RADIOECOLOGICAL GIS FOR COMPUTER MAPPING RADIONUCLIDE CONTAMINATION OF THE AREAS UNDER THE IMPACT OF THE MILITARY-INDUSTRIAL COMPLEX FACILITIES

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Abstract

To assess the radioecological consequences of the cold war period and for planning actions decreasing the radiation risks related to operation of the Russian military-industrial complex specialised a complex geoinformation system has been created. RadGIS includes a set of regional GIS decribing radioactive contamination of the environment.

Introduction

Project RADARM performed during the period of 1994 to 1997 in the framework of the International Program "Legacy of the Cold War" on the initiative of the Green Cross Russian (GCR) and with the financial support of the Green Cross International (IGC) resulted in creation of the geoinformation systems (RadGIS) that served the basis for the radioecological cadastre of the areas adjacent to the enterprises of the nuclear fuel cycle (NFC). The main objective of the RADARM Project was the creation of the complex computer data base using GIS technology for assessment of the radioecological legacy of the cold war period and for planning actions decreasing the radiation risks related to operation of the Russian military-industrial complex [10].

RadGIS that includes both the bases and a set of thematic digitized maps of various scales characterizes the influence of the potentially dangerous nuclear installations on the environment and the health of population of the following Russian regions: the nuclear weapon test sites and their impact zones (the Altai region affected by the Semipalatinsk test site and the one on the Novaya Zemlya Archipelago); the areas close to the weapon plutonium production (Krasnoyarsk Mining Chemical Combine in Krasnoyarsk-26 and the Siberian Chemical Combine in Seversk; ship repair plants of the Northern-West region of Russia and the Primorsky Krai, locations of liquid and solid radioactive waste disposal.

RadGIS “Altai”

Semipalatinsk test site holds a particular place in the history of the nuclear weapon tests in the former USSR. It is here where on August 29, 1949 the USSR tested its first nuclear charge that put an end to the USA monopoly in possess of nuclear weapons. The last explosion at this test site took place on October 19th, 1989. The first thermonuclear and hydrogenous explosion installations have also been tested here on August 12, 1953 and November 22, 1955 respectively.

In total within the period of 1949 to 1990 approximately 470 nuclear explosions have been executed at Semipalatinsk test site including 120 atmospheric ones [1]. Maximum input into the total radioactive contamination occurred in the period from 1949 to 1962 during the explosion mostly in the atmosphere of the 127 nuclear charges. After the Moscow Treaty on Banning of the Nuclear Tests in Atmosphere, Space and under Water signed in 1963 nuclear tests were performed exclusively under ground at different depths. The total amount of underground explosions equaled to 340.

After the test in Semipalatinsk contaminated aerial masses moved as a rule from the explosion site to the Altai region forming the contamination of the surface along the trace.

The radioactive fallout during the period of 1949 to 1962 was followed by the corresponding radiation impact on the environment and the population of the Altai region. The nearest settlements of the Altai region are situated at a distance of 140-150 km from the test site. According to the available data 22 explosions had direct influence on the radiation situation in the Altai region [2].

To assess the radioecological situation in this region RadGIS "Altai" has been created. It has been based on the small scale thematic maps and the schemes of radiation contamination in vector format (Fig. 1).

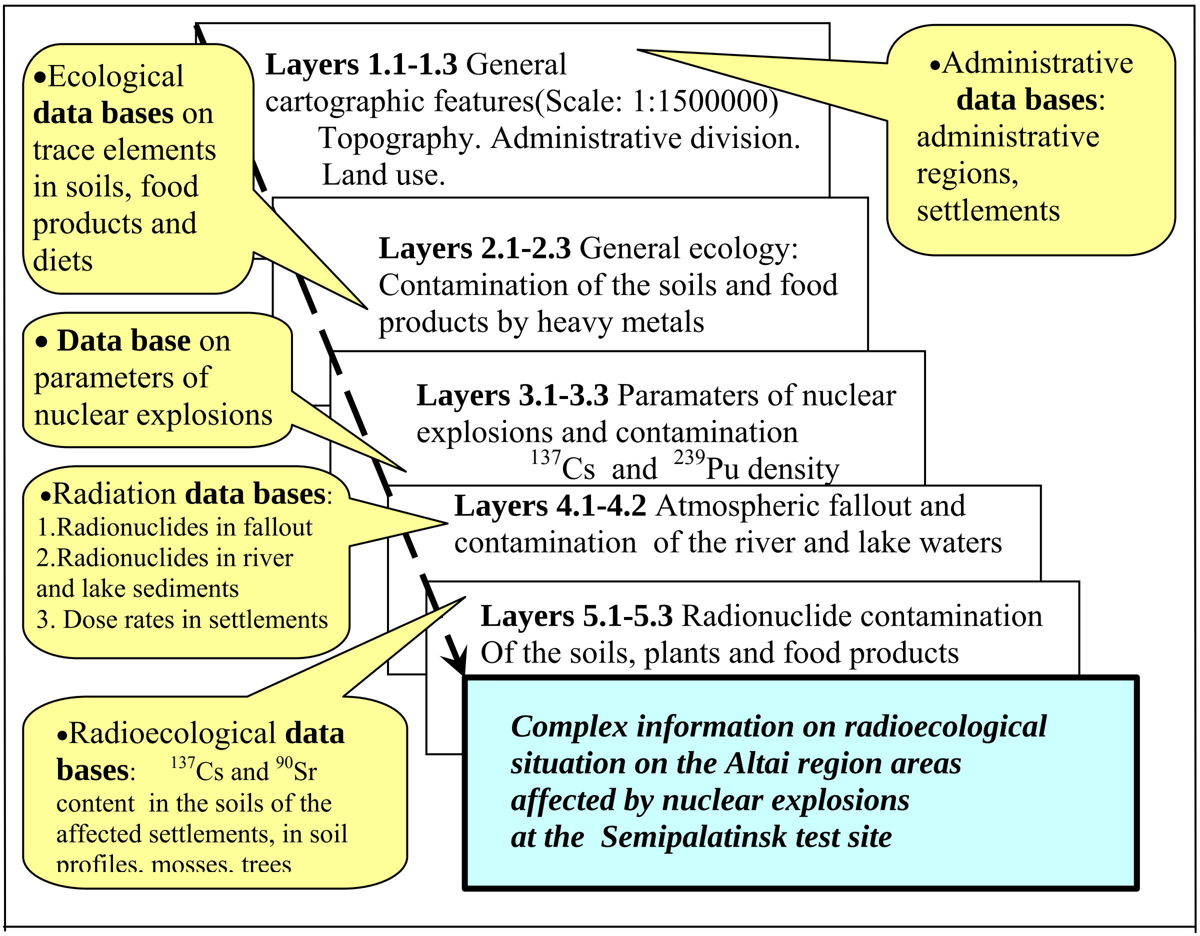

Fig.1. Cartographic layers and data bases including radioecological information about the Altai regions affected by the Semipalatinsk nuclear testing

Within the contamination zone stretching in the SW-NE direction there are 27 local regions and 5 towns numbering 1,6 thousand residents that makes up 60,9% of the total population of the Altai region. Among the residents living on the contaminated areas 38,9% are farmers. Natural conditions of the Altai region are favourable for agricultural development. Therefore the soil and land-use maps were included in the RadGIS "Altai". The areas of chernozems occupying the plains are most suitable for cropping and especially grain production. The Uglovsky region most affected by radioactive contamination is situated in the dry steppe zone and characterized by the development of the meat and milk production and sheep breeding. By present time the global ^{137}Cs contamination in the Altai region equals to 2035 Bq/m^2 [3].

During the nuclear tests only the gamma-emitters exposure dose rates have been registered. The density of contamination was not recorded. Nowadays some dozen years after the atmospheric tests it is practically impossible to create a map of contamination of the region by the gamma-emitters using traditional measurement technique (air-gamma survey, soil sampling) since the present difference between density of contamination and the local background level is negligible. Therefore the main technique applied was modeling radioactive aerosol transfer and deposition on the soil surface. ^{239}Pu contamination due to the 14 nuclear explosions having maximum radiation effect within the region is presented in the Fig. 2.

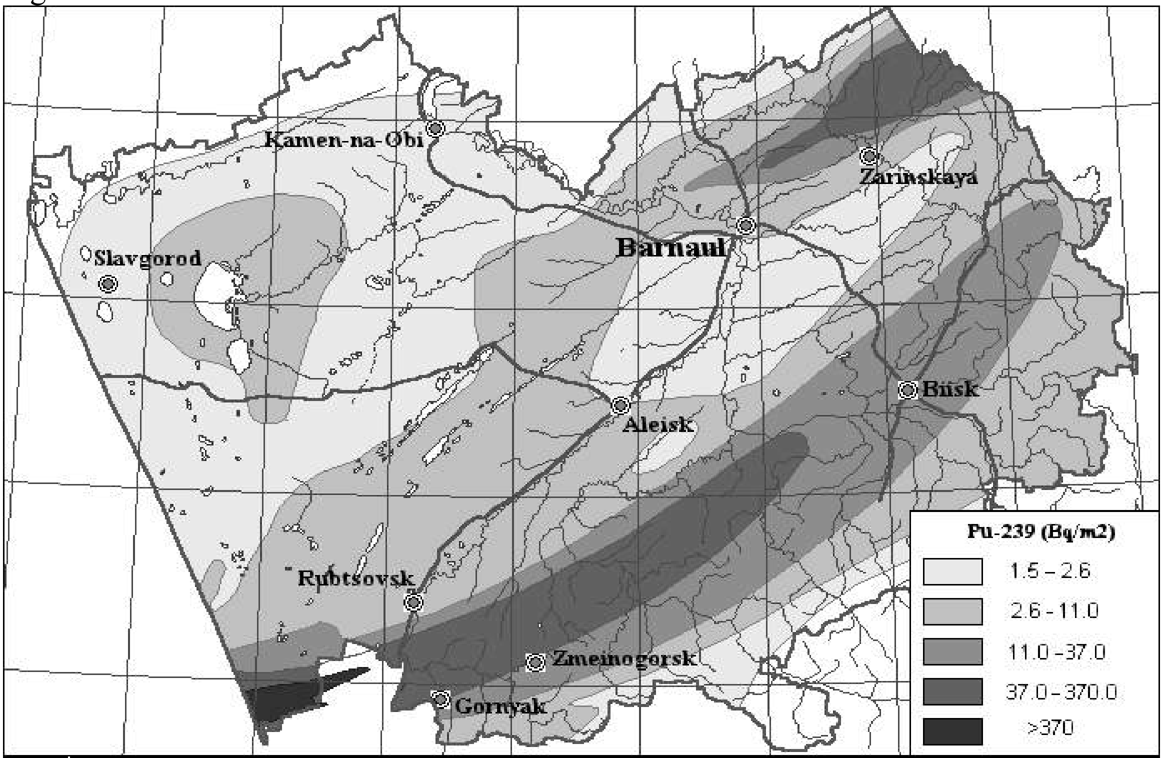

Fig. 2. The density of contamination by ^{239}Pu resulting from the total of 14 explosions [2]

The first nuclear test of August 29, 1949 is now proved to impose the maximum influence on the Altai environment. In 1992 the maximum ^{137}Cs contamination due to the 14 explosions equaled to 925 Bq/m^2 [3]. Except for a small areas of the Uglovsky, Rubtsovsky and Loktevsky regions situated in the impact zone of the first explosion (29.08.1949) the contamination level over the major part varies in the limits of the background values.

To estimate the consequences of the nuclear testing RadGIS "Altai" uses: 1)the maps of contamination by plutonium isotopes, 2) the maps of the dose loads, 3)the data base on the soil contamination by Pu isotopes, radionuclides of ^{137}Cs and ^{90}Sr in approximately 500 settlements, and 4)different assessments of the dose loads due to 14 explosions obtained with the help of various calculation technique.

RadGIS "Novaya Zemlya"

Up to 1954 the USSR did not tested nuclear weapon under water. When in 1954 they finished the creation of the nuclear torpedo it was decided to test it on the area of Archipelago "Novaya Zemlya". Due to declassification of the archives that has started in accordance with the decision of the USSR government since May 1990 numerous primary data on radionuclide concentration in the environment of the Russian Arctic and Novaya Zemlya in particular are available at present. This provided good possibilities for application of various approaches towards the assessment of the radioecological situation in Novaya Zemlya region including geo-information technique.

From September 21, 1955 to October 24, 1990 (the date of Declaration of the Acting Moratorium) they made in total 130 nuclear explosions [8] including 88 ones with releases to the atmosphere (85 aerial, one surface and two over the water), 3 underwater and 39 underground tests.

Ninety nuclear explosions performed in atmosphere, over and under water in the first six years of testing period (up to 1963) produced the major part contamination of the Novaya Zemlya Archipelago. In 1955-1962 the most powerful nuclear explosions not only in the USSR but in the whole world have been executed here [8].

RadGIS "Novaya Zemlya" incorporates the data characterizing the radioactive contamination of the terrestrial part due to nuclear weapon testing at the site "Severny" and contamination of the adjacent marine environment. During radioecological analysis of the area due regard was given to characterization of the main sources of contamination of the Barents and Kara Seas such as nuclear weapon tests, discharge of the liquid radioactive waste, burial of the solid radioactive wastes, spent nuclear fuel and dumping of nuclear reactors.

RadGIS 'Novaya Zemlya" includes vector maps of the scale 1:2000000, characterizing relief and hydrography (rivers, lakes, glaciers). Complex information about the radioecological situation on the Novaya Zemlya Archipelago contains cartographic data on the test site boundaries, the location of explosions, parameters of the nuclear explosions. The surface contamination of the terrestrial part is obtained from the air-gamma survey of 1964 (scale 1:100000) and of 1977 (scale 1:500000).

The most "dirty" place is situated in the Chernaya Inlet where the explosion took place on October 7, 1957. The trace of eastern direction is easily followed on the air-gamma survey maps of 1964 (Fig. 3) and of 1977 (Fig. 4). According to the measurements of the first three days after the test the explosion trace was followed as far as 1500 km from the epicenter and covered a part of the Southern Island, the Yamal and Taimyr Peninsulas. Up to 90% of the total activity precipitated within 400 km zone, 50% - not farther than 30 km from the epicenter.

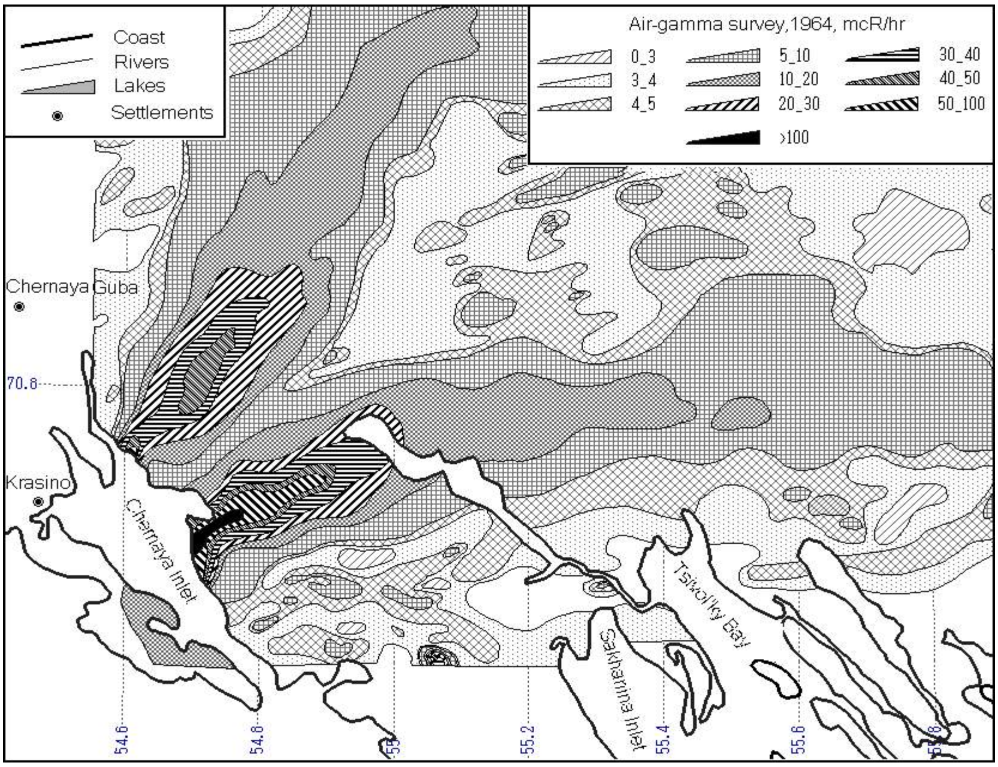

Fig.3. Radiation situation in the Chernaya Inlet in 1964.

Air-gamma survey in the Chernaya Inlet carried out in 1964 (Fig. 3.) revealed several tens of localities some hundred with the diameter from the few hundred meters to 5 km with the dose rates exceeding the background value of 20 μR/h.

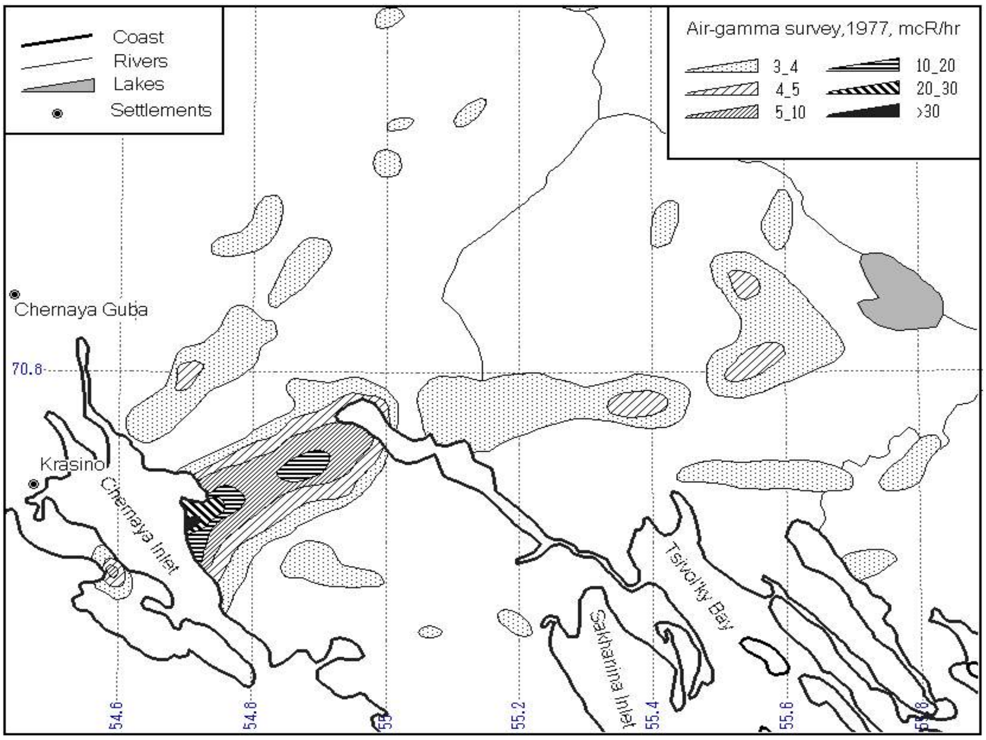

Fig.4. Radiation situation in the Chernaya Inlet in 1977.

The most important among these sites were as follows [8]:

A) the trace of the over-ground explosion executed on October 7th, 1957, in the form of a spot 0.5 km in diameter. Maximum exposure dose rate in the center of the trace in 1964 reached 300 μR/h. The soil samples were contaminated by the following isotopes: ^{137}Cs, ^{144}Ce, ^{125}Sb, ^{106}Ru, ^{90}Sr, ^{60}Co, and $^{152,154,155}Eu$.

B) the NE-directed trace of the over-water explosion in the Chernaya Inlet carried out in 1961. Maximum exposure dose rate in 1964 equaled to 40-50 μR/h. Radioactive fallout within the trace was formed by ^{90}Sr and ^{137}Cs. The density of the surface radioactive contamination varied from 3.7 to 44.4 kBq/m^2.

The air-gamma survey of the same area was repeated in 1977 13 years after the first detailed investigation (Fig. 4). Since 1964 the radiation level became more than 4 times lower. Radionuclides of ^{106}Ru, ^{144}Ce, ^{125}Sb that considerably contributed to the total dose rate in 1964 practically decayed completely. Temporally sequenced air-gamma survey data comparison (Figs 3 and 4) showed considerable contraction of the radioactive trace area with time. For example, the area of the trace limited to the isoline of 5 μR/h equaled to 430 km^2 in 1964 and to 30 km^2 in 1977. The area with the dose rate exceeding 10 μR/h decreased from 133 to 10 km^2 [8].

RadGIS-SCC

Siberian Chemical Combine (SCC) as an enterprise of a nuclear fuel cycle is one of the environmental sources of radioactive contamination. Is has started to operate in 1953 and by its production volume is one of the biggest in the world. SCC includes several installations that are potentially dangerous for the local population and the environment. Several reactor plants for production of the weapon plutonium and the electrical power as well as the radiochemical and chemical smelting plants are located on its area [5].

SCC and the corresponding administrative center – the town of Seversk are situated 15 km to the NW of the regional center, the city of Tomsk downstream the river of Tom' on its right bank (Fig.5). The sanitary protective zone covers the area of 192 km^2, while that of the monitoring zone equals to 1560 km^2. The town of Seversk and a part of the Tomsk city are situated in the monitoring zone [6].

During a long period of its operation the SCC produced a great amount of radioactive wastes. According to estimations the activity of the liquid radioactive waste buried in geological formations reaches 10^9 Ci [9]. The necessity in permanent monitoring of the radiation situation due to the LRW burial is caused by the proximity of the burial sites and SCC itself to the city of Tomsk. Water supplies of the Seversk are situated only 8-9 km away from the LRW burial sites, that of the city of Tomsk – 14 km away. Liquid industrial waste of the SCC are flowing through the local stream Romashka to the river of Tom' and can be transported further downstream to the river of Ob'. Besides this there is another source of permanent environmental contamination such as the gas-aerosol releases during the normal period of SCC enterprises' operation. Potential danger of the environmental contamination still exists in case of an accident at the SCC. In particular meteorological conditions the city of Tomsk may be endangered. On April 6th, 1993 there has been an accident at the SCC followed by the radioactive cloud that has moved in the NE direction outside the SCC sanitary protective zone [4].

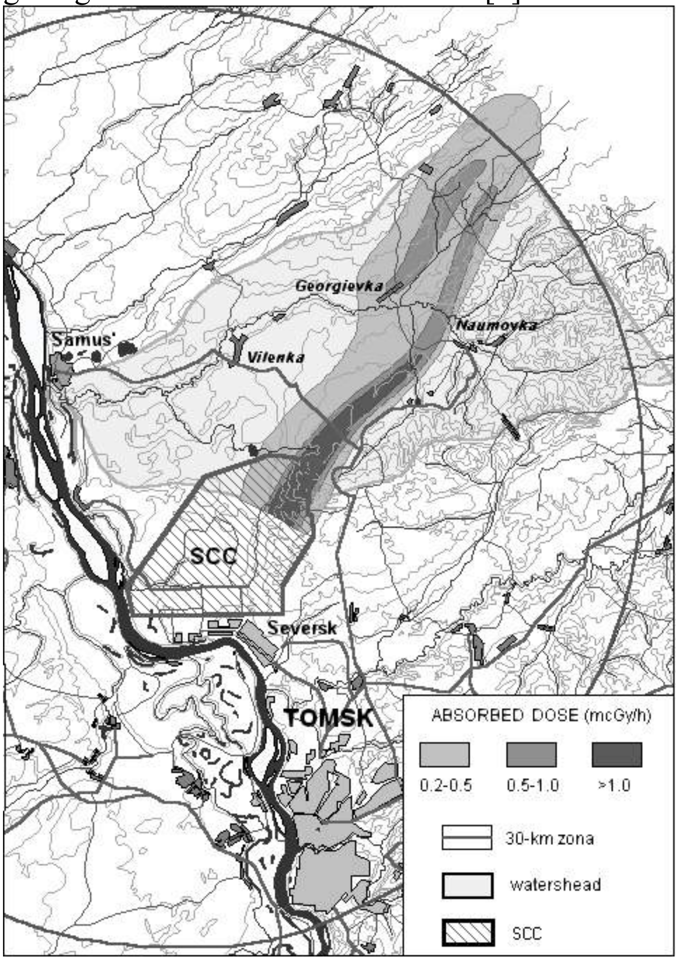

Fig. 5. Radiation situation in the vicinity of the SCC in 1993.

Mass media informed of the radiation situation around the SCC after the accident of April 6th, 1993 when due to the destruction of the technological installation at the chemical plant radionuclides have been released to the atmosphere. To assess the scale of the accident various institutions have been involved including independent experts. Obtained data have been used in the RadGIS created for the zone neighboring SCC. RadGIS includes digitized topographic maps of the scale 1:200000. Radiation situation is presented by radioecological data bases (air-gamma survey data, the data on contamination of the snow and vegetation cover, the ground waters and the bottom sediments).

Fig. 5 shows a fragments of the zone in the vicinity of the SCC including radioactive trace revealed during the air-gamma survey performed by SPA "Typhoon" in April 12,13, 1993. The trace is stretching to the northern-east direction for more than 20 km and corresponds to the wind direction at the moment of the accident. Two of the settlements namely Georgievka and Naumovka has been covered by the radioactive trace. It also spread over the basin of the river Samus'ka.

Enhanced ^{137}Cs contamination densities up to 5 kBq/m^2 have been found not only to the NE of the SCC along the radioactive trace of the April, 1993, but also in patches situated in the SE direction from the combine. On the rest of the area 30-40 km around the SCC the mean ^{137}Cs contamination is 2-3 times the regional background value (1.85 kBq/m^2) in all directions.

Surface surveys of the area within the zone contaminated by the release in April, 1993, took part in 1993-1994. According to the obtained data the maximum value of contamination 5-6 km away from the explosion site for various radionuclides was as follows: ^{95}Nb – 2.4-2.7 kBq/m^2, ^{106}Ru – 0.7-0.8 kBq/m^2 [4]. Within the radioactive trace contamination by $^{239,240}Pu$ reached 670 - 850 Bq/m^2 with background values equal to 74-138 Bq/m^2, and that of ^{137}Cs – 7.3-9.2 kBq/m^2. Outside the trace contamination density of the soil cover reaches for $^{239,240}Pu$ - 175-480 Bq/m^2, and for ^{137}Cs – 1.6-3.0 kBq/m^2.

RadGIS "Primorie"

Main sources of radioactive contamination in the Primorie region are related to the Navy installations and the ship repairing plants. From 1967 to 1992 the northern-west part of the Japanese Sea was used for disposal of the solid radioactive waste. The accident in the Chazhma Bay that occurred on the nuclear submarine in August 1985 was followed by radionuclide contamination the sea side and the Dunai Peninsular (Fig. 6).

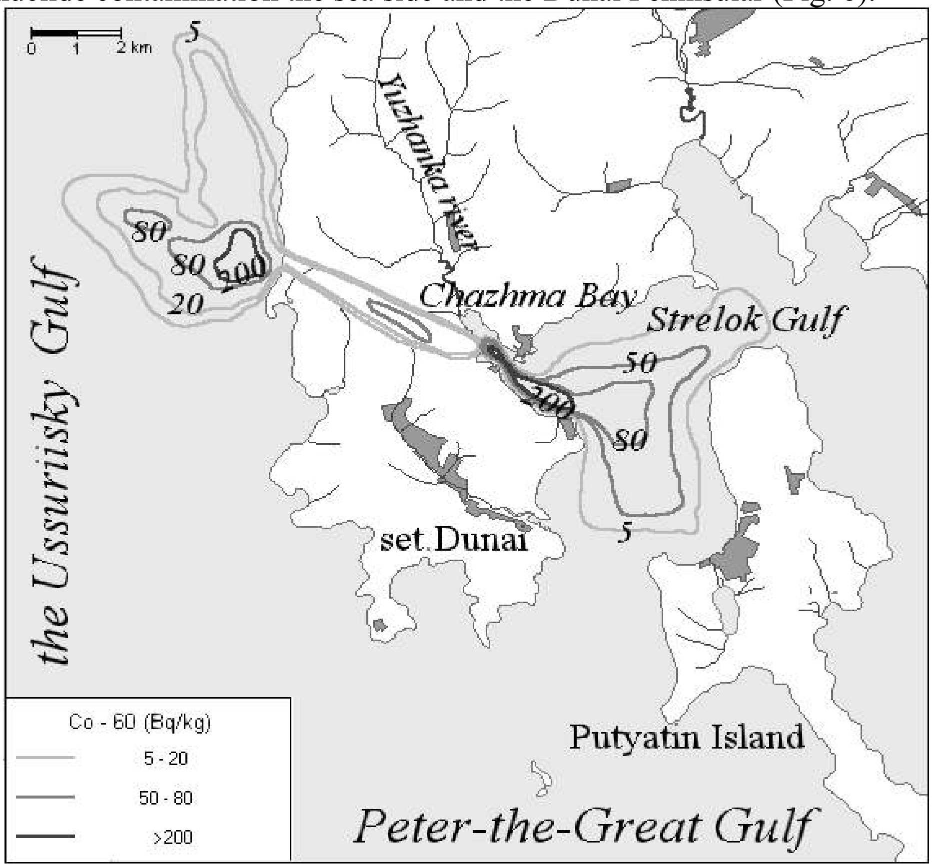

Fig. 6. Radiation situation in the vicinity of the Chazhma Bay

The created RadGIS "Primorie" includes information on radionuclide contamination of the total region based on the data from the radiometric monitoring stations beloning to the Russian Hydrometeorological Service. These contains the summary beta-activity and ^{137}Cs and ^{90}Sr concentrations. RadGIS "Primorie" contains also the results of the complex oceanologic investigations performed in 1988, 1994 and 1996 in the Ussuriysky Bay and the Peter the Great Gulf. Cartographic information set incorporates the data on artificial and natural radionuclides in sea water, bottom sediments and hydrobiontes, as well as some water parameters such as salinity and temperature in the top 2-cm water layer.

Detailed information in the RadGIS "Primorie" concerns the two regions: the Bol'shoi Kamen' Bay where the ship repairing plant is situated and the Chazhma Bay where there was an accident on the nuclear submarine followed by the release of radioactive material to the environment.

Cartographic layers of the RadGIS part devoted to the Bol'shoi Kamen' Bay characterize bathimetry, the velocity and directions of the streams important for assessment of radionuclide transport. Radiological information includes the data on regular grid separate exposure dose rate measurements (the 50x50 m grid size) in bottom sediments of the bay, the isolines of bottom sediment contamination with ^{60}Co and ^{137}Cs, and the contamination of algae by particular radionuclides. The available information on the town of Bol'shoi Kamen' and the surrounding areas includes the data on summary beta-activity of aerosols and concentration of the long lived radionuclides in these aerosols in several control points; the radionuclide contamination of the soil cover.

The accident on the nuclear submarine that happened in the Chazhma Bay on August 10, 1985 lead to formation of a contaminated trace up to 650 m wide stretching through the Chazhma Bay and the Dunai Peninsular in the NW direction as long as 3,5 km. Radioactive contamination of the Dunai Peninsular (Fig. 6) is 95% ^{60}Co [7].

Maximum ^{60}Co specific activity in 1992 in the epicenter of the accident reached 10-20 kBq/kg. The area of the bottom sediments producing exposure dose rate over 240 μR/h equaled 0.1 km^2. The radioactive contamination was partly transported to the Strelok Bay. However the activity of the bottom sediments in this bay did not exceeded 5 Bq/kg.

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