Assessment of the risk of polychlorinated biphenyls exposure in the indigenous population of coastal Chukotka

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Abstract. Traditional economic activities, severe climate, foodstuffs contamination by polychlorinated biphenyls and other persistent pollutants, tobacco smoking and alcohol abuse, as well as geographical remoteness of the Arctic settlements predetermine the increased risks levels for the health of the indigenous communities of the Arctic. A study was conducted to elaborate a toxicokinetic model of health risk assessment that uses quantitative determination of 15 polychlorinated biphenyl congeners in blood serum. This model can be used for the assessment of carcinogenic and non-carcinogenic risks among vulnerable population groups. It has been found that the major source of health disturbance risks among the indigenous people of coastal Chukotka, that relate to the intake of polychlorinated biphenyls into human body, is marine animals and fish. The maximum effect of social factors on the intensity of polychlorinated biphenyl exposure is reported in the coastal areas of Chukotka. The low social and economic status of the indigenous population increases the adverse effect of polychlorinated biphenyl exposure up to 4-14 times. To enhance the effectiveness of measures for reducing the harmful effect of polychlorinated biphenyl on human body, it is necessary that their home areas are cleaned off of contaminants and hazardous waste, awareness of risks and ways to prevent them is enhanced, household environments are devoid of contaminants, social and economic status is improved, and behavioral risk factors are prevented.

1. Introduction
Special conditions for traditional economic activities, severe climate, foodstuffs contamination by polychlorinated biphenyls and other persistent pollutants, tobacco smoking and alcohol abuse, as well as geographic isolation of the Arctic communities predetermine the increased risks for the health of the Arctic indigenous population. Subsisting on traditional food and often enjoying low social status, the small indigenous communities can be exposed to environmentally persistent organic pollutants, in particular, polychlorinated biphenyls (PCBs), to a much greater extent than other populations. The highest PCB concentrations in the indigenous people were registered in the coastal areas of Chukotka Autonomous Area. The analysis of these chemicals in the blood of Uelen coastal village residents did not show any statistically and actually significant changes in their concentrations over the period from 2001 to 2010. At the same time, the tendency is evident for the rate of the diseases potentially related to PCB exposure to grow, indicating the ingress of PCBs into the indigenous communities [1].
The negative consequences of the PCB exposure in the indigenous people of the Arctic are evidenced by adverse pregnancy outcomes; increased perinatal mortality; elevated incidence of miscarriages; congenital malformations; stillbirths, premature births; and low birth weight. PCBs also cause immunosuppression and are carcinogenic [2, 3]. In 2016, the International Agency for Research on Cancer found out that PCBs belong to group 1 of cancer risk factors (carcinogenic for humans) [4].

PCBs tend to accumulate in human body mainly as a result of previous economic activities which were carried out without proper consideration of their dangerous outcomes. Taking into account the findings of the studies conducted in late 1990s–early 2000s, the following measures were developed and introduced in order to reduce PCB exposure: a number of household areas were cleared off of hazardous waste, and medical prevention measures were introduced. [3]. However, the actual impact of the rehabilitation measures undertaken to reduce PCB concentrations in human body and related health disorders were considered to be insufficient [1, 5]. This could be due to inadequate consideration of social, cultural and behavioural factors specific to the indigenous populations of the Arctic, which can have a significant impact on the intensity of PCB effect on human body, leading to the related health disorders.

The current risk assessment procedures are based on determining doses of chemicals ingress into the body, which requires series of laboratory analyses into the chemicals contents in the environmental, as well as the analysis of the vehicles for the ingress – mainly through questionnaires, which may lead to significant uncertainties of calculations. Therefore, we deem it more expedient to employ toxicokinetic (biokinetic) models as allowing for more precise calculation of personal health risk levels and for recommendations to reduce them.

1.1. Purpose of the study

The study aimed at developing a toxicokinetic model for polychlorinated biphenyl risk assessment and at carrying out health risk assessment among the indigenous residents of coastal Chukotka (by the example of Uelen village of Chukotka Autonomous Area) while taking into account their social, economic and behavioural characteristics.

Some text.

2. Materials and methods

The study covered the permanent indigenous residents of Uelen village (Chukotka Autonomous Area). The primary survey and questioning took place in 2001. The cohort of Uelen residents included 251 individuals (aged 18 to 71, 132 women). In 2010 the study covered 86 individuals (aged between 27 and 67 years, 48 women). 50 Uelen residents aged 18-69 years (26 of them women) were randomly selected from the indigenous population group examined in 2001 and had chemical and toxicological tests for PCB concentrations. In 2010 a follow up study was conducted (42 residents aged 27 to 67 years, 23 women).

Blood samples were analyzed for polychlorinated biphenyl content (aggregate and individual analyses for 15 congeners: 28/31, 52, 99, 101, 105, 110, 118, 128, 138, 153, 156, 170, 180, 183, 187) – a total of 1,380 chemical and toxicological tests of venous blood. Blood tests for PCB concentrations were carried out in the accredited laboratories of Typhoon Scientific and Production Association (Obninsk, Kaluga Region) and Unilab Analysis AS (Tromsø, Norway) using one and the same procedure [2, 6]. Informed consents to surveying and blood sampling for PCBs were obtained from all the study participants.

The filled-out questionnaires were analyzed for socioeconomic (income level, occupation) and behavioural (alcohol consumption, diet) information. Also, the awareness among the indigenous population of ways to prevent PCB exposure was explored. The data analysis additionally made use of the statistical records obtained from health care facilities (summaries of outpatient medical histories and birth histories); vital records offices and public bodies in Chukotka Autonomous Area; Hydrometeorological Service’s and Consumer Rights Protection Service’s offices for Chukotka Autonomous Area.
The analysis made use of the data of the Arctic Monitoring and Assessment Program [7] on the PCB concentrations in food, environment and household surfaces. The amount of food being consumed by the indigenous residents was determined through questioning, and the State Statistics Committee data for products purchased in retail shops were also used. Health risks calculation was carried out according to the procedure R 2.1.10.1920-04 (Guidelines for Human Health Risk Assessment from Environmental Chemicals) [8]. Health risks were assessed taking into account the dietary intake of PCBs via traditional foods (fish, sea animals, venison), grocery store food, household surfaces (scrapings), soil (orally and inhalatively), drinking water (orally), and atmospheric air. To determine PCB concentrations entering the body through contaminated household surfaces, the Department of Toxic Substances Control (USA) method was used [9].

To calculate the risk of PCB exposure, a toxicokinetic model was developed based on the correlation between the average daily PCB intake and the aggregate sum of 15 PCB congeners in blood serum (determination coefficient 0.600). This model is presented in the form of a linear regression equation:

\[ x = \frac{(y - c)}{B} = \frac{(y - 1.789)}{0.031} \]

the upper limit of 95% confidence interval is: \[ x = \frac{(y - 0.011)}{0.018} \]

the lower limit of 95% confidence interval is: \[ x = \frac{(y - 3.567)}{0.045} \]

where \( y \) is PCB concentration in serum (\( \mu g / l \)), \( B \) is non-standardized coefficient (PCB), \( c \) is a constant, \( x \) is the PCB intake (ng / kg * day).

For the purpose of the model, we compiled a cohort of 18 indigenous nonparous females aged from 18 to 57 years – all permanent residents of Uelen village in Chukotka. We used the data from the 2001 questionnaire survey (average daily food consumption); the result of chemical-analytical venous blood plasma tests for PCB concentrations (2001); as well as the 2001 data on PCB concentrations in foodstuffs [7].

The model for converting the PCB serum concentration into daily average dose is based on the total PCB intake from traditional foods consumed by the indigenous population (venison, meat and fat of sea animals, fish). The toxicokinetic model allows to assess PCB exposure risks without conducting a questionnaire study or determining the PCB concentrations in foodstuffs. Where the PCB content in blood plasma is very low (due to dispersion of random error), the model should use the upper limit of the 95% confidence interval or, a priori, consider the health risk to be acceptable. Despite the fact that the 95% confidence interval has a wide range, this model is able to significantly reduce the numerous uncertainties in risk assessment that relate to estimated daily dose and are so typical of the questionnaire survey method used for determining consumption rates of the foodstuffs potentially contaminated by PCBs. This is especially important when assessing this individual risk levels, for example, in pregnant women and other vulnerable population groups.

Our study focused also on the influence of socio-economic and behavioral factors on the risk of PCBs exposure and content in human body. Since the groups under study were mostly homogeneous in sex and age and heterogeneous in social status, the PCB-related health risk levels were analyzed without classifying the participants according to age and sex. Male groups, however, were subclassified according to occupation, given that traditional subsistence (hunting, fishing and reindeer herding) is practiced only by male population.

Reference dose values for calculating non-carcinogenic risk (HQ) and cancer slope factors (CSF) for calculating carcinogenic risk (CR) were determined in accordance with the recent data from the Environmental Protection Agency (EPA, USA). CSF for dietary intake of PCBs equals 2 mg / kg * day-1 (inhalation and drinking water - 0.4 mg / kg * day-1) [10].

The Mann-Whitney criterion and the t-criterion for independent samples were calculated, and a regression analysis was performed. The normal distribution was estimated using the Kolmogorov-Smirnov criterion. The critical level of significance of the null statistical hypothesis was assumed 0.05; the method of confidence intervals was used to estimate significance of the differences. PCB concentrations and exposure are given as arithmetic mean or median with indication of 95%
3. Results and discussion

The risks from PCBs ingress into the body are mainly caused by the consumption of traditional foods – sea animals (walrus and seal meat and fat) and sea fish (chum salmon, humpback salmon, char). The main pathway for PCBs to enter the body through contact with contaminated household surfaces (98%-99% of the total dose) is oral, resulting also from secondary contamination of food (Table 1).

| Risk factor                  | Carcinogenic risks       | Non-carcinogenic risks | Relative contribution, % |
|-----------------------------|--------------------------|------------------------|--------------------------|
| Atmospheric air             | 9.6*10^{-3}[1.2*10^{-3}-1.8*10^{-3}] | 8.0*10^{-6}[1.0*10^{-2}-1.5*10^{-2}] | <0.1                     |
| Drinking water              | 2.0*10^{-5}[2.1*10^{-5}-3.8*10^{-5}] | 1.7*10^{-4}[1.8*10^{-3}-3.2*10^{-3}] | <0.1                     |
| Household surfaces          | 4.7*10^{-5}[7.2*10^{-6}-8.7*10^{-6}] | 0.078                  | 18.6                     |
| Soil                        | 7.1*10^{-8}[1.2*10^{-8}-1.3*10^{-8}] | 5.3*10^{-4}[9.0*10^{-5}-9.7*10^{-4}] | <0.1                     |
| Grocery store food          | 6.1*10^{-6}              | 0.010                  | 2.4                      |
| Traditional foods           | 2.0*10^{-4}[5.3*10^{-5}-5.4*10^{-4}] | 0.32[0.09-0.90]        | 79.0                     |
| Risk total                  | 2.5*10^{-4}[6.6*10^{-5}-6.3*10^{-5}] | 0.41[0.11-1.06]        | 100                     |

The relative contribution of foodstuffs (including grocery store food) to the overall PCB exposure exceeds 80%, which validates the use of the toxicokinetic model for risk assessment. The contributor to PCB exposure that ranks the second is contaminated household surfaces and secondary contamination of foodstuffs. It should be noted that as the indigenous people move to new homes, the contaminated household surfaces are likely to lose their impact.

In Table 2, the PCB exposure-related health risks among Uelen residents are given in relation to social and behavioral factors, determined using the said toxicokinetic model.

| Indicator                                      | Value                                   | Carcinogenic risks       | Non-carcinogenic risks |
|-----------------------------------------------|-----------------------------------------|--------------------------|------------------------|
| Monthly household income per capita (RUR 11,113.5) | below subsistence minimum               | 3.4*10^{-4} [1.6*10^{-4} - 7.9*10^{-4}] | 0.57 [0.26-1.32]        |
|                                               | above subsistence minimum               | 2.6*10^{-5} [0.0 - 2.4*10^{-5}] | 0.04 [0.00-0.40]        |
| Marine mammal fat consumption                 | high                                    | 4.8*10^{-4} [2.5*10^{-4} - 1.0*10^{-3}] | 0.81 [0.42-1.72]        |
|                                               | low                                     | 8.8*10^{-5} [0.0 - 3.5*10^{-5}] | 0.15 [0.00-0.58]        |
| Alcohol consumption                           | low (up to 2 bottles of vodka per month) | 4.1*10^{-5} [0.0 - 1.7*10^{-5}] | 0.14 [0.00-0.56]        |
|                                               | high (4+ bottles of vodka per month)    | 3.9*10^{-4} [1.9*10^{-4} - 8.7*10^{-4}] | 0.65 [0.32-1.45]        |
| Occupational activity, the village of Uelen   | Traditional subsistence (hunters, fishermen, reindeer herders) | 5.8*10^{-4} [3.2*10^{-4} - 1.2*10^{-3}] | 0.97 [0.53-2.00]        |
|                                               | other occupations                       | 1.4*10^{-4} [1.8*10^{-5} - 4.4*10^{-4}] | 0.24 [0.03 - 0.74]       |
| Awareness of PCB exposure prevention          | Unaware                                 | 3.8*10^{-4} [1.8*10^{-4} - 8.5*10^{-4}] | 0.63 [0.30-1.41]        |
|                                               | Aware                                   | 6.7*10^{-5} [0.0 - 3.1*10^{-4}] | 0.11 [0.00-0.52]        |
It has been found that low income, high sea animal fat consumption, alcohol abuse, traditional subsistence and lack of awareness of PCB exposure prevention increase PCB-related health risks by 4-14 times.

The low income among the indigenous people does not allow them to buy the costly, imported products from grocery stores, self-caught fish and, in coastal areas, sea animals (containing significant amounts of PCBs) remaining their main source of food (up to 90% of the diet) [11]. Their low social status is what increases the exposure to persistent organic pollutants and some of the heavy metals. Yet, the impact of such exposure is manifest only in some of the Arctic areas – in response to only some of the persistent pollutants. The highest exposure to persistent organic pollutants is found in the coastal village of Uelen, Chukotka Autonomous Area: it largely relates to PCB exposure [12]. Similarly, in individuals practicing traditional subsistence the increased health risk levels due to PCB exposure are directly linked with the consumption of traditional food and the low incomes, the traditional subsistence being least rewarding of all sectors of Chukotka Autonomous Area’s economy [13].

Despite the sanitary awareness raising campaign conducted in the early 2000s, the vast majority of the indigenous people (90%) remain unaware of the risks associated with exposure to PCBs and measures to prevent them, which increases the risk of PCB exposure by 5.7 times.

Alcohol abuse is high among the indigenous population, and home brewing is common. In one respect, alcohol is an obstacle to receiving quality education and well-paid jobs, ultimately forcing the indigenous communities to subsist on the cheap traditional food with high PCB content. On the other side, home brewing per se is a health risk: PCBs migrate to home brew from the multiple use plastic containers. This fact is responsible for a 4.6-fold increase in the risk of PCB exposure.

Please see Table 3 for the impact of socio-economic and behavioral factors on PCB concentrations in indigenous people’s blood.

| Indicator                                      | Value                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------|
| Monthly household income per capita           | PCB content in blood serum depending on the expression of social and behavioral factors. |
| Monthly household income per capita           | PCB content in blood serum depending on the expression of social and behavioral factors. |
| Monthly household income per capita below subsistence minimum (RUR 11,113.5 monthly), n = 33 | 7.12 ± 3.91                                                          |
| Monthly household income per capita above subsistence minimum, n=9 | 2.92 ± 0.82                                                          |
| Monthly household income per capita significance of differences (p) | 0.001                                                                |
| Occupation                                     | PCB content in blood serum depending on the expression of social and behavioral factors. |
| Occupation traditional trades (hunters, fishermen, reindeer herders) n=6 | 10.35 ± 4.75                                                        |
| Occupation other occupations n=12            | 5.53 ± 2.92                                                          |
| Occupation significance of differences (p)    | 0.007                                                                |
| Alcohol consumption                            | PCB content in blood serum depending on the expression of social and behavioral factors. |
| Alcohol consumption low (up to 2 bottles of vodka per month), n=17 | 3.42 ± 2.65                                                        |
| Alcohol consumption high (4+ bottles of vodka per month), n=25 | 8.05 ± 4.11                                                        |
| Alcohol consumption significance of differences (p) | ＜0.001                                                        |
| Awareness of PCB exposure prevention          | PCB content in blood serum depending on the expression of social and behavioral factors. |
| Awareness of PCB exposure prevention Unaware, n=38 | 6.53 ± 2.87                                                        |
| Awareness of PCB exposure prevention Aware, n=4 | 3.23 ± 0.74                                                        |
| Awareness of PCB exposure prevention significance of differences (p) | 0.001                                                                |

The consumption of commercial fish and marine mammals, as well as pollution of dwellings by PCBs, are what can be managed only poorly: the current Russian legislation does not provide for any regulations to monitor the PCB concentrations. It is therefore impossible to monitor the actual food consumption and how food is treated. In this context, highly relevant are healthy diet recommendations for the High North residents, that restrict or ban consumption of certain foods [7], but for such recommendations to prove effective they need to be complemented by measures to enhance the education and income levels among the indigenous people, and to remove the accumulated environmental damage. The lack of vitamins and microelements could be made up for by
importing food products from eco-safe areas of the Arctic. For them to be affordable to the indigenous communities, new jobs should be created, access to vocational education ensured, and governmental subsidies allocated to retail businesses. Subsidies should target also the trades being traditionally practiced by the communities in the Far North, Siberia, and the Far East, and ample sanitation outreach should be in place that uses the indigenous community-friendly methods.

The increased non-carcinogenic PCB exposure risk among the indigenous Arctic people who enjoy low social status, results, first of all, in immunity decrease [15], which increases the risk of infectious and parasitic diseases and some respiratory diseases. In addition, the risk of developing diseases of the endocrine and urogenital systems, congenital malformations, and adverse pregnancy outcomes increases [7]. An unacceptable carcinogenic risk is predicted for residents of the village of Uelen (mainly due to the intake of PCB with traditional food, especially among those engaged in traditional trades). Currently, the mortality rate from malignant neoplasms in Chukotka coastal areas is at a consistently low level (Chukotka District – 119.6 per 100,000 residents; Russia – 201.6 per 100,000 residents according to the data for 2016), but this can be explained by early mortality from external causes and circulatory system diseases.

4. Conclusions
A toxicokinetic model has been developed for assessing health risks that uses quantitative determination of 15 polychlorinated biphenyl congeners in blood serum. Since the model achieves a reduced scope of uncertainty, which would have otherwise been greater if the model used the “estimated daily dose” principle, it allows for individual risk assessment, for example, in pregnant women and other vulnerable population groups.

Among the indigenous population of coastal Chukotka, the main source of the increased health risks related to the ingress of polychlorinated biphenyls into human body is traditional nutrition (consumption of self-caught fish and sea animals), which is responsible, in the total exposure risk profile, for more than 80%. One more source of polychlorinated biphenyls is contaminated household surfaces. Leading to secondary food contamination, they are responsible for 19% contribution to PCB-related health risks. However, as residents move to new houses, their influence is likely to decrease. The low socioeconomic status is likely to be significantly increasing the risk of exposure to polychlorinated biphenyls. Social status is what increases the exposure to persistent organic pollutants and some of the heavy metals. The highest exposure to persistent organic pollutants is found in the coastal village of Uelen, Chukotka Autonomous Area. The engagement in traditional trades (hunting, fishing, reindeer herding), the traditional diet (meat and fat of marine mammals), the lacking awareness of PCBs, and the alcohol abuse increase the PCB exposure risks by 4-14 times.

A number of recommendations and proposals have been developed aiming to improve the effectiveness of measures towards reducing the PCB exposure and better medical and demographic situation. In addition to cleanup operations and decontamination of hazardous wastes, these recommendations and proposals include a set of measures to increase awareness of how PCB exposure could be reduced; monitor and decontaminate household surfaces; improve socio-economic status and prevent behavioral risk factors among the indigenous people of the Russian Arctic.

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