Methodology for radioecological assessment of radionuclides permissible levels in the seas – protection of human and marine biota

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Abstract. The methodology of radioecological assessment was developed for radionuclides permissible levels in sea waters. The control concentrations were calculated under the following conditions: exposure from consumption of marine foodstuffs should not exceed 10 % of the permissible dose limit. Radiation doses to marine biota of lower than 1 % of the lethal dose or significant dose of chronic exposure are assumed not to lead to a significant impact on populations or communities. Hygienic criteria are more rigid than radioecological ones for most radionuclides. Real concentrations of radionuclides (^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu and some others) in sea water are 10^3-10^4 times lower than control concentrations. The proposed control concentrations of radionuclides in sea water, ensuring the radiation safety of the population, ensure the radiation safety of marine flora and fauna as well.

1. INTRODUCTION

The permissible specific activities of radionuclides in drinking water established by the radiation safety standards are unusable for marine water bodies, since the determining pathway of exposure for sea waters is the consumption of marine foodstuffs by the population. Unlike fresh water, sea water practically is not used as a source of drinking water. Early attempts in estimating the limits of radionuclides content in sea waters were made in [1,2].

The subject of this paper is radioecological assessment of permissible levels (control concentrations - CC) of radionuclides in sea waters ensuring the radiological protection of the human population, as well as marine biota.

2. CONTROL CONCENTRATIONS OF RADIONUCLIDES IN SEA WATER CALCULATED FROM HYGIENIC CRITERIA

The control concentrations of radionuclides in sea water ensuring the radiation safety of the population were calculated under the following conditions [3]:

- radiation dose to the population from consumption of marine foodstuffs should not exceed 10 % of the permissible dose limit for the population in accordance with [4] (1 mSv/year), i.e. should be lower than 0.1 mSv/year;
- dose is assessed for a near-shore population group characterized by a considerable consumption of marine foodstuffs;
- as several radionuclides are present in sea water, it is necessary to calculate control levels of the radionuclide mixture, taking into account the control concentrations of individual radionuclides and the activity proportion of the total activity of the mixture.

The calculated control concentrations of radionuclides satisfy both Russian and international criteria and standards for ensuring the radiation safety of the population [4,5].

The control concentrations were calculated using the following relationship:

$$X_k = PD_k /(E_k \, \Sigma F_{ik} \, R_i),$$

where X_k is the control concentration of the radionuclide k in sea water, which ensure that 0.1 mSv/year is not exceeded for the critical group of the population;

$PD_k = 0.1$ mSv/year is the dose limit for the critical group of the population from consumption of marine foodstuffs containing the radionuclide k (at a dose quota for the marine chain of 10 % of the total dose limit);

E_k are the dose coefficients for the radionuclide k, Sv/Bq in the assessment of dose from consumption of marine foodstuffs [4,6];

F_{ik} are the concentration factors of the radionuclide k in the marine foodstuff i (fish, crustaceans, mollusks, algae or birds) [7,8];

R_i are the values of the annual consumption of marine foodstuffs [9,10]. The consumption rates used for assessment of control concentrations in the Russian seas were as follows: fish - 40 kg/year; other marine foodstuffs (crustaceans, mollusks, seaweeds) - 4 kg/year.

The control concentrations of radionuclides in sea water in the commercial fishing zone and in the mixed catching zone are given in Table 1.

Table 1.The control concentrations of radionuclides in the commercial fishing zone and in the zone of mixed catching (a dose quota of 0.1 mSv/year for the population), Bq/l

Radionuclide	Fishing zone	Mixed catching	Radionuclide	Fishing zone	Mixed catching
^{3}H	14000*	13000*	^{99}Tc	130	30
^{51}Cr	300	250	^{106}Ru	180	3.3
^{54}Mn	8.8	5	^{129}I	0.8	0.7
^{59}Fe	1.4	0.5	^{131}I	11	10
^{60}Co	0.7	0.5	^{134}Cs	1.3	1.2
^{59}Ni	40	34	^{137}Cs	1.9	1.8
^{63}Ni	17	14	^{144}Ce	10	1.3
^{65}Zn	0.6	0.1	^{147}Pm	19	12
^{89}Sr	160	150	^{152}Eu	6	2.5
^{90}Sr	16	15	^{154}Eu	4	1.8
^{95}Zr	130	9	^{239,240}Pu	0.25	0.03
^{95}Nb	140	47	^{241}Am	0.25	0.012

Note. * at a dose quota for the tritiated water of 1 % of the total dose limit.

The following comments can be made to the Table 1.
- In the zone of mixed catching of fish, crustaceans, mollusks and algae, control concentrations (CC) are more rigid than in a purely fishing zone.
- The radionuclides ^{241}Am, ^{239}Pu, ^{240}Pu, ^{59}Fe, ^{60}Co, ^{65}Zn, and ^{129}I, which are characterized by high values of accumulation in individual marine foodstuffs, have the lowest CC.
- For tritium CC in sea water are higher than the permissible specific activities established by [4]. This is associated with the fact that tritium does not accumulate in marine foodstuffs and sea water is not used for drinking.
- Unlike [4] CC for ^{137}Cs in sea water are more rigid than those for ^{90}Sr, since ^{137}Cs accumulates in edible parts of marine foodstuffs to a greater extent.
- Real concentrations of radionuclides (^{90}Sr, ^{137}Cs, ^{239}Pu, ^{240}Pu and some others) in sea water are 10^{3}- 10^{4} times lower than CC.

3. CONTROL CONCENTRATIONS OF RADIONUCLIDES IN SEA WATER CALCULATED FROM RADIOECOLOGICAL CRITERIA

The control concentrations of radionuclides in sea water ensuring the radiation safety of marine flora and fauna were calculated under the following conditions:

. radiation dose to sea animals should not exceed 100 mGy/year;
. radiation dose to sea plants should not exceed 1000 mGy/year.

These doses correspond to about 1 % of LD_{50} (at which 50 % of the organisms die after single exposure). On chronic exposure, doses exceeding 10 mGy/day to aquatic fauna can be ecologically significant [11-13].

Radiation doses to marine biota of lower than 1 % of the lethal dose or significant dose of chronic exposure are assumed not to lead to a significant impact on populations or communities, though may have some probabilistic physiological effects on individual organisms.

Dose assessments were made for critical groups of marine biota characterized by the highest exposure level at a given content of radionuclides in sea water.

Doses to marine biota were assessed using the IAEA procedures and models described in the works [14-16].

Control concentrations were determined with the following relationship:

$$X_k = PC_{ik} / (F_{ik} B_{ik} + F_{dk} B_{dk}),$$

where X_k is the control concentration of the radionuclide k in sea water;
PC_{ik} is the ecological dose limit for the ith group of marine organisms from exposure to the radionuclide k, Gy/year;
F_{ik} is the concentration factor of the radionuclide k in the ith group of marine organisms [7,8];
B_{ik} is the dose factor for the ith group of marine organisms on internal exposure to the radionuclide k, Gy/year/Bq/kg [14-17];
F_{dk} is the concentration factor of the radionuclide k in bottom sediments [7];
B_{dk} is the dose factor for the ith group of marine organisms on external exposure to the radionuclide k from bottom sediments, Gy/year/Bq/kg [14-17].

Table 2   presents the control concentrations of radionuclides in sea water calculated from radioecological criteria. Fish and mollusks are the critical groups of marine organisms for most radionuclides.

Table 2. The control concentrations of radionuclides in sea water calculated from radioecological criteria, Bq/l

Radionuclide	CC	Critical group	Radionuclide	CC	Critical group
[3]H	1700000	Mammals	[99]Tc	1000	Mollusks
[51]Cr	6000	Fish	[106]Ru	30	Mollusks
[54]Mn	8	Fish	[129]I	1100	Algue
[59]Fe	4	Fish	[131]I	400	Algue
[60]Co	2	Fish	[134]Cs	13	Fish
[59]Ni	850	Fish	[137]Cs	30	Fish
[63]Ni	1100	Fish	[144]Ce	6	Fish
[65]Zn	11	Fish	[147]Pm	200	Fish
[89]Sr	120	Fish	[152]Eu	7	Fish
[90]Sr	60	Fish	[154]Eu	5	Fish
[95]Zr	3	Fish	[239,240]Pu	6	Mollusks
[95]Nb	8	Fish	[241]Am	1	Mollusks

As seen from comparison Table 1 and Table 2, hygienic criteria are more rigid than radioecological ones for most radionuclides, with the exception of [95]Zr and [95]Nb characterized by high concentration factors in bottom sediments. For [54]Mn and ^{89}Sr the control concentrations calculated from radioecological criteria are close with those calculated from hygienic criteria.

4. CONCLUSIONS

Based on the current requirements for ensuring the radiation safety of the population and the environment, the methodology of the radioecological assessments were developed for radionuclides permissible levels in sea waters.

The proposed control concentrations of radionuclides in sea water, ensuring the radiation safety of the population, ensure the radiation safety of marine flora and fauna as well, i.e. satisfy both hygienic and ecological criteria of protection from radioactive contamination of the marine environment.

Acknowledgments

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