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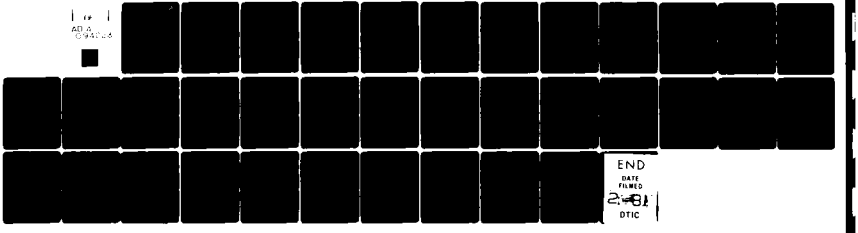

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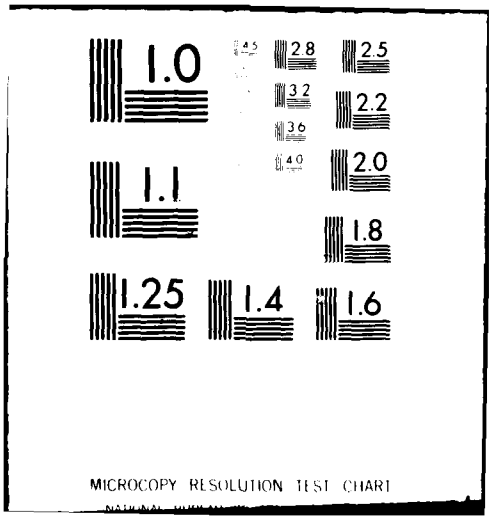
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SCOPING THE IMPACT OF NUCLEAR BURSTS AT SEA ON THE ENVIRONMENT

Advanced Research and Applications Corporation
1223 E. Arques Avenue
Sunnyvale, California 94086

20 April 1979

Final Report for Period 1 August 1978—20 April 1979

CONTRACT No. DNA 001-78-C-0377

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: DNA 4936F	2. GOVT ACCESSION NO.: AD-A094223
3. RECIPIENT'S CATALOG NUMBER:	
4. TITLE (and Subtitle): SCOPING THE IMPACT OF NUCLEAR BURSTS AT SEA ON THE ENVIRONMENT	5. TYPE OF REPORT & PERIOD COVERED: Final Report for Period 1 Aug 78—20 Apr 79
	6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): H. Lee	8. CONTRACT OR GRANT NUMBER(s): DNA 001-78-C-0377
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Advanced Research and Applications Corporation, 1223 East Arques Avenue, Sunnyvale, California 94086	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Subtask V99QAXNF035-26
11. CONTROLLING OFFICE NAME AND ADDRESS: Director, Defense Nuclear Agency, Washington, D.C. 20305	12. REPORT DATE: 20 April 1979
	13. NUMBER OF PAGES: 36
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): F035	15. SECURITY CLASS (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE: N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

12 35

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B325078464 V99QAXNF03526 H2590D

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Naval Warfare
Nuclear Weapons
Radioactivity
Ocean Contamination

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a scoping analysis on phenomena and effects of nuclear detonations at sea. It provides, with the use of example calculations, estimates of the short- and long-term radiological impacts on the ocean environment. The example calculated results showed that the radiation rates in the sea at early times, out to distances beyond severe vessel damage, are sufficiently high to warrant concern; however, because of radioactive decay and diffusive expansion, the radioactivity is reduced to negligible hazard levels within about one to two days.

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SUMMARY

In the event of a nuclear war, it is likely that nuclear weapons will be used on naval targets. This study consists of a scoping analysis on phenomena and effects of nuclear detonations at sea. Specifically, it includes a modeling structure for assessing the short- and long-term radiological impacts on the ocean environment for nuclear detonations at sea, and the use of the modeling structure to estimate the nature and magnitude of ocean contamination and the associated radiological hazards for nuclear detonations at sea.

The example calculated results showed that the radiation rates in the sea at early times and at distances beyond severe vessel damage are sufficiently high to give significant exposure doses to people in the water, on the surface of the water and above the water surface. Because of radioactive decay and diffusive expansion the radioactivity is reduced to negligible hazard levels within about one to two days after burst. The consumption of fish living within the contaminated water also would not result in hazardous exposure doses.

Conversion factors for U.S. customary
to metric (SI) units of measurement.

To Convert From	To	Multiply By
calorie	joule (J)	4.186800
curie	disintegration/second	3.700000 x E + 10
day (mean solar)	second (s)	8.640000 x E + 4
degree (angle)	radian (rad)	1.745329 x E - 2
electron volt	joule (J)	1.602190 x E - 19
foot	metre (m)	3.048000 x E - 1
gram	kilogram (kg)	1.000000 x E - 3
hour (mean solar)	second (s)	3.600000 x E + 3
kiloton (nuclear equi. TNT)	tera joules (TJ)	4.183
knot	metre/second (m/s)	5.144444 x E - 1
liter	metre^3 (m^3)	1.000000 x E - 3
megaton (nuclear equi. TNT)	peta joules (PJ)	4.183
mile	metre (m)	1.609344 x E + 3
mile^2	metre^2 (m^2)	2.589988 x E + 6
rad (radiation dose absorbed)	gray (Gy)*	1.000000 x E - 2
rem (RBE=1)†	gray (Gy)	1.000000 x E - 2
roentgen	coulomb/kilogram (C/kg)	2.579760 x E - 4

*The gray (Gy) is an accepted unit equivalent to joule/kilogram (J/kg).

†RBE = Relative Biological Effectiveness (of radiation energy).

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1. INTRODUCTION

In the event of a nuclear war, it is highly likely that nuclear weapons will be detonated at sea. Candidate sea targets for nuclear weapons include off-shore installations as well as surface and undersea vessels. The vessels warranting attack with high yield weapons are ballistic missile submarines and large aircraft carriers. The reason is that their nuclear weapons systems have the potential for massive destruction. The nuclear inventory aboard any one of both types of vessels is large. However, the reason submarines are used for ballistic missile platforms is that they are difficult to locate. It is unlikely therefore that nuclear weapons will be used against them. Unlike the SLBM submarines, aircraft carriers will not only be easier to detect, but their utility requires them to be within aircraft range of the battle arena. Nuclear weapon bursts at sea could also be used to overcome or degrade the capabilities of submarine detection and location systems.

Antisubmarine and anti-surface-vessel nuclear weapon systems are integral parts of the U.S. and Soviet Union navies. The appropriate burst altitudes are deep underwater for submarines and low airbursts for surface vessels although underwater bursts are also effective against surface vessels. Both navies also have surface-to-air and air-to-air capabilities.

The primary nuclear burst effects are the release of thermal energy, the propagation of a shock wave, and the release of initial and residual radiation. The relative impacts of these effects will be different depending on weapon yield and burst altitude. A nuclear burst high above the sea is an airburst and consequently the effects are no different from an airburst over land. The thermal energy absorbed by the sea, relative to its capacity, is insignificant as is the absorbed shock. The effects on structures or vessels on the sea surface would be similar to those for structures or equipment on land. There would be no local fallout.

A nuclear burst on the sea surface would produce a fireball that would radiate thermal energy directly to the sea as well as to the atmosphere. Initial radiation would also be radiated into the sea and the atmosphere. A radioactive cloud and base surge would be produced. Water waves of large magnitude would be propagated radially from the burst area. Some of the thermal energy directed into the sea will be dissipated with the vaporization

of large quantities of sea water and the remainder is readily absorbed by the sea with relatively insignificant effects. The shock energy in water, although propagated at a higher speed and to greater distances than the air blast, is also readily absorbed by the sea although local effects will occur. The water shock as well as the air blast will cause damage to sea and shore targets that are at relatively close range. Initial radiations into the sea will be readily absorbed within a limited range and consequently will not produce any significant effect. A major fraction of the residual radioactivity produced will be carried off to become worldwide fallout and about 20 percent or less is expected to deposit locally.

The effects of a deep underwater burst are essentially contained within the sea. The surface or atmospheric disturbances, if any, are relatively insignificant, although a base surge and surface waves would be produced. The thermal energy would be almost entirely absorbed by the water, but because a very large volume is intrinsically involved in the absorption of energy, temperature increases beyond the initial burst bubble radius would not be significant. Temperature increases within the initial burst bubble radius would be rapidly dissipated. Strong water shock overpressures of short duration would be propagated to significant distances. All of the radioactivity produced, except for the noncondensible gases, would remain in the water.

The radioactive materials in the water could pose a significant radiation hazard to personnel aboard submarines or surface vessels operating in the contaminated zone. The residual radioactivity in the water could also degrade or negate existing or potential capabilities to detect or locate other radioactive sources in the sea, e.g., the radioactive wake of a nuclear powered vessel. The radioactive materials may also have short-term and long-term adverse effects on sea and shore life.

This study consists of a scoping analysis on radiological phenomena and effects of nuclear detonations at sea. The objectives of the research are to develop a modeling structure for assessing the environmental impacts that could evolve from nuclear detonations at sea, to assess the data requirements and their availability for implementing the model, and to perform scoping assessments.

In this report the modeling components, from radioactive materials production to its distribution in the sea and the associated radiation exposures, are presented along with discussions on the uncertainties of the modeling functions and inputs. To perform the scoping assessments, modeling gaps are bridged with assumptions to provide a complete modeling structure, simplified functions are provided wherever appropriate, and representative inputs are used.

2. NUCLEAR EXPLOSIONS

2-1 GENERAL

Nuclear Explosions are generally separated into two categories: that from the nuclear fission of heavy elements and that from the nuclear fusion of light elements. Nuclear fission reactions, however, are used to initiate nuclear fusion in thermonuclear weapons and consequently fission products are also produced in thermonuclear explosions. The energy released in a thermonuclear explosion originates roughly in equal amounts from fission and fusion processes. (Reference 1) In "boosted" fission weapons where the neutrons produced by the fusion process are used to increase the neutron population, the nuclear fusion reaction is only a small fraction of the total yield. (Reference 1)

The common units of nuclear weapon yield are the kiloton (KT) and the megaton (MT) energy equivalent of TNT. The energy released by the explosion of 1000 tons of TNT is defined to be 10^{12} calories. In the International System of Units, 1 KT = 4.2×10^{12} joules and 1 MT = 4.2×10^{15} joules. Besides the 4.2×10^{12} joules of energy immediately released with the explosion of a 1 KT nuclear weapon, additional nuclear decay energy resides with the residual fission products. This decay energy which is about 10 percent of the total energy yield is dissipated at decreasing rates with time.

About 70 to 80 percent of the total energy released from a nuclear explosion is initially emitted in the form of x-rays which are converted to thermal radiation in atmospheric explosions. Most of the primary thermal radiation energy serves to heat the immediate surroundings and the expended thermal energy is converted into shock energy and lower temperature radiation. In the atmospheric explosion, the remaining thermal energy, about 35 to 45 percent of the total, is dissipated to the surroundings as radiant energy. For underwater bursts, the remaining thermal energy is absorbed by the immediate surrounding water. The surrounding waters also absorb the decay energy of the fission products remaining in the water.

Nuclear fission and fusion processes also release neutrons to interact with surrounding matter. For atmospheric explosions, neutron interaction with nitrogen produces significant quantities of carbon-14. For nuclear bursts at sea, neutron interaction with the dissolved salts produces sodium-24 and chlorine-38.

2-2 RADIONUCLIDE PRODUCTION

The radioactive materials produced and released to the environment by a nuclear explosion consist of fission products, activation products and fissile materials (and their radioactive daughter products) that were not fissioned nor activated. The fission products constitute the primary potential radiological hazard source. The activation products constituting significant potential hazards are limited to a few, and the hazards associated with fissile materials that were neither activated nor fissioned are relatively insignificant.

The relative amounts of the fission product radionuclides produced depend on the fissile materials in the weapon, namely U-235, U-238, and Pu-239. Crocker (Reference 2) lists, among others, the total fission product exposure rates for fission-spectrum neutron fission of U-235 and Pu-239, and for thermonuclear neutron fission of U-238. Normalized to a contamination density of one KT per mi^2, the unfractionated fission product exposure rates at three times after fission are as follows:

Fissile Material	R/hr per KT/mi^2		
	1 hr	10 hr	100 hr
U-235	3110	168	8.70
Pu-239	2730	149	8.70
U-238	2920	160	8.13

The major contributing radionuclides to the exposure doses at various times after burst are also similar for the three fissile materials. (Reference 2) For example, the two highest radionuclide contributors to the exposure rate at various times are listed below for the three fission cases.

Time After Burst	Highest Radionuclide Contributors to Exposure Rate		
Fissile Material	U-235	Pu-239	U-238
1 hr	I-134 Cs-138	I-134 Cs-138	I-134 Cs-138
1 day	I-132 I-135	I-132 I-135	I-132 I-135
1 wk	I-132 La-140	I-132 La-140	I-132 La-140
1 mo	Zr-95 La-140	Zr-95 La-140	Zr-95 La-140
1 yr	Zr-95 Nb-95	Zr-95 Rh-106	Zr-95 Rh-106
10 yrs	Sb-125 Ba-137m	Sb-125 Ba-137m	Sb-125 Ba-137m

The production of the radionuclides contributing significantly to fallout internal exposures are also similar. The equivalent quantities of these radionuclides, referenced to 1 hour and 30 days after burst, estimated from Reference 2 data for the three fission cases along with the totals for all fission products are listed below.

Radionuclide	10^3 Ci/KT (at 1 hr and 30 days equivalent)					
	U-235		Pu-239		U-238	
	1 hr	30 days	1 hr	30 days	1 hr	30 days
Sr-89	22.3	15.0	10.6	7.14	16.7	11.3
Sr-90	0.182	0.182	0.063	0.063	0.084	0.84
Zr-95	30.3	22.1	20.9	15.2	24.7	18.0
Mo-99	692	0.39	681	0.38	612	0.35
Ru-103	23.3	13.8	50.3	29.7	38.9	23.0
Ru-106	0.53	0.50	4.0	3.78	2.9	2.74
Te-132	470	0.76	475	0.77	398	0.65
I-131	148	11.2	185	14.0	158	11.9
Cs-137	0.187	0.187	0.20	0.2	0.16	0.16
Ba-140	145	28.6	122	24.1	128	25.3
La-140	2.5	32.9	2.0	27.8	2.1	29.1
Ce-141	56	29.8	43	23.0	49.2	25.9
Ce-144	5.6	5.2	3.53	3.28	4.53	4.19
All F.P.	430,000	265	420,000	251	440,000	260

3. RADIOLOGICAL CONTAMINATION

3-1 RADIOACTIVITY PARTITIONING

The effects of nuclear weapon debris on the environment depends on its temporal and spatial distribution within the environment and therefore it is necessary to partition the nuclear debris so that their interactions with the environment could be separately assessed. For atmospheric bursts, it has been common practice to separate the fallout into local and worldwide fallout. The local fallout is characterized by early arrival, short deposition duration and high deposition density. Fallout deposited within one day has been arbitrarily classified as local fallout. Worldwide fallout is characterized by late arrival (greater than one day), long deposition duration, and low deposition density. Worldwide fallout is also commonly separated into tropospheric fallout (nuclear debris confined to the troposphere), and stratospheric fallout (nuclear debris that had been injected into the stratosphere).

For nuclear bursts in water, it is also desirable to separate the nuclear debris in the water into two compartments: a surface layer, which is a part of man's biosphere, and at greater depths where the radioactivity pathways to man are tenuous. The factors affecting the distribution of nuclear debris among the above locational categories are the weapon yield and the height or depth of burst. An attempt to simplistically partition the nuclear debris from available information follows.

All nuclear bursts will produce residual radioactivity. The distribution of the radioactivity, however, will be different for airbursts, water surface bursts, and underwater bursts. Airbursts, be definition, will not produce significant amounts of local fallout, that is, the height of burst is at altitudes to virtually preclude fallout within one day. The nuclear debris produced, therefore, will eventually deposit as worldwide fallout. Some of the debris will circle the globe many times prior to deposition. Deposition densities will be diminished because fallout will occur over an extremely large area and radioactivity will be diminished by radioactive decay prior to deposition. Worldwide fallout will deposit on both land and sea.

The minimum burst height at which local fallout would not be appreciable is estimated in ENW (Reference 1) to be

$$h_a = 180\ W^{0.4}\ (ft) \tag{1}$$

where W is the weapon yield in KT. Thus at $h_a \geq 180^{0.4}$, most of the nuclear debris are categorized as worldwide fallout. If the nuclear cloud and tropopause altitudes are used to partition the worldwide fallout into tropospheric and stratospheric fallout fractions, then for nuclear airbursts in the polar latitudes, i.e., greater than 30^o north or south, the fallout would be tropospheric for weapon yields less than 100 KT, and stratospheric for weapon yields greater than 2 MT. These are approximations only, since the nuclear cloud and tropopause altitudes vary with atmospheric conditions. Taking into consideration that the nuclear cloud altitude increases with nuclear yield, the fallout fractions for airbursts can be approximated as follows:

$$W \leq 100\ KT;\quad f_t = 1.0;\quad f_s = 0 \tag{2}$$

$$100\ KT < W < 2\ MT:\quad f_t = (4.573 - W^{0.2})/2.061;\quad f_s = 1 - f_t \tag{3}$$

$$W \geq 2\ MT:\quad f_t = 0;\quad f_s = 1 \tag{4}$$

In the above equations, the subscript t denotes tropospheric and the subscript s denotes stratospheric.

The distribution of residual radioactivity resulting from a water surface burst depends on the weapon yield and the atmospheric conditions. In general, local fallout is increased with higher humidity and the effect is more pronounced with low nuclear yields. In a relatively dry atmosphere, the percent of the fission product activity deposited locally has been estimated to be less than 3 percent for weapon yields less than 10 KT, about 10 percent for 100 KT, about 5 percent for 1 MT and about 20 percent for 10 MT weapons. (Reference 3) Reference 3 also indicated a data point where about 90 percent of the fission product activity was deposited locally for a 20 KT surface burst in a humid atmosphere. UNSCEAR (Reference 4) estimates the local fallout for water surface bursts at 20 percent.

Besides fission products, nuclear bursts on the sea surface also produce activation products. The more significant activation products are carbon-14 from the activation of the nitrogen in the atmosphere and sodium-24 from the activation of the sodium in sea water. The penetration of neutrons through sea water is relatively limited, however, and consequently the sodium-24 produced is within the volume of sea water that is vaporized and carried aloft with the fission products. Although a considerable amount of sodium-24 will be produced by a sea surface burst, its 15 hour half-life limits its significance to early times when the activity of the fission products dominate. Since carbon-14 is the product of nitrogen activation, its deposition is assumed to be worldwide. Its contribution to early local exposures, in any event, would be negligible. Because of the quantities produced and its long half-life, however, it will contribute to long-term exposure doses.

For a nuclear burst on the sea surface, virtually all of the radioactive materials are carried aloft as fallout. As discussed earlier, the fraction that could deposit locally varies widely. For a relatively dry atmosphere, a representative estimate of the local fallout is 10 percent. If it is estimated that the local fallout fraction is 0.1 (for all yields), then the worldwide fraction is 0.9. The local fallout fraction decreases with burst height and the worldwide fraction increases (from about 0.9 for a surface burst) to unity for an airburst. For the transition zone between the surface and airburst altitudes, the local fallout fractions for ground surface bursts may be estimated by

$$f_{\ell}(h) = f_{\ell}(o)\left(180 - \frac{h}{W^{0.4}}\right)\left(360 + \frac{h}{W^{0.4}}\right)/2(180)^3$$

where $f_{\ell}(o)$ is the local fallout fraction for $h = 0$.

The above relationship could also be used to estimate the change in the local fallout fraction for bursts over water by substituting 0.1 for $f_{\ell}(o)$, even though it may not be technically appropriate. Since the fractional change with burst height is minimal and the estimation error for the local fraction for $h = 0$ could be relatively large (depending on atmospheric humidity and perhaps yield), only a simple relationship is warranted. Until such time that the fallout partitioning for water surface burst can be estimated with greater accuracy, a simplified relationship for estimating the local and worldwide

fallout fractions for bursts in the transition zone is suggested as follows:

$$h = 0: \quad f_\ell = 0.1; \quad f_t = 0.01; \quad f_s = 0.89 \tag{5}$$

$$0 < h \leq 180\ W^{0.4}: \quad f_\ell = 0.1 - (h/1800\ W^{0.4}) \tag{6}$$

$$f_w = 0.9 + (h/1800\ W^{0.4}) \tag{6a}$$

$$W < 100\ \text{KT}: \quad f_t = f_w; \quad f_s = 0 \tag{6b}$$

$$100\ \text{KT} \leq W \leq 2\ \text{MT}: \quad f_t = f_w(4.573 - W^{0.2})/2.061,\ 0.01 \leq f_t \leq f_w \tag{6c}$$

$$f_t = 0.01, \text{ all } f_w\ (4.573 - W^{0.2})/2.061 < 0.01 \tag{6d}$$

$$f_s = f_w - f_t \tag{6e}$$

$$h < 180\ W^{0.4}; \quad W > 2\ \text{MT}: \quad f_t = 0.01; \quad f_s = f_w - f_t \tag{7}$$

where the subscript ℓ is for local fallout and subscript w is for worldwide fallout.

For deep underwater bursts, except for the non-condensible radioactive gases, all the radioactivity remains in the water. The initial contaminated volume and its geometry and location depends on the weapon yield, depth of burst and water depth. Because it has never been considered to be critically important and because of insufficient data, neither a subtle empirical model nor a vigorous theoretical model has been developed to depict the dispersion of radioactivity from underwater bursts. A simplified mathematical model for estimating the distribution of radioactive debris and exposure rates for underwater nuclear bursts, however, has been developed by Ksanda (Reference 5) and modified by Rinnert. (Reference 6) They envisioned a deep pool of radioactivity that is left at lower depths as the explosion products are buoyed to the surface with the explosion bubble to form a surface pool of radioactivity. The different features of the two pools of radioactivity are primarily that the deep pool is

at depths where the water is relatively inert and the surface pool is in the surface stratum that is relatively dynamic.

It has been estimated that for a scaled depth of unity, the fraction of the activity in the surface pool is between 0.4 and 0.7. (References 5 and 6) The scaled depth of burst, $\tilde{D}$, is defined as:

$$\tilde{D} = D/A_m \tag{8}$$

where D is the depth of burst (ft), and A_m is the radius of the first maximum of the underwater bubble and is estimated by

$$A_m = 1500 \left[W/(D + 33) \right]^{1/3} \text{ (ft)} \tag{9}$$

It has also been estimated that for $\tilde{D}$ greater than 13, all the radioactivity would be trapped in the water. (Reference 5) As the scaled depth of burst is decreased (from 13), the fraction of the radioactivity in the surface pool is increased along with a decrease in the deep pool fraction. It has also been estimated that for $\tilde{D} < 1$, there would be no deep pool of radioactivity. In addition, for $\tilde{D} = 0$, the radioactivity remaining in the water is virtually zero, i.e., all the radioactivity leaves the water to become fallout.

Although it can be safely assumed that the fraction of radioactivity in the deep pool increases with increasing depth, specific values have not been assigned. Also, although the fallout fraction is estimated to be unity at $\tilde{D} = 0$ and between 0.3 and 0.6 at $\tilde{D} = 1$, there are insufficient data to partition the radioactive materials for $0 < \tilde{D} < 1$. (Reference 7) Reference 7 also estimates the fraction of the activity in the water for burst depth equivalent to $\tilde{D} = 1$ to be about 0.9 with 0.1 in the base surge. However, if it is assumed that the activity in the surface pool is proportional to its initial volume and that the fallout fraction decreases linearly from unity at $\tilde{D} = 0$ to 0.45 at $\tilde{D} = 1$, and decreases linearly from 0.45 at $\tilde{D} = 1$ to zero at $\tilde{D} = 13$, then the radioactivity can be accordingly partitioned for fallout, surface pool and deep pool fractions as functions of $\tilde{D}$.

To separate the fallout fraction into local, tropospheric, and stratospheric fractions, it is necessary to consider the decrease in the nuclear cloud altitude with increasing depth of burst. Here the data are very limited. In the BAKER test, where the scaled depth of burst was approximately 0.11, the nuclear cloud altitude was decreased by about a factor of 2.2. If it is assumed that the decrease in the nuclear cloud height, for all yields, is proportional to $\tilde{D}$, then the various fallout fractions can be readily estimated for various $\tilde{D}$ and weapon yields as follows:

$$f_t + f_s = f_w \tag{10}$$

$$0 < \tilde{D} \leq 1: \quad f_\ell = 0.1 + 0.35\,\tilde{D};\ f_w = 0.9\,(1 - \tilde{D}) \tag{11}$$

$$W \leq 100\ \text{KT}: \quad f_t = f_w \tag{12}$$

$$0 < \tilde{D} \leq 1/6;\ 100\ \text{KT} < W \leq 20\ \text{MT}: \quad f_s = f_w(1-6\tilde{D})(W^{0.2}-2.512)/4.736 \tag{13}$$

$$1/6 < \tilde{D} \leq 1;\ 100\ \text{KT} < W \leq 20\ \text{MT}: \quad f_s = f_w\,(W^{0.2}-2.512)/4.736 \tag{14}$$

$$0 \leq \tilde{D} \leq 1: \quad f_{sp} = 0.55\,\tilde{D} \tag{15}$$

$$1 \leq \tilde{D} \leq 13: \quad f_\ell = 0.45\,\left(1 - \frac{\tilde{D} - 1}{12}\right) \tag{16}$$

$$\tilde{D} > 1: \quad f_{sp} = 0.55\,\tilde{D}^{-3/4};\ f_{dp} = 1 - (f_\ell + f_{sp}) \tag{17}$$

$$\tilde{D} > 13: \quad f_\ell = 0 \tag{18}$$

The above equations required many unsubstantiated assumptions and therefore they are intended as rough approximations of the partition of radioactivity with depth of burst. They are, nevertheless, adequate for ferreting out the relative importance of the various radiological partitions for nuclear bursts at sea. Local fallout will generally be deposited on the sea surface and will readily mix into the surface strata. Depending on the direction of the surface current and wind directions aloft, the local fallout will increase the radioactivity concentration in the surface pool or will enlarge the area of the surface pool or both. The worldwide fallout, both tropospheric and stratospheric, may be

treated as an entirely separate problem. Its effects in the area of local fallout and the area occupied by the radioactivity initially injected into and left in the water are insignificant.

3-2 RADIOACTIVITY DISTRIBUTION IN THE SEA

Radioactive fallout is carried by the winds aloft and its deposition distribution on the earth's surface is determined by the interaction of the wind on each fallout particle and the falling velocity of each particle. Under certain meteorological conditions, moisture will condense on the fallout particles and increase their falling velocity. They could also be scavenged from the atmosphere by rain.

Radioactivity injected into the sea or deposited on the sea surface will diffuse and will be carried by currents and will thus be distributed. Although the settling velocity of nuclear debris in water is extremely slow, it is rapidly mixed in the turbulent surface stratum. In the previous section, the radioactivity remaining in the water for subsurface bursts was divided into two adjoining pools of radioactivity, a surface pool and a deep pool. The shapes and sizes of these pools of radioactivity have been estimated as follows: (References 5 and 6)

Surface pool radius at 0.75 hour

$$R_S\ (t = 0.75) = 4800\ (W/\tilde{D})^{1/4}\ \text{(ft)}\quad \tilde{D} > 1 \tag{19}$$

$$R_S\ (t = 0.75) = 4800\ W^{1/4}\quad \text{(ft)}\quad \tilde{D} \leq 1 \tag{20}$$

Surface pool radius for $0.01 \leq t \leq 0.75$ hr

$$R_S(t) = R_S\ (t=0.75) \cdot \left(\frac{t}{0.75}\right)^{0.21 + 0.32\ e^{-8.1\ \tilde{D}}}\ \text{(ft)} \tag{21}$$

Surface pool radius for $t > 0.75$ hours

$$R_S(t) = R_S\ (t=0.75) + 180\ (t-0.75)\quad \text{(ft)} \tag{22}$$

Surface pool depth at $t = 0.75$ hour

$$Z_s\ (t=0.75) = 0.021\ R_s\ (t=0.75)\quad \text{(ft)} \tag{23}$$

Surface pool depth for $t \geq 0.75$ hour

$$Z_s(t) = Z_s\ (t=0.75) + 10\ (t - 0.75) \quad (ft) \tag{24}$$

where Z_s for $t > 0.75$ may be limited by the thermocline or the sea bottom.

Deep pool radius at 0.01 hour at $0 \leq Z_1 \leq Z_2$

$$R_d(t=0.01) = R_s(t=0.01) - (R_s(t=0.01) - A_m)(Z_1/Z_2) \quad (ft) \tag{25}$$

where A_m is defined in Equation 9,

Z_1 = stratum depth - Z_2 (t=0.75), and

$Z_2 = D + A_m - Z_s\ (t=0.75)$

Deep pool radius for $t > 0.01$ hour

$$R_d(t) = R_d\ (t=0.01) + 180\ (t - 0.01) \quad (ft) \tag{26}$$

Deep pool depth at t = 0.01 hour

$$Z_d\ (t=0.01) = D + A_m \quad (ft) \tag{27}$$

Deep pool depth for $t > 0.01$ hour

$$Z_d\ (t) = Z_d\ (t=0.01) + 10\ (t - 0.01) \quad (ft) \tag{28}$$

where Z_d may be limited by the sea bottom.

The distribution of activity within the above geometries are assumed to be gaussian radially and uniform vertically, where the activity concentration at the radial perimeter is equal to the center concentration times e^{-4}.

A simple method of modeling the movement of the two pools of radioactivity is to have them move independently of one another with a sharp shear line between the two pools. Alternatively, each pool could be subdivided into several strata, each with its own current velocity and direction. The latter model is more suitable for computer resolution, however, its utility will generally be limited by the availability of data on strata currents.

3-3 ACTIVITY CONCENTRATIONS

For a uniform contaminated pool the activity concentration is

$$\overline{C}_i = A_i/\pi R^2 \Delta Z \tag{29}$$

where A_i is the activity of radionuclide i,
R is the pool radius, and
ΔZ is the pool thickness.

Since the distribution is assumed to be gaussian radially, a few reference values would be helpful in describing the distributed concentrations. Using the gaussian distribution equation

$$\phi(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \tag{30}$$

$\phi(x) = 0.3989$ for $x = 0$, $x = 2.482$ for $\phi(x) = e^{-4}$. Thus, the activity concentration at the center of the pool is $0.3989/e^{-4}$ or 21.8 times greater than at the perimeter of the pool. The radius at which the activity concentration is equal to the average concentration of the pool can be determined by finding x for $\phi(x) = V/A$. Since

$$V = 2\pi \int_0^{2.482} x\phi(x)\, dx = 2.3914 \tag{31}$$

$$\text{and } A = \pi\ (2.482)^2 = 19.353$$

it follows that

$$\phi(x) = 0.1236$$

$$e^{-x^2/2} = 0.1236\sqrt{2\pi} = 0.3098$$

$$x_{\overline{C}} = 1.531$$

and that

$$R_{\overline{C}} = \frac{x_{\overline{C}}}{x} R = \frac{1.531}{2.482} R = 0.617 R \tag{32}$$

where R is the radius of the pool. Relative to the average concentration, the concentration at the center of the pool is

$$C_o = \overline{C} \frac{0.3989}{0.1236} = 3.23 \overline{C} \tag{33}$$

and the concentration at R is

$$C_R = \overline{C} \frac{e^{-4}}{0.1236} = 0.148 \overline{C} \tag{34}$$

4. RADIATION EXPOSURES

For a sea contaminated by one or more nuclear bursts, the radiation exposures of interest are: 1) external exposures above the sea surface, 2) external exposures on the sea surface, 3) external exposures under the sea surface, and 4) internal organ exposures from the ingestion of radioactively contaminated fish.

For an object immersed in an infinite homogeneous source, e.g., a contaminated sea, the immersion dose is approximated by: (Reference 8)

$$R = k\ C\ E\ e^{-\mu t}\ \left(1 + \frac{\sigma_s}{\sigma_a + \sigma_s}\ \mu t\right) \tag{35}$$

where k is the dose conversion factor,

C is the activity concentration,

E is the energy released per disintegration,

μ is the linear attenuation coefficient of the shielding material,

t is the thickness of the shield,

σ_s is the scattering coefficient, and

σ_a is the absorption coefficient.

Without shielding (t = 0), and the use of familiar units, then the dose rate at an immersed point is

$$R\ \left(\frac{rad}{hr}\right) = 2.13\ C\ \left(\frac{Ci}{m^3}\right)\ E\ \left(\frac{MeV}{disint}\right) \tag{36}$$

The dose rate on the surface is

$$R\ \left(\frac{rad}{hr}\right) = 1.06\ C\ \left(\frac{Ci}{m^3}\right)\ E\ \left(\frac{MeV}{disint}\right) \tag{37}$$

The dose rate above the surface can be approximated by

$$R\ \left(\frac{rad}{hr}\right) = 1.06\ C\ \left(\frac{Ci}{m^3}\right)\ E\ \left(\frac{MeV}{disint}\right)\ \pi \ell n\ \left(1 + \frac{r^2}{h^2}\right)\ e^{-\mu_a h} \tag{38}$$

where C is the activity concentration directly below the measurement point,

r is the radius of the contaminated surface pool,

μ_a is the linear attenuation coefficient for air, and

h is the height above the water surface.

Equation provides a reasonable approximation of the exposure dose rate above a contaminated surface pool if a limit of about 100 is placed on r/h, that is, for all cases where r/h is greater than 100, a value of 10,000 should be used for r^2/h^2.

The energy per disintegration of fission products varies over a wide range and the composition of the fission products changes with time. Instead of performing separate calculations for each fission product, E = 1.0 MeV and E = 0.7 MeV per disintegration are estimated to be applicable for early and late times after burst, respectively.

Internal organ exposures from consuming fish are estimated by calculating radioactivity concentrations in fish flesh, multiplying by the fish consumption rate, and converting the radioactivity consumption rate to exposure doses for various internal organs. The fish flesh activity concentration is estimated by: (Reference 9)

$$D_{if} = a_{wu}(i)\, C_{iw} \qquad (39)$$

where a_{wu} is the ratio of the radioactivity in fish flesh to the radioactivity in the water, and

C_{iw} is the concentration of radioactivity (radionuclide i) in the water.

For seawater, the following a_{wu} values were tentatively selected for estimating the Sr-90 and Cs-137 in food fish. (Reference 9)

	a_{wu} (activity/gm fish / activity/ml water)	
Species	Cs-137	Sr-90
Fish, carnivorous	0.5	0.3
Fish, herbivorous	2	4
Shrimp	2	5
Oyster	2	5

The dose received by an individual consuming the radioactively contaminated fish is estimated by:

$$D_{ik} = C_{if}\, m_f\, (DC)_{ik} \qquad (40)$$

where m_f is the mass of fish consumed, and

$(DC)_{ik}$ is the dose conversion factor for radionuclide i and organ k.

Also, the estimated average fish consumption rate in the U.S. is 26 grams per person day and the maximum diet is 200 grams per person day. The maximum dose conversion factors listed in Reference 10 for the ingestion of Sr-90 and Cs-137 are as follows:

	$(DC)_i$ (rem/Ci ingested)	
Organ	Cs-137	Sr-90
Whole body	5.5×10^4	8.4×10^4
Marrow	5.6×10^4	2.9×10^5
Bone	5.6×10^4	1.1×10^6
Thyroid	5.6×10^4	3.3×10^3
Lung	5.6×10^4	3.7×10^3
Lower large intestine	6.6×10^4	8.1×10^4

5. EXAMPLE CALCULATIONS

The previous section provides the procedures for assessing ocean contamination and the radiation exposure dose that would result from nuclear bursts at sea. To provide a perspective of the radioactive concentrations and radiation exposures that could occur, it is necessary to perform example calculations. Using the Equations (1 through 40) and the inputs presented in the previous sections, the pertinent results are presented here.

Critical heights and depths of burst

	Yield (KT)			
	1	10	100	1000
Minimum height for no local fallout (ft)	180	450	1140	2850
Depth for no world-wide fallout (ft)	240	430	760	1350
Minimum depth for no fallout (ft)	1650	2930	5220	9280

Contaminated pool dimensions for deep underwater bursts:

Given:
1) Scaled depth of burst = 13
2) Thermocline depth = 300 ft
3) Ocean bottom = 10,000 ft
4) Weapon yields are 1 KT, 10 KT, 100 KT, and 1 MT
5) Fission fraction = 1.0

Surface and deep pool radii and depths for 1 KT

Time After Burst (hr)	R_s (ft)	Z_s (ft)	R_d (ft)	Z_d (ft)
1	2,600	56	330	1,800
10	4,200	150	2,000	1,800
100	20,000	300	18,100	1,800
1000	182,000	300	180,000	1,800

Surface and deep pool radii and depths for 10 KT

Time After Burst (hr)	R_s (ft)	Z_s (ft)	R_d (ft)	Z_d (ft)
1	4,500	97	400	3,200
10	6,200	190	2,000	3,200
100	22,000	300	18,200	3,200
1000	184,000	300	180,000	3,200

Surface and deep pool radii and depths for 100 KT

Time After Burst (hr)	R_s (ft)	Z_s (ft)	R_d (ft)	Z_d (ft)
1	8,000	170	580	5,600
10	9,700	260	2,200	5,600
100	26,000	300	18,200	5,600
1000	188,000	300	180,000	5,600

Surface and deep pool radii and depths for 1 MT

Time After Burst (hr)	R_s (ft)	Z_s (ft)	R_d (ft)	Z_d (ft)
1	14,000	300	1,050	10,000
10	16,000	300	2,700	10,000
100	32,000	300	19,000	10,000
1000	194,000	300	181,000	10,000

Average radioactivity concentrations and immersion dose rates for 1 KT

Time After Burst	Surface Stratum		Deep Stratum	
(hr)	(Ci/m^3)	(r/hr)	(Ci/m^3)	(r/hr)
1	1.05	2.16	24	49.6
10	9.43×10^{-3}	1.95×10^{-2}	4.11×10^{-2}	8.52×10^{-2}
100	1.31×10^{-5}	2.72×10^{-5}	3.17×10^{-5}	6.56×10^{-5}
1000	1.0×10^{-8}	7.0×10^{-9}	2.02×10^{-8}	2.93×10^{-8}

Average radioactivity concentration and immersion dose rates for 10 KT

Time After Burst	Surface Stratum		Deep Stratum	
(hr)	(Ci/m^3)	(r/hr)	(Ci/m^3)	(r/hr)
1	2.01	4.17	88.9	184
10	3.4×10^{-2}	7.08×10^{-2}	0.224	0.464
100	1.08×10^{-4}	2.25×10^{-4}	1.7×10^{-4}	3.54×10^{-4}
1000	9.78×10^{-8}	1.42×10^{-7}	1.10×10^{-7}	1.59×10^{-7}

Average radioactivity concentrations and immersion dose rates for 100 KT

Time After Burst	Surface Stratum		Deep Stratum	
(hr)	(Ci/m^3)	(r/hr)	(Ci/m^3)	(r/hr)
1	3.64	7.53	242	500
10	0.102	0.211	1.06	2.19
100	7.77×10^{-4}	1.61×10^{-3}	9.77×10^{-4}	2.02×10^{-3}
1000	9.37×10^{-7}	1.36×10^{-6}	6.3×10^{-7}	9.13×10^{-7}

Average radioactivity concentrations and immersion dose rates for 1 MT

Time After Burst	Surface Stratum		Deep Stratum	
(hr)	(Ci/m^3)	(r/hr)	(Ci/m^3)	(r/hr)
1	6.73	13.9	413	854
10	0.325	0.673	3.94	8.15
100	5.13×10^{-3}	1.06×10^{-2}	5.02×10^{-3}	1.04×10^{-2}
1000	8.80×10^{-6}	1.28×10^{-5}	3.49×10^{-6}	5.06×10^{-6}

Dose to fish consumers for 1 MT case

		D_{ik}(rem/day)			
Time After Burst	Sr-90	a_{wu} = 5; 26g/day		a_{wu} = 5; 200g/day	
(hr)	(Ci/m^3)	Whole Body	Bone	Whole Body	Bone
1	7.88×10^{-5}	1.02×10^{-3}	1.02×10^{-2}	7.88×10^{-3}	7.88×10^{-2}
10	1.19×10^{-5}	1.55×10^{-4}	1.55×10^{-3}	1.19×10^{-4}	1.10×10^{-3}
100	2.41×10^{-7}	3.13×10^{-6}	3.13×10^{-5}	2.41×10^{-5}	2.41×10^{-4}
1000	2.65×10^{-9}	3.45×10^{-8}	3.45×10^{-7}	2.65×10^{-7}	2.65×10^{-6}

Time After Burst	Cs-137	Whole Body Dose (rem/day)	
(hr)	(Ci/m^3)	a_{wu} = 2; 26g/day	a_{wu} = 2; 200g/day
1	1.49×10^{-4}	4.35×10^{-4}	3.34×10^{-3}
10	2.26×10^{-5}	6.57×10^{-5}	5.06×10^{-4}
100	4.56×10^{-7}	1.32×10^{-6}	1.02×10^{-5}
1000	5.02×10^{-9}	1.46×10^{-8}	1.13×10^{-7}

Contaminated pool dimensions for shallow underwater bursts

Given: 1) Scaled depth of burst = 1
2) Thermocline depth = 300 ft
3) Weapon yields are 1 KT, 10 KT, 100 KT, and 1 MT
4) Fission fraction = 1.0
5) Since $\tilde{D} = 1$, $f_s = 0.55$

W = 1 KT

Time After Burst (hr)	R_s (ft)	Z_s (ft)	V (m^3)	C (Ci/m^3)
1	4,845	103	2.151×10^8	1.125
10	6,465	198	7.362×10^8	2.074×10^{-2}
100	22,665	300	1.371×10^{10}	7.027×10^{-5}
1000	184,665	300	9.101×10^{11}	6.679×10^{-8}

W = 10 KT

1	8,581	182	1.192×10^9	2.030
10	10,201	272	2.518×10^9	6.064×10^{-2}
100	26,401	300	1.860×10^{10}	5.18×10^{-4}
1000	188,401	300	9.473×10^{11}	6.417×10^{-7}

W = 100 KT

1	15,234	300	6.194×10^9	3.907
10	16,844	300	7.572×10^9	0.2017
100	33,044	300	2.914×10^{10}	3.306×10^{-3}
1000	195,044	300	1.015×10^{12}	5.989×10^{-6}

W = 1000 KT

1	27,037	300	1.951×10^{10}	12.40
10	28,657	300	2.192×10^{10}	0.6966
100	44,857	300	5.370×10^{10}	1.794×10^{-2}
1000	206,857	300	1.142×10^{12}	5.323×10^{-5}

6. DISCUSSION OF RESULTS

The results obtained from the example calculations show that the size of the surface pool of radioactively contaminated water ranges from about 1 to 2 miles in diameter at 1 hour after burst for a 1 KT burst to 6 to 10 miles in diameter at 1 hour after burst for a 1 MT burst. The growth of the contaminated pool diameter is then about 360 feet per hour. For bursts deep enough to produce a deep pool in addition to a surface pool, the deep pool diameter could be considerably smaller (depending on the depth of burst) than the surface pool diameter but because their growth rates are similar, their diameters become similar at later times.

The radioactive concentrations in the deep pool at early times are sufficiently high that a relatively short exposure period would provide a lethal exposure dose. The radioactive concentrations in the surface pool of contaminated water are sufficiently high at early times to give significant exposure doses to people in the water, on the surface of the water, and above the water surface. However, because of radioactive decay and diffusive expansion, the radioactivity is reduced to negligible hazard levels about one to two days after burst. The consumption of fish living within the contaminated water also would not result in hazardous exposure doses.

The contamination of the sea from underwater nuclear bursts, however, could be significant with respect to increasing its current background radioactivity. Although the radial diffusion expansion rate of the contaminated water is relatively slow (180 ft/hr), pool elongation could proceed much faster. For example, the North Atlantic current typically has speeds on the order of about 1 knot. Thus, an underwater nuclear burst in the western part of the North Atlantic would produce a contaminated patch about 70 miles wide by 1000 miles long at 1000 hours after burst. For a 1 MT burst at a depth of 9300 feet, the activity in the surface layer would be about twice the present radioactivity level which consists mostly of K-40. Thus many nuclear bursts are required to contaminate a significant part of an ocean and to increase the background radioactivity to much higher levels.

The presence of large volumes of sea water that is lightly contaminated with radioactivity within the confines of an ocean, e.g., the Atlantic Ocean,

will be of negligible biological significance. Within a smaller and shallower body of water, e.g., the North Sea or, the Baltic Sea, diffusive expansion is more limited. Thus the nuclear injections required to double the background radioactivity in these waters at 1000 hours after burst are about 1.5 MT and 600 KT respectively for the North Sea and the Baltic Sea. The Mediterranean Sea has a much greater volume and an injection of over 100 MT of fission debris would be required to double the background radioactivity at 1000 hours after burst. Much higher injections of fission debris are required to cause the radioactivity concentrations to become biologically significant.

Raising the radioactivity concentration in the seas or in large patches of water in the oceans, however, could degrade existing or potential capabilities to detect or locate other radioactive sources in the sea. For example, it may diminish or negate a developed capability to track the radioactive wake of a nuclear vessel. At early times, e.g., within a few days after a nuclear burst, the radioactivity concentrations of fission products and induced Na-24 in the contaminated volume would be several orders of magnitude greater than that left in the wake of a nuclear submarine.

Because the estimated dose rates in the water, on the surface of the water and above the water surface, at radial distances beyond severe vessel damage at early times are in the critical range, i.e., sufficient to cause radiation sickness or fatalities, the development of refinements to the calculative process is warranted. Specifically, the development of refinements on the partitioning and distribution of radioactive materials for nuclear bursts in the surface zone, i.e., from low air bursts over water to shallow depth bursts in water, is recommended. At later times the radioactivity concentrations are diminished so that they do not represent a hazard, however, the concentrations are sufficient to significantly increase background levels. Studies of the effects of these concentrations on potential submarine detection capabilities also appear to be warranted.

REFERENCES

1. Glasstone, S., and Dolan, P. J., "The Effects of Nuclear Weapons," U.S. Department of Defense and U.S. Department of Energy, U.S. Government Printing Office, 1977.

2. Crocker, G. R., and Turner, T., "Calculated Activities, Exposure Rates, and Gamma Spectra for Unfractionated Fission Products," USNRDL-TR-1009, Contract AT(49-7)-1963, Mod. 5, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 28 December 1965.

3. Huebsch, I. O., "Fallout Predictions for Water-Surface Nuclear Bursts," USNRDL-TR-67-147, Contract NWER A7, Subtask 10.007, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 28 November 1967.

4. "Report of the United Nations Scientific Committee on the Effects of Atomic Radiation," General Assembly, Official Records: 17th Session, Supplement No. 16 (A/5216), United Nations, New York, 1962.

5. Ksanda, C. F., "Analysis and Prediction of the Properties of Diffusing Radioactive Pools from Nuclear Explosions in the Ocean," U.S. Naval Radiological Defense Laboratory, San Francisco, California, 19 December 1963. Unpublished.

6. Rinnert, H. R., "Exposure Rate History and Total Exposure for a Surface or Subsurface Traversal of a Radioactive Pool," USNRDL-TR-67-51, U.S. Naval Radiological Defense Laboratory, San Francisco, California, 12 May 1967.

7. Levine, D., Nuclear Explosion at Sea, A State of the Art Study of Selected Nuclear Weapons Effects, Naval Ordnance Laboratory, White Oak, Silver Springs, January 1972. Unpublished.

8. Evans, R. D., "The Atomic Nucleus," McGraw-Hill Book Company, New York, New York, 28 May 1972.

9. Miller, C. F., and P. D. LaRiviere, "Introduction to Long-Term Biological Effects of Nuclear War," Contract No. N228-(62479)69928, SRI, Menlo Park, California, April 1966.

10. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Appendix VI, Calculation of Reactor Accident Consequences, WASH-1400 (NUREG 75/014), Nuclear Regulatory Commission, October 1975.

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