CONCLUSIONS

The assessment of the long-range atmospheric transport and depositions of mercury (Hg), selected polychlorinated biphenyls (PCBs), and lindane (γ-HCH) to the selected five administrative units of the Russian part of the Arctic region has been carried out on the simulation results of 1996.

This assessment involves:

- *Development of the System of Diagnosis of lower Atmosphere (SDA) for generation of meteorological data for hemispheric modeling.*
- *Adaptation of geophysical data, information on land cover, leaf area index, organic carbon content in soil, and chemical reactant concentrations in the atmosphere for the hemispheric scale.*
- *Survey of physical-chemical properties of Hg and selected POPs and their model parameterization.*
- *Collection and processing of official emission data and expert estimates within the hemispheric scale.*
- *Elaboration and testing of atmospheric transport module common for Hg and POPs transport models.*
- *Development of hemispheric Eulerian model oriented on peculiarities of mercury behaviour in the Arctic region, in particular mercury depletion events.*
- *Development of hemispheric multicompartment model for the evaluation of POP concentrations in various environmental compartments (air, soil, vegetation, seawater, ice cover) with special emphases on POP transport by sea currents and on ice cover dynamics in the Arctic.*
- *Evaluation of transport pathways and the contamination load of the considered pollutants to the Russian North and to the Arctic as a whole from Russian sources and sources located within the Northern Hemisphere.*

Basic outcome

Mercury (Hg)

The assessment of pollution by Hg using the developed hemispheric MSCE-Hem-Hg model is based on the global inventory of mercury emissions. Major conclusions drawn from modeling results obtained for 1996 are presented below.

- Atmospheric long-range transport of mercury from industrial regions of the Northern Hemisphere markedly contributes to the pollution of the Arctic as a whole, and regions of the Russian North in particular. Natural sources as well as the re-emission of previously deposited mercury can make a considerable contribution to Arctic contamination.

- Mercury concentration levels in the ambient air slightly vary over all regions of the Russian North (mean annual values 1.4-1.8 ng/m^3). Deposition fluxes vary more significantly (from 4 to 25 g/km^2/y) depending on the precipitation amount. The highest depositions are over areas adjacent to the Arctic coast due to mercury depletion events.
- For all the regions of the Russian North the influence of Russian emission sources dominates over those of external regions. The main external contributors to the pollution of the Russian North are Eastern and Western Europe, China, the Americas, and Central Asia. The relative importance of these contributors varies in different regions of the Russian North. Mercury depletion events phenomenon results in an increased role being played by external sources in the pollution of the region.
- The largest contribution to mercury deposition in **Murmansk Oblast** is made by Russian sources (35%) from which 13% belongs to the sources of this region. The most important external sources are Eastern Europe (12%), China (11%), the Americas (10%), and Western Europe (10%).
- Similar contributions to the pollution of Murmansk AO are obtained for **Nenets AO**. The most important contribution is made by Russian mercury emission sources (35%). Along with local sources from **Nenets AO** (7%) emissions from the regions of the European part of Russia considerably contribute to the pollution of this region (24%). The most important external contributors are Eastern Europe (13%), China (11%), and the Americas (10%).
- The Ural region and two central regions of European Russia (CVV and CVN) make up the main contribution (16%) to the pollution of **Yamalo-Nenets AO and Taimyr AO** from Russian sources (30%), whereas regional sources do not play a substantial role. The main external contributors are China (12%), Eastern Europe (12%), the Americas (11%) and Central Asia (11%).
- Russian regions contribute about 30% of the total annual mercury deposition to **Sakha Republic.** Among them the most significant contribution is made by regional sources (6%). Major external contributors are China (15%), the Americas (11%), Eastern Europe (11%), and Central Asia (10%).
- Similar to other regions of the Russian North the main contribution to the pollution of **Chukotka AO** is made by Russian sources (26%). Emission sources from Eastern Siberia and the Far East dominate over other Russian regions in the mercury contamination of **Chukotka AO**. The main external contributor to the pollution of the region is China (17%), whose contribution is comparable with that of Russian sources and slightly varies during the year. Among others, the Americas contribute 11% and Central Asia 10%.

Polychlorinated biphenyls (PCBs)

The assessment of pollution by PCBs is based on the modeling results of the long-range transport of four selected PCB congeners (PCB-28, PCB-118, PCB-153, PCB-180) within the Northern Hemisphere for 1996. These results were obtained using the developed hemispheric multicompartment MSCE-POP model and the global historical inventory of PCB emissions. The main conclusions are presented below.

- Model evaluation of pollution by PCBs has provided concentrations of selected congeners in the main environmental compartments (atmosphere, soil, seawater and vegetation) and their depositions for 1996. Verification of modeling results showed a reasonable agreement between computed values and available measurements of PCB concentrations in air and in precipitation. The application of the constant value of the specific aerosol surface to the calculation of gas/particle partitioning leads to uncertainties in depositions and mean annual air concentrations

ranging within about 20-30% for the Russian North. For other regions of the Northern Hemisphere the uncertainties are higher. In further model development the spatial distribution of the specific aerosol surface should be taken into account.

- PCB-153 concentrations gradually decrease from 2.6 pg/m^3 in Murmansk Oblast to 0.7 pg/m^3 in Chukotka AO. The decrease in deposition flux ranges from 200 mg/km^2/y to 50 mg/km^2/y. A similar pattern of concentration and deposition variations is observed for other congeners.
- PCBs accumulated mostly in soil. Heavy PCB congeners make the highest contribution to long-term accumulation. According to preliminary estimates, the fraction of air concentrations caused by the re-emission process from soil amounts to 30-80%, depending on the congener and region.
- The largest contribution to the depositions in **Murmansk Oblast** is made by Russian sources (44%). Among other emission sources significant contributions are made by North-Western Europe (35%) and South-Eastern Europe (14%). **Murmansk Oblast** depositions are formed mostly by local sources (about 22%).
- The contributions of different source groups to the pollution of **Nenets AO** are similar to those of Murmansk Oblast. Contributions of Russia and North-Western Europe are slightly lower (41% and 31%), but contributions of South-Eastern Europe and the Americas are slightly higher (18% and 6%) in comparison with Murmansk Oblast. The main contribution from sources in the Russian Federation is made by the Central and Volgo-Viatsky regions (15%) and by the Northern region (10%). The contribution of local sources to **Nenets AO** is negligible.
- Major contributions to the depositions to **Yamalo-Nenets and Taimyr AO** are made by Russia (47%), North-Western Europe (26%) and South-Eastern Europe (16%). Among the Russian sources the largest contribution to depositions is made by the Central and Volgo-Viatsky regions (12%).
- Russia (38%), North-Western Europe (23%) and South-Eastern Europe (16%) are major contributors to depositions in **Sakha Republic**. Among the Russian sources of PCB emissions, the main contribution is made by regional sources (13%).
- The most essential contributors to depositions in **Chukotka AO** are the following: Russia (25%), North-Western Europe (22%) and South-Eastern Europe(19%). A comparable contribution is also made by American sources (17%). The main contribution from Russian sources is made by emissions from **Chukotka AO** itself (8%).
- These estimates of contributions to the selected regions are based on PCB-153 data. The contributions of other congeners are given in Annex A.

γ-Hexachlorocyclohexane (γ-HCH)

A Model evaluation of pollution by γ-HCH was made with the use of the hemispheric multicompartment MSCE-POP model and available emission data. The collected emission dataset is not consistent and does not include all sources of the Northern Hemisphere. Pathways of γ–HCH transport from main source groups to regions-receptors were examined.

- Air concentration levels in regions-receptors are within the range 0.05 – 0.5 ng/m^3, and deposition flux is from 1 to 10 g/km^2/y. Air concentration levels in four regions (Murmansk Oblast, Nenets AO, Yamalo-Nenets AO and Taimyr AO, and Sakha Republic) are similar to one another. Average concentrations in Chukotka AO are two times lower. Annual deposition flux values decrease more substantially from region to region, in an eastward direction.

- γ–HCH accumulates mainly in seawater. About 80% of all γ–HCH content in the environment is contained in this medium. An essential part of γ–HCH is transported to the Arctic by sea currents from the Atlantic Ocean. It was found that the marine pathway is significant for marine concentrations near the borders of the Russian North.
- The main contribution to γ–HCH depositions in **Murmansk Oblast** is made by sources in Western Europe (54%), followed by Russia - 17%, and India - 9%. The Russian contribution to depositions is mostly made by sources from the Central and Volgo-Viatsky regions (5%) and Central-Chernozem, Volga, and North-Caucasian regions (4%).
- Similar to Murmansk Oblast, major contributions to the pollution of **Nenets AO** are made by emission sources from Western Europe (49%), Russia (23%), and India (9%). The main sources in the Russian Federation are the Central and Volgo-Viatsky regions (8%) and Central-Chernozem, Volga, and North-Caucasian regions (8%).
- For **Yamalo-Nenets and Taimyr AO** the major contributors are Western Europe (48%), Russia (21%), and India (10%). The main sources in the Russian Federation are the Central and Volgo-Viatsky regions (7%) and Central-Chernozem, Volga, and North-Caucasian regions (8%).
- The major contributors to the pollution of the **Sakha Republic** are the following: Western Europe (36%), India (19%), and Russia (11%). The main sources in the Russian Federation are the Central and Volgo-Viatsky regions (3%) and Central-Chernozem, Volga, and North-Caucasian regions (4%).
- For **Chukotka AO** main contributions to contamination are made by India (27%), Western Europe (27%), China (19%), and the Americas (11%). The contribution of Russian sources accounts for 5%.
- Contamination levels in regions-receptors undergo substantial seasonal variations due to changes in meteorological conditions and variations in emissions.

Some general conclusions could be made on the ground of the performed investigations:

- Europe, North America, and South-eastern Asia are the most sizeable emission sources of mercury, PCBs and γ-HCH. The bulk of Russian emissions are located in the European part of the Russian Federation. Due to geographical location and meteorological conditions, European sources make the basic contribution to the contamination of western regions of the Russian North. Asian and North American sources play more significant roles in the pollution of the eastern territories of the Russian Arctic, though the contribution of European sources is still considerable.
- The obtained results make it possible to predict contamination levels in the Russian Arctic for the near future. The analysis of the emission data shows that mercury emissions decrease in Europe and North America, whereas they grow in South-eastern Asia. The influence of Asian sources may become prevailing, thus contamination levels of this pollutant in some regions of the Russian North may increase in the future. As to γ-HCH, its usage is prohibited in most countries, although it is still utilized in Asia. Thus the relative influence of Asian countries on pollution of the Russian Arctic by γ-HCH is likely to increase. At the same time PCB contamination levels are expected to decrease with emission reduction, though contamination due to accumulation in environmental media remains significant.