Potential Impact Of Atmospheric Releases At Russian Far East Nuclear Submarine Complexes

F. Parker[1,2], A. Mahura[1,3,4], K. Compton[1], K. Brown[1], M. Takano[1,5],
V. Novikov[1,6], A. Baklanov[3], J.H. Sørensen[3]
[1] International Institute for Applied Systems Analysis,
A-2361-Laxenburg, Austria
[2] Vanderbilt University, Nashville, TN,
P.O. Box 1596 37235 USA
[3] Danish Meteorological Institute, Lyngbyvej 100
DK-2100 Copenhagen, Denmark
[4] Institute of Northern Environmental Problems,
Kola Science Center, Apatity, Russia
[5] Japan Atomic Energy Research Institute
Tokai-mura, Naka-gun, Ibaraki 319-1195, Japan
[6]Russian Research Center-"Kurchatov Institute",
1, Kurchatov Sq., Moscow, 123182, Russia.

ABSTRACT

An "Assessment of the Impact of Russian Nuclear Fleet Operations on Far Eastern Coastal Regions" is being performed as part of the Radiation Safety of the Biosphere Project (RAD) of the International Institute for Applied Systems Analysis (IIASA) of Laxenburg, Austria. To the best of our knowledge, this is the first comprehensive unclassified analysis of the potential impact of accidents at the Russian Far East nuclear submarine sites near Vladivostok and Petropavlovsk. We have defined the situation there based upon available information and studies commissioned by RAD in collaboration with Russian research institutes including Russian Research Center-"Kurchatov Institute", Institute of Northern Environmental Problems and Lazurit Central Design Bureau. Further, in our original work, some in collaboration with the staff of the Danish Meteorological Institute (DMI) and members of the Japan Atomic Energy Research Institute, we have calculated the nuclide trajectories from these sites in the atmospheric boundary layer, less than 1.5 kilometers high, and determined their probability of crossing any of the nearby countries as well as Asiatic Russia. We have further determined the concentrations in each of these crossings as well as the total, dry and wet depositions of nuclides on these areas. Finally, we have calculated the doses to the Japanese Island population from typical winter airflow patterns (those most likely to cross the Islands in the minimum times), strong north winds, weak north winds and cyclonic winds for conditions similar to the Chazhma Bay criticality accident (fresh fuel) and for a criticality accident for the same type of reactor with fuel being withdrawn (spent fuel). The maximum individual committed dosages were less than 2×10^{-7} and 2×10^{-3} mSv, respectively. The long-term external doses by radionuclides deposited on the ground and the internal doses by consumption of foods were not evaluated as it is believed that such doses can be avoided by social controls. In other calculations taking these longer term doses into account and determining the sum of the maximum individual committed dosages (SMICD), we found for each of the surrounding countries to be less than 1 mSv. In that part of Russia the (SMICD) is less than 6 mSv. For releases from the Petropavlovsk sites the (SMICD) for each of the surrounding countries is less than 0.3 mSv. In that part of Russia the (SMICD) is less than 6 mSv.

INTRODUCTION

Concern about environmental radioactive contamination has been intense for many years and particularly about conditions in the USA and the Former Soviet Union (FSU) because of conditions that prevailed in the development and testing of nuclear weapons during World War II and the Cold War. The recent film, “K-19: the Widowmaker” (1), based on a true incident aboard a Soviet nuclear submarine made clear to the general public the problems inherent in nuclear energy when accidents occur. Revelations about these wartime conditions in the USA started to become known in the 1970s but accelerated after the 1984 court case that resulted in the Department of Energy being forced to open its sites to federal and state environmental regulatory authorities (2). Since then, there have been many articles, reports and books on the topic including DOE’s report (3) and many dose reconstruction reports dealing with specific sites such as the Oak Ridge report (4). Prior to dissolution of the Former Soviet Union, Environmental conditions in the Soviet Union were largely unknown though there were unofficial reports of conditions there (5). Only after Perestroika did it become possible for more details to emerge though there are still many unknowns. There are 2 books that discuss what is publicly known about radioactive environmental conditions in the FSU (6,7). (There are many Web sites with information and some of the more important are given later in the paper.)

The latter book was prepared as a joint effort of the Russian Ministry of Atomic Energy (Minatom) and the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. (7) The USA and the Soviet Union founded IIASA in 1972 as an organization where their scientists and engineers could work together on problems of mutual interest even during the Cold War. Since that time over 16 countries have joined, primarily through their National Academies of Sciences. In 1994, the Radiation Safety of the Biosphere Project (RAD) was initiated to study the nuclear environmental impacts of the Cold War. The first objective was to compare the impacts upon the USA and the Former Soviet Union where the earliest major efforts were carried out and where data indicated that the impacts had been the greatest. As indicated above, because of the disparity in the information available on conditions in the USA and the FSU, comparisons could not be made until more information was available on conditions in the FSU. Therefore, the first RAD studies were on conditions at the three large spent fuel reprocessing centers in Russia, Mayak, Krasnoyarsk-26 and Tomsk-7 where the greatest amount of radioactive material was in the environment (8). The next most important centers of concern were the conditions at bases of the Russian Northern and Pacific nuclear fleets, Murmansk and vicinity and Vladivostok and Petropavlovsk, Kamchatka and their vicinity, respectively. (6,7) Though there are other Russian fleets, these are the only ones with nuclear ships. There are different numbers published for the submarines in each fleet, the number that have been decommissioned and the state of the spent fuel and the hulls from a variety of Russian and other reports, we have chosen to use what were the official numbers used in our joint book (7) and recent figures presented by the Deputy Minister of Minatom, Table 1 (9).

Table I Nuclear Submarines Decommissioned in Russia December 2000 (9)

Submarines	Northern Fleet	Pacific Fleet
Written-off from the Navy	108	76
With unloaded spent nuclear fuel (SNF) from the reactors	48	32
With SNF non-unloaded from the reactors	60	44
Dismantled with formation of single-, three- and multi-compartment units	42	18
sent to plants for scrapping	29	

The different estimates do not vary sufficiently to markedly change the impact. About 250 nuclear submarines were built in the Former Soviet Union and close to 200 have been retired. Over half of the submarines withdrawn from service are in the Northern Fleet. Russia is experiencing problems with the infrastructure and equipment to dismantle these submarines and to process their spent fuel. Spent fuel is stored in obsolete onshore and floating storage facilities, inside reactors of retired submarines at dockside at the shore facilities and in transport containers. Many of the withdrawn submarines are moored at naval bases and in many cases have their nuclear fuel aboard. In addition, their operational wastes and discharged spent nuclear fuel are held in floating or dockside stores under conditions which in many cases do not meet current Russian regulations. In some instances, the spent fuel cannot be removed from the reactors or stores with normal equipment. There is a lack of transport trains to take the spent fuel to Mayak for reprocessing and in some cases reprocessing is not possible with present equipment.

NORTHERN FLEET

Conditions of the Northern fleet at Murmansk and vicinity have been studied by many groups, International Atomic Energy Agency (IAEA)(10), CEG (Contact Expert Group)(11), Arctic Military Environmental Cooperation, (AMEC)(12), Minatom (13), Bellona(14), etc. The Strategy Working Group of the CEG reported that "The Spent Nuclear Fuel at the Naval Bases in NW Russia currently creates a significant risk of:

- criticality accidents which could lead to the release of fission products into the atmosphere and sea
- ingress of water into the stores, or sinking of the floating stores, leading to contamination of the sea
- diversion of high-enriched fuel, with implications for terrorism and proliferation of nuclear weapons." (15)

A seminar "The Ecological Problems of the Nuclear Powered Submarines (NPS) Decommissioning" was recently, July 4-9, 2001, held at Severodvinsk, Russia where problems of the Northern Fleet were discussed in detail. (16) They stated that "retired nuclear powered submarines (NPS) are a threat not for Russia only but also for other countries. Nuclear and radiation safety, prevention of radionuclides spreading into environment from reactor compartments, solid and liquid radioactive waste is the essential condition for the ecological safety, ensuring and environment effect elimination". They then listed 13 needs, some of them quite generic but others quite specific such as "rehabilitation of facilities and area of the available on-shore technological facilities, first at the area of Andreev Bay". Despite the similarity in the problems at the Pacific Fleet's sites, comparatively little work had been done to determine the exact conditions there.

PACIFIC FLEET

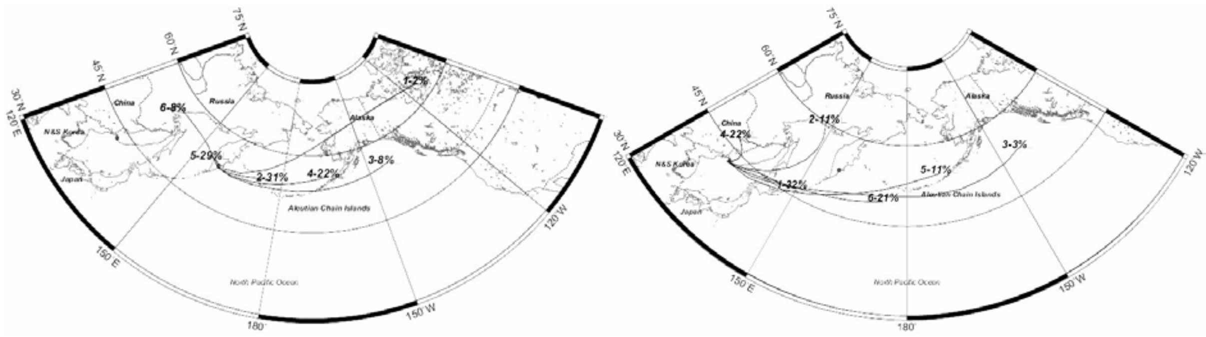
There was so little information presented at this conference on the conditions at the Pacific Fleet sites that it was recommended that a similar conference be held in the Far East in the following year. The suggested international conference, "Ecological Problems in Nuclear-Powered Submarines Decommissioning and the Development of Nuclear Power in the Region" (ECOFLOT-2) was held at Vladivostok, Russia, September 16-20, 2002 where the problems at the Pacific Fleet sites were discussed (17). The Chief of the Ecological Safety of the Armed Forces of the Russian Federation, A.I. Yunak, stated "Since the 1980s of the last century the nuclear powered submarines decommissioning rate has greatly increased. It has become obvious that the recycling capacities of the Navy ship-repair yards and civil industry are low and do not meet the recycling rate. This has resulted in the accumulation of retired submarines in the places of stationing in the Kamchatka and Primorie. Besides the NPS decommissioned, of great concern for the Navy are the vessels of atomic technological servicing accumulated in the Kamchatka and Primorie that are also retired and are to be recycled."(18) In fact, 2 decommissioned submarines sunk off the northeastern Kamachatka Peninsula in 1997 and 1999 (19).

However, problems in the Far East had come to the world's attention earlier when a criticality accident with a new core occurred on the submarine K-314 in Chazhma Bay, near Vladivostok, during refueling on August 10, 1985. Ten people were killed and the local area was contaminated (20).

Because so little external analysis had been devoted to conditions at the Far East, IIASA decided to concentrate its next efforts on conditions there. The main nuclear areas of concern in the Russian Far East are the home bases of the Pacific Fleet at Vladivostok and Petropavlovsk as the Russians have only one nuclear power facility in the Far East at Bilibino where there are 4 light water cooled, graphite moderated reactors of 12 MWe each. Further, fuel on Kamchatka cannot, at present, be shipped to Vladivostok area for transport to Mayak for storage in secure circumstances or reprocessing. Even shipment from the Vladivostok area is problematic at the present time.

Based upon this and upon analysis of conditions at the Northern Fleet and analysis of the impact of discharges to the open ocean (21) it became obvious that though local conditions could be severe, there was not sufficient unclassified information available to analyze them. It was also obvious that the only other major technical impact would be by atmospheric transport. It was decided to look at transboundary atmospheric impacts. At about the same time, it was becoming apparent that air masses from the Asian continent could move rapidly and only slightly diluted across the Pacific Ocean (22,23). This lent a degree of urgency to the studies. It was also apparent from the studies that Japan and the USA territories could be impacted.

The climate of the North Pacific is complex because of significant variations in the radiative effects at the ground surface, the unequal distribution of land and water surfaces over which the winds travel and the horizontal transport of heat energy toward the northern latitudes from the south. In addition, the important processes such as wind field characteristics, temperature and humidity fields, precipitation in various forms, etc. take place in numerous scales, local-, meso-, regional-, large-, hemispheric and global. The wind patterns in the southern and eastern parts of the North Pacific region are remarkably uniform. The western part of the North Pacific is dependent upon the monsoons. During the summer rainy season, winds blow from the ocean toward the land. During the dry winter season, winds blow from the Asian continent toward the ocean. The three centers of major atmospheric activity, Aleutian Low, Siberian (Asian) High and the Honolulu High influence the transport of air masses within the North Pacific and Arctic regions. During the winter the Siberian High covers most of northeastern Asia and the Aleutian Low dominates the northern part of the Pacific Ocean resulting in the prevailing flows of the air from Asia towards the Aleutian Chain. In the summer time these conditions are reversed and the prevailing flows are in the opposite direction. Because we are interested in the impact on people, we also need to take into account the precipitation in the region as it can wash large amounts of the radionuclides out of the atmosphere. In the far northern regions during the winter the low temperatures and the limited low-level moisture supply will limit the washout during this period. In summer-fall time period, the intensity of cyclone development will depend greatly on the conditions of the underlying surfaces. In spring there is the intense transport of heat and moisture from southern to the northern latitudes that triggers cyclone development. The air parcel movements in the North Pacific can vary widely with season and latitude and longitude of origin of the pollutants. Figure 1a and 1b show the annual trajectories from the Petropavlovsk and Vladivostok areas, respectively. (24)



(a) (b)

Figure 1 Annual atmospheric transport pathways from the Petropavlovsk (a) and Vladivostok (b) Sites

Details of monthly and seasonal flows are shown in the report. From the computer files, it is also possible to study individual days when there is sufficient meteorological data to input.

In considering accidents aboard submarines, it is important to realize that the reactors are much lower in power, 65-70 MWt, (details of nuclear submarine reactors are classified but the nuclear powered ice breakers are said to have similar reactors). These numbers are taken from a Bellona report (25) and are more than a magnitude lower than a nominal civilian power reactor of 1000 MWe. Despite the classification, the Russians have suggested using a "theoretical submarine" that has 65 canisters, each containing 7 spent fuel assemblies, per reactor.(26) They have stated that a number of submarines at dockside have low buoyancy and about half have fuel on board.

A paper commissioned by IIASA reanalyzed the Chazma Bay accident (27) to give us further insight into local impact. Sivintsev has calculated that only 5 x 10^{18} fissions are possible with the quantity of fresh fuel in a submarine reactor before it blows apart. Consequently, to get the radionuclides high enough into the troposphere requires additional energy inputs such as diesel fuel, accelerants from missiles, or oxygen generating chemicals. If the contaminants are not injected high enough into the troposphere, they will only have a local effect and not a regional and/or global effect.

Our first study on the impact on the Japanese Islands considered 2 reactivity accidents, the Chazhma Bay submarine accident to be used as a validation of the model used and a hypothetical, worst case accident. (28). Only a single winter time condition, January 1997, was analyzed as it had been shown that the predominant flows toward Japan occurred mainly during the winter time. A deterministic code, WSPEEDI, (29) was used for the numerical analysis. This code is the Worldwide version of System for Prediction of Environmental Emergency Dose Information (SPEEDI) developed by Japan Atomic Energy Research Institute.. The accumulated external gamma dose during cloud passage is calculated from the time integrated air dose rate. The model also takes into account the cumulative committed internal dose due to inhalation during the period of time the contaminated air passes the site. The model accounts for complex sources, terrain conditions and the heterogeneous non-steady state conditions in the atmosphere. The only accidents studied were those that could occur during refueling with fresh fuel and spent fuel unloading in the Vladivostok area.

Releases from the Vladivostok sites could reach the Japanese Islands in 12 hours, 36 hours and 18 hours for the three January 1997 wind conditions that were investigated, strong North winds, weak North winds and cyclonic winds, respectively. These analyses show how much the wind patterns can vary over a small region in a very short time. It is also clear that China and the Korean Peninsula could be reached earlier due to their proximity to the Vladivostok sites. Takano's (28) and Romanova's (30) analyses were based upon the radionuclide releases from a Russian submarine accident reported in a NATO study (31). Using this input data and the wind conditions noted above, the doses to the maximally exposed individuals are shown in Table 2 (32).

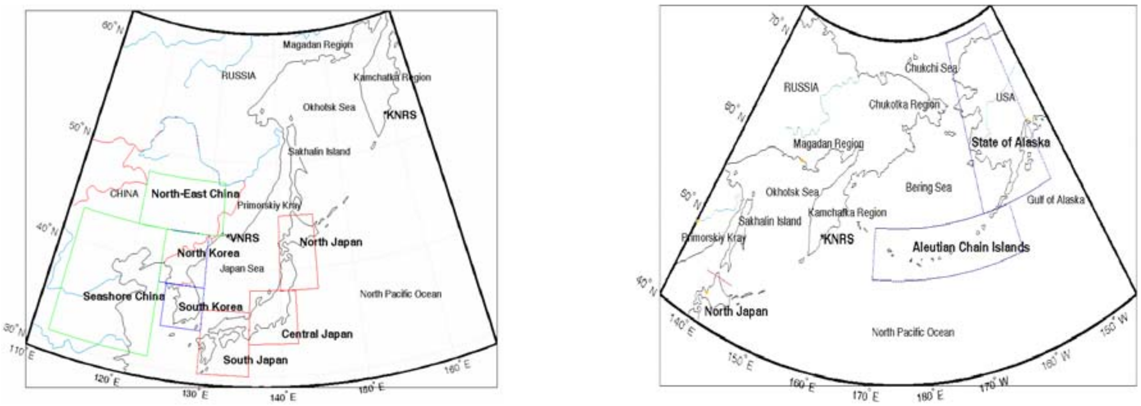
It can be seen that the highest dose resulting from a reactivity accident involving fresh fuel is expected to occur in Japan under strong north wind conditions but would be less than 2 x 10^{-7} mSv. Doses from a reactivity accident involving spent fuel would be higher, less than 2 x 10^{-3} mSv in Japan and 2 x 10^{-3} in Korea. All of these doses would be well below the internationally accepted limit of 1 mSv/yr (33).

Table 2. Estimated Total Dose in Affected Areas of Japan and Korea (mSv)

WIND PATTERN	**AFFECTED COUNTRY**	**DOSE (mSv)**	**REACTIVITY ACCIDENT: FRESH FUEL**			**REACTIVITY ACCIDENT: SPENT FUEL**		
			I-131	**1-133**	**I-135**	**Cs-137**	**Cs-134**	**Sr-90**
Strong North Wind	**Japan**	**External**	3E-10	6E-09	2E-08	4E-06	4E-07	
		Internal	3E-08	6E-08	2E-08	4E-04	4E-05	7E-04
Weak North Wind	**Japan**	**External**	3E-10	6E-09	2E-10	4E-06	4E-06	
		Internal	3E-08	6E-09	2E-10	4E-04	4E-05	7E-04
Cyclonic Wind	**Japan**	**External**	3E-10	6E-09	2E-09	4E-06	4E-06	
		Internal	3E-09	6E-09	2E-09	4E-04	4E-05	7E-04
	Korea	**External**	3E-10	6E-10	2E-09	4E-06	4E-06	
		Internal	3E-09	6E-09	2E-09	4E-04	4E-06	7E-04

Because of this variability, the impact over the entire year on regional countries has been studied (34) (35). There are a number of approaches to modeling atmospheric pollutant transport over long distances. The two approaches most commonly used are the isobaric and the isentropic. In the isobaric approach it is assumed that air parcels are moving along the surfaces of constant pressure while in the isentropic approach, it is assumed that air parcels are moving along the surfaces of constant potential temperature. Modeling using fully three-dimensional trajectories would be preferable but it requires a larger number of variables and parameters and consequently increases computer time for each run. We have chosen the isentropic approach to project the mean motion of a diffusing cloud because it provides realistic results with less computational effort (36) (37). The calculated trajectories over a reasonable period of time should be in agreement with the general synoptic scale patterns.

The countries outside of Russia that are of interest are shown in Figure 2a and 2b. (34)



(a) (b)

Figure 2. Impacted Regions (a) Eastern North Pacific (b) Western North Pacific

The contiguous US was not considered as on the average it takes more than 5 days to reach those regions from the Pacific Fleet's centers, the reduction in accuracy after 5 days of transport and the increased computer resources needed for statistical analyses of the longer time series.

To speed our studies we joined with the Danish Meteorological Institute (DMI) (38) where a number of models and methodology had been developed in the course of its Arctic Risk Studies. Fuller discussion of the results of this collaboration is found in our joint publication, "Probabilistic Analysis of Atmospheric Transport and Deposition Patterns from Nuclear Risk Sites in Russian Far East" (34) Four major models and techniques were used: (1) Isentropic Trajectory Model (39), (2) Long range Transport and Dispersion model-Danish Emergency Response Model of the Atmosphere (40), (3) Cluster analysis (34) and (4) probability field analysis (41). To the results of these studies, we added the dose analysis (42).

The most critical item in the analysis, after obtaining suitable models, is sufficient and accurate data. We used the gridded Dataset DS082.0-NCEP Global Troposphere Analyses (from 1987 till April 1996) (43) to calculate five day forward trajectories from Vladivostok and Petropavlovsk. For the atmospheric transport and deposition we used the meteorological data from the European Center for Medium-Range Weather Forecasts (44). For cluster analysis we used the SAS methodology (45) as described in (46) that showed the major airflow patterns as shown in Figure 1. The probabilistic analysis of these airflows was carried out to provide a general overview of the likely direction of the radioactive cloud as well as the probability that it would reach or pass any particular geographical area. The typical transport times to each of the geographical regions studied were calculated. Because some of the radionuclides of interest, such as I-131, have relatively short half-lives and because dispersion and dilution increase with transport time, the sites reached in 1 and 5 days were also calculated. See Mahura (34) for more detailed analysis of the results. For example, for radionuclides injected into the boundary layer, ~1500 m, 32% of all forward trajectories would reach the North Japan region but if one takes the percentage of days that at least one trajectory reaches the North Japan region, the percentage increases to 54.5. They could be considered the upper and lower bounds of the probability of an impact on that region from a short term, less than one hour, and a longer term, several hours, release.

For both Vladivostok and Petropavlosk sites, westerly flow is dominant throughout the year. The flows occur more than 60% of the time within the boundary layer, less than1.5 km above sea level, and 85% of the time at higher altitudes, above 3 km above sea level. For the Vladivostok sites, North China, 35-87%, and North Japan, 32-54%, regions are at the highest risk of possible impact because of their proximity to the release sites and the prevailing wind patterns. The probability of impact is lower for the Korean peninsula as the airflow patterns are generally of western origin. On average, atmospheric transport to northern China is likely to require less than 1 day and only slightly over 1 day to reach northern Japan. These aggregated numbers hide the daily and monthly variability of these trajectories shown in Figure 3. (34)

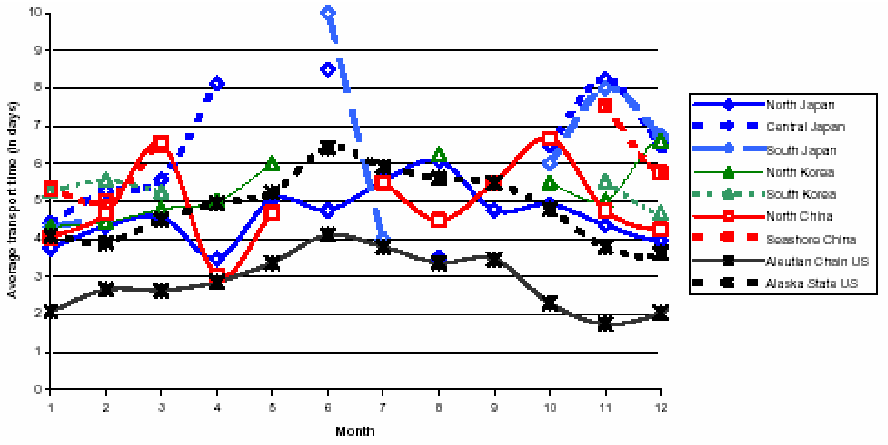


Figure 3a. Monthly Average Transport Times from Petropavlovsk Sites to the Impacted Regions

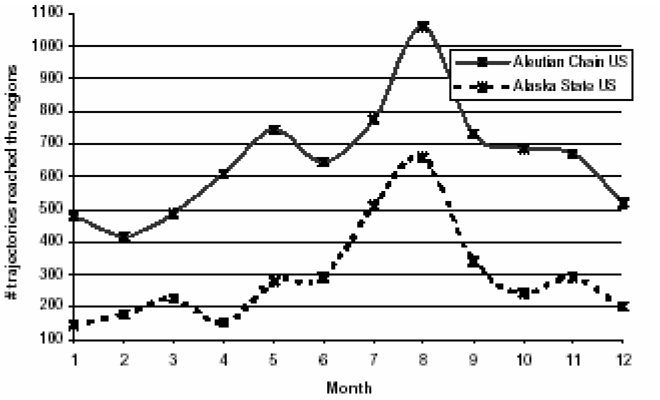


Figure 3b. Monthly Variations in the number of trajectories originating at low altitudes within the boundary layer in Kamchatka Oblast and reaching impacted regions in the Eastern Pacific

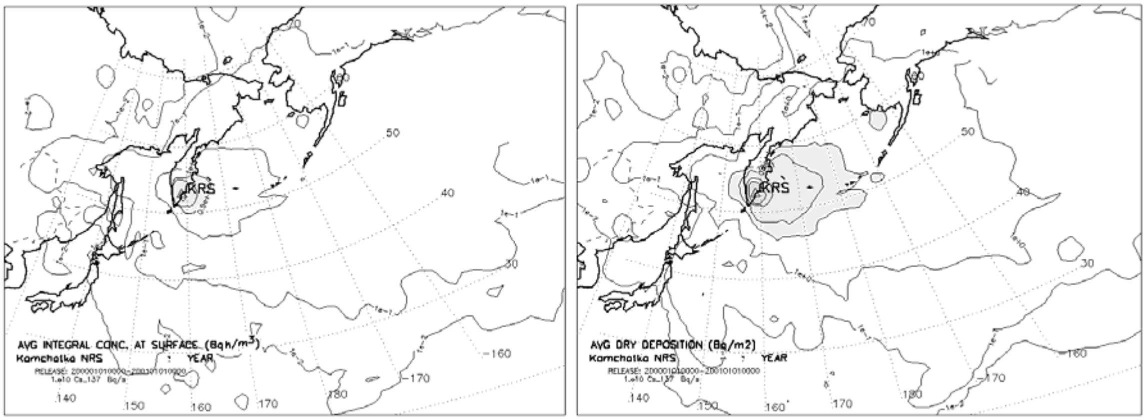
Except for US territories, radionuclides transported within the boundary layer reach all other regions more than half the time. For the Petropavlovsk sites, US regions are at the highest risks. The lower and upper bounds of the probability of impact for the Aleutian Islands are 30-54% and for Alaska 13-32%. Average transport time to these regions is 3 and 5 days, respectively. The likelihood of impact is less than 10% for all other regions. Only the Aleutian Islands are reached in less than one day in greater than a few percent of the time. The trajectory studies did not take into account the dispersion of the contaminants in the atmosphere nor the reduction due to radioactive decay and wet and dry washout.

The next studies took into account dispersion and washout. The details are also given in (34). The parameters examined in a probabilistic sense were airflow, precipitation and relative humidity, fast transport, mixing height layer, dry, wet and total deposition concentrations and doses. Several assumptions were made for this part of the study: 1. Continuous hypothetical release of 10^{10} Bq/sec of ^{137}Cs for one day.(this release is similar to that calculated in the NATO studies for releases from 1 reactor in a nuclear submarine) 2. Only one, key radionuclide, Cs-137, was considered. 3. Simulation was on a daily basis for 5 days. 4. Only one year, 2000, was modeled because of computer time constraints. For worst case analyses, based upon the conditions in 2000, specific days were modeled and then later used for the dose analyses.

As would be expected at both Vladivostok and Petropavlovsk sites, the integrated atmospheric and the dry deposition concentrations were higher in the vicinity of the sites and decreased with distance. They also had elliptical deposition patterns reflecting the dominant airflow patterns such as was seen in the East Urals Trace. Though wet deposition is also high near the Fleet sites, it is strongly dependent on the rainfall patterns that are frequently cellular. As has been observed elsewhere, the areas with wet deposition can have concentrations an order of magnitude greater than areas with only dry deposition.

Releases of 10 x 10^{10} Bq/sec with a puff release every 60 minutes of ^{137}Cs for one day from the Vladivostok sites result in integrated concentrations of 10^{-1} Bq-h/m^3 at the seashore of China during October-November and March. The same concentrations occurred over the Aleutian Islands Chain during March-April and October-December. However, over the Japanese territories it is higher than 10^{+1} Bq-h/m^3 during October-April. The dry deposition over the Japanese territories will be higher than 10^{+2} Bq/m^2 during October-November. During December-February and October-November, the populated territories with the deposition higher than 10^1 Bq/m^2 are situated to southeast and southwest of the site, respectively. The total area where wet deposition is higher than 10^0 Bq/m^2 will be larger during November-April in comparison with other months. The Japanese territories are minimally affected by wet deposition during July, and highly affected during September-April. During summer months, the wet deposition field is limited to a 1500 km circle around the site.

For the Petropavlovsk sites, releases of 10 x 10^{10} Bq/sec with a puff release every 60 minutes of ^{137}Cs for one day resulted in integral concentrations during October-March and August, at the western shore of the State of Alaska of 10^0 Bq·h/m^3. During January-May and September, integral concentration over the northern territories of Japan is 10^{-1} Bq·h/m^3, although in other months these territories appear unaffected. The dry deposition during March, July, and September, at the western shore of the State of Alaska is 10^{-1} Bq/m^2. During June-August and October-November, the territory of Japan appears unaffected, although in other months radionuclides might be deposited there in concentrations up to $0.5 \cdot 10^{+1}$ Bq/m^2 at any day of a month. During January, over the northeastern territories of China the deposition concentration is 10^1 Bq/m^2. The total area of the wet deposition field increases significantly during November-February reaching a maximum in December, with a minimum during summer months. During winter months, there are local maximums of wet deposition over the Russian Far East and State of Alaska territories. During summer months, the wet deposition field is more extended in the northeastern direction from the site, although in other months it propagates more in the eastern direction. This field diminishes significantly during June-September. During January, a large area of the continental Asian part of Russia is also affected by wet deposition. The annual integrated concentration (a) and dry deposition (b) for 2000 for Cs-137 releases are shown in Figure 4.



(a) Petropavlovsk (b)

Figure 4. Integrated Concentration (a) and Dry Deposition (b) for 2000 for Cs-137 Releases

Mahura (34) only provided the deposition and integrated atmospheric concentrations for ^{137}Cs but determined that reasonable estimates for Sr-90 and I-131 concentrations could be made from the available Cs-137 information. The simplest relationship between Sr-90 or I-131 and Cs-137 concentrations is a linear one. To see if such a relationship is reasonable, Brown (42) used the data from the five worst cases to see if a unique, linear relationship exists between them. He used S-Plus (47) to show that the 10 pair-wise correlations between the I-131 (at the desired time period in hours) and Cs-137 data and those for the Sr-90 versus Cs-137 manifested high correlations. Therefore, he used simple, linear relationships to estimate the Sr-90 and I-131 deposition data from the calculated Cs-137 information. Using the transfer factors from the UNSCEAR (48) methodology, he computed the effective dose commitments for the maximum total depositions for Cs-137, Sr-90, and I-131 for the Vladivostok and Petropavlovsk sites.(42)

Table 3.Maximum Total Dose Commitment (per Person) Estimates by Pathways from Cs-137 Releases at Petropavlovsk Sites using UNSCEAR Methodology

Region	Maximum Total (mSv)	Ingestion (mSv)	Ingestion (%)	Inhalation (mSv)	Inhalation (%)	External Exposure (mSv)	External Exposure (%)
Regional	4E+00	2E+00	36	3E-03	0.1	3E+00	64
China	3E-02	1E-02	36	2E-05	0.1	2E-02	64
Japan	4E-02	2E-02	36	3E-05	0.1	3E-02	64
Mongolia	2E-03	6E-04	36	1E-06	0.1	1E-03	64
N. Korea	8E-03	3E-03	36	6E-06	0.1	5E-03	64
Russia	4E+00	2E+00	36	3E-03	0.1	3E+00	64
S. Korea	6E-04	2E-04	36	5E-07	0.1	4E-04	64
Aleutians	1E-01	5E-02	36	9E-05	0.1	8E-02	64
USA Main	2E-01	7E-02	36	1E-04	0.1	1E-01	64

Here, we show only the results for the Petropavlovsk sites for Cs-137 in Table 3 as they have the greatest effect on US territories. We show the rounded total maximum effective dose commitment for the region and each country as well as the components of the total by type (i.e. ingestion, inhalation, and external exposure) from releases from the Petropavlovsk. Those regions that were not affected are not shown in the tables. Similar results can be shown for Sr-90 and I-131 but only the totals are shown in Table 4.

Table 4 Maximum Total Individual Dose Commitments from Cs-137, Sr-90 and I-131 Releases at Petropavlovsk and Vladivostok Sites using UNSCEAR Methodology

(a) Petropavlovsk

Isotope	Cs-137	Sr-90	I-131
	MaxTotal	MaxTotal	MaxTotal
Region	(mSv)	(mSv)	(mSv)
Regional	4E+00	2E+00	2E-01
China	3E-02	1E-02	3E-10
Japan	4E-02	2E-02	2E-04
Mongolia	2E-03	6E-04	
N. Korea	8E-03	3E-03	
Russia	4E+00	2E+00	2E-01
S. Korea	6E-04	1E-04	
Aleutians	1E-01	5E-02	2E-03
USA Main	2E-01	8E-02	2E-04
Vietnam			

(b) Vladivostok

Isotope	Cs-137	Sr-90	I-131
	MaxTotal	MaxTotal	MaxTotal
Region	(mSv)	(mSv)	(mSv)
Regional	4E+00	2E+00	3E-01
China	1E+00	4E-01	7E-02
Hong Kong	8E-04	1E-07	
Japan	6E-01	2E-01	1E-02
Mongolia	1E-02	4E-03	3E-09
N. Korea	6E-01	3E-01	4E-02
Russia	4E+00	2E+00	3E-01
S. Korea	2E-01	7E-02	6E-03
Taiwan	3E-02	1E-02	
Aleutians	9E-03	3E-03	4E-05
USA Main	2E-02	2E-03	3E-17
Vietnam	4E-10	3E-14	

On the basis of individual countries, the dose commitments in Table 4 can be summarized by the following order:

For Petropavlovsk: Regional = Russia >> USA Main > Aleutians > Japan > China > N. Korea > Mongolia > S. Korea.

That is, for releases from the Petropavlovsk sites, the maximum dose commitment is found in Russia and is almost two orders of magnitude higher than that for any country. It should be noted that separating the Aleutian Islands from the U.S. mainland, as in this study, had little impact on the results. Further it should be noted that even for the maximum case, Russia, the sum of the maximums is only 6 mSv.

For Vladivostok: Region = Russia > China > N. Korea > Japan > Taiwan > USA Main > Mongolia > Aleutians > Hong Kong > Vietnam

Therefore, even though the maximum dose commitment resides in Russia (as found for the Petropavlovk releases), the values for other surrounding countries (e.g., China, N. Korea, and Japan) are not orders of magnitude lower than that for Russia, but only approximately four to eight times lower. Further it should be noted that even for the maximum case, Russia, the sum of the maximums is only 6 mSv.

Conclusions

To the best of our knowledge, this first comprehensive unclassified analysis of the potential impact of accidents at the Russian Far East nuclear submarine sites near Vladivostok and Petropavlovsk has defined the situation there based upon available information and studies commissioned by the Radiation Safety of the Biosphere Project of the International Institute for Applied Systems Analysis. Further, in our original work, some in collaboration with the Danish Meteorological Institute and the Japanese Atomic Energy Research Institute, we have calculated the nuclide trajectories from these sites in the atmospheric boundary layer, less than 1.5 kilometers high, and determined their probability of crossing any of the nearby countries as well as Asiatic Russia. We have further determined the concentrations in each of these crossings as well as the total, dry and wet depositions of nuclides on these areas. Finally, we have calculated the doses to the Japanese Island population from typical winter airflow patterns (those most likely to cross the Islands in the minimum times), strong north winds, weak north winds and cyclonic winds using Japanese codes for conditions similar to the Chazhma Bay criticality accident (fresh fuel) and for a criticality accident for the same type of reactor with fuel being withdrawn (spent fuel). The maximum individual committed dosages were less than 2×10^{-7} and 2×10^{-3} mSv, respectively. The long-term external doses by radionuclides deposited on the ground and the internal dose by consumption of foods were not evaluated, as it is believed that such doses can be avoided by social controls.

In a more detailed analysis using Danish codes and taking these longer term doses into account, we have further calculated the maximum individual committed dosages from the Petropavlovsk and Vladivostok sites for Russia and each of the surrounding countries. The sum of the maximum individual committed dosages (SMICD) from the Petropavlovsk sites were less than 0.3 mSv except for Russia where the (SMICD) was less than 6 mSv. The (SMICD) from the Vladivostok sites were less than 1 mSv except for Russia where it was less than 6 mSv.

These dosages were only for criticality accidents from a single submarine reactor and where the nuclide cloud did not rise above 1.5 kilometers. The probabilities of criticality incidents where there is storage of more than 1 core in facilities onshore or afloat and with added energy from other possible sources should be studied as they most likely would produce greater dosages.

ACKNOWLEDGMENTS

Financial support of this study included grants from the United States Departments of Energy (DOE) and of Defence (DOD), Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), and Vanderbilt University. Support was also provided by the Japan Atomic Energy Research Institute for the Japanese participation in the study and by the Danish Meteorological Institute in developing and running some of the models. Support in terms of data and knowledge was also provided by participants from Minatom, Kurchatov Institute, Institutes of the Russian Academy of Sciences and the Russian Navy. We appreciate the contributions of all of these participants and the numerous individuals who helped in many ways though the results and conclusions are own.

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