THE ENVIRONMENTAL PROBLEMS OF THE BALTIC SEA BASIN

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THE MAIN ENVIRONMENTAL PROBLEMS OF THE BALTIC SEA AND THE WAYS TO SOLVE THEM

The Baltic Sea is a unique ecological system, an integral part of the global ecological system, which is in urgent need of protection from destructive anthropogenic impact stemming from the production and consumption of nuclear energy and artificial radionuclides, agriculture, oil and oil product transportation, and sewage and solid waste treatment. The article outlines the main environmental problems of the Baltic Seas and the ways to solve them.

Key words: *Baltic Sea, ecology, eutrophication, artificial radionuclides (^{235}U, ^{239}Pu, ^{240}Pu, ^{134}Cs, ^{137}Cs, ^{90}Sr, ^{3}H), heavy metals (Cu, Cd, Hg, Pb), oil.*

Up to the present time geochemistry of the Baltic Sea and hydrological processes proceeding in its waters are well enough investigated [1]. The unique geographical position of the Baltic Sea, shallow waters, low salinity of its waters, and pretty complicated water exchange with the Northern Sea are the primary factors playing the major role in formation of natural biodiversity of the Baltic Sea and therefore causing its extremely low ability to autopurification on the first hand and high sensitivity to anthropogenous influence on the other, whereas the average time of full renovation of water composes approximately 30—50 years [2]. Such a big values make it difficult to carry out the natural self-cleaning processes which are going on in its brackish sea water rendering essential influence on ecological situation in the region. For the last 50 years the ecological situation in the Baltic Sea has considerably worsened, and according to the environmental forecasts if the present rate of water pollution were kept as the same as today for further 10 years, the Baltic Sea water probably might never be used for domestic purposes, whereas its unique marine fauna risks to disappear forever [3].

That is why environmental problems in the Baltic region including Russia, Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Germany and Denmark, the environmental problems have a paramount social, economic and socio-political meaning. These problems are affected by various anthropogenous factors and industrial-economic spheres of human activity, such as manufacture and consumption of atom energy, the industry, agriculture, transport, fishery, military uses, wastes, processing of sewage waters [4]. There have been lots of big industrial cities lying on the Baltic coast in which people suffer from the waste pollution covering sea water, soil and air. According to the World Health Organization (WHO) the principal cause for anxiety is made up with high percent of allergic and oncology diseases detected in this region [5].

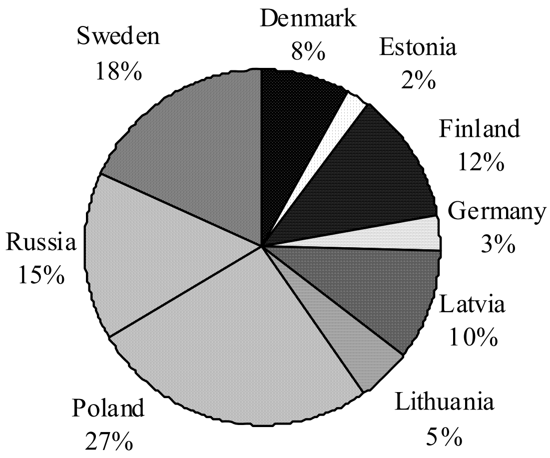
All this results in complex pollution of the Baltic Sea waters, distraction of its biodiversity, and degradation of natural environment. The basic part of water pollution make up industrial-household waste products and waste products of agriculture, oil and oil products, artificial radionuclides from nuclear plant engineering (polonium ^{210}Po, uranium ^{235}U and ^{238}U, plutonium ^{239}Pu and ^{240}Pu, strontium ^{90}Sr, caesium ^{134}Cs and ^{137}Cs) and heavy metals (copper (Cu), cadmium (Cd), mercury (Hg), lead (Pb)) [6]. Thus, about 50 % of total of heavy metals Cu, Cd, Hg, Pb enter into the Baltic Sea waters with an atmospheric precipitation, the basic part — through dumping in water area or through a river drain household and industrial wastes [7]. All these factors leads to essential pollution of the Baltic Sea waters, destruction of marine ecological system and severe degradation of natural environment. This in turn, harms a variety of other industries, including fishing and tourism [8]. Species of marketable fish such as herring, salmon and cod living in the Baltic Sea are strongly affected by pollution from urban areas, industries, and agriculture fertilizers. As a result the contents of caesium (Cs), strontium (Sr), as well as heavy metals of Zinc (Zn), cadmium (Cd), lead (Pb) and mercury (Hg) in the herring and cod caught in the Baltic Sea far in 5 times exceed threshold limit values [9], while in zooplankton — 3 times [10].

The constant serious sourse of ecological danger of the Baltic Sea however are waste products of military production and chemical weapons. Today the Baltic Sea is an underwater arsenal of various kinds of military weapons and wastes of different epochs. After the second world war into the Baltic Sea it were dropped down approximately 3 million tons of the chemical weapons contained 14 poisonous warfare agent substances of which highly toxic substances as the sulfur mustard gas (1,5-dichloro-3-thiapentane) and phosgene $COCl_2$ are well known [11]. According to the present estimates there are more than 50 potential dangerous dumps of toxic substances and radioactive wastes of cold war epoch in the Baltic Sea and its coastal area [12]. By an average estimation at the bottom of the Baltic Sea there are 267 thousand tons of bombs, shells and mines which were flooded down to the Baltic Sea waters after the ending of the Second world war. There are more than 50 thousand tons of fighting poison gases inside of them [13]. Because of insufficient ability of autopurification of the Baltic Sea waters, dangerous poisonous substances from adjacent dumps and wastes are gradually leaking into the Baltic Sea. Thus, acording to military estimates the speed of water corrosion of ammunition makes up approximately 15—80 years, and artillery shells — 20—140 years [14].

The agriculturally advanced costal areas and the densely populated industrious countries also play an important role in deterioration of ecological situation in the Baltic region. The second important factor contributing to the degradation of the Baltic Sea is the destruction of its natural wetlands, particularly in the western parts of its catchment area. Important agricultural areas are located in Russia, Estonia, Latvia, Lithuania and Poland, with the latter accounting for about 40 percent of arable land in the entire catchment area of the Baltic Sea region [15]. As a result of intensive agriculture, the amounts of nitrogen-phosphoric nutrients dumped into the water of the Baltic Sea have increased seven times during the last 50 years, having severe ecological effects on the ecosystem and living organisms. The nutrient input from agriculture includes ammonia (NH_3), nitrogen (nitrates $(NO_3)^-$ and organic nitrogen), and phosphorus in composition with phosphates $(PO_4)^{3-}$, manure storage and silage heaps. Present estimates are indicated that due to the result of fertilizers washout from arable lands and municipal sewage waters containing the waste products of agriculture and fishing annually into waters of the Baltic Sea enter 600 000 tons nitrogen and 25 000 tons phosphorus per year; while due to anthropogenous activity — 86000 tons of nitrogen and 2100 tons of phosphorus respectively (data for 2006) [16]. Somewhat over 50 percent of this amount comes from agricultural runoff from the areas bordering the eastern and southeastern Baltic coast (from St. Petersburg region to Schleswig-Holstein region). 40 % of nitrogen supply comes directly from the atmosphere and through nitrogen-fixation, a natural process caused by some plankton algae, while only 10 % of the phosphorus supply derives from the atmosphere [17]. Nitrogen and phosphorus discharges to the Baltic Sea and its distribution on various human activities in 2006 are shown in Figure 1 and Figure 2 respectively. Thus on a share of Poland is 27 % and 39 % from the general emission of nitrogen and phosphorus, Russia — 15 % and 11 %, Sweden — 18 % and 13 %, Finland — 12 and 13 %, Latvia — 10 % and 10 %, Lithuania — 5 % and 5 %, Germany — 3 % and 2 %, and Estonia — 2 % and 2 % of nitrogen and phosphorus (fig. 1). The greatest amounts of phosphorus and nitrogen come from the agriculture (delivers 44 % of nitrogen and 45 % of phosphorus), municipal wastewater treatment plants (24 % of nitrogen and 20 % of phosphorus), and the industry (6 % of nitrogen and 17 % of phosphorus). The forestry gives 4 % of nitrogen and 1 % of phosphorus, storm waters — 1 % of nitrogen and 5 % of phosphorus whereas with internal inland waters it enters up 19 % of nitrogen (fig. 2).

The strongest anthropogenous influence, caused by increasing exogenous nitrogen and phosphorus contents, creates a problem of eutrophication, i. g. an impetuous growth of invasive blue-green seaweed species *Nodularia spumigena, Aphanizomenon flos-aquae, Anabaena flos-aquae* and *Dinophysis dinoflagellates* [18]. The zone of eutrophication in the Baltic Sea has 1,6 thousand km in length and 190 km in width and it is distinctly visible from airspace (fig. 3). Eutrophication in its turn leads to substantial internal input of algal toxins into the Baltic Sea. The rapidly multiplying blue green algae consume a lot of oxygen for its growth which causes the amount of oxygen at the bottom of the Sea to be further decreased.

Nitrogen discharges to the Baltic Sea in 2006



Phosphorus discharges to the Baltic Sea in 2006

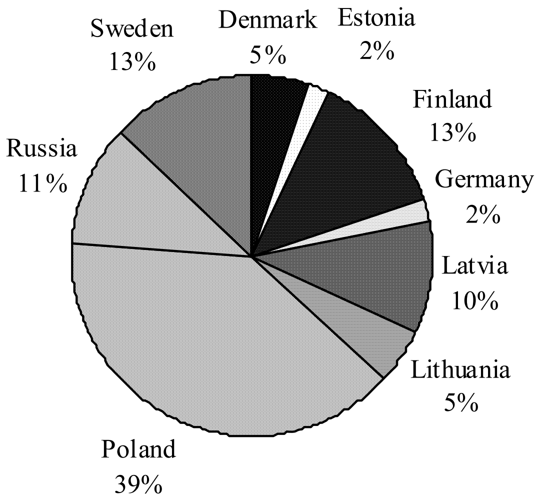


Fig. 1. Nitrogen (top diagram) and phosphorus (bottom diagram) discharges to the Baltic Sea in 2006, from both anthropogenic sources and natural background loads (source: Helsinki Commission [16])

It is believed that the one third part of a bottom of the Baltic Sea suffers from serious lack of oxygen [19]. Shortage of oxygen, in its turn, limits growth and development of living organisms at the Sea bottom, which, eventually, destroys food for zooplankton and fish [20]. As the result of this, biogenic organic substances are not completely utilized and therefore may decay at deficiency of oxygen in water, allocating into the environment pernicious for sea inhabitants hydrogen sulphide (H_2S) [21]. Now the concentration of H_2S in hydrosulphuric zones at the bottom of the largest hollows of the Baltic Sea — Bornholm, Gotland and Gdansk is so great, that there can not exist any one living organism in such hydrosulphuric contained waters.

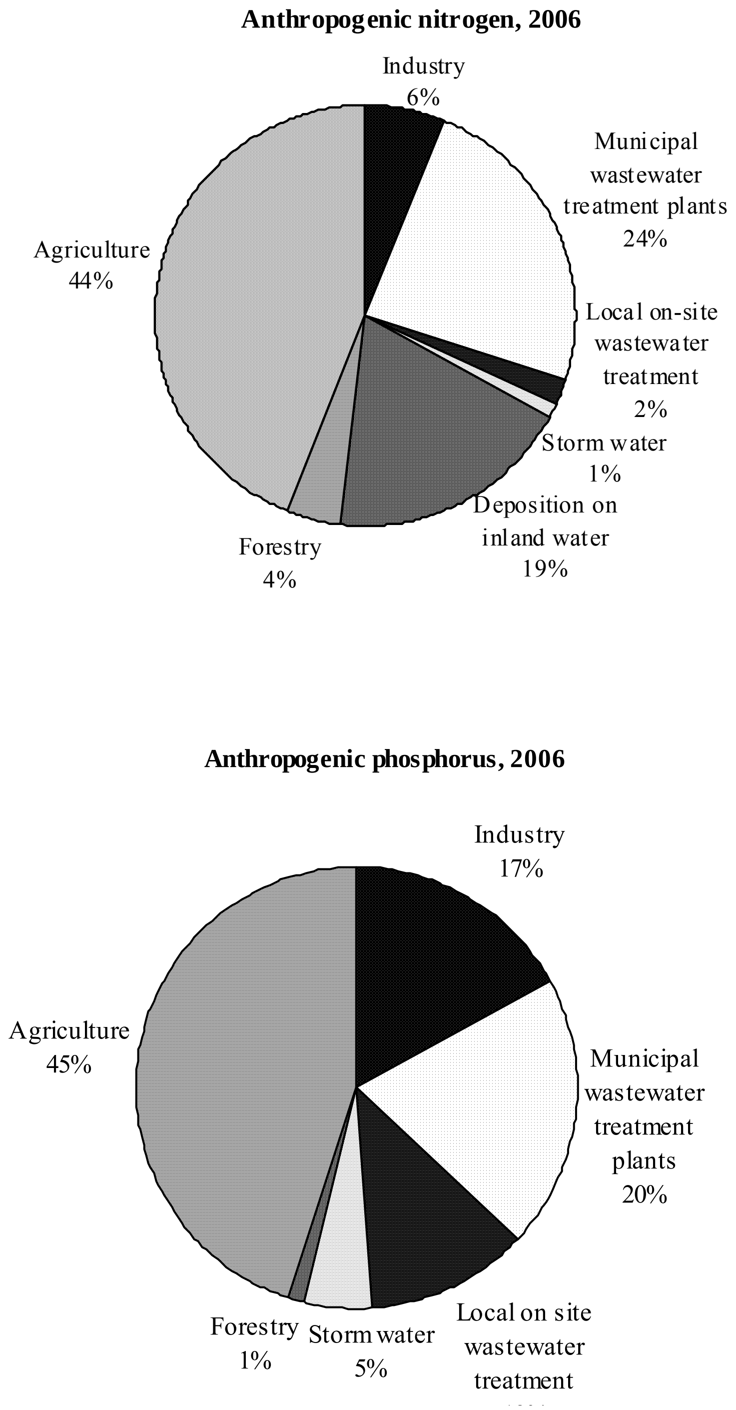


Fig. 2. Nitrogen (top diagram) and phosphorus discharges (bottom diagram) to the Baltic Sea in 2006 from human activities (source: Environmental Protection Agency [17])

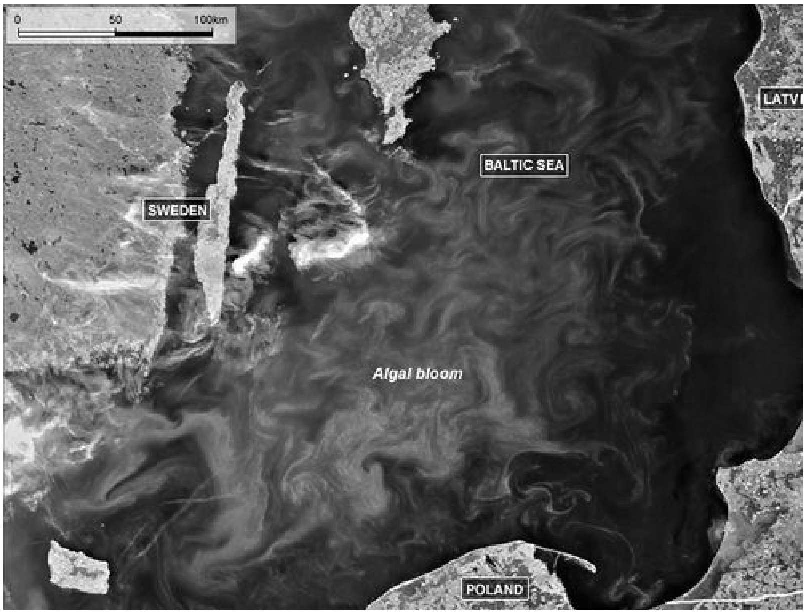


Fig. 3. Blue-green algae blooms in the Baltic Sea as it is shown from airspace (according to the data of European Space Agency, 29 July 2005)

Additionally, there are plenty of oil containing wastes and sewage waters, pouring out annually to the Baltic Sea from household and industrial factories located nearby to its coastal line in Russia, Finland, Sweden, Estonia, Latvia, Lithuania, Poland, Germany, and Denmark. Because of unrestricted and environmentally unregulated industry, factory wastes were disposed directly into the Baltic Sea or into rivers which fed the Baltic. These chemicals run off land and into the water supply, eventually ending up in the Baltic Sea. Thus, every year to the Baltic Sea enter up to 600 thousand tons of oil and oil products, 4 thousand tons of copper (Cu), 4 thousand tons of lead (Pb), 50 tons of cadmium (Cd) and 33 tons of mercury (Hg) [22]. The basic source of water pollution is the city sewage system through which it has annually dumped approximately 1500 million cubic meters of sewage liquids pouring out into waters of the Neva river and the Neva Bay [23]. Furthermore, Ladoga lake, the river Neva and its inflows, especially in the area of Saint Petersburg suffering significant pollution caused by heavy metals and oil products. Alongside with it a serious sources of pollution also pose enterprises and organizations engaged in transportation and recycling of oil and oil products. Now 15 % of the world's maritime transport takes place on the Baltic Sea. The intensity of movement of 5000 tones displacement oil tankers transporting oil products in this region, makes approximately 8—10 oil tankers a day, and the annual sea-borne fright turnover of oil products reaches 160 million tones in 2010 [24]. At the present time the international project “Nord Stream” on transportation of the Russian gas to the countries of the Western Europe with summary capacity of 55 billion m^3 gas per year is being carried out. It is expected, that it will be one of the most extended underwater gas lines in the world on which to Europe in 2025 it will be imported 80 % of natural gas from the Southern Russian oil and gas deposit Yuzhno-Russkoye field located in Yamal-Nenets autonomous region. However, the project, is seen as controversial for various reasons, including potential environmental damage to ecology of the Baltic Sea [25].

Other harmful organic substances detected in Baltic Sea waters are DDT, chlorinated terpenes, halogenated paraffins, polyaromatic hydrocarbons and chlorinated pesticides, such as chlordane and dieldrine [26]. These substances are highly toxic and some are also bioaccumulating. The ban on the use of mercury compounds, in particular in the paper industry, and a drastic reduction of mercury discharges from the chlorine-alkali industry, have resulted in some decrease of mercury concentrations in fish, but many coastal water areas are still seriously contaminated.

The unfavourable ecological situation in the Baltic Sea area is also seriously aggravated by the presence and functioning of several powerful nuclear reactor plants on the Baltic coast on territory of Russia, Sweden, Germany, Finland, Ukraine and Belarus. The production of electric power by nuclear power stations and capacity of nuclear reactors of the countries in the Baltic region in 1990—2010 are shown in Table 1 and Table 2 respectively. From these data it is shown, that on a share of Germany and Russia it is 30,3 % and 13,1 % from the general energy production in the Baltic region whereas capacities of working reactors will have been increased in 2010.

Table 1

The production of electric power by nuclear power stations of the countries in the Baltic region in 2000 [27]

Western Europe	Production, tWt-hour	% from general production	Eastern Europe	Production, tWt-hour	% from general production
Sweden	71,4	52,4	Lithonia	12,7	83,4
Germany	152,8	30,3	Ukraine	79,6	43,8
Finland	18,7	28,1	Russia	108,8	13,1

Table 2

Capacities of nuclear reactors of the countries in the Baltic region in 1990—2010, mWt (a source: the Bulletin on an atomic energy [28])

Country	2000	2005	2010
Belarus	0	0	900
Germany	21320	21320	20980
Lithonia	2500	1250	0
Russia	19840	24540	28190
Ukraine	12150	15040	16940
Finland	2540	2650	4150
Sweden	9440	8840	8840
Common value:	67790	73640	80000

According to the data of HELCOM, along the contiguous coastal line of the Baltic Sea there are placed 6 acting nuclear power plants: 3 Swedish power plants (Forsmark on the east coast of Uppland, Oskarsham at the Kalmar Strait, and Ringhals on Varo Peninsula, 2 Finish power plants (Loviisa on the Southern coast of Finland and Fennovoima Olkiluoto Nuclear Power Plant on the shore of the Gulf of Bothnia), and 1 Russian nuclear powerful plant in the Gulf of Finland — the Leningrad nuclear power plant [29]. In February 2010 Russia started the construction of Baltic nuclear power plant (also refered to as Kaliningrad nuclear power plant) in 13 kilometers south-east of Neman, in Kaliningrad Oblast. The atomic power station will be consisted of two power units with general capacity of 2,3 GWt. It is planned, that after its construction the Kaliningrad area from energy deficiency region will turn in a big exporter of the electric power. Russia also has future disputable plans to rebuild Karelskaja powerful plant situated at Suojärvi in Karelia.

Normal authorized discharges from nuclear power plants can only be detected locally in very small amounts (Denmark, Estonia, Latvia, Norway, and Poland have no nuclear power plants). In areas of atomic power plant arrangement there are additionally situated storage facilities and depositories for radioactive elements. There are several wastes of spent radioactive nuclear fuel disposals and depositories on the territory of the Russian Federation, Sweden at Forsmark, in northeastern Estonia, in Latvia at the Daugava river, in Lithuania at the defunct in 2009 Ignalina nuclear power plant. Some local soil and water contamination in the region derived from uranium ore (^{235}U and ^{238}U) processing, plutonium ^{239}Pu and ^{240}Pu, strontium ^{90}Sr, caesium ^{134}Cs and ^{137}Cs, nuclear plant engineering as well as products of collateral disintegration of nuclear fuel, including tritium (^{3}H), which is formed as a fission product of nucleus of uranium ^{235}U fission (on 1 GWt of capacities in a reactor it is formed 1,15 10^{11} Bq/day of tritium, TLV for tritium ^{3}H is $1{,}9 \cdot 10^{-8}$ mg/m^3) [30]. Tritium is also produced in heavy water-moderated reactors when a deuterium nuckleus captures a neutron. In water ^{2}H tends to bind to hydroxyl-radicals (OH^-) to form tritiated water (H^3HO), and it can easily be ingested by drinking. Tritium can get into environment with gaseous or liquid waste products as it is directly on nuclear power plants, and at the further processing the irradiated nuclear fuel as well. According to the data on quantitative estimation of tritium input into atmosphere and hydrosphere with gaseous and liquid waste products of nuclear power plants, pressurized water reactors (PWR) generate into atmosphere 7,4—33, in hydrosphere 33 GBq/MWt (electricity)/year of tritium; graphite moderated high power channel-type reactors (RBMK) — 22 and 1,5 GBq/MWt (electricity)/year of tritium [31]. Higher levels of emissions of tritium are observed on nuclear power plants using heavy water reactors [32]. For example in Lithuania, tritium (^{3}H) concentrations in groundwater in the region of the radioactive depository of the defunct Ignalina nuclear power plant are from 1000 to 10 000 times higher than the background values [33]. And practically the same situation is with deuterium (^{2}H) in composition of fulfilled heavy water ($^{2}H_2O$) after nuclear plants. Today, heavy water is widely used in power plant engineering as both a moderator to slow down the fast neutrons released by nuclear uranium ^{235}U fission and a heat transfer agent [34]. The ratio between heavy and usual water in natural waters makes up 1:5500 [35]. Although being not radioactive, heavy water, however, exerts a toxic effect on an organism because the speed of chemical reactions involving heavy water is altered substantially from ordinary water, as is the strength of deuterium bonds it forms, which affects cellular processes and metabolism [36]. That is why further production, distribution and using of heavy water in power nuclear engineering should be put under strictly international moniroring and controle.

It should be noted, however, that the major source of radionuclide contamination of the Baltic Sea was the fallout after the catastrophe at the Chernobyl atomic power station in April, 1986, when the set of radioactive elements and products of its disintegration of radioactive isotopes of strontium ^{90}Sr and caesium ^{134}Cs and ^{137}Cs [37] was allocated into an atmosphere which concentration having been increased tens times above the norm (fig. 4). So, in Sweden the density of distribution of ^{137}Cs reached 60—80 kBq/m^2, in Finland — 30—60 кBq/m^2. There were found sites with ^{137}Cs contents up to 80—90 кBq/m^2 in Greece, Romania, Switzerland, Austria and Germany with the average density of distribution of fallout in Europe being changed from 20 (Portugal) up to 90 кBq/m^2 (Austria).

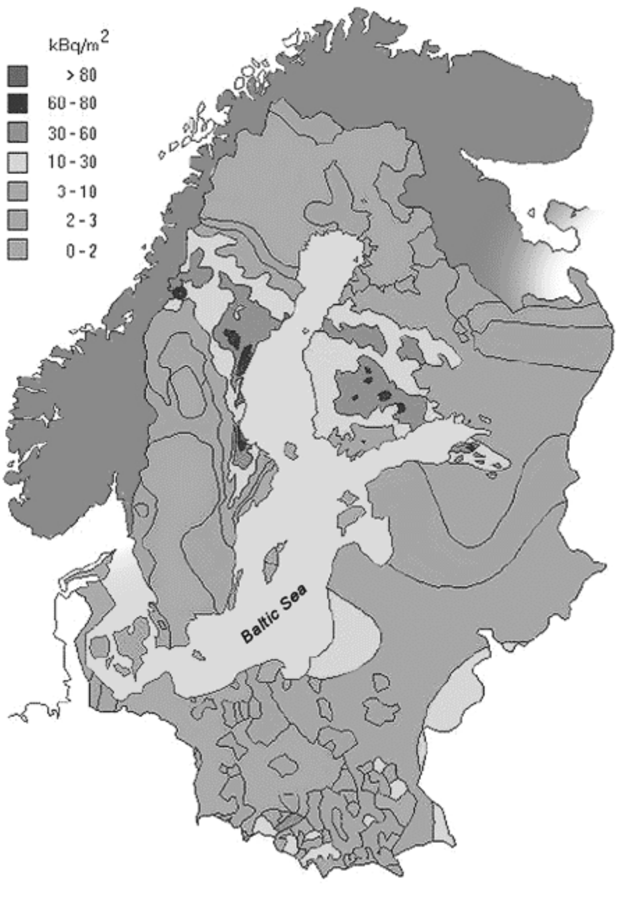


Fig. 4. The density of distribution of Chernobyl fallout after the failure at the Chernobyl atomic power station in April, 1986 (according to the data of Finnish Centre for Radiation and Nuclear Safety [38])

The Gulf of Finland was among the most contaminated regions in the Baltic Sea. The dynamics of accumulation of isotopes of ^{90}Sr, ^{134}Cs and ^{137}Cs in waters of the Gulf of Finland for the period of 1970—2007 (fig. 5) was investigated by experts from the Finnish Centre for Radiation and Nuclear Safety [38]. Thus, the contents of ^{137}Cs in the Baltic Sea were drastically increased in 1986 more than ten times with one of the most polluted area being the central part of gulf of Finland (fig. 5). There in June, 1986 the average level of contents of ^{137}Cs was increased in 60 times in comparison with 1985, but by 1991 it was decreased half due to powerful drains of the Neva river and processes of sedimentation of radionuclides and their further washing out outside of the border of contaminated region [39]. The further measurements of radioactivity shown the stable tendency of reduction in concentration of radioactive caesium ^{137}Cs in east part of Finland Gulf due to the inflow of relatively clean waters of the Neva river. Alongside with ^{90}Sr, ^{134}Cs and ^{137}Cs in southern regions of the Baltic Sea there were also detected concentrations of isotopes of iron ^{55}Fe, ^{63}Ni, polonium ^{210}Po, uranium ^{235}U and plutonium ^{239}Pu and ^{240}Pu which are bioaccumulated by marine species [40]. The last fact testifies to a wide spectrum of radioactive pollution in this region.

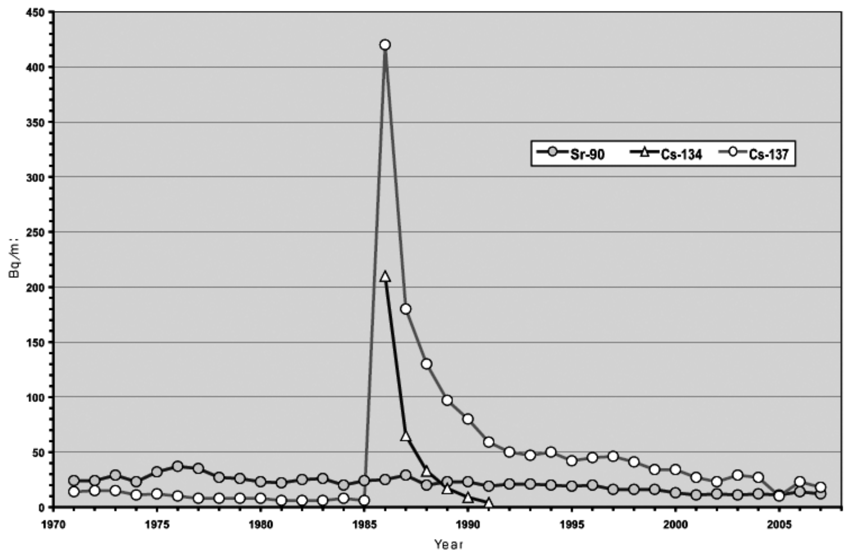


Fig. 5. The dynamics of distribution of isotopes of ^{90}Sr, ^{134}Cs and ^{137}Cs in the waters of Gulf of Finland and Koporye Bay in period of 1970—2007 (according to the data of Finnish Centre for Radiation and Nuclear Safety [38])

Taking into account the data on radio-activity of the Baltic Sea region for 1970—2007, experts of working group of HELCOM [41] have calculated dozes of irradiation of the population living in the Baltic Sea region, for the 100-years period (till 2050). The maximal collective doze caused by influence ^{137}Cs and ^{90}Sr, — 160 people-Sv/year was registered in 1986. This value is comparable to the annual doze received due to natural radionuclides detecting in seafoods (200 people-Sv). The full collective doze which might be received due to influence artificial radionuclides, is estimated to be 2600 people-Sv. About 66 % of this doze are caused by Chernobyl fallouts, 25 % — global fallouts, 8 % — influence of the European factories on processing of waste products of nuclear plants, and only 0,04 % fall at a share of the nuclear objects placed in the Baltic Sea region. At the same time the collective doze caused by a natural radio-activity of seafoods, designed on the same period, is ten times higher — about 20 thousand people-Sv [41]. These alarming data require realization of special aims directed towards further improvement of ecological situation in the Baltic region.

The most significant stage for the protection of the Baltic Sea is the Baltic Sea joint comprehensive environmental program created in 1992 at participation of Russia and the countries of the Baltic region of the Helsinki Commission (*The Helsinki Commission, HELCOM*), which is directed towards the development and investment of complex international reforms, institutional strengthening and human resource development, supporting applied research to build up the knowledge base needed to develop solutions, transfer technology, and broaden understanding of critical environmental problems and environmental research and education among the public [42].

Russia also carries out bilaterial cooperation both at international and intergovernmental levels. There have been operated more than 20 agreements, including agreements with Austria, Spain, Netherlands, Romania, Japan have been signed. Development of the international cooperation of Russia with countries of the Baltic region is directed on improvement of ecological conditions in the Baltic Sea basin and frontier regions of Finland, Republic Karelia and Russia, carrying out a joint teamwork in the international reserves and national parks. Within the framework of the intergovernmental agreement it has been developed wide international cooperation of Russia with the Baltic countries for protection of the sea environment, in particular to carry out the international monitoring of radioactive pollution of the Baltic Sea.

Several joint measures furthermore have been taken by the Baltic countries in order to reduce the use and entrance of hazardous substances into the Baltic Sea such as oil and oil products, cadmium (Cd) and mercury (Hg) [43]. It is also planned to reduce of nitrogen and phosphorus contents in brackish Baltic Sea water in 2020. The result of this is that in some polluted areas of the Baltic Sea in 2005 there was found a class of annelid marine worms known as polychaetes *Marenzelleria neglecta, Monoporeia affinis Lindström*, and *Hediste diversicolor*, which are capable to perform enzymatic sulphide oxidation in the mitochondria at concentrations up to 50 microM [44]. Their discovery in the Baltic Sea water has became a good news for ecologists because it means that the lifeless polluted Baltic Sea waters start to gradually come to life. Worms have migrated to the Baltic Sea from the Atlantic ocean, and there is a good news now that they also have been detected in the Finland gulf.

The existence of polychaets on the bottom of the Baltic Sea testifies that dead lacking oxygen zones start to be gradually saturated by oxygen and therefore be populated with marine forms of life that adapt themselves to polluted waters of the Baltic Sea. This in its turn means that there are started to appear the necessary amounts of oxygen in brackish sea waters and there soon will be necessary amounts of food for fishes and other marine inhabitants. There is a good positive indicator allowing us to hope that the bad ecological situation in the Baltic Sea might be changed for the better in the near future.

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