P-5-323

The Radioecological Risk of Decommissioning of Nuclear Submarines - Possible Accidents and Normal Conditions

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INTRODUCTION

Extremely urgent for the Northern Fleet of Russia is the problem of assessment of radioecological hazard of various stages of decommissioning of nuclear submarines. At the moment in connection with reduction of arms and for technical reasons number of nuclear submarines removed from operation is increased. As of a beginning 1997 of operation is removed more than 130 nuclear submarines , almost half from them - on Northern fleet. The fulfilling nuclear fuel is unloaded only on 1\3 of nuclear submarines removed from operation. In the nearest years floating technical bases for the operations of defuelling of submarine reactors with storages of fulfilling nuclear fuel are subject decommissing.

Under the normal conditions of the implementation of the whole technological chain of decommisioned nuclear submarine there are guaranteed the observance of the dose limitation system, established by the ICRP, and execution of main principles of radiation safety, that proves to be true with the help of the multifunctional system of radiation control. Situation with the formation of a constant stain of pollution of sea bottom owing to constant organized discharge of insignificant amounts radionuclides with products of corrosion from temporary storage of reactor compartments is considered also.

As hypothetical accidents are considered: accidents with spontaneous reaction at unloading of spent nuclear fuel from reactors (the major danger - air ejection); navigational failure of liquid radioactive waste (LRW) transport (release to the water area of 300 m3 of LRW with specific activity E (9) Bq/ l).

RESALTS

The consequences of accident of the first type are reported on 3d International Conferences on Radioactivity of Arctic (1). Hypothetical accidents of nuclear submarines reactors leading to the most severe consequences are connected with reactor core mentling and arising of the spontaneous chain reaction when reactor compensating lattices are mistakenly removed during reactor spent core refueling. Possibility of reactor core mentling is estimated at the amount less than 1,0E(-7) per a reactor in the year annually.

The results of estimations of the potential radiation burdens of such accident on the axis of the radioactive cloud trail show that in the case of radionuclides transfer by air in the direction of a conventional inhabited locality (500-1000 m, the typical distance for the village) maximum doses on the territory of this one can be as follows: whole body dose - about 0,5E(-3) Sv; dose on skin (basal layer) - 1,0E(-3) Gy; dose on lungs (acute exposure) - 6,3E(-2) Gy; dose on thyroid gland - up to 2,0 Gy.The neutral and stable states of atmosphere in this case will be the most unfavourable weather conditions. Exposure of the population to the radiation, depending upon residing at the contaminated territory, will be maximal in the specified accident at the expense of ingress of a great deal of long-life radionuclides (Cs-137, Sr-90 etc.) to the atmosphere. When performing the calculation it was assumed that: wind velocity is 2 m/sec; height of roughness of the underlaying surface is 0.1 m; rainfalls are unavailable. The greatest density of a ground contamination on the territory of inhabited locality will be observed at the neutral and stable state of the atmosphere and can be as much as 100 MBq/m2 (48 MBq/m2 by I-131, 16 MBq/m2 by Cs-137, 2,2 MBq/m2 by Sr-90), , annual whole body dose - 0,14 Sv, dose on skin (basal layer) - 0,45 Gy. During the first month at a constant stay on the open country there will be formed 20% of mentioned radiation burdens. When assessing doses of exposure received by the population at the expense of residing at the contaminated territory there weren’t taken into account: availability of snow cover, inconstant stay on the open country, shielding of the buildings. Internal exposure of the population at the expense of radionuclides intake via drinking water and food in the cases of beyond the design-basis accidents on nuclear submarines will be caused by use of wild berries, mushrooms, fresh-water and sea fish for food, as well as by contamination of water supply sources of the ihhabited locality by radionuclides.

Below there are given results of assessment of impact of above mentioned actors upon the population residing in the region of nuclear submarines basing.

In principle, pollution of lakes, which are used for a water supply of the inhabited locality can produce drinking water contamination rate in the early moment tentatively up to 2200 Bq/ l by I-131, 370 Bq/ l by Cs-137 and 74 Bq/ l by Sr-90. Approximate and conservative estimates show, that within 10 days in consequence of sedimentation and water bodies self-clarification the concentration of radionuclides in drinking water will reduce more than a hundred times. Therewith the total dose of the internal exposure of the settlement residents at the expense of the present factor will not exceed the annual dose limit. It should be also pointed out that this radiation exposure factor is easy to eliminate by the performing of measures on water purification or by making use of non-contaminated water body for water supply of the inhabited locality.

In the case of the beyond the design-basis accident connected with arising of spontaneous chain reaction when refueling reactor core and if the wind blows up in the direction of the bay it is possible water area contamination at the expense of radionuclides fallout on the water surface during radioactive cloud spreading. Analysis of the results of the calculations shows, that within 1 month concentration of water pollution is completly levels off and does not exceed 3,7 E(-5) Bq/ l. Within the same period the bottom contamination rate is stabilized, too. Water contamination rate in the early moment may run at small sites of a water area to 37,0 Bq/ l by Cs-137 and 3,7 Bq/ l by Sr-90. The area of these sites is not more than 10% of a total bay area, what, in this instance, is about 4 km2. The levels of bottom contamination by Sr-90 is one order lower than contamination by Cs-137, what is connected with lower rate of Sr-137 concentration in suspensions.

On the basis of obtained data about radioactive contamination of the water area in the region of nuclear submarines basing there can be defined radiation burdens on the hydrobionts and potential doses of internal exposure of the critical groups of population at the extense of sea fish consumption. The calculations preformed on the basis of the data about anticipated levels of the contamination shown, that radiation burdens on the hydrobionts will not exceed E(-11) Gy/day. Towards the end of the first year after accident specific activity of the fishes, inhibiting the region of potential contamination will not exceed amount 14,8E(-5) Bq/kg by “critical” radionuclide Cs-137. The consumption of such fish in amounts of 5 kg per year can lead to additional exposure of the critical group of the population (amateur fishermen) in doses of 1,5E(-12) Gy.

Situation with the formation of a constant stain of pollution of sea bottom owing to constant organized discharge of insignificant amounts radionuclides with products of corrosion from temporary storage of reactor compartments is considered also.

The probable contamination of hydrobionts (q_p) was estimated under the formula:

$$q_p = 1/m\ q_b\ K^f\ K_1\ 1/A_s, \ \text{Bq/kg} \qquad (1)$$

Where:

q_b - concentration of radionuclides in a ground, Bq/kg;
K^f - factor of accumulation of radionuclides in hidrobiont;
K_1- amendment on a share of mastering of radionuclides in edible fabrics of fishes;
m - factor of multipleof excess of weight of a body a fish above weight of its daily forage. At accounts it was accepted m = 10;
As - adjustment factor, taking into account concentration of an element in water on the formula:

$$A_s = (S_1 / S_2)^{-0,8} \qquad (2)$$

Where:

S_1 - concentration of radionuclide in "reference" water, mg/ l;
S_2 - concentration of radionuclide in sea water, mg/ l.

Initial data for account of concentration of radionuclide in a ground were the maximum concentration of products of corrosion in a ground 10 Bq/dm2 (6,64 Bq/kg). The percentage of radionuclides in a mix of products of corrosion was defined on a parity of their accumulation in a ground (factor q_b). Settlement meanings q_p (the formula 1) for the specified object are submitted in tab. 1.

Table 1.

The concentration of radionuclides in hydrobionts

Radionuclide	K^d / m	K_l	A_s	q_b (ground), Bq/kg	q_p (fish), Bq/kg
Fe-55	300	0,2	6,3	6,10	58,10
Co-60	8	0,8	6,3	0,06	0,06
Ni-59,63	10	0,8	4,0	0,19	0,38
Tc-99	4	0,2	6,3	0,23	0,03
Mo-99	2	0,2	40	0,06	6 E(-4)
TOTAL				6,64	58,57

The account of an equivalent dose H for critical group of the population at consumption a fish with the greatest possible level of pollutionof radionuclides, products included in structure of corrosion, was made under the formula:

$$H = q_p \; B_s \; W_g \,, \; \text{Зв} \qquad (3)$$

Where:

q_p - contents of radionuclide in 1 kg a fish, Bq;
B_s - factor of dose, Sv/Bq (2);
Wg - weighing factor.

The data of account are submitted in tab. 2.

Table 2.

Account of an annual equivalent dose for critical group of the population at consumption a fish, caught in region of accommodation of the storage
(in a year of the greatest possible receipt of radionuclides in the sea)

Radionuclide	Dose at consumption of 1 kg a fish, Sv/year	Dose at consumption of 5 kg a fish, Sv/year
Fe-55	1,56 E(-9)	7,8 E(-9)
Co-60	1,04 E(-10)	5,2 E(-9)
Ni-59	4,93 E(-13)	2,47E(-12)
Ni-63	1,37 E(-12)	6,85 E(-12)
Tc-99	4,9 E(-13)	2,45 E(-12)
Mo-99	9,41 E(-13)	4,71 E(-12)

The data, brought in tab. 2 testify, that the equivalent dose for critical group of the population at the expense of consumption a fish, caught in region of accommodation of storage, will not exceed 1,0E(-8) Sv. The accounts of radiating risk for an expected level of doses have not practical sense.

The account of doses for hydrobionts was made under the formula:

$$P_{\Sigma} = P_{1\gamma} + P_{1\beta} + P_{2\gamma} + P_{2\beta} \text{ , Gy/day} \qquad (4)$$

Where:

P_{Σ} - complete capacity of a dose;
$P_{1\gamma\text{-}\beta}$ - capacity of a dose, caused external scale γ-, β-exposure;
$P_{2\gamma\text{-}\beta}$ - capacity of a dose, caused internal scale γ-, β- exposure.

The capacity of a dose external exposure paid off under the formulas:

$$P_{1\gamma} = \frac{8\pi}{M} q_{в} J \text{ , Gy/day} \qquad (5)$$

Where:

q_b- concentration of radionuclides in water, Bq/ l;
J - complete scale γ- constant taken into account of radionuclides;
M - linear factor of easing of scale γ- quantum, см2 (-1).

$$P_{1\beta} = 51{,}1 \ \overline{E}_p \, q_{в}\text{, Gy/day} \qquad (6)$$

Where E_p - average energy γ-radionuclide, Mev. In accounts was used E_p = 0,111 Mev radionuclide Tc-99.

The capacities of dozes internal exposure paid off under the similar formulas.
The results of accounts are submitted in tab. 3.

Table 3.

The doses for hydrobionts

Type of exposure	10 years	100 years
External	2,1 E(-11)	2,1 E(-14)
Internal	3,0 E(-6)	3,0 E(-6)

As it is visible from data tab. 3, total dose on hydrobionts is determined internal exposure. The maximum expected capacity of a dose for bentos hydrobiont (weighed in is thicker than water plankton and fineer marine animals) thus will not exceed 3 E (-6) Gy/day.

According to a data (3) it is accepted, that capacity of a dose exposure bionts, caused artificial radionuclides in water, should not exceed E(-2) Gy/day for organs of fishes.

According to a data, resulted in work (4), any adverse effects at fishes is not observed at exposure below 4,8E(-2) Gy/day.

The estimation of radiologic capacity of environment was made on the basis of test objective levels of pollution sea water $KKg_{(w)}$ and $KKg_{(b)}$ (5) for radionuclide Fe-55, the meanings of which are accordingly equal 2E(3) Bq/l and 2E(8) Bq\kg. The greatest interest thus is represented by an estimation of size additional dose for the account discharge ΔP, dependent from period of half-disintegration (in this case for Fe-55, which makes T1\2 = 2,6 years). The size ΔP was estimated under the formula:

$$\Delta P = KKg_{(w,b.)} \{0{,}63K + [1 - \exp(-I)]\} \qquad (7)$$

Where К and I - whole and fractional part of the attitude(relation) T\ T1\2.

The sizes P for T = of 10 and 100 years are submitted in tab. 4.

Table 4.

Sizes ΔP for sea water, polluted Fe-55

Period of time, T	$KKg_{(w)}$, Bq/l	$KKg_{(b)}$, Bq/kg	ΔΠ, Bq/l	ΔΠ, Bq/kg	q_w, Bq/l	q_b, Bq/kg
10 years	2 E(3)	2 E(8)	4,92 E(3)	4,92 E(8)	3 E(-2)	6,64
100 years	2 E(3)	2 E(8)	4,86 E(4)	4,86 E(8)	3 E(-2)	6,64

Comparison of sizes of control concentration in water $KKg_{(w)}$ and in a ground $KKg_{(b)}$ for sea bays, allowable volumetric activity of drainage waters (ΔP) and settlement (expected) sizes of volumetric activity radionuclides in drainage waters allows to make a conclusion, that examined conditions of functioning storage of reactor of compartments cannot result in excess of radiologic capacity of sea bay.

Hypotetical failure for the estimation of the greatest possible radioecological consequences for hydrobiocenosis was considered, connected with receipt in sea liquid radioactive waste. At navigating failure of the tanker with liquid radioactive waste in the sea can arrive 300 м3 liquid radioactive waste with the high contents radionuclides (up to E(14) Bq). In account was accepted, that the receipt occurs during 30 days. At similar failure 1 % of the area of a bay can be polluted above 30-40E(3) Bq/l during the first days. In 20 days the area of bottom of a bay with a level of pollution up to 3-4 Bq/dm2 can reach 20 %.

Were determined doses for hydrobionts and possible sizes of equivalent doses for critical groups of the population. Initial data for account q_p were the maximum meanings of concentration radionuclides in a ground q_b on 1st year after hypotetical failure.

Initial data and the results of accounts are submitted in the tabl. 5

Table 5.

Estimation of the contents of radionuclides inhydrobionts

Radionuclide	K^f /m	K_1	A_s	g_b (ground), Bq/l	g_p (fish), Bq/kg
Cr-51	200	1,5	1,0	-	-
Mn-54	13	1,3	6,3	1,8 E(2)	4,9 E(2)
Co-60	80	0,8	6,3	2,9 E(2)	3,0 E(3)
Sr-90	0,2	4,2	121,0	1,1 E(2)	4,0 E(-1)
Zr-95	15	0,2	6.3*	0,1 E(2)	0,5 E(1)
Ru-106	10	0,7	6,3*	0,7 E(2)	8,2 E(1)
Cs-137	2,5	8,0	172,0	1,1 E(2)	1,3 E(1)
Ce-144	2,5	0,2	19,1	2,2 E(2)	0,6 E(1)
TOTAL				9,9 E(2)	35,9 E(2)

*) Note: the Sizes As for Zr-95 and Ru-106 correspond Co-60.

The results of accounts of doses exposure of hydrobionts are submitted in the tabl. 6

Table 6.

Results of an estimation of capacity of a doses exposure of hydrobionts after hypotetical accident

Radionuclide	Capacity of a dose internal exposure on 1st year after failure, Gy/day	Capacity of a dose external γ-exposure after failure, Gy/day		Capacity of a dose external β-exposure after failure, Gy/day	
		1st day	30 day	1st day	30 day
Co-60	4,0 E(-6)	9,8 E(-5)	1,1 E(-5)	3,9 E(-9)	4,4 E(-10)
Sr-90	4,0 E(-6)	-	-	3,0 E(-9)	2,0 E(-10)
Zr-95	8,4 E(-8)	1,9 E(-6)	1,6 E(-7)	3,6 E(-9)	3,0 E(-10)
Ru-106	1,1 E(-8)	2,1 E(-6)	1,4 E(-7)	1,5 E(-10)	1,0 E(-11)
Cs-137	3,2 E(-8)	6,8 E(-6)	4,5 E-7)	2,8 E(-9)	1,8 E(-10)
Ce-144	6,2 E(-9)	1,4 E(-6)	9,4 E(-7)	1,2 E(-8)	7,9 E(-10)
TOTAL	4,13 E(-6)	1,1 E(-4)	1,16 E(-5)	2,69 E(-8)	1,92 E(-9)

The results of accounts of an equivalent dose H for critical group of the population at consumption a fish with the greatest possible level of pollution of radionuclides are submitted in tabl. 7

Table 7.

Account of an annual equivalent dose for critical group of the population at consumption 1 kg a fish, caught from region of failure

Radionuclide	Factor of dose, Sv/Bq	Specific activity a fish, Bq/kg	H, Sv/kg
Mn-54	7,3 E(-10)	4,9 E(2)	3,6 E(-7)
Co-60	7,0 E(-9)	3,0 E(3)	2,1 E(-5)
Sr-90	3,9 E(-8)	4,0 E(-1)	1,6 E(-8)
Zr-95	1,5 E(-9)	0,5 E(1)	0,7 E(-8)
Ru-106	5,8 E(-9)	8,2 E(1)	4,7 E(-7)
Cs-137	1,4 E(-8)	1,3 E(1)	1,8 E(-7)
Ce-144	5,3 E(-9)	0,6 E(1)	3,0 E(-8)
TOTAL			2,2 E(-5)

The analysis of data on probable doses exposure hydrobionts has shown, that the maximum sizes of doses external exposure will be formed in near future after failure (1,4E(-4) Gy/day - 1 day; 1,5E(-5) Gy/day - 30 days) and correspond to dynamics of the contents radionuclides in water environment. The capacity of a dose internal exposure on 1st year after failure does not exceed 4,0 E(-6) Gy/day.

Accounts show, that to the end 1st year after failure the specific activity a fish, living in region of probable pollution, for the given group radionuclides can make 4,0E(-1) ...3,0E(3) Bq/kg. Consumption of a similar fish in quantity 1 kg can result to additional exposure of critical group of the population in doses up to 2,0E(-5) Sv. Accordingly, the additional size of radiating risk at the expense of the given influence will not exceed 1,0 E(-6) $year^{-1}$.

CONCLUSION

Set of received data allows to make a conclusion about conformity of a level of radiating risk of various stages of decommisioned nuclear submarines to the modern requirements.

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