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CONSEQUENCES WHICH MOTHERS' IRRASIATION HAS: RISKS OF CHILDREN'S CONGENITAL MALFORMATIONS

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It is vital to examine radiation-induced effects in children whose parents were exposed to radiation at their workplaces as it allows to work out standards for technogenic irradiation doses permissible for people in their reproductive age. It also helps to predict adverse consequences of parents being exposed to radiation for their children. Our goal was to analyze congenital malformations (CM) in children whose mothers were employed at "Mayak" Production Association (Mayak PA) and had accumulated pre-conception external gamma-radiation doses. Retrospective examination was performed on 1,190 people born in 1949–1969, 238 of them being children of female workers employed at radiation-hazardous production. We achieved maximum comparability of groups made of children population living in Ozersk in terms of age, birth year, and parents' age at a childbirth, via careful sampling. CM frequency was compared with χ^2 criterion, Fisher's exact criterion. We calculated odds relations (OR) with 95% confidence interval. To detect any latent factors, we applied factor analysis via principal components method with consequent Varimax normalized rotation. Gonads in female workers employed at Mayak PA were exposed to external gamma-radiation doses within 0.09–3523.7 mGy range; average accumulated dose was equal to 373.6 ± 34.2 mGy. Each tenth child in a group of children born by irradiated mothers was born by a mother who had an accumulated pre-conception external gamma-radiation dose on her gonads which was higher than 1 Gy. CM comparative analysis revealed that there were no statistically significant differences between groups in terms of CM frequency in general and as per various nosologic forms. OR in general was equal to 0.86 (0.46–1.59); 0.88 (0.35–2.2) among boys; 0,84 (0.36–1.94) among girls. We also detected difference in CM structure: CM of the nervous system, respiratory organs (23 % each), and the musculoskeletal system CM (15.3 % among all the malformations) prevailed among all the CM in children born by irradiated mothers; CM of the musculoskeletal system (23.3 %) and the nervous system (21.7 %) were most widely spread among children born by intact parents. We also noted there were gender discrepancies in the CM structure in the compared groups. We didn't register any chromosome pathologies in both groups. CM were diagnosed in those children born by those irradiated mothers whose gonads were exposed to accumulated pre-conception external gamma-radiation doses within 1.9–1635.5 mGy, with average dose being equal to 307.5 mGy. Factor analysis performed on children born by female workers employed at atomic production revealed four factors which characterized pre-concepption mothers' irradiation (21.5 % dispersion), antenatal children's period (17.1 % dispersion), obstetrician-gynecological case history (12.9 % dispersion), and mothers' bad habits, namely alcohol intake and smoking (11 %) dispersion). Given all the detected peculiarities, it is highly advisory to continue research on larger children's groups and longer observations periods.

Key words: *congenital malformations, children, radiation exposure, pre-conception irradiation, reproductive age, odds relation, factor analysis.*

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Long-term industrial irradiation has its remote effects on workers' health; to assess them is a vital task both in terms of providing radiation safety for people in their reproductive age and predicting unfavorable consequences for their offspring. A lot of authors stated in their works that cytogenetic effects and genomic instability could possibly be transferred to offspring across the generations [1, 2]. But at the same time some authors don't find any correlations between irradiation of gonads and genetic diseases occurrence in offspring [3]; they even think that trans-generation effects are not very likely to be detected in any actual epidemiologic situation [4]. Epidemiologic research which focused on parents irradiation as a potential teratogenic risk factor was conducted among offspring of those who had suffered atomic bombing [5, 6]; among children whose parents underwent diagnostic and curative exposure to radiation [7, 8]; offspring of professionals who had contacted ionizing radiation [9–12]. In spite of great number of research works in the field, radiation-induced effects in offspring of irradiated parents are still being widely discussed.

"Mayak" Production Association (Mayak PA) is the first nuclear cycle enterprise in our country which started its operations in 1948; it is located near a closed town called Ozersk. Personnel cohort employed at Mayak PA has a very distinctive peculiarity: women account for approximately 25% of all the production staff, and it is a relatively big share as opposed to any other atomic production in Russia [13]. This peculiarity allows to consider offspring of female workers employed at Mayak PA to be quite representative in terms of assessing consequences which mothers' irradiation has for their children' bodies.

Our research goal was to analyze congenital malformations (CM) in children born by female workers employed at Mayak PA who had accumulated preconception doses of external gamma-irradiation.

Data and methods. We performed our retrospect research basing on the data obtained from the Ozersk Children's Health Register, a computer database which contains personal medical data (clinical, social and epidemiological ones) taken from children's outpatient cards (112/u unified format) [14]. At present this Register contains data on 15,568 children younger than 15 who spent their childhood in Ozersk.

Dosimetric characteristics of parents' occupational irradiation were obtained from the "Mayak-2008 Workers Dosimetric System" [15]. We applied values of accumulated pre-conception external gamma-irradiation on ovaries. Doses of external gamma-irradiation were calculated as per Monte-Carlo technique according to individual dosimeters readings and spatial-energy distribution of photon radiation field at a workplace. To make a comparison, we also give values of an equivalent for an absorbed external gamma-irradiation dose on the body surface Hp (10) and preconception absorbed doses of external gamma-irradiation on the large intestines.

Data on health of mothers employed at Mayak PA, including their obstetrician-gynecological case histories, chronic pathologies, and any bad habits, were obtained from patients' cards of Mayak PA personnel.

To include a child into our focus group, we applied the following criteria: 1) a child should be born in Ozersk in 1949-1969; 2) a child's mother was employed at Mayak PA and had an accumulated preconception dose of external gamma-irradiation on her gonads; 3) a child's father didn't have any accumulated doses of pre-conception occupational irradiation, he hadn't moved to Ozersk from territories contaminated with radiation, and he hadn't previously taken part in liquidation of any radiation disasters. As a result, our basic group of Mayak PA female workers' offspring was made up of 238 children (148 girls and 90 boys) who corresponded to all the above mentioned criteria and whose medical documentation was available to us.

Our reference group was created basing on data from the Ozersk Children's Health Register: we carefully sampled a control for each child from the focus group, the ratio being 1:4, allowing for sex, year of birth, parents' age at the moment when a child was born, and medical documentation availability.

We applied the following criteria to include children into our reference group: 1) a child should be born in Ozersk in 1949-1969; 2) a child's parents had never been exposed to any occupational irradiation, had never taken part in any elimination of radiation disasters and had never lived on territories with radiation contamination. As a result, our reference group included 952 children (592 girls and 360 boys). The groups which were made up of Ozersk children population were comparable in terms of scope and quality of medical services available to them, climatic and geographic conditions of their living, and possible technogenic changes in the surrounding environment.

We analyzed the category XVII "Congenital malformations, deformations, and chromosomal disorders" (codes Q00–Q99) in the X International Classification of Diseases (ICD-10) [16] in this work; we concentrated only on such cases when the malformations and diseases were first diagnosed in children younger than 15.

The data were statistically analyzed with STATISTICA Version 10 software package (StatSoft, USA). The descriptive statistics for normally distributed signs is given with mean values (M) ± standard deviation (s); when distribution was not normal, we applied a median and interquartile range (25th and 75th percentiles). Frequencies were compared with χ^2 criterion and Fisher's exact test; discrepancies were considered to be valid at $p<0.05$. We calculated odds relation (OR) with 95% confidence interval. To detect any latent factors which explained correlations between the examined variables, we conducted a factor analysis via basic components technique with the consequent Varimax normalized rotation [17]. We selected this rotation technique due to more obvious interpretation of factor loadings as opposed to other rotation strategies. A number of factors was determined as per Kaiser's criterion, factors' own values being not less than 1. Factor loadings being > 0.7 were considered to be significant for the interpretation.

Results and discussion. Mothers of children from the focus group started their work at Mayak PA in 1948-1966. External gamma-irradiation doses including preconception ones and intrauterine doses are characterized in Table 1. As doses distribution was closed to normal the Table contains both mean values and medians.

The highest doses were detected among workers employed at Mayak PA during the first years of its functioning. A maximum dose of external gamma-irradiation on gonads reached 3,523.7 mGy among irradiated mothers. An average accumulated dose of external gamma-irradiation on gonads amounted to 373.6±34.2 mGy among Mayak PA female workers. We should note that there were data on intrauterine irradiation of 182 children (76.5%). The doses varied from 0.01

Table 1

Characteristics of external gamma-irradiation doses accumulated by mothers and intrauterine doses

Dose	Doses range	Mean value of a dose ± standard deviation	Median [interquartile range]
Dose on gonads, mGy	0,09–3523,7	373,6 ± 34,2	136,8 [29,3; 533,2]
Dose on the large intestines, mGy	0,09–3898,7	388,9 ± 36,2	139,9 [30,7; 554,8]
Dose Hp (10), mSv	0,13–4533,2	481,9 ± 43,9	191,1 [37,8; 731,3]
Dose in utero, mGy	0,01–261,9	25,8 ± 2,8	8,4 [0,56; 28,2]

Table 2

Distribution of offspring depending on an accumulated pre-conception dose of external γ – irradiation on mother's gonads

Dose range, mGy	Focus group overall (n=238)			Boys (n=90)			Girls (n=148)		
	Abs.	%	Average dose, mGy	Abs.	%	Average dose, mGy	Abs.	%	Average dose, mGy
0,01–25,0	54	22,7	8,6	22	24,4	10,4	32	21,6	7,3
25,1–100,0	56	23,5	53,1	18	20,0	47,1	38	25,7	55,9
100,1–250,0	26	10,9	165,4	8	8,9	183,9	18	12,2	157,2
250,1–500,0	36	15,1	358,7	15	16,7	362,9	21	14,2	355,7
500,1–1000,0	43	18,1	703,6	18	20,0	686,8	25	16,9	715,7
>1000,0	23	9,7	1652,3	9	10,0	1744,6	14	9,4	1592,9
Всего	238	100	373,6	90	100	400,6	148	100	357,1

to 261.9 mGy; an average dose amounted to 25.8±2.8 mGy, as mothers were exposed to radiation at early stages of their pregnancies.

Pre-conception irradiation of female workers employed at Mayak PA which we observed can be explained not only by imperfect production technology, very tight production schedules existing at enterprises in the state defense sphere, and absence of any experience in working with sources of ionizing radiation, but also with the concepts on permissible radiation exposure at production which existed at that time. Distribution of offspring depending on a mother's pre-conception external gamma-irradiation dose on gonads is given in Table 2.

Most children were born within mothers' irradiation range up to 100 mGy, and their distribution as per sex was different. Almost one quarter of boys (24.4%) were born by workers with an accumulated pre-conception dose of external gamma-irradiation on their gonads up to 25 mGy, while girls' mothers in more than one quarter of cases (25.7%) had an accumulated dose on their gonads which was within 25.1 - 100 mGy range. Each tenth child was born by a mother with an accumulated external gamma-irradiation dose on their gonads being more than 1 Gy.

CM analysis in children born by mothers who were exposed to occupational irradiation revealed that 13 CM cases in 12 children out of 238 live-birth infants were registered (one child had both cerebral malformations and the larynx malformations). As for the reference group, 60 malformations were registered in 55 children out of 952 (one child had three different malformations, and two children had two CM each). Data on CM distribution as per systems in both groups are given in Table 3.

We didn't reveal any statistically significant discrepancies either in overall CM frequency or in the groups (p>0.05). In order to check a hypothesis on a possible

Table 3

CM structure in the compared groups

CM (as per ICD-10)	Focus group						Reference group					
	Boys (n=90)		Girls (n=148)		Both sexes (n=238)		Boys (n=360)		Girls (n=592)		Both sexes (n=952)	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
CM in the nervous system (Q00-Q07)	2	33,3	1	14,3	3	23,1	6	22,2	7	21,2	13	21,7
CM of the eyes, ears, face and neck (Q10-Q18)	0	0	0	0	0	0	7	25,9	2	6,1	9	15,0
CM in the circulation system (Q20-Q28)	0	0	1	14,3	1	7,7	3	11,1	6	18,2	9	15,0
CM in the respiratory organs (Q30-Q34)	2	33,3	1	14,3	3	23,1	1	3,7	1	3,0	2	3,3
Cleft lip and cleft palate (Q35-Q37)	0	0	0	0	0	0	2	7,4	0	0	2	3,3
Other congenital anomalies in the digestive organs (Q38-Q45)	0	0	1	14,3	1	7,7	5	18,5	1	3,0	6	10,0
CM in the genitals (Q50-Q56)	1	16,7	0	0	1	7,7	1	3,7	0	0	1	1,7
CM in the urogenital system (Q60-Q64)	0	0	1	14,3	1	7,7	0	0	0	0	0	0
CM in the musculoskeletal system (Q65-Q79)	1	16,7	1	14,3	2	15,3	2	7,4	12	36,4	14	23,3
Other CM (Q80-Q89)	0	0	1	14,3	1	7,7	0	0	4	12,1	4	6,7
Chromosomal anomalies not classified in other categories (Q90-Q99)	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	6	100	7	100	13	100	27	100	33	100	60	100

influence exerted by mother's pre-conception irradiation on CM occurrence in children, we calculated odds relation with 95% confidence interval. OR value in the compared groups showed there was no statistically significant correlation between mothers' occupational irradiation and malformations in their children: OR without division by sex amounted to 0.86 (0.46–1.59); OR value among boys was 0.88 (0.35–2.2); OR value among girls, 0.84 (0.36–1.94).

We should note that our analysis of outpatient cards which contained exacted diagnoses up to an age of 15 years inclusive helped us to allow for malformations which were diagnosed not only at a child's birth but also at older ages.

CM in the nervous system and the respiratory organs were most frequently diagnosed among children born by irradiated mothers (23.1% of all the malformations in the overall focus group). Three cases of microcephalia were registered among CM in the nervous system. Congenital malformations in the respiratory organs were congenital larynx stridor, congenital pulmonary collapse, and nose sinuses hypoplasia. CM in the musculoskeletal system took the second place among children born by irradiated mothers (15.1% of all the malformations); they were ribs anomalies and the navicular bone anomaly. CM in the circulatory system, digestive organs and urogenital organs have equal shares, 7.7% each.

CM structure among boys was different from that among girls. Thus, CM in the nervous system and respiratory organs were registered among boys more frequently, 2 cases each (33.3%), while we detected similar shares (14.3%) of CM in the nervous system, respiratory organs, digestive organs, circulatory system, urogenital system, and the musculoskeletal system among girls.

A case of microcephalia with the right hemisphere atrophy was detected in the boys sub-group. A number of authors [18, 19] state that cerebral damages occurring at the early stages of ontogenesis are the leading cause of perinatal mortality and account for 60-70% of children neurologic pathology; they also mention that neurological symptomatology in children with cerebral malformations is polymorphic and non-specific.

A combined congenital heart disease (Botallo's duct non-closure and interatrial septum defect) was detected among girls. A CM in the urogenital system with an abnormal ureter passage was diagnosed in a girl suffering from obstructive chronic pyelonephritis. We didn't detect any chromosome pathologies in children born by Mayak PA female workers.

As for the reference group, CM were most frequently registered there in the musculoskeletal system (23.3%); they were congenital thigh deformations, dentofacial anomalies, and disorders in sternocleidomastoid muscle development. The second place belonged to CM in the nervous system (21.7%) with 6 microcephalia cases among them. CM in the eyes, ears, face and neck (Q10-Q18) and CM in the circulatory system made equal contributions (15% each) in the CM structure among children born by intact parents.

Boys born in families where parents weren't exposed to any production irradiation most frequently (25.9%) had eyes anomalies, such as congenital cataract, lacrimal apparatus malformations, and ear anomalies. Two children had cleft palates. CM in the digestive organs among boys in this group were represented by a congenital hypertrophic pyloric stenosis and Hirschsprung's disease.

CM in the musculoskeletal system were most frequently registered among girls in the reference group (36.4%); most of them were congenital thigh malformations. We detected three rare congenital malformations among those girls: acoustic meatus atresia, congenital erythroblastosis, and internal organs inversion (Situs viscerum inversus). We didn't detect any chromosome anomalies in the reference group either. Genitals malformations in both groups were represented by single cryptorchism cases.

We compared congenital frequency as per nosologic forms and didn't detect any significant discrepancies both in overall groups and in boys and girls sub-groups ($p>0.05$). The data on CM structure presented here are a bit different from national statistics and EUROCAT international register where the greatest contribution into CM structure is made by CM in the circulation system, musculoskeletal system, and urogenital system [20, 21]. However, relatively small number of CM in the examined groups doesn't allow us to make any ultimate conclusions.

CM cases in the focus group were registered within mothers' pre-conception doses range of 1.9-1,635.5 mGy of external gamma-irradiation on gonads, an average accumulated dose amounted to 307.5 mGy. Given the concept of the true threshold for

CM induction which is equal to 100 mGy [22], in future we plan to analyze dependence of CM in children on a pre-conception dose accumulated by their mothers.

Undoubtedly, apart from parents exposure to radiation, there are multiple exo- and endogenous factors which can be teratogenic; such factors include a mother's health prior to conception, parents' age at the moment a child was born, mother's bad habits, data on pregnancy course, gestation terms etc. Scientists are still searching for possible teratogenic factors and assessing their influences on an embryo. Thus, C. Malagoli et al [23] analyzed magnetic fields effects; J.A. Makelarski et al [24] described increased risks of anencephalia and encephalocele caused by cumulative pesticides effects; C.A. Snijder et al [25] focused on congenital heart diseases risks caused by a father's pre-conception exposure to chemicals; G. Vermes et al.[26] consider acute and chronic infectious diseases of mothers as leading anorectal malformations causes.

In order to reveal non-radiation teratogenic factors in both children groups, we analyzed pre-morbid background including data on gestation age, anthropometric parameters of newborns, obstetrician-gynecologic case histories of their mothers, and mothers' chronic pathologies.

195 children (81.9%) among those born by Mayak PA female workers were full-term; there were 756 full-term children (79.4%, p>0.05) in the reference group; prematurity was detected in 8 (3.4%) newborn infants in the focus group and in 40 (4.2%) newborns in the reference group (p>0,05). Multiple pregnancy in the focus group was detected in 4 cases (1.7%), and there was no statistically significant discrepancy with the reference group (14 cases 1.5%). Deliveries were normal in 186 cases (78.2%) in the focus group and in 768 cases (80.7%, p>0.05) in the reference group. Abnormal deliveries and cesarean operations were detected in 11 (4.6%) cases in the focus group and 26 (2.7%) cases in the reference group (p>0.05). Distribution as per an ordinal number of a pregnancy didn't have any statistically significant differences in both groups: first-time mothers prevailed in them (p>0.05), the second and the following births were registered for 79 (33.2%) female workers employed at Mayak PA and 283 (29.7%) of women who were not exposed to occupational irradiation, p>0.05. Average age of a mother at the moment of childbirth amounted to 26.5 in both groups. Anthropometric parameters in newborns from both groups in general didn't have any statistically significant discrepancies.

We analyzed bad habits of Mayak PA female workers and revealed that smoking mothers accounted for only 5.9% (14 people); most women (78.2% or 186 people) had utterly negative attitudes towards smoking; smoking status of the remaining 15.9% (38 people) wasn't known. 58.4% (139 people) didn't drink alcohol at all; 6.7% (16 people) drank very little; 10.1% (24 people) were moderate drinkers; 3.4% (8 people) were heavy drinkers; there were 2 registered cases of chronic alcoholism (0.8%); there is no information about the remaining women.

86 (36.1%) mothers of children in the focus group had problems in their obstetrician-gynecological case histories, such as abortions, acute and chronic gynecologic pathology prior to conception. Two mothers of children from the focus group had stillbirths in their case histories; we detected 16 stillbirths among mothers of children from the reference group, p>0.05. According to data taken from outpatient cards of female workers employed at Mayak PA,

123 (51.7%) women suffered from chronic somatic pathologies, which mostly were chronic pathologies in the gastrointestinal tract, bronchopulmonary diseases, and chronic tonsillitis.

In order to reveal any latent factors which explained correlations between the examined variables, we performed a factor analysis in the focus group applying basic components technique with Varimax normalized rotation (Table 4).

Table 4

Results of factor analysis performed on the focus group

Factor Loadings (Varimax normalized) Extraction: Principal components (Marked loadings are >,700000)				
Variables	Factor - 1	Factor - 2	Factor - 3	Factor - 4
Mother's age at the moment of childbirth	0,234932	–0,099351	0,604849	0,004919
Number of previous pregnancies	–0,075804	–0,063024	**0,895051**	0,020828
Number of previous abortions	–0,045748	0,142250	**0,858895**	–0,022471
Gestation age	0,038028	**0,850093**	0,087218	0,033758
Multiple pregnancy	–0,035862	**0,821534**	0,096067	–0,069278
Parity of delivery	–0,004183	**0,798718**	0,088540	0,046689
Family's living conditions	0,028691	0,260954	0,346532	0,209597
External gamma-irradiation dose in utero	0,320166	–0,211909	–0,277238	0,169278
Alcohol intake by a mother	0,100919	0,026284	–0,044865	**0,876280**
Smoking status of a mother	0,095016	–0,009167	0,003251	**0,900915**
Dose on gonads*	**0,990472**	0,027625	0,059691	0,029901
Dose on the large intestines*	**0,990072**	0,025616	0,055103	0,024006
Dose Hp (10)*	**0,990920**	0,032839	0,059017	0,028047
Chronic somatic diseases of a mother	0,018702	0,384251	–0,175641	–0,081635
The current pregnancy course	0,131938	0,095392	–0,115523	–0,193230
Expl.Var	3,149281	2,342627	2,182580	1,707441
Prp.Totl	0,209952	0,156175	0,145505	0,113829

Note: * means mother's accumulated absorbed doses of external gamma-irradiation.

4 complex independent factors were spotted out among 15 features in the group of children born by mothers employed at Mayak PA. The total share of the explained dispersion amounted to 62.5%. The most significant factor was that related to mothers' pre-conception irradiation as it made the greatest contribution (21.5%) into the dispersion; factor loadings of such variables as "Dose on gonads", "Dose on the large intestines", and 'Dose Hp (10)" were also high (0.99 each).

The second factor included gestation age of a child, multiple pregnancy, and parity of delivery (factor loadings were 0.85, 0.82 and 0.79 correspondingly). It accounted for 17.1% of the overall dispersion. The greatest loadings in the third factor were represented by the variables which characterized a mother's obstetrician case history, a number of previous pregnancies and abortions; this factor accounted for 12.9% of the overall dispersion. The least contribution into the dispersion (11%) was made by the factor characterizing bad habits of a mother, alcohol intake and smoking (factor loadings were 0.87 and 0.9 correspondingly). P.M. Sullivan at al. [27] examined 14,128 congenital heart diseases cases against 60,938 control cases and proved that smoking during pregnancy was a risk factor for certain phenotypes of congenital heart diseases.

To make a comparison, we conducted a factor analysis according to the same procedures on the reference group which included children born by intact mothers. As a result, two factors with their overall share of the explained dispersion equal to 63.8% were detected in this group. The second factor included gestation age of a child, multiple pregnancy, and parity of delivery, accounted for 38.4% of the overall dispersion (factors loading were 0.86, 0.9 and 0.79 correspondingly). The second factor was related to a parity of pregnancies and a number of previous abortions (factor loadings were 0.89 and 0.8 correspondingly). The second factor accounted for 25.4% of the overall dispersion.

It is interesting to note that after all the variables which described mother's occupational pre-conception irradiation were excluded, factors solution among children born by Mayak PA female workers became similar to that existing in the reference group: contributions made by a mother's obstetrician case history and their children's antenatal period remained significant and explained 61.8% of the overall dispersion. Therefore, the factor analysis performed with basic components technique allowed to reveal latent factors which explained correlations between the observed features in the group of children born by Mayak PA female workers.

Conclusion. We performed retrospect analysis of CM in 1,190 children aged under 15, 238 of them being born by mothers who had accumulated pre-conception doses of external gamma-irradiation. The analysis revealed that:

1) there were no statistically significant discrepancies in CM frequency both overall and as per nosologic forms between two groups: overall, OR amounted to 0.86 (0.46–1.59); OR among boys, 0.88 (0.35–2.2); OR among girls, 0.84 (0.36–1.94);

2) there were some discrepancies in CM structure: CM in the nervous system and respiratory organs (23% each) and CM in the musculoskeletal system (15.3%) prevailed among children born by irradiated mothers; CM in the musculoskeletal system (23.3%) and CM in the nervous system (21.7%) prevailed among children born by intact parents;

3) there were some sex-depending discrepancies in the CM structure: CM in the nervous system and respiratory organs were more frequently registered among boys from the focus group (33.3% each) while contribution made into CM structure by CM in the nervous system, respiratory organs, digestive organs, circulatory system, urogenital system, and the musculoskeletal system were the same among girls (14.3% each).

4) there were no chromosome pathologies in either group;

5) CM were diagnosed in children born by mothers with accumulated pre-conception doses of external gamma-radiation on their gonads within 1.9–1,635.5 mGy, an average dose being equal to 307.5 mGy.

Factor analysis performed on the group of children born by female workers employed at atomic production spotted out 4 factors characterizing mothers' pre-conception irradiation (21.5% of the dispersion), offspring's antenatal period (17.1% of the dispersion), obstetrician-gynecological case history (12.9% of the dispersion), and bad habits of mothers, such as alcohol intake and smoking (11% of the dispersion). After we excluded all the variables which characterized mothers' pre-conception occupational irradiation, factors solution in the compared groups didn't have any significant discrepancies.

Damaging factors are multiple and variable, and it doesn't always allow to get a clear concept of what actually prevails in CM etiology [20, 28, 29] and to confirm the leading role which parents' irradiation plays in CM induction. If we take bigger offspring groups and an extended period of observations, it will allow us to continue analyzing remote consequences of parents' occupational irradiation including quantitative assessment of the contribution made by mothers' pre-conception irradiation into CM risks run by their offspring.

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