

## Radiation consequences of hypothetical accidents associated with transportation of spent nuclear fuel of nuclear submarines aboard floating technical base

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Reload of spent nuclear fuel of nuclear submarines and its subsequent transportation for reprocessing may be carried out by the vessel – floating technical base (FTB). Up to 4 reactor cores can be taken aboard, transportation can occur for distance of dozens and thousands kilometers. In case of the accidents with infringement of protective barriers, FTB may occur to be a significant source of radiation hazard.

Two hypothetical accidents associated with explosion aboard and sinking the FTB are analyzed in the report. In the first case a source term for the release and aerial radionuclide spreading out have been estimated, in second case radiation consequences have been estimated for water way taking into account remaining protective barriers. Main task of the assessments was radiation impact at long distances from the source.

Source term calculations took into account liquid radioactive waste (LRW,  $\sim 10^{13}$  Bq) and spent nuclear fuel (SNF,  $\sim 10^{16}$  Bq) on board of FTB.

Conservative assumptions have been done for aerial release combining dispersal of SNF due to internal explosion and release elevation due to large fire. Full dispersal and elevation of 2% of SNF in one tank was taken, initial distribution of radionuclides along height of release was considered. “Low” part of release was associated with fume column, “high” part was associated with ascending high temperature cloud. Calculations were performed for “dry” and “wet” (atmospheric precipitations during cloud propagation) sediments. The results of radiation consequences expected for severe accident due to aerial release at pass of FTB from Kamchatka to Primorye are presented in following table for several points. Calculations have been done by computer code “Nostradamus”.

Main results of calculation of radiation consequences due to explosion on board of FTB

Parameter		Assessment		
		<i>Western part of Aleutian islands</i>	<i>Petropavlovsk-Kamchatsky city</i>	<i>Northern shore of Hokkaido</i>
Distance from the place of accident, km		1000	20	50
Time of cloud arrival, hour		25	1,25	3
Time of inhalation, hour		35	0,25	0,5
Effective inhalation dose, micro Sv		1,7	1400	55
Surface contamination (max.), Bq/m <sup>2</sup>	“dry” deposition	900	$1 \cdot 10^6$	$3 \cdot 10^4$
	“wet” deposition	6500	$2 \cdot 10^6$	$1,8 \cdot 10^5$
Maximal effective annual dose, micro Sv	“dry” deposition	<2	1800	60
	“wet” deposition	2,5	1800	100

At the aerial release maximal annual effective dose equivalent to shore population at distances of 20...1000 km varies from units of micro to units of milli-Sievert.

Following protective barriers were considered at the analysis of water release: compartment of SNF storage, tank of SNF storage, case for fuel assemblies, shell of fuel elements, SNF matrix.

Leaching rate for SNF radionuclides at the contact of matrix with sea water was assumed of  $5 \cdot 10^{-3} \text{ year}^{-1}$ . Undamaged shell of fuel elements was supposed to provide matrix insulation for 5 year. Rate of radionuclide release from damaged tank of SNF storage and vessel compartment were taken as  $1 \text{ year}^{-1}$ .

It was demonstrated that radionuclide release is prolonged and varies for the time. Maximal release rate is expected in 5 years after the vessel flood being of approximately  $6 \cdot 10^5 \text{ Bq/s}$  for  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ .

Calculations of radionuclide content in sea water have been done for near vicinity of the source as well as for large parts of water area as a whole. For the first case Gaussian-type model of admixture dispersion was applied, for the second one – compartment (box) model.

It was assessed that contamination area downward predominant flow direction where concentrations exceed reference levels (e.g. 10% of permissible  $^{137}\text{Cs}$  concentration having been taken as  $350 \text{ Bq/m}^3$ ), may be up to 2500 m long and 700 m wide. Maximal concentrations above permissible levels are expected for area within distance from the source about 500 m.

Assessments of marine water contamination, radionuclide content in sea food and expectable doses to critical group of shore population, taking into account dynamics of radionuclide release and propagation, indicate insignificant radiation impact in average over the water area. Radionuclide content in fish muscles does not exceed hundredth parts of Becquerel per kilogram, expectable annular dose equivalent to critical population group is assessed to be of tenth parts of micro Sievert. Maximal possible radiation impact is an order of magnitude less than the impact due to global fallouts of atmospheric nuclear tests.

At the same time, in the vicinity of the sunken FTB extremely high radionuclide concentration in sea water and marine biota are expected. Death of all bottom biota is possible at the distance of hundred meters from the source.

Area of high (more than permissible) radionuclide concentrations in sea water can spread from sunken vessel for the distance of several kilometers. If contaminated area covers the places of long (several months) time residence of fish school, it is expected that a lot of species in fish catch will have concentration of  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$  about 10 and 100 Bq/kg respectively. These levels are though two orders of magnitude small than permissible ones, but they are easily detectable. Appearance at the market such a “contaminated” fish can appreciably undermine competitiveness of definite fishery areas.

Way of contaminant transport within upper turbulent layer of sea water due to cloud landing or LRW release was considered as well.

Upper turbulent sea water layer for high geographic altitudes has distinct low border. Layer of “jump” (seasonal thermal wedge) with thickness of dozens meters is located lower. Temperature in this level descends abruptly (several degrees of  $C^0$ ) in depth, and the effect of type of admixture reflection from this layer can take place. The most hazardous surface contamination may occur in summer, when vertical scale of upper turbulent layer may be only of dozen of meters.

Three scenarios of macro turbulence in surface sea water layer were considered:

- scenario A (most pessimistic), when drift of contaminated spot occurs with minimal horizontal dilution factors correspondent to minimal observed effective admixture diffusion coefficients (about  $10 \text{ m}^2/\text{s}$ ) in upper water layer;
- scenario B (optimistic), when drift of contaminated spot occurs with maximal horizontal dilution factors correspondent to maximal observed effective admixture diffusion coefficients (about  $10 \text{ m}^4/\text{s}$ ) in upper water layer;
- scenario C (intermediate) with minimal dilution along the flow direction and maximal dilution across the flow.

Long (up to one and half month) drift of contamination spot is possible for scenarios A and C, when due to landing of radioactive cloud on the water surface due to accident with explosion on board of FTB concentrations in upper water layer may exceed recommended permissible concentrations. For surface flow of 20 cm/s distance of “hazardous” spot transport may be of about 500 km. For “optimistic” scenario hazardous concentrations may be observed only for  $^{137}\text{Cs}$  approximately for twenty days.