated considering the internal intake of I-131 of the pregnant woman. Basically the internal intake was through inhalation. The inhalation model has the assumption that inhalation intake of I-131 before evacuation is in proportion to average-standardized thyroid dose for inhabitants of Pripyat received before evacuation (605 mGy) without intake of stabile iodine (Repin 1996).

The parameter of the model of inhalation intake in pregnant woman presented in ICRP Publication 88 differs from the model of inhalation intake presented in ICRP Publication 66 by the referent parameters of intake. Mean ventilation rate documented in ICRP 88 is 0.737 m^3/ h for female members of the public during pregnancy and in ICRP 66 it is 0.926 m^3/h. The gamma dose rate, mR/h.

The details of radionuclide intake of pregnant woman found in ICRP 88 were taken into consideration in our calculations.

The reference gestation terms for calculation of dose coefficients after the model of ICRP Publication 88 for acute intake have the following range (Table .3):

Table 3 Reference gestation terms accepted for calculation of dose coefficients for acute intake (ICRP Publication 88)

Conception	0 to 2 weeks
5 weeks	> 2 to 8 weeks
10 weeks	> 8 to 12 weeks
15 weeks	> 12 to 20 weeks
25 weeks	> 20 to 30 weeks
35 weeks	>30 weeks to birth

The calculated thyroid doses according to direct measurement of radioactive iodine in the thyroid of inhabitants from Kiev are shown In Table .4.

Table 4 Mean thyroid doses (mGy) for adults in 6 sectors of Kiev (Likhtarev et al 1995)

Mean age (years)	Age group at the accident (years)	Dose in mGy in Kiev sectors						
		1	2	3	4	5	6	Mean
17	16- 18	37	37	41	47	62	62	47.7
44	> 18	31	32	35	40	52	53	40.5

Further details of the dose calculations for the exposed mothers from Pripyat and the unexposed mothers from Kiev and the children *in utero* from both groups are presented in Annex 2.

PRENATAL AGE AT EXPOSURE

An important factor which determines the nature of the insult from ionizing radiation to the developing brain is the gestational age. There are possible errors in the estimation of prenatal age at exposure. Postovulatory age is usually estimated from the onset of the last menstrual period, and adjustment is then made for the differences between that date and the probable date of fertilization (usually taken to be 2 weeks later). Women with irregular menstrual cycles or who miss a menstrual period could possibly erroneously identify the onset of their last cycle (ICRP Publication 49, 1986). In order to avoid the aforementioned uncertainties concerning the estimation of prenatal age at the time of the Chernobyl accident we used the formulas offered by Otake et al (1991) for estimation of prenatal age at atomic bombing in Hiroshima and Nagasaki:

$$\textit{Days of pregnancy (Y)} = 280 - (\textit{date of birth} - \textit{April } 26^{th}\textit{, 1986}),$$

where the day of birth has been obtained by interviewing the mothers of the children. The mean duration of pregnancy is taken to be 280 days. The days from birth were counted back until the accident and subtracted from the 280 days, the duration of a pregnancy. Since the duration is calculated from the beginning of the last menstrual cycle, additionally 14 days have to be subtracted. Gestational weeks after fertilization at the time of the accident were thus calculated by the following equation:

Gestational weeks (G) = (Y — 14 days) / 7 days, where G was taken to be zero if G<0.

According to different radiosensitivity of the fetus the gestational time is divided into 4 periods in relation to the Chernobyl accident. Table 2.5 shows the 4 groups in weeks at the moment of the accident. In the exposed group there are less children who were at the earliest stages of prenatal development. A possible explanation are increased numbers of abortions and miscarriages due to the Chernobyl accident.

Table.5 Distribution of periods of cerebrogenesis on 26.04.1986

Weeks of gestation	Exposed group from Pripyat (n=154)	Comparison group from Kiev (n=143)	χ^2	p
0–7	19 (12.3%)	35 (24.5%)	7.3	<0.01
8–15	29 (18.8%)	28 (19.6%)	0.03	>0.05
16–25	48 (31.2%)	32 (22.4%)	2.9	>0.05
26+	58 (37.7%)	48 (33.5%)	0.5	>0.05

3 DESCRIPTION OF THE COHORTS

The investigation was performed on a cohort of prenatally exposed children, who were born between April 26th, 1986 and February 26th, 1987 from mothers, who had been evacuated from Pripyat to Kiev. The control group comprises children from Kiev, who were randomly picked out from the classes of the *in utero* exposed children in Kiev.
Inhabitants of the town of Pripyat (n=49,360) and railway station Yanov (n=254) were evacuated on April 27th, 1986, the residents of the 10-kilometre zone surrounding the Chernobyl NPP (n≈10,000) were evacuated on May 2nd — 3rd, 1986; and on May 4th, 1986 a stepwise evacuation of the population of the 30-kilometre zone surrounding the Chernobyl NPP was started. Until the middle of August, 1986 there were 90,784 people evacuated from 81 settlements of the Ukraine (National Report of Ukraine, 1996).
These acutely prenatally exposed child-evacuees from Pripyat towards Kiev are the most adequate cohort for comparison with the Japanese prenatally exposed cohort of children from Hiroshima and Nagasaki because of the quasi acute prenatal exposure and the urbanized sample.

For the WHO Pilot Project «Brain Damage in Utero» the International Advisory Board estimated the number of births in the interval April 26th, 1986 to February 26th, 1987 in the Ukrainian radioactively contaminated areas (including the Chernobyl exclusion zone) to be 1,400. However, in 1993–1994 we could identify only 1,293 of these children, 272 (21%) of them were evacuees from the Chernobyl exclusion zone. The reduced number of the identified prenatally irradiated children could be explained by both medical and spontaneous abortions (miscarriages) or migration. According to the National Register of Ukraine the cohort of prenatally irradiated children in Ukraine consisted of 733 children, including 272 (37%) children born to mothers who had been evacuated from the Chernobyl exclusion zone in 1986. 145 (52%) of them live in Kiev, 133 (48%) in 26 oblasts of the Ukraine (3–10 children per oblast). We have identified an additional 69 prenatally irradiated child -evacuees living in Kiev according to the data of the Clinical and Epidemiological Register of the Scientific Centre of Radiation Medicine of the Academy of Medical Sciences (SCRM AMS) of the Ukraine. Thus, 347 prenatally irradiated child-evacuees including 214 living in Kiev were identified. Among the latter there is the subcohort consisting of 182 children-evacuees from the town of Pripyat. From the subcohort of 182 prenatally irradiated children-evacuees from the town of Pripyat living in Kiev we examined 154 (84.6%) children for the study (exposed group). The comparison group consisted of 143 gender- and age-matched children selected from the classrooms of the children of acutely exposed group. Table .6 shows the gender distribution.

Tabl .6 Gender distribution

Gender	Exposed group from Pripyat (n=154)	Comparison group from Kiev
Boys	75 (48.7%)	76 (53.1%)
Girls	79 (51.3%)	67 (46.9%)

The children of the exposed group were, at the time of examination, half a year younger than the comparison group (12.5 vs 13 years) due to older girls in the comparison group (Table 2.7). However, due to age standardization of the tests the age differences at the time of examination do not influence the results of intelligence and emotional/behavioral assessments.

Table 7 Distribution of age at the moment of examination (months)

Gender	Exposed group from Pripyat (n=154) [M±SD]	Comparison group from Kiev (n=143) [M±SD]	t	p
Boys and girls	151±22.3	156.1±16.5	–2.2	=0.02
Boys	151.2±21.9	153.9±18.8	–0.8	>0.05
Girls	150.7±22.8	158.7±13.2	–2.5	=0.01

2.4 MENTAL AND SOMATIC HEALTH

Clinical examination

The children of the acutely prenatally exposed and the comparison groups were examined by clinical psychiatric interview and clinical neurological examination at the Department of Neurology, SCRM of AMS of Ukraine. The mental disorders and the diseases of the nervous system were assessed according to the diagnostic criteria of ICD-10 (Chapter V: Mental and Behavioral Disorders & Chapter VI: Diseases of the Nervous System published by WHO in 1992). ICD-10 diagnostic was made on the base of clinical psychiatric and neurological examinations, psychometry, conventional and QEEG taking into account the results of profound clinical, laboratory and instrumental examination at the Children Department of the Out-Patients' Clinic of the Radiation Register of the SCRM of AMS of Ukraine.

Children of both groups were officially included into the Clinical and Epidemiological Register of the SCRM of AMS of Ukraine and were thoroughly examined by a chief pediatrician, paediatric-psychoneurologist, pediatric-endocrinologist, pediatric-Ear-Nose-Throat (ENT), paediatric-ophtalmologist, pediatric-cardiologist, paediatric-haematologist, paediatric-pulmonologist, pediatric-gastroenterologist, pediatric-surgeon, pediatric-gynecologist (for girls), and a geneticist . General and biochemical blood tests, immunological tests, urine tests, coprograms, thyroid and visceral ultrasonography, electrocardiogram (ECG), fibrogastoscopy, cardiac ultrasonography and in some instances magneto resonance imaging (MRI) for diagnostic reasons, were performed.

Questionnaires for children

Wechsler Intelligence Scale for Children (WISC)

The WISC is an individually administered clinical instrument for assessing the intellectual ability of children aged from 6 to till 16 years, 11 months. The version for the Ukrainian children of the WISC (Wechsler 1992) was used, which was adapted and normalized by Prof. YuZ Gilbukh and colleagues from the Research Institute of Psychology of the Academy of Pedagogic Sciences of the Ukraine (Gilbukh (Ed.) 1992). This test is normalized for gender and age. It consists of 2 main subtests, each measuring a different facet of intelligence, the Verbal, the Performance and together the Full Scale IQ. The verbal and the performance scales have 5 subtests each. Annex 3 shows the details of the test. Intelligence can manifest itself in many forms and for this reason David Wechsler viewed intelligence not only as a particular ability but also as an aggregate and global entity, the «capacity of the individual to act purposefully, to think rationally and to deal effectively with his or her environment». Specific IQ score ranges and their corresponding qualitative diagnostic categories are presented in table 8:

Table .8 IQ ranges and their diagnostic categories (Wechsler 1992)

IQ	Classification
130 and above	Exceptionally high
120–129	High
110–119	High average
90–109	Average
80–89	Low average
70–79	Low
69 and below	Exceptionally low

Child Behavior Check List (CBCL) for ages 4–18 by T. Achenbach

This test can reveal behavioral and emotional disorders in children. A Russian adaptation (Carter et al 1995) of the CBCL questionnaire (Achenbach 1991) was used. The CBCL is designed to record in a standardized format children's competence and problems as reported by their parents (or parent surrogates). It can be self-administered or administered by an interviewer. The CBCL is normalized on gender and age. For analysis of the answers there are 3 groups of interest. Scales entitled *Activities, Social and School* are provided for scoring the competence items. Beside describing children in terms of competence, the CBCL is designed to identify syndromes or problems. The following eight syndromes are displayed in the CBCL profile: *withdrawn, somatic complains, anxious/depressed, social problems, thought problems, attention problems, delinquent behavior and aggressive behavior.* The syndrome scales referred to as withdrawn (I), somatic complains (II), and anxious/depressed (III) are grouped under the heading *Internalizing.* The syndrome scales referred to as delinquent (dissocial) behavior (VII) and aggressive behavior (VIII) are grouped under the heading *Externalizing.*
By processing CBCL raw scores and applying transformation, standardized *T*-scores and percentiles were obtained. *T*-scores are most effective for statistical comparison between groups, but percentiles are useful for comparison of an individual child with group norms. Although the Russian adaptation of the CBCL questionnaire was used, the conversion tables for T-scores and percentiles were German. Consequently, the classification on "normal" and "abnormal" child should be used with caution. Comparison between the groups of exposed and non-exposed children is therefore more reliable.

The Youth Self-Report (YSR)
This test is designed for obtaining self-reports from youths at ages 11 to 18. The questionnaire has 89 similar problem items in common with the CBCL. As in the CBCL, the following eight cross-informant syndromes are displayed in the YSR profile: *withdrawn, somatic complains, anxious/depressed, social problems, thought problems (schizoid/obsessive behavior), attention problems, delinquent (dissocial) behavior, and aggressive behavior*. The interpretation of the YSR syndrome scales is the same as for the CBCL. It should be noted again that although the Russian adaptation of the YSR questionnaire was used, the conversion tables for T-scores and percentiles were German. Therefore only a quantitative comparison between the groups of exposed and non-exposed children is reliable. There is a clear impact of transcultural peculiarities on mental health and, consequently, assessment of mental disorders. Validation of the psychodiagnostic instrument must be done on the target population.

Rutter Scale A(2

Rutter Scale A(2) was used for assessment of child's problems associated with health, hyperactivity, behavioral and emotional disorders (Rutter and Hersov 1985). The mother completes the scale. Translation and validation of the Rutter Scale A(2) for the former USSR population had been done in WHO Pilot Project "Brain Damage in Utero" within the framework of IPHECA. On the Rutter Scale A(2) 31 items are selected to cover three main areas. They are problems associated with health, habits and peculiarities of behavior. If a child has a total score of 13 and more, he/she may have some deviations (problems). If a child has an emotional score that exceeds the behavioral score, he/she is considered to have emotional deviations (problems). If a child has a behavioral score that exceeds the emotional score, he/she is considered to have behavioral deviations (problems). A child with the same (identical) emotional and behavioral scores is not differentiated.

School performance

School performance for a random sample of 25 children was evaluated from school records. Scores from 1 to 12 in ascending order evaluate school performance. That concerns the following subjects: algebra, geometry, geography, physics, chemistry, information science, Ukrainian language, Ukrainian literature, Russian language, Russian literature, foreign language, foreign literature, history of Ukraine, history of the World and law.

Questionnaires for mothers

Vocabulary subtest of the Wechsler Adult Intelligence Scale (WAIS)

This test was used for the assessment of the verbal abilities of mothers (Wechsler 1997). This subtest estimates how the mother understands special words and how she can explain the meaning to her child. Translation and validation of the vocabulary subtest of the WAIS for the former USSR population had been done in the WHO Pilot Project "Brain Damage in Utero" within the framework of IPHECA. For the vocabulary subtest of the WAIS 35 words were orally presented to the mother which she then had to define. All meanings were checked by standard dictionaries and scored according to the quality of the definition. Each word was assigned a score of 2, 1, or 0 where the maximum score possible was 70 points.

Zung Self-Rating Depression Scale (SDS)

The Zung Self-Rating Depression Scale (SDS) is designed for estimation of the level of unmasked depression by self-estimation (Zung and Wonnacott, 1970). If the score result is: less than 50, depression is absent; between 50 and 59 depression is mild between 60 and 69, depression is moderate to significant and more than 70 depression is severe to very severe.

Post-traumatic Stress Disorder Questionnaires: Impact of Events Scale (IES) and Irritability, Depression, Anxiety (IDA)

The questionnaires for assessment of post-traumatic stress disorder (PTSD) in a parent include the "Impact of Events Scale", IES (Horowitz et al 1979) and the clinical scale for the self-assessment of irritability the "Irritability, Depression, Anxiety", IDA (Snaith et al 1978), which were used for assessment of symptoms associated with PTSD. These scales were used for the assessment of psychological stress due to different catastrophic events.

Translation and validation of the IES and IDA for former USSR population had been done in epidemiological studies of immigrants, Chernobyl survivors, to Israel (Cwikel et al 1997a,b, Yevelson et al 1997). The summarized score gives the result. For the IES a score: less than 15 was considered to be «no case»; 15–30 – «case»; and more than 30 – «case with significant disorders». For the IDA the result: less than 4 was considered to be «no case»; 4–8 —«case» and more than 8 — «case with significant disorders».

The General Health Questionnaire (GHQ-28*)*

The General Health Questionnaire (GHQ-28) was used for assessment of a psychopathology in a parent on the basis of self-estimation (Goldberg 1981). The GHQ-28 consists of 4 subscales with 7 items each that estimate somatoform symptoms (GHQ-28A), anxiety/insomnia (GHQ-28B), social dysfunction (GHQ-28C), and severe depression (GHQ-28D). Translation and validation of the GHQ-28 for former USSR population had been done in WHO Pilot Project "Brain Damage in Utero" within the framework of IPHECA. There were two methods used for scoring the GHQ-28: the «GHQ scoring» for 4 scores of the symptoms severity (0–0–1–1) and the «Likert scoring» (0–1–2–3). The usual way of GHQ-28 scoring is a case identification, or so-called «GHQ scoring». If the total sum on 4 subscales is less than 5 it is «no case», 5–15 is a «case», and more than 15 is a «case with considerable disorders». However, the "Likert scoring" ("0–1–2–3") is much more sensitive due to higher evaluation of each from 4 subscales and total score, than according to the «0–0–1–1» estimation.

Stress-events scale of mothers related to the Chernobyl accident

On the base of the scale of stress-factors of the DSM-IV (American Psychiatric Association,1994) we elaborated the Stress-Event Scale for mothers related to the Chernobyl accident. The scale is a questionnaire with 10 items to be answered by a mother and analyzed by an examiner who uses a score from 1–5 per question. The scale is designed for assessment of the level of real stress-factors (but not their perception) following the Chernobyl accident for pregnant women from the accident until the birth of their child. Among these factors are evacuation, lack of information about relatives, migration, difficulties of medical care, etc. These factors determine the level of psychological stress in a pregnant woman as a result of the Chernobyl accident.

DATABASE FORMATION

For the objectives of the subproject from the general database another database has been formed, which allows the analysis of the data for each child separately. If there were several records for a child we took the record with the assessment of the WISC test and included the latest results of the other psychometric examinations.

Finally, the «one-line» database in Excel format has been created for 154 children born from mothers evacuated from Pripyat to Kiev and 143 control children from Kiev. This database was exported to MS STATISTICA-5.0&6.0 for analysis. Table 2.11 shows the number of records, which are implemented in the database.

Table 11 Examined children in the general database

Groups	Number of children	Number of examinations (records)
Acutely exposed group (Pripyat–Kiev)	154	192
Comparison group (Kiev)	143	157
Radioactively contaminated areas (Chernobyl, other exclusion zone settlements, areas of 3rd -^{137}Cs deposition 185–555 kBq·m^{-2}- and 4th -^{137}Cs deposition 37–185 kBq·m^{-2}- categories)	44	52
Rejected, since outside of the catchments area and not born during the period 26.04.86-26.02.87	12	13
TOTAL	353	414

There are officially in the National Register of Ukraine only 145 prenatally irradiated children-evacuees from Pripyat to Kiev. However, according to our identification there are 182 such children. Thus, the acutely exposed group (n=154) consists of 84.6% of these children.

STATISTICS

The statistical analysis was done in MS STATISTICA-5.0&6.0 software, using the following methods: t-test for independent samples; t-test for dependent samples (paired t-test); correlation analysis; Chi-square test.

The t-test is the most commonly used method to evaluate the differences in means between two groups (*www.statsoftinc.com*). The groups can be independent (e.g., exposed and comparison groups) or dependent (e.g., IQ discrepancies between verbal and performance IQs within the group). *t-test for independent sample* allows to compare means for two groups (within a variable). The t-test can be used even if the sample sizes are very small, as long as the variables are approximately normally distributed and the variation of scores in the two groups is not reliably different. *Dependent samples test (paired t-test)*. The t-test for dependent samples can be used to analyze designs in which the within-group variation (normally contributing to the error of the measurement) can be easily identified and excluded from the analysis. Specifically, if the two groups of measurements (that are to be compared) are based on the same sample of observation units that were tested twice, then a considerable part of the within-group variation in both groups of scores can be attributed to the initial individual differences between the observations and thus accounted for (i.e., subtracted from the error). This, in turn, increases the sensitivity of the design. The *p-level* reported with a t-test represents the probability of error involved in accepting our research hypothesis about the existence of a difference. Technically speaking, this is the probability of error associated with rejecting the hypothesis of no difference between the two categories of observations (corresponding to the groups) in the population when, in fact, the hypothesis is true.

Correlation is a measure of the relation between two or more variables. The measurement scales used should be at least interval scales, but other correlation coefficients are available to handle other types of data. Correlation coefficients can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation. The most widely-used type of correlation coefficient is Pearson r (Pearson, 1896), also called linear or product-moment correlation (the term correlation was first used by Galton, 1888). Using non technical language, one can say that the correlation coefficient determines the extent to which values of two variables are "proportional" to each other. The value of the correlation (i.e., correlation coefficient) does not depend on the specific measurement units used. Proportional means linearly related; that is, the correlation is high if it can be approximated by a straight line (sloped upwards or downwards). This line is called the regression line or least squares line, because it is determined such that the sum of the squared distances of all the data points from the line is the lowest possible. Pearson correlation assumes that the two variables are measured on at least interval scales.

Qualitative data may be analyzed by use of the *Chi-square test*. The object of the test is to determine whether the difference between observed frequencies and those expected from a hypothesis are statistically significant. The test is performed by comparing a computed test statistic, χ^2, with a one-tailed critical value found in a chi-square table. The critical value depends on the selected α and on the number of degrees of freedom, the latter reflecting the number of independent differenced as computed from the data. The test statistic is computed as the sum of the ratios of squared differences to expected values. As in other tests of significance, if the computed test statistic exceeds the critical value, the null hypothesis is rejected (Kuzma, 1984).

RESULTS

DOSE DISTRIBUTION

Doses in utero were individually reconstructed for children of both groups by the earlier method (fetal thyroid dose assumed to be equal to thyroid dose of mother) (Likhtarev et al 1994, Repin 1996) and according to the model of ICRP Publication 88. The in utero doses on embryo and fetus, the brain and on thyroid in the exposed group in Pripyat are significantly higher than in the comparison group from Kiev. Especially high are the doses on the fetal thyroid (table 3.1a). Moreover, the in utero doses on embryo, fetus and thyroid according to the model of ICRP Publication 88 are higher in comparison to the former dose reconstructions, where the transfer factor of iodine from the mother to the child is considered to be 1. Doses on the fetal brain remain equal (table 3.1b).

Table12. Doses in utero according to the model of ICRP Publication 88

Dose	Exposed group from Pripyat	Comparison group from Kiev	t	p
Dose on embryo and fetus, mSv				
Min–Max	10.4–269.2	0–2.7		
Geometric Mean	58.7	1.2		
Median	61.6	1.2		
M±SD	65.4±33.9	1.2±0.3	22.5	<0.001
Dose *in utero* on brain, mSv				
Min–Max	0.001–101.6	0–1.7		
Geometric Mean	18.6	0.8		
Median	18.4	0.8		
M±SD	19.2±11.3	0.8±0.2	19.5	<0.001
Dose *in utero* on thyroid, mSv				
Min–Max	0–3210.5	0–110.7		
Geometric Mean	417.1	24.5		
Median	746.3	27.4		
M±SD	760.4±631.8	44.5±43.3	13.5	

Table 13. Doses in utero according to the former dose reconstructions, where the transfer factor of iodine from the mother to the child is considered to be 1

Dose	Exposed group from Pripyat	Comparison group from Kiev	t	p
Dose on embryo and fetus, mSv				
Min–Max	7.8–156.8	0–2.7		
Geometric Mean	29.5	1.2		
Median	29.6	1.2		
M±SD	34.1±19.9	1.95±8.64	16.3	<0.001
Dose *in utero* on brain, mSv				
Min–Max	5.1–101.9	0–1.5	18.8	<0.001
Geometric Mean	19.1	0.8		
Median	19.2	0.8		

M±SD	21.7±12.1	0.7±0.3		
Dose *in utero* on thyroid, mSv				
Min–Max	0–2041	44.1		
Geometric Mean	644.8	44.1		
Median	605	44.1		
M±SD	687.5±314.0	44.1	19.5	<0.001

There are 20 children from Pripyat (13.2%) who had been exposed *in utero* >100 mSv (Figure 3.1) – the threshold dose for medical abortion due to prenatal irradiation (European Commission 1998; ICRP Publication 84, 2000).

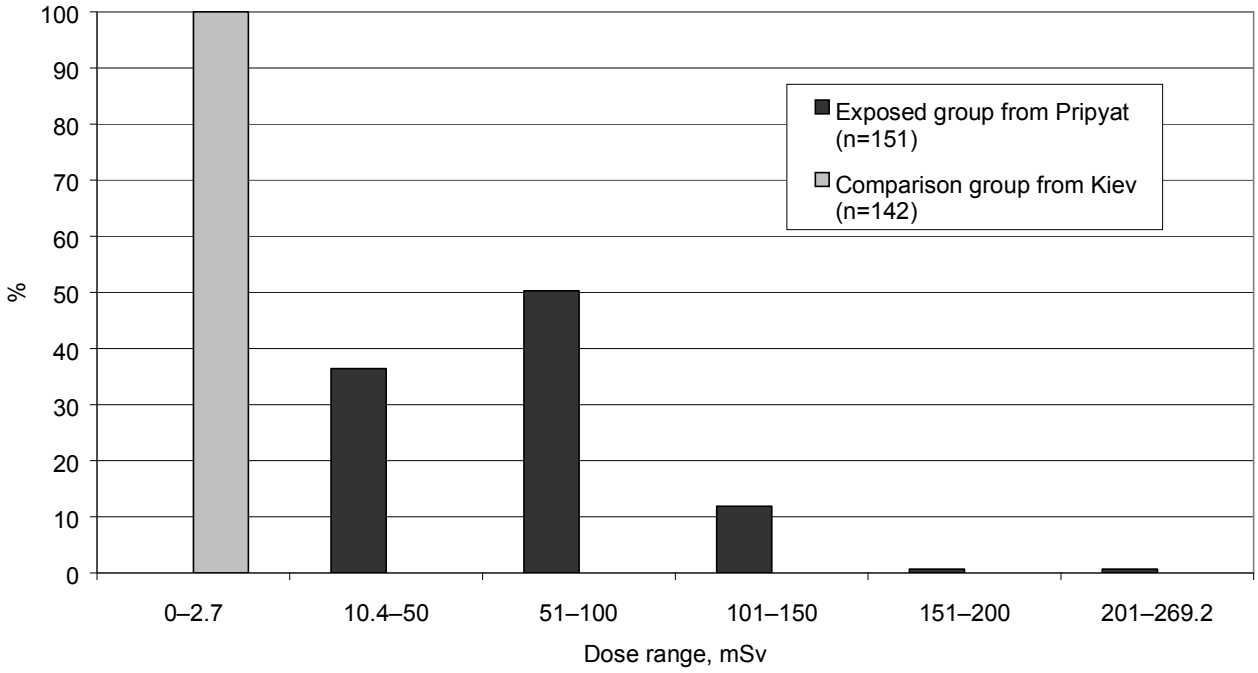

Fig. 5. Distribution of doses on embryo and fetus

Note: 3 values are missing in the exposed group and 1 in the comparison group

CONFOUNDING FACTORS

There are several factors, which could influence the mental health of children by CNS traumata at birth or pre- and postnatally, and act thus as confounding factors for the assessment of the mental abilities of the *in utero* exposed children (table 2.9).

Table 14. Description of confounding factors

Score	Severity	Description
0	Absent	No exogenous and/or endogenous factors in perinatal period and/or later life could reasonably affect nervous system and mental health of a child
1	Mild	Presence of exogenous and/or endogenous factors in perinatal period and/or later life could *possibly slightly* affect nervous system and mental health of a child: mild to moderate gestosis, premature birth, threat of miscarriage, Gilbert's disease, duodenum ulcer, bronchitis, etc.
2	Moderate	Presence of exogenous and/or endogenous factors in perinatal period and/or later life could *possibly moderately* affect nervous system and mental health of a child: severe gestosis, mild asphyxia, amniotic water aspiration, anemia moderate to severe, ABO-conflict, loop of cord, neonatal head haematoma, etc.
3	Severe	Presence of exogenous and/or endogenous factors in perinatal period and/or later life could *severely* affect nervous system and mental health of a child: — moderate asphyxia, resuscitation, leniceps, infant incubator, mild traumatic brain injury (MTBI), meningitis, toxoplasmosis, etc.
4	Very severe	Presence of exogenous and/or endogenous factors in perinatal period and/or later life could *possibly very severely* affect nervous system and mental health of a child: — Apgar (1-2), delivery brain damage, brain odema, pre- and perinatal encephalopathy, severe asphyxia, mother's alcoholism (alcoholic fetal syndrome), physical retardation, placenta exfoliation, rachitis, atelectatic pneumonia, cerebral tumor and neurosurgery, moderate to severe traumatic brain injury, etc.

There are more children with severe confounding factors (n=3) in the control group, than in the exposed children (table 2.10).

Table15. Distribution of children with confounding factors

Confounding factor score	Exposed group from Pripyat (n=151)*	Comparison group from Kiev (n=101)**	χ^2	P
0 (absent)	71 (47%)	42 (42%)	0.72	>0.05
1 (mild)	50 (33%)	35 (35%)	0.06	>0.05
2 (moderate)	15 (10%)	6 (6%)	1.26	>0.05
3 (severe)	11 (7%)	15 (15%)	3.74	<0.05
4 (very severe)	4 (3%)	3 (3%)	0.02	>0.05

** 3 x missing definite data ** 42 x missing definite data*

Children from the control group often did not come with the mother to the consultation and therefore no information about the confounding factors of 42 children could be generated.

Distribution of i*n utero* doses on the brain is presented in Figure 6

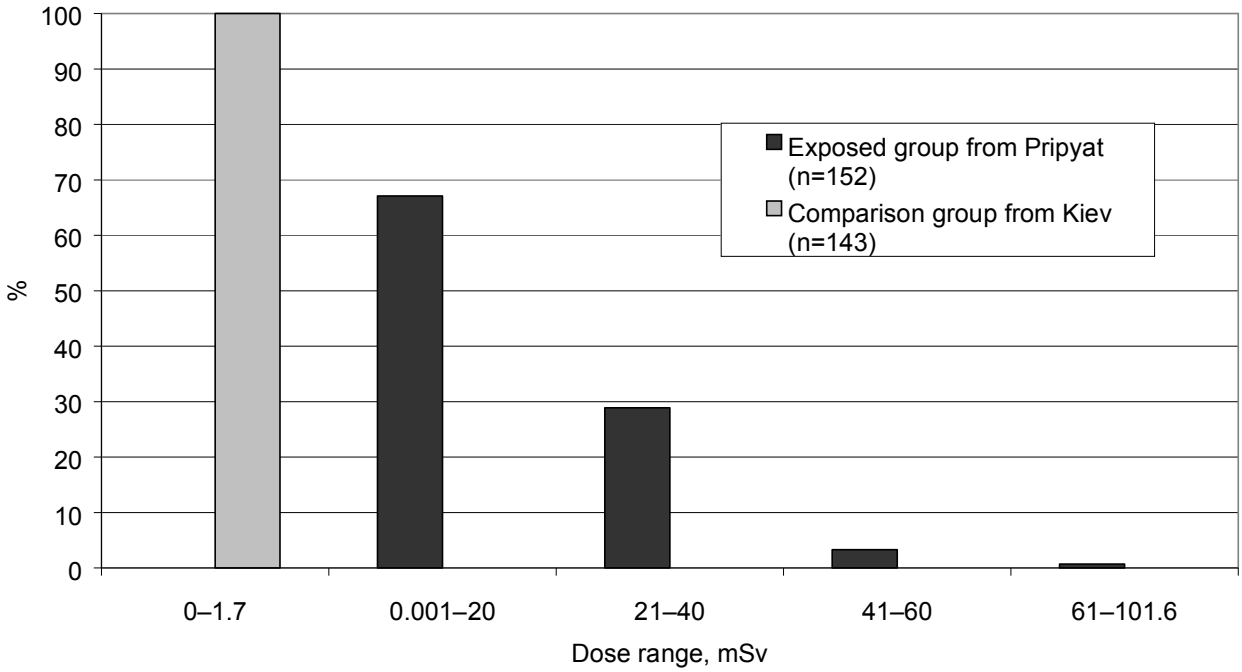

Fig. 6. Distribution of in utero doses on the brain Note: 2 values missing in exposed group

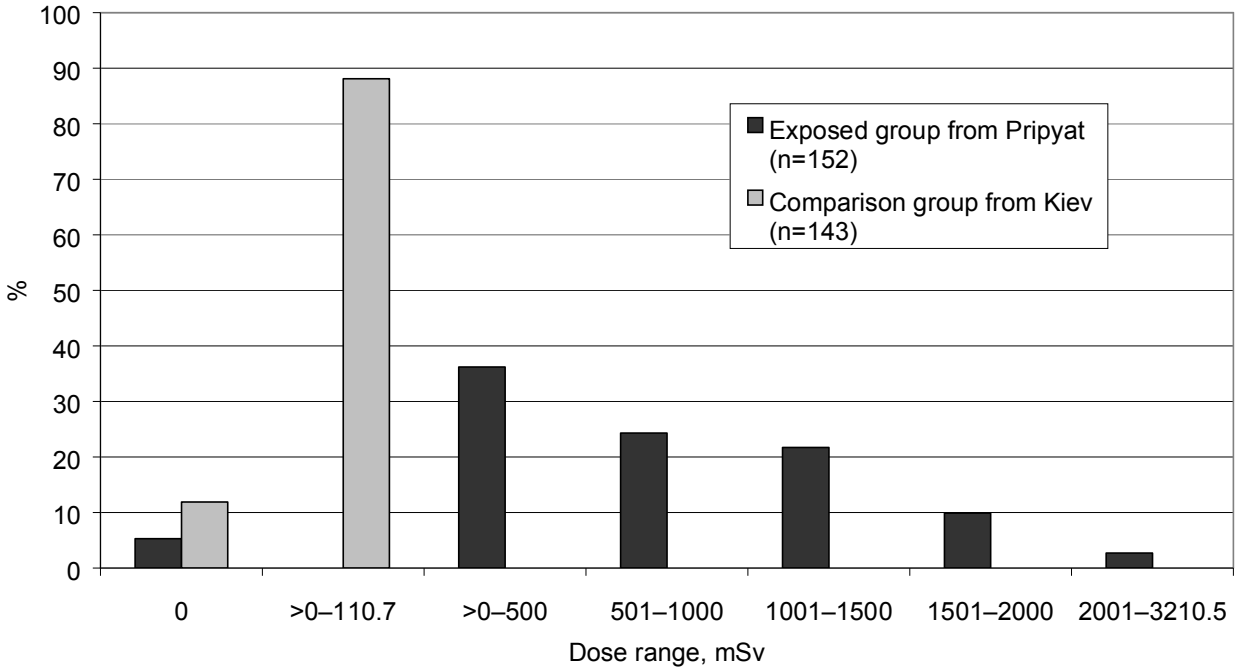

Fig. 7. Distribution of doses on the thyroid in utero Note: 2 values missing in exposed group

There are 52 children from Pripyat (33.8%) with *in utero* thyroid doses >1Sv (Figure 7).

According to the model of ICRP Publication 88 there is a strong influence of gestational age on the thyroid doses *in utero*: the later the intrauterine period at the time of exposure — the higher the *in utero* thyroid doses (table 3.2). According to the radiosensitivity of the embryo or fetus the time of gestation is divided into 4 periods (ICRP Publication 49).

Table 16. Geometric means of the in utero thyroid doses (mSv) related to the periods of cerebrogenesis (weeks of gestation) at 26.04.1986

Weeks of gestation	Exposed group from Pripyat		Comparison group from Kiev	
	(mSv)	(n=152)	(mSv)	(n=143)
0–7	0.39	19	0.02	35
8–15*	40.9	28	1.5	28
16–25*	623.7	47	46.1	32
26+	1225.5	58	94	48

* 1 value missing

There are significant differences in assessment of intrauterine doses, especially on the thyroid, when the different models are used (table 16). It should be mentioned, that there exists a third model of the *in utero* thyroid dose assessment — Balonov–Zvonova's model (modification of the Johnson's model) that uses other coefficients in dependence of the gestational age (Zvonova et al 1998). Therefore, validation of these different dosimetric models is outstanding, as well as a possible revision of the prenatal doses.

Table 17. Correlation matrices of prenatal doses, reconstructed on the base of the former calculations (thyroid dose of mother assumed to be equal to fetal thyroid dose - Likhtarev et al 1994, Repin et al 1997) and ICRP Publication 88

Variable	Dose *in utero* on thyroid, former	Dose on embryo and fetus, former	Dose *in utero* on brain, former
Dose *in utero* on brain, ICRP-88			$r=0.8$; $p<0.001$
Dose on embryo and fetus, ICRP-88		$r=0.5$; $p<0.001$	
Dose *in utero* on thyroid, ICRP-88	$r=0.06$; $p>0.05$		

MENTAL HEALTH OF CHILDREN

Wechsler Intelligence Scale for Children (WISC)

The WISC test measures two facets of intelligence, the verbal IQ and the performance IQ, which compose the full IQ. Verbal IQ involves testing short- and long term memory, as well as language development, whereas performance IQ involves assessing the visual perception and imagination abilities of the children (see Annex 3). The average IQ value of a standard population is 100 and follows a normal distribution (Wechsler 1992). In both groups of the present study the children grew up in Kiev, the capital city of the Ukraine, where they were promoted and cultured as in no other place of the Ukraine. This might be the reason for the elevated average IQ value by 10-20 points in this study.

In both groups of children the analysis of the test revealed significant differences of intelligence of exposed in comparison to the control children, as the t-test for independent sample confirm (tables 18,19). The relationship of the IQ values to exposure doses is presented in chapter below.

Table 18. Intelligence quotient (IQ) of all examined children

Index	Exposed group from Pripyat (n=140)	Comparison group from Kiev (n=136)	t	p
Full scale IQ				
M±SD	112.2±15.2	119.6±11.6	–4.5	<0.001
Median	112	120		
Min-Max	46–151	76–147		
Verbal IQ				
M±SD	106.6±14.3	117.2±13.1	–6.4	<0.001
Median	108	119		
Min-Max	56–144	85–144		
Performance IQ				
M±SD	116.1±16.9	118.5±10.8	–1.4	>0.05
Median	120	120		
Min-Max	44–153	71–140		
IQ discrepancies pIQ–vIQ				
M±SD	9.5±14.4	1.2±11.9	5.2	<0.001
Median	10	–0.5		
Min-Max	–29–(+54)	–22–(+33)		
Paired t-test *p*	7.8 <0.001	1.2 >0.05		

Whereas performance IQ (pIQ) is comparable in the exposed and the comparison group of children, verbal IQ (vIQ) and full IQ are significantly lower in the exposed group. Also the IQ discrepancy, the difference from pIQ and vIQ values, is significantly higher in the exposed group due to vIQ deterioration. When the IQ discrepancies reach values higher than 25 points, there is suspicion of brain damage (Rutter and Hersov 1985). The results show great variations in IQ discrepancy, but they are of statistical significance (paired *t*-test) in the exposed group, in spite of the fact that the mean values are below 25 points.

When eliminating children with moderate to very severe confounding factors from both groups of the study, reducing thus the size of the exposed group to n=108 and the comparison group to n=73, the same significant differences of the IQ values are observed (table 19).

Table 19. IQ of children without moderate to very severe confounding factors.

Index	Exposed group from Pripyat (n=108)	Comparison group from Kiev (n=73)	t	p
Full scale IQ				
M±SD	112.9±13.3	118.6±10.8	–3	<0.003
Median	112	120		
Min-Max	76–151	96–137		
Verbal IQ				
M±SD	106.7±13.2	115.8±13.2	–4.5	<0.001
Median	108	116		

Min-Max	70–143	85–138		
Performance IQ				
M±SD	117.2±15.2	118.7±9.6	–0.7	>0.05
Median	119	121		
Min-Max	74–153	97–140		
IQ discrepancies pIQ–vIQ				
M±SD	10.4±14.7	2.9±12.5	3.6	<0.001
Median	10	3		
Min-Max	–29–(+54)	–22–(+33)		
Paired t-test *p*	7.4 <0.001	1.9 >0.05		

Verbal IQ and the IQ discrepancies are still significantly different in both groups of children.

Table 19 shows the distribution of all exposed and comparison children on different IQ subgroups. Intelligence of exposed children significantly differs from the control group by:

1. Increased frequency of low IQ (IQ<90), especially of verbal IQ
2. Increased frequency (2 times) of average IQ (91–110) and decreased frequency (more than 3 times) of high IQ (121–140)
3. Increased frequency of IQ discrepancies: about 14% of the exposed and 4.5% of the control children have IQ discrepancies of more than 25 points and show thus a disharmoniously developed intelligence
4. There are 2 cases (1.4%) of mental retardation — mild (IQ=59) and moderate (IQ=49) — in the exposed group (due to moderate to significant confounding factors, as is shown in Table 3.7)

Table 20. Intelligence distribution in all examined children

IQ range	Exposed group from Pripyat (n=140)	Comparison group from Kiev (n=136)	χ^2	p
Full scale IQ				
<70	2 (1.4%)	0	1.96	>0.05
70–80	2 (1.4%)	1 (0.7%)	0.31	>0.05
81–90	3 (2.1%)	0	2.95	>0.05
91–110	53 (37.9%)	30 (22.1%)	8.19	<0.01
111–120	40 (28.6%)	38 (27.9%)	0.01	>0.05
121–140	39 (27.9%)	65 (47.8%)	11.7	<0.001
>140	1 (0.7%)	2 (1.5%)	0.37	>0.05
Verbal IQ				
<70	2 (1.4%)	0	1.96	>0.05
70–80	4 (2.8%)	0	3.94	<0.05
81–90	11 (7.9%)	4 (2.9%)	3.24	>0.05
91–110	66 (47.2%)	33 (24.3%)	6.65	<0.01
111–120	37 (26.4%)	41 (30.1%)	0.01	>0.05
121–140	18 (12.9%)	56 (41.2%)	13.2	<0.001
>140	2 (1.4%)	2 (1.5%)	0.42	>0.05
Performance IQ				
<70	2 (1.4%)	0	1.96	>0.05
70–80	1 (0.7%)	1 (0.7%)	0	>0.05
81–90	4 (2.8%)	0	3.94	<0.05
91–110	38 (27.1%)	29 (21.3%)	1.27	>0.05
111–120	30 (21.4%)	40 (29.4%)	2.32	>0.05
121–140	59 (42.2%)	66 (48.6%)	1.14	>0.05
>140	6 (4.4%)	0	5.96	<0.05
IQ discrepancies pIQ–vIQ				
<–25	5 (3.6%)	0	4.95	<0.05
–25 – (–15)	3 (2.1%)	12 (8.8%)	5.99	<0.05
–14 – 15	86 (61.4%)	107 (78.7%)	9.76	<0.01
16 – 25	27 (19.3%)	11 (8.1%)	7.29	<0.01
>25	19 (13.6%)	6 (4.4%)	7.03	<0.01

After sorting out from both group the children with moderate to very severe confounding factors, the intelligence of exposed children (Table 3.7) still significantly differs from the control group by the same criteria as in table 3.6.

Table 21. IQ distribution in children without moderate to very severe confounding factors

IQ range	Exposed group from Pripyat (n=108)	Comparison group from Kiev (n=73)	χ^2	p
Full scale IQ				
<70	0	0	—	—
70–80	2 (1.8%)	0	1.37	>0.05
81–90	1 (0.9%)	0	0.68	>0.05

91–110	42 (38.9%)	18 (24.7%)	3.98	<0.05
111–120	33 (30.6%)	19 (26%)	0.44	>0.05
121–140	29 (26.9%)	36 (49.3%)	9.6	<0.01
>140	1 (0.9%)	0	0.68	>0.05
Verbal IQ				
<70	1 (0.9%)	0	0.68	>0.05
70–80	3 (2.8%)	0	2.1	>0.05
81–90	8 (7.4%)	3 (4.1%)	0.83	>0.05
91–110	53 (49.1%)	17 (23.3%)	12.21	<0.001
111–120	30 (27.8%)	25 (34.2%)	0.86	>0.05
121–140	12 (11.1%)	28 (38.4%)	18.78	<0.001
>140	1 (0.9%)	0	0.68	>0.05
Performance IQ				
<70	0	0	—	—
70–80	1 (0.9%)	0	0.68	>0.05
81–90	3 (2.8%)	0	2.1	>0.05
91–110	30 (27.8%)	16 (21.9%)	0.79	>0.05
111–120	26 (24.1%)	20 (27.4%)	0.25	>0.05
121–140	42 (38.9%)	37 (50.7%)	2.46	>0.05
>140	6 (5.5%)	0	4.19	<0.05
IQ discrepancies pIQ–vIQ				
<–25	4 (3.7%)	0	2.76	>0.05
–25– (–15)	2 (1.8%)	5 (6.9%)	2.93	>0.05
–14–15	62 (57.4%)	55 (75.3%)	6.13	<0.01
16–25	23 (21.4%)	9 (12.3%)	2.41	>0.05
>25	17 (15.7%)	4 (5.5%)	4.47	<0.05

In order to demonstrate graphically the differences of both IQ values in the exposed and control cohort of children a distribution of the fraction of children below a specific IQ is calculated. Figure 8 shows, that the control children demonstrate a similar distribution of verbal and performance IQ. However, the distribution of the IQ values of the exposed children (verbal and performance IQ) show distinct differences.

When plotting verbal and performance IQ separately it is obvious that the exposed children have clearly a lower verbal IQ throughout the whole cohort; the distribution is starting earlier and never meets the distribution of the control children (figure 3.5).

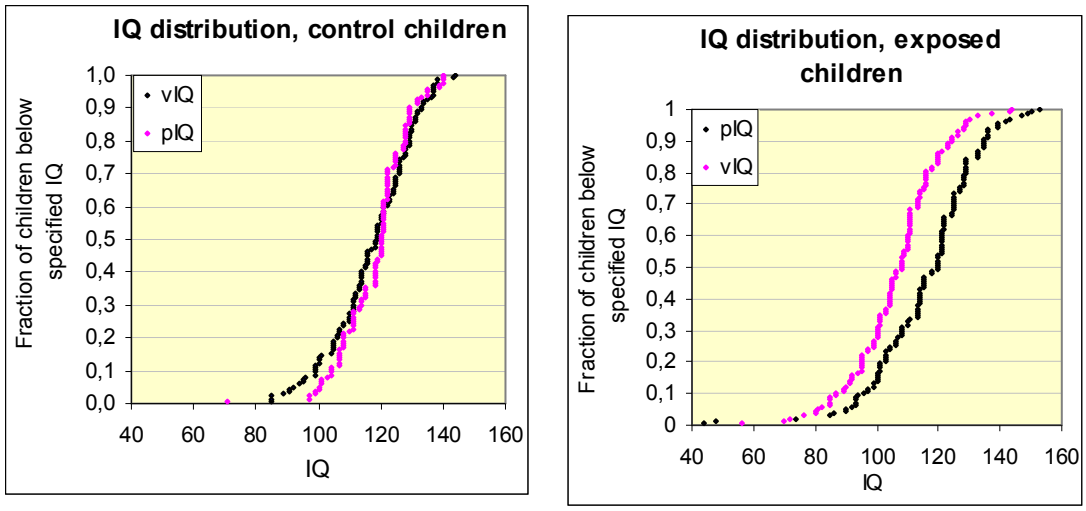

Fig. 8. Fraction of control and exposed children below specific verbal and performance IQ

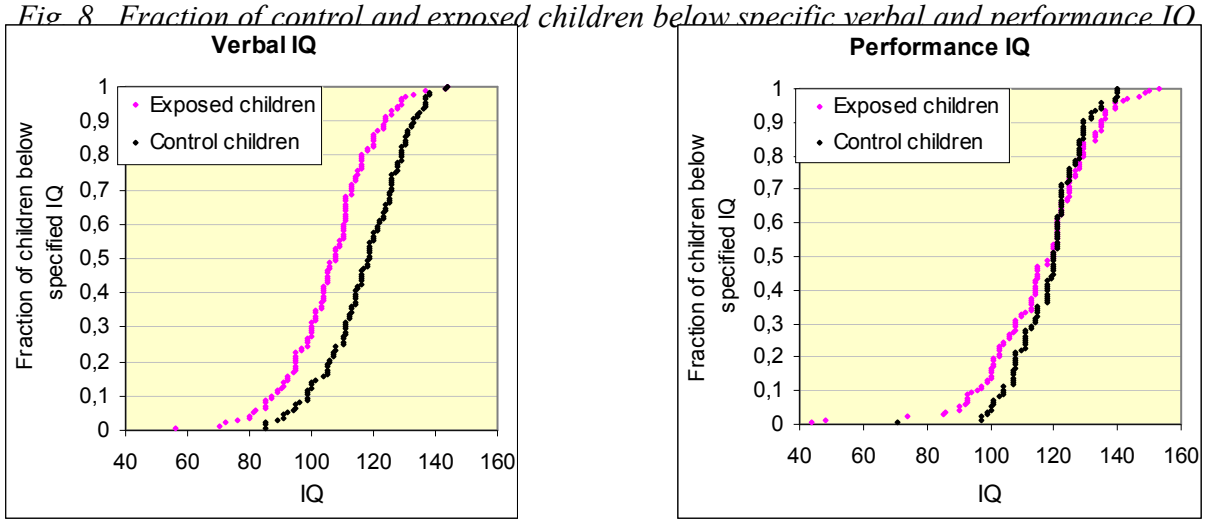

Fig. 9. Fraction of control and exposed children below specific IQ, differentiated by verbal and performance IQ

Intelligence quotient and gender

There is no interaction between intelligence and gender of the children in the exposed study group, but there is a tendency especially to lower verbal IQ values in girls of the control group (tables 3.8 and 3.9). This is a general tendency of the girls from the control group, with or without confounding factors (control girls are 1/2 years older than the exposed girls).

Table 22. Intelligence quotient in dependence on gender in all children

Index	Boys [M±SD]	Girls [M±SD]	t	p
Exposed group (n=140)				
n	68	72		

Full scale IQ	111.9±15.2	112.6±15.2	–0.3	>0.05
Verbal IQ	106.6±13.9	106.5±14.8	0.04	>0.05
Performance IQ	115.5±17.1	116.7±16.8	–0.4	>0.05
IQ discrepancies IQp–IQv	8.9±13.9	10.1±15	–0.5	>0.05
Control group (n=136)				
n	72	64		
Full scale IQ	121.8±12.3	117.1±10.4	2.4	=0.02
Verbal IQ	120.1±13.6	114±11.8	2.8	=0.006
Performance IQ	119.8±11	117±10.3	1.5	>0.05
IQ discrepancies IQp–IQv	–0.3	3	–1.6	>0.05

Table 23. Intelligence quotient in dependence on gender in children without moderate to very severe confounding factors

Index	Boys [M±SD]	Girls [M±SD]	t	p
Exposed group (n=108)				
n	51	57		
Full scale IQ	112.7±13.9	113±12.8	–0.1	>0.05
Verbal IQ	106.8±13.4	106.7±13.1	0.03	>0.05
Performance IQ	116.9±15.6	117.4±15	–0.2	>0.05
IQ discrepancies IQp–IQv	10.1±14.1	10.7±15.3	–0.2	>0.05
Control group (n=73)				
n	35	38		
Full scale IQ	120±11.3	117.3±10.2	1.1	>0.05
Verbal IQ	117.6±14.2	114.1±12.1	1.1	>0.05
Performance IQ	120.3±9.6	117.1	1.4	>0.05
IQ discrepancies IQp–IQv	2.8	2.9	–0.06	>0.05

Intelligence quotient and gestational period

As was explained in the introduction the gestation time, which is directly related to the period of cerebrogenesis, is most important, when assessing a possible radiation effect (ICRP Publication 49, 1986). There is no observed clear dependence of intelligence and the periods of cerebrogenesis at 26.04.1986 in children with or without moderate to very severe confounding factors, however (Tables 3.10 and 3.11).

Table 24. Intelligence of all children related to the periods of cerebrogenesis at 26.04.1986 (gestation periods in weeks)

Index	Exposed group from Pripyat (n=140) [M±SD]	Comparison group from Kiev (n=136) [M±SD]	t	p
0–7 weeks				
n	*17*	*35*		

Full scale	109.7±15.6	123.7±9.5	–4	<0.001
Verbal IQ	103.3±16	121.3±12.1	–4.5	<0.001
Performance IQ	114.7±15	122.1±8.8	–2.2	=0.03
IQ discrepancies: IQp–IQv	11.3±12.4	0.8±12.1	2.9	=0.005
8–15 weeks				
n	*27*	*26*		
Full scale	113.2±11.1	114.6±11.1	–0.5	>0.05
Verbal IQ	106.8±13.2	111,5±13.1	–1.3	>0.05
Performance IQ	117.4±10.6	115.4±9.5	0.7	>0.05
IQ discrepancies: IQp–IQv	10.6±13.2	3.9±13	1.8	=0.07
16–25 weeks				
n	*42*	*30*		
Full scale	111.4±18.9	119.3±13	–1.97	=0.052
Verbal IQ	106.3±16	117.8±14.8	–3.1	=0.003
Performance IQ	115±21.4	118±10	–0.7	>0.05
IQ discrepancies: IQp–IQv	8.7±14.7	0.2±10.5	2.7	=0.008
26+ weeks				
n	*54*	*45*		
Full scale	113.2±13.7	119.4±11.8	–2.3	=0.02
Verbal IQ	107.7±13.1	117±11.8	–3.7	<0.001
Performance IQ	116.8±16.4	117.7±12.8	–0.2	>0.05
IQ discrepancies: IQp–IQv	9.1±15.7	0.6±12.2	2.9	=0.004

Table 25. Intelligence of children without moderate to very severe confounding factors related to the periods of cerebrogenesis at 26.04.1986 (gestation period in weeks)

Index	Exposed group from Pripyat (n=108) [M±SD]	Comparison group from Kiev (n=73) [M±SD]	t	p
0–7 weeks				
n	*14*	*17*		
Full scale	109.8±13.8	124.5±7.5	–3.8	<0.001
Verbal IQ	102.8±14.1	121.4±10.7	–4.2	<0.001
Performance IQ	115.4±13.9	123.5±12.6	–2.1	=0.048
IQ discrepancies: IQp–IQv	12.6±12.1	2.1±12.6	2.4	=0.025
8–15 weeks				
n	*24*	*13*		
Full scale	111.2±9.9	111.1±10.9	0.05	>0.05
Verbal IQ	104.3±10.7	105.7±12	–0.35	>0.05
Performance IQ	116.5±10.9	115.5±10	0.28	>0.05
IQ discrepancies: IQp–IQv	12.1±11.9	9.8±10.3	0.61	>0.05
16–25 weeks				
n	*26*	*21*		
Full scale	115.3±14.5	116.8±12.3	–0.4	>0.05
Verbal IQ	108.7±14	115.2±15.4	–1.5	>0.05
Performance IQ	120±16.4	117.4±9	–0.7	>0.05
IQ discrepancies: IQp–IQv	11.3±15	2.2±11.8	2.3	=0.027

26+ weeks				
n	*44*	*22*		
Full scale	113.4±14.1	120.1±8.6	–2.1	=0.04
Verbal IQ	108.2±13.5	118±10.2	–2.99	=0.004
Performance IQ	116.4±17.1	118±10.6	–0.4	>0.05
IQ discrepancies: IQp–IQv	8.3±16.7	0.04±13.5	2	=0.049

Tables 24.25 show that verbal IQ of the exposed cohort of children is significantly lower in comparison to the control group especially during exposure in the first 7 weeks, in both tables. The least differences are observed in children of the gestation period 8-15 weeks. The p value is increasing when the children with confounding factors are excluded, except in the group of children of the first period: 0-7 weeks. Performance IQ is on the contrary comparable in all periods, except the first period. IQ discrepancies follow the same scheme: significant differences in all periods except the second one and higher p-values in the group of children without confounding factors. Most differences are thus seen in the first, third and fourth periods of cerebrogenesis, irrespective of the presence of confounding factors. This result is in contradiction to the results of the Japanese studies, where the second period appeared to be the most vulnerable.

Emotional-behavioral sphere and school performance

Child Behavior Checklist (CBCL) and Youth Self Report (YSR) by Achenbach Emotional and behavioral sphere is a crucial issue of a child's mental health and his/her social adaptation. We assessed this sphere by the Achenbach test [annex 3 (*2-3*)] and Rutter A(2) scale [annex 3 (*4*)]. The emotional and behavioral spheres of exposed children in comparison to the control group were slightly elevated concerning (table 3.12):

- Somatic complaints
- Internalization (withdrawn, somatic complaints, and anxious/depression)
- Total problem scores (syndrome scales)

Table 26. Emotional and behavioral disorders in all children irradiated in utero according to the Achenbach test

Scale	Exposed group from Pripyat (n=70) [*T* score, M±SD]	Comparison group from Kiev (n=77) [*T* score, M±SD]	t	p
The Child Behavior Checklist (CBCL)				
Competence scales				
Activities	52±4	51.4±4.9	0.8	>0.05
Social	45.3±6.8	44.4±9.3	0.6	>0.05
School	46.4±7.6	46.5±6.5	–0.1	>0.05
Total competence score	50.5±7.9	50.4±10.5	0.1	>0.05
Syndrome scales				
Withdrawn	61.7±7.8	58.3±8.1	2.5	=0.01
Somatic complaints	72.6±7.2	68.1±9.5	3.1	=0.002
Anxious/depressed	61.9±7.9	60.6±8.7	0.9	>0.05
Social problems	58.4±8.3	57.9±8.4	0.3	>0.05
Thought problems	56.8±7.4	56.0±8.8	0.6	>0.05

Attention problems	61.8±8.5	61.5±8.5	0.2	>0.05
Delinquent behaviour	54.6±5.2	53.8±5.0	0.9	>0.05
Aggressive behaviour	57.5±6.6	58.3±7.8	–0.6	>0.05
Internalizing	68.0±7.7	63.4±10.5	2.9	=0.004
Externalizing	56.1±7.2	55.9±8.8	0.1	>0.05
Total problem score	64.1±7.5	61.7±10.1	1.6	>0.05
The Youth Self-Report (YSR)				
Syndrome scales				
Withdrawn	58.4±7.2	57.7±6.8	0.6	>0.05
Somatic complaints	63.6±9.0	59.0±9.0	3.1	=0.002
Anxious/depressed	59.7±6.9	57.9±7.2	1.6	>0.05
Social problems	58.7±7.2	56.9±7.3	1.6	>0.05
Thought problems	59.5±8.0	58.3±8.7	0.9	>0.05
Attention problems	62.9±8.1	60.9±8.3	1.4	>0.05
Delinquent behaviour	57.8±5.8	56.4±6.8	1.3	>0.05
Aggressive behaviour	60.4±7.4	59.1±7.3	1.1	>0.05
Internalizing	62.3±7.4	58.5±9.6	2.7	=0.008
Externalizing	59.7±7.4	56.7±10	2	=0.047
Total problem score	71.1±6.1	68.8±6.7	2.2	=0.03

After sorting out from both group the children with moderate to very severe confounding factors (table 26), the emotional and behavioral disorders differ in exposed children partly even more from the comparison group by all parts of internalization* (withdrawn, somatic complaints* and anxiety/depression) and the total problem score*, when assessing the CBCL test. The evaluation of the YSR test reveals a slightly elevated score of social and attention problems. Altogether the children assessed themselves less gravely than the parents, especially concerning the syndrome scale withdrawn.

*Note: * — emotional and behavior disorders are of clinical significance*

Table27. Emotional and behavioral disorders in children irradiated in utero according to Achenbach test without moderate to very severe confounding factors

Scale	Exposed group from Pripyat (n=54) [*T* score, M±SD]	Comparison group from Kiev (n=61) [*T* score, M±SD]	t	p
The Child Behavior Checklist (CBCL)				
Competence scales				
Activities	52.3±3.7	51.5±5.1	0.9	>0.05
Social	44.8±6.8	44.9±9	–0.1	>0.05
School	47±7.6	47±6.3	0.05	>0.05
Total competence score	50.5±7.3	51.2±10.3	–0.4	>0.05
Syndrome scales				
Withdrawn	61.2±7.7	56.5±7.2	3.3	=0.001
Somatic complaints	72.5±7.7	67.2±9.6	3.1	=0.002
Anxious/depressed	61.4±7.5	58.4±7.8	2.1	=0.04
Social problems	57.5±7.5	56.5±8	0.7	>0.05

Thought problems	56.7±7.2	54.6±7.9	1.5	>0.05
Attention problems	61±8.5	59.9±8.3	0.7	>0.05
Delinquent behavior	54.8±5.6	53.2±4.6	1.6	>0.05
Aggressive behavior	57.5±6.8	57.3±7.5	0.1	>0.05
Internalizing	67.7±7.7	61.3±10.5	3.7	<0.001
Externalizing	55.9±7.4	54.8±8.8	0.7	>0.05
Total problem score	63.8±7.4	59.7±9.9	2.4	=0.02
The Youth Self-Report (YSR)				
Syndrome scales				
Withdrawn	58.3±7	57.1±6.7	0.9	>0.05
Somatic complaints	63.2±8.7	59.1±8.9	2.5	=0.01
Anxious/depressed	59.3±6.9	57.6±6.9	1.3	>0.05
Social problems	58.9±7.1	56±6.4	2.3	=0.02
Thought problems	59.7±7.5	58.4±8.7	0.8	>0.05
Attention problems	63.1±7.8	59.6±7.6	2.4	=0.02
Delinquent behavior	57.6±5.9	55.8±6.5	1.6	>0.05
Aggressive behavior	59.8±6.9	58.2±7	1.2	>0.05
Internalizing	61.7±7.7	58±9.8	2.3	=0.02
Externalizing	59.2±7	55.6±10	2.2	=0.03
Total problem score	70.7±6.4	68.1±6.5	2.2	=0.03

There are no revealed differences between both groups in emotional and behavioral disorders according to Rutter A(2) scale (table 27).

Table 28. Emotional and behavioral disorders by Rutter A(2) scale

	Exposed group from Pripyat (n=148)	Comparison group from Kiev (n=91)	t	p
Rutter A(2) scale [M±SD]	13.5±7	12±7.2	1.6	=0.12

There are also no revealed differences between both groups concerning school performance (table 28). It is estimated by a weighting factor from 1 to 12 in ascending order. A random sample of 27 and 25 children was evaluated.

Table 29. School performance

Subject	Exposed group from Pripyat (n=27) [M±SD]	Comparison group from Kiev (n=25) [M±SD]	t	p
Algebra	6.3±2.1	6.5±1.9	–0.4	>0.05
Geometry	6.3±2	6.3±1.7	0.007	>0.05
Geography	7.8±1.6	8.1±1.6	–0.6	>0.05
Physics	6.1±1.8	6.7±1.7	–1.3	>0.05
Chemistry	6.5±2.2	6.5±2	–0.1	>0.05
Information science	8.7±1.1	8.4±1.6	0.2	>0.05
Language Ukrainian	6.6±1.8	7.4±1.8	–1.6	>0.05
Literature Ukrainian	7.3±1.8	7.8±1.9	–1	>0.05

Language Russian	8±1	7.3±2.1	0.6	>0.05
Literature Russian	8.8±0.6	7.4±1.6	1.4	>0.05
Language Foreign	7.5±1.8	7.3±1.9	0.4	>0.05
Literature Foreign	6.9±2	7.2±2.2	–0.4	>0.05
History of Ukraine	7.4±1.8	6.9±1.8	1	>0.05
History of World	7.7±1.9	7.3±1.8	0.8	>0.05
Law	7.4±1.8	7.7±2	–0.5	>0.05

NEUROPSYCHIATRIC DATA

Diseases of nervous system and the mental and behavioral disorders in children have been diagnosed by clinical examination using the ICD-10 criteria. The results presented in table 3.16 show that prenatally exposed children have more neuropsychiatric disorders than the control children.

Table 30. Diseases of Nervous System (G) and Mental and Behavioral Disorders (F) according to the ICD-10 of all children

Disease or disorder	Exposed children (n=154)	Control children (n=143)	χ^2	p
Diseases of Nervous System				
Neurologically healthy	86 (55.8%)	117 (81.8%)	23.1	<0.001
Unconfident indication of epilepsy (G40)	12 (7.8%)	2 (1.4%)	6.7	<0.01
Migraine (G43)	5 (3.2%)	0	4.7	<0.05
Other headache syndromes (G44)	42 (27.3%)	23 (16.1%)	5.4	<0.05
Sleep disorders (G47)	5 (3.2%)	2 (1.4%)	1.1	>0.05
Cerebral palsy (G80)	2 (1.3%)	0	1.9	>0.05
Other disorders of autonomous nervous system (G90)	4 (2.6%)	0	3.8	<0.05
Neurological comorbidity	6 (3.9%)	1 (0.7%)	3.3	>0.05
Mental and Behavioral Disorder				
Mentally healthy	20 (13%)	72 (50.3%)	48.4	<0.001
Organic mental disorders (F06 & F07)	32 (20.8%)	9 (6.3%)	13.1	<0.001
Neurotic, stress-related and somatoform disorders (F40–F48)	72 (46.7%)	42 (29.4%)	9.5	<0.01
Non-organic sleep disorders (F51)	8 (5.2%)	5 (3.5%)	0.5	>0.05
Mental retardation (F70)	3 (1.9%)	1 (0.7%)	0.8	>0.05
Disorders of psychological development (F80–F89)	10 (6.5%)	0	9.6	<0.01
Childhood behavioural and emotional disorders (F90–F98)	37 (24%)	23 (16.1%)	2.9	>0.05
Mental comorbidity	28 (18.2%)	9 (6.3%)	9.6	<0.01

Among children without moderate to very severe confounding factors children irradiated *in utero* again have even more neuropsychiatric disorders in comparison to the control children, the data relation did not change in comparison to table 3.16 (table 30).

Table 31. Diseases of the Nervous System (G) and Mental and Behavioral Disorders (F) according to the ICD-10 in children without moderate to very severe confounding factors

Disease or disorder	Exposed children (n=121)	Control children (n=77)	χ^2	p
Diseases of the Nervous System				
Neurologically healthy	73 (60.3%)	66 (85.7%)	14.5	<0.001
Unconfident indication of epilepsy (G40)	9 (7.4%)	1 (1.3%)	3.7	<0.05
Migraine (G43)	3 (2.5%)	0	1.9	>0.05
Other headache syndromes (G44)	31 (25.6%)	10 (13%)	4.6	<0.05
Sleep disorders (G47)	4 (3.3%)	0	2.6	>0.05
Other disorders of autonomous nervous system (G90)	3 (2.5%)	0	1.9	>0.05
Neurological comorbidity	2 (1.6%)	0	1.3	>0.05
Mental and Behavioral Disorder				
Mentally healthy	19 (15.7%)	45 (58.4%)	39.3	<0.001
Organic mental disorders (F06 & F07)	20 (16.5%)	3 (3.9%)	7.3	<0.01
Neurotic, stress-related and somatoform disorders (F40–F48)	56 (46.3%)	20 (26%)	8.2	<0.01
Non-organic sleep disorders (F51)	6 (4.9%)	3 (3.9%)	0.12	>0.05
Mental retardation (F70)	1 (0.8%)	0	0.64	>0.05
Disorders of psychological development (F80–F89)	9 (7.4%)	0	6	<0.05
Childhood behavioral and emotional disorders (F90–F98)	31 (25.6%)	9 (11.7%)	5.7	<0.05
Mental comorbidity	21 (17.2%)	3 (3.9%)	8	<0.01

MENTAL HEALTH OF MOTHERS

There are no differences in verbal IQ of mothers in both groups, assessed by vocabulary subtest of WAIS (table 32). Thus, the deterioration of the verbal IQ of the exposed children cannot be explained by the influence of the verbal IQ of their mothers, although there is a natural tendency of the vIQ of the children in both groups to increase with increase of the verbal subtest of WAIS of the mothers.

Table 32. Mother's intelligence (Vocabulary subtest of WAIS)

	Exposed group from Pripyat (n=132)	Comparison group from Kiev (n=77)	t	p
Vocabulary subtest of WAIS [M±SD]	41.4±12.8	40.4±14.7	0.5	>0.05

Note: Vocabulary subtest of WAIS is a subtest of verbal IQ

Mothers of children evacuated from Pripyat experienced much more real stress events (evacuation, lack of information about relatives, migration, difficulties of medical care, etc.) (Table 33).

Table 33. Evaluation of stress events of the mothers (by questionnaire of SCRM*)*

	Exposed group from Pripyat (n=136)	Comparison group from Kiev (n=62)	t	p
Score of stress-factors [M±SD]	15.8±6.1	4.7±5.5	12.1	<0.001

For the assessment of mother's mental health possibly related to stress the following tests were used:

- *Zung Self-Rating Depression Scale (SDS)* — measures unmasked depression
- *Impact of Events Scale (IES)* —posttraumatic stress disorders (PTSD) related to the Chernobyl accident
- *Irritability, Depression, Anxiety Scale (IDA)* —arousal associated with PTSD
- *General Health Questionnaire (GHQ-28)* —somatoform disorders (GHQ-28A), anxiety/ insomnia (GHQ-28B), social dysfunction (GHQ-28C), and severe depression (GHQ-28D)

There are significant mental health problems in mothers of children evacuated from Pripyat (Table 34):

Table 34. Mental health data of the mothers

Scale	Exposed group from Pripyat [M±SD]	Comparison group from Kiev [M±SD]	t	p
Zung Self-Rating Depression Scale (SDS)	n=112 54.6±10.8	n=74 47.7±12.7	4	<0.001
Impact of Events Scale (PTSD)	n=124 19.7±10.6	n=71 12.5±10	4.6	<0.001
Irritability, Depression, Anxiety Scale (IDA)	n=112 4.8±2.7	n=69 3.8±2.8	2.3	=0.02
GHQ-28A (somatoform disorders)	n=134 10±4.6	n=80 7.3±3.9	4.3	<0.001
GHQ-28B (anxiety/ insomnia)	n=134 8±5.1	n=80 5.5±4.3	3.7	<0.001
GHQ-28C (social dysfunction)	n=134 8.5±3.2	n=80 7.6±3.1	2.1	=0.04
GHQ-28D (severe depression)	n=134 4.3±4.2	n=80 2.9±3.2	2.5	=0.01
GHQ-28 (by Likert: 0–1–2–3)	n=134 30.6±14.1	n=80 23.2±10.9	4	<0.001
GHQ-28 (case-no case: 0–0–1–1)	n=134 8.3±6.9	n=80 5.1±5.1	3.6	<0.001

- *PTSD*: in exposed mothers the scores of both PTSD scales (IES and IDA) are significantly higher than in controls.
- *Somatoform disorders*: according to subscale GHQ-28A evacuated mothers experience more somatoform disorders.
- *Anxiety/Insomnia*: according to subscale GHQ-28B evacuated mothers experience more anxiety symptoms and insomnia.

- *Social dysfunction*: according to subscale GHQ-28C evacuated mothers experience more social problems.

- *Depression in exposed mothers*: the averaged scores of SDS reveal a tendency for depression (50–59 scores corresponding to mild depression), whereas mothers from Kiev do not show depressions at all (<50); according to subscale GHQ-28D evacuated mothers experience rather severe depression symptoms.

DOSE EFFECT RELATIONS

Dose dependence of the IQ

Correlation between IQ and prenatal doses for the children of both study groups are presented in Table 35 and 36. Table 35 shows the results of combined analysis of both groups together. The control group is in the combined cohort the group with the low exposure dose and has thus by presenting half of the cohort a considerable weight. Table 36 shows the same analysis but with only the exposed group of children. The weak, but statistically significant correlation of the prenatal dose with IQ reduction demonstrated in table 35 disappeared, however, in the analysis shown in table 3.6, therefore only the exposed children were analyzed. This effect is a hint at a possible discrepancy between both groups, since in identical cohorts, where all parameters are equal with the exception of the radiation dose, the correlation would not depend on the presence or absence of the low-dose group. The IQ of the control group is on average higher than the IQ of children of the exposed group with low exposure doses, comparable to those of the control children (fig. 10), indicating that the exposed children demonstrate a verbal disadvantage irrespectively of the received dose. Fig 11 demonstrate the same effect for the doses to the thyroid. There is no correlation of the verbal IQ with the thyroid doses of the exposed children.

Table 35. Correlations between IQ and prenatal doses in the combined groups

Variable	IQ	vIQ	pIQ	pIQ—vIQ
ICRP Publication 88				
Dose *in utero* on brain	r=–0.16 p=0.006	r=–0.21 p<0.001	r=–0.07 p>0.05	r=0.15 p=0.01
Dose on embryo and fetus	r=–0.16 p=0.007	r=–0.23 p<0.001	r=–0.04 p>0.05	r=0.2 p=0.001
Dose *in utero* on thyroid	r=–0.1 p>0.05	r=–0.16 p=0.009	r=–0.01 p>0.05	r=0.15 p=0.01
Thyroid dose of mother assumed to be equal to fetal thyroid dose				
Dose *in utero* on brain	r=–0.19 p=0.004	r=–0.25 p<0.001	r=–0.07 p>0.05	r=0.2 p=0.002
Dose on embryo and fetus	r=–0.19 p=0.004	r=–0.26 p<0.001	r=–0.07 p>0.05	r=0.2 p=0.002
Dose *in utero* on thyroid	r=–0.21 p=0.004	r=–0.31 p<0.001	r=–0.06 p>0.05	r=0.25 p<0.001

Table 36. Correlations between IQ and prenatal doses in only the exposed group

Variable	IQ	vIQ	pIQ	pIQ—vIQ
ICRP Publication 88				
Dose *in utero* on brain	r=0.06 p>0.05	r=0.13 p>0.05	r=–0.01 p>0.05	r=–0.15 p>0.05

Dose on embryo and fetus	r=0.11 p>0.05	r=0.15 p>0.05	r=0.05 p>0.05	r=–0.09 p>0.05
Dose *in utero* on thyroid	r=0.11 p>0.05	r=0.14 p>0.05	r=0.06 p>0.05	r=–0.06 p>0.05
Thyroid dose of mother assumed to be equal to fetal thyroid dose				
Dose *in utero* on brain	r=0.05 p>0.05	r=0.09 p>0.05	r=0.01 p>0.05	r=–0.08 p>0.05
Dose on embryo and fetus	r=0.05 p>0.05	r=0.09 p>0.05	r=0.001 p>0.05	r=–0.09 p>0.05
Dose *in utero* on thyroid	r=–0.06 p>0.05	r=–0.06 p>0.05	r=–0.05 p>0.05	r=–0.005 p>0.05

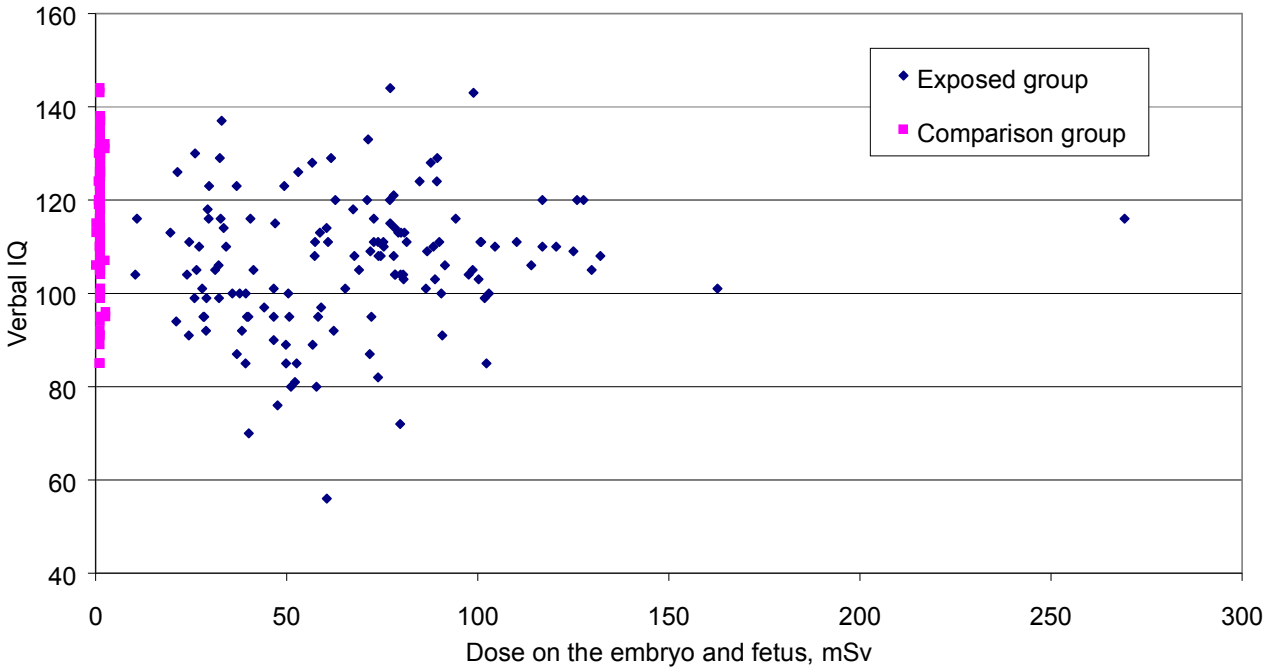

Fig10. Dependence of verbal IQ on the dose on the embryo and fetus (ICRP 88)

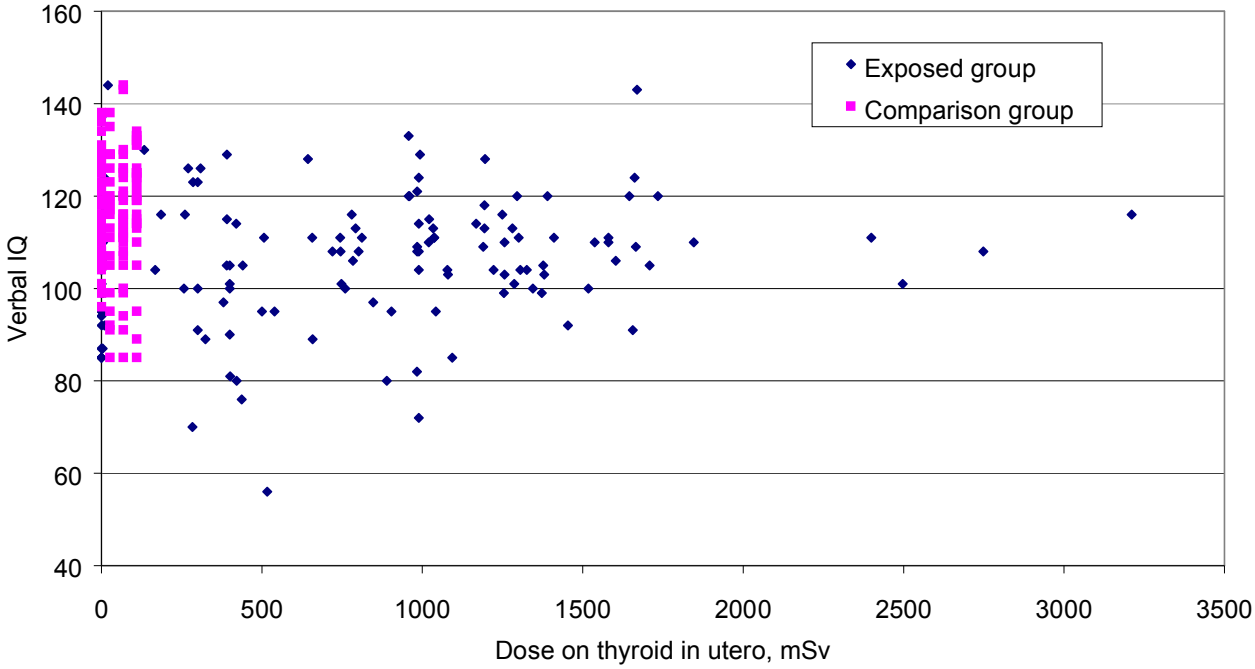

Fig. 11. Dependence of verbal IQ on the thyroid dose in utero *(ICRP 88)*

Another important result is the IQ discrepancy, the difference between performance and verbal IQ. In children these discrepancies are of clinical significance, if they exceed the value of 25. This is the case in 19 instances of the exposed children and in 6 instances of the control group. The exposed children demonstrated in only 3 cases a negative discrepancy (< –25), in all the other cases performance IQ was higher than verbal IQ, resulting in a positive discrepancy (<25). Generally the pIQ-vIQ discrepancies are randomly distributed in either direction in the control group, but in the exposed group mainly to the positive values: IQ discrepancy > 0 in 56 instances from 116 in the control group (without children with confounding factors) and in 100 instances from 122 in the exposed group (without children with confounding factors). This means in other words, that in the exposed group half of the children (57) show IQ discrepancies < 0 whereas in the exposed group only 19 children; in each group are 3 children with a discrepancy of 0. Plotting the cases of IQ discrepancy higher than 25 point against prenatal fetal dose gives a positive correlation r=0.53 (p=0.018) (figure 12). The power of this correlation between the discrepancy >25 and fetal doses assessed by the model of ICRP Publication 88 is increasing with increasing discrepancy: at pIQ-vIQ>27 (n=11), correlation with the fetal dose is r=0.78 (p<0.004), at pIQ-vIQ≥30 (n=9), correlation with fetal dose is r=0.93 (p<0.001) and correlation with the *in utero* thyroid dose by ICRP-88 is here r=0.75 (p<0.02) in 9 cases (figure 13). Below the discrepancy of 25 there is no correlation with dose observed.

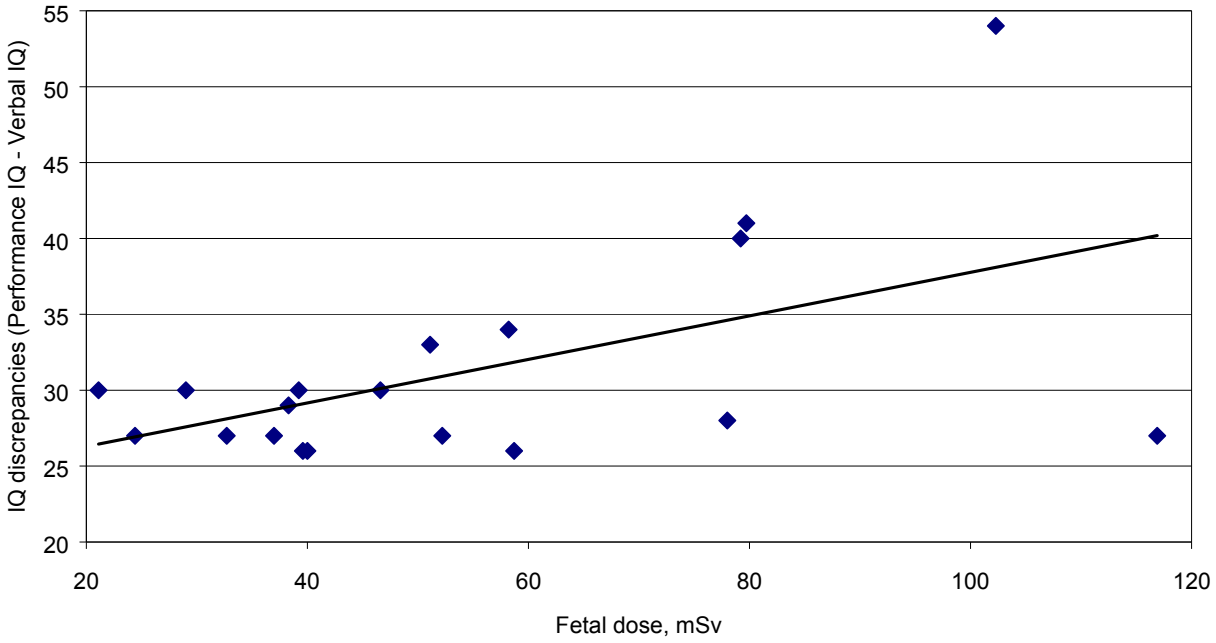

Fig. 12. Dependence of IQ discrepancy (>25 points) on the fetal dose (with trend line)

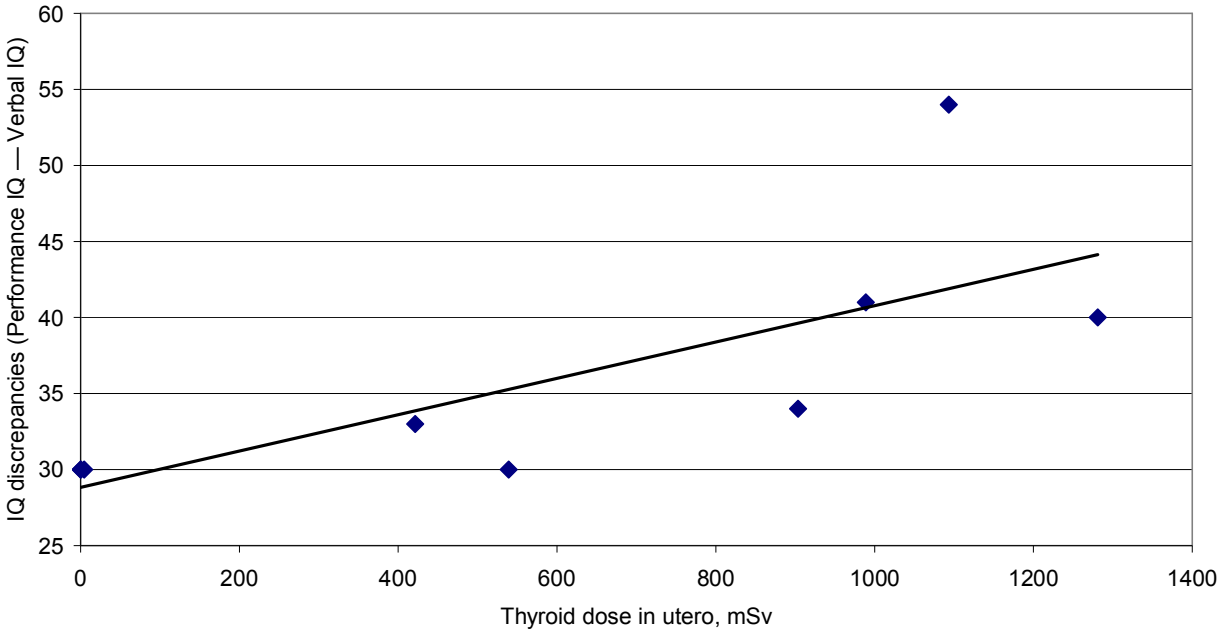

Fig. 13. Dependence of IQ discrepancy (≥30 points) on the thyroid dose in utero *(ICRP 88)*

. Dose dependence of the results of the Achenbach test

Correlation between the main results of the Achenbach test and prenatal doses for all children of both study groups are presented in Table 37 and 3.8. Table 37 shows the results of combined analysis of exposed and control children together. Table 3.8 shows the same analysis but for only the exposed group of children. A correlation between doses and competence or problem scores of CBCL could not be established. The weak, but statistically significant correlations of the

prenatal doses (calculated by the former model) with increasing total problem score, assessed in the YSR by children themselves, demonstrated in table 37 disappeared however in the analysis shown in table 38.

Table 37. Correlations between main results of the Achenbach test and prenatal doses in the combined groups

Variable	Total competence score (CBCL)	Total problem score (CBCL)	Total problem score (YSR)
ICRP Publication 88			
Dose *in utero* on brain	r=0.02; p>0.05	r=0.11; p>0.05	r=0.14; p>0.05
Dose on embryo and fetus	r=0.06; p>0.05	r=0.08; p>0.05	r=0.16; p>0.05
Dose *in utero* on thyroid	r=0.09; p>0.05	r=0.08; p>0.05	r=0.12; p>0.05
Thyroid dose of mother assumed to be equal to fetal thyroid dose			
Dose *in utero* on brain	r=0.03; p>0.05	r=0.14; p>0.05	r=0.24; p=0.01
Dose on embryo and fetus	r=0.03; p>0.05	r=0.13; p>0.05	r=0.24; p=0.008
Dose *in utero* on thyroid	r=0.07; p>0.05	r=0.12; p>0.05	r=0.27; p=0.009

Table 38. Correlations between main results of the Achenbach test and prenatal doses in the exposed group

Variable	Total competence score (CBCL)	Total problem score (CBCL)	Total problem score (YSR)
ICRP Publication 88			
Dose *in utero* on brain	r=0.06; p>0.05	r=0.02; p>0.05	r=0.007; p>0.05
Dose on embryo and fetus	r=0.18; p>0.05	r=-0.05; p>0.05	r=0.02; p>0.05
Dose *in utero* on thyroid	r=0.25; p=0.04	r=-0.04; p>0.05	r=0.01; p>0.05
Thyroid dose of mother assumed to be equal to fetal thyroid dose			
Dose *in utero* on brain	r=0.03; p>0.05	r=0.23; p>0.05	r=0.04; p>0.05
Dose on embryo and fetus	r=0.04; p>0.05	r=0.23 p>0.05	r=0.04; p>0.05
Dose *in utero* on thyroid	r=0.07; p>0.05	r=0.07; p>0.05	r=-0.02; p>0.05

Dose dependence of the neuropsychiatric investigations

The children from the exposed group were separated into the healthy group with 17 children and the group with neuropsychiatric disorders. (n=137). There is no clear interaction between prenatal doses and the neuropsychiatric disorders, as it is shown in table 3.25.

Table 39. Prenatal doses influence on the neuropsychiatric disorders in the exposed group

Dose (ICRP Publication 88)	Healthy children (n=17)	Children with neuropsychiatric disorders (n=137)	t	p
Dose *in utero* on brain, mSv (M±SD)	19.5±5.3	19.2±11.8	0.1	>0.05
Dose on embryo and fetus, mSv	63±29.4	65.7±34.5	–0.3	>0.05
Dose *in utero* on thyroid, mSv	650.7±537.3	773.3±638.1	–0.7	>0.05

CORRELATION OF THE CHILD DATA WITH THE MENTAL HEALTH OF THE MOTHERS

Intelligence quotient of the children and the mental health of the mothers

Correlation between children IQ and mothers' verbal abilities for the children of both study groups are presented in Table 40 and 41. Table .40 shows the results of the control children. Table 41 shows the same analysis but for the exposed group of children. There is weak to moderate statistically significant correlations of the mothers' verbal abilities, assessed by the vocabulary subscale of WAIS, with the full scale, verbal and performance IQ of the children. IQ discrepancies, however, do not correlate with mothers verbal abilities. The observed correlations are slightly higher in the exposed children.

Table 40. Correlations between children's IQ and mothers' verbal abilities in the control group

IQ (children,	IQ	vIQ	pIQ	pIQ—vIQ
Vocabulary subscale, WAIS (mothers, n=77)	r=0.22; p=0.06	r=0.16; p>0.05	r=0.25; p<0.05	r=0.02; p>0.05

Table 41. Correlations between children's IQ and mothers' verbal abilities in the exposed group

IQ (children,	IQ	vIQ	pIQ	pIQ—vIQ
Vocabulary subscale, WAIS (mothers, n=132)	r=0.31; p<0.001	r=0.36; p<0.001	r=0.19; p<0.05	r=–0.12; p>0.05

Correlation between children's IQ and mothers' mental health for the children of both study groups are presented in Table 41 and 42. Table 41 shows the results of analysis of control children. Table 42 shows the same analysis but of the exposed group of children.
There are weak statistically significant correlations of the mothers' mental health deterioration, assessed by IES and GHQ-28, with the decrease of full scale and performance IQ of the children. Verbal IQ, however, does not correlate with mothers' mental health. IQ discrepancies decrease in proportion to the mothers' mental health deterioration in the exposed group.

Table 42. Correlations between children's IQ and mothers' mental health in the control group

Variables	IQ of children (n=136)			
	IQ	VIQ	PIQ	PIQ—vIQ
Zung Self-Rating Depression Scale (SDS) (n=74)	r=0.1; p>0.05	r=0.1; p>0.05	r=–0.0001; p>0.05	r=–0.11; p>0.05
Impact of Events Scale (PTSD) (n=71)	r=–0.01; p>0.05	r=0.002; p>0.05	r=–0.04; p>0.05	r=–0.03; p>0.05
Irritability, Depression, Anxiety Scale (IDA) (n=69)	r=0.12; p>0.05	r=0.09; p>0.05	r=0.1; p>0.05	r=–0.01; p>0.05
GHQ-28A (somatoform	r=0.12; p>0.05	r=0.12; p>0.05	r=0.02; p>0.05	r=–0.11; p>0.05

disorders) (n=80)				
GHQ-28B (anxiety/ insomnia) (n=80)	r=0.11; p>0.05	r=0.08; p>0.05	r=0.05; p>0.05	r=–0.04; p>0.05
GHQ-28C (social dysfunction) (n=80)	r=0.03; p>0.05	r=0.04; p>0.05	r=–0.04; p>0.05	r=–0.07; p>0.05
GHQ-28D (severe depression) (n=80)	r=0.11; p>0.05	r=0.14; p>0.05	r=0.09; p>0.05	r=–0.07; p>0.05
GHQ-28, (n=80) (by Likert: 0–1–2–3)	r=0.09; p>0.05	r=0.1; p>0.05	r=–0.03; p>0.05	r=–0.12; p>0.05
Stress-factors	r=–0.04; p>0.05	r=–0.01;	r=–0.07; p>0.05	r=–0.04;

Table 43. Correlations between children's IQ and mothers' mental health in the exposed group

Variables	IQ of children (n=140)			
	IQ	VIQ	PIQ	PIQ—vIQ
Zung Self-Rating Depression Scale (SDS) (n=112)	r=–0.08; p>0.05	r=–0.06; p>0.05	r=–0.08; p>0.05	r=–0.04; p>0.05
Impact of Events Scale (PTSD) (n=124)	r=–0.07; p>0.05	r=0.04; p>0.05	r=–0.15; p=0.05	r=–0.21; p<0.05
Irritability, Depression, Anxiety Scale (IDA) (n=124)	r=0.06; p>0.05	r=0.14; p>0.05	r=–0.02; p>0.05	r=–0.16; p>0.05
GHQ-28A (somatoform disorders) (n=134)	r=–0.16; p>0.05	r=–0.08; p>0.05	r=–0.2; p<0.05	r=–0.15; p>0.05
GHQ-28B (anxiety/ insomnia) (n=134)	r=–0.18; p<0.05	r=–0.08; p>0.05	r=–0.23; p<0.01	r=–0.18; p<0.05
GHQ-28C (social dysfunction) (n=134)	r=0.006; p>0.05	r=0.02; p>0.05	r=–0.01; p>0.05	r=–0.03; p>0.05
GHQ-28D (severe depression) (n=134)	r=–0.17; p>0.05	r=–0.09; p>0.05	r=–0.21; p<0.05	r=–0.15; p>0.05
GHQ-28 (by Likert: 0–1–2–3) (n=134)	r=–0.16; p=0.06	r=–0.08; p>0.05	r=–0.21; p<0.05	r=–0.16; p=0.07
Stress-factors (n=136)	r=–0.06; p>0.05	r=0.008; p>0.05	r=–0.12; p>0.05	r=–0.15; p>0.05

Emotional and behavioral disorders of the children and mental health of the mothers

Correlation between the main results of the Achenbach test and the mothers' mental health, for the children of both study groups, is presented in Table 44 and 45. Table 44 shows the results for the control children. Table 45 shows the same analysis but for the exposed group of children. The children with confounding factors are included, their exclusion would not change the result. The moderate statistically significant correlations of the mother's depression (SDS), PTSD and mental health deterioration (GHQ-28) with increasing total problem score, assessed by mothers (CBCL) and children (YSR) are demonstrated. The total competence score does not show any correlations with mothers' mental health, however.

Table 44. Correlations between main results of the Achenbach test and mothers' mental health in the control group

Variables	Total competence score (CBCL) (n=72)	Total problem score (CBCL) (n=72)	Total problem score (YSR) (n=77)
Zung Self-Rating Depression Scale (SDS) (n=74)	r=–0.05; p>0.05	r=0.6; p<0.001	r=0.21; p>0.05
Impact of Events Scale (PTSD) (n=71)	r=0.15; p>0.05	r=0.4; p<0.001	r=0.24; p>0.05
Irritability, Depression, Anxiety Scale (IDA) (n=69)	r=0.14; p>0.05	r=0.42; p<0.001	r=0.16; p>0.05
GHQ-28A (somatoform disorders) (n=80)	r=–0.1; p>0.05	r=0.44; p<0.001	r=0.22; p>0.05
GHQ-28B (anxiety/ insomnia) (n=80)	r=–0.08; p>0.05	r=0.56; p<0.001	r=0.33; p<0.01
GHQ-28C (social dysfunction) (n=80)	r=–0.11; p>0.05	r=0.35; p=0.001	r=0.07; p>0.05
GHQ-28D (severe depression) (n=80)	r=0.001; p>0.05	r=0.37; p<0.01	r=0.04; p>0.05
GHQ-28 (by Likert: 0–1–2–3) (n=80)	r=–0.12; p>0.05	r=0.57; p<0.001	r=0.25; p<0.05
Stress-factors (n=62)	r=0.04; p>0.05	r=0.14; p>0.05	r=0.005; p>0.05

Table 45. Correlations between main results of the Achenbach test and mothers' mental health in the exposed group

Variable	Total competence score (CBCL) (n=76)	Total problem score (CBCL) (n=67)	Total problem score (YSR) (n=70)
Zung Self-Rating Depression Scale (SDS) (n=112)	r=–0.06; p>0.05	r=0.49; p<0.001	r=0.25; p=0.05
Impact of Events Scale (PTSD) (n=124)	r=0.06; p>0.05	r=0.26; p=0.05	r=0.06; p<0.05
Irritability, Depression, Anxiety Scale (IDA) (n=124)	r=–0.14; p>0.05	r=0.54; p<0.001	r=0.17; p>0.05
GHQ-28A (somatoform disorders) (n=134)	r=–0.04; p>0.05	r=0.21; p>0.05	r=–0.01; p>0.05

GHQ-28B (anxiety/ insomnia) (n=134)	r=0.03; p>0.05	r=0.27; p<0.05	r=0.03; p>0.05
GHQ-28C (social dysfunction) (n=134)	r=–0.06; p>0.05	r=0.26; p<0.05	r=0.08; p>0.05
GHQ-28D (severe depression) (n=134)	r=–0.1; p>0.05	r=0.23; p>0.05	r=0.03; p>0.05
GHQ-28 (by Likert: 0–1–2–3) (n=134)	r=0.04; p>0.05	r=0.28; p<0.05	r=0.04; p>0.05
Stress-factors (n=136)	r=–0.01; p>0.05	r=0.09; p>0.05	r=–0.09; p>0.05

Worsening of the mental health of the mothers is closely associated with emotional and behavioral disorders in children of both groups assessed by the problem score of CBCL. This can be explained by a projection of the psychological problems of the mothers on their children leading to a psychosomatic "victim circle". The competence score is reflecting activity and socialization of children and appear to be independent from the problems of the mothers.

According to the evaluation of the children of both groups (YSR test) they have considerable fewer problems than suggested by the evaluation of their mothers (CBCL test). The reason could be a specifity of the education in the GUS countries: the children were overprotected and each little symptom is registered by the parents and possibly over interpreted. This is in contrast to the Western traditions of education, where the independence of children is encouraged. Thus, in Germany, children reported more symptoms than their parents did (Seiffge-Krenke I, Kollmar F,1998). At the same time with increased levels of depression mothers tended to report more internalizing problems compared to the children (Berg-Nielsen TS et al 2003).

Neuropsychiatric data of the children and the mental health of the mothers

There are weak, but statistically significant relationships between the mental health of the mothers and the neuropsychiatric disorders in children. As it is shown in table 3.32, among the mothers of the children of the exposed group with the neuropsychiatric disorders there are much more depression (SDS and GHQ-28D) and somatization (GHQ-28A), as well as mental disorders, in general (GHQ-28).

Table 46. Relationships between the mental health of the mothers with the neuropsychiatric disorders in children of the exposed group

Tests of the mothers	Healthy children (n=17)	Children with neuropsychiatr ic disorders (n=137)	t	p
Zung Self-Rating Depression Scale (SDS) *(M±SD)*	46.3±6.8	55.7±10.8	–3	<0.01
Impact of Events Scale (PTSD) *(M±SD)*	19.8±10.8	19.7±10.6	0.02	>0.05
Irritability, Depression, Anxiety Scale (IDA) *(M±SD)*	5±3.4	4.7±2.6	0.32	>0.05
GHQ-28A (somatoform disorders)	7±4.5	10.4±4.5	–2.8	<0.01
GHQ-28B (anxiety/ insomnia) *(M±SD)*	5.2±3.8	8.4±5.1	–2.3	<0.05
GHQ-28C (social dysfunction) *(M±SD)*	7.7±2.8	8.6±3.2	–1.07	>0.05
GHQ-28D (severe depression) *(M±SD)*	2.2±2.2	4.5±4.3	–2.1	<0.05
GHQ-28 (by Likert: 0–1–2–3) *(M±SD)*	22.2±10.6	31.7±14.2	–2.6	<0.01
Stress-factors *(M±SD)*	14.3±5.7	16±6.2	–1.1	>0.05

A similar situation is observed in the comparison group. As table 3.33 shown, there are more depression (SDS), somatization (GHQ-28A), anxiety (GHQ-28B), as well as mental disorders in general (GHQ-28) among the mothers of the children with neuropsychiatric disorders, than among mothers of healthy children.

Table 47. Relationships between the mental health of the mothers with the neuropsychiatric disorders in children of the comparison group

Tests of the mothers	Healthy children (n=67)	Children with neuropsychiatric disorders (n=76)	t	p
Zung Self-Rating Depression Scale (SDS) *(M±SD)*	44.4±13.5	50.2±11.7	–1.97	=0.051
Impact of Events Scale (PTSD) *(M±SD)*	11±9.7	13.9±10.2	–1.2	>0.05
Irritability, Depression, Anxiety Scale (IDA) *(M±SD)*	3.7±2.9	3.9±2.8	–0.4	>0.05
GHQ-28A (somatoform disorders)	6.3±3.8	8.3±3.7	–2.3	<0.05
GHQ-28B (anxiety/insomnia) *(M±SD)*	4±3.9	6.7±4.2	–3.2	<0.01
GHQ-28C (social dysfunction) *(M±SD)*	7.3±2.7	7.8±3.4	–0.7	>0.05
GHQ-28D (severe depression) *(M±SD)*	2.5±2.9	3.3±3.4	–1.2	>0.05
GHQ-28 (by Likert: 0–1–2–3) *(M±SD)*	20±10.1	26±11	–2.5	<0.05
Stress-factors *(M±SD)*	5.2±6.4	4.3±4.7	0.7	>0.05

Discussion

The UNSCEAR Report-2000, Annex J: Exposure and Effects of the Chernobyl Accident (*61*) touched the problem of the psychological development of the children who were exposed to radiation from the Chernobyl accident *in utero* basing on a one publication only (*21*) where cognitive, emotional and behavioural disorders in prenatally irradiated children were attributed exclusively to unfavourable social-psychological and social-cultural factors.

The WHO Pilot Project «Brain Damage in Utero» International Advisory Board assumes that prenatal exposure to the Chernobyl disaster can give rise to a dysfunctional child, either because of organic damage to the developing brain or because of the disturbed psychosocial milieu. Indeed, intelligence peculiarities, neurophysiological abnormalities, and neuromental health deterioration in the children acutely prenatally exposed to both radiation and stress are etiologically multifactorial. In spite of the children were affected by multiple exposure including prenatal stress and current social, economical, and medical problems in their families, the «dose—effects» relationships concerning both intelligence and EEG-parameters, which are the most marked at the critical periods of cerebrogenesis, testify to significant contribution of prenatal irradiation into the brain damage.

This study confirms and develops the results of the WHO Pilot Project «Brain Damage in Utero» (*15, 17*) and relevant studies (*18–22*) concerning mental health and intelligence deterioration in children exposed *in utero* as a result of the Chernobyl disaster. Unlike to the study (*21*) where the authors did not find evidences of the contribution of prenatal irradiation on the children's intelligence deterioration, we have done it. The differences between the results of the study (*21*) and ours we can explain by follows: 1) different sample: we examined acutely exposed in 1986 children, but they — those resettled in 5–7 years after the disaster, and 2) different measures: they analysed full scale IQ only, but we — verbal IQ (including subtests), performance

IQ (including subtests), WISC performance/verbal discrepancies, and full scale IQ. Exactly deterioration of verbal IQ and WISC performance/verbal discrepancies, with verbal decrements, were in proportion to the foetal thyroid dose.

Our data do not confirm the results of the studies (*23–25*) concerning similarity and normality of mental and physical health, intelligence similarity of acutely prenatally exposed children in the Chernobyl exclusion zone evacuated to Kiev and children-classmates living in Kiev, as well as that the most important risk factors were maternal somatization and Chernobyl-related stress. A possible explanation of the differences between the results of the studies (*23–25*) and ours study seems to be as follows: 1) Restricted neuropsychological battery for children's intelligence assessment allowed them (*25*) to measure spatial intelligence only, which indeed looks likely to be intact; 2) An absence of clinical neuropsychiatric examination by ICD-10 or DSM-IV criteria and screening-like physical examination in the works (*23, 24*) resulted their conclusion concerning evacuee children's mental and physical welfare to be the point at issue. 3) Inadequate using of gestation months for analysis, but not periods of cerebrogenesis (0–7, 8–15, 16–25, and 26+ weeks after fertilisation), and possible uncertainties in the gestation term estimation did not enable in the studies (*23–25*) to estimate the most important single factor in determining the nature of the insult to the developing brain from ionising radiation (*2*) — exposure in critical and «non-critical» periods of prenatal development. 4) An absence of dosimetrical data for both children-evacuee and non-evacuee did not enable them (*23–25*) to study a possible dose—effect relationship and to estimate the contribution of ionising radiation towards intelligence and psychological development of the children. However, the most important reason of the differences between their and our studies seems to be the different paradigms of the researches: psychosocial model of the studies (*23–25*), and neuropsychiatric or neurobilogical — in us.

It should be noted the limitations and uncertainties of this study. First of all, there is the problem of a representativeness of the sample taking into account a possible bias towards «improving selection», where some disabled children due to neuropsychiatric problems could be dropped out from the study. Ideally, the all parentally exposed children, or at least all those who had been evacuated from the Chormobyl exclusion zone, should be involved in the study. The sample — evacuee in Kiev and non-evacuee classmates living in Kiev — looks quite good from the point of view of similarity of informational and urban saturation environment, providing as much as possible in Ukraine and similar for the all examined children opportunity for intellectual development. On the other hand, classmates from Kiev are not exactly «non-irradiated» group. Moreover, again they should be randomised from population sample in order to predict the bias due to both the noted above «improving selection», and «deteriorating selection» when, for instance infants prodigy attending special advanced schools, are also out of the sample. It should be also stressed the uncertainties of individual doses estimation due to an absence at present of generally accepted agreement concerning model of foetal dose assessment. Probably, like in Japan, there will be further new dosimetrical systems and reassessment of psychometrical, neurophysiological and other data. As it was mentioned above, our sample corresponds to the Japanese sample (2): prenatally exposed to atomic bomb radiation survivors of the foetal dose category less than 0.01 Gy (n=1,201) — to the Ukrainian comparison group, and those of the dose category 0.01–0.09 Gy (n=322) — to the Ukrainian acutely exposed group. However, there is an extremely important radiological difference between the Japanese and Ukrainian samples — prenatal exposure to radioactive isotopes of iodine. The prenatally exposed to atomic bomb had not been irradiated by radioiodine, but the prenatally exposed children as a result of the Chernobyl disaster received quite significant foetal thyroid doses. This fact makes to be difficult to extrapolate the all data (risks, thresholds of the effects, etc.) from the Japanese sample on the Chernobyl one. It seems, that the acutely prenatally exposed children at the Chornoby exclusion zone is an unique sample that should be used for reassessment of risks of prenatal irradiation at radiation accidents on nuclear reactors.

The results of this study agree with the Japanese studies concerning 1) dose related full scale IQ reduction (*10*), 2) an increase of paroxysmal disorders (*62*), 3) critical periods of cerebrogenesis — 8–15 and, especially, 16–25 weeks after fertilisation (*2*). The most vulnerability of the brain under exposure at 16–25, but not 8–15 weeks after fertilisation, as in the Japanese sample, we can explain by 1) maximal radioiodine concentration in foetal thyroid at about the 20–25 weeks (*33*), 2) more «delicate» than in atomic bomb survivors intelligence disturbances that corresponds exactly to the events of the brain creation at 16–25 weeks after fertilisation (neuronal differentiation, limbic system and brain asymmetry forming, apoptosis beginning etc. (*58–60*)). An absence of dramatical increase of mental retardation, especially its severe form, as well as microcephalia obviously can be explained by significantly lower than that in atomic bomb survivors foetal doses of irradiation.

Following recommendation of Shull & Otake (*63*) concerning future studies of the prenatally exposed survivors and the WHO Pilot Project «Brain Damage in Utero» International Advisory Board for the second phase of the project, we used QEEG and WISC. This resulted in interesting findings of verbal IQ reduction and WISC performance/verbal discrepancies, with verbal decrements, which were in proportion to the foetal thyroid dose, especially among those children exposed at 16–25 weeks after fertilisation. Previously we reported (*16, 26, 27*) about TSH level grows with foetal thyroid dose increase with a 0.3 Sv threshold. Probably, these children had been affected by intrauterine hypothyroidism resulted in intelligence disturbances during the life. Obviously, an international psychoendocrine study should be organise for exploration of functions of the pituitary-thyroid system as a possible biological basis of mental health problem in children irradiated in utero as a result of the Chernobyl disaster.

The prenatally acutely exposed children have quite distinguished pattern of summarised EEG spectral power (increased δ- and β- and decreased θ- and α-power), in comparison with both the classmates and literature normative data (*41, 55*). Foetal dose and thyroid foetal dose were the predictors of this QEEG-pattern, especially among children irradiated at 16–25 weeks after fertilisation.

Neurophysiological abnormalities together with intelligence disturbances, both dose-related, especially at 16–25 weeks after fertilisation, as well as a «concentration» of the most severe neuropsychiatric disorders among the children exposed at the critical periods of cerebrogenesis, can testify to the developing brain abnormalities due to multiple factors with effects of prenatal irradiation.

Verbal IQ deterioration together with lateralisation of abnormal electrical activity to the left hemisphere support our previous report about the predominance of the left hemisphere dysfunction in prenatally irradiated children (*28*). Association of verbal IQ and left hemisphere is well-known (*64*), full scale IQ is closer related to the left than to the right hemisphere (*56*). It seems that the left hemisphere is more vulnerable to exogenous impacts including ionising radiation, than the right hemisphere, probably due to dominating of the left brain and, consequently, its more functional activity.

A possible cerebral basis of intelligence disturbances in prenatally irradiated children is dysfunction of the left frontal, temporal and parietal lobes, involving the cortico-limbic system, prefrontal cortex, temporal associative area, and the tertiary parietal associative area at the left, dominating, hemisphere (*56, 57*). However, the predominance of the left hemisphere dysfunction is leading towards higher risk of schizophrenia spectrum disorders in prenatally irradiated children, that is why the long-term follow up study of this cohort is of great importance for clinical medicine and neuroscience.

Thus, the neuromental health of the acutely prenatally irradiated children at the Chernobyl exclusion zone is deteriorated in comparison with the non-evacuee classmates living in Kiev due to more frequency of episodic and paroxysmal disorders, organic, including symptomatic, mental disorders, somatoform autonomic dysfunction, disorders of psychological development, and

behavioural and emotional disorders with onset usually occurring in childhood and adolescence. Obviously, their neuromental health disorders are etiologically heterogeneous including psycho-social and economic factors, medical problems in their families, however an effect of real stress events (but not only their perception) during pregnancy together with prenatal irradiation cannot be excluded.

Intelligence of the acutely prenatally irradiated children is deteriorated due to reduction of full scale and verbal IQ, as well as WISC performance/verbal discrepancies, with verbal decrements. In spite of the children's intelligence is multifactorial, the contribution of prenatal irradiation was revealed.

Characteristic neurophysiological changes of the acutely prenatally irradiated children are also etiologically heterogeneous, but the dose—effect relationship, especially at critical periods of cerebrogenesis, can testify the impact of prenatal irradiation.

This study suggests that prenatal exposure to ionising radiation at thyroid foetal dose 0.2–2 Gy and foetal dose 11–92 mSv can result in detectable brain damage.

The data obtained reflect great importance, interdisciplinarity, and complexity of such problem as brain damage *in utero* following radioecological disaster and a necessity to integrate international efforts to its solving.

4. CONCLUSIONS

1. Individual dose reconstruction of the *in utero* exposed children was carried out considering internal and external exposure. The ICRP Publication-88 was applied for calculation of effective fetal, equivalent brain and thyroid internal doses for children of both groups. There were significantly higher doses revealed to the fetus, the fetal brain and the thyroid in the exposed children born from mothers evacuated from Pripyat. The effective fetal doses (M±SD) in the exposed group was 65.4±33.9 mSv and in the control group 1.2±0.3 mSv. ,.
The equivalent in utero brain doses were 19.2±11.3 mSv and 0.8±0.2 mSv for the exposed and control group respectively. Especially high are the doses to the fetal thyroid: 760.4±631.8 mSv in the exposed and 44.5±43.3 mSv in the control group. There were 52 children from Pripyat (33.8%) who had been exposed *in utero* to thyroid doses >1 Sv; 20 of these children (13.2%) received *in utero* doses of >100 mSv.

2. The Intelligence Quotient measured by the Wechsler Intelligence Scale for Children (WISC) revealed a lower value of the verbal and therefore full scale IQ, as well as higher IQ discrepancies (pIQ-vIQ) due to verbal IQ deterioration in the exposed children from mothers of Pripyat in comparison to children from mothers of Kiev. The exclusion of children with confounding factors did not influence the general result: full scale IQ - 112.9±13.3, verbal IQ - 106.7±13.2, performance IQ - 117,2±15,2 and IQ discrepancy - 10.4±14.7 in exposed children, full scale IQ - 118.6±10.8, verbal IQ - 115.8±13.2, performance IQ 118,7±9,6 and IQ discrepancy - 2.9±12.5 in control children. The intelligence discrepancies > 25 points are higher in the exposed children.

3. Emotional and behavioral disorders measured by the Achenbach test are higher in the exposed children for the following categories: 1) withdrawn; 2) somatic complaints; 3) anxious/depression; 4) social problems; 5) attention problems; 6) internalization (withdrawn, somatic complaints, and anxious/depression); 7) externalization.

4. Prenatally exposed children have more neuropsychiatric disorders than the control children from Kiev for the following categories: 1) paroxysmal states; 2) organic mental disorders; 3) neurotic, stress-related and somatoform disorders; 4) disorders of psychological development; 5) childhood behavioral and emotional disorders, revealed by clinical examination using ICD 10.

5. Verbal abilities are comparable in mothers of both groups assessed by the Vocabulary subtest of WAIS. There is a correlation between the verbal intelligence of the mothers and the intellectual level of their children. The evacuated mothers experienced a high amount of real stress events (evacuation, lack of information about relatives, migration, difficulties of medical care). There are significant mental health problems in mothers from Pripyat for the following categories: 1) depression; 2) PTSD; 3) somatoform disorders; 4) anxiety/Insomnia; 5) social dysfunction.

6. There is no dependence of the IQ deterioration and mental health disorders of the *in utero* exposed children with radiation dose. When IQ discrepancies of the prenatally irradiated children exceeded 25 points, there appeared to be a correlation with the fetal dose.
No correlations of the results of the WISC, the Achenbach tests and the neuropsychiatric disorders with dose could be revealed. The small sample size does not allow final conclusions, however.

7. There is a correlation between mothers' mental health deterioration with decreasing performance and therefore full scale IQ in children. Verbal IQ, however, does not correlate with mothers' mental health. Therefore IQ discrepancies decrease in proportion to the mothers' mental health deterioration in the exposed group. There are statistically significant relationships between the mental health of the mothers and the neuropsychiatric disorders in children. Among the mothers of the children of the exposed group with the neuropsychiatric disorders there is much more depression and somatization, as well as mental disorders.

5. OUTLOOK

This study should be continued as follows: for the increase of the size of the cohort; identification of further children irradiated in utero and children exposed at the age of 0–1 years is necessary; the identification and forming of cohorts of age -, gender - and urban/rural-matched children from radioactively clean areas of the Ukraine the verification and development of the currently available dosimetric models the assessment and verification of neuropsychiatric disorders, and the risk analysis of the influence of radioiodine in prenatal period and during the 1st year of life on brain development should be done.

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6. ABBREVIATIONS

Bq	Becquerel
CBCL	Child Behavior Check-List
Ci	Curie
95% CI	95% confidence interval
CT	Computerized Tomography
cEEG	Computerized Electroencephalography
GHQ-28	General Health Questionnaire
GRS	Gesellschaft für Reaktorsicherheit
Gy	Gray
IAEA	International Atomic Energy Agency
IQ	Intelligence Quotient
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
ICD-10	International Classification of Diseases, Injuries and Causes (WHO)
ICRP	International Commission on Radiological Protection
IES	Impact Event Scale
IPHECA	International Programme on the Health Effects of the Chernobyl Accident
MRI	Magnetic Resonance Imaging
mSv	Millisievert
PTSD	Post-Traumatic Stress Disorder
SCRM of AMS	Scientific Centre for Radiation Medicine of Academy of Medical Sciences of Ukraine (Научный центр радиационной медицины АМН Украины)
SDS	Self-Rating Depression Scale
TSH	Thyroid-Stimulating Hormone
WAIS	Wechsler Adult Intelligence Scale
WISC III	Wechsler Intelligence Scale for Children
WHO	World Health Organization
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

7. GLOSSARY

Absorbed dose: Energy which is transferred by radiation to matter per unit mass. This dose is given in Gray (Gy), where 1 Gy = 1J/kg.
Apgar score (Virginia Apgar, an American anesthetist 1909-1974): evaluation of newborn infant's physical status by assigning numerical values (0 to 2) to each of five criteria: heart rate,

respiratory effort, muscle tone, response to stimulation, and skin color (Stedman's Concise Medical Dictionary, 1987).

Asphyxia: impaired or absent exchange of oxygen and carbon dioxide on a ventilatory basis; combined hypercapnia and hypoxia or anoxia (Stedman's Concise Medical Dictionary, 1987).

Behavioral Disorders (ICD-10: F91): disorders characterized by a repetitive and persistent pattern of dissocial, aggressive, or defiant conduct. These disorders include: conduct disorder confined to the family context [F91.0], unsocialized conduct disorder [F91.1], socialized conduct disorder [F91.2], oppositional defiant disorder [F91.3] and other childhood behavioral disorders (ICD-10, 1992).

Brain Damage *in utero*: brain injury due to exogenous insults during the intrauterine or prenatal period (from fertilization to the beginning of delivery).

CBCL (Achenbach Test): Child Behavior Check-List by Achenbach — questionnaire for assessment of psychopathological disorders in children and adolescents (Remschmidt, 2001).

Cell Differentiation: cell specialization or the acquiring or the possession of character or function different from that of the original type cells resulting in forming of specialized cells, organs and tissues during development.

Cerebral Cortex: the layer of gray matter covering the entire surface of the cerebral hemisphere characterized by a laminar organization of its cellular and fibrous components such that its nerve cells are stacked in defined layers varying in number from one, as in archiocortex to the hippocampus, to five or six in the larger neocortex (Stedman's Concise Medical Dictionary, 1987).

Cerebral Dominant Hemisphere: the left cerebral hemisphere in right-handed people and in approximately $^{2}/_{3}$ of left-handed people, where the language neural centers are localized. According to functional specialization the dominant hemisphere is verbal, serial, analytic, controlled, logical, propositional, rational, and social (The American Psychiatric Press Textbook of Neuropsychiatry, 1997).

Cerebral Non dominant Hemisphere: the right cerebral hemisphere in right-handed people and in approximately $^{2}/_{3}$ of left-handed people. According to functional specialization the non dominant hemisphere is nonverbal, parallel, holistic, creative, pictorial, appositional, intuitive, and physical (The American Psychiatric Press Textbook of Neuropsychiatry, 1997).

Cerebrogenesis: brain development including embryonic and postnatal overlapping stages: neuronal mitosis, migration, axonal/dendrite outgrowth, programmed cell death (apoptosis), synaptic production, myelination, synaptic elimination/pruning (*Gestational Weeks*↓) (The American Psychiatric Press Textbook of Neuropsychiatry, 1997).

Cohort: a group of persons sharing the same experience followed over time since the date of this experience (beginning, date of inclusion).

Computerized Electroencephalography (cEEG): Quantitative EEG, Brain Mapping, Topographic **Mapping of EEG and Evoked Potentials.** A modern informative non-invasive technology of assessment of brain functional state at rest and in the process of processing sensory and cognitive information.

95% Confidence interval (95% CI): range around a mean in which 95% of the values of a sample survey are located.

For a Poisson distribution this is approximately: 95% CI = $[n \pm 1.96 \cdot \sqrt{n}]$.

Confounding Factor: this factor C may bias the relationship between a risk factor F and a disease D, if C is linked both to F and D. If C is positively linked to F and D, an apparently positive relationship between F and D can be due to the sole presence of C. Inversely, if C is linked positively to F and negatively to D, the relationship between F and D can be obscured by C. It is essential to identify the potential confounding factors and account for them when planning the study (use of matching) and performing the analysis (use of adjustment procedures).

Control: persons free of the disease or health disorder or manifestation of an effect under investigation, randomly sampled in the population where the cases occurred, and having the same age and sex characteristics as cases.

Computerized Tomography (CT): Computerized axial tomography (CAT), the gathering of anatomical information from a cross-sectional plane of the body, presented as an image generated by a computer synthesis of x-ray transmission data obtained in many different directions through the given plane. The method was offered in 1967 by British engineer Goldfrey Hounsfield) (Stedman's Concise Medical Dictionary, 1987).

Cytoarchitecture*:* arrangement of cells in a tissue; commonly referring to the arrangement of nerve-cell bodies in the brain, especially the cerebral cortex (Stedman's Concise Medical Dictionary, 1987**).**

Disorders of psychological development (ICD-10, F80–F89): the disorders have the following features in common: a) an onset that is invariably during infancy or childhood; b) an impairment or delay in the development of functions that are strongly related to biological maturation of the central nervous system, and c) a steady course that does not involve the remissions and relapses that tend to be characteristic of many mental disorders. These disorders include: specific developmental disorders of speech and language [F80], specific developmental disorders of scholastic skills [F81], specific developmental disorders of motoric function [F82], mixed specific developmental disorders of speech [F83], pervasive developmental disorders [F84] and other disorders of psychological development (The ICD-10, 1992).

EEG: electroencephalogram is a graphic record of the electrical activity in the brain obtained by an electroencephalograph. The pattern of the EEG reflects the state of the patient's brain and the level of consciousness in a characteristic manner.

Effective Dose: the quantity obtained by multiplying the equivalent dose (↓)to various tissues and organs by a weighting factor appropriate to each and summing the products. **Unit Sievert, symbol Sv**. Frequently abbreviated to dose.

Equivalent Dose: was introduced by the *International Commission on Radiological Protection* (ICRP), since different types of radiation vary in their relative biological effectiveness (RBE). The quantity obtained by multiplying the absorbed dose by an official radiation specific weighting factor W_R to allow for the different effectiveness of the various ionizing radiations in causing harm to tissue. W_R for photons (□or x-ray) is 1, for □-rays it is 20. **Unit Sievert, symbol Sv. 1Sv = 1J/kg.**

Embryo [G. *embryo*]: the developing organism from conception until approximately the end of the second month; developmental stages from this time to birth are commonly designated as fetal (ICRP Publication 49, 1986; Stedman's Concise Medical Dictionary, 1987).

Embryogenesis: The process of the development of the embryo, extending from the end of the 2^{nd} week, when the embryonic disk is formed, to the end of the 8^{th} week, after which the conceptus is usually spoken of as a fetus (Stedman's Concise Medical Dictionary, 1987).

Emotional Disorders with onset specific to childhood (ICD-10, F93): many emotional disorders in childhood seem to constitute exaggerations of normal developmental trends rather than phenomena that are qualitatively abnormal in themselves. These disorders include: separation anxiety disorder of childhood [F93.0], phobic anxiety disorder of childhood [F93.1], social anxiety disorder of childhood [F93.2], sibling rivalry disorder [F93.3] and other childhood emotional disorders (The ICD-10, 1992).

Evoked Potentials of the Brain: the reaction of cerebral electrical activity in response to stimuli of different sensor modality (somatosensor, visual, auditory) or cognitive stimuli (event-related potentials). They allow an assessment of the functional state of different systems from their periphery to the cerebral cortex of brain, as well as cerebral information processes.

Fetal: Relating to a fetus.

Fetal Dose: equivalent dose to the fetus; unit Sievert, symbol Sv.

Fetus: the product of conception from the end of the eighth week to the moment of birth (ICRP Publication 49, 1986; Stedman's Concise Medical Dictionary, 1987).

Gestation: Pregnancy.

Gestational Weeks: Terms of intrauterine development corresponding to the main events in cerebrogenesis. The brain develops in 4 overlapping stages.

T**he first stage (0–7 weeks after fertilization** is the commencement of neuronal mitosis during which the brain produces two to three times the full adult complement of neurons.
The second stage (8–15 weeks) is the first critical period of cerebrogenesis and corresponds to the most rapid proliferation of neuronal elements and substantial migration of neurons to the neocortex from their proliferate zones near the cerebral ventricles.
The third stage (16–25 weeks) is the second critical period of cerebrogenesis and corresponds to the progress of neuronal differentiation and synaptogenesis and the beginning of the formation of brain cytoarchitecture. The most striking neurobiological event at this stage is programmed cell death or apoptosis, when more than 50% of migrated neurons are eliminated prior to birth.
The fourth stage (26+ weeks) indicates cell differentiation, progressive growth of dendrites and axons, further formation of synapses and cerebral cytoarchitecture (ICRP Publication 49, 1986; The American Psychiatric Press Textbook of Neuropsychiatry, 1997).

General Health Questionnaire – 28 (GHQ-28): Questionnaire for study of psychopathology on the basis of self-estimation. This assesses somatoform symptoms, anxiety/insomnia, social dysfunction and severe depression.
Gray: the unit of absorbed dose equal to 1 J/kg in any medium. 1 Gy = 100 rad.
Impact of Event Scale (IES): Scale by Horowitz for diagnostics of symptoms characteristic for post-traumatic stress disorder.
In utero: Within the womb; not yet born; intrauterine; prenatal (Stedman's Concise Medical Dictionary, 1987).
Ionizing Radiation: radiation capable of producing ion pairs in biological material(s).
IQ: Intelligence Quotient. Quantitative index of intellectual development, measured with tests on intelligence. The ratio of mental age to chronological age (IQ=MA/CA·100). The term was introduced by W. Stern (1912). The standardized type presents a scale of evaluations with an average value of 100 and a standard deviation of 16. IQ 40–70 scores corresponds to different degrees of mental retardation, 90–109 is the norm - 120–129 is a high level of intellectual development (Burlachuk & Morozov, 1989).
IQ Discrepancy: disharmony of verbal and performance IQs, measured as the difference between performance and verbal IQ. When this difference exceeded 15 scores for adult and 25 for children clinical significance is expected (Rutter & Hersov, 1985).
Japanese studies on brain damage *in utero*: Over the years, the Atomic Bomb Causality Commission (ABCC) and its successor, the Radiation Effects Research Foundation (RERF), have established a number of neuropsychiatric effects in individuals prenatally exposed to the atomic bombing of Hiroshima and Nagasaki. Mainly they are: mental retardation, microcephaly, and seizures. A recent reanalysis of the dosimetry data indicated that the dose threshold for the development of mental retardation after intrauterine irradiation at gestation terms of 8–15 weeks is 0.06–0.31 Gy. At gestation term of 16–25 weeks, it is 0.28–0.87 Gy (ICRP Publication 49, 1986; Otake et al. 1996).
Magnetic Resonance Imaging (MRI): Diagnostic method for obtaining an image of organs by means of nuclear magnetic resonance. By exposure to a magnetic field and under the influence of radio-frequency impulses hydrogen protons were excited; the impulses emitted by hydrogen ions, can be more or less intensive in proportion to the concentration of hydrogen-containing structures in the parts of the organism of interest, were transmitted to a computer, where the organ image is formed.
Mental Health: absolute psychic, social and physical well-being, rather then only absence of mental disorders.
Mental Retardation (ICD-10: F70–F79): A condition of arrested or incomplete development of the mind, which is especially characterized by impairment of skills manifested during the developmental period, which contribute to the overall level of intelligence, i.e. cognitive, language, motoric and social abilities. According to the Japanese studies on brain damage *in utero* following the atomic bombing, severe mental retardation implies an individual who is

unable to perform simple calculation, to make simple conversation, to care for himself or herself, or was or is institutionalized. Such individuals are generally found to have an intelligence tests score, which is less than 70 on conventional tests (ICRP Publication 49, 1986).

Mitosis: mitotic or indirect nuclear division; the usual process of cell reproduction consisting of a sequence of modification of the nucleus (prophase, prometaphase, metaphase, anaphase, telophase) that result in the formation of two daughter cells with exactly the same chromosome and DNA content as that of the original cell (Stedman's Concise Medical Dictionary, 1987).

Neocortex: that portion of the gray matter covering the cerebral hemispheres showing stratification and organization characteristic of the most highly evolved type (ICRP Publication 49, 1986) *(See cerebral cortex)*.

Neuroblast: An embryonic nerve cell Neuron: Nerve cell, neurocyte; the morphologic and functional unit of the nervous system, consisting of the nerve cell body, the dendrites, and the axon (Stedman's Concise Medical Dictionary, 1987). Under normal circumstances, the mature neuron is a nonproliferation cell (ICRP Publication 49, 1986).

Neuronal Migration: Moving of the neurocytes to the places of their final location in the period of prenatal development.

Organ Dose: equivalent dose to the organ; unit Sievert, symbol Sv.

Organic mental disorder: Cluster of mental disorders integrated according to their etiology such as organic brain disease, damage and dysfunction. Dysfunction can be primary (e.g., direct and selective brain disease and damage) or secondary (e.g., system diseases and disorders, affecting the brain only as one of the ensembles of organs or systems of the body). The term "Symptomatic mental disorders" relates to the latest subgroup (The lexicons of psychiatry, 2001).

Organogenesis*: formation of organs during development.*

Performance IQ: "Practical intelligence" "Intelligence of action", nonverbal areas of intelligence such as spatial relationships. It is considered performance IQ is mainly referred to the functions of the no dominant hemisphere. According to the WISC, the performance IQ scale includes subtest as follows: 1) picture completion; 2) picture arrangement; 3) block design; 4) object assembly; and 5) coding (Burlachuk & Morozov 1989; Gilbukh 1992; Wechsler 1992).

Post-Traumatic Stress Disorder, PTSD (ICD-10 F43.1): this disorder arises as a delayed and/or protracted response to a stressful event or situation (either short- or long-lasting) of an exceptionally threatening or catastrophic nature, which is likely to cause pervasive distress in almost anyone (The ICD-10 1992; The lexicons of psychiatry 2001).

Prenatal: preceding birth

Pripyat town: "The town of atomic power engineers" is situated 3 km from the Chernobyl NPP where power plant workers and their families lived. Residents of Pripyat (49,360 persons) and of the nearest railway station, Yanov (254 persons), 3 km from the reactor, were the first to be evacuated (Annex J, UNSCEAR 2000).

Rutter Scale A (2): Rutter A (2) Behavior Rating Scale for parental rating assesses problems associated with health, hyperactivity, and behavioral and emotional disorders in children (Rutter 1967).

Sievert (Sv): unit of the dose equivalent and effective dose.

Stressful Life Event: Any external event, requiring from the individual changes in the continuous process of adaptation and stress adaptation. For instance, change of settlement, school entrance or graduation, change of job or failures in its searching, significant separation, birth or death of family members. These events can be necessary, but not sufficient causes of disease, they can somewhat influence the time of its beginning (The lexicons of psychiatry 2001).

Thyroid Fetal Dose: *equivalent dose* to the thyroid of the fetus; unit *Sievert*, symbol Sv.

Verbal IQ: Verbal areas of intelligence, ability to express themselves verbally and to understand what is being said to him/her. It is considered verbal IQ is mainly referred to the functions of the dominant hemisphere. According to the *WISC*, the verbal IQ scale includes following subtest: 1) information; 2) comprehension; 3) similarities; 4) vocabulary; and 5) digit span (Burlachuk & Morozov, 1989; Gilbukh, 1992; Wechsler, 1992).

WAIS: Wechsler Adult Intelligence Scale: Test on intelligence for examination of persons at age 16–64 years. Consists of subtests forming verbal and performance scales (Burlachuk & Morozov, 1989; Wechsler, 1997).

Wechsler Intelligence Tests: A group of the most known and widely used tests on intelligence. They are used to evaluate intellectual development in children (WISC) and adults (WAIS). For the first time offered in 1939 by David Wechsler. They are standardized on the sample at age 7–69 years (Burlachuk & Morozov, 1989; Gilbukh, 1992; Wechsler, 1992, 1997).

WISC: Wechsler Intelligence Scale for Children. Test on intelligence for examination of children at age 6–16 years. Consists of subtests forming verbal and performance scales (Burlachuk & Morozov, 1989; Gilbukh, 1992; Wechsler, 1992).

Zung Self-Rating Scale for Depression (SDS): Clinical scale for evaluation of the level of unmasked depression on the basis of self-estimation (Zung & Wonnacott 1970).

ANNEX 1

Neuroembryological background

The brain develops in 4 overlapping stages. The main developmental event of the first stage (0–7 weeks after fertilisation) is the commencement of neuronal mitosis during which the brain produces two to three times the full adult complement of neurons (Teicher et al., 1997). Impaired cell division presumably gives rise to fewer neurons and different abnormalities (ICRP Publication 49, 1986).

The second stage (8–15 weeks) is the first critical period of cerebrogenesis and corresponds to the most rapid proliferation of neuronal elements and substantial migration of neurones to the neocortex from their proliferative zones near the cerebral ventricles (Rakic, 1978, 1994, 2002; Sidman & Rakic, 1982; Landis, 1983). Learning disorders and some form of mental retardation may arise from abnormal migration (Teicher et al. 1997).

The third stage (16–25 weeks) is the second critical period of cerebrogenesis and corresponds to the progress of neuronal differentiation and synaptogenesis and the beginning of the formation of brain architecture (ICRP Publication 49, 1986). The most striking neurobiological event at this stage is programmed cell death or apoptosis, when more than 50% of migrated neurones are eliminated prior to birth (Teicher et al. 1997). Programmed cell death, essential to the development of the normal brain and its adnexa, could be accelerated or otherwise altered by ionising radiation (ICRP Publication 49, 1986).

The fourth stage (26+ weeks) indicates cell differentiation, progressive growth of dendrites and axons, further formation of synapses and cerebral cytoarchitecture (ICRP Publication 49, 1986; UNSCEAR Report 1993). Synaptic development is also characterised by distinct waves of overproduction and elimination (Teicher et al. 1997). Possible damage of thalamocortical innervation (at 24–33 weeks) is indicated by abnormal cortical differentiation, and by involution of subpial granular layer (at 24–38 weeks) — so-called marginal heterotopias (ICRP Publication 49, 1986).

Table A 1.1 Temporal pattern of prenatal brain development

Gestational age (weeks)	Brain developmental events
0–7	The first rudiment of the nervous system: the midline ectoderm neural plate — week 3 (England, 1996) or day 16 (ICRP Publication 49, 1986) Neural folds close to form neural tube — week 3 (UNSCEAR 1993 Report) or day 18 (ICRP Publication 49, 1986) The main divisions of the central nervous system: forebrain, midbrain, hindbrain, and spinal cord — week 4 (England, 1996) or day 20 (ICRP Publication 49, 1986) The forebrain (prosencephalon) divides into the telencephalon, the rostral forebrain, with the primordia of the cerebral hemispheres and the caudal forebrain (diencephalon). The midbrain (or mesencephalon) remains as before. The hindbrain (or mesencephalon) forms the metencephalon and myelencephalon (week 5) (England, 1996) Synapses beging to form — weeks 6–7 (Zecevic, 1998) Neuroblasts generation and their mitotical activity. The cell population doubles approximately every 8 h (ICRP Publication 49, 1986)
8–15	Cell multiplication (ICRP Publication 49, 1986) Following their last cell division, neurons migrate to their appropriate positions (Sidman & Rakic, 1982) Two-wave cortical neurons migration: 1) at about the 10th week and 2) much lager, begins at about the 11th week and terminated at about the 15th or 16th (Sidman & Rakic, 1982); the last areas of the cortex to show completion of neuronal migration are the cinguli and the anterior insulae (ICRP Publication 49, 1986) Thalamocortical projections appear (ICRP Publication 49, 1986) Corpus callosum forms; Purkinje cell migration complete, inward migration of external granule cells begins — weeks 12–15 (UNSCEAR 1993 Report) Neuronal prolifertion complete — up to the 16th week (Dobbing & Sands, 1973)
16–25	Progress of neuronal differentiation; proper brain architecture beging to form (ICRP Publication 49, 1986) Increase of synaptogenesis occurring synchronously at different areas of neocortex (Zecevic, 1998) Occurrence of programmed cell loss (Cowan et al., 1984) Active phase of natural nerve cell death — weeks 16–20 (UNSCEAR 1993 Report) Neuronal migration to neocortex complete; granule cells of cerebellum and dentate gyrus of hippocampus continue to proliferate and migrate; primary gyri and sulci form; myelination begins — weeks 20–24 (UNSCEAR 1993 Report) Axonal/dendritic outgrowth (Teicher et al., 1997). Limbic system and its connection forms (Joseph, 1996) Brain asymmetry and hemisphere dominating form — 12–27 weeks; lateralisation of motor functions — 15–18 weeks (McCartney & hepper, 1999)
26 to end of term	Cell differentiation, cerebral cytoarchitecture organisation and synaptogenesis continues (ICRP Publication 49, 1986) Granulic cell migration and glial proliferation conitue (UNSCEAR 1993 Report) Secondary gyri and sulci form (UNSCEAR 1993 Report) Robust growth of dendrites and axons and synaptogenesis (UNSCEAR 1993 Report)

ANNEX 2

Psychometric methods

1. Wechsler Intelligence Scale for Children (WISC) for assessment of child's intelligence
The WISC is an individually administered clinical instrument for assessing the intellectual ability of children aged from 6 years (in the Ukrainian adaptation by Gilbukh et al., 1992 already from 5 years on) to 16 years, 11 months. The WISC consists of several subtests, each measuring a different facet of intelligence. The child's performance on these various measures is summarised in three composite scores, the Verbal, Performance and Full Scale IQs, which provide estimates of intellectual abilities of children.

Intelligence can manifest itself in many forms and it is for this reason that David Wechsler saw intelligence not only as a particular ability but as an aggregate and global entity, the «capacity of the individual to act purposefully, to think rationally and to deal effectively with his or her environment».

The intellectual ability of the children of the study of the French-German Initiative was assessed by the adapted and normalised version for the Ukrainian children of the WISC (Wechsler, 1992), which was carried out by Prof. Yu.Z. Gilbukh and colleagues from the Research Institute of Psychology of Academy of Pedagogic Sciences of Ukraine (Gilbukh (Ed.), 1992). The WISC is normalised for gender and age.

There are two main scales in this intelligence test: the verbal and the performance scale with 5 subtests each. Table A 3.1 shows the details of both scales (Freeman, 1965; Gilbukh (Ed.), 1992).

Table A 3.1 Description of the WISC subtests

Subtest	Verbal Scale
1. Information	A series of orally presented questions that estimate the child's knowledge about common events, objects, places and people (long-term memory, association and organization of individual experience)
2. Similarities	A series of orally presented pairs of words for which the child explains the similarity of the everyday objects or concepts they represent (analysis of relationships, acquirement of verbal notion)
3. Vocabulary	A series of words is presented orally which the child defines (language development, acquirement of notions)
4. Digit Span	A series of orally presented number sequences which the child repeats verbatim for Digits Forward and in reverse order for Digits Backward (short-term memory, creation of auditorial images, and sometimes — visual images)
5. Comprehen-sion*	A series of orally presented questions that demand from the child to solve everyday problems or to show understanding of social rules and concepts (abstract reasoning, organization of knowledge, acquirement of notions)

Subtest	Performance Scale
1. Picture Completion	A set of pictures of common objects and scenes, in each of which is missing an important part which the child identifies (visual perception of relations - visual insight, visual imagination)
2. Block Design	A set of modelled or printed two-dimensional geometric patterns which the child replicates using two-colour cubes (form perception, visual

	perception: analysis and visual-movement coordination)
3. Object Assembly	A set of puzzles of common objects, each presented in a standardised configuration, which the child assembles to form a meaningful whole (visual perception: synthesis, visual-movement integration)
4. Coding	A series of simple shapes (Coding A) or numbers (Coding B) each paired with a simple symbol. The child draws the symbol in its corresponding shape (Coding A) or under its corresponding number (Coding B), according to a key. Coding A and B are included on a single perforated sheet in the Record Form (short-term mechanic memory, visual-movement integration, visual imagination)
5. Picture Arrangement*	A set of coloured pictures, presented in a mixed-up order, which the child rearranges into a logical story sequence (visual perception of relations - visual insight, synthesis of non-verbal material)

* — subtests could be excluded

Scaled scores («weighted», or standardised raw scores) are used for assessment of the results of the tests by determination of its place at a special scale with the data of norms in a standardised sample. For scaled scores for the subtests of the WISC the mean score is M=10 with a standard deviation of SD=3, and for full IQ the mean score is M=100 with the standard deviation of SD=16 (Burlachuk & Morozov 1989).

According to the Manual of the adapted WISC (Gilbukh (Ed.), 1992) it is possible to use 8 or 10 subtests. We used eight subtests in order to prevent a possible exhaustion of the children during following testing and examinations, which would affect the following examinations. The sum of the scaled scores of the subtests on the abbreviated scale was prorated to obtain the verbal and performance score. To prorate the child's score on four verbal and four performance subtests we multiplied the sum of the four scaled scores by 1.25. The sums of the scaled scores of the verbal and performance subtests were prorated separately and the resulting verbal and performance scores were summed to yield the full scale IQ score.

Scaled score equivalents of raw scores, standardised to age, and IQ equivalents of sums of scaled scores for verbal, performance, and full scales were obtained from the norms and conversion tables for Ukrainian children (Gilbukh Ed.1992). The child's performance on various subtests yields three composite scores. The sum of the scaled scores of the verbal subtests yields the verbal IQ (vIQ) and the sum of the scaled scores of the performance subtests — the performance IQ (pIQ). The mean of the scores of the verbal and performance subtests yield the full scale IQ (fsIQ).

Testing procedures were performed at standard conditions at the Neurology Department of the SCRM of AMS of Ukraine in a quiet, adequately lit, well-ventilated room without an accompanying adult; seating and material arrangement was corresponding to recommendations (Wechsler 1992; Gilbukh (Ed.) 1992) together with co-operative relationships between the child and the examiner. The entire test was administered in a single session.

Rating (primary scoring, or obtaining the rates to be summarised for each subtest resulting in raw or preliminary scores for each subtest) of the WISC subtests is presented in table A 3.2:

Table A 3.2 Rating (primary scoring) of the WISC subtests

Subtest	Rating
Verbal Scale	
1. Information	Rates: 0 and 1; 30 items; max rate=30
2. Similarities	Rates: 0 and 1 (items 1–4) & 0,1 and 2 (items>4); 16 items; max rate=28
3. Vocabulary	Rates: 0 and 2 (items 1–5) & 0,1 and 2 (items>5); 40 items; max rate=80
4. Digit Span	Digits forward Rates: maximal recalled correct number of digits; 2 trials, 7 sequences from 3 to 9 digits; max rate=9 Digits backrward Rates: maximal recalled correct number of digits; 2 trials, 7 sequences from 2 to 8 digits; max rate=8 Rate Digit Span = digits forward + digits backward; max rate =17
5. Comprehen-sion*	Rates: 0, 1 and 2; 14 items; max rate=28
Performance Scale	
1. Picture Completion	Rates: 0 and 1; 20 items; max rate=20
2. Block Design	A, B and C blocks Rates: 0 and 2; max rate=6 1—7 blocks Rates: 0 and 4—7 according to the time of performance; Max rate=55
3. Object Assembly	4 tasks, estimation according to the time of performance Girl — Rate: 4–7; Horse — Rate: 6–9; Face — Rate: 6–9; Car — Rate: 6–9 Max rate=34
4. Coding	Rate: 1 for each correct square; 7 tasks do not estimate Max rate=93
5. Picture Arrangement*	A, B, C, D tasks — training and 7 tasks to be rated as 4—7 according to the time of performance Max rate=57

* — subtests could be excluded

Processing of the results includes 11 steps (Gilbukh (Ed.) 1992):

1. Rating (primary scoring) of each task of each subtest (see Table 2);
2. Summarising rates for each subtest resulting in raw or preliminary scores on subtests;
3. Registration of the raw scores in the Record Form;
4. Transformation of the raw scores into the scaled score or weighting of the raw scores. This procedure is aiming to standardise all preliminary scores («to reduce to a common denominator») since a possible maximum of preliminary scores in various subtests can be different. Special tables designed on the base of standardised samples are used. For each age interval (4 months) there is a special table;
5. Registration of the scaled scores in the Record Form
6. Summarising of the scaled scores of the verbal subtest resulted in verbal score; summarising of the scaled scores of the performance subtests resulted in performance score; summarising of the verbal and performance scoresadded up in full scale score;
7. Registration of these 3 scores in the Record Form;

8. Prorating (when 8 subtests were used only). Verbal and performance scores are extrapolated using the corresponding table. Full scale score will be obtained by averaging over the prorated verbal and performance scores;
9. Registration of prorated scores in the Record Form;
10. Finding of verbal, performance and full scale IQ by the table for IQ determination. This table uses verbal, performance and full scale scores taking into account possible prorating.
11. Registration of vIQ, pIQ and fullIQ in the Record Form.

The conventional IQ ranges for description of intellectual abilities is presented in table A 3.3 (Gilbukh (Ed.) 1992).

Table A 3.3 The conventional IQ ranges by Gilbukh (Ed.) 1992

IQ	Quality level
141–170	Mental endowments
111–140	Increased mental abilities
91–110	Mental norm
71–90	Decreased mental abilities
30–70	Mental retardation

2. Child Behaviour Checklist (CBCL) for ages 4–18 by T. Achenbach for assessment of child's behaviour and emotions
The CBCL is intended to serve as one component of multiaxial empirically based assessment. Other components include teacher reports, standardized tests, physical assessment, and direct assessment of the child, such as observations, interviews, and structured self-reports. Parents are typically among the most important sources of data about children's competencies and problems. They are usually best informed about their child's behaviour in general and in situations. Parent reports should therefore be obtained in the assessment of children's competencies and problems whenever possible.

A Russian adaptation (Carter et al. 1995) of the CBCL (Achenbach 1991) was used. The CBCL is designed to record in a standardised format children's competencies and problems as reported by their parents or parent surrogates. It can be self-administered or administered by an interviewer. The 20 competence items obtain parent's reports of the amount and quality of their child's participation in sports, hobbies, games, activities, jobs, chores and friendships; how well the child gets along with others, plays and works alone; school functioning. A parent gets a questionnaire about her/his child with 118 questions. Each of the 118 specific problem items and two open-ended problem items is scored on a 3-step response scale (0, 1 or 2, this stand for "no, some times and often"). The CBCL is normalised on gender and age.

For analysis of the answers there are 3 groups of interest. Scales entitled Activities, Social, and School are provided for scoring the competence items. The CBCL total competence score is the sum of raw scale scores from the Activities, Social, and School scales.

Assignment of percentiles and T scores to competence scales.

The percentile for an observation x is found by dividing the number of observations less than x by the total number of observations and then multiplying this quantity by 100.

P50 (50th percentile) is equal a median distribution of the test results, P<50 and P>50 equal ranks of results lower or higher of the mean result (Burlachuk & Morosov 1989). Assessment of percentiles for comparison of the results of the tests with the data of groups is a common technique (scaled scores) in psychological diagnostics (Burlachuk & Morosov 1989).
a percentile of 75 - 25 (50 ± 25) is the norm
a percentile greater than 75 is considered above the norm
a percentile less than 25 is considered below the norm

T scores are also scaled (normalized and standardized) scores, which can obtain any desired form. In general in psychological diagnostic, T scores are obtained by multiplication of the normalized and standardized value by 10 and adding of a constant (k=50) (Burlachuk and Morozov 1989). The same procedure is done in Achenbach test.

Percentiles are displayed on the left side of the competence profile and T scores are displayed on the right side. The percentiles enable the user to compare a child's raw score on each competence scale shown in the column of the graphic display with percentiles for the normative samples of the child's sex and age range. The T scores provide a system (column of values) that is similar for all scales. The intervals on the left side of the profile encompass differing numbers of percentiles in order to correctly correspond to the T score intervals on the right side of the profile.

At the top of each competence scale, the author assigned a T score of 55 to all raw scores at the 69th percentile and above. At the lower end of the scale, the author based T scores on percentiles down to the 2nd percentile (T score = 30). Achenbach then divided the remaining raw scores into equal T score intervals down to a T score of 20. Broken lines at T scores of 30 and 33 demarcate a borderline clinical range that spans from about the 2nd to the 5th percentile of the normative sample.

Beside describing children in terms of competences, the CBCL is designed to identify syndromes of problems. The following eight syndromes are displayed in the CBCL profile: withdrawn, somatic complains, anxious/depressed, social problems, thought problems, attention problems, delinquent behaviour, and aggressive behaviour. Profiles for hand scoring the CBCL display scores for every problem item, as well as raw scores and T scores for the syndrome scales, internalizing, externalizing, and total problem score. Normal, borderline, and clinical ranges can also be read off from the profile.

To equalize the starting points (lowest value) of all syndrome scales, Achenbach assigned a T score of 50 to all raw scores that meet midpoint percentiles of ≤50. For the highest scores on the syndrome scales, he assigned T scores from 71 to 100. A T score of 70 corresponds to the 97.7th percentile.

The syndrome scales referred to as withdrawn (I), somatic complains (II), and anxious/depressed (III) are grouped under the heading Internalizing. The syndrome scales referred to as delinquent (dissocial) behaviour (VII) and aggressive behaviour (VIII) are grouped under the heading Externalizing. These groupings of syndromes reflect a distinction that has been detected in numerous multivariate analyses of children's behavioural/emotional problems. The two groups of problems have been variously called personality problem versus conduct problem, internalising versus externalising, inhibition versus aggression, and overcontrolled versus undercontrolled. The relations between internalising and externalising scores are analogous to the relation between verbal and performance IQ scores on intelligence tests (Achenbach, 1991) — like verbal IQ and performance IQs are the parts of the total IQ, internalizing and externalizing are the parts of emotional and behavioural aspects of the life.

The eight scales of the profiles are arranged in order starting with the three internalizing scales on the left, followed by three scales that did not have consistently high loadings on either the internalizing and externalizing factors (social problem, thought problems, attention problems), and ending with the two externalizing scales on the right. T scores were assigned to the internalizing and externalizing scores in the same way as was done for the total problem score.

Scoring the Competence Scales

II-A. Quantity of nonsports activities. If parent reported:
0 or 1 activity — enter 0 below profile
2 activity — enter 1 below profile
3 or more activities — enter 2 below profile
Do not count listening to radio or TV, goofing off, or similar activities.

Activities scale. Do not score if data are missing for more than 1 of the 5 scores indicated beside the Roman numerals below. The Roman numerals correspond to those on pages 1 and 2 of CBCL and on profile scoring form. If a parent checked more than 1 box where only 1 should be checked, score the box closest to «average».

I-A. Quantity of sports. If parent reported:
0 or 1 sport — enter 0 on profile
2 sports — enter 1 on profile
3 or more sports — enter 2 on profile

I-B. Mean of participation & skill in sports. If reported no sports, enter 0.
For each response of less than average or below average — score 0
Average — score 1
More than average or above average — score 2

Excluding blanks and «don't know» responses, compute the mean of these scores by summing them and dividing by number of scores you have summed. Enter this mean on the profile.

II-B. Mean of participation & skill in activities. Compute in the same way as specified in I-B for sports.

IV-A. Quantity of jobs. If parent reported:
0 or 1 job — enter 0 on profile
2 jobs — enter 1 on profile
3 or more jobs — enter 2 on profile

IV-B. Mean job quality. Compute as specified in I-B.

Total score for Activities Scale. Sum the 5 scores just entered for the items or the Activities Scale. If missing data prevent computation of 1 score, substitute the mean off total to nearest .5.

Social scale. Do not score if data are missing for more than 1 of 6 scores.

III-A. Quantity of organizations. If parent reported:
0 or 1 — enter 0 on profile
2 — enter 1 on profile
3 or more — enter 2 on profile

III-B. Mean of participation in organizations. Compute as specified in I-B.

V-1. Quantity of friends. If parent checked 0 or 1 — enter 0 on profile
2 or 3 — enter 1 on profile
4 or more — enter 2 on profile

V-2. Contacts with friends. If parent checked less than 1 — enter 0 on profile
1 or 2 — enter 1 on profile
3 or more — enter 2 on profile

VI-A. Behaviour with others. For each of the first three items (item a, b, c):
If parent checked worse — score 0
above average — score 1
better — score 2
Excluding any items for which the parent did not check a box, compute the mean of these scores and enter it on the profile.

VI-B. Play/work alone. (Item d) If parent checked worse — score 0
above average — score 1
better — score 2

Total score for Social Scale. Sum the 6 scores just entered for the items of the Social scale/ If missing data prevent computation of 1 score, substitute the main of the other 5 scores for the missing score in computing the total. Round off total to nearest .5.

School scale. Do not score if the child does not attend school or if data are missing for any of the 4 scores indicated below for Items VII 01 through VII-4, which appear on page 2 of CBCL and on the School scale of the profile scoring form.

VII-1. Academic performance. For each academic subject checked:
failing — score 0
below average — score 1
average — score 2
above average — score 3
Enter the mean of these scores on the profile. (Academic subjects include reading, writing, arithmetic, Russian, Ukrainian, foreign language, history, biology, geography, and similar subjects. Do not count physical education, art, music, home economics, driver education etc.)

VII-2. Special Class. For any type of remedial special class (for retarded, emotionally disturbed, learning disabled, perceptual-motor handicapped, reading readiness, resource room, behaviour problems, etc): — enter 0 on profile
not in remedial class — enter 1 on profile.

VII-3. Repeated Grade. If any grades were repeated — enter 0 on profile
no grades repeated — enter 1 on profile.

VII-4. School problems. If the parents entered any school problem that was present in the last 6 months but not already scored above: — enter 0 on profile
no problem beside those scored above — enter 1 on profile.

Total score for School Scale. Sum the 4 scores just entered on the school scale of the profile, unless any score is missing. After computing the total, round off to the nearest .5.

Total competence score. A total competence score is obtained by summing the totals of the 3 scales (sum of raw scale scores from the Activities, Social and School scales). T scores for total competence scores are listed in the box on the right-hand side of the hand-scored competence profile.

T scores were then assigned from the 2nd percentile (T=30) to the highest possible raw score, which was assigned a T score of 80. Raw score below the second percentile were divided into equal intervals for assignment to T scores from 10 through 29. T scores below 37 are considered to be clearly in the clinical range, whereas T scores from 37 to 40 are in the borderline clinical range. The borderline clinical range is indicated by broken lines in the right box of the hand-scored profile.

Competence scales (Activities, Social, and School) T scores interpretation is as follows: the T score decreasing is associated with the relevant problems in a child. Consequently, for each Competence scales T=30–33 (the 2nd to the 5th percentile of the normative sample) corresponds to a borderline clinical range, and T<30 (<2nd percentile) — clinical sample. At the same time, for the Total competence score T scores below 37 are considered to be clearly in the clinical range, whereas T scores from 37 to 40 are in the borderline clinical range.

Problem scales. According to the manual (Achenbach, 1991) do not score if data are missing for more than 8 items, not counting No 2, 4, 56h and 113. If a parent circled two numbers for an item, score the item 1. There are 120 problem items, even though the numbers range from 1-113 (items 56a-h comprise 8 items).

Item scores

With the help of a template the scores of the items were assigned to one of the 8 problem syndromes. The Roman numerals beside each item number on the template indicate the syndrome scales on which the item is scored. If the parent circled 0, 1 or 2 beside an item, enter the 0, 1 or 2 on the appropriate syndrome scale of the profile.

A three-step response scale (0, 1, 2) was chosen because it is more precise than a present/absent scale. For each item that describes the child currently or within the last 6 months, parents have to circle the 2 if the item is very true or often true for their child; the 1 if the item is somewhat or sometimes true for their child; and the 0 if the item is not true. The score 1 can be used when mild or ambiguous instances of problem would mart a forced choice between present and absent difficulty. Research has shown that more differentiated scales for scoring problem items are vulnerable to respondent characteristics that reduce the discriminative power of items below that obtained with three-step response scale. In addition, multicategory response scales have not been found to increase the differentiation of syndromes empirically derived from ratings of behavioural/emotional problems.

Syndrome scale scores

To obtain the total raw score for each syndrome scale, sum the 0s, 1s, and 2s you have entered for the scale.

Graphic display and T scores

To draw a graphic display for the competence and syndrome scales, mark the number on each scale that equals the score obtained for that scale. Then draw a line to connect the marked values in the graphic display. Percentiles based on non-referred children can be read off on the left side of the graphic display. T scores can be read off on the right side.

Broken lines are printed across the profile at the scores 67 and 70. These represent a borderline clinical range in which scores are not so clearly in the clinical range as those that are above T= 70. Just as with the competence scales, there is no well-validated criterion for categorically distinguishing between children who are «normal» and those who are «abnormal» with respect to each syndrome. Because children are continually changing and because all assessment procedures are subject to errors of measurement and other limitations, no single score precisely indicates a child's status. Instead, a child's score on a syndrome scale should be a particular informant at the time the informant completes the CBCL.

Internalizing and externalizing

A box at the bottom of the problem profile outlines the computation of internalising and externalizing scores as follows: Internalizing = the sum of raw scores for syndrome Scales I+II+III, minus the score for Item 103 to avoid counting Item 103 twice, because it is on both Scales I and III. Externalizing = the sum of raw scores for syndrome Scales VII+VIII. A T score for each internalizing and externalizing raw score is listed in the right box of the profile.

Total problem score

To compute the total problem score, sum the 1s and 2s on the CBCL and enter the sum in the box to the far right of the profile. Omit Items 2.Allergy and 4.Astma. If the parent has entered a problem for Item 56h or 113 that is not covered by another item, include the score for 56h or 113. If more than one problem has been entered for item 113, count only the one having the highest score. The total problem score can be cross-checked by subtracting the number of items scored as present from the sum of 1s and 2s. The difference should equal the number of 2s, omitting Items 2 and 4. (The number and sum of items can not be computed by adding scale totals, because some items appear on more than one scale). If parent circled 2 for the remaining 116 specific problem items and 2 for problems entered by the parent on items 56h and 113, the total problem score would be 118 x 2 = 236. A T score for each total problem score is listed in the box to the right of the profile. T scores of 60 to 63, which span these percentiles, were therefore chosen to demarcate the borderline clinical range.

An interpretation of the Syndrome scales (withdrawn, somatic complains, anxious/depressed, social problems, thought problems, attention problems, delinquent behaviour, and aggressive behaviour) as well as Internalizing, Externalizing and Total problem score is opposite to the Competence scales: the T score increasing is associated with the relevant problems in a child. Consequently, for each Syndrome scales T=67–70 corresponds to a borderline clinical range, and T=71–100 (>97.7th percentile) — clinical sample. At the same time, for the Internalizing, Externalizing, and Total problem score T scores >63 are considered to be in the clinical range, whereas T scores from 60 to 63 are in the borderline clinical range.

3. Youth Self-Report (YSR)

Although parent's reports are important in the assessment of children's problems and competencies, they have repeatedly stressed the need for multiple sources of data. The relevant and feasible sources of data depend on the age of the children and the conditions under which they are evaluated.

The YSR has been developed using the same general methodology as the CBCL/4–18. The YSR is designed for obtaining self-reports from youths at ages 11 to 18. The questionnaire has 89 similar problem items in common with CBCL, but each instrument also has additional items designed for the type of user.

As in the CBCL, the following eight cross-informant syndromes are displayed in the YSR profile: withdrawn, somatic complains, anxious/depressed, social problems, thought problems (schizoid/obsessive behaviour), attention problems, delinquent (dissocial) behaviour, and aggressive behaviour. Profiles for hand scoring the YSR display scores for every problem item, as well as raw scores and T scores for the syndrome scales, internalizing, externalizing, and total problem score. Normal, borderline, and clinical ranges are presented in the profiles.

4. Rutter Scale A(2)

The Rutter Scale A(2) was used for assessment of child's problem associated with health, hyperactivity, behavioural and emotional disorders (Rutter, 1967; Rutter and Hersov, 1985). A mother completes the scale. Translation and validation of the Rutter Scale A(2) for former USSR population had been done in WHO Pilot Project "Brain Damage in Utero" in the frame of IPHECA.

In the Rutter Scale A(2) 31 items are selected to cover three main areas. They are problems on health, habits and peculiarities of behaviour. Each item estimates as 0, 1, or 2. Consequently, the total score may be from 0 to 62.

"Problems of health" consists of positions A, B, C, D, E, F and G. If a parent answers "never" so score 0, "sometimes" score 1, "often" —score 2 is received. "Habits" consist of positions I, II, III, IV, and V. If a parent reported "no" so score 0, "yes, insignificant" score 1, or "yes, expressed" score 2 is received. "Peculiarities of behaviour" consist of 18 positions. If a parent reported "does not correspond" so score 0, "correspond to some extend" score 1 and "correspond completely" score 2 is received.

The identification of a child with emotional or behavioural deviations (problems) includes two stages:
If a child has a total score of 13 and more, he/she may have some deviations (problems);
If a child has an emotional score that is exceeding the behavioural score, he/she is considered to have emotional deviations (problems). If a child has the behavioural score exceeding the emotional score, he/she is considered to have behavioural deviations (problems).
A child with the same (identical) emotional and behavioural scores is not differentiated.
Subscore of emotional problems is the sum of scores on the items B, G, V, and 15. Subscore of behavioural problems is the sum of scores of the items III, 3, 13, 17, and 18.

5. Vocabulary subtest of the Wechsler Adult Intelligence Scale (WAIS)

Vocabulary subtest of the Wechsler Adult Intelligence Scale (WAIS) was used for assessment of verbal IQ of a mother (Wechsler, 1997). This subtest estimates how mother understand some words that meaning she can explain to her child. Translation and validation of the vocabulary subtest of the WAIS for former USSR population had been done in WHO Pilot Project "Brain Damage in Utero" in the frame of IPHECA.
Vocabulary subtest of the WAIS consist of a set of 35 words which were orally presented and has to be defined by a parent. All meanings are taken from standard dictionaries and scored according to the quality of the definition. Each word is scored as 2, 1, and 0. Regionalisms and slang not found in dictionaries are to be scored as 0.

- The response score 2 indicates a good understanding of the word in one of the following ways:
good synonym;
major use;
one or more definitive or primary features of an object;
general classification to which the word belongs;
correct figurative use of the word;
several less definitive but correct descriptive features that cumulatively indicate understanding of the word;
for verbs, a definitive example of action or a causal relationship.

A response score 1 is a response that is not incorrect but shows poverty of content in the following ways:
vague or less pertinent synonym;
minor use, not elaborated;
an attribute that is correct but not definitive or has not a distinguishing feature;
an example using the word itself, not elaborated;
a concrete instance of the word, not elaborated;
a correct definition of a related form of the word.

A response score 0 means:
an obviously wrong answer;
a common expression that contains the word and shows no real understanding of its meaning, even after inquiry;
the response that is not totally incorrect but is very vague or trivial or shows great poverty of thought, even after questioning.

Maximum score: 70 points.

6. Zung Self-Rating Depression Scale (SDS)
The Zung Self-Rating Depression Scale, SDS (Zung and Wonnacott, 1970) is designed for estimation of the level of unmasked depression on the base of self-estimation. The scale includes 20 items. A special scale is used with value from 1 to 4. The sum of the values is converted using a conversion table. If the result of conversion is less than 50, the depression is absent; 50–59 — the depression is mild; 60–69 — moderate to significant; and more than 70 — a severe to very severe depression is noted.

7. Questionnaires for Post-Traumatic Stress Disorders: Impact of Events Scale (IES) and Irritability, Depression, Anxiety (IDA)
The questionnaires for assessment of post-traumatic stress disorder (PTSD) in a parent include the “Impact of Events Scale”, IES (Horowitz et al. 1979) and the clinical scale for the self-assessment of irritability the “Irritability, Depression, Anxiety”, IDA (Snaith et al., 1978), that was used for assessment of arousal associated with PTSD. These scales estimates PTSD-related symptoms by self-estimation and they are used for the assessment of psychological stress due to different catastrophic events. Translation and validation of the IES and IDA for former USSR population had been done in epidemiological studies of immigrants, of Chernobyl survivors who went to Israel (Cwikel et al. 1997a,b; Yevelson et al., 1997).
The IES contains 15 questions about Chernobyl accident’s reminiscences. The IDA contains 4 questions to estimate the agitation because of PTSD. Following scores are used:
0 — never;
1 — rare;
2 — sometimes;
3 — often.

The summary result is total score. For the IES the result less than 15 was considered to be «no case», 15–30 – «case», and more than 30 – «case with significant disorders». For the IDA: the result less than 4 was considered to be «no case», 4–8 —«case» and more than 8 — «case with significant disorders».

8. General Health Questionnaire (GHQ-28)

The General Health Questionnaire (GHQ-28) was used for assessment of psychopathology (Goldberg, 1981; Goldberg & Williams, 1988) in a parent by self-estimation. The GHQ-28 consists of 4 subscales with 7 items (in total, 28 items) that estimate somatoform symptoms (GHQ-28A), anxiety/insomnia (GHQ-28B), social dysfunction (GHQ-28C), and severe depression (GHQ-28D). Translation and validation of the GHQ-28 for former USSR population had been done in WHO Pilot Project "Brain Damage in Utero" in the frame of IPHECA.

There were used two methods of scoring of the GHQ-28: the «GHQ scoring» (0–0–1–1) and the «Likert scoring» (0–1–2–3):

Question	Answer			
	Column 1	Column 2	Column 3	Column 4
Have you recently been feeling sad and gloomy?	Less than usual	No more than usual	Rather more than usual	Much more than usual
Likert scoring	0	1	2	3
GHQ scoring	0	0	1	1

The usual way of the GHQ-28 scoring is a case identification, or so-called «GHQ scoring». If the total sum on 4 subscales is less than 5, it is «no case», 5–15 is a «case», and more than 15 is a «case with considerable disorders». However, if the subscale scores are required there are marginal advantages in scoring this as "0–1–2–3" or "Likert scoring". It has also been pointed out that the Likert scoring produces a less skewed score distribution than the GHQ scoring.

9. Stress-events scale of mothers related to the Chernobyl accident

On the base of the scale of stress-factors of the DSM-IV (1994) we elaborated the Stress-events scale of mother related to the Chernobyl accident. The scale is the questionnaire with 10 items to be answered by a mother and further to be scored by an examiner from 1–5. The scale is designed for assessment of the level of the real stress-factors (but not their perception) following the Chernobyl accident in a pregnant woman from the accident till the birth of the child. Among these factors there are evacuation, lack of information about relatives, migration, difficulties of medical care, etc. These factors could determine the level of psychological stress in a pregnant woman as a result of the accident.

Procedure of examination in the following order:

Child	Mother
Medical examination of the child	CBCL
WISC	Rutter A(2)
YSR	WAIS (Vocabulary subtest)
EEG	SDS
	IES
Psychoneurological examination of the child	IDA
	GHQ-28

	Stress-events scale

The tests for the mothers were performed during testing of the children in a separate room. The whole procedure lasted about 3–4 hours.

ANNEX 4

According to the tasks of the Project 3 the tables in Excel format were prepared. These tables consist of aggregated data on intelligence and in utero thyroid doses of examined cohorts (table A 4.1 and on periods of cerebrogenesis (tables A 4.2–A 4.6). The description of the fields of these tables was also provided. To the Chernobyl Centre also the tables which contain the general description of the sub-project 3.4.1 (table A 4.7) and the methods used (table A 4.8) were transferred.

Table A 4.1 Intelligence Quotient (IQ) and the in utero thyroid dose of examined cohorts

Parameter	Acutely exposed group (Pripyat–Kiev) n=154		Comparison group (Kiev) n=143	
	M	SD	M	SD
Thyroid dose in utero (mSv)	760.4	631.8	44.5	43.3
Total IQ	112.2	15.2	119.6	11.6
Verbal IQ	106.6	14.3	117.2	13.1
Performance IQ	116.1	16.9	118.5	10.8

Table A 4.2 Intelligence Quotient (IQ) for children exposed during the first 7 weeks of gestation

Parameter	Acutely exposed group (Pripyat–Kiev) n=17		Comparison group (Kiev) n=35	
Thyroid dose in utero (mSv)	Geometric Mean: 0.39		Geometric Mean: 0.02	
	M	SD	M	SD
Total IQ	109.7	15.6	123.7	9.5
Verbal IQ	103.3	16	121.3	12.1
Performance IQ	114.7	15	122.1	8.8

Table A 4.3 Intelligence Quotient (IQ) and in utero thyroid dose for children exposed during the 8–15th week of gestation

Parameter	Acutely exposed group (Pripyat–Kiev) n=27		Comparison group (Kiev) n=26	
Thyroid dose in utero (mSv)	Geometric Mean: 40.9		Geometric Mean: 1.5	
	M	SD	M	SD
Total IQ	113.2	11.1	114.6	11.1
Verbal IQ	106.8	13.2	111.5	13.1
Performance IQ	117.4	10.6	115.4	9.5

Table A 4.4 Intelligence Quotient (IQ) and in utero thyroid dose for children exposed during the 16–25th week of gestation

Parameter	Acutely exposed group (Pripyat–Kiev) n=42		Comparison group (Kiev) n=30	
Thyroid dose in utero (mSv)	Geometric Mean: 623.7		Geometric Mean: 46.1	
	M	SD	M	SD
Total IQ	111.4	18.9	119.3	13
Verbal IQ	106.3	16	117.8	14.8

Performance IQ	115	21.4	118	10

Table A 4.5 Intelligence Quotient and in utero thyroid dose for children exposed during the 26th and the following weeks of gestation till birth

Parameter	Acutely exposed group (Pripyat–Kiev) n=54		Comparison group (Kiev) n=45	
Thyroid dose in utero (mSv)	Geometric Mean: 1225.5		Geometric Mean: 94	
	M	SD	M	SD
Total IQ	113.2	13.7	119.4	11.8
Verbal IQ	107.7	13.1	117	11.8
Performance IQ	116.8	16.4	117.7	12.8

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