RADIATION RISK GROUPS OF NSC KIPT PERSONNEL

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The characteristics of the NSC KIPT personnel registered on individual dose control in 2017 in terms of the "dose matrix" are given. The methodologies UNSCEAR-94, BEIR VII, ICRP 2007, currently used to calculate individual radiation risks are described. The main results of calculations of the relative, attributive and absolute radiation risks of personnel for 2017 for various localizations and different groups of radiation risks, banded according to the different methodologies are presented.

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INTRODUCTION

Occupational diseases are a large number of diseases that cause not only loss of working capacity, but also deaths of people. On the average for European countries, the annual number of occupational cases diseases per 100.000 workers is 30.1 [1]. In Ukraine, this indicator for 2013 is equal to 13.3. This may be due to the lack of identification of occupational diseases cases because of different approaches to identify the criteria for occupational diseases diagnostics and the government attitude to the problem in whole.

The fatal accidents rate per 100 thousand employees in Ukraine in 2013 was 11.3 [2].

Over the last 20 years, the average annual dose of NSC KIPT personnel that are on individual dose control (IDC) is 1.42 mSv/year. The average individual annual radiation risk of cancer, associated with irradiation at such a dose calculated by the ICRP coefficients, is $0.0584 \cdot 10^{-3}$, or 5.84 cases per 100.000 people. The risk of hereditary diseases from a such dose in the first two generations is 0.17 per 100.000 people, and the total radiation risk is 6.01 cases per year per 100.000 people.

Thus, the radiation risk of NSC KIPT employees is comparable and it does not exceed the risk of employees in many other common occupations in the world.

Nevertheless, according to radiation-epidemiological data [5], obtained from a representative sample of participants in the liquidation of the consequences of the Chernobyl accident, small doses are statistically significant risk factors for the occurrence of malignant neoplasm (MN), and the maintenance of the dose-effect relationship for radiation cytogenetic markers in somatic cells of irradiated persons with MN in the long term after the Chernobyl accident confirms the radiogenic character of these diseases. The dose dependence of MN in this group is not monotonous, a maximum of 10…15 cGy, a minimum of 25 cGy [5]. However, it is commonly believed that the practical risk of MN begins after a dose of 10…15 cGy [6]. And the question of the action of small doses of radiation is still open.

Thus, the ***purpose of this paper*** is to calculate the radiation risks of NSC KIPT personnel registered on IDC in 2017 for various localizations and various groups of radiation risks.

1. CHARACTERISTICS OF THE PERSONNEL OF THE NSC KIPT, CONSISTING OF THE IIR

305 employees, 246 men (80.7%) and 59 women (19.3%) was registered on IDC in NSC KIPT at the beginning of 2018. The average age of men in this cohort was 61 years, women – 56 years. The average length of service years on IDC among men was 23 years, among women – 21 years. The average accumulated dose for men was 62.41 mSv, for women – 43.21 mSv. The distribution of personnel by sex and age, length of service years on the IDC and the accumulated dose, as well as the accumulated dose dependence from the age and the length of service years are shown in Figs. 1–4. The trends of the average and maximum annual doses for this cohort over the working experience are shown in Fig. 5.

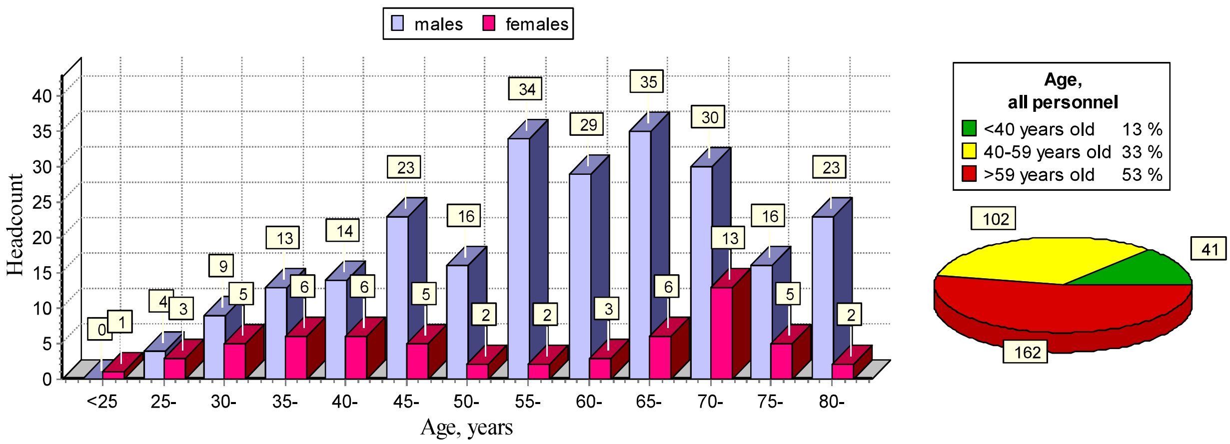

Fig. 1. Distribution of personnel by sex and age

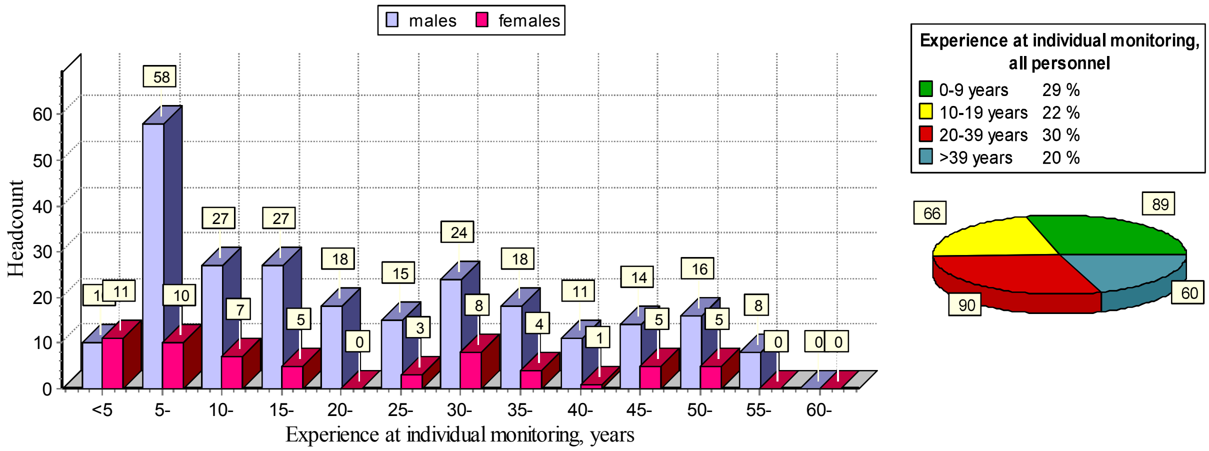

Fig. 2. Distribution of personnel by sex and length of service years on IDC

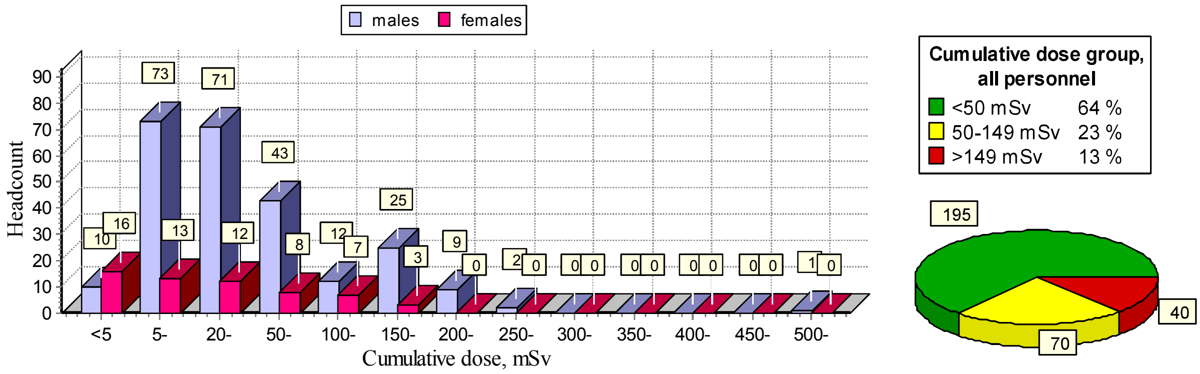

Fig. 3. Distribution of personnel by sex and accumulated dose

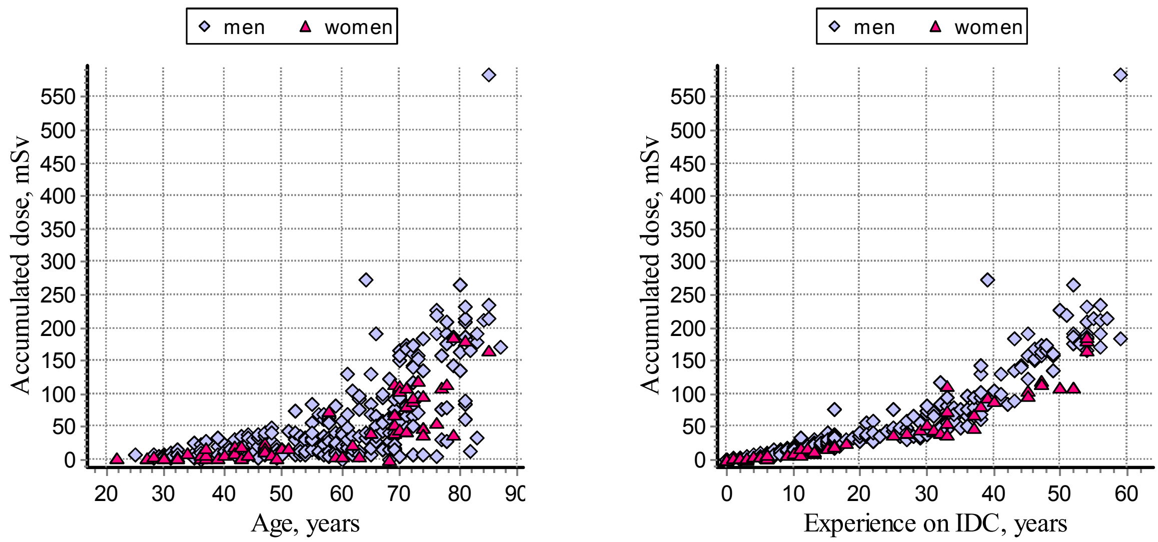

Fig. 4. The accumulated dose dependence from age and length of service on the IDC years

About half of the personnel at the DCO are people aged 60 years and over who have experience at the IDC for 20 years or more (see Figs. 1, 2). 36% of the personnel have greater than 50 mSv accumulated a dose (see Fig. 3). The accumulated dose dependences from age and length of service at IDC have an exponential nature (see Fig. 4). The average annual dose since 1993 does not exceed 2 mSv (Fig. 5).

The main characteristics of the personnel annual doses, weighted average by the IDC experience, are shown in Tabl. 1. The distribution of personnel by weighted average annual doses and the dependence of weighted average annual doses from service years on IDC are shown in Fig. 6.

Table 1

The personnel weighted average doses

Personnel	Weighted average annual doses, mSv		
	min	average	max
Men	0.29	1.52	4.94
Women	0.08	1.01	2.24
All	0.08	1.42	4.94

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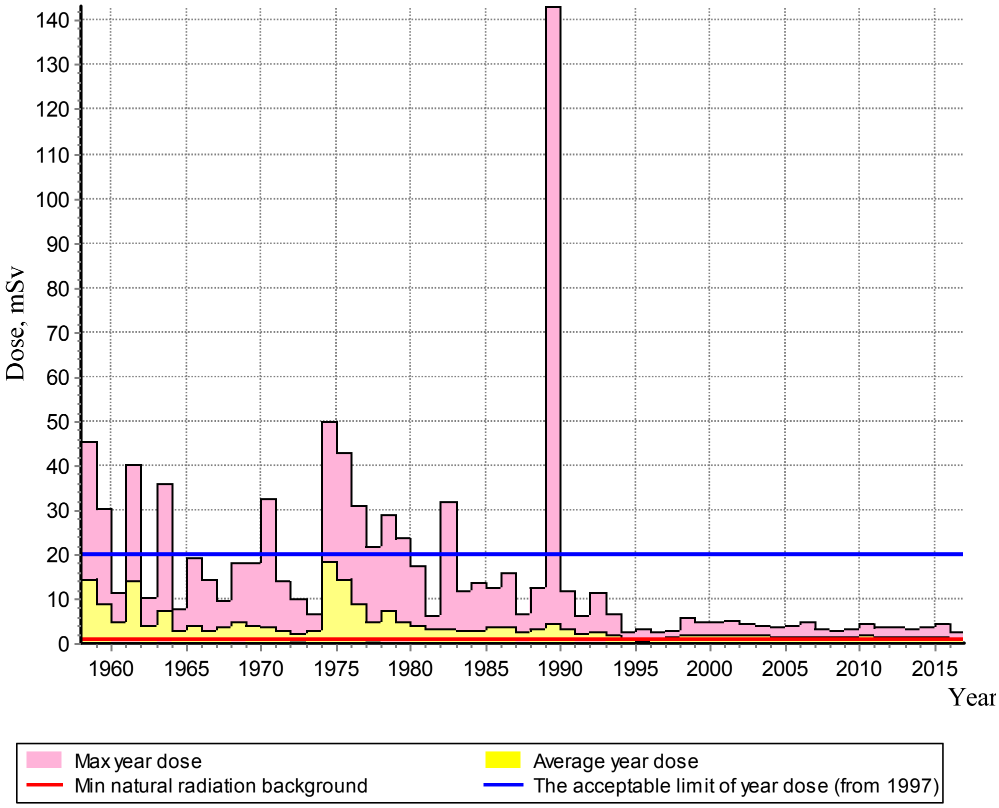

Fig. 5. Annual average and maximum dose trends

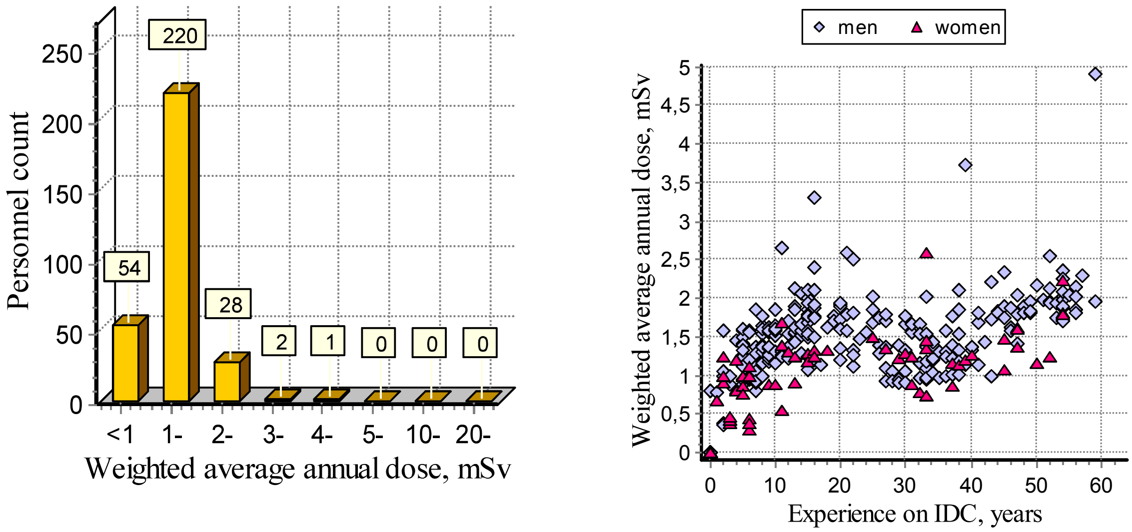

Fig. 6. Distributions of personnel by weighted average annual dose

2. RADIATION RISKS CALCULATING MODELS

The IAS IDC software are currently using the UNSCEAR-94 UNSCEAR [7], BEIR VII [8], ICRP 2007/Preston 2007 [9, 10] models to calculate individual radiation risks for NSC KIPT personnel.

All these models suggest to use the linear dependence of the risk from the received dose to calculate the radiation risks of solid cancers and to use the linear-quadratic dependence to calculate the leukemia risk, and also include a modifying exponential function that takes into account the effect from the age while irradiation and the effect from the age in the target year. They differ by the values of these functions coefficients and the values of the weight coefficients to determine the degree of dependence of radiation risk from the background oncological diseases.

Thus, the UNSCEAR-94 model assumes a 100% linear dependence of solid cancers radiation risks from the background incidences – it prefers a multiplicative ERR (excess relative radiation risk) model for solid cancers. And for leukemia the UNSCEAR-94 uses an additive EAR (excess absolute risk) model – zero dependence of the leukemia radiation risk from background incidences.

The BEIR VII model uses both EAR and ERR models to calculate radiation risks. It uses 0.7 weight for the ERR model for solid cancers (except lung, thyroid and female breast cancers) and for leukemia, and 0.3 weight for the EAR model. For lung, the BEIR VII weighting factor of the ERR model is proposed to be 0.3. For the thyroid gland – 1 (ERR-model), for the breast – 0 (EAR-model).

Models ICRP 2007 and Preston 2007 use the same functions to calculate risks and differ only by the coefficients for some localizations of solid cancers. They completely copy the UNSCEAR-94 EAR model to calculate the leukemia risk. For solid cancer ICRP 2007 and Preston 2007 propose to use 0.5 weight coefficients for ERR and EAR models, except for lung, thyroid and breast cancer risks. For risks of lung cancer, thyroid and breast cancer its use the same weight coefficients of the ERR model (0.3, 1, 0) as BEIR VII model.

The BEIR VII model offers also the coefficients to calculate the upper and lower bounds of 95% confidence intervals (CIs) of risks. The Preston 2007 model offers coefficients to calculate the upper and lower bounds of a 90% CI of risks.

The UNSCEAR-94, BEIR VII and ICRP 2007/Preston 2007 models are presented below.

The ERR-model of UNSCEAR-94 to calculate the relative radiation risk of solid cancers is:

$$ERR_{sol}(s,l,g) = a_{s,l} \times D_g \times \exp\left(b_l \times (g-25)\right), \quad (1)$$

where Dg is the radiation dose (in Sv) at the age g; a and b are the parameters that depend on the sex s and oncology localization l.

The UNSCEAR-94 EAR model for calculating the absolute radiation risk of leukemia is:

$$EAR_{LEU}(s,g,u) = a_{s,g} \times D_g \times (1 + 0.79 \cdot D_g) \times \exp\left(-b_{s,g} \times (u-g-25)\right), \quad (2)$$

where a and b are parameters that depend from age at exposure g and sex s.

The weighted geometric mean of the absolute radiation risk in the BEIR VII and ICRP 2007 / Preston 2007 models is calculating by the formula:

$$EAR = (EAR_R)^w \cdot (EAR_A)^{(1-w)}, \quad (3)$$

where EAR_R is the absolute radiation risk value calculated by the multiplicative ERR model, and EAR_A is the absolute radiation risk value calculated by the additive EAR model.

In BEIR VII, the EAR_R and EAR_A values for solid cancers are calculating using the formulas:

$$EAR_{SOL\ R}(D,s,g,u) = m_0 \cdot \beta_{Rs} D_g \exp(\gamma_R \cdot g^*) \cdot (u/60)^{\eta_R}, \quad (4)$$

$$EAR_{SOL\ A}(D,s,g,u) = m_0 \cdot \beta_{As} D_g \exp(\gamma_A \cdot g^*) \cdot (u/60)^{\eta_A}, \quad (5)$$

where $g^* = \begin{cases} \dfrac{g-30}{10}, & g < 30; \\ 0, & g \geq 30, \end{cases}$

β, γ, η – the model parameters; g – age at exposure of dose Dg; u – age for which the radiation risk is calculated.

To calculate the risks of leukemia, BEIR VII uses the following formulas:

$$EAR_{LEU\ R}(D_g,s,g,u) = m_0 \cdot \beta_{Rs}\left(D_g + \theta_R D_g^{\ 2}\right)\exp(\gamma_R \cdot g^* + \delta \cdot \ln\left(\frac{u-g}{25}\right) + \phi_R \cdot g^* \cdot \ln\left(\frac{u-g}{25}\right)), \quad (6)$$

$$EAR_{LEU\ A}(D_g,s,g,u) = \beta_{As}\left(D_g + \theta_A D_g^{\ 2}\right)\exp(\gamma_A \cdot g^* + \delta \cdot \ln\left(\frac{u-g}{25}\right) + \phi_A \cdot g^* \cdot \ln\left(\frac{u-g}{25}\right)), \quad (7)$$

where $g^* = \begin{cases} \dfrac{g-30}{10}, & g < 30; \\ 0, & g \geq 30, \end{cases}$

β, γ, δ, ϕ – the model parameters.

In ICRP 2007/Preston 2007, the EAR_R and EAR_A values for solid cancers are calculated using similar formulas. The difference is that the value of the coefficients are given for the attained age of 70, rather than 60 years. And the influence of age upon irradiation on the risk value is taken into account over the whole period of time, not just up to 30 years:

$$EAR_{SOL\,R}(D_g,s,g,u) = \beta_{Rs} D_g \exp\left(\frac{\gamma_R}{100\%} \cdot \frac{g-30}{10}\right) \cdot \left(\frac{u}{70}\right)^{\eta_R}, \quad (8)$$

$$EAR_{SOL\,A}(D_g,s,g,u) = m_0 \cdot \beta_{As} D_g \exp\left(\frac{\gamma_A}{100\%} \cdot \frac{g-30}{10}\right) \cdot \left(\frac{u}{70}\right)^{\eta_A}, \quad (9)$$

where β, γ, η – model parameters; g – age at exposure to dose Dg; u – age for which the radiation risk is calculated.

In all three models, risks are calculated for such localizations of solid cancers as: lung, stomach, liver, colon, bladder, female breast. The differences between the models in the remaining calculated localizations are shown in Tabl. 2.

Table 2

The differences between the models

Localizations	UNSCEAR-94	BEIR VII	ICRP/ Preston 2007
Gullet	+	–	+
Thyroid gland	–	+	+
Ovary	–	+	+
Prostate	–	+	–

3. THE RESULTS OF RADIATION RISKS CALCULATIONS

The main results of calculations of radiation risks for 2017 according to UNSCEAR-94, BEIR VII models (the upper limit of 95% CI), Preston 2007 (the upper limit of 90% CI): relative risks (ERR), attributable risks (AR) and the absolute risks (EAR) are presented in Tables 3–5.

The background cancer incidence data of Kharkiv region in 2014 from [11] were used for calculations.

4. RADIATION RISK GROUPS

The assessment of individual radiation risks is carried out primarily for the purpose of implementing the concept of social acceptable risk: according to international practice and the current Norms of Radiation Safety of Ukraine (NRBU-97), an acceptable individual absolute radiation risk upon technogenic exposure of personnel in the normal mode of operation should not exceed the value 10^{-3} per year [12, 13].

In terms of the absolute radiation risk, the personnel working with sources of ionizing radiation could be referred to one of the following groups of absolute radiation risk:

– negligible risk: $EAR_{ALL} < 10^{-4}$;
– acceptable risk: 10^{-4} EAR_{ALL} 10^{-3};
– high radiation risk: $EAR_{ALL} > 10^{-3}$.

An attributive radiation risk shows the association of cancer with occupational exposure. In some European countries, personnel working with IRS could receive compensation payments in the case of cancer, if the value of attributive risk exceeds the established thresholds, usually 20…75%, depending from localization [14].

Table 3

The personnel excess radiation risks of 2017, UNSCEAR-94 model

Localizations	ERR, %			AR, %			EAR, $*10^{-3}$		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
All tumours	0.00	1.74	18.41	0.00	1.66	15.55	0.000	0.245	**3.050**
All solid tumours	0.00	1.61	18.52	0.00	1.53	15.63	0.000	0.236	**3.010**
Leukemia	0.00	5.40	35.41	0.00	4.86	26.15	0.000	0.009	0.052
Lung	0.00	3.12	28.97	0.00	2.84	22.46	0.000	0.060	0.592
Bladder	0.00	5.86	68.09	0.00	5.03	**40.51**	0.000	0.062	0.923
Female breast	0.00	1.13	16.11	0.00	1.04	13.88	0.000	0.017	0.221
Liver	0.00	2.86	39.46	0.00	2.62	28.30	0.000	0.006	0.084
Colon	0.00	1.80	20.54	0.00	1.71	17.04	0.000	0.023	0.310
Stomach	0.00	0.64	7.03	0.00	0.63	6.57	0.000	0.007	0.076
Esophagus	0.00	2.51	36.22	0.00	2.25	26.59	0.000	0.004	0.037
Other sites	0.00	1.28	17.30	0.00	1.23	14.75	0.000	0.110	**1.656**

Table 4

The personnel excess radiation risks of 2017, BEIR VII model (the upper limit of 95% CI)

Localizations	ERR, %			AR, %			EAR, $*10^{-3}$		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
All tumours	0.00	1.97	21.83	0.00	1.88	17.92	0.000	0.273	**3.617**
All solid tumours	0.00	1.71	19.14	0.00	1.64	16.07	0.000	0.235	**3.112**
Leukemia	0.03	12.84	161.52	0.03	9.96	**61.76**	0.000	0.038	0.505
Lung	0.00	3.54	54.87	0.00	3.06	**35.43**	0.000	0.061	**1.122**
Bladder	0.00	5.76	60.69	0.00	4.94	**37.77**	0.000	0.049	0.822
Female breast	0.00	1.72	15.03	0.00	1.62	13.06	0.000	0.025	0.156
Liver	0.00	4.46	52.37	0.00	4.01	**34.37**	0.000	0.008	0.112
Colon	0.00	3.11	30.06	0.00	2.92	23.11	0.000	0.036	0.454
Stomach	0.00	1.99	17.87	0.00	1.91	15.16	0.000	0.021	0.229
Thyroid	0.00	6.55	72.81	0.00	3.89	**32.68**	0.000	0.002	0.033
Uterus	0.00	0.71	3.89	0.00	0.70	3.74	0.000	0.005	0.020
Ovary	0.00	2.90	14.76	0.00	2.71	12.86	0.000	0.010	0.045
Other sites	0.00	1.35	12.72	0.00	1.31	11.28	0.000	0.078	0.885

Table 5

The personnel excess radiation risks of 2017, Preston 2007 model (the upper limit of 90% CI)

Localizations	ERR, %			AR, %			EAR, $*10^{-3}$		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
All tumours	0.00	1.11	11.76	0.00	1.08	10.52	0.000	0.145	**1.948**
All solid tumours	0.00	0.97	11.74	0.00	0.94	10.51	0.000	0.136	**1.908**
Leukemia	0.00	5.40	35.41	0.00	4.86	26.15	0.000	0.009	0.052
Lung	0.00	3.53	68.66	0.00	2.97	**40.71**	0.000	0.058	0.987
Bladder	0.00	10.37	250.14	0.00	6.63	**71.44**	0.000	0.099	**2.289**
Liver	0.00	19.81	487.85	0.00	10.48	**82.99**	0.000	0.039	0.833
Colon	0.00	4.51	103.01	0.00	3.72	**50.74**	0.000	0.065	**1.555**
Other sites	0.00	1.95	27.25	0.00	1.83	21.41	0.000	0.169	**2.604**

Table 6

Comparison of the values of the personnel main characteristics and risks in the total absolute radiation risk groups generated by the UNSCEAR-94, BEIR VII, Preston-2007 models

Value	UNSCEAR-94	BEIR VII (upper limit of 95% CI)	Preston-2007 (upper limit of 90% CI)
High absolute radiation risk group			
Group size	17 pers. (5.5%)	26 pers. (8.4%)	1 pers. (0.3%)
Age, years	75 [63, 84]	79 [63, 91]	84
Experience on IDC, years	50 [38, 58]	52 [38, 58]	58
Accumulated dose, mSv	225.54 [159.45, 582.53]	215.04 [161.44, 582.53]	582.53
EAR_{ALL}, $*10^{-3}$	1.2607 [1.0112, 3.0503]	1.2728 [1.0138, 3.6171]	1.9484
Socially acceptable absolute radiation risk group			
Group size	112 pers. (36.4%)	117 pers. (38.1%)	112 pers. (36.4%)
Age, years	70 [51, 91]	68 [51, 87]	72 [54, 91]
Experience on IDC, years	38 [14, 58]	34 [14, 55]	41 [15, 58]
Accumulated dose, mSv	98.37 [34.27, 211.57]	83.24 [25.98, 187.18]	120.78 [37.07, 269.05]
EAR_{ALL}, $*10^{-3}$	0.4531 [0.1034, 0.9995]	0.4045 [0.1002, 0.9913]	0.3478 [0.1002, 0.8196]
Negligibly small absolute radiation risk group			
Group size	178 pers. (58.1%)	164 pers. (53.5%)	194 pers. (63.3%)
Age, years	50 [24, 82]	48 [24, 81]	51 [24, 82]
Experience on IDC, years	10 [1, 29]	9 [1, 29]	11 [1, 33]
Accumulated dose, mSv	15.35 [0.21, 53.16]	13.75 [0.21, 51.79]	17.91 [0.21, 70.76]
EAR_{ALL}, $*10^{-3}$	0.0169 [0.0000, 0.0968]	0.0203 [0.0000, 0.0966]	0.0193 [0.0000, 0.0984]

The personnel also could be divided by attributive risk groups by the values of solid cancers (AR_{SOL}), leukemia (AR_{LEU}) and respiratory systems (AR_{RESP}) attributive risks:

– negligible risk: $AR_{SOL} < 10\%$, $AR_{LEU} < 50\%$, $AR_{RESP} < 20\%$;

– potential risk: $AR_{SOL} \geq 10\%$, or $AR_{LEU} \geq 50\%$, or $AR_{RESP} \geq 20\%$;

– high potential risk: $AR_{SOL} \geq 20\%$, or $AR_{LEU} \geq 75\%$, or $AR_{RESP} \geq 30\%$.

The values of the personnel main characteristics and risks by the groups of absolute and attributive radiation risks generated with different models are given in the Tables 6 and 7. In square brackets the minimum and maximum values of indicators in the risk group are given, before them – the average values of indicators.

As can be seen from Tabl. 6, the high absolute radiation risk group generated by the results of BEIR VII model has the biggest group size: 26 people – 8.4% of the personnel. The average age of the group is 79 years (the minimum – 63 years), the average length of service years at IDC is 52 years (min – 38 years), the average accumulated dose is 215.04 mSv (min – 161.44 mSv).

In Fig. 7 the distribution of background cancer incidence values of solid cancers and leukemia is shown. As we can see from this figure the background cancer morbidity in solid cancers for women over 35 years and men over 40 years exceed the established risk limit of 10^{-3}/year, that indicates a rather vulnerable general health status of the population.

According to [5, 15], about 30…35% of oncological diseases in the world are associated with smoking, 35…40% – with unhealthy diet, 4…5% – with the professional activity, 1…2% – with environmental pollution, 2…3% – alcohol consumption, 4…5% – ionizing radiation, 2…3% – ultraviolet radiation. A fresh vegetables and fruits diet in combination with high physical activity can prevent more than 20% of lung cancer, 33% of breast cancer, 66% of colon tumors. Quitting smoking reduces the probability of cancer by 60…70%.

Table 7

Comparison of the personnel main characteristics and risks in the total attributive radiation risk groups generated by the UNSCEAR-94, BEIR VII, Preston-2007 models

Value	UNSCEAR-94	BEIR VII (upper limit of 95% CI)	Preston-2007 (upper limit of 90% CI)
High potential attributive radiation risk group			
Group size	0 pers. (0%)	3 pers. (0.9%)	4 pers. (1.3%)
Age, years	–	82 [80, 84]	84 [80, 91]
Experience on IDC, years	–	54 [53, 58]	55 [53, 58]
Accumulated dose, mSv	–	307.78 [162.64, 582.53]	276.38 [162.64, 582.53]
EAR_{ALL}, *10-3	–	1.7998 [0.8277, 3.6171]	0.9073 [0.5399, 1.9484]
Potential attributive radiation risk group			
Group size	3 pers. (0.9%)	3 pers. (0.9%)	3 pers. (0.9%)
Age, years	82 [78, 84]	77 [63, 91]	80 [77, 86]
Experience on IDC, years	54 [53, 58]	49 [38, 58]	51 [46, 55]
Accumulated dose, mSv	309.66 [162.64, 582.53]	211.69 [182.19, 269.05]	154.85 [111.63, 183.83]
EAR_{ALL}, $*10^{-3}$	1.5584 [0.6015, 3.0503]	1.1182 [1.0388, 1.2165]	0.4976 [0.3748, 0.6417]
Negligibly small attributive radiation risk group			
Group size	304 pers. (99.1%)	301 pers. (98.2%)	300 pers. (97.8%)
Age, years	58 [24, 91]	58 [24, 87]	58 [24, 87]
Experience on IDC, years	22 [1, 58]	22 [1, 56]	22 [1, 56]
Accumulated dose, mSv	54.79 [0.21, 269.05]	53.24 [0.21, 260.21]	53.38 [0.21, 269.05]
EAR_{ALL}, $*10^{-3}$	0.2319 [0.0000, 1.4792]	0.2492 [0.0000, 1.6620]	0.1317 [0.0000, 0.8196]

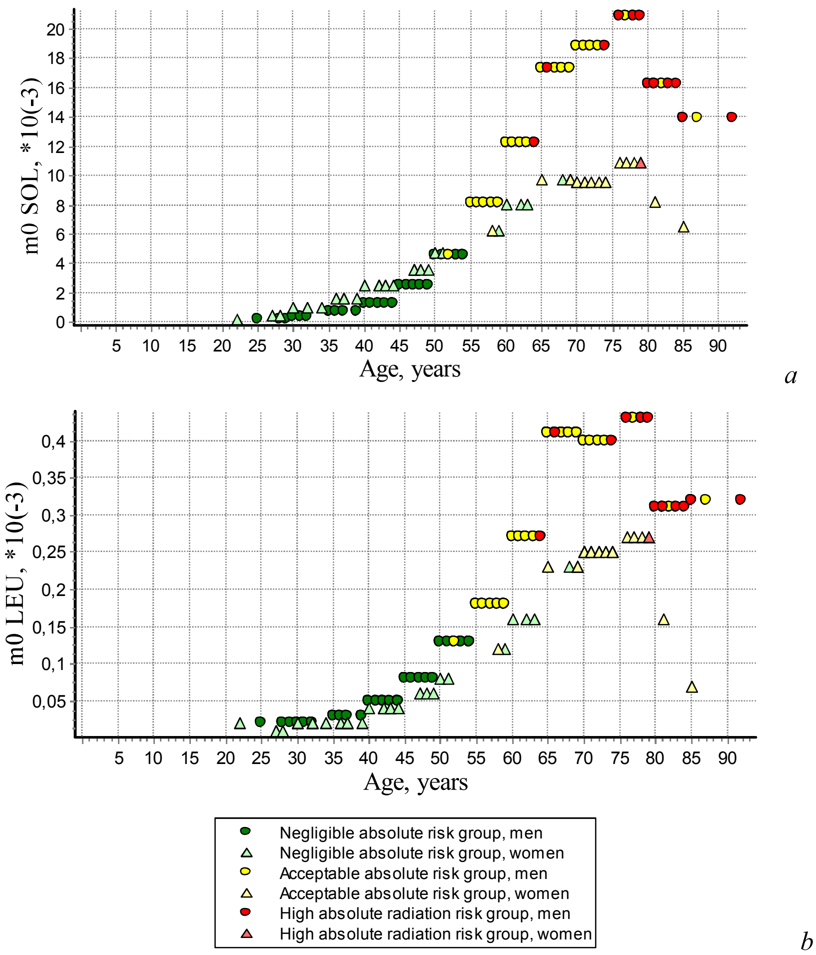

Fig. 7. The distribution of background cancer incidence values used in the calculation of risks for 2017: a – solid cancers, b – leukemia

From the results of Tabl. 7, the group of high attributive radiation risk formed according to the results of the Preston-2007 model has the maximum count of personnel (4 people – 1.3% of personnel). The average age of the group is 80 years (the minimum age is 77 years), the average length of service years at the IDC is 51 (min – 46 years), the average accumulated dose is 154.85 mSv (min – 111.63 mSv). In a case when the person from the given group has a cancer disease, it can be acknowledged a professional disease.

All personnel below 51 years old with a length of service years at IDC up to 14 years were referred to the group of negligible absolute radiation risks by all three methods of calculation, which indicates a sufficiently high level of radiation protection for NSC KIPT personnel working with sources of ionizing radiation.

CONCLUSIONS

The calculated NSC KIPT personnel radiation risks data allows us to conclude the following:

– over the last 20 years the NSC KIPT personnel received minimal additional professional doses, which can not cause a significant increase in the probability of cancer in the future;

– the high absolute risks of personnel are associated with the old age (high background values of cancer cases) and high doses received before 1993;

– the 4 employees of the NSC KIPT (minimum age is 77 years, minimum length of service years is 46) in a case of cancer disease could ask for material help due professional disease becase they have high attributive radiation risks according to the Preston-2007 model.

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ГРУППЫ РАДИАЦИОННЫХ РИСКОВ ПЕРСОНАЛА ННЦ ХФТИ

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Дана характеристика персонала ННЦ ХФТИ, состоящего на ИДК в 2017 году, в терминах «дозовой матрицы». Описаны методологии UNSCEAR-94, BEIR VII, ICRP 2007, используемые в настоящее время для расчетов индивидуальных радиационных рисков. Представлены основные результаты вычислений относительных, абсолютных и атрибутивных рисков на 2017 год для различных локализаций злокачественных новообразований (ЗН) и различных групп радиационного риска, сформированных по различным методологиям.

ГРУПИ РАДІАЦІЙНИХ РИЗИКІВ ПЕРСОНАЛУ ННЦ ХФТІ

О.В. Мазілов, І.О. Стаднік

Надана характеристика персоналу ННЦ ХФТІ, що перебуває на ІДК у 2017 році, у термінах «дозової матриці». Описано методології UNSCEAR-94, BEIR VII, ICRP 2007, які використовуються на даний час для розрахунків індивідуальних радіаційних ризиків. Представлені основні результати обчислень відносних, абсолютних і атрибутивних ризиків на 2017 рік для різних локалізацій злоякісних новоутворень (ЗН) і різних груп радіаційного ризику, сформованих за різними методологіями.