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Biology and Medicine

AMCHITKA BIOENVIRONMENTAL PROGRAM

BIOENVIRONMENTAL SAFETY STUDIES, AMCHITKA ISLAND, ALASKA CANNIKIN D+2 MONTHS REPORT

Compiled

by

James B. Kirkwood and R. Glen Fuller

June, 1972

Prepared for the U. S. Atomic Energy Commission
under Contract No. AT(26-1)-171

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PREFACE

This report summarizes information submitted by all investigators participating in the Amchitka Bioenvironmental Program, primarily during the period up to 2 months following the Cannikin detonation. Since technical reviews and editing have required considerable time, some additional information obtained more recently has been incorporated to enhance the value of the report. The contributions of all program personnel are gratefully acknowledged.

FOREWORD

Project Cannikin, the underground nuclear test conducted in the fall of 1971, at Amchitka Island, Alaska, was originally expected to take place in September or early October, 1971. Many of the pretest background data were collected when it was believed the original plan could be adhered to. However, the test was unavoidably delayed until November, a delay that had some disappointing consequences for the success of the field studies designed to identify and document the prompt bioenvironmental effects of the detonation.

November 6, 1971, the day on which the test was conducted, was preceded by several days of bad weather that hampered late pretest data collection, observations, and preparations for testtime experiments. On November 5, when the preparations for live-box experiments with selected test animals were to have been completed, Amchitka was swept by a violent storm that produced hurricane-force winds, rain, and fog. Precipitation totalled 0.47 inch, and wind gusts exceeded 80 knots (over 90 mph). Wind damage was extensive. While the weather had improved somewhat by the next day, with clearing skies and increased visibility, the storm on the day before the test forced the abandonment of all planned experiments with captive fish in live boxes in the marine environment. The storm also interfered to a lesser extent with the live-box experiments in freshwater lakes and streams. Also, because the shallow lakes on Amchitka are subject to stirring and mixing of bottom sediments by wind, the effects of Cannikin on turbidity, and suspended and dissolved organic matter in the lakes were difficult to distinguish from the effects of the November 5 storm winds. Intermittent bad weather, with poor visibility, heavy seas, and moderately strong winds continuing after the Cannikin detonation, seriously hampered efforts of field parties documenting the bioenvironmental effects of the test.

The delay of Cannikin until November meant that some of the pretest data collected in anticipation of the earlier event date were less useful for comparison with post-Cannikin data. In view of this, and because of the unfavorable weather that prevailed before, during, and after the test, the present report cannot give as precise and well-documented an assessment of the prompt bioenvironmental consequences of Cannikin as its authors and contributors would like to have submitted. Despite these adversities, a large amount of useful information was collected, certainly enough to enable an evaluation of the early bioenvironmental effects of Cannikin. Certain effects, such as those related to changes in surface drainage, cannot be fully assessed yet, and are the subject of continuing study.

All of the principal investigators involved in the Cannikin phase of the Amchitka Bioenvironmental Program (Appendix F) submitted input data and analyses for this D+2 months report. These contributions varied considerably in format, in amount of factual detail provided, and in the degree of extrapolation made from the data presented. The compilers of this report have undertaken the task of integrating the reports from the various contributors into a single, unified report of Cannikin bioenvironmental effects. To the best of their ability, they have presented the significant data and observations provided by all investigators. They have, however, exercised their judgment in determining the extent to which the data justify extrapolation regarding the long-term effects of the Cannikin test on Amchitka ecosystems. In general, they have followed a policy of caution, avoiding speculative judgments and projections. For adopting this policy, they accept full responsibility.

J.B.K/R.G.F.
Columbus, Ohio
June, 1972

ABBREVIATIONS USED IN THE TEXT

ADF&G	Alaska Department of Fish and Game
AEC	United States Atomic Energy Commission
AEC-NVOO	AEC's Nevada Operations Office, Las Vegas, Nevada
AHRC	Arctic Health Research Center, U. S. Public Health Service Fairbanks, Alaska
ASU	Air sampling units
BCL	Battelle's Columbus Laboratories, Columbus, Ohio
BYU	Brigham Young University, Provo, Utah
D-1	One day before Cannikin
D-day	November 6, 1971, the day Cannikin was detonated
D+1	One day after Cannikin
EIC	Eberline Instrument Corporation, Santa Fe, New Mexico
FRI	University of Washington, Fisheries Research Institute, Seattle, Washington
FWS	United States Department of the Interior, Fish and Wildlife Service
H-hour	1100 Bering Standard Time, the time Cannikin was detonated
H+1	One hour after Cannikin
LRE	University of Washington, Laboratory of Radiation Ecology, Seattle, Washington
M/V Commander	Motor vessel Commander used for marine fishing and oceanographic data collecting
M/V Pacific Apollo	Motor vessel Pacific Apollo used for transporting the gamma probe and for other tasks not included in this report
NMFS	National Marine Fisheries Service, NOAA, U. S. Department of Commerce
OSU	The Ohio State University, Columbus, Ohio
RAMS	Remote area monitoring system used to measure gross gamma intensity
SI	Smithsonian Institution, Chesapeake Bay Center for Environmental Studies, Edgewater, Maryland
Sandia	Sandia Laboratories, Albuquerque, New Mexico
SZ	The point on the land at the top of the device-emplacement hole
TLD	Thermoluminescent dosimeter
UAz	University of Arizona, Tucson, Arizona
USGS	U. S. Geological Survey
USU	Utah State University, Logan, Utah
UT	University of Tennessee, Knoxville, Tennessee
WERL	Western Environmental Research Laboratory, Environmental Protection Agency, Las Vegas, Nevada

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CANNIKIN D+2 MONTHS REPORT

Compiled

by

James B. Kirkwood and R. Glen Fuller

June, 1972

ABSTRACT

Cannikin, an underground nuclear test of less than 5 megatons, was fired on November 6, 1971, at Amchitka Island, Alaska. Pre- and postevent studies were conducted by a number of investigators to assess the effects of Cannikin on the Amchitka ecosystems. This report gives the preliminary evaluation of those effects, based on analysis of data collected during the first 2 months after the test, supplemented in a few instances by more current information.

Individuals of several species of marine mammals, waterfowl, and marine and freshwater fish were killed by the test, but no animal population on or around the Island was jeopardized. The total numbers killed can only be estimated, and the reliability of the estimation is generally low because stormy weather around test time hampered observation and recovery of casualties, especially in the marine environment.

During posttest beach searches, 18 dead sea otters, 3 injured sea otters, 2 abandoned sea otter pups, and 4 dead harbor seals were found. This very probably represents only a fraction of the total number of sea otters and seals killed, but data for reliable estimations of total losses are not available.

Individuals representing at least 5 species of marine fish were killed, and about 300 specimens were recovered. Most of these were rock greenling found on an intertidal bench uplifted as a result of ground motion from Cannikin. Judging by comparison of pre- and postevent bottom-trawl catch data, investigators estimated that thousands of rock sole, an offshore bottom fish, were probably killed.

Intertidal communities of algae, invertebrates, and fish are being affected along a 2-km section of the Bering Sea coast, where the intertidal bench was permanently uplifted by as much as 1.1 m in some places. The extent of the bioenvironmental effects attributable to this uplift cannot be determined without further investigation.

Several hundred Dolly Varden and about 10,000 threespine stickleback were killed in freshwater lakes near Cannikin surface zero. About 70 percent of these fish were killed when the lakes they inhabited were drained by tilting, or through fissures that opened in the lake bottoms.

Eighteen dead birds, representing 7 species of waterfowl, were recovered post-Cannikin. The total number of birds killed cannot be precisely estimated; comparison of population counts made before and after Cannikin showed no significant decline in density of any species of birds.

No dead bald eagles or peregrine falcons were found, but six eagle nesting sites and three peregrine eyries were destroyed or damaged. Two of the eyries were among a group of three located fairly close together and used by a single nesting pair. The effect of the loss of 2 out of 3 alternative nest sites on the nesting behavior of this pair will not be known until the 1972 nesting season. The third eyrie, damaged by Milrow, sustained further damage from Cannikin.

The effects of Cannikin on geomorphic features were considerably greater than had been predicted. Coastal rockfalls and turf slides on the Bering Sea coast adjacent to Cannikin were extensive. A minimum of some 25,000 m^3 of rock and turf were dislodged along the Bering Sea coast, a large fraction of it along a 2-km section of coastline. Much smaller amounts of rock and turf were dislodged along the Pacific Ocean coast. Inland, 6 small lakes near Cannikin surface zero were completely drained and 10 were partially drained. New lakes are forming in the sink formed when the Cannikin-cavity collapse reached the surface. Some ponding is also occurring along streams where turf slides or bank caving dammed the stream flow. Stream flow in the lower region of the stream draining the Cannikin site has been greatly reduced; runoff from the upper portion of the drainage is now being intercepted by the collapse sink.

BACKGROUND

Amchitka Island, Alaska, was the site of an underground nuclear test, Project Long Shot, conducted in October, 1965, by the U. S. Department of Defense with the Atomic Energy Commission's (AEC) assistance. The bioenvironmental effects of that test are described by Seymour and Nakatani (1967).

Since the fall of 1967, after Amchitka was again selected as a potential site for underground nuclear testing, Battelle's Columbus Laboratories (BCL) has coordinated and conducted research on the marine, freshwater, and terrestrial ecosystems of Amchitka (Figure 1). These investigations are designed to predict, evaluate, and document the effects on the biota and environment from nuclear tests, to recommend measures for minimizing adverse effects, and to predict and evaluate the potential hazards to man that might result from the accidental release of radionuclides to the environment and their subsequent transport to humans via marine food chains. The studies are being conducted by BCL, BCL's subcontractors and consultants, and other contractors of the U. S. Atomic Energy Commission's Nevada Operations Office (AEC-NVOO). All studies are sponsored by AEC-NVOO as part of its supplemental nuclear-test-site program. A list of all reports emanating from these studies to date is given in Appendix E.

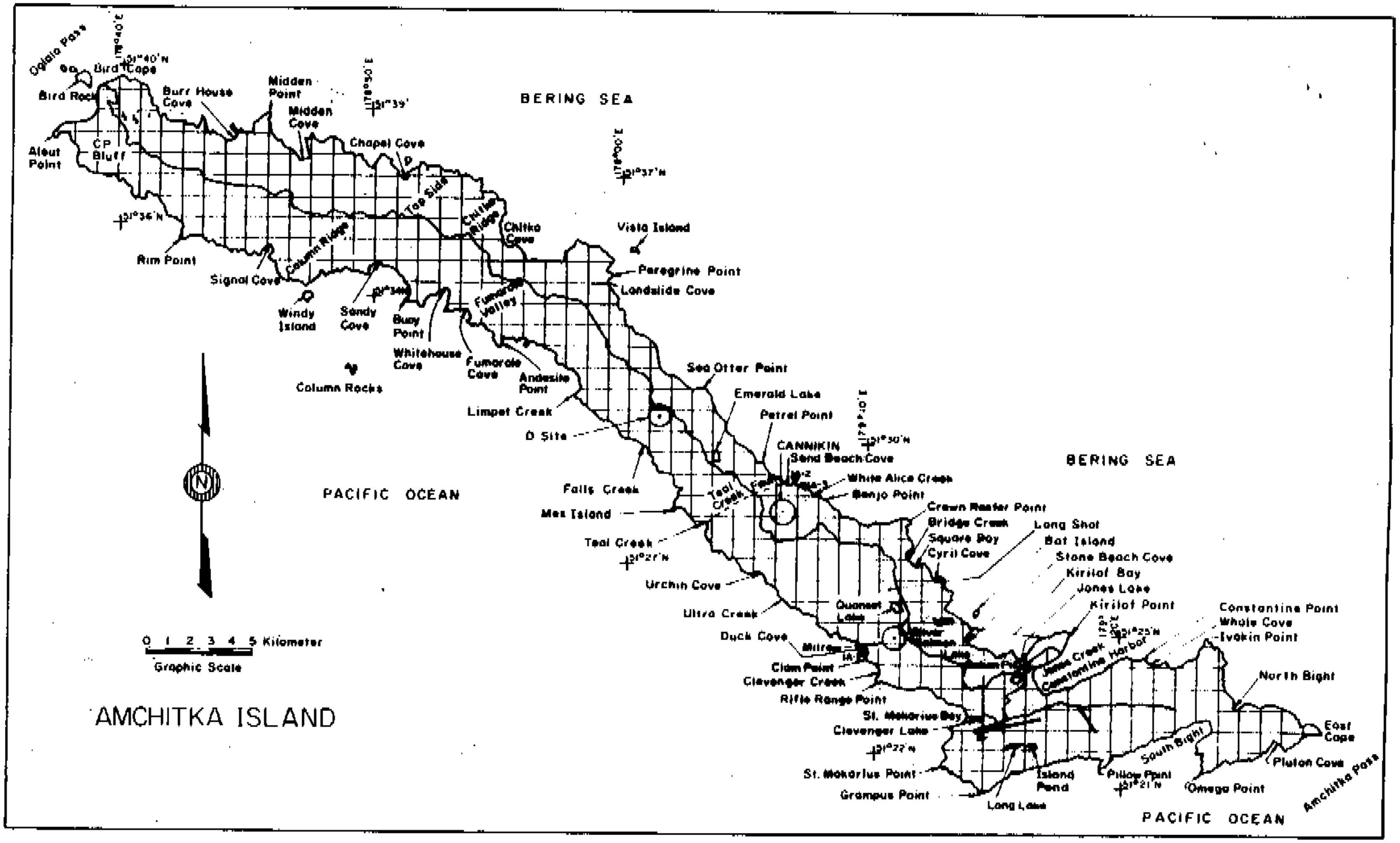

FIGURE 1. MAP OF AMCHITKA ISLAND, ALASKA, SHOWING LOCATIONS REFERRED TO IN THIS REPORT

By 1969 it had been tentatively concluded that nuclear devices of high yield (1 megaton or higher) could be detonated safely underground at Amchitka, but experimental verification of this conclusion was considered desirable. By the fall of 1969, preparations were completed for the detonation of a "calibration" nuclear test, Project Milrow, with a design yield of about 1 megaton. Preevent predictions were that an underground detonation of that magnitude, carried out during the autumn, would have only slight and transient effects on Amchitka's ecosystems. Among the objectives of Milrow was to test the reliability of these predictions, and to provide baseline information from which the effects of a somewhat higher yield shot at this site could be predicted.

Extensive observations, experiments, and measurements were carried out in conjunction with Milrow. Late pre-and early posttest visual surveys, sample collections, and photography were used to identify and document effects of the calibration shot on the terrain and the biota. Sea otters, fish, and marine invertebrates were held in pens or live boxes at various distances from SZ* to determine their response to ground shock and the associated pressure pulses in the freshwater and marine environments; these shock forces and water-pressure pulses were also recorded at a number of stations, some of which were located near the pens and boxes in which animals were held.

Milrow was detonated at 12:06 p.m. Bering Daylight Time, October 2, 1969. The ground-shock and water-pressure pulses generated by Milrow were reported by Merritt (1971), and the early bioenvironmental effects detected within the first few weeks following the test were reported by Kirkwood (1970) and Merritt (1970). The effects noted were

- A few fish in the nearshore marine environment may have been injured or killed, but no dead fish were recovered in postevent searches.
- Rock and soil slides that occurred in a few coastal areas near SZ smothered some animals and plants in the intertidal and subtidal zones.
- Two freshwater lakes near SZ were partially drained; these lakes were not of major importance for fish or as bird-nesting areas.
- One freshwater lake about 3.5 km from SZ suffered a decrease in zooplankton.
- Numerous threespine sticklebacks were killed in two small lakes near SZ. This fish is an important link in the food chain of Dolly Varden and some bird species. (Natural reproduction of sticklebacks occurred in these lakes during the season following Milrow, and populations are expected to return to normal in 1-3 years.)
- Approximately 2900 and 7600 m^3 of rock and peat materials fell along the Pacific Ocean and Bering Sea coasts, respectively. (This disturbance of the coastal cliff habitat did not appreciably affect the nesting of bald eagles, peregrine falcons, or other cliff-nesting birds in subsequent seasons.)

* Surface zero; the point on the land surface at the top of the device-emplacement hole.

As predicted, the immediate effects of Milrow on the bioenvironment were slight. Almost all of the animals held in live boxes survived the detonation, and data were collected on the ground-shock forces and pressure pulses to which these test animals had been exposed. Subsequent investigations have largely confirmed the early conclusions regarding the effects of Milrow, but one additional bioenvironmental disturbance was later detected. In April, 1970, beach reconnaissance during a period of daytime low tides disclosed evidence of a recent uplift of ~12 cm in a section of the intertidal rock bench, about 1400-m from Milrow SZ, on the Pacific Ocean shore. This vertical displacement is thought to have been due to Milrow (on the basis of indirect evidence). The shift, although slight in the vertical dimension, produced detectable changes in the species composition of algal and invertebrate communities over an estimated several thousand square meters of intertidal bench. These changes are still under investigation. The intertidal area affected is a very small portion of the total amount of intertidal-bench habitat along the Island.

PREDICTIONS OF CANNIKIN BIOENVIRONMENTAL EFFECTS

Following Milrow, plans were initiated for a larger-yield underground nuclear test on Amchitka. This test, Cannikin, was tentatively scheduled for the fall of 1971, at a site about 8 km NW of the Milrow site. The Cannikin device was designed for a yield of less than 5 megatons (AEC Environmental Statement, Cannikin, 1971). The exact design yield is classified information and cannot be reported here. The focus of the Amchitka bioenvironmental studies was shifted to the locale of the proposed Cannikin test, and background data on which to base effects predictions, and document the ecological effects of Cannikin, were collected and analyzed.

Predictions of the probable effects of Cannikin on Amchitka ecosystems were reported in an Environmental Statement (AEC, 1971). These predictions were updated, on the basis of contributions from all investigators participating in the Amchitka Bioenvironmental Program, and presented by Kirkwood and Fuller (1971); a summary of the updated predictions is given in the abstract of that report.

> "The effects of Cannikin on the environment and biota in the terrestrial, freshwater, and marine ecosystems of Amchitka are predicted to be of somewhat greater magnitude than the effects of Milrow. However, no plant or animal population is expected to be endangered. These predictions are based on the assumption that the Cannikin detonation will occur in the autumn, and that predictions of ground shock and underwater pressure changes supplied by AEC-NVOO are essentially correct.

Cannikin is expected to affect terrestrial habitats over a larger area than Milrow did; small rock falls and turf slides are predicted along several miles of coastline. However, the total amount of material involved is not considered likely to be of ecological consequence, since no single large falls are predicted.

Bald eagle nesting sites and peregrine falcon eyries occupied in 1971 are not likely to be destroyed, although one or two eagle nesting sites and one falcon nesting site may be rendered unusable. Population densities, distributions, and reproductive potentials of these species are not expected to be significantly affected. Other avian populations should not be threatened.

Some fraction of the fish in freshwater streams and lakes near Cannikin surface zero may be killed, but otherwise effects in the freshwater ecosystem will be minor.

Combining the relevant estimates yields a prediction that perhaps 20 to 240 sea otters might be exposed to overpressures severe enough to rupture their eardrums and ultimately result in their death, but past observations on the effects of harvest and transplant removals from the populations suggest a loss of this magnitude would have no long-range effect on population. Populations of other marine mammals (Steller's sea lions and harbor seals) will also be unaffected.

Fish populations in the marine environment will not be endangered, although sizable numbers of individuals of Pacific cod and some rockfish species may be killed if the 'worst credible' predictions prove correct. Small intertidal bench areas may be disrupted, but succession and recolonization will be expected to restore the biota of such areas, and effects on food webs in the marine environment will be minimal. No adverse effects of ecological consequence are expected in the marine ecosystem around Amchitka."

Information furnished by AEC-NVOO indicated that the Cannikin test was designed for complete containment of radioactivity underground (U. S. Atomic Energy Commission, 1971). It was therefore anticipated that the bioenvironmental effects of Cannikin would be confined to those associated with ground motion and pressure pulses in water.

EARLY BIOENVIRONMENTAL EFFECTS OF CANNIKIN

Cannikin was detonated at 11:00 a.m. Bering Standard Time, November 6, 1971, about a month later than had been anticipated previously. This report gives the results, through January 6, 1972, of the Cannikin-related bioenvironmental studies and analyses designed to identify and evaluate the immediate effects of Cannikin on Amchitka ecosystems. Pretest baseline data were collected in terrestrial, freshwater, and marine ecosystems in the vicinity of Cannikin SZ. Live-box testtime experiments were readied for the test. Comparable bioenvironmental data were collected posttest, and fishes exposed in the testtime experiments were examined. Ground-motion and underwater pressure pulses were recorded at a number of stations by Sandia Laboratories (Appendix A) to provide data for interpreting effects observed on experimental animals and on free-living biotic populations. Terrain features within the area expected to be affected by the Cannikin detonation were photographed before and after the test, using large-format photography and various film types (Appendix D).

This report contains data collected and interpretations made by the many investigators who participated in the Amchitka Bioenvironmental Program (Appendix F), as compiled by the authors.

The emphasis of this report is focused on effects observed or measured during the early postevent period, but the potential long-term significance of these effects is discussed where practicable. In some instances, however, such a projection would necessarily be so speculative as to be unjustified. Posttest studies are continuing in order to document and quantify any long-term effects of Cannikin on the Island's ecosystems; results of these studies will be covered in subsequent reports.

This report addresses only the question of effects attributable to the detonation of the Cannikin device. Bioenvironmental disturbances resulting from construction, site preparation, drilling, and related AEC activities on Amchitka are beyond the scope of the report, and will be dealt with as appropriate in other reports. (An example of such nonnuclear disturbance can be seen in Plate 1, an aerial photograph of Cannikin SZ taken before the detonation. Some 11 hectares (28 acres) of tundra vegetation have been destroyed at the drill site proper; this does not include access roads, cable runs, etc., which also appear in the photo*.)

This D+2 months report differs from the Project Cannikin D+30 Day Report (U. S. Atomic Energy Commission, 1972) in a few particulars because it includes additional data and analyses that have become available since that report was released.

Marine Ecosystems

Pre-Cannikin predictions were that detonation-generated ground-motion and pressure pulses in the ocean might kill or injure substantial numbers of marine mammals and fish in waters around Amchitka. A major portion of the Cannikin test-related studies was therefore focused on documenting effects of the test in the marine environment. The following activities provided information for assessing prompt effects of Cannikin on marine mammals and other marine biota, and on nearshore physical features of the marine environment:

*Area measured on BCL vertical photography.

- Late pretest (D-2 and D-1*) searches for dead animals were conducted on all beaches within about 7 km of SZ.

- Starting late in the afternoon of D-day (as soon as reentry parties could reach the area), and continuing for several days thereafter, the Bering Sea and Pacific Ocean beaches adjacent to Cannikin SZ were searched for dead or injured animals; whenever possible, such animals were recovered by the searchers and brought to the biological laboratories for examination.

  During the beach searches obvious physical changes in the coastal area affecting marine biota were also noted. The searches were conducted by personnel representing the Alaska Department of Fish and Game (ADF&G), the AEC-NVOO Office of Effects Evaluation, BCL, the U. S. Department of the Interior's Fish and Wildlife Service (FWS), the U. S. Department of Commerce's National Marine Fisheries Service (NMFS), the University of Arizona (UAz), the University of Washington's Fisheries Research Institute (FRI), and the University of Washington's Laboratory of Radiation Ecology (LRE). (Numerous helicopter overflights were also made along the coast during the early posttest period to assist in the search for and recovery of any dead or injured marine animals in this area.)

- Late pretest and early posttest visual counts of sea otters in the Bering Sea and Pacific Ocean adjacent to Cannikin SZ were made from a helicopter by personnel of BCL and FWS.

  Postevent visual counts of sea otters along the adjacent Bering Sea coast were also made by a UAz investigator from shore observation stations. ADF&G personnel also counted sea otters from a helicopter along the Bering Sea coast adjacent to Cannikin SZ on D+11 through D+13.

- Autopsies of mammals, birds, and fish collected immediately after Cannikin were made by a veterinarian from the Arctic Health Research Center, U. S. Public Health Service (AHRC). One otter collected on D+16 was autopsied by a UAz biologist.

- Pre- and posttest sampling of offshore marine fish populations with bottom and midwater trawls and salmon longline was carried out from the M/V Commander by FRI.

- Pre- and posttest fish populations in nearshore waters were sampled with trammel nets by FRI. Pre- and posttest visual observations were also made by FRI biologists along marked transects established in the intertidal-bench area of the Bering Sea coast. Subtidal bottom transects were sampled pre- and postevent by biologist/divers of NMFS to ascertain the effect of the test on green sea urchin (*Strongylocentrotus polyacanthus*) populations (sea urchins are one item in the sea otter diet).

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*D-day, the day when the device was detonated; D-1, one day before the device was detonated; D+1, one day after the device was detonated.

- Physical changes on the beach and in the nearshore waters (rock and tundra falls, turbidity near shore, etc.) were recorded on aerial photographs by BCL and were observed by FRI biologists and others. NMFS divers, searching for evidence of physical disturbance on the sea bottom, made a brief reconnaissance in two shallow subtidal areas in the Bering Sea off Cannikin SZ. Changes in the elevation of the intertidal bench were measured at a few locations by Holmes & Narver, Inc., surveyors, although completion of the surveys will not be possible until daytime low tides occur in spring 1972.

Marine Mammals

Marine mammal investigations at Amchitka were carried out by personnel of UAz, ADF&G, BCL, and FWS; many other bioenvironmental program personnel also assisted in testtime searches and observations. The objectives of the Cannikin-related marine mammal studies were: (1) to determine changes in Amchitka marine mammal populations attributable to Cannikin; (2) to locate and recover marine mammals injured or killed by the test; and (3) to determine the cause of injury or death for animals recovered. Marine mammal studies were directed primarily, but not exclusively, to effects on the sea otter (Enhydra lutris).

Before Cannikin it was predicted that perhaps 20 to 240 sea otters might be killed or fatally injured by underwater pressure pulses from the shot (Kirkwood and Fuller, 1971). For reasons given in that report, it was postulated that otters experiencing underwater overpressures of 100 psi* or more might be fatally injured. Isobars enclosing the areas where such overpressures were expected, at the ocean floor, were plotted for the Bering Sea and Pacific Ocean waters off Cannikin SZ** (Figure 2), and these areas were taken into account in planning sea otter studies, and in predicting potential otter casualties. The wide range in number of casualties predicted indicates that many factors involved in the prediction were not precisely known: e.g., the absolute number of otters within the postulated area of hazard; their daily behavioral patterns of diving, resting, hauling out, etc.; and the influence of weather, sea state, and season on behavior.

Pre-Cannikin studies included visual counts from shore stations and from helicopter overflights. Beach transects were surveyed monthly during the year prior to Cannikin to determine the pattern of natural mortality of sea otters and other marine mammals. Figure 2 shows the preevent transects. Post-Cannikin investigations involved counts from shore and helicopter, beach searches, and autopsies of dead or wounded animals recovered. Figure 3 shows the beaches surveyed intensively post-Cannikin. The areas searched post-Cannikin do not coincide exactly with the pre-Cannikin beach transects because of shottime weather conditions. The strong northwesterly winds that prevailed after Cannikin (Appendix B) caused animals affected by the shot to drift southeastward; thus, searches were focused in that direction. The distribution of the animals found, as shown in Figure 3 (particularly on the Pacific Ocean coast), demonstrates the effect of the winds on the distribution of casualties.

*Instruments used are marked for psi; metric equivalent 6.89×10^3 N/m^2.

**M. L. Merritt, personal communication, 1970.

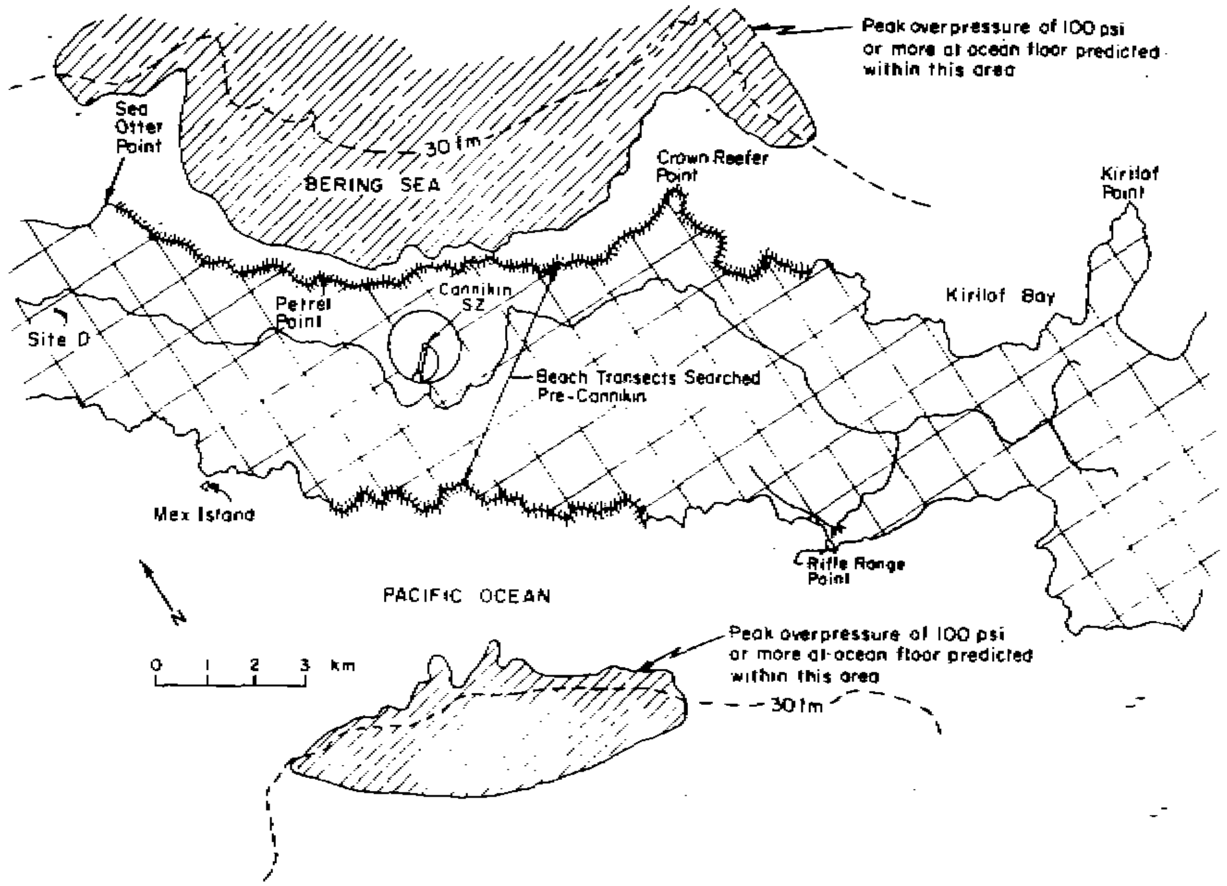


FIGURE 2. BEACH TRANSECTS SEARCHED PRE-CANNIKIN TO ESTABLISH NATURAL MORTALITY OF SEA OTTERS AT AMCHITKA

The results of the pre-Cannikin beach surveys and the post-Cannikin searches are combined in Figure 4. The post-Cannikin searches were more intensive, and the areas searched were greater than those covered during other months of the year. However, Figure 4 shows that a relatively large number of sea otter mortalities occurred at a time when natural mortality in the area was probably at a low level; the autopsies performed on animals recovered, discussed below, support the conclusion that most of the animals found dead or injured shortly after the test were in fact casualties of Cannikin.

Table 1 lists the dead or fatally injured sea otters, and abandoned otter pups, found during the post-Cannikin beach searches. Cause of death is given when possible. Autopsies show that 8 of the 13 autopsied were killed by pressure effects in water, 2 were crushed by rock falls, and 3 were killed by vertical acceleration (upthrust of the ground). Other otters recovered were so badly deteriorated, either through putrefaction or scavenging, that autopsies could not be made to determine cause of death. However, skulls of the sea otter skeletons found on D+20 showed fractures of the orbital part of the frontal bone, believed to be evidence of pressure pulse damage, so it was assumed that these animals were killed by pressure effects from Cannikin.

Animals killed by pressure pulse exhibited bleeding from the mouth and nose, and sometimes from the ears. The lungs and associated tissues were severely

TABLE 1. SUMMARY OF OBSERVATIONS ON 23 SEA OTTERS BELIEVED TO HAVE BEEN AFFECTED BY CANNIKIN

Date Retrieved or Seen	Location		Condition	Sex:Weight, kg	Comments
	Pacific	Bering			
D-Day		x	Injured[a]	Female: 19.0	Fatally injured by pressure pulse in water
D+1	x		Dead[a]	Female: 21.8	Killed by vertical acceleration forces
D+2	x		Dead[a]	Female: 11.3	Killed by pressure pulse in water
D+2	x		Dead[a]	Female: 19.0	Ditto
D+2	x		Dead[a]	Male: 17.2	"
D+2	x		Dead[a]	Female: 21.8	Killed by vertical acceleration forces
D+2	x		Dead[a]	Female: ~18.1	Killed by pressure pulse in water
D+3	x		Dead[a]	Female: 20.9[b]	Crushed by rockfall on beach
D+3	x		Dead[a]	Female: 18.6	Ditto
D+3	x		Dead[a]	Female: 20.4[b]	Killed by pressure pulse in water
D+3	x		Dead[a]	-- : ~17.2	Killed by vertical acceleration forces
D+3	x		Dead[a]	Female: 22.6[b]	Killed by pressure pulse in water
D+3	x		Dead[a]	--	Carcass deteriorated; autopsy not feasible
D+4	x		Dead[a]	--	Caught on offshore rocks
D+4	x		Injured	--	Crippled; not recovered
D+4	x		Abandoned	--	Pup; not recovered
D+4	x		Injured	--	Crippled; not recovered
D+4		x	Abandoned	--	Pup; recovered but released
D+16		x	Dead[a]	--	Killed by pressure pulse in water; recovered by bottom trawl ~2.5 km offshore
D+20		x	Dead	--	Skeleton only; skull showed evidence of pressure pulse damage
D+20		x	Dead	--	Ditto
D+20		x	Dead	--	Only part of skeleton found; cause of death not known
D+20		x	Dead	--	Skeleton only; cause of death not known
Total	16	7			

(a) Autopsy performed.
(b) Lactating.

hemorrhagic, sometimes with rupture of the lungs. Severe hemorrhage had also occurred along the vertebral column and within the spinal canal. Superficial hemorrhage was usually seen on the brain. The internal parts of the ears suffered varying degrees of damage. The larger air passages in the lungs typically contained inspired stomach contents as well as blood. The abdominal viscera were little affected.

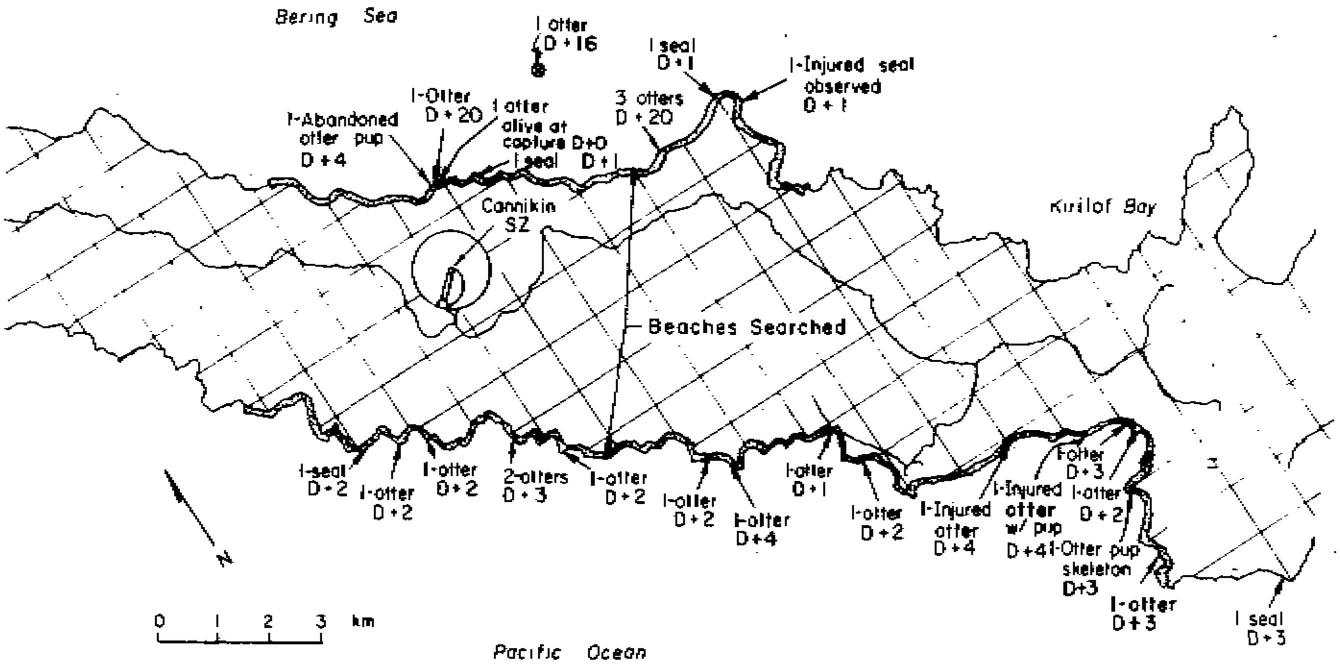


FIGURE 3. BEACHES SEARCHED POST-CANNIKIN AND LOCATIONS OF DEAD MARINE MAMMALS RECOVERED AND ANIMALS INJURED OR ABANDONED (PUPS)

Sea otters killed by vertical acceleration showed thoracic and abdominal effects of trauma, and one animal had broken ribs and fractures of the skull. Of the two sea otters crushed by falling rocks, one had a crushed head, while the posterior part of the body of the other had been crushed, causing rupture of the abdominal viscera and severe hemorrhage in the muscles of the rear legs.

In summary, 23 sea otters were recovered or observed that could have been killed by Cannikin, 10 of which were killed by pressure pulses, 2 by rockfalls, and 3 by vertical acceleration. Four died of causes that may have been related to Cannikin but this could not be determined with certainty, and 4 injured or abandoned animals probably died due to indirect causes related to Cannikin.

While it is assumed that the otter casualties reported in the foregoing discussion represent a fraction of the total number of otters killed by Cannikin, it is not realistic to guess what that fraction is. The assumption that not all dead and injured animals were accounted for by the post-Cannikin searches is based mainly on the following considerations:

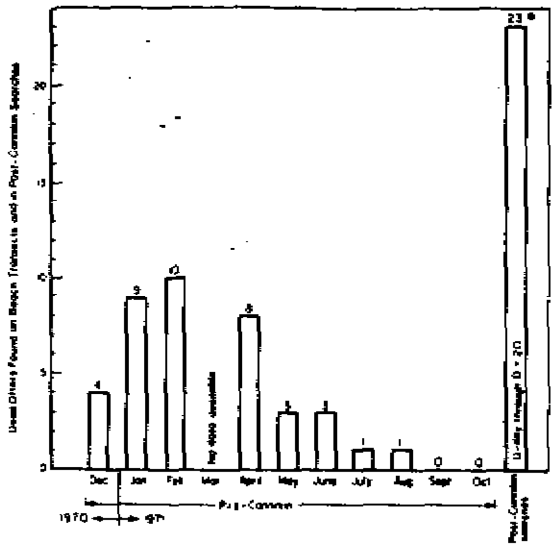


FIGURE 4. NUMBERS OF SEA OTTERS FOUND DEAD OR INJURED ON AMCHITKA BEACHES, 1970-1971

*Includes one dead otter recovered in bottom trawl ~2.5 km offshore in Bering Sea, and two abandoned pups.

(1) During the early post-Cannikin period, wind direction and force were such that most animals killed on the Bering Sea side of the Island may have drifted away from shore and hence could not have been sighted or recovered, particularly under the unfavorable weather conditions.

(2) It has been suggested by the UAz biologist studying sea otter behavior that at least some animals killed by pressure pulses while diving may not have resurfaced, because of changes in relative buoyancy caused by the pressure effects. Such casualties of course would not have been found in the beach searches. Some support for this hypothesis is given by the fact that one dead otter was recovered in a bottom trawl at a depth of 30 fathoms in the Bering Sea on D+16; autopsy by the UAz biologist indicated death was due to pressure effects.

(3) The two animals crushed by fallen rocks were found only because the carcasses were partially exposed; others may have been completely buried and hence not seen.

(4) Comparison of pre- and post-Cannikin observations and counts of sea otters along the coasts adjacent to Cannikin SZ suggests a sizeable population reduction in close-in areas in the early postshot period.

Viewing conditions shortly before and after D-day were unfavorable for censusing sea otters, but some counts were made. Many variables confound the results of these counts, and their usefulness as a basis for quantitatively assessing the sea otter losses due to Cannikin is clearly limited.

Post-Cannikin sea otter counts were made by the UAz biologist, assisted by ADF&G biologists, from selected cliffside viewing points along a section of Bering Sea coast extending from Cyril Cove to Sea Otter Point, on D+13 to D+15. Because of unfavorable weather conditions, no late pre-Cannikin counts were made in the same area by the same technique, so no strictly comparable pretest data are available for comparison with the post-Cannikin counts. However, the UAz investigator reports that his observations made immediately post-Cannikin indicate that there were obviously fewer animals along the Bering Sea coast, between Crown Reefer Point and Sea Otter Point, than there were preevent. His observations along the Pacific coast indicated no large localized population reductions, but losses did occur in the Pacific, since 16 of the 23 casualties listed in Table 1 were found on the Pacific Ocean coast.

BCL and FWS observers made a series of pre- and post-Cannikin sea otter counts along the Bering Sea and Pacific Ocean coasts during helicopter overflights from D-16 through D-3 (16 counts) and from D-day through D+15 (7 counts). Since viewing conditions were generally unfavorable, the counts can be considered to reflect only relative abundance, rather than anything like a complete census. The areas covered in these counts were from Crown Reefer Point to Chitka Point on the Bering Sea coast, and from Rifle Range Point to ~1.6 km north of Mex Island on the Pacific (Figure 1).

The average numbers of sea otters counted during the post-Cannikin helicopter surveys were about half as large as the numbers counted before Cannikin.* The observers believe that the counts show evidence of a real decline in sea otter population on both coasts adjacent to Cannikin SZ after the test. The size of the decline cannot be reliably estimated, in terms of absolute numbers of animals, from these counts.

On January 12, 1972, AEC-NVOO convened an Advisory Panel to review AEC activities relating to sea otters and, on the basis of this review, to recommend to AEC-NVOO the future scope of sea otter research activities at Amchitka Island. Members of the Panel were:

Leo K. Bustad
Director
Radiobiology Laboratory
University of California
Davis, California

Douglas G. Chapman
Dean
College of Fisheries
University of Washington
Seattle, Washington

Karl W. Kenyon
Wildlife Biologist
Bureau of Sport Fisheries and Wildlife
Seattle, Washington

Charles M. Loveless
Assistant Director-Research
Bureau of Sport Fisheries and Wildlife
Washington, D. C.

Vincent Schultz
Professor of Zoology
Washington State University
Pullman, Washington

Clayton S. White
Director
Lovelace Foundation
Albuquerque, New Mexico

The investigators involved in the Cannikin-related sea otter studies presented their data, and their judgments regarding the impact of Cannikin on the Amchitka sea otter population. Stressing the many factors that make precise assessment of the impact impossible, the Panel concluded: "Based on data presented to us, it is impossible to estimate reliably the number of sea otters killed by Cannikin. It is suggested that the data collected next summer may reflect the general magnitude of the loss".

While available data are inadequate for a precise quantitative assessment of sea otter losses due to Cannikin, participants in the marine mammal studies agree that these losses will have no long-term adverse affects on the Amchitka Island sea otter population. There was no clear evidence of habitat damage that would reduce carrying capacity of the area, and the population is expected to return to normal levels through natural reproduction.

The two other marine mammals commonly occurring in the nearshore habitat around the Island are Steller's sea lions (Eumetopias jubata) and harbor seals (Phoca vitulina). No dead sea lions were found after Cannikin, and there is no evidence that the Island population of these animals was affected. Four dead harbor seals were recovered after the test, two on the Pacific coast and two on the Bering Sea shore. Autopsies showed that these four seals were killed by pressure pulses in the water.

* Recent (May-June, 1972) shore surveys along the Bering Sea coast off Cannikin SZ counted less than half as many otters as were counted in the same sector in June, 1971.

All had severely hemorrhagic lungs and both lungs had ruptured in one animal. All showed some degree of damage to ears and eyes, and pressure had forced the eyes inward enough to bilaterally shatter the orbital bone.

The seal population of Amchitka has not been monitored closely, but its distribution appears to vary considerably from natural causes. There is no evidence that this population was adversely affected by Cannikin, although a few animals were killed.

Other Marine Biota

To investigate the effects of the Cannikin test in the marine waters adjacent to Cannikin SZ, FRI investigators planned to (1) extrapolate from the reports of the Long Shot and Milrow tests and from literature sources, to predict both the lethal pressure thresholds for important marine fishes and the seawater pressure regimes that might be expected from the Cannikin shock wave, (2) design and conduct testtime experiments to determine the effect of the detonation on representative fishes, (3) observe and record any fish kills attributable to Cannikin, (4) determine the mechanisms of any damage experienced by marine fish from the test, (5) compare pre- and postevent fish catches in both nearshore and offshore waters, and (6) study the short- and long-term effects of intertidal displacement and subtidal bottom disruption. NMFS investigators collected data on the pre- and postevent population densities and size distributions of sea urchins in selected areas in the Bering Sea and Pacific Ocean off Cannikin SZ.

Studies and experiments for Cannikin were planned by FRI with consideration for baseline data collected prior to the test, experience gained from the Milrow test, and predictions of possible Cannikin effects on the marine environment. Because of adverse weather conditions immediately before the test, important experiments with captive marine fish in live boxes could not be carried out; hence the evaluation of Cannikin effects on the marine ecosystem is limited. Observations of sea urchin populations were successfully completed by NMFS investigators; preevent data were collected September 2 to 5, 1971, and postevent counts were made on November 11 to 16, 1971.

Although high winds and accompanying heavy seas on D-1 made it impractical to carry out the planned marine live box experiments and related water-pressure measurements, one "string" of two live boxes was set in Constantine Harbor in water 18 m (10 fm) deep, approximately 7.5 hr before the detonation. One was located near the bottom at 16 m (9 fm), and the other at 2 m (1 fm). The lower box contained 6 rock greenling (Hexagrammos lagocephalus), 4 Pacific cod (Gadus macrocephalus), 3 Pacific halibut (Hippoglossus stenolepis), 2 red Irish lord (Hemilepidotus hemilepidotus), and one each of rock sole (Lepidopsetta bilineata), great sculpin, (Myoxocephalus polyacanthocephalus), and dusky rockfish (Sebastes ciliatus). The upper box contained 10 rock greenling and 6 Pacific cod.

The boxes were retrieved at about H+3 and the fish were examined for evidence of test-related injury. Only one fish, a Pacific cod 67 cm long, from the upper box, exhibited any abnormality. This fish had a "bubble" in its right eye and appeared to have some difficulty in maintaining equilibrium. The fact that no such symptoms were shown by any of the other fish suggests that this one may have been affected by handling, probably during the setting or retrieval operations. No pressure-measurement gauges were exposed with the Constantine Harbor live boxes, so no data are available regarding the pressure changes to which the fish were exposed. The test does indicate that fish of the species included in the live boxes, in shallow water at distances of ~15 km or more from SZ were not adversely affected by Cannikin.

Starting at approximately H+4, biologists were able to survey sections of Bering Sea and Pacific Ocean beaches near Cannikin SZ. The survey was limited since the daylight remaining after the search began was brief. A few rock greenling, some still alive, were found stranded in an uplifted intertidal area of the Bering Sea beach. Intensive beach searches began on D+1 and continued through D+3; intermittent surveys continued for approximately 2 weeks more.

The searches yielded 277 rock greenling, 7 Pacific sandfish (Trichodon trichodon), 1 longnose lancetfish (Alepisaurus ferox), 1 great sculpin, 8 Pacific cod skeletons, and the skull of an unidentified rockfish, Sebastes sp. All except the cod and rockfish remains were recovered from the uplifted intertidal bench on the Bering Sea coast adjacent to Cannikin SZ, between Banjo Point and Sand Beach Cove* (see Figure 5).

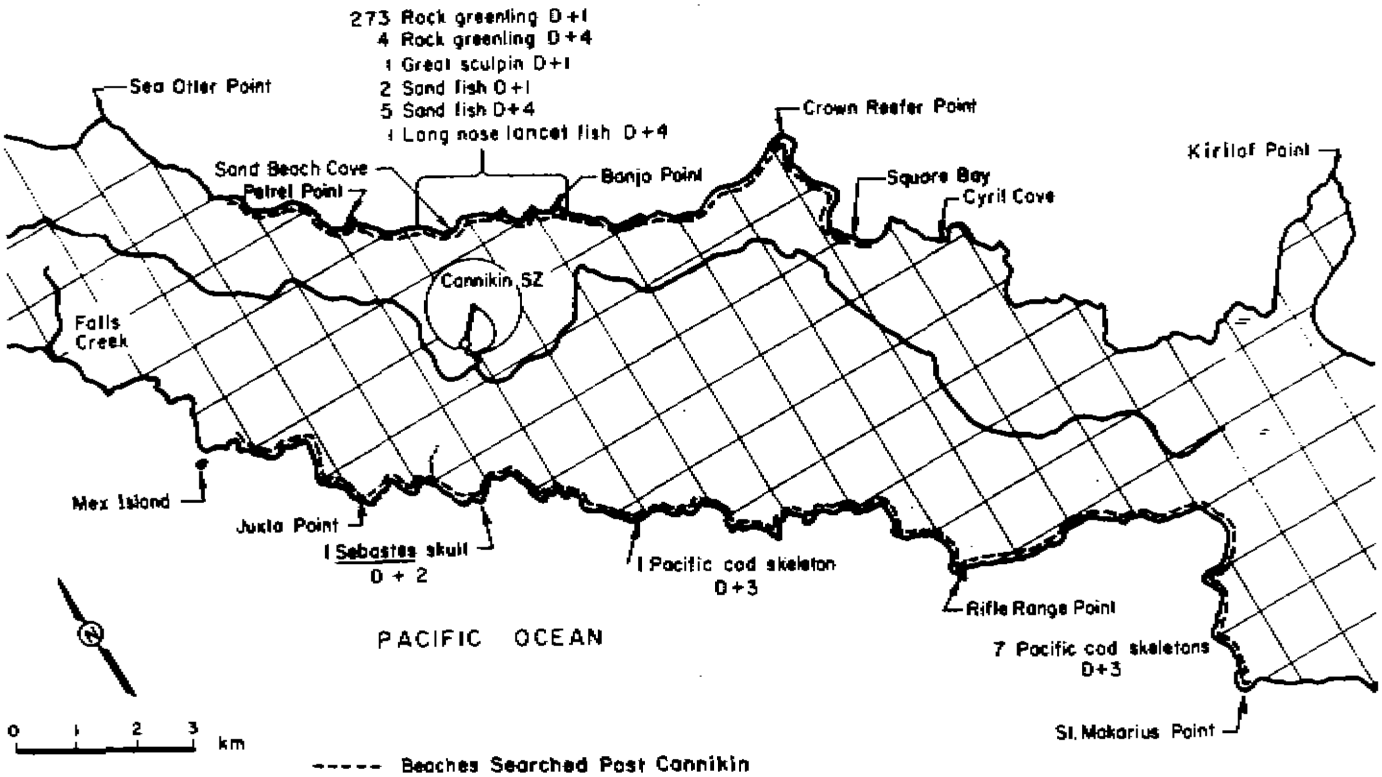


FIGURE 5. BEACHES SEARCHED POST-CANNIKIN AND LOCATIONS OF DEAD, INJURED, AND STRANDED FISH AND SKELETONS OF FISH RECOVERED FROM MARINE AREAS POST-CANNIKIN

The lancetfish, an offshore pelagic species, is often driven ashore by storms, and its good physical condition suggests that this was what had happened to the specimen recovered. The Pacific sandfish commonly burrows upright into sand of the intertidal zone, but the fish recovered were stranded in the Sand Beach Cove area as a result of intertidal-bench uplifting. Several of the fish were found still alive, though high and dry in the sand of the upper part of the beach.

* The uplifted bench region on the Bering Sea coast adjacent to Cannikin SZ is discussed in a later section of this report. Preliminary and incomplete survey information indicates that the extent of uplift was on the order of 0.25 to 1.1 m (see Appendix A).

Of the 277 rock greenling recovered, 23 were autopsied. About half of these exhibited hemorrhaging or other damage in the brain cavity and/or in the viscera. The others, exhibiting no evident injury, are assumed to have suffocated on being stranded by the uplifting of the intertidal bench. Thus, it appears that the greenling were killed either by stranding or by physical injury incurred from rapid vertical acceleration of the bench. Rock greenling characteristically feed over the intertidal bench at high tide (Simenstad, 1971).

The tide was at a slack high of about 1 m in Constantine Harbor at the time of the Cannikin detonation, so it is likely that a large number of greenlings were over the bench when it was uplifted. It is estimated, based on prior sampling, that several thousand greenlings may have been over the affected bench at testtime; thus, the 277 specimens recovered represent an unknown fraction of the total rock greenling mortality in this area. Some localized reduction in rock greenling abundance is also suggested by the trammel-net catch data discussed later in this section.

Eight Pacific cod skeletons and 1 rockfish skull (all freshly cleaned by amphipods) were found on Pacific Ocean beaches on D+2 and 3. As freshly cleaned fish skeletons on the beaches of Amchitka are uncommon (especially in such numbers), it is likely that these fish were killed by Cannikin. Of the 8 Pacific cod skeletons, 7 were found along the east shore of St. Makarius Bay about 14 km from Cannikin GZ. This is approximately the same distance from SZ as the fish (including Pacific cod) held in the live box in Constantine Harbor, which were unaffected by the event. It may be assumed that the fish were probably nearer SZ at testtime, and drifted to the recovery location under the influence of the northwesterly winds that prevailed at testtime and for several hours afterward (Appendix B).

The first post-Cannikin helicopter overflight began about H+2 and lasted for 1 hour. During this flight, weather and sea conditions were poor for observations but numerous gulls and sea otters were observed within about 5 km of SZ. All groups of gulls observed within this area were investigated from a distance of about 30 m because it had been hypothesized by FRI biologists and others that concentrations of feeding gulls might indicate the location of fish killed by the test. No dead or injured fishes were observed floating on the nearshore sea surface during the post-Cannikin beach and helicopter surveys.

Direct evidence of mortalities in the nearshore region is limited to those fish recovered from the beaches. The number of fish recovered probably represent only a fraction of the fish killed because (1) dead or injured fish could have drifted away from the search areas under the influence of winds and currents, (2) fish could have been buried in kelp, cliff falls, and mud slides, (3) they could have been picked up by predators or scavengers, and (4) some may have been missed by the survey parties. It is noteworthy that the only fishes found in shore searches on the Bering Sea side were on the uplifted section of the beach between Banjo Point and Sand Beach Cove. Others were probably affected in the Bering Sea waters (on the basis of predicted magnitude and areal extent of the pressure pulses), but drifted away from the Island under the influence of offshore wind and were not recovered.

Because trammel nets are highly efficient in shallow waters and produce minimal injury to the fish caught, they were selected as the gear type for sampling nearshore fish populations adjacent to Cannikin SZ to determine abundance of fishes. Nearshore sampling was concentrated along the Bering Sea coast because this area is closer to Cannikin SZ than the corresponding North Pacific coast and was, therefore, expected to experience greater underwater pressure pulses.

Preevent sampling included two trammel net sets, and postevent sampling, seven sets. The locations and catch data for these sets are given in Figure 6 and Table 2, respectively.

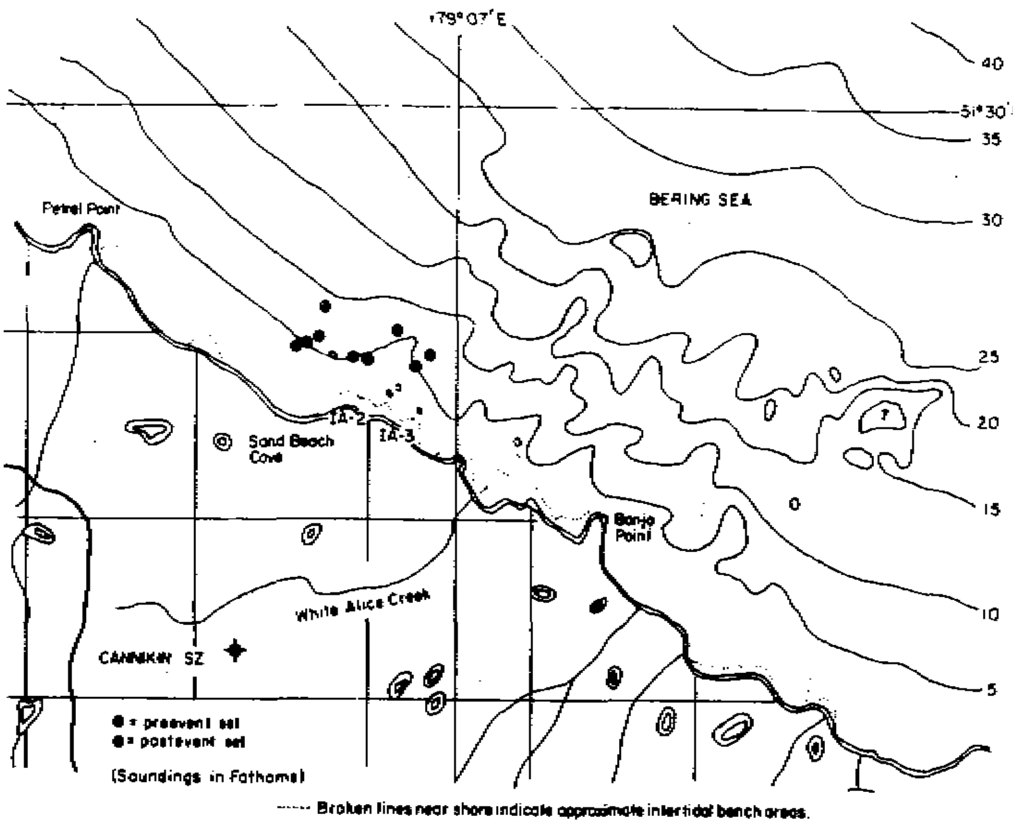


FIGURE 6. TRAMMEL NET SETS IN THE VICINITY OF CANNIKIN SZ

Broken lines near shore indicate approximate intertidal bench areas. The 1,000-m UTM grid is shown on land.

The two distinct inshore fish communities found in the nearshore Bering Sea waters off Cannikin SZ are associated with rock-algae and sand-gravel habitats (Isakson, et al., 1971). One preevent set was made in each of these communities; of the postevent sets, four were in the rock-algae and three in the sand-gravel areas.

Only one species, the rock greenling, was caught in sufficient numbers to provide a meaningful comparison between preevent and postevent catches. The data for this species show a considerable reduction in catch per unit of effort (fish/hour) in the first postevent samplings made on D+5. Catches in the sand-gravel area remained very low throughout the 10-day post-Cannikin sampling period, but by D+15 the catch per unit of effort in the rock-algae habitat had returned nearly to pretest levels (Figure 7).

FRI planned to utilize three methods to detect and evaluate the effects of Cannikin in the offshore waters: live-box experiments, visual observations from the M/V Commander, and comparison of pre- and postevent catches made with standard fishing gear. As noted earlier, the live-box experiments planned for offshore locations were abandoned because of adverse sea conditions.

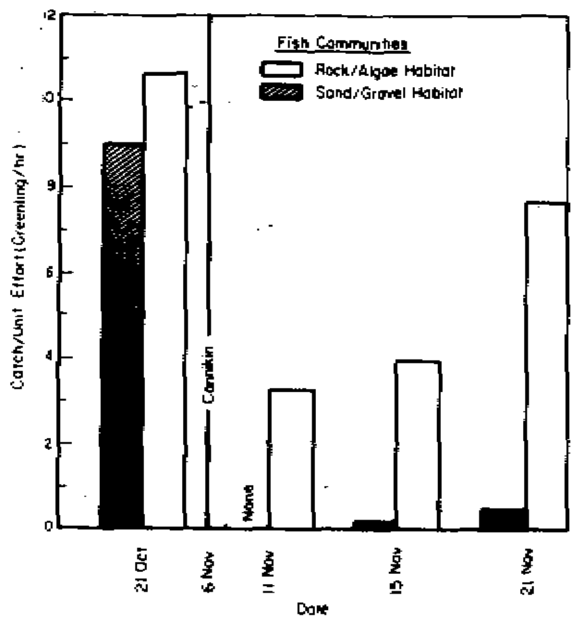


FIGURE 7. NUMBER OF ROCK GREENLING CAUGHT PER HOUR, IN NEARSHORE BERING SEA WATERS ADJACENT TO CANNIKIN SZ, PRE- AND POSTEVENT

Catches from two fish communities are presented.

Direct observations for any floating dead fish were planned for the early posttest period, as soon as the vessel was permitted to move into the area off Cannikin SZ. It was anticipated that in the event of a large fish kill, some stunned or dead fish would float to the surface where they could be located and collected. However, weather and sea conditions at, and just after, testtime reduced the probability of seeing fish on the surface. A heavy, wind-driven chop superimposed on 6-9 m seas churned the sea surface into a white froth, and observers aboard the M/V Commander saw no dead or injured fish, birds, or marine mammals as they passed Cannikin SZ, 6 to 8 km offshore, at H+2 hours.

Sampling of offshore fish populations from the M/V Commander began on August 27 and continued through November 21. Forty-four bottom trawl hauls, 40 midwater trawl hauls, and 14 salmon longline sets were made. Catches for the midwater trawls are not presented in this report because the catches have yet to be counted and identified. Hence, the only basis available at this time for evaluating the effects of Cannikin on the offshore fish populations is the comparison of pre- and postevent catches by bottom trawls and salmon longline sets.

Twenty-seven bottom trawl hauls were selected for comparison, based on proximity to SZ and similarity of location and depth (Figure 8). All were in the Bering Sea, at distances ranging from 3 to 11 km from Cannikin SZ. Table 3 gives the catch data for these 27 trawl hauls. A one-way analysis of variance was done on the catch data of each species, or group of species, using the time periods (preevent and postevent) as treatments. Table 4 presents the results of these analyses for the trawl hauls. These analyses show a statistically significant decline in catches of rock sole after the Cannikin event. The results for other bottom fishes show no significant changes in catches, but the catches were so small that comparison is hardly meaningful.

It is believed that the catch data for rock sole provide the most reliable information available for assessing effects of Cannikin in the adjacent Bering Sea offshore marine environment. There was a marked decline in the catches of this species following Cannikin. This decline could have resulted from a normal offshore movement, but no reference to such offshore movement of rock sole during October has been found in the literature, in FRI catch data from previous years, or in data collected by the International Pacific Halibut Commission. It is concluded that the decline in catches of rock sole is probably an effect of Cannikin, i.e., evidence of a large mortality (the investigators believe a reasonable estimate would be thousands of fish).

Fishes other than rock sole may have suffered some mortality, but because of the small catches and large variance among samples, no significant changes in abundance were detected. However, some additional direct and indirect evidence of fish kill attributable to Cannikin is available: On D+3 one dead dusky rockfish (Sebastes ciliatus) was taken in a bottom trawl (Haul 33) in the Bering Sea about 6 km from Cannikin SZ.

Also it is to be noted that before Cannikin, large schools of fish were detected (with the M/V Commander echo sounder) "hovering" around rock pinnacles. This behavior is characteristic of the rockfishes. These schools were not detected after Cannikin.

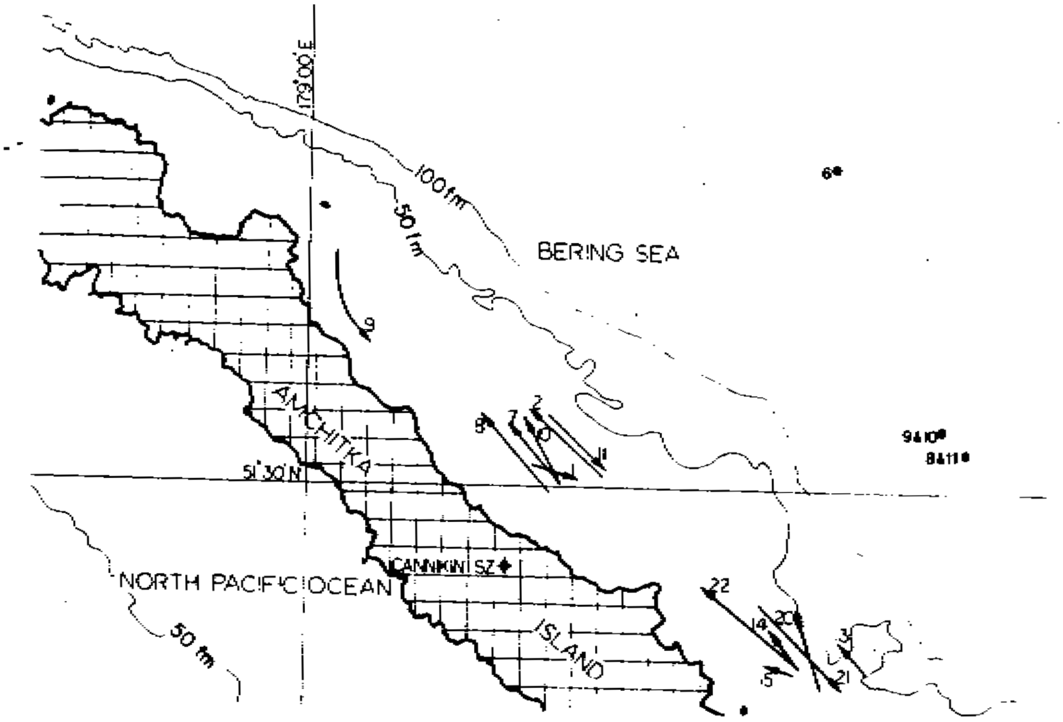
TABLE 2. TRAMMEL NET SETS AND CATCHES IN BERING SEA NEARSHORE WATERS, IN VICINITY OF SZ, PRE- AND POST-CANNIKIN, 1971

			Catch								
Habitat Type[(a)]	Date	Depth, m	Rock greenling	Pacific cod	Atka mackerel	Pacific halibut	Total fish	Sampling Duration, hr:min	Total Catch/Unit of Effort (fish/hr)	Catch/Unit of Effort (rock greenling/hr)
					Pre-Cannikin					
S-G	21 Oct	11	18				18	2:00	9.00	9.00
R-A	21 Oct	9	24				24	2:15	10.67	10.67
					Post-Cannikin					
R-A	11 Nov	11	11				11	3:20	3.30	3.30
S-G	11 Nov	9					0	3:20	0.00	0.00
R-A	15 Nov	7	20		1		21	5:00	4.20	4.00
S-G	15 Nov	15	1			4	5	5:20	0.94	0.19
R-A	21 Nov	13	16				16	2:15	7.11	7.11
R-A	21 Nov	9	18				18	2:10	8.31	8.31
S-G	21 Nov	10	1	1			2	2:00	1.00	0.50

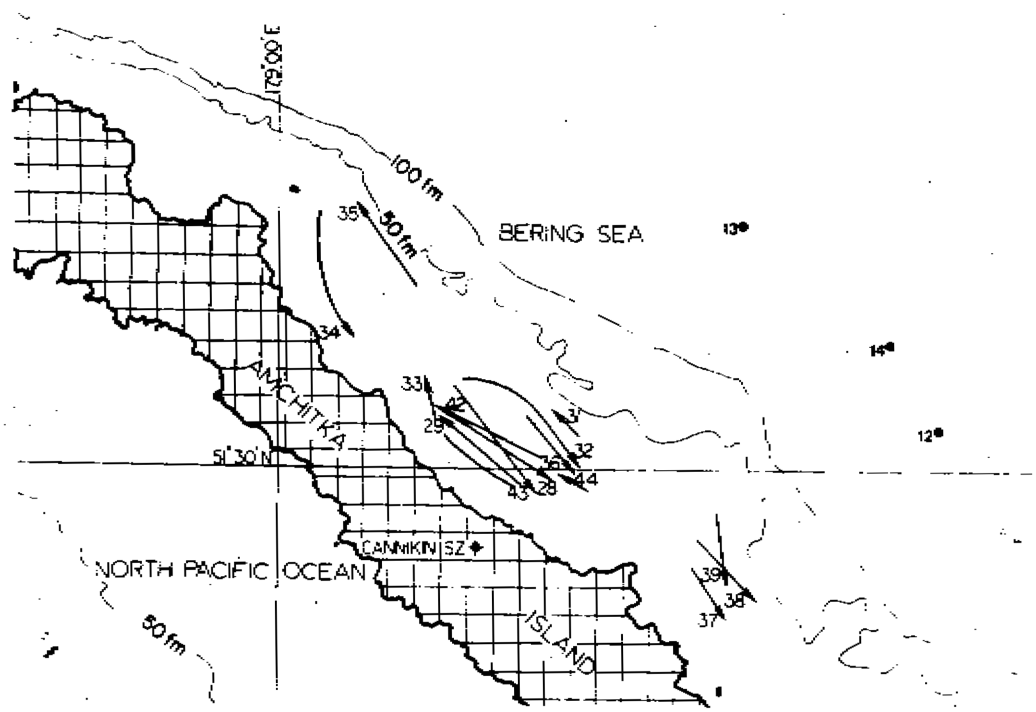
(a) R-A = Inshore Rock-Algae Habitat.
S-G = Inshore Sand-Gravel Habitat.

Comparison of salmon longline data showed no significant change in salmon catches (Table 4). Five preevent and three postevent sets were chosen for this comparison on the basis of proximity to Cannikin SZ and to each other. The comparison indicates that salmon populations in the vicinity of Amchitka were not effected by the Cannikin event.

The intertidal study areas IA-2, IA-3, and the intertidal region off Banjo Point (Figure 6) were inspected during the period December 1-8, 1971. Preevent sampling was conducted at the IA-2 and IA-3 areas in September and these beaches were walked by various investigators during the late pre-Cannikin period. It is by comparing the post-Cannikin status of the beach areas with the condition of the same areas as observed pre-Cannikin that the intertidal disturbances observed can be attributed to Cannikin. Of 45 plots established in the IA-2 and IA-3 areas, 7 were completely buried by cliff falls and 3 others were partially buried. The remaining plots were sampled for algae and 19 were sampled for invertebrates during a survey in December, 1971. The detailed plot data will be presented in a later report. This report is limited to visual observations.



Pre-Cannikin (September-October)



Post-Cannikin (November)

→ Bottom Trawl
● Salmon Long-Line Set

FIGURE 8. LOCATIONS AND DIRECTIONS OF BOTTOM TRAWL HAULS

TABLE 3. BOTTOM TRAWL SETS AND CATCHES IN THE BERING SEA OFF AMCHITKA, PRE- AND POST-CANNIKIN

(See Figure 8 for locations)

Set	1	2	7	8	9	10	11	13	14	15	20	21	22	28
Date	9-13	9-13	9-16	9-16	9-16	9-17	9-17	10-4	10-4	10-4	10-11	10-11	10-11	11-7
Depth, fm	33	40	32	27	28	35	48	40	50	40	50	50	46	20
Duration, hr	0.4	0.6	0.7	1.0	1.2	0.7	1.0	0.3	0.5	0.5	0.6	0.9	1.0	0.8
Species														
Pacific ocean perch				1										
Pacific cod	2						8				4	21	6	
Pacific halibut	8	24	14	51	2	2	11	2	4	5	22		9	
Rock sole	79	162	77	143	83	41	265	27	103	97	151	55	91	
Arrowtooth flounder	4	2	1			1							1	
Rex sole		1												
Poachers		5	3	4		2	8				16	2	3	
Sturgeon poacher								5	6					
Sculpins		1		1		2	6			2	1	1	15	1
Northern staghorn								7						
Great sculpin										1				
Searchers													1	
Snailfish						1								

Set	29	31	32	33	34	35	36	37	38	39	42	43	44
Date	11-7	11-7	11-7	11-9	11-9	11-9	11-9	11-11	11-11	11-11	11-21	11-21	11-21
Depth, fm	25	40	30	22	25	38	35	27	35	40	24	30	35
Duration, hr	0.9	0.7	0.8	0.7	0.8	0.7	0.6	0.3	0.3	0.3	1.0	1.0	0.4
Species													
Pacific ocean perch												1	
Dusky rockfish				1 (dead when caught)									
Packific cod		3	36	1		14	1						
Pacific halibut	4	42	48	11	4	17	10		1	5	4	65	27
Rock sole		45	12	6	2	75	12		7	7		20	7
Arrowtooth flounder					1					1		2	
Rex sole		2											
Poachers		7					1		1	2			
Sturgeon poacher													
Sculpins		1	8	23	3	2	29		1	1	1		2
Northern staghorn													
Great sculpin													
Searchers		4											
Snailfish													
Lithodid crabs												1	

TABLE 4. STATISTICAL COMPARISONS OF PRE- AND POSTEVENT BOTTOM-TRAWL AND SALMON LONGLINE CATCHES

The trawl catches are given as number of fish caught per hour of fishing effort and the salmon catch as actual numbers caught since there is little difference in longline set duration.

Species or Group	Preevent Mean ± Std. Dev.[a]	Postevent Mean ± Std. Dev.	d.f.[b]	F[c]
Rock sole	154.46 ± 79.92	21.57 ± 29.78	1, 25	33.75, p<.01
Pacific halibut	16.77 ± 16.18	33.64 ± 45.35	1, 25	1.61, N.S.
Pacific cod	3.77 ± 6.57	5.21 ± 12.61	1, 25	0.14, N.S.
Sculpins	4.77 ± 7.12	7.93 ± 14.37	1, 25	0.51, N.S.
Poachers	6.31 ± 8.08	1.64 ± 3.10	1, 25	4.04, N.S.
Salmon	10.20 ± 7.63	3.00 ± 2.65	1, 6	2.36, N.S.

(a) Std. Dev. = Standard deviation or deviation of the observations.
(b) d.f. = Degrees of freedom (in this case, one less than the number of observations made).
(c) F = Test for significance. p<.01 = there is less than 1 percent chance of being wrong; N.S. = not significant.

Early post-Cannikin visual observations by FRI biologists suggest that the intertidal bench on the Bering Sea shore was noticeably uplifted along a section of coastline some 2 km long, extending from just southeast of Banjo Point to Sand Beach Cove. Preliminary survey data (Appendix A, Table A-5 and Figure A-5) indicate that the maximum uplift of about 1.1 m occurred off the point immediately east of Sand Beach Cove, with a secondary maximum of about 0.9 m near the mouth of White Alice Creek. The uplift diminished gradually from the White Alice Creek effluence toward Banjo Point, where an upward displacement of about 0.25 m was recorded by the survey.

Some species of algae are dying in the uplifted intertidal section. On the shoreward portions of the benches, the populations of Fucus distichus, Clathromorphum circumscriptum, and C. loculosum are dead or dying. Corallina spp. throughout the area are exhibiting some die-off. The species most severely affected throughout the uplifted area are Iridaea cornucopiae and Halosaccion glandiforme. For the kelp, a mixed picture results from the complicated physiography of the benches. On the inner channels that were previously washed by wave action but are now dry, Hedophyllum sessile and Laminaria longipes are dying off. This is less apparent on the seaward faces of the benches. These effects are primarily evident at IA-2; IA-3 appeared to have little die-off.

Studies of the Milrow-uplifted IA-1 area in Duck Cove (Figure 1) which was lifted about 13 cm, have shown that algal communities were radically altered and the process continues (Burgner et al., 1971). Despite the fact that the uplifting at IA-2 and IA-3 is considerably greater, a pattern of die-off and change in the intertidal algal community similar to that observed at the IA-1 area is expected.

The uplifting at IA-2 has also affected invertebrate communities. Certain species are dying off relatively rapidly, whereas others have either moved down out of those areas no longer suitable for habitation or are remaining but are not yet severely affected. Those showing early die-off are the sessile species found in the Hedophyllum and Laminaria zones such as the solitary tunicates, Styela spp., and a particularly widespread green encrusting sponge. The major sessile species of the upper intertidal zone, Mytilus edulis (bay mussel) and Balanus glandula (the acorn barnacle), have not shown extensive die-off. Evidence of movement of an upper intertidal species into areas formerly not occupied by that species was shown by Littorina aleutica (a periwinkle). Eleven individuals of this species were recorded in a 0.25-m^2 plot formerly in the Laminaria zone, which is not normally occupied by this species. There is also evidence of increased predation on invertebrates by gulls and oystercatchers. This is particularly noticeable with the limpets, Acmaea spp. Uplifting has resulted in limpets being exposed for longer times at low tide. Oystercatchers feed on limpets, and are now afforded a greater opportunity to search out and consume their prey. Increased oystercatcher predation was indicated by the large number of limpet shells overturned and empty on the bench, and by the sighting of large flocks of oystercatchers and gulls near IA-2 after Cannikin. No invertebrates at IA-3 were visibly affected by uplifting at the time of the initial postshot survey.

The reduction in populations of intertidal macroinvertebrates, due to uplifting of portions of the intertidal bench, is likely to have an indirect effect on nearshore fish populations, particularly on rock greenling, which feed on the benches at high tide. Such reduction in the feeding habitat of nearshore fish species will be limited to some area in the vicinity of Cannikin SZ. The size of the area that may be affected has not been determined, but it will be relatively small compared to the total area of intertidal bench habitat around Amchitka.

NMFS diver/biologists conducted pre- and post-Cannikin sampling in the shallow waters off Amchitka to detect effects of Cannikin on the biota and habitat in this zone. Sampling was carried out at four sites (Figure 9), of which two (Sites 2 and 3) are adjacent to SZ, and two (Sites 1 and 4) are beyond the predicted influence of Cannikin and serve as controls. The quantitative sampling was focused on determining densities and size compositions of the green sea urchin (Strongylocentrotus polyacanthus) populations at each site. The pre-Cannikin sampling was done September 2 to 5, 1971, while the post-Cannikin sampling was done November 11 to 16, 1971 (D+5 to D+10). Qualitative observations included a cursory visual inspection of the subtidal bottom environment at the sea urchin sampling sites and at two supplemental sites (Figure 9) in the Bering Sea off Cannikin SZ. The object of these observations was to note any massive changes in the bottom topography, or any evidence of adverse effects on the biota.

Observations at the four established sampling sites indicated few effects of Cannikin in the benthic environment. Pre- and posttest data on urchin population densities are presented in Table 5. No reductions in the densities or changes in the size compositions of the urchin populations could be attributed to the test. The apparent drop of 33 percent in the density of urchins at Site 4 is probably related solely to urchin behavior and the morphology of the substrate at this site. Much of the bottom is a sand-silt mixture into which the urchins often burrow, especially during periods of heavy wave surge. The rough seas before, during, and following the test probably caused more urchins than usual to be buried in the substrate and thus not observable by the divers during the posttest sampling. Qualitative inspections at the sea urchin sampling sites disclosed no dead or injured organisms; the only damage seen was at Site 2 where small pieces of live coralline algae had broken from the edges of large patches of this algae.

Observations at two supplemental sites in the Bering Sea near SZ disclosed some slight-to-moderate substrate disruption and associated biological damage. The most extensive damage was found in the area about 1.8 km from SZ, which was apparently near an active fault line. Numerous large blocks of rock were broken from the bedrock outcrop and had been tumbled. The new positions of these rocks were evidenced by the freshly fractured surfaces exposed and the presence of yet-living algae (Laminaria sp. and others) on the underside of some of the largest fragments.

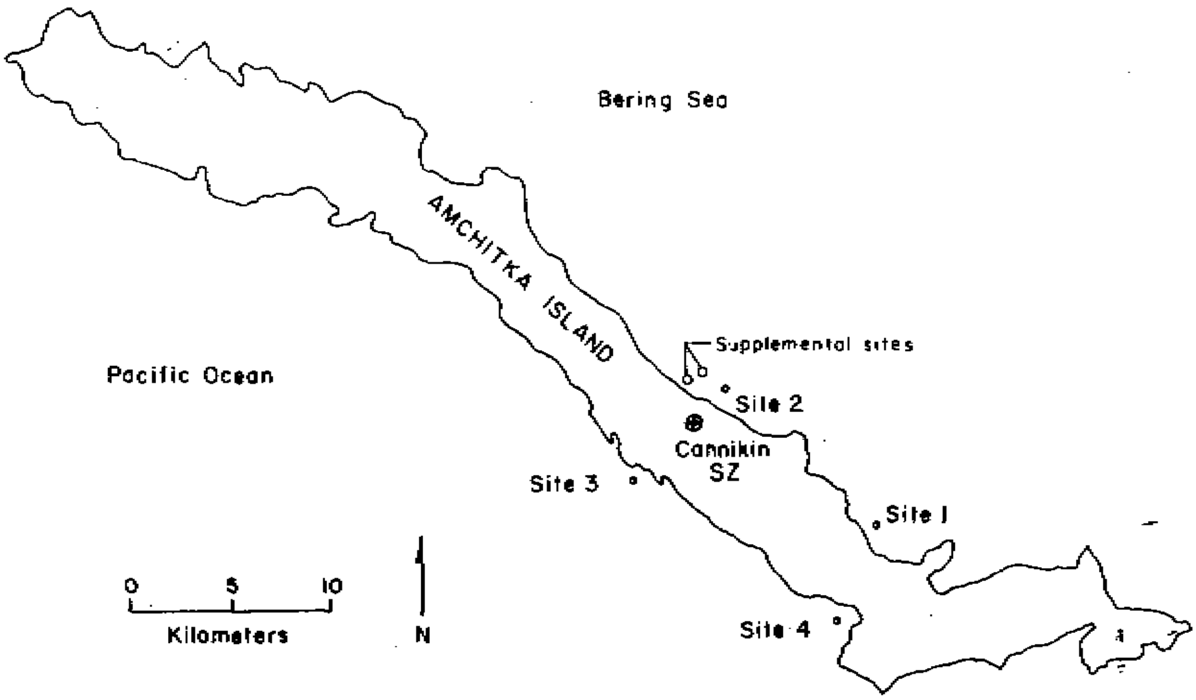


FIGURE 9. SEA URCHIN SAMPLING SITES AT AMCHITKA

TABLE 5. SEA URCHINS (STRONGYLOCENTROTUS POLYACANTHUS) IN SAMPLING PLOTS BEFORE AND AFTER CANNIKIN

Location	Time	Average(a)	Range(b)
Site 1 – Bat Island	Pretest	71.0	45-103
	Posttest	79.6	34-122
Site 2 – Bering "C"	Pretest	25.8	4-47
	Posttest	30.4	13-67
Site 3 – Pacific "C"	Pretest	81.7	27-146
	Posttest	78.7	41-123
Site 4 – St. Makarius Bay	Pretest	45.7	24-73
	Posttest	30.8	13-80

(a) Average number of urchins collected in twenty 0.25-meter-square plots.
(b) Range in number of urchins per plot.

At the site 2.6 km from SZ several large "flakes" had broken from the vertical face of a low bedrock escarpment. Here, also, encrusting organisms were displaced to more shaded and confined positions on the undersides of the rock fragments. The algae and other encrusting organisms so displaced could be expected to die because of insufficient light or water circulation.

These post-Cannikin underwater observations were extremely limited, and the divers were able to inspect carefully only two very small areas, in addition to the preselected sampling sites. Subsequent field trips will include more-extensive underwater surveys to determine if there are other areas of substrate disruption, and to assess possible biological effects.

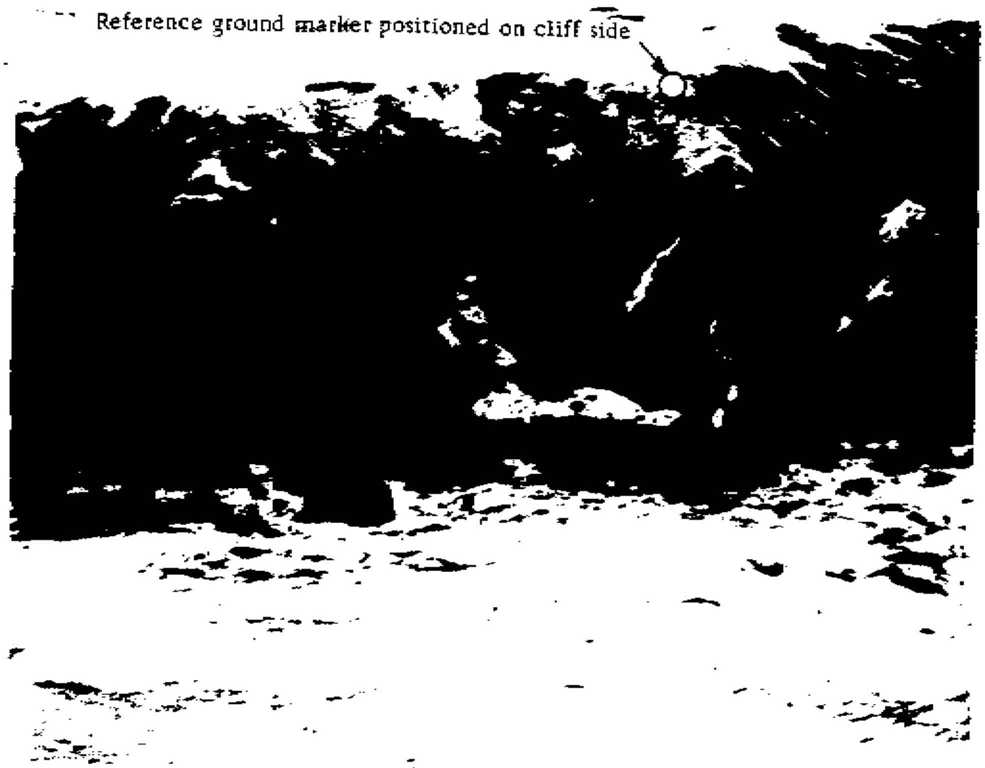
Physical Changes

Rockfalls and turf slides, especially on the Bering Sea coast from just east of Banjo Point to just west of Petrel Point, smothered some marine organisms in localized areas of the upper intertidal zone, but there is no indication that this will seriously affect the marine ecosystem. There were also some changes in elevation of coastal areas on the Bering Sea side (Figure 10) that will produce changes in the intertidal communities. (The area involved is described in Appendixes A and C.) The biological consequences of this phenomenon will be monitored and described in future reports.

Underwater substrate disruption was noted during very limited surveys by NMFS biologist/divers at two sites in the Bering Sea near SZ. Areas of such disruption are probably more extensive, especially in areas of offshore extensions of active faults. The biological effects of these substrate breaks may be locally severe, but are probably of only short-term and very localized significance. Future underwater surveys will be designed to measure the extent of such bottom damage and to monitor recovery of disturbed areas.

Turbidity may have adversely affected marine biota in localized areas of nearshore habitat (Figure 11). The turbidity was evident soon after the detonation – mostly along the Bering Sea coast in areas of extensive cliff spalling and turf falls. Most of the turbidity resulted from dispersion of fine soil and rock particles (derived from the erosion of soil and rock thrown onto the beach and into the intertidal zone by ground shock). Some marine organisms may have been smothered as the particles settled to the bottom, but any such effect on benthic populations is likely to be transient. For several days after Cannikin high turbidity was evident, in some places even extending out into the kelp beds normally frequented by feeding and resting sea otters. The effect of such turbidity on sea otter feeding behavior and distribution is not known. Temporary periods of high turbidity are to be expected in the nearshore waters along the Bering coast for several months whenever heavy rains or unusually high seas erode and disperse particles from the material thrown from the cliffs by Cannikin.

For several hours post-Cannikin a plume of muddy water was visible in the Pacific Ocean off the mouth of Falls Creek, which drains the Drill Site D area. This resulted from a detonation-induced breach of the dike around a drilling-mud pond, from which an estimated 30,000 bbl (4800 m^3) of mud and water escaped before the breach was closed. The mud flowed down the stream from the site, and some of it was discharged into the Pacific Ocean on the extensive intertidal bench at the mouth of the stream (Figure 12). The effects, if any, of this material on the marine ecosystem in that area have not yet been determined.



a. Photographed on D-14

b. Photographed on D-6

FIGURE 1[illegible]. AN INTERTIDAL BENCH AREA AT APPROXIMATELY THE SAME TIDE STAGE, BEFORE (a) AND AFTER CANNIKIN. BERING COAST, 1.6 KM, AZIMUTH 24° FROM CANNIKIN SZ. TAKEN WITH INFRARED COLOR FILM WHICH DEPICTS LIVING VEGETATION AS RED. THE BENCH AREA IS UPLIFTED AND MUCH OF IT IS NOT COVERED BY WATER IN THE POST-CANNIKIN PHOTOGRAPH

(BCL Photograph Nos. 4A-21 and 4B-103)

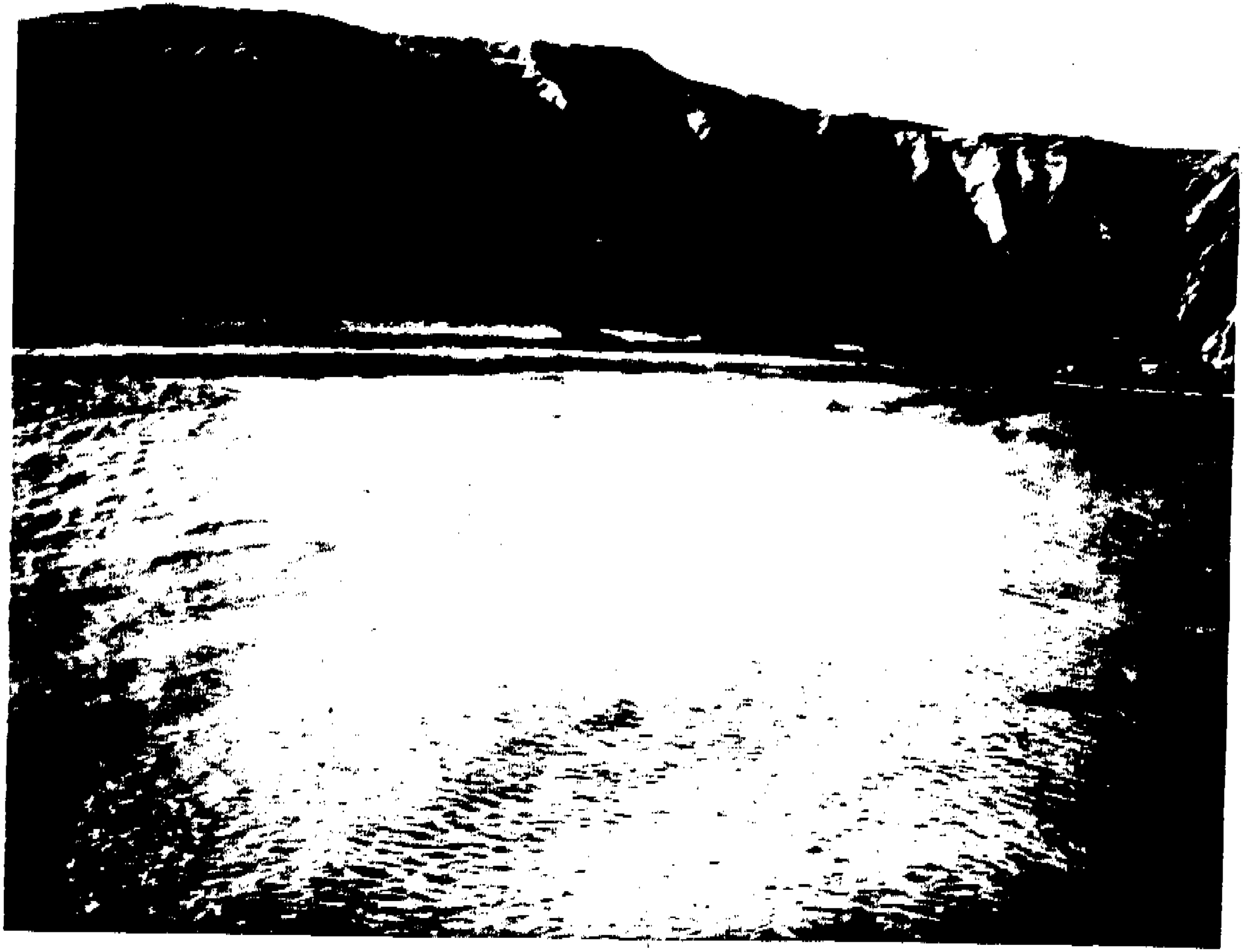
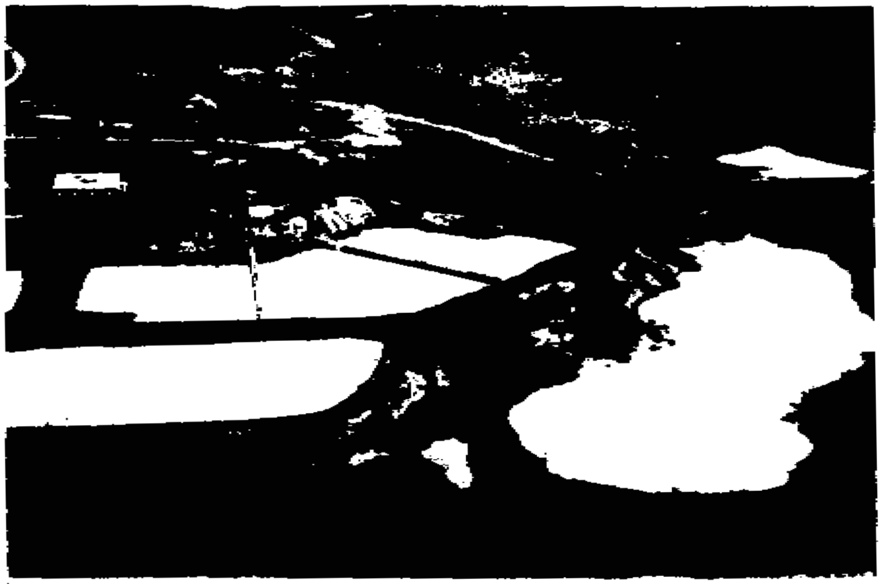
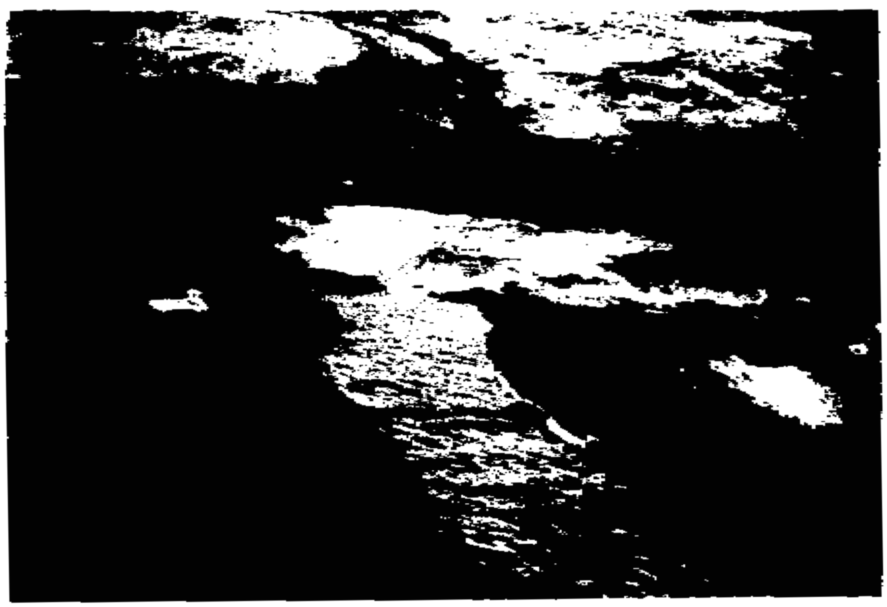


FIGURE 11. TURBIDITY IN NEARSHORE WATERS OFF THE BERING COAST ON D-DAY, [illegible] P.M., AZIMUTH 85° FROM CANNIKIN SZ
(BCL Photograph No. 6B-10)



a. Holding Ponds at Site D on D+1, After Repair of Dike



b. Pacific Ocean at Mouth of Falls Creek, on D+1

FIGURE 12. DRILLING MUD HOLDING PONDS AND RESULTS OF SPILL IN NEARSHORE PACIFIC OCEAN WATERS AT MOUTH OF FALLS CREEK, WHICH DRAINS THE SITE D AREA

The Falls Creek effluence is ~7 km, azimuth 295°, from Cannikin SZ. (BCL photograph numbers 2B-98 and 2B-108.)

Freshwater Ecosystems

The freshwater ecosystems of Amchitka were studied by investigators from BCL and Utah State University (USU). Physical changes were documented with aerial photography by BCL.

Limnology

The objectives of the testtime limnology studies conducted by BCL were to detect short-term effects of Cannikin, including the detection of changes in abundance among phyto- and zooplankton genera, and to monitor any gross chemical or physical changes occurring in the lakes as a result of Cannikin. The data were evaluated in the perspective of normal seasonal trends in these parameters.

Data were collected between September 16 and 21, and between October 13 and November 17, 1971. Twenty-seven lakes were studied to detect possible changes produced by Cannikin (Figure 13). These lakes were selected on the basis of (1) morphology and relative permanence, (2) location with respect to Cannikin SZ, (3) accessibility, (4) existence of prior sampling data, and (5) relationship to the freshwater fisheries investigations.

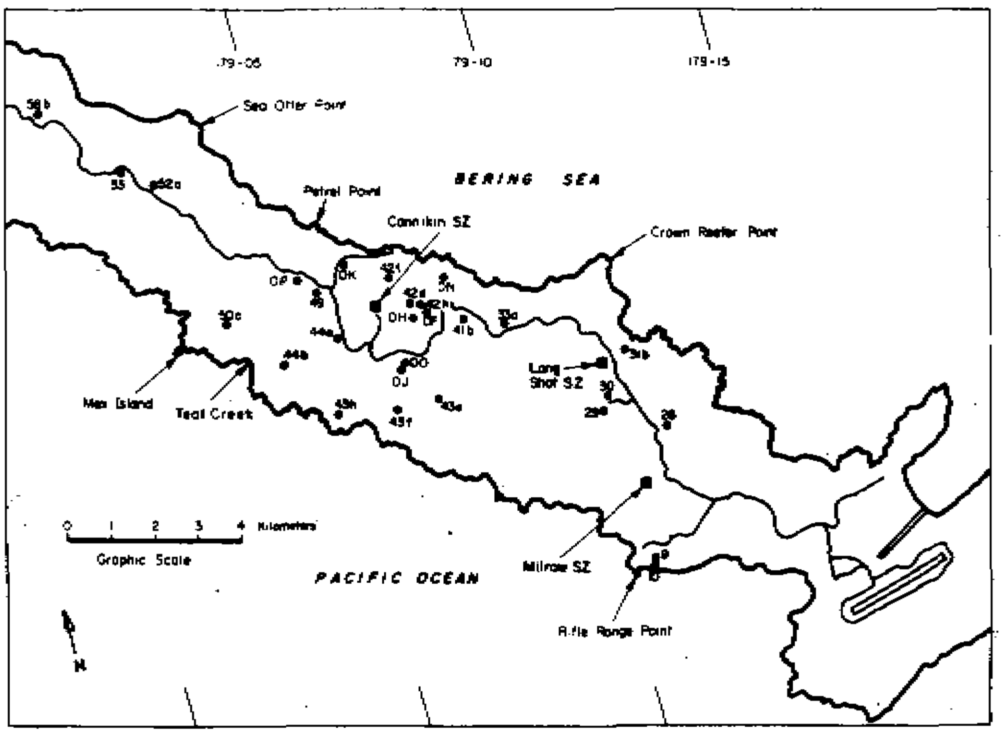


FIGURE 13. CANNIKIN INTENSIVE-STUDY LAKES, LIMNOLOGICAL STUDIES

Five criteria were selected as indicators of immediate test-related disturbance of the study lakes: (1) partial or complete drainage of a lake due to fracture of the bottom seal or to a breach of the peat retaining dam, (2) increase in alkalinity due to the rupture of the peat mat with resulting exposure of surface drainage water to alkaline subsurface mineral soil or bedrock, (3) decrease in primary productivity as detected by a reduction of pH, (4) reduction in plankton populations due to direct or indirect effects of the ground shockwave, and (5) increase in suspended-silt load due to disturbance of sediments. These types of changes were anticipated to be subtle changes in short-term evaluation. These potential effects were generally masked by the severe storm which struck Amchitka on D-1.

Analyses of samples from the intensive-study lakes during preevent sampling produced water-chemistry values generally similar to those obtained during the previous autumn. Values of pH in most of the lakes were either decreasing or remaining relatively stable during the preevent sampling period. This was, no doubt, a reflection of decreasing primary production in the lakes with the advancing season and also dilution of lake water with slightly acidic rainwater during periods of increased precipitation. Preevent alkalinity values in most of the lakes were essentially unchanged from those measured in autumn, 1970. About 22 percent were slightly decreased and another 9 percent were slightly increased. In about half the lakes alkalinities were increasing during October and November, 1971, while none of the intensive-study lakes were decreasing in alkalinity.

Changes in pH post-Cannikin ranged from -0.55 to +0.54 pH units. The largest positive changes occurred in Lakes 30, 31b, and 58b. The greatest negative changes were observed in Lakes 9, 42e, DH and 49. There was no apparent relationship between the changes in pH and the distance of the lakes from SZ.

The only increases in alkalinity noted in the intensive-study lakes post-Cannikin were in two lakes within 1.4 km of SZ. Alkalinity in Lake DH increased from 3.0 mg/l ($CaCO_3$ equivalent) pretest to 6.0 mg/l posttest; the corresponding change in Lake DO was from 0.5 mg/l pretest to 1.1 mg/l posttest. Lake DH was almost completely drained as a result of Cannikin, and the sample analyzed was obtained from a small pool of water remaining in the lake bottom. Shoreline banks slumped into Lake DO at test-time. Alkalinity decreased in Lakes 26, 31b, 33a, DN, 44b, DP, 50c, and 58b. These decreases ranged from 0.5 mg/l in Lake 58b to 8.7 mg/l in Lake 50c. Most of these lakes have a natural high variance in alkalinity. The decreases in alkalinity observed were probably caused by the effects of the storm on D-1, and not by Cannikin.

Organic matter in Amchitka lakes is derived from several sources. Principal allochthonous inputs include organic matter flowing into the lakes in incoming streams, materials eroded from the shoreline by wave action, and excretory products of waterfowl. Slight contributions, no doubt, result from windblown matter entering the lakes. Autochthonous organic matter is contributed by primary production of plants and bacteria, decomposition processes, resuspension of organics from surface sediments, and excretion of organic matter by aquatic biota. Human occupancy and man-made disturbances would be expected to increase the concentration of organic matter in some lakes in localized areas.

Of the 26 lakes sampled for organic matter during mid-October, 14 were resampled during mid-November following Cannikin. For the 14 lakes treated as a single group, the mean value for dissolved organic matter was 32 percent higher than in the lakes posttest, as compared to the mid-October samples. A t-test showed this difference to be significant at the 95 percent confidence level. Pre- and postevent means for total and particulate organic matter were not significantly different by this test.

The significant increase in dissolved organic matter was probably not related to Cannikin, but was due primarily to the decomposition of plankton organisms with decreasing water temperatures. The variance in the amount of particulate organic matter indicates a considerable difference in standing crops of plankton in these lakes in mid-October. This was confirmed by microscopic examination of plankton samples. As water temperatures decreased in November, the more-abundant plankton populations decreased, resulting in a considerable decrease in the variance of the particulate organic matter concentrations in the mid-November samples.

While the preceding analysis indicates no widespread effects of Cannikin on organic-matter concentrations in Amchitka lakes, a localized test-related effect on lakes near SZ can be shown by treating the data in a different manner. On the basis of distance from SZ, the 14 lakes may be partitioned into two groups: Seven "close-in" lakes (44a, DK, DO, DJ, DP, 41b, and 49) are within 2.2 km from SZ; the other 7 (30, 52a, 53, 26, 9, 10, and 58b) are at distances of 6.2 to 9.8 km from SZ, and may be considered as "controls".

The mean particulate organic matter in the close-in lakes increased from 3.4 mg/l preevent to 9.9 mg/l postevent. In contrast, particulates in the control lakes decreased from 14.0 mg/l preevent to 6.5 mg/l postevent. The increase in particulate organic matter in the postevent samples from the close-in lakes no doubt resulted from increasing amounts of particulates entering the lakes from their watersheds, from bank slumping, and from resuspension of bottom sediments by ground motion.

There is no reason to believe that the considerable decrease in particulate organic matter in the control lakes was test-related. Two of the lakes in this group that showed substantial reduction in particulate organic matter had high zooplankton and phytoplankton populations during the October sampling period. It is probable that the normal seasonal decline in these populations was responsible for the reduction in particulates in the control lakes between the pre- and postevent sampling periods. This assumption is supported by the fact that in the control group of lakes, dissolved organic matter increased 53 percent from 3.2 mg/ml to 4.9 mg/ml between the two sampling periods. Dissolved organic matter in the close-in lakes increased only slightly – from 3.1 mg/l preevent to 3.5 mg/l postevent (an increase of 13 percent).

Any event-related changes that may have occurred in phytoplankton populations or in water clarity would have been obscured by the effects of the severe storm on D-1. Hence no effects of Cannikin on these parameters were measured.

Fish

Effects of Cannikin on natural fish populations, on penned individuals, and on salmon eggs artificially emplaced in stream gravel, were monitored in the freshwater streams and lakes.

The distribution and approximate numbers of fish were documented in 12 lakes and 4 streams within 2 km of SZ before and after Cannikin (Figure 14). This area was selected as the anticipated zone of major effects (on the basis of the Milrow experience and shock predictions supplied by Sandia).

Dolly Varden (Salvelinus malma) were present in 5 of the lakes and in all 4 streams; threespine stickleback (Gasterosteus aculeatus) occurred in 10 of the lakes but in none of the streams. Pink salmon (Oncorhynchus gorbuscha) were not found within

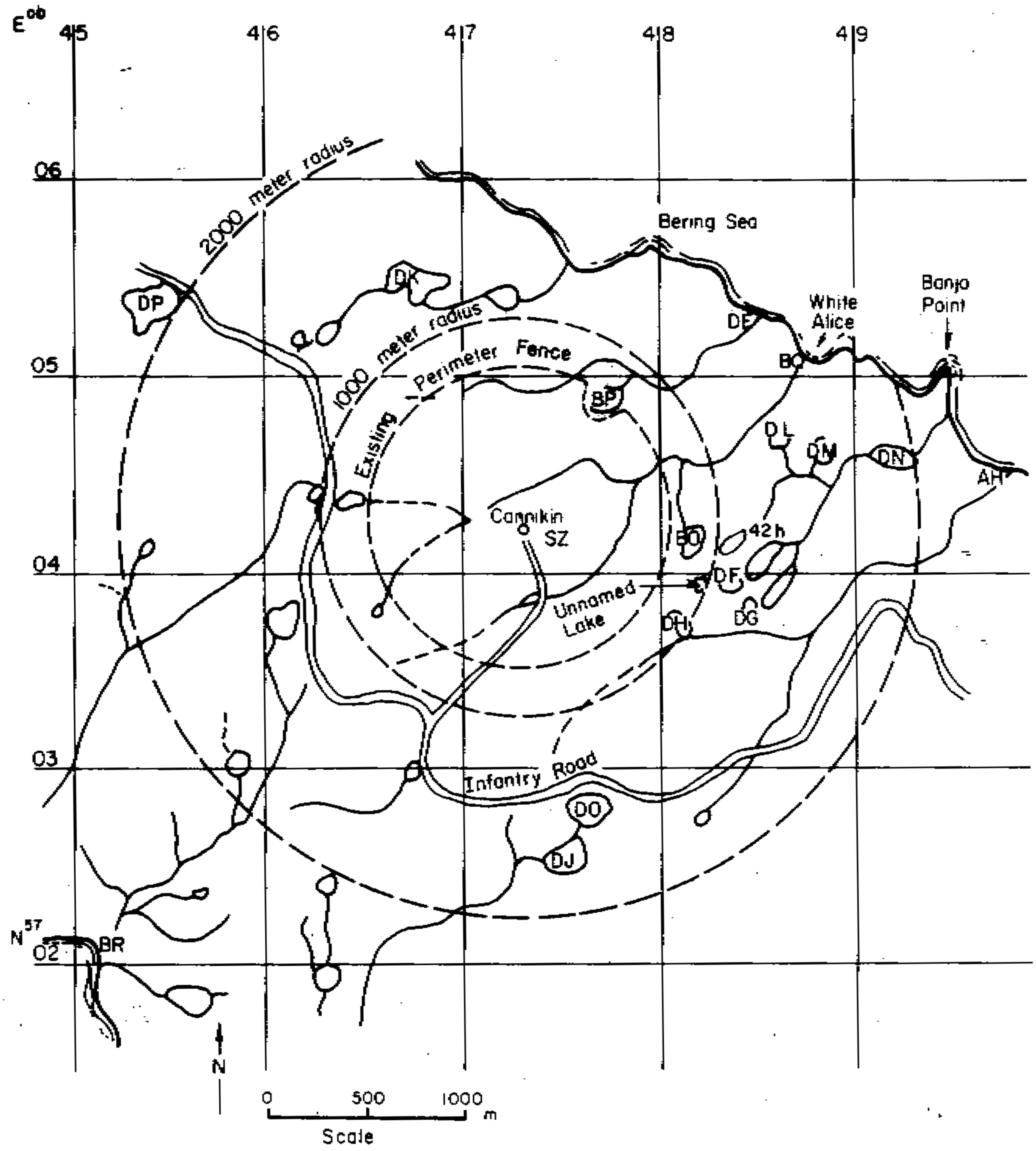


FIGURE 14. LAKE AND STREAM STATIONS NEAR CANNIKIN USED IN FRESHWATER VERTEBRATE AND INVERTEBRATE STUDIES

Grid is UMT 1000-meter, Zone 60.

2 km of SZ during pretest studies, although they spawned in one stream (Station BR) during late August, 1970. During 1971, spawning salmon were observed no nearer to Cannikin SZ than Fumarole Cove stream, about 17 km from SZ.

Testtime experiments during Cannikin involved Dolly Varden, threespine stickleback, and live, eyed pink salmon eggs. They were held in pens in lakes and streams varying in distance and direction from SZ to evaluate effects of ground motion and pressure pulses on individual organisms at known water depths and over known bottom types. Many of these live pens were accompanied by pressure gages and accelerometers intended to measure physical forces generated by the detonation (see Appendix A).

The exact locations of the live pens, a description of each type, and the species and numbers of fish held are presented in Table 6. Each type of pen was field tested with appropriate species and numbers of fish before Cannikin to determine how long they could be held without harm. Live fish could be held in a healthy state in all pens for a minimum of 7 days, and up to 14 days except during very adverse weather conditions. Fish used in all experiments were captured from lakes and streams on Amchitka.

TABLE 6. LOCATIONS AND DESCRIPTIONS OF LIVE PENS IN LAKES AND STREAMS

	Stickleback (A Pen)(a)				Dolly Varden				Salmon Egg Holders		
	Bottom Set		Floating Set		B Pen(a)		C Pen(a)		D and E Pen(a)		Distance
Station(b)	No.	Type Bottom	No.	Type Bottom	No.	Type Bottom	No.	Type Bottom	No.	Type Bottom	From SZ, meters
AH-stream	0	--	0	--	0	--	0	--	2&2	Gravel	1,700
BO-lake	1	Hard rock-mud	1	Soft mud	0	--	1	Soft mud	0	--	810-820
BP-lake	1	Hard sand	1	Hard sand	2	Hard sand	0	--	0	--	720-740
BQ-stream	0	--	0	--	0	--	0	--	2&2	Gravel	1,500
BR-stream	0	--	0	--	0	--	0	--	2&2	Gravel	2,730
DE-stream	0	--	0	--	0	--	0	--	2&2	Gravel	1,500
DF-lake	1	Hard mud	1	Hard mud	0	--	0	--	0	--	1,000
DG-lake	0	--	0	--	0	--	0	--	0	--	1,180
DH-lake	0	--	0	--	1	Soft mud	0	--	0	--	940
DJ-lake	1	Hard mud	1	Soft mud	0	--	0	--	0	--	1,600
DK-lake	1	Hard rock-mud	1	Soft mud	1	Hard rock-mud	1	Soft mud	0	--	1,210-1,250
DL-lake	0	--	0	--	0	--	0	--	0	--	1,350
DM-lake	0	--	0	--	0	--	0	--	0	--	1,520
DN-lake	1	Hard rock-mud	1	Hard rock-mud	1	Hard rock-mud	0	--	0	--	1,300
DO-lake	0	--	1	Soft mud	1	Soft mud	0	--	0	--	1,430-1,450
DP-lake	1	Hard rock-mud	1	Hard rock-mud	1	Hard rock-mud	0	--	0	--	2,050-2,070

(a)

Type Pens	Dimensions (material)	Contents
A	7.5 x 30 x 30 cm (3 x 12 x 12 in.) - 1/16-in. mesh (galvanized wire)	25 fish
B	60 x 90 x 90 cm (2 x 3 x 3 ft) - 1/2-in. mesh (hardware cloth)	6-8 fish
C	90 x 120 x 180 cm (3 x 4 x 6 ft) - 1-in. mesh (cotton netting)	8-10 fish
D	10 x 30 x 30 cm (4 x 12 x 12 in.) - 1/16-in. mesh (plastic screen)	500 eggs
E	30-cm x 10-cm-diameter cylinder (clear plastic)	500 eggs

(b) Refer to Figure 14 for exact locations of stations.

In addition to the penned fish described above, approximately 8,000 live eyed pink salmon eggs were held in containers in the four streams nearest Cannikin SZ (Table 6). An additional 2,000 live eggs were retained at the base camp, about 15 km from SZ, to serve as experimental controls. The eggs, provided by the NMFS Biological Laboratory, Auke Bay, Alaska, were from a natural population of pink salmon from Sashin Creek, near the southern tip of Baranof Island, southeastern Alaska. These eyed eggs had been fertilized about 60 days prior to their shipment and were in a life-history stage relatively immune to shock and other environmental stresses. Eggs from Amchitka stocks of salmonids were not used for testtime experiments because pink salmon spawners on Amchitka were too few and scattered to provide adequate numbers of eggs, and the spawning period of Dolly Varden on the Island occurred later in the fall than the Cannikin test date.

All of the pink salmon eggs used were thoroughly mixed to help insure that all lots (control and experimental) were comparable. Two types of containers were used: plastic cylinders with 3-mm-diameter holes to permit water circulation, and rectangular, flexible, small-mesh screen containers fabricated on the Island. Before the salmon eggs were introduced, the plastic cylinders were weighted with small stones to overcome their buoyancy. The mesh containers were filled with gravel, as from a natural redd, into which the eggs were mixed. Both were buried in the stream gravel.

Post-Cannikin studies began on D-day and continued through D+3, during which time all accessible lakes and streams were resurveyed by similar seining and electrofishing techniques as used pretest. The shoreline of each lake and stream suspected to have been affected was surveyed by walking its perimeter and wading through its waters. Numbers and locations of dead fish found were recorded, and samples were taken for later examination. Estimates of numbers of fish killed were on the basis of previous seining results and extrapolation of numbers from dead fish actually collected. Additional surveys were made on D+31 to D+39.

A summary of observations on lakes and streams affected by Cannikin from D-day to D+3 is presented in Table 7. After Cannikin, fish were found stranded on mud flats and in small puddles of those lakes drained by the detonation (BO, DF, DH, and 42h). In these and other lakes up to 1,800 m from SZ (DH, DL, DM, and DN) some fish were also tossed onto the shoreline by the rapid upward movement of the ground. In additional lakes (DK, DM, and DN), seine hauls and shoreline walks revealed dead and moribund stickleback in the water. When examined these fish exhibited extensive internal damage: hemorrhaging, ruptured air bladders, and disrupted kidneys. On the basis of these necropsy findings, it is believed that death was due to pressure pulses.

On the basis of preevent seining results and postevent observed mortalities, an estimated 10,000 threespine stickleback and about 700 Dolly Varden were killed by Cannikin. A breakdown of these numbers by cause of death is presented in Table 8.

Strong winds on the eve of D-day (see Appendix B) severely hampered live-pen experiments. Probably all of the threespine stickleback in 7 of 15 live pens containing stickleback died before Cannikin as a result of being beaten against pens by gale-force winds. Only 9 of the 25 fish in an eighth pen in Lake DJ were alive after the test; necropsy indicated the other 16 probably died before the test. A ninth pen was found upside down with the lid off and the fish gone. The 25 stickleback in the bottom pen in Lake DK were also found dead post-Cannikin. Evidence indicated they had been smothered by bottom silt probably stirred by storm winds on D-1.

TABLE 7. POST-CANNIKIN FRESHWATER FISH SURVEY

Lake	Distance From SZ, meters	Time of Visit	Condition of Fish in Holding Pens: Dolly Varden	Stickleback: Float Pen	Stickleback: Bottom Pen	Seine Hauls	Fish Found in Shoreline Survey: On Shore	Fish Found in Shoreline Survey: In Water
BO	810	D+1	12--alive	25--alive	25--alive	--	0	0
		D+3[a]	12--dead	25--dead	25--dead	--	Many stickleback found stranded on mud flats of drained lake	
BP	720	D+1	6--alive[b]	not examined		--	0	0
		D+3	15--alive	25--dead	25--dead	--	0	0
DF	1,000	D+1		25--dead	pen not found	--	Many stickleback found stranded on mud flats of drained lake. Less than 25 tossed on shore	5--dead or feeble stickleback
DH	940	D+1	6--alive	--	--	--	Less than 30 Dolly Varden tossed on shore	0
		D+3[a]	6--alive	--	--	14 live Dolly Varden (1 haul)	0	0
DJ	1,600	D-day	--	16--dead 9--alive	25--dead	--	0	0
		D+1	--	16--dead 9--alive	25--dead	--	0	0
		D+2	--	--	--	81 live stickleback from a 20-m haul	0	0
DK	1,210	D-day	7--alive 8--alive	25--dead[c]	25--dead[d]	--	0	0
		D+2	7--alive 8--alive	--	--	45--live stickleback 9--dead stickleback[c]	0	2 stickleback dead or feeble[c] 1--Dolly Varden dead
DL	1,350	D+3	--	--	--	--	7 stickleback found tossed on shore	0
DM	1,520	D+3	--	--	--	--	0	2--dead stickleback[c] and several others--feeble
DN	1,800	D+3	7--alive	1--dead 24--alive	2--dead[c] 23--alive	#1-12 live stickleback 1--live Dolly Varden #2--47 live stickleback	23--dead stickleback	12--dead[c] stickleback
DO	1,430	D-day	6--alive	25--dead	--	--	0	0
		D+1	6--alive	--	--	--	0	0
		D+2	6--alive	--	--	--	0	0
DP	2,050	D-day	1--dead 1--feeble 6--alive	25 escaped	25--dead	--	0	0
		D+1	1--dead 1--feeble 6--alive	--	--	--	0	(1--dead greater scaup)
		D+2	6--alive	--	--	--	0	0

(a) Lake drained after subsidence crater formed at H+38.
(b) Second pen not checked.
(c) Internal hemorrhage, air bladder ruptured, kidney disrupted.
(d) Smothered by bottom silt; believed due to stirring by storm winds on D-1.

TABLE 8. ESTIMATE OF STICKLEBACK AND DOLLY VARDEN KILLED BY CANNIKIN IN LAKES

(Exclusive of mortality of fish held in experimental pens)

		Cause of Death					
		Lake Drained Fish Stranded		Pressure Pulse		Fish Thrown Clear of Water and Stranded	
Location	Distance From SZ, meters	Stb[(a)]	DV[(a)]	Stb[(a)]	DV[(a)]	Stb[(a)]	DV[(a)]
Small pond near pump station	350	0	100	0	0	0	0
Lake BO	810	2,030	300	0	0	0	0
Lake DH	940	0	270	0	0	0	30
Lake DF	1,000	5,000	0	0	0	0	0
Lake DK	1,210	0	0	2,000	0	0	0
Lake DL	1,350	0	0	0	0	15	0
Lake DM	1,520	0	0	50	0	15	0
Lake DN	1,800	0	0	850	0	40	0
Totals		7,030	670	2,900	0	70	30
Estimated Total Fish Kill		7,700		2,900		100	
Estimated Totals by Species:	Stickleback 10,000						
	Dolly Varden 700						

(a) Stb = stickleback
DV = Dolly Varden.

Death of some stickleback in five of the live pens can be attributed to the effects of Cannikin. In Lake DK, 1210 m from Cannikin SZ, all 25 fish in the floating pen were found dead. Necropsies showed that these fish had extensive internal hemorrhage, ruptured air bladders, and disrupted kidneys; these are characteristic symptoms of pressure effects. In Lake DN, 1800 m from SZ, one dead fish and 24 live ones were found in the floating pen; the bottom pen contained two dead and 23 live fish. Examination of the dead fish indicated that only the two from the bottom pen were killed by pressure effects of Cannikin. One pen in Lake DF was not found and is presumed to have been lost through a fissure that opened in the lake bottom. All stickleback in both live pens in Lake BO survived the D-1 storm winds and the detonation, but were killed by stranding when the lake drained during subsidence.

Of the 69 Dolly Varden held in live pens during Cannikin, 55 survived the test unharmed. Twelve were killed by stranding when Lake BO drained. In Lake DP, two fish were found dead post-Cannikin, but cause of death could not be ascertained; it is not thought to be test related.

Four of the six plastic cylinders used to hold eyed pink salmon eggs during Cannikin were damaged by ground motion. The spring pins holding the top of the two containers in stream DE were jerked loose and a portion of eggs in one cylinder and all those in the other were lost. Both cylinders in White Alice Creek were cracked by the event but no eggs were lost. The two mesh bags holding eggs in White Alice Creek were buried by a rock slide. All the other containers were recovered without damage.

No dead eggs were found in any of the 12 containers recovered when they were examined on D+1 and D+3. A portion of the eggs from each of the four experimental streams was removed D+3, placed in shipping trays, and returned to Logan, Utah. The control eggs, held in the shipping tray during Cannikin, were also returned. All egg groups, control and experimental, were placed in separate hatching trays for observation of hatching and mortality. Facilities for these observations were provided through the courtesy of Mr. Ron Goede of the Utah Experimental Hatchery in Logan, and the Utah Division of Wildlife Resources. Data on hatching and mortality of these salmon eggs while held at the Logan Hatchery are presented in Table 9.

TABLE 9. HATCHING SUCCESS FOR FIVE GROUPS OF PINK SALMON EGGS HELD DURING CANNIKIN ON AMCHITKA, ALASKA

Data were taken after eggs were held 32 days in hatching troughs.

Location	Type Holder	Distance From SZ, m	Total Eggs	Total Eggs Hatched	Percent Hatched
Stream BR	Mesh bag	2730	204	194	95.1
Stream BR	Cylinder	2730	248	232	93.5
Stream DE	Cylinder	1500	113	102	90.3
Stream BQ	Cylinder	1500	336	297	88.4
Control			273	270	98.9

Next to the control, highest hatching success and lowest egg mortality was observed in the two egg groups held in Stream BR, the station farthest from SZ (Figure 14). Lowest hatching success was observed in one of the groups closest to SZ (Station BQ), in the stream which received most physical damage. While under observation in the hatching troughs, numerous larvae in this latter group died attempting to hatch or were hatched deformed. Many of the symptoms were typical of eggs affected by shock.

The initial hatching rate was considerably lower for groups at Station BQ than at the other locations, although after D+29 it accelerated over that of the other groups.

A Chi^2 test of significance between each experimental group of eggs and the control group shows that the hatching success of eggs in only one stream (Station BQ) differed from the control, and then only at the 30 percent level of significance (70 percent confidence limits). Because the control eggs were handled differently from the experimental eggs (the experimental eggs were subjected to more handling during transport to streams, placement in containers, burial in gravel in streams, retrieval, and transfer back to camp), it is difficult to relate the cause of any mortality of eggs to Cannikin.

Additional groups of eggs were left in each stream after Cannikin to determine survival and hatchability in the field. The two groups of eggs in Stream BR, the station farthest from SZ, were recovered on D+37 and only five dead eggs were found in one group. Fifteen eggs in each group had hatched and the remaining eggs were all alive (about 200 per group). The cylinder in Stream AH was partly filled with mud and silt and all but 34 eggs and 14 hatched fry were dead (about 280 eggs). All remaining eggs in White Alice Creek (Station BQ) were found dead. There was no silt in the cylinder and the reason for loss of these eggs cannot be determined conclusively. The stream had earlier been contaminated by drilling wastes from the Cannikin site, and residual materials from this contamination may have been released by ground shock at testtime. It should also be noted that after subsidence, the flow rate in the lower section of the stream where the eggs were located was drastically reduced.

To summarize, about 10,000 threespine stickleback and 700 Dolly Varden were killed by Cannikin. No adult or immature salmon were near Cannikin SZ during the event, and no salmon kills were recorded. Threespine stickleback and/or Dolly Varden were found dead in eight lakes or ponds, 350-1800 m from SZ. Fish kills in these lakes and ponds resulted from the following: fish were stranded as a result of lake drainage by tilting or cracking of lake beds, fish were killed by detonation-generated pressure pulses that ruptured air bladders and blood vessels, and a few fish were stranded when ground motion tossed the lakewater ashore. Only stickleback were killed by pressure effects and only a fraction of the stickleback populations in the three lakes where this occurred were killed. Most of the fish killed by Cannikin, about 70 percent, were killed by stranding when four lakes, 1000 m or less from SZ, drained.

Physical Changes

Physical alteration of lake and stream beds occurred in two phases of ground motion: the first resulted from the detonation, and the second from the formation of the subsidence crater at H+38 hours.

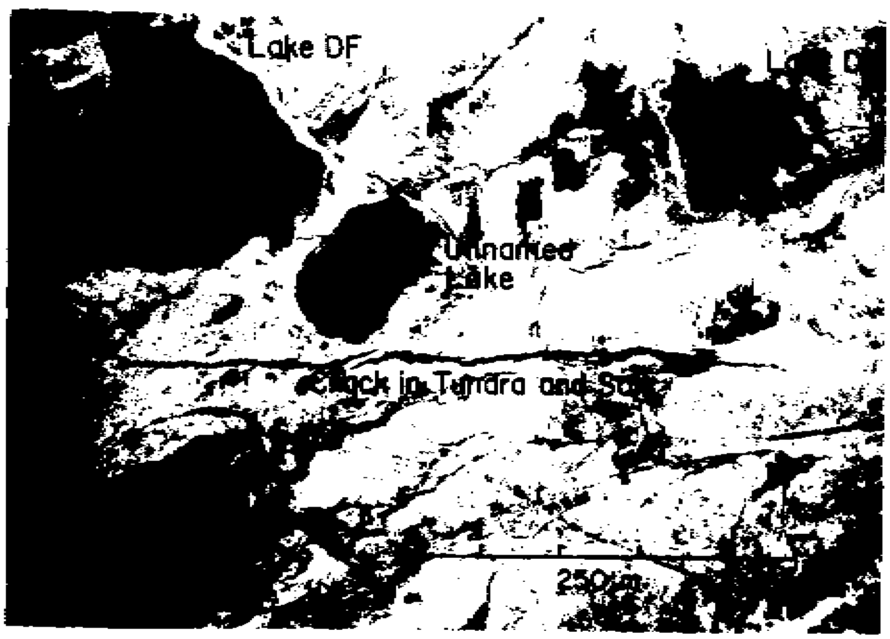
Resulting fissures and scarps, described elsewhere in this report, drained six freshwater lakes within 1.2 km of SZ. Four of the lakes (BO, DF, DH, and an unnamed lake) were among a cluster of seven lakes located about 1 km east of SZ (Figures 14 and 15). A fifth (44a) was about 1.2 km southwest of SZ, and the sixth (an unnamed lake) was located about 0.9 km west of SZ. Ten other lakes were changed because of water loss and slumping of banks.

Lakes BP, BO, and DH, at the periphery of the anticipated collapse crater, were noticeably tilted away from SZ on D+1. However, on D+3, after crater subsidence, these three lakes were noticeably tilted toward SZ. A large fracture developed on the west shore of Lake BO through which the lake completely drained. Tilting and draining apparently occurred quite rapidly, because a "slosh" zone on the shoreline on the downward side was apparent after drainage.

Lake BP, 0.74 km northeast of SZ, had a decreased water level following Cannikin. This probably resulted from water splashing out of the lake at testtime and during the storm on D-1. No cracks in the bottom seal were observed.

Only White Alice Creek (Figure 14) sustained major channel disruption. Flows in the two tributaries of this creek on either side of Cannikin SZ were severely altered, both by blockage of the stream channels and by the terrain changes that took place on formation of the subsidence crater (Appendix C). In many places, stream banks caved in and mounds of turf temporarily blocked the channels. The most notable blockage resulted from a large tundra slide into White Alice Creek below the confluence of the two branches, about 1.1 km northeast of SZ (Figure 16). Flow was interrupted and temporary ponding occurred behind the slide. A long scarp resulting from Cannikin formed a 1.2-meter-high bank across the south branch of White Alice Creek just east of SZ, and a new lake promptly formed behind it. The lake shows up prominently in Plate 2, taken on D+5, and was still there when USU investigators visited the site on D+31.

a. Photographed on D-53



b. Photographed on D+5

FIGURE 15. FRESHWATER LAKES BEFORE AND AFTER CANNIKIN

The center of the photo is about 0.9 km from SZ, azimuth 110°. Note cracks in lake bottoms, and long scarp in tundra, in the post-Cannikin photograph. (BCL photograph numbers 13A-74 and 1B-87.)

Photographed on D+5

FIGURE 16. A TUNDRA SLIDE INTO THE CHANNEL OF WHITE ALICE CREEK, 1.1 KM FROM SZ, AZIMUTH 69°

Note ponding in stream channel above slide. (BCL Photograph No. 7B-148)

Stream discharge at the mouth of White Alice Creek was markedly altered. U. S. Geological Survey (USGS) personnel reported that flow at the stream gage in the lower reach of the stream stopped immediately after the event, but resumed at a much reduced rate on late D-day and early D+1 (Appendix C). Throughout the lower section of the stream, rock and turf slides created many small temporary dams, through which the stream has carved a meandering course (observed on D+34).

Temporary high turbidity was observed by USGS personnel in Clevenger Creek and Constantine Spring on D+1. And, as noted earlier, water and drilling wastes escaped through a broken mud pond dike at Site D and flowed down Falls Creek into the Pacific Ocean until the break was repaired on D+1 (Figure 12).

A notable effect of Cannikin on the freshwater ecosystem of Amchitka is expected to be the formation of a new lake in the subsidence crater (Plate 2 and Appendix C). Three shallow ponds now in the crater will probably coalesce as the sink fills, forming one of the largest and deepest lakes on the Island.

In summary, the Cannikin detonation and subsequent formation of a collapse crater drained six lakes and modified 10 others by changing water levels and/or slumping of shore materials. The course and flow rate of one stream, White Alice Creek, was drastically altered, and a new lake is forming in the collapse sink, which intercepts the upper drainage of this creek. Falls Creek was contaminated throughout most of its course by drilling wastes from a holding pond at Site D. The long-term effects of these changes on freshwater fishes and other freshwater biota are yet to be determined.

Terrestrial Ecosystems

Most studies of terrestrial ecosystems of Amchitka were designed to measure the long-term effects of Cannikin. Major emphasis in these studies was placed on avian ecology; studies were also conducted on soils and plant ecology. The avifaunal studies were carried out by investigators from the Chesapeake Bay Environmental Center, Smithsonian Institute (SI) with assistance from a scientist from Brigham Young University (BYU). Soils studies were conducted by a geomorphologist from The Ohio State University (OSU); and plant ecology studies were conducted by a scientist from the University of Tennessee (UT).

Avian Ecology

Studies on the avifauna of Amchitak during late October and early November of 1971 were centered around Cannikin. The principle objectives were to document test-related avian mortality, changes in avian population densities, and damage to habitats (especially nesting sites used by bald eagles and peregrine falcons).

Personnel in the avian ecology program were on the Island October 18 through October 25, and November 9 through November 15, 1971. Thus, testtime observations on avian populations ended 11 days before, and began again three days after, the test. The census counts discussed below must be interpreted in light of the 14-day period between the last pretest counts and the first posttest censuses. Sixteen dead waterfowl (Table 10 and Figure 17) were found during the early posttest searches. These birds were autopsied by a veterinarian of AHRC. His report is as follows:

> "Findings indicated that eight birds (seven harlequin ducks and one pelagic cormorant) had been killed by vertical acceleration while they rested on rocks. The force was transmitted in such a way as to cause fractures of the legs, ribs, and spine, and the lungs were macerated in all.
>
> "Seven birds were evidently killed by overpressures in water. These animals had no broken bones, and the abdominal viscera were little affected. All had severely hemorrhagic lungs, and some were bleeding from the ears. The scaup had extensive, encapsulated intraabdominal and intrathoracic abscesses, but it was fat and in excellent condition.
>
> "The thick-billed murre had died from natural causes. Depletion of the pectoral muscle and lack of fat indicated a chronic disorder of undetermined nature. The lungs and internal organs of this bird were normal in gross characteristics."

In addition to these 16 birds, two more harlequin ducks were found later. One appeared to have been killed by vertical acceleration. The other exhibited symptoms of both pressure pulse and acceleration effects; this suggests that the bird may have been in a dive and close to the bottom upon arrival of the shock wave.

The number of dead birds recovered along the coasts should not be construed as representing the total test-related mortalities among avian populations residing in the marine littoral waters. It is believed likely that an undetermined number of birds were killed along the Bering Sea coasts, but were never recovered because of the strong off-shore wind blowing on that side of the Island after the test.

TABLE 10. DEAD WATERFOWL FOUND AFTER CANNIKIN (NOVEMBER 6-9)

Species	Number Found
Horned grebe (Podiceps auritus)	1
Pelagic cormorant (Phalacrocorax pelagicus)	3
Greater scaup (Aythya marila)	1
Oldsquaw (Clangula hyemalis)	1
Harlequin duck (Histrionicus histrionicus)	8
Common murre (Uria aalge)	1
Thick-billed murre (Uria lomvia)	1
Total	16

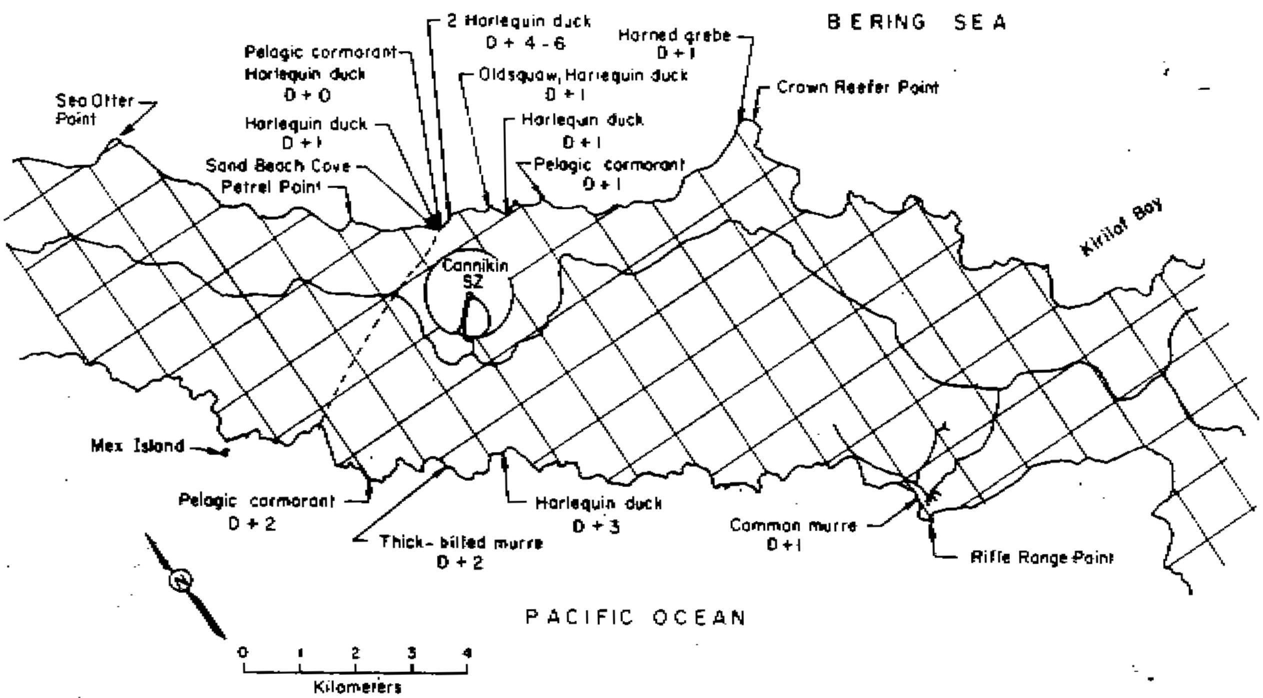


FIGURE 17. LOCATIONS OF DEAD WATERFOWL RECOVERED POST-CANNIKIN

No dead terrestrial birds were found. Two or three small dead birds were reported to have been seen near SZ after Cannikin, but a search of the area failed to confirm the report. Rock ptarmigan and snow buntings were common around SZ following the test and this, combined with the unsuccessful searches for dead birds, suggests that test-related mortality among the tundra-dwelling birds was low.

Pre- and posttest visual censuses of avian populations in the marine littoral waters were made during helicopter flights between Kirilof Point and Chitka Cove on the Bering Sea side and between St. Makarius and Andesite Points on the Pacific Ocean side of the Island. The results (Table 11) show that the number of birds seen on the posttest census was about 10 percent less than that seen on the pretest census. This difference was mainly a result of a high pretest count of glaucous-winged gulls. The gull is a highly mobile species whose movement from area to area is dictated by weather conditions and local food supplies. Consequenty, it is believed that the difference between the pre- and posttest counts of this species was not test related.

TABLE 11. HELICOPTER CENSUSES OF BIRDS ON THE BEACHES AND IN NEARSHORE WATERS BETWEEN KIRILOF POINT AND CHITKA COVE AND BETWEEN ST. MAKARIUS AND ANDESITE POINTS, BEFORE AND AFTER CANNIKIN

Species	Pretest Count October 21	Posttest Count November 11
Cormorant, red-faced and pelagic, combined (Phalacrocorax urile and Phalacrocorax pelagicus)	390	457
Emperor goose (Philacte canagica)	75	10
Mallard (Anas platyrhynchos)	18	23
Pintail (Anas acuta)	1	0
Common teal (Anas crecca)	40	0
Bufflehead (Bucephala alberola)	0	2
Oldsquaw (Clangula hyemalis)	0	3
Harlequin duck (Histrionicus histrionicus)	1147	1250
Common eider (Somateria mollissima)	65	1
Red-breasted merganser (Mergus serrator)	0	4
Black oystercatcher (Haematopus bachmani)	36	30
Glaucous-winged gull (Larus argentatus glaucescens)	712	457
Common raven (Corvus corax)	0	1
Totals	2484	2238

The common eider also declined in the posttest census; but, as these birds normally move well offshore at about this time of year, the decline is considered normal. The common teal usually inhabits the freshwater lakes in the autumn, but occasionally small flocks are seen in the marine littoral waters. One flock of 40 was seen on the pretest census, but none was seen on the posttest count, even though the numbers present on the freshwater lakes appeared to be normal. The decline in the numbers of emperor geese in the marine littoral waters cannot be explained; their numbers should be increasing at this time as the winter birds arrive. The numbers of this species will be estimated during a future winter field trip.

Aerial censuses of bald eagle and peregrine falcon populations were made around the perimeter of the Island before (October 21) and after (November 11) the test. On the pretest flight, 234 bald eagles and 18 peregrine falcons were counted, and on the posttest census 203 bald eagles and seven peregrine falcons were recorded. Weather conditions for the posttest census were poor, and high winds forced the helicopter to fly a considerable distance out from the cliffs. Consequently, the reduction in numbers of raptors counted posttest was probably weather related. Special emphasis will be placed upon future studies of the peregrine falcon and bald eagle populations to ascertain if any population decline has occurred as a result of the test.

Habitat changes resulting from the test consisted of soil and overlying vegetation slipping into the ocean from banks along both sides of the Island. They are described in another part of this report. This area is unimportant for the nesting of any avian species (Williamson and Emison, 1969), but is utilized by foraging winter wrens, Lapland longspurs, snow buntings, and rosy finches at certain times of the year. As the 6 ponds in the vicinity of Cannikin SZ that were drained and about 10 others that partially drained have never been noted to harbor any concentrations of aquatic birds, these habitat changes are unlikely to affect avian populations.

The effects of the Cannikin detonation on sea stacks and rocky cliffs were of particular concern, since such structures are used as nesting sites by bald eagles and peregrine falcons. At least three bald eagle nesting sites along the Bering coast (and a fourth that is occasionally used) and two bald eagle nesting sites on the Pacific coast were lost in cliff and stack falls (Figures 18 and 19). No peregrine falcon nesting sites used in 1971 were lost, but one used in 1969 and another used in 1970 were destroyed. The sites destroyed were in a group of three sites located fairly close together on Petrel Point (Figure 20). Only one of these sites was used in any given year, hence only a single pair of peregrine falcons appears to have been involved in their use. Whether the loss of two sites will affect the use of the remaining site cannot be determined until the 1972 nesting season. A peregrine falcon eyrie at Stone Beach Cove (Figure 18) that was damaged by Milrow was further damaged by Cannikin. The Cannikin-induced damage appears to be more extensive than that produced by Milrow.

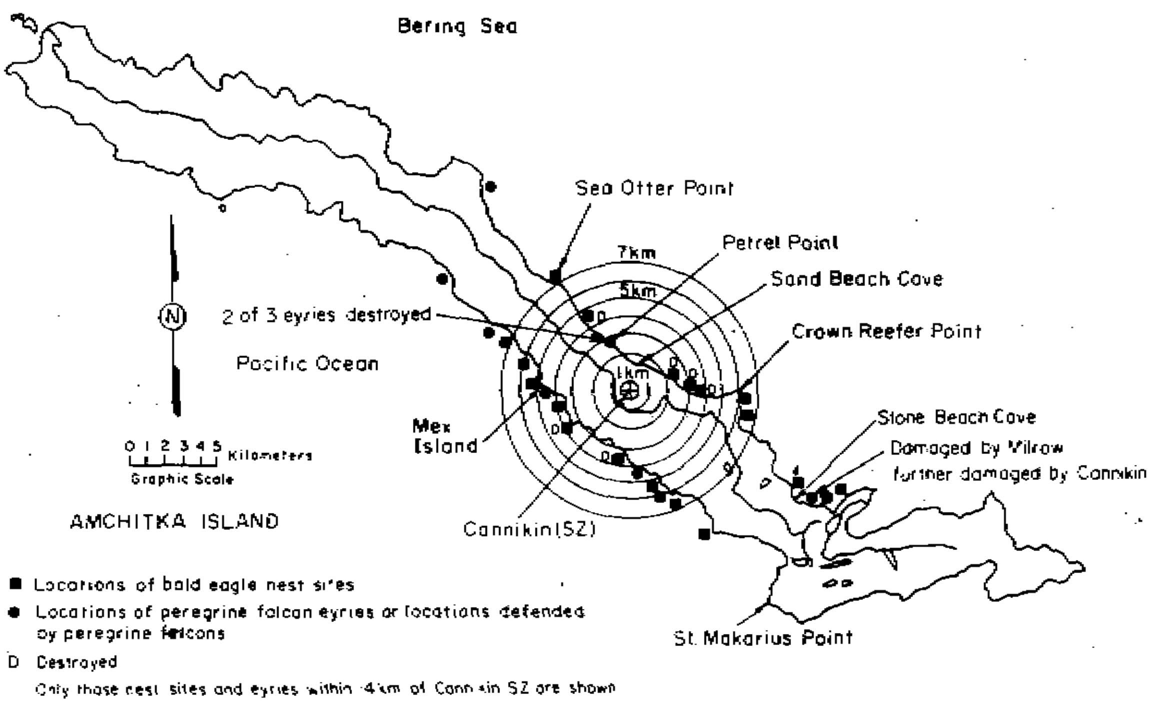


FIGURE 18. BALD EAGLE AND PEREGRINE FALCON NESTING SITES NEAR CANNIKIN SZ

a. Photographed on D-17

b. Photographed on D + 5

FIGURE 19. A SEA STACK USED AS A BALD EAGLE NESTING SITE, BEFORE AND AFTER CANNIKIN

Located on Pacific Ocean coast ~3.4 km, azimuth 236°, from Cannikin SZ. (SI photographs)

a. Photographed on D-12

b Photographed on D+1

FIGURE 20. PETREL POINT, WHERE PEREGRINE FALCONS HAVE NESTED DURING THE PAST 3 YEARS, BEFORE AND AFTER CANNIKIN

Two of the three nest sites utilized in different years by a single pair were destroyed. Petrel Point is located on the Bering Sea coast ~2.5 km, azimuth ~336°, from Cannikin SZ. (BCL photograph numbers 4A-26 and 2B-72.)

The six bald eagle nest sites destroyed by Cannikin represents about 10 percent of the number of sites used in any given year by the 55-60 breeding pairs of eagles that inhabit the Island. However, eagles have a low degree of nest-site tenacity and there are numerous suitable alternative sites that can be utilized. At most, 19 breeding pairs of peregrine falcons are on Amchitka, and this species exhibits strong nest-site tenacity. Only further observations during the next breeding season will determine whether the losses of bald eagle nest sites and peregrine falcon eyries have had any adverse effects on the reproductive success of these raptors. Certainly, there is no reason to believe that the Amchitka raptor population as a whole has been jeopardized.

The immediate test-related damage to avian populations appeared to be greatest among the diving birds inhabiting the marine littoral waters within 3.3 km of SZ. The total number of birds killed could not be determined precisely, but comparison of post- and pretest censuses indicated relatively little change in population numbers of most species. No evidence of mortality to tundra-dwelling birds was found, although an unconfirmed report of two or three small dead birds near SZ was received. Because of low counts in the posttest census, the population densities of emperor geese and peregrine falcons will be estimated during future field trips. The long-term effects of Cannikin, particularly those that might result should there be any subsequent release of radionuclides into the environment, can be determined only through future studies and comparison of pre- and posttest data.

The damage to sea stacks, cliffs, and beach ridges was considerable near SZ. Follow-up studies on the nesting success and density of the raptors and colonial cliff-nesting birds are necessary to determine how disruptive the loss of nesting sites may be to the Amchitka populations of these species.

Geomorphology

Two slope-movement grids were installed in April, 1971, to monitor movements in the tundra which might be induced by Cannikin (Figure 21). One grid was located near the mouth of Ultra Basin in an area of known, natural slope movements, about 2 km southeast of SZ. The second was established on a potentially unstable slope approximately 1 km northeast of SZ. These grids were placed in areas believed most likely to be affected by Cannikin, and that had maximum expression of the soils and vegetation range for that part of the Island. A survey of these and the two similar grids established prior to Milrow was completed in April, 1971. A preevent survey of all grids was completed in September, 1971. These 4 grids are also being used to study the effects on plant communities (see next section).

In late October, soil-moisture levels were determined for each of the soils involved in each grid at 4 depths, one always at the mineral soil-organic interface, i.e., zone of potential sliding. It was observed that prior to Cannikin the soils were quite wet; however, all values were within the range previously established for each soil type, although they were frequently near the high end of the range. Except at the Ultra Basin site, moisture levels increased with depth toward the mineral soil-organic contact. This and several other lines of evidence suggest that soil-moisture generally was somewhat above normal just prior to the event; statistical evidence to support this is lacking.

The inland surface effects of Cannikin were, as expected, more severe than those of the lower-yield Milrow event. Cannikin produced numerous examples of differential movement along faults. The surface expression of these movements was linear scarps or cracks (Plate 2 and Figure 15). Of these, major displacements or cracks are oriented obliquely to the topographic grain, i.e., approximately N70-80E following generally the trend of the major drainage, or are oriented parallel to or subparallel to the topographic grain, i.e., N30E. Displacements along these trends do not appear great, except where they may coincide with arcuate fractures produced by chimney collapse where differential movement may exceed 2.5 m. It seems likely that the fault control has strongly influenced the pattern of collapse fractures. Continuation of the major faults south and west of the main road show little surface effects of the event This is consistent with the relatively minor cliff destruction at the termini of these faults on the Pacific Ocean cliffs.

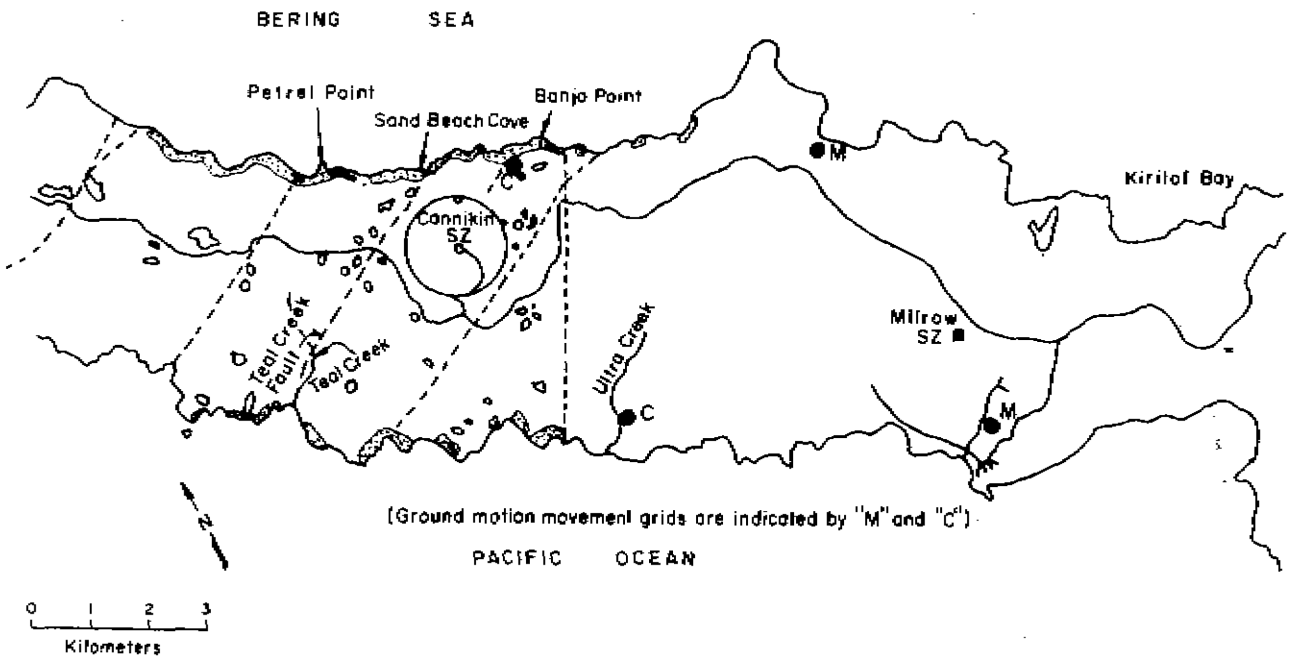


FIGURE 21. APPROXIMATE LOCATION OF MAXIMUM SEA CLIFF TURF AND ROCKFALLS INDUCED BY CANNIKIN

Fault lineaments taken from USGS Bathymetric and Geologic Map of Amchitka Island, USGS-474-74, von Huene et al., 1971, are approximate, inferred from physiographic and seismic evidence, pre-Cannikin.)

An important, although generally not apparent, effect of Cannikin involves the valleyward shift over relatively low slopes (to 8 degrees) of sizable slabs of turf. Many of these slabs may be more than 10 m^2 and involve thickness of about 1.5 m of a_2 or b soil (description of soil types in Everett, 1971). The slides occur at or just below the mineral soil-organic interface, and lateral movement may range up to 20 cm. Cracks often formed by such slab movement between bh and a_2 or b soils but sometimes occurred entirely in the a_2-b soil. Because of the thick spongy mat of vegetation, the crack is seldom seen. The crack may be filled with water to within about 0.5 m of the surface. Where such shifts took place near the valley bottom or along restricted segments of the streams, ponding occurred.

In some topographic depressions surface water flow suggests collapse of the subsurface drainage that forced the flow to the surface. Not every "turf glide" has resulted in damming of surface flow or collapse of the subsurface drainage. Opening of the cracks along the slope may result in some drainage of the immediately adjacent peat, but low lateral hydraulic conductivity will minimize this effect.

One of the most common and obvious forms of surface disruption is the tearing of the organic mat and some ejection of mineral soil and rocks just off ridge crests. Such areas are noticeable east of Teal Creek Fault (Figure 21) and on ridges, especially those parallel to a major fault or topographic alignment. Such cracks have occurred because of the proximity of bedrock, thin cover of organic material, and abrupt change in slope. The breaks probably resulted in a shift downslope of the steeply sloping organic cover, such as has occurred at the movement grid established east of White Alice Creek. Postevent surveys of this grid should document the extent of movement.

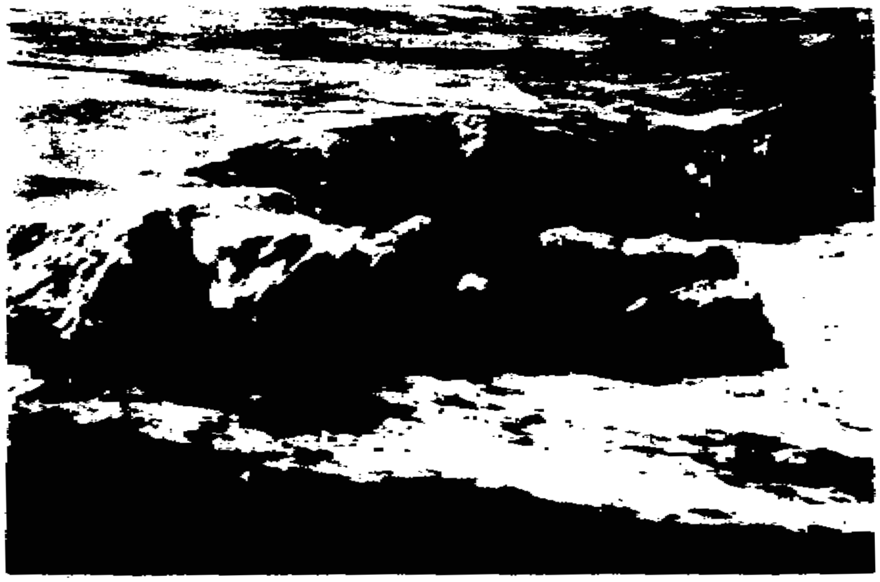
Associated with the crack systems that contributed to the drainage of the small ponds just east of the SZ perimeter fence is a tundra thrust sheet, i.e., a sheet of tundra approximately 1 m thick, thrust eastward from a shallow basin up and over (0.5-1.0 m) adjacent undisturbed tundra. The thrust plane was at the peat-bedrock (rubble) interface. In some places water was also ejected. In other areas of this basin "turf glides" occurred. This combination of disturbances has brought about ponding.

Subsidence and collapse of underground drainage channels will result in ponding and related changes in vegetation which may be extensive, especially east of SZ. The full impact of this will not be fully apparent until the summer of 1972. Changes in soil moisture and vegetation associated with faults, thrusts, "turf glides", etc., will be localized and may not be fully complete for several seasons.

Significant soil eruptions produced by hydrostatic pressure were noted approximately 1.4 km eastsoutheast of SZ, another at the northwest corner of SZ pad, and a third in the beach sands of Sand Beach Cove, approximately 1.2 km north of SZ. All eruptions are associated with major fault traces.

Cannikin produced substantially more coastal rockfalls and turf slides than Milrow. These effects are most apparent along the sea cliffs facing the Bering Sea, from a point just east of Banjo Point to just west of Petrel Point (Figures 21 and 22). Except for the rockfall at Petrel Point, all the major rockfalls occurred in the eastern half of this sector, as did the principal uplift of intertidal bench referred to earlier. Preliminary calculations of the principal rock and turf falls along this coastal segment indicate that a minimum of some 25,000 m^3 of rock and turf were dislodged by Cannikin. This value was determined from pre- and postevent high-quality oblique air photographs. This minimum value exceeds the latest pretest estimation by an order of magnitude (Kirkwood and Fuller, 1971).

Several factors contributed to the large amount of damage in this relatively short segment of coast: (1) the uplift and major-rock-fall area is bounded by two major cross-Island faults; one crosses the Bering Sea coastline just east of Banjo Point and the other, the Teal Creek Fault, lies between Petrel Point and SZ and crosses the Bering Sea coast at Sand Beach Cove. Pending geologic confirmation, it appears that numerous small faults and joint systems for which no surface or outcrop evidence existed occur between the two major faults. Differential movement on these small faults, coupled with the general uplift between the two major faults, served to focus energy in this area; (2) the



a. Photographed on D-14

b. Photographed on D+1

FIGURE 22. SEA CLIFFS ALONG THE BERING SEA COAST, BEFORE AND AFTER CANNIKIN

Banjo Point, ~2.2 km, azimuth 70°, from Cannikin SZ. (BCL photograph numbers 4A-12 and 2B-53.)

highly jointed and apparently more-resistant Banjo Point formation forms most of the Bering Sea cliff between these major faults. Natural erosion of this formation produced numerous narrow, projecting headlands. The extent of deep weathering and joint separation on these headlands contributed to the rockfall from the upper portions of these features; (3) turf falls and slides were numerous. The Teal Creek fault is the boundary, on the Bering Sea coast, between the Banjo Point formation to the east and the Chitka Point formation to the west. Cliff segments composed of the less resistant Chitka Point formation do not generally erode to free-standing headlands. They frequently support ancient sand dunes or are veneered with sandy soils. As a consequence, turf falls and slides were the dominant forms of mass movement produced by Cannikin in these areas. Such movements contributed a minimum of 5000 m^3 to the total for this coast segment. For the most part they involved thin sheets of turf which moved over bedrock on the steep (to 43 degrees) slopes, such as those just east of Banjo Point. Other smaller slides were channeled in natural erosion chutes. Many of the turf slides, especially between SZ and west of Petrel Point, showed evidence of fluid flow, as shown by their bulbous termini as well as by the semiliquid condition of their surfaces several days after the event. Such flows were characteristic of areas capped by ancient sand dunes or where the sand content of the soil was high (Group b soils). Sands whose moisture exceeds a critical value are easily fluidized by vibration.

Damage to sea cliffs on the Pacific side was not as great as expected. Estimates based on comparison of pre- and post-Cannikin photographs place the combined rock and turf fall at 2000 m^3, compared to the preevent maximum prediction of 3170 m^3. Damage was heaviest eastward from Teal Creek, for a distance of about 2 km along the coast. Several small sea stacks were toppled in this area. In local areas further east toward Ultra Creek, several turf and/or rockfalls occurred. Just as on the Bering Sea coast, the location of maximum damage was strongly fault controlled.

Rain wash and freeze-thaw, especially during the winter of 1971-72, will produce additional minor rockfall along both coasts.

Terrestrial Vegetation

Four grid plots described under the Geomorphology Section (Figure 21) were chosen for plant-community studies because they are located in areas where the degree of drainage restriction was well defined by soil differences, and the composition of the plant communities varied greatly. Vegetation maps were prepared for each of the plots, and preshot aerial and ground photographs were taken of each.

Because a notable effect of ground shock produced by Milrow had been the explosive disruption of moss (turf) mounds (Kirkwood, 1970), an effort was made to determine the cause of this phenomenon. In a crude attempt to estimate internal pressures generated in turf mounds by the detonation, 10 sealed cans were planted ~0.5-m deep in four turf mounds approximately 1.5 km from Cannikin SZ. (Similar mounds close to Milrow SZ had exploded during that detonation in a way that suggested increased hydrostatic pressure was responsible.) None of the cans planted in the turf mounds were crushed or completely ejected, but some movement occurred in two of the mounds. The two mounds appeared to have been compacted by the shock, while the tundra around them had a "fluffed" appearance.

The number of turf mounds fractured by the shock produced by Cannikin was much smaller than anticipated. Only 7 definitely fractured mounds were found, all just east of, and within 1 km of SZ. There were fewer of these features close to Cannikin SZ than to Milrow SZ, but even some mounds in relatively similar locations did not visibly fracture as a result of the Cannikin shock.

Changes in drainage resulting from Cannikin can be expected to cause shifts in the composition of the plant communities in affected areas. It seems likely that the relatively mesic crowberry meadow community, which is most widespread in the Cannikin locality, will be most severely altered, with the shifts either to wetter sedge-lichen meadow or toward drier crowberry-stripe communities.

Effects of Cannikin on plant-community structure will not become apparent until after one or more growing seasons, but it is now possible to predict the kinds and, with some reliability, the magnitude of changes that are likely to occur: (1) plant communities that will be inundated by the new lake(s) will be lost; (2) terrestrial plant communities will develop on the exposed bottoms of lakes that drained and do not refill with water (the first stages of this succession will be dominated by sedges); (3) plant communities will eventually grow on surfaces newly exposed by rockfalls and turf slides [this succession will begin with bryophytes and be followed by graminoid species (sedges and grasses)] ; (4) two plant communities along the sea coast near SZ will be relocated because of the change in soil moisture (this will result as a consequence of the turf slides along the bench-like terraces just inland from the cliff tops). The drier grass community (primarily Elymus, Festuca, and Calamagrostis spp.) will be located further inland from its pre-Cannikin location, and the sedge-lichen community will, as before, be inland from the grass community. Although this shift will vary greatly according to terrain and distance from SZ, it is expected to involve a 2000 to 3000-m^2 area. The area where the shift will be most pronounced will be between Banjo Point and Petrel Point. In this area the extension inland of the grass community may be as much as 10 m, though averaging only about 1 to 2 m.

It will be some time before a complete assessment can be made of the changes to the vegetative cover of Amchitka caused by Cannikin. Ecological processes on Amchitka differ greatly from those in more moderate climates at similar latitudes, and recovery from disturbance will be slow.

Bioenvironmental Radioactivity

The nuclear tests at Amchitka were designed to contain all radioactivity underground. However, biological and environmental samples were collected for radionuclide analyses since the inception of the current bioenvironmental research program in 1967 (see Vogt et al., 1968; Isakson and Seymour, 1968; and Held, 1971). Objectives of this program are to obtain and interpret data on the kinds and amounts of radionuclides in the Amchitka ecosystems, and to differentiate between radioactivities that may be of Amchitka origin and those originating from worldwide fallout.

During the period covered in this report, the radionuclide analyses and resultant conclusions were the responsibility of the Laboratory of Radiation Ecology, University of Washington (LRE). The samples analyzed were collected by LRE, BCL and its subcontractors, and by FWS, ADF&G, and UAz personnel. On-site radiological monitoring was also conducted by Eberline Instrument Corporation, and an off-site radiological surveillance and public safety program was carried out by the Environmental Protection Agency, Western Environmental Research Laboratory.

Samples from the terrestrial, freshwater, and marine ecosystems at Amchitka and its environs were collected and analyzed. Seafoods and radionuclides potentially available to man through food webs were emphasized. However, organisms other than seafoods were also collected and analyzed in a search for indicator organisms (species that concentrate one or more radionuclides). Concentrations of some radionuclides besides those potentially hazardous to man were measured to provide clues to the origin of radionuclides found at Amchitka; the detection of unexpected radionuclides or unexpected ratios of radionuclide concentrations would be an alert to the possibility of a local release of radioactivity.

The samples collected near Cannikin, Milrow, and Long Shot test sites over a period of 14 months before Cannikin were analyzed for various radionuclides (Figure 23 shows locations and type of samples collected). With the exception of tritium in water samples taken near Long Shot SZ*, all of the radionuclides detected were from worldwide atmospheric fallout. Radionuclides in this category and identified in various samples were: ^{47}Sc, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{65}Zn, ^{95}Zr-^{95}Nb, ^{103}Ru, ^{106}Ru-^{106}Rh, ^{108m}Ag, ^{110m}Ag, ^{125}Sb, ^{137}Cs, ^{140}Ba-^{140}La, and ^{144}Ce-^{144}Pr. The concentrations of the radionuclides found were within the range of values reported for similar samples from other parts of the northern hemisphere (see Held, 1971).

These baseline data will enable identification of any local release of radionuclides at Amchitka by either qualitative or quantitative changes in the radionuclide content of biological or environmental samples collected post-Cannikin. No significant differences were found between the pre-Cannikin baseline samples and post-Cannikin samples collected in November and December, 1971. Some samples remain to be analyzed, but priority in analysis was given to kinds of samples most likely to concentrate radionuclides and to samples from areas believed to be most susceptible to release of radionuclides by seepage near the faults at Duck Cove and Sand Beach Cove (Figure 21). It is therefore unlikely that the results of analyses of the other samples collected in November and December will change the conclusion that there was no release of radionuclides following Cannikin.

Snow and particulates filtered from air at Amchitka during the first week of December, 1971, contained 12-day half-life ^{140}Ba-^{140}La, not detected in samples collected early in November, and a higher concentration of ^{95}Zr-^{95}Nb than did samples collected pre- and post-Cannikin in November. The ^{140}Ba-^{140}La and increases in ^{95}Zr-^{95}Nb were from worldwide fallout generated by the Communist Chinese atmospheric nuclear detonation on November 18, 1971; they were also seen in rainwater from Seattle, Washington.

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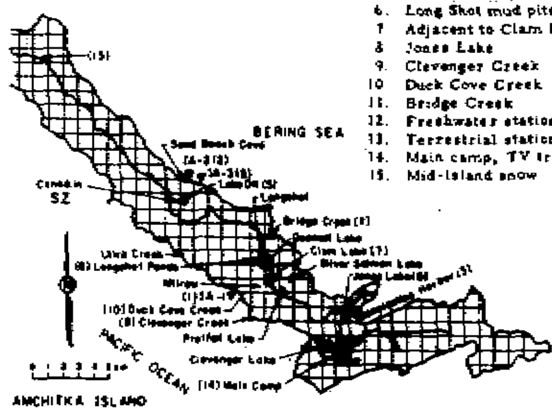
*Slow seepage of tritium to the surface from Project Long Shot is a well-documented special case. Above-background levels of tritium in surface and subsurface water samples collected near Long Shot SZ (Long Shot mud ponds and drainage ditches, small natural ponds adjacent to SZ, and hydrologic test holes located 180 meters or less from SZ) have been reported by Castagnola, 1969; Essington, Forslow, and Castagnola, 1970; and Held, 1971. The highest tritium concentration reported in these Long Shot surface-water samples was about 1.4×10^{-5} μCi/ml, some 30 times as high as that in background samples collected at Amchitka locations distant from the Long Shot site. However, the highest tritium levels in surface water from the vicinity of Long Shot SZ were still well below the Concentration Guide of 1×10^{-3} μCi per ml of water, accepted by the U. S. Atomic Energy Commission as a radiation-protection standard for continuous exposure of populations in an uncontrolled area (USAEC Manual, Chap. 0524, Standards for Radiation Protection).

Analyses of Amchitka seawater and freshwater samples for tritium are now being carried out by the U. S. Geological Survey. Tritium in commercial seafood products from the North Pacific and Bering Sea fisheries is being monitored by the Environmental Protection Agency, Western Environmental Research Laboratory. That laboratory is also measuring the tritium content of certain biological samples collected in the marine environment around the Island.

Types of Samples	Sampling Locations
Salmon	4, 12
Halibut	4
Greenling	1, 2, 3, 4
Dolly Varden	1, 4, 8, 9, 11, 12
Stickleback	5, 8
Rats	1, 2
Ptarmigan	13
Resident shore or marine littoral birds	4
Migratory waterfowl	4, 12
Sponges	1, 2
Other marine invertebrates	1, 2, 3, 4
Marine algae	1, 2, 3, 4
Freshwater algae	6
Moss and Ranunculus	5, 8, 9, 10, 11
Lichens	7, 13
Snow	15
Filter-sorption bed collections (water-borne particulates and exchangeable ions)	1, 2, 3, 4, 5, 6, 8
Air filters (operated continuously to intercept incoming worldwide fallout)	14



Key to Sampling Locations

1. Duck Cove (Pacific), intertidal zone at FRI study site IA-1
2. Uplifted area in Bering Sea intertidal zone adjacent to Site C
3. Constantine Harbor
4. Ocean or shore stations of opportunity
5. Lake DK (near Site C)
6. Long Shot mud pits
7. Adjacent to Clam Lake
8. Jones Lake
9. Clevenger Creek
10. Duck Cove Creek
11. Bridge Creek
12. Freshwater stations of opportunity
13. Terrestrial stations of opportunity
14. Main camp, TV transmitter hardstand
15. Mid-island snow

FIGURE 23. LOCATION OF SAMPLING SITES FOR RADIOACTIVITY STUDIES

The limits of detection for each analysis depends on the size of the sample available and the concentrations and kinds of other radionuclides present in the sample. In general, the limit of detection for gamma-emitting radionuclides in biological samples was less than 30 pCi/kg of fresh tissue, or approximately 1/100 of the concentration of naturally occurring ^{40}K in fish flesh. The limit of detection for gamma-emitting radionuclides in seawater separated with a large-volume water sampler (see Silker, Perkins, and Rieck, 1971) is approximately 10^{-2} pCi/l water, or approximately 1/30,000 of the concentration of naturally occurring ^{40}K in oceanic waters.

An _in situ_ gamma probe (Riel, 1966) was also used aboard the M/V _Pacific Apollo_ during the testtime period. With this instrument, gamma-emitting radionuclide concentrations at specific marine locations can be measured within a few minutes or hours of release, depending on the limit of detection being sought. The gamma probe is a less-sensitive method than the large-volume water sampler; for example, the limit of detection for ^{95}Zr in seawater with the probe is approximately 1 pCi/l water for a 1-hr count. On D+1, four sampling locations in the Bering Sea (Figure 21) near SZ showed no detectable gamma activity other than that from naturally occurring ^{40}K. This result is consistent with the results of analyses of large-volume water samples collected on D+3 at Duck Cove and Sand Beach Cove; concentrations of ^{95}Zr-^{95}Nb were 1×10^{-3} pCi/l and 1 x 10^{-4} pCi/l, respectively. The concentrations of ^{95}Zr-^{95}Nb measured at both stations on D+28 with the large-volume water sampler were 4 x 10^{-2} pCi/l; the increased concentrations also reflect the increase of worldwide fallout from the Chinese nuclear detonation.

No radionuclides detected at Amchitka are attributable to a release from Cannikin or Milrow. However, sampling and analyses of a broad spectrum of biological and environmental samples will continue quarterly until June, 1972, then sampling will be conducted less frequently unless radionuclides that can be related to either Cannikin or Milrow are discovered.

The on-site monitoring for Cannikin, conducted by EIC, involved the use of a Remote Area Monitoring System (RAMS), which measures gross gamma intensity, Air Sampling Units (ASU's), and Thermoluminescent Dosimeters (TLD's). RAMS units (18) were located in a circle of ~760 m (2500 ft) radius around SZ, at SZ (2), and at the Recording Trailer Park (2). Two TLD's were placed at each RAMS station. Battery operated ASU's (9) were located at alternate RAMS stations in the arc. Gasoline-powered ASU's were operated at the Main Camp, at the Control Point (NW Camp), and at two sites near Infantry Road, one ~1740 m (~5700 ft) eastsoutheast of SZ, the other ~1920 m (~6300 ft) northwest of SZ.

On D-day all RAMS units functioned properly up to zero time. As a result of the detonation, one unit at SZ, one at the Recording Trailer Park, and one unit in the arc failed because of wire breakage. The other RAMS units operated reliably until they were shut down on D+4. No radiation levels in excess of that from the 2mR/hr check source located on each probe was observed or recorded.

Air-sampling units located with the RAMS units in the arc were started automatically at zero time by a seismic switch and were operated through H+48 hours. Analysis of the filters and charcoal cartridges from these air samplers, by gross gamma counting, showed no event-related activity; the limit of detection was 10^{-12} μCi/cc of air.

The gasoline-powered ASU's were operated from D-1 through D+4. The filters and cartridges from these samplers showed no event-related activity.

The 36 TLD units (two located at each of the 18 RAMS units on the 820-m arc) were recovered and read at approximately D+10. The readings indicated no exposure above the preshot background accumulation rate of 6 mrad/month.

EIC also carried out an environmental sampling program designed to determine the levels of various radionuclides in vegetation, soil, and bottom mud from streams, in the immediate area around Cannikin SZ, the postshot drilling pad, and the surface drainage systems nearest SZ. Collection of samples was initiated in August, 1971, and continued through D+8. Analysis of postdetonation environmental samples showed no evidence of any contamination resulting from Cannikin.

An extensive off-site radiological surveillance and public safety program for Cannikin was conducted by the Western Environmental Research Laboratory (WERL) of the Environmental Protection Agency. The WERL program included a wide range of air sampling, dosimetry, and environmental and foodstuff sampling and analysis, at stations in the Aleutian chain, the Alaskan Peninsula, and the Alaskan mainland. This off-site radiological surveillance has indicated no change in environmental radioactivity background levels as a result of Cannikin. (U. S. Environmental Protection Agency, Western Environmental Research Laboratory, December, 1971.)

SUMMARY

Concerning the bioenvironmental consequences of the Cannikin nuclear test, the most important findings made during the period covered by this report can be summarized as follows:

- During posttest beach searches, 18 dead sea otters, three injured sea otters, two abandoned sea otter pups, and four dead harbor seals were found. The number of marine mammals killed by Cannikin cannot be determined precisely.

- Individuals representing at least five species of marine fishes were killed. Of the ~300 dead fish recovered, most were rock greenling found on an uplifted intertidal bench area. The number of fish killed in offshore waters is not known, but the investigators believe that thousands of bottom fish may have been killed, as indicated by the reduced catch per unit of effort of rock sole in the Bering Sea adjacent to SZ.

- Invertebrate animals and plants were affected locally in an intertidal bench area on the Bering Sea coast that was uplifted. Part of the area was buried by cliff falls, and the uplift of the bench is causing die-off of some algae, and die-off or migration of invertebrates that cannot adjust to the change. The affected area is about 2 km long, and comprises only a small fraction of the total intertidal bench area of Amchitka.

- Six lakes were drained, ten were partly drained, and one large new lake is forming. It is expected to become one of the largest and deepest lakes on Amchitka.

- Several hundred Dolly Varden, and perhaps 10,000 threespine stickleback fishes were killed in the freshwater lakes near SZ. Live, eyed pink salmon eggs emplaced in stream gravels within 1500 m of SZ survived the detonation with little reduction in hatchability.

- Eighteen dead birds representing seven species of waterfowl were recovered during the early post-Cannikin surveys. While the total number of birds killed is not known, comparison of pre- and post-event counts produced no evidence that Cannikin affected the population density of any species.

- No dead bald eagles or peregrine falcons were found. Six eagle nesting sites were destroyed, two of three peregrine falcon eyries located at Petrel Point were destroyed and one eyrie damaged by Milrow was further damaged by Cannikin. The six eagle nesting sites represent about one tenth of the sites occupied in any one year by the 55-60 nesting pairs of bald eagles, but numerous suitable alternative nesting sites exist. About 18 nesting pairs of peregrine falcons are on Amchitka. Since peregrine falcons exhibit a high degree of nest-site tenacity, it is not as yet known how the loss or damage of three eyries will affect reproductive success in succeeding seasons.

- Rockfalls and turf slides of about ten times greater magnitude than predicted occurred along about 5 km of the Bering Sea coast adjacent to SZ. It is estimated that at least 25,000 m^3 of rock and turf were dislodged along this section of coast. In all other coastal areas the effects were minor.

- Numerous cracks and low scarps were formed in the tundra at the time of the detonation and when the subsidence crater formed.

- No increase in background radiation levels attributable to Cannikin were detected in posttest sampling.

- No animal, bird, or fish population on or around Amchitka Island was jeopardized by the Cannikin detonation.

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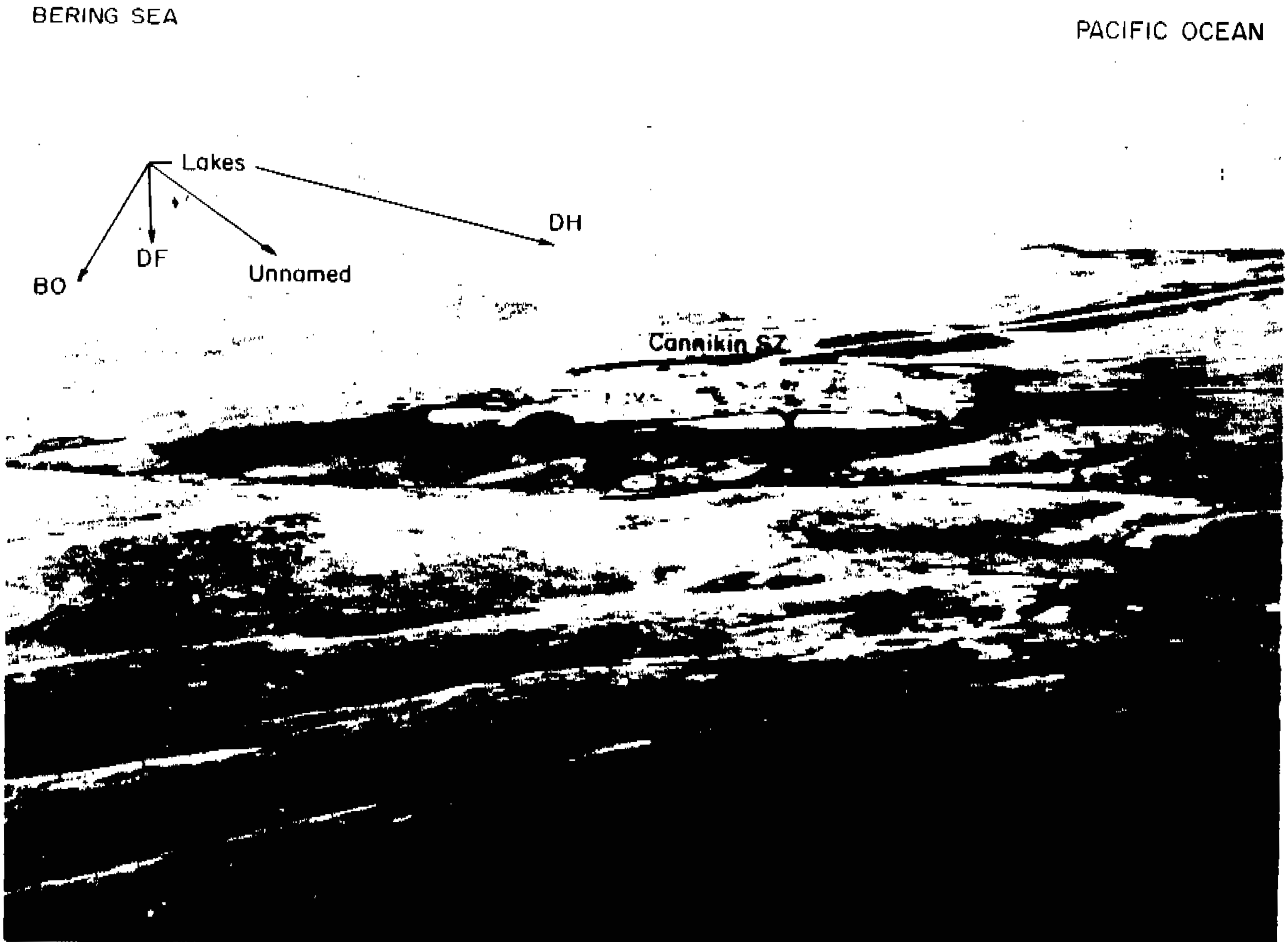

PLATE I. SURFACE ZERO AREA ON NOVEMBER 4, 1971, TWO DAYS BEFORE THE CANNIKIN UNDERGROUND NUCLEAR TEST [Looking South-East]

(Battelle Columbus Laboratories Photograph No. 2A-33)

Plate II. SURFACE ZERO AREA ON NOVEMBER 11, 1971, FIVE DAYS AFTER THE CANNIKIN UNDERGROUND NUCLEAR TEST AND AFTER FORMATION OF THE COLLAPSE CRATER [Looking South-East]

(Battelle Columbus Laboratories Photograph No. 7B-71)

APPENDIX A

PRELIMINARY REPORT

CANNIKIN GROUND MOTION AND WATER PRESSURES

Data from Sandia Laboratories,
Albuquerque, New Mexico

APPENDIX A

PRELIMINARY REPORT

CANNIKIN GROUND MOTION AND WATER PRESSURES

by

M. L. Merritt
Sandia Laboratories

Four projects are relevant to biological experimenters' need for information on ground motion and water pressures resulting from Cannikin. Sandia, as part of the Lawrence Livermore Laboratory technical program, measured underground and surface accelerations and velocities. Relevant data from this project are tabulated in Table A-1. The Earth Sciences Laboratory of NOAA (formerly the Coast and Geodetic Survey) measured ground motion with seismic instruments as far away as Shemya and Adak (West and Christie, 1971).* Relevant data from this project are given in Table A-2. Sandia, as part of the NVOO effects program, installed a number of active and passive accelerometers and pressure gages at points coordinated with experimenters of the bioenvironmental program. (Active gages are gages and recording systems that yield the whole history of the phenomenon being measured; passive gages are self-recording gages that indicate only the peak values.) Relevant accelerations from this project are given in Table A-3, and pressure data in Table A-4. The Holmes and Narver survey crew measured the heights of a great number of points on land before and after Cannikin, to obtain information on uplift or subsidence of those points. A selection of such data, including all coastal data now in hand, is given in Table A-5; the locations of a number of the survey points are shown on Figure A-8.

The Sandia surface measurements and active measurements of water pressure gave limited coverage because generator power was lost 1.8 seconds after the detonation. As a result all data from station S33 were lost, and slap-down pulses were lost on several other stations, including SB4 on the Bering Sea beach. (Experience says that the largest acceleration at surface zero is usually the first pulse, AV-1 in Table A-1. The loss of measured slap-down pulses, AV-2 in Table A-1, at station SO and SO-1 is probably thus not critical.) Typical vertical acceleration and velocity records (those for station SFSS) are shown in Figures A-1 and A-2. The acceleration pulse of 10 g at 0.55 seconds is at shock arrival. Velocity jumps to 520 cm/sec, then decreases at the 1-g rate symptomatic of spall, i.e., failure of rock in tension below the surface. When the spalled material hits bottom again at 1.55 seconds, there is a second or slap-down acceleration pulse 10 g, and velocity returns to near zero.

Peak values of these vertical accelerations (AVg), as well as those from instruments which measured only peaks, are plotted versus slant range (R) from the underground shot point in Figure A-3. The statistically best linear fit to these data is

$$AV_g = 96.5\, R_{km}^{-1.91} \;.$$

*West, L. R. and R. K. Christie, 1971. "Observed Ground Motion Data, Cannikin Event", ERC, NVO-1163-230

TABLE A-1. SURFACE MOTION

(Preliminary)

Location	Coordinates N	Coordinates E	HR, km	SR, km	θ, deg	t_a, sec	AV-1, g	AV-2, g	UV, cm/sec	dV, cm
SO	4134	6238	0.015	1.79	294	0.400	36	–	(1300) 1250	(775)
SO-1	4182	6307	0.099	1.792	238	0.450	30	–	(1200) 1100	(590)
S1	4020	6047	0.320	1.822	239	0.455	17	>10	(1000) 945	(450)
S3	4338	5367	0.967	2.053	279	0.510	15 15	35 >20	(580) (670) 610	(220)
SB4	5484	6482	1.309	2.170	7	0.550	10	>6	(640) 640	(250)
SF5S	4973	5307	1.284	2.221	308	0.545	10	16	(580) 520	(170)
SF5N	5144	4970	1.657	2.458	305	0.610	6	26	(400) 400	(107)
S6	5233	4833	1.821	2.572	305	0.650	6	25	(290) 335	(81)
SF12S	6099	4001	3.007	3.513	301	0.905	3.2	4.5	(260) (240)	(53)
SF12N	6177	3590	3.380	3.836	306	0.990	3.2	8.8	(230) 230	(48)
S18	7688	2229	5.387	5.690	300	1.480	4.0	–	(200) 240	(36)

Source: W. R. Perret, Sandia, private communication.

Coordinates are relative to N 5,700,000 E 640,000.
Numbers in parentheses are results of raw integration.
>denotes signal or integral did not reach peak.

Notation. HR = horizontal range
SR = slant range
θ - azimuth
t_a = first arrival time
AV-1 = amplitude of vertical acceleration, first pulse
AV-2 = same, second or slap-down pulse
UV - amplitude of vertical velocity
dV - amplitude of vertical transient displacement.

TABLE A-2. ERC/ESL SURFACE MOTION

Station	SR, km	θ, deg	t_a, sec	AV, g	A-vector, g	UV, cm/sec	U-vector, cm/sec	dV, cm	d-vector, cm
MO4	10.4	315	2.28	0.60	0.79	35	41	6.6	14.2
MO1	14.7	118	2.80	0.24	0.54	17	32	5.3	11.3
MO3	14.7	133	2.48	data questionable					
MO2	14.8	137	4.00	0.16 0.27	0.29 0.27	11.8	20	4.4	10.4
MO5	15.8	142	2.80	0.52	0.65	29	35	7.3	9.8
MO6	18.7	119	3.58	0.18	0.28	13.3	22	4.0	8.0
MO7	20.7	312	4.63	0.136	0.21	11.6	14	3.5	5.45
M10 (NW-CP)	36.5	300	6.10	0.060	0.089	8.5	12.5	4.4	7.2
SS1	57.4	35		0.040					
RAT	65.0	304		0.020					
AMA	126	99		0.015					
MO9 (Adak)	305	80	42.43	0.0024	0.0039	0.22	0.27	0.06	0.095
MO8 (Shemya)	370	294	52.23	0.0023	0.0042	0.23	0.60	0.06	0.16

Source: West and Christie, NVO-1163-230.

Notation: SR - slant range
θ - azimuth
t_a - first arrival time
AV - amplitude of vertical acceleration
UV - amplitude of vertical velocity
dV - amplitude of vertical transient displacement.

TABLE A-3. PEAK-READING ACCELEROMETERS

Location	Coordinates N	Coordinates E	HR, km	SR, km	θ, deg	AV, g	Gage Type
BP Lake	4760	6720	0,70	1,92	36	22,5	AD30
S3	4340	5370	0,97	2,03	278	29	AD50
CTB20	2960	6490	1,24	2,18	171	14,8	AG10
DK Lake	5390	5880	1,28	2,20	337	>30	AD30
DE Stream	5240	7410	1,51	2,34	47	16	AD20
AH Stream	3410	7670	1,55	2,37	159	19	AG30
C4	5010	7660	1,57	2,38	60	15,5	AG10
S.T.P.	5215	4840	1,80	2,54	304	14,9	AG10
S6	5240	4835	1,82	2,55	305	NG	AD
C5	4435	8680	2,37	2,97	85	17,5	AG10
C2	6480	5280	2,52	3,09	336	12,8	AG10
BR Stream	2100	4274	2,92	3,43	227	14,5	AD15
S12	6170	3580	3,38	3,83	306	12,0	AG10
C7	2330	3160	3,67	4,08	239	7,7	AG5
Microwave Station	3055	10020	3,87	4,26	103	17,0	AG10
Emerald Lake	6470	3170	3,89	4,28	306	10,7	AG10
Emerald Lake	6480	3100	3,95	4,34	306	15,7	AG10
C1	8330	3060	5,28	5,57	322	2,4	AG2
S18	7675	2240	5,37	5,66	311	8,5	AG5
C6	3920	12160	5,84	6,11	92	7,4	AG5
S33	11415	-1200	10,43	10,59	314	1,2	AG2

Notation: HR = horizontal range
SR = slant range
θ = azimuth
t_a = first arrival time
AV = amplitude of vertical acceleration.

Gage type: AD = accelerometer from Dynasciences Corp.
AG = accelerometer from Teledyne-Geotech
number is nominal gage range.

TABLE A-4. PRESSURE GAGES

Location	Coordinates N	Coordinates E	HR, km	SR, km	θ, deg	Depth, cm	t_a, sec	P_1, atm	t_2, sec	P_2, atm
BP	4760	6760	0.72	1.93	37	50-38	.50	.58	1.675	1.15
	4760	6760	0.72	1.93	37	50-38				.98
	4820	6800	0.79	1.96	37	50-38				.77
BO	4100	7140	0.82	1.97	98	45-0				.49
DH	3660	7080	0.92	2.01	125	35-23				2.01
DF	3950	7300	1.01	2.06	106	50-0				1.13
DG	3780	7430	1.18	2.14	110	45-15				.95
DK2	5390	5867	1.29	2.20	339	75	.58	.58	1.778	2.79
	5390	5867	1.29	2.20	339	75				1.73
DK1	5460	5710	1.41	2.28	334	45	.61	.88	1.741?	–
DO	2760	6560	1.45	2.30	168	50				1.77
DE	5240	7410	1.51	2.34	45	25		.47		
						25		.12		
AH	3410	7670	1.55	2.37	299	30				1.71
						30-buried		.22		
DP1	5340	4570	2.10	2.76	303	45	.71	.31	1.504	2.10
	5340	4570	2.10	2.76	303	45				1.58
DP2	5400	4550	2.15	2.80	304	75	.72	.41	1.500	.58
BR	2100	4270	2.92	3.43	224	45				1.08
						45				>.7
S12	6270	3660	3.38	3.83	309	30				.28
Emerald	6510	3185	3.91	4.30	307	90				.66
S18	7075	2390	4.88	5.20	306	25				.60

A number such as 50-38 means 50 cm preshot, 38 postshot.

Notation: P_1 = magnitude of first pressure pulse
t_2 = arrival time of second pressure pulse
P_2 = magnitude of second pressure pulse (for active gages) or of peak pressure (for passive gages).
HR = horizontal range
SR = slant range
θ = azimuth
t_a = first arrival time
AV = amplitudes of vertical acceleration.

TABLE A-5. SOME SURVEY RESULTS

Location	Coordinates N, m	Coordinates E, m	Dist., R, km	Az., θ deg	Elevation Pre, ft	Elevation Post, ft	Change Ft	Change m
Surface Zero	5,704,186	646,322	0.		207.68	191.70	-15.98	-4.87
Greatest down	4018	6650	.37	117			-50 to -60	-15 to 18
Greatest up	4447	6520	.33	37	150.13	156.53	+6.40	11.95
USGS 1B	7261	4502	3.57	329	20.099	20.390	+.291	+.09
TP 71	7110	4733	3.33	331	15.503	15.789	+.286	+.09
USGS 5BE	6472	5360	2.48	337	2.900	3.150	+.250	.08
TP 113	6286	5528	2.25	339	1.080	1.387	+.307	.09
TP 119	6100	5654	2.03	341	2.462	2.938	+.476	.145
FRI 0+00	5560	6825	1.46	20	1.907	5.415	+3.508	1.07
FRI <1	5590	6869	1.51	21	2.485	5.778	+3.293	1.00
FRI <2	5632	6940	1.57	23	2.313	5.329	+3.016	.92
FRI <3	5575	6998	1.54	26	3.395	6.325	+2.930	.89
FRI <4	5542	7058	1.54	28	2.202	4.579	+2.377	.725
TP 155	5476	7235	1.58	35	0.711	2.485	+1.774	.54
FRI <6	5380	7286	1.53	39	1.185	2.934	+1.749	.53
TP 158	5350	7280	1.51	39	7.211	9.098	+1.887	.575
TP 160	5314	7352	1.53	42	0.965	3.234	+2.269	.69
TP 161	5302	7415	1.56	44	1.570	3.729	+2.159	.66
TP 162					2.264	4.167	+1.903	.58
TP 163	5284	7508	1.62	47	1.205	2.937	+1.732	.53
TP 164	5302	7571	1.67	48	7.004	8.714	+1.710	.52
TP 166	5209	7598	1.64	51	1.478	3.567	+2.089	.64
TP 167	5149	7634	1.63	54	0.421	2.612	+2.191	.67
TP 170	5020	7715	1.62	59	1.356	4.145	+2.789	.85
TP 171	5008	7790	1.68	61	1.260	4.310	+3.050	.93
TP 174	5077	7900	1.81	61	0.645	2.591	+1.946	.59
TP 176	5020	7937	1.82	63	0.819	2.192	+1.373	.42
TP 177	5044	7982	1.87	63	2.626	4.424	+1.798	.55
TP 178	5089	8000	1.91	62	1.036	2.381	+1.345	.41
TP 180	5002	8060	1.92	65	1.503	2.905	+1.402	.43
TP 181	4963	8117	1.96	67	1.729	3.148	+1.419	.43
TP 182	4930	8200	2.02	69	1.351	2.775	+1.424	.43
TP 183	4885	8225	2.03	70	2.885	4.117	+1.232	.38
TP 185	4843	8315	2.10	73	0.447	1.729	+1.282	.39
TP 190	4930	8372	2.18	71	2.080	2.912	+.832	.25
TP 191	4948	8402	2.22	70	1.597	2.470	+.873	.27
TP 192	4915	8420	2.22	72	1.900	2.777	+.877	.27

Source: O. Sammons, Holmes and Narver Surveyors, private communication.

R = range

θ = azimuth.

(See Figure A-8.)

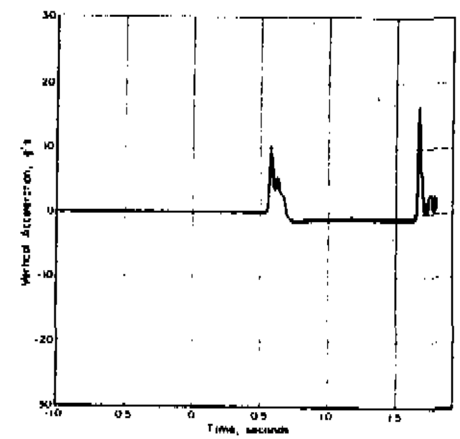

FIGURE A-1. VERTICAL ACCELERATION, STATION SFSS (HORIZONTAL RANGE 1.3 KM, AZIMUTH 308°)

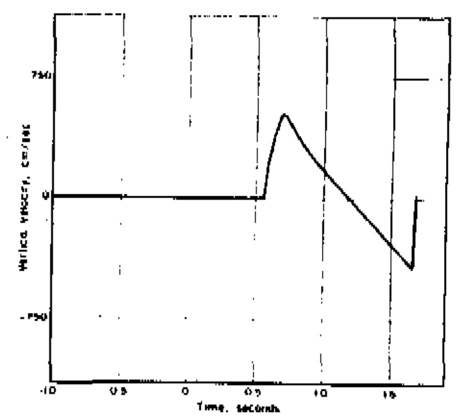

FIGURE A-2. VERTICAL VELOCITY, STATION SFSS (HORIZONTAL RANGE 1.3 KM, AZIMUTH 308°)

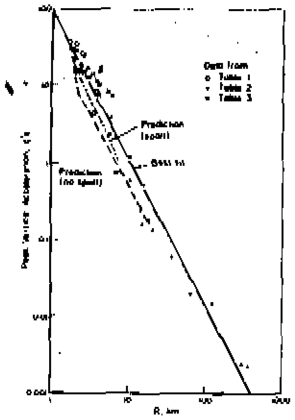

FIGURE A-3. PEAK ACCELERATIONS VERSUS SLANT RANGE

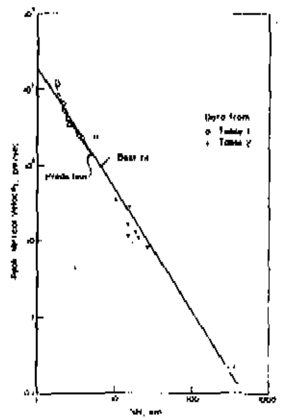

FIGURE A-4. PEAK VELOCITIES VERSUS SLANT RANGE

This fitted curve is about 50 percent above preshot predictions available to biological program investigators. Individual points vary by a factor of two about this fitted curve.

Similarly peak values of vertical velocity ($UV_{cm/sec}$) are plotted versus slant range (R) in Figure A-4. The statistically best linear fit is

$$UV_{cm/sec} = 2005\ R_{km}^{-1.61}$$

This fitted curve agrees well with preshot predictions.

Pressure measurements were made with time-resolved and with peak-measuring instruments, but only in shallow ponds and streams on land. Instruments were not installed on FRI's fish-holding pens to measure pressures at sea because bad weather kept the pens from being deployed. Mounts of instruments in ponds and streams consisted of stakes driven into the bottom or weights resting on the bottom, holding gages with their sensitive elements looking sideways (the so-called side-on position, with diaphragm vertical) so as to avoid reading dynamic pressures. Five time-resolved records resulted, two each in lakes DP and DK, and one in lake BP*. These are shown in Figure A-5. All records show an initial slowly rising and falling pulse, the one in Figure A-5a with an amplitude of about 0.3 atmosphere. They then fall to a constant level of about -0.05 atmosphere, and remain there until a second signal, unless power fails first. (The extra spike at 1.7 seconds is a power transient present on all records, and is to be ignored.) In Figure A-5a the second signal is a very sharply rising signal that reached an apparent amplitude of 2.1 atmosphere. The first pressure signal is interpreted as being the initial ground shock wave coming into the water from the rock below, limited to low pressures by reflection in tension from the upper water surface. Water is thrown up into the air at this time, and thereafter both ground and the water over it are in free fall. The gage, relieved of the pressure of the water over it, reads a steady -0.05 atm. Photography of DK lake and a nearby unnamed lake indicates that during this time the surface of the water rises faster than the ground, and takes on a white foamy appearance. It is thus possible that the gage is out of water, but if so the steadiness of the pressure observed implies that air has entered the space around the gage. The second pulse is not well explained. Photography indicates that it occurs at the time of slap-down (spall closure) in the bedrock underlying the lake. The surface of the water continues to rise, faster than before and with a more irregular and spiked appearance.

There are two possible explanations of the second pulse. One possibility is that the overlying water has been thrown free of the gage and the observed signal is a response to mud and other bottom materials thrown up by the slap-down acceleration pulse. In this case the oscillations of the second pulse seen in expanded time scale in Figure A-6 might be due to the irregular nature of the bottom coming up. Figure A-6a, on the other hand, has only a single spike. The field engineer reports that lake BP had a hard bottom about 15 cm (6 inches) thick with soft material below that, and that this layer was apparently undisturbed after Cannikin, whereas lakes DP and DK had soft mucky bottoms. The difference in bottoms is consistent with the difference in wave shapes, and lends weight to the hypothesis that the second pressure pulse is a response to bottom materials.

* See Figure 14 in body of the report for location of these lakes

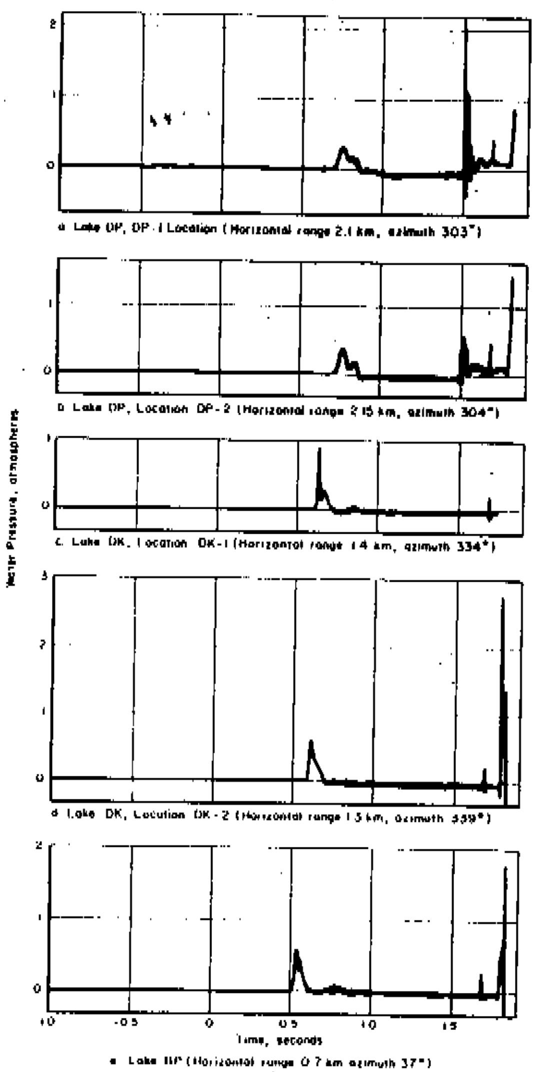

FIGURE A-5. TIME-RESOLVED LAKE PRESSURE RECORDS

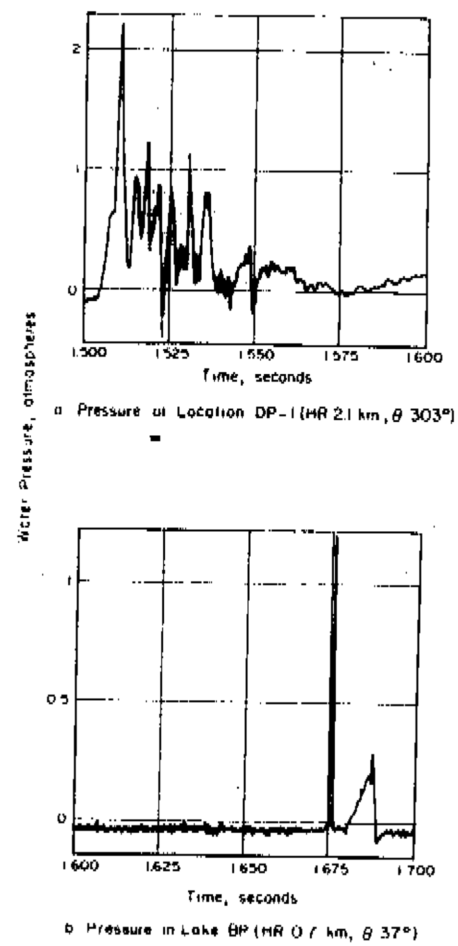

FIGURE A-6. EXPANDED VIEWS OF SECOND PULSE

The second possibility is that the second pulse observed in the pressure records is real. Simple theory (Newton's Second Law of Motion) indicates that the average pressure in shallow ponds should be related to the accelerations of the bottoms of these ponds as

$$\Delta P = \rho h a \quad ,$$

where

ΔP = pressure

ρ = density

h = depth of water

a = acceleration.

A more complicated theory that accounts for reflections within the layer of water (Merritt, 1971)*, applied to shallow water, indicates that for waves whose accelerations rise to their peak in times shorter than the reflection time in the water, pressure in the water overshoots and oscillates about what the simple theory would predict; whereas for waves whose rise times are longer than reflection times in the water, pressure follows what the simple theory would predict. Under this hypothesis the initial pressure pulse observed on each of these five gages is a nonoscillatory response to the slowly applied first acceleration pulse, and the second pulse is the oscillatory result of a very sharp slap-down acceleration pulse. If this be true, these pressure records can also be interpreted as acceleration records. Two of the five happen to be near acceleration gage installations. The pressure record at BP interpreted as acceleration yields 23 g, the acceleration there measured directly was 22.5 g. Similarly the results at DK-2 are 37 g and > 30 g. On the other hand, comparison at seven positions between accelerations derived from peak pressures measured by passive gages (P_s in Table A-4) and accelerations read by peak-reading accelerometers (AV in Table A-3) are much less satisfactory, differing generally by a factor of two. This discrepancy could, however, be due to unsatisfactory gages.

Perhaps the tell-tale observation about those second pressure pulses is that derived from the biological experiments. Postshot, many stickleback were observed killed by apparently Cannikin-related injuries. These fish, considered as biological pressure gages, imply that the second pressure pulses measured in freshwater ponds were indeed real.

In Table A-4, the apparent pressures due to slap-down are tabulated in a column headed P_S; those due to the first pulse in a column headed P_1. There is every reason to believe that if the active gages, whose operating principle was a metal diaphragm actuating a variable-reluctance pickup, responded to the slap-down; then the passive gages also responded similarly to the slap-down, since their operating principle was a diaphragm pushing an indenter cutting soft metal. The passive gages were not affected by the 1.8-second power loss, so that their results are an upper limit to the pressure where they were.

It has been noted by Everett of O.S.U., by the U.S. Geological Survey, and others that the pattern of permanent uplifts and subsidences around Cannikin is far from symmetric (with the lowest point being displaced from surface zero) and that the greatest

*Merritt, M. L. 1971. "Ground Shock and Water Pressure from Milrow". BioScience 21(12): 696-700.

coastal disturbances were between adjacent faults to the north and south of Cannikin - not that there was no disturbance beyond, just much less. Uplift on the Bering coast (Table A-5) is 2 to 4 times the 30 cm predicted there. Increased accelerations, however, were not localized to this region but as Figure A-3 indicates were general out to a distance of 6 km. That most of these high-acceleration measurements were made on passive gages suggests the presence of a systematic error. However, the further coincidence that all the time-resolved or active measurements to this distance have wave shapes indicative of an underlying spall suggests that these high readings are real. At this point in time the issue cannot be resolved.

Finally, what were the pressures in the sea to either side of the island? And in particular, were there sharply rising pulses of pressure there? On Milrow direct measurements were made of underwater pressure and of sea floor motion (Merritt, 1969).* Four out of five Milrow measurement stations (W8, 13, 16, 20) were in a region of possible spall; two (W8, 20) were in a region of cavitation. There is no indication in the Milrow records of a spall-induced pressure spike or bottom spall signal such as we have construed on land in Cannikin. In addition, the records show no sharp spikes at the end of cavitation, which is the water equivalent of slap-down. At each of the five Milrow underwater stations one of the two bottom pressure gages was recorded on IRIG channel 12, which is effectively a low-pass system with a cutoff frequency of 220 Hz; similarly a gage at each station at partial depth was on IRIG channel 13, with a cutoff frequency of 330 Hz. These gages would have recorded any spike with rise time of 3 to 5 milliseconds or longer. I conclude that there was no such pressure spike in deep water on Milrow, and none either on Cannikin.

It remains only to estimate the underwater pressures at Cannikin at sea in the absence of any direct measurement. Since the Milrow underwater pressure wave shapes are well accounted for as the superposition of waves reverberating in the water layer, each similar to the velocity of the sea floor, and since the vertical velocities measured on Cannikin are very close to those predicted (Figure A-4), the preshot predictions of deep-sea pressures remain as good estimates of what happened as can be made at this time. These estimates are repeated in Figure A-7.

Ocean-bottom overpressure and the region within which all underpressures are equal to complete pressure release or cavitation are given in Figure A-7. The most widespread effect is cavitation; its areal coverage is greater than the 100 psi (6.8 atm) contour.

*Merritt, M. L. 1969. "Underwater Motion and Overpressures, Milrow Event". Sandia Labs, [illegible].

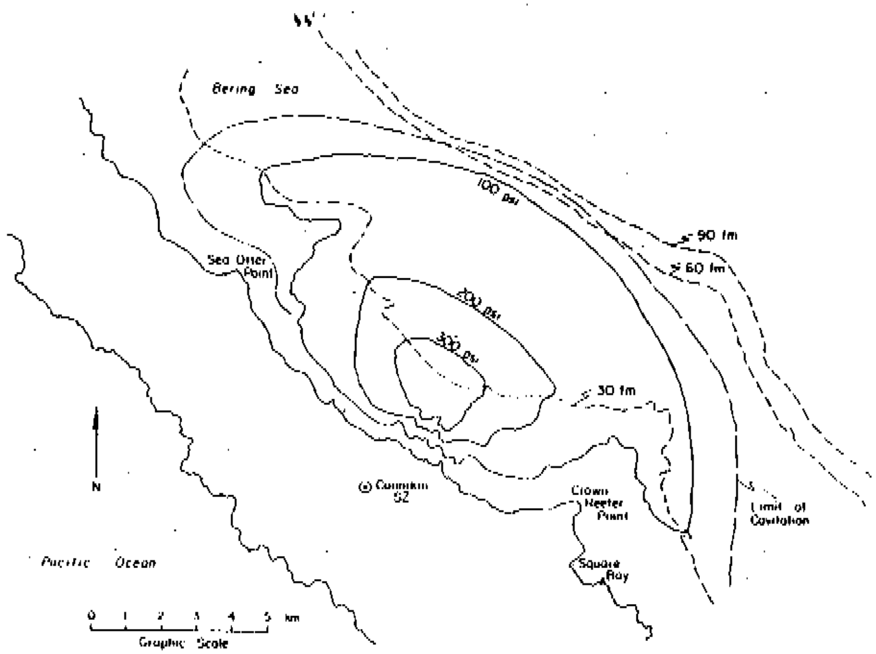

FIGURE A-7. PREDICTED OVERPRESSURE CONTOURS (AT OCEAN BOTTOM) AND LIMIT OF CAVITATION IN BERING SEA, FOR CANNIKIN

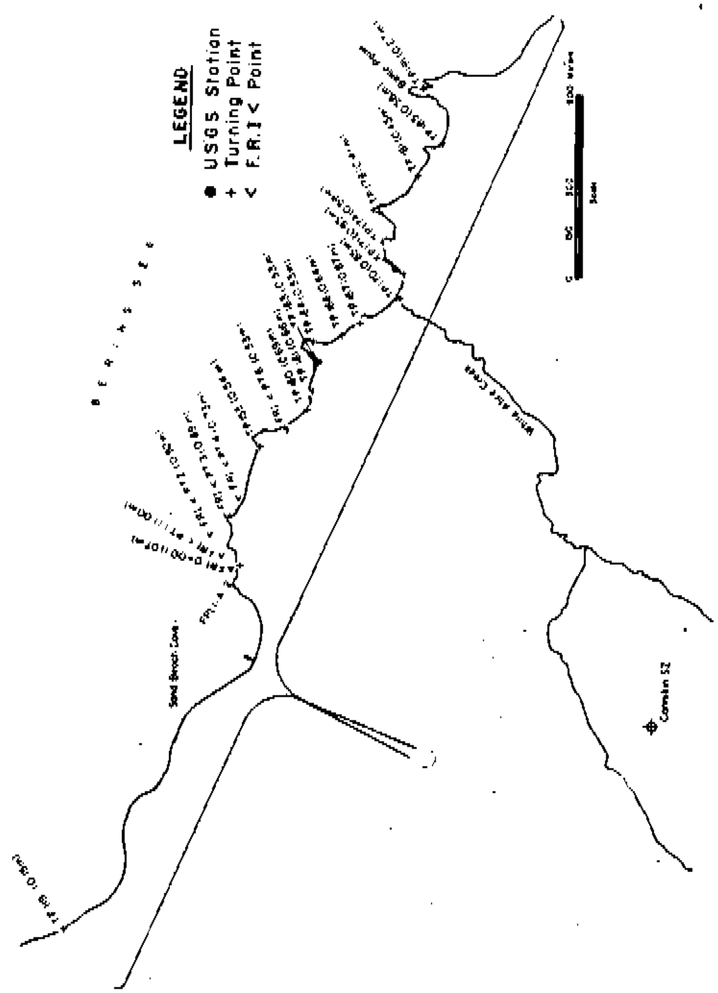

FIGURE A-8. LOCATIONS OF SELECTED SURVEY POINTS, ON BERING SEA COAST, REFERRED TO IN TABLE A-5

Numbers in parentheses show amount of vertical uplift in meters.

CONCLUSIONS

Measured peak vertical accelerations on land were in the order of 50 percent larger than the Cannikin predictions available to biological investigators. Measured peak vertical velocities were as predicted. Permanent uplifts in a section of the Bering Sea coast were 0.25 to 1.1 m - considerably larger than predicted; coastal uplifts elsewhere have not yet been determined.

Pressures in shallow on-shore waters consisted of a short duration pulse of no great amplitude - generally less than 0.7 atm after which the waters and any free swimming fish in them were thrown upwards in a state of pressure relief. On slap-down of spalled rock a hundred meters or more beneath lake and stream beds, sharp second pulses of 1 to 2 atmosphere amplitude resulted.

In the absence of direct measurements, and because surface velocities were as predicted, underwater overpressures and underpressures at sea are construed to have been as predicted preshot.

APPENDIX B

METEOROLOGICAL CONDITIONS AT AMCHITKA FROM D-2 THROUGH D+7

National Oceanic and Atmospheric Administration,
Air Resources Laboratories, Las Vegas, Nevada

APPENDIX B

METEOROLOGICAL CONDITIONS ON AMCHITKA FROM D-2 THROUGH D+7

National Oceanic and Atmospheric Administration,
Air Resources Laboratories, Las Vegas, Nevada

The National Oceanic and Atmospheric Administration, Air Resources Laboratory – LV (ARL-LV) collected meteorological data on Amchitka in support of the Cannikin test. Since the local weather conditions prevailing before, during, and after shottime are believed to have had a considerable influence on the testtime findings of the Amchitka Bioenvironmental Program, the ARL-LV data are included here. The direction and force of the winds during and after shottime are particularly important, since they undoubtedly influenced the distribution of marine mammals, birds, and fishes killed or injured by the detonation. ARL-LV has concluded, on the basis of a review of all weather data available from the area, that the best information on the direction and velocity of the winds over the southeastern half of the Island, where Cannikin SZ is located, is that recorded by the sensors on Tower 8, an 88-ft. tower located at the Main Camp. Data were collected at this station only on D-1, D-day, and D+1.

This Appendix presents, in addition to the Tower 8 data, the weather data collected at the Amchitka, Alaska, airstrip. However, the reader is advised that wind directions as given at the airstrip consistently differ by 20-30 degrees from the directions recorded by the Tower 8 instrument. Concurrent wind data from military ships steaming in the vicinity of the southeast end of Amchitka Island corroborate the Tower 8 data.

ARL-LV also collected meteorological data at the Northwest Camp. However, for the purposes of this report, it is believed that the Tower 8 data and the airfield data (with due allowance for the difference discussed above) most nearly represent the weather conditions prevailing in the vicinity of Cannikin SZ during the period of interest.

TABLE B-1. RECORDED SURFACE WINDS

	November 5, 1971 (D-1)					November 6, 1971 (D-Day)					November 7, 1971 (D+1)			
	Main Camp Tower 8		Amchitka Airport			Main Camp Tower 8		Amchitka Airport			Main Camp Tower 8		Amchitka Airport	
Time, BST	Direction, deg	Speed, kt	Direction[(a)], deg	Speed, kt	Gusts, kt	Direction, deg	Speed, kt	Direction[(a)], deg	Speed, kt	Gusts, kt	Direction, deg	Speed, kt	Direction[(a)], deg	Speed, kt
0000	230	16	--	--	--	270	40	240	30	50	320	11	--	--
0100	220	16	--	--	--	270	41	240	32	48	290	19	--	--
0200	210	18	--	--	--	270	34	250	28	40	300	18	--	--
0300	220	20	--	--	--	280	32	260	26	40	300	16	--	--
0400	190	17	--	--	--	280	31	260	25	40	290	15	--	--
0500	230	18	190	14	--	290	39	250	25	40	280	16	--	--
0600	220	17	190	17	--	300	40	260	25	44	280	19	--	--
0700	210	19	190	16	--	310	37	--	--	--	280	16	250	14
0800	200	21	170	18	--	290	36	--	--	--	260	15	250	14
0900	200	22	170	20	--	310	40	--	--	--	270	17	250	13
1000	180	25	160	18	--	300	32	--	--	--	280	10	250	13
1100	170	32	150	20	30	300	35	--	--	--	270	11	240	12
1200	170	39	140	30	40	310	28	--	--	--	270	11	250	10
1300	170	47	140	35	53	310	34	--	--	--	270	13	240	14
1400	180	50	140	40	60	310	33	--	--	--	260	11	240	12
1500	190	51	160	36	50	310	30	280	20	30	260	19	240	13
1600	210	50	170	36	55	310	26	--	--	--	240	09	--	--
1700	230	58	190	35	63	310	26	290	20	30	220	08	--	--
1800	240	59	200	40	62	310	32	280	20	30	200	08	--	--
1900	250	50	210[(b)]	45	65	310	27	--	--	--	160	08	--	--
2000	260	48	220[(c)]	35	66	310	26	--	--	--	150	11	--	--
2100	270	45	230[(d)]	30	60	300	22	--	--	--	150	14	--	--
2200	270	44	240[(e)]	35	60	300	24	--	--	--	150	18	--	--
2300	270	42	240	35	54	320	18	--	--	--	150	18	--	--

(a) 20 to 30 degrees should be added to all values in this column to compensate for a consistent inaccuracy in the instrument.
(b) Variable 190 to 230.
(c) Variable 200 to 240.
(d) Variable 210 to 250.
(e) Variable 220 to 260.

TABLE B-2. HOURLY WEATHER (AS AVAILABLE), AMCHITKA, ALASKA (AIRFIELD)

Time, BST	Sky Condition[a]	Visibility, mi	Weather and Obstructions to Vision	Sea Level Pressure, mb	Temp, F	Dew Point Temp, F	Wind Direction[b], deg	Wind Speed[c], kt
November 4, 1971 (D-2); Solar Radiation Total 136 Langleys; 24-Hour Precipitation 0.06 Inch								
0800	1500' scattered							
	2500' broken	10		1013.9	39	30	270	24G35
0900	1500' scattered							
	3500' broken	10		1015.2	38	33	270	20G32
1000	2000' scattered							
	3000' broken	15		1015.7	39	34	280	22G30
1100	2000' scattered							
	3000' broken	15		1016.7	40	35	280	20G30
1200	2000' scattered							
	3000' broken	15		1017.4	40	30	280	20G30
1300	2500' broken	20		1018.4	42	33	270	20G30
1400	2500' broken	20		1019.2	43	30	270	20G30
1500	2500' broken	20		1019.8	39	35	260	18G28
1600	2000' broken							
	8000' broken	15		1020.5	41	34	260	14G24
1700	2500' broken	15		1021.1	40	34	250	18
November 5, 1971 (D-1); Solar Radiation Total 9 Langleys; 24-Hour Precipitation 0.40 Inch								
0500	400' obscured	3	Fog	1017.7	43	43	190	14
0600	400' obscured	4	Fog	1017.0	43	43	190	17
0700	400' broken							
	3000' overcast	5	Very light rain & fog	1016.0	43	43	190	16
0800	400' broken							
	3000' overcast	6	Very light rain & fog	1015.0	43	43	170	18
0900	500' obscured	4	Very light rain & fog	1013.3	43	43	170	20
1000	500' overcast	3	Light rain & fog	1011.8	44	42	160	18
1100	500' overcast	3	Light rain & fog	1008.7	44	42	150	20G30
1200	400' overcast	2	Light rain & fog	1002.9	44	43	140	30G40
1300	400' overcast	1-1/2	Rain & fog	996.0	44	42	140	35G53
1400	300' obscured	1	Rain & fog	989.2	44	42	140	40G60
1500	300' obscured	1	Rain & fog	986.6	43	43	160	36G50
1600	500' overcast	1-1/2	Light rain & fog	983.6	44	44	170	36G55
1700	1500' overcast	2	Very light rain & fog	982.6	44	44	190	35G63
1800	1500' overcast	1-1/2	Very light drizzle & fog	982.6	45	41	200	40G62
1900	1500' overcast	1-1/2	Very light drizzle & fog	982.6	44	40	210	45G65
2000	1500' overcast	3	Fog	985.8	44	39	220	35G66
2100	1500' overcast	4	Very light drizzle & fog	988.4	44	39	230	30G60
2200	1500' overcast	3	Very light drizzle & fog	990.6	43	39	240	35G60
2300	1500' overcast	4	Very light drizzle & fog	993.2	43	39	240	35G54
2400	1500' overcast	4	Very light drizzle & fog	995.3	43	39	240	30G50

November 6, 1971 (D-Day); Solar Radiation Total 139 Langleys; 24-Hour Precipitation 0.04 Inch

0000	1500' overcast	4	Very light drizzle & fog	995.3	43	39	240	30G50
0100	1500' overcast	4	Very light drizzle & fog	997.1	43	39	240	32G48
0200	1000' overcast	6	Fog	998.4	43	39	250	28G40
0300	1500' broken							
	3000' broken	6	Light drizzle & fog	999.8	43	39	260	26G40
0400	900' broken							
	2500' overcast	6	Fog	1000.9	42	40	260	25G40
0500	1500' overcast	6	Light rain & fog	1002.5	42	40	250	25G40
0600	1500' scattered							
	3000' overcast	7	Very light rain	1004.5	41	40	260	25G44
1500	2000' scattered	20		1019.9	41	30	280	20G30
1700	2500' broken	20		1023.3	39	32	290	20G30
1800	2500' broken	20		1024.2	M	M	280	20G30

November 7, 1971 (D+1); Solar Radiation Total 139 Langleys; 24-Hour Precipitation 0.04 Inch

0700	Clear	20		1033.7	38	29	250	14
0800	Clear	20		1033.5	37	30	250	14
0900	2000' scattered	20		1033.7	38	31	250	13
1000	2000' scattered	20		1034.9	38	31	250	13
1100	2000' broken							
	20,000' broken	20		1035.2	42	36	240	12
1200	2000' broken							
	20,000' broken	25		1035.2	42	33	250	10
1300	2000' scattered							
	20,000' broken	25		1035.2	42	33	240	14
1400	2000' scattered							
	20,000 broken	25		1034.9	42	32	240	12
1500	2500' scattered							
	20,000' overcast	25		1034.5	42	33	240	13

November 8, 1971 (D+2); Solar Radiation Total 39 Langleys; 24-Hour Precipitation 0.41 Inch

0700	200' obscured	1/2	Very light rain & fog	1015.3	42	42	130	24G34
0800	100' obscured	1/2	Light rain & fog	1014.3	42	42	130	24G34
0900	100' obscured	1/4	Light rain & fog	1013.3	43	43	130	24G34
1000	100' obscured	1/4	Very light rain & fog	1012.3	44	44	140	20G30
1100	100' obscured	1/4	Very light rain & fog	1011.3	45	45	150	16G26
1200	100' obscured	1/8	Very light drizzle & fog	1010.6	46	46	170	15G25
1300	100' obscured	1/8	Very light drizzle & fog	1009.3	46	46	170	18
1400	100' obscured	1/8	Fog	1008.3	46	46	170	17
1500	100' obscured	1/8	Very light rain & fog	1008.0	46	46	170	15
1600	100' obscured	1/8	Very light rain & fog	1007.0	45	45	170	14
1700	100' obscured	1/8	Very light rain & fog	1006.3	45	45	170	14
1800	200' obscured	3/8	Light rain & fog	1005.3	45	45	170	18
1900	200' obscured	1/2	Very light rain & fog	1004.0	46	46	170	18
2000	200' obscured	1/2	Light rain & fog	1002.6	46	46	170	20

TABLE B-2. (Continued)

Time, BST	Sky Condition[a]	Visibility, mi	Weather and Obstructions to Vision	Sea Level Pressure, mb	Temp, F	Dew Point Temp, F	Wind Direction[b], deg	Wind Speed[c], kt
			November 9, 1971 (D+3); Solar Radiation Total 78 Langleys; 24-Hour Precipitation Trace					
0700	200' obscured	1/2	Moderate drizzle & fog	996.1	42	42	280	12
0800	200' obscured	1/2	Very light rain & fog	996.7	42	42	280	10
0900	100' scattered							
	500' scattered							
	2000' overcast	6	Fog	997.1	42	42	240	10
1000	200' thin broken							
	1800' overcast	6	Fog	997.4	42	42	220	13
1100	300' overcast	6	Fog	997.1	42	42	220	15
1200	600' broken							
	1500' overcast	7		996.7	43	42	220	16
1300	500' overcast	7		996.4	43	42	220	19
1400	500' broken							
	2000' overcast	7		996.1	44	42	230	20
1500	500' scattered							
	2000' scattered	7		995.7	44	42	220	20
1600	900' scattered							
	1500' broken	7		995.7	43	41	210	17
1700	900' scattered							
	2000' broken	7		995.4	42	40	200	18G26
			November 10, 1971 (D+4); Solar Radiation Total 112 Langleys; 24-Hour Precipitation 0.04 Inch					
0700	2000' broken	10		998.8	39	32	240	25G35
0800	2000' broken	10		999.1	37	32	230	20G30
0900	2000' broken	10		999.9	36	31	240	20G30
1000	2000' broken	10		1000.1	37	32	240	25G38
1100	2000' broken	10		1000.5	37	35	240	22G34
1200	2000' broken	10		1000.8	37	35	240	24G36
1300	1500' scattered	15		1000.1	40	31	240	24G36
1400	1500' broken	15		1000.1	40	31	240	25G38
1500	1500' broken	15		1000.1	40	31	240	24G39
1600	2000' broken	10		1000.5	39	29	240	25G40
1700	2000' broken	10		1000.5	39	29	240	23G32

November 11, 1971 (D+5); Solar Radiation Total 75 Langleys; 24-Hour Precipitation 0.06 inch

0700	2500' broken	10		1006.3	37	33	240	16
0800	2500' broken	10		1006.3	37	30	240	16
0900	2500' broken	25		1007.0	37	30	240	16
1000	2500' broken	25		1007.3	39	32	250	16
1100	2500' scattered	25		1007.0	41	32	210	17
1200	2500' scattered 20,000' broken	25		1007.0	41	32	210	18
1300	2500' scattered 20,000' overcast	20		1005.3	41	32	180	17
1400	2500' scattered 12,000' overcast	20		1004.3	40	33	170	16
1500	2500' scattered 12,000' overcast	20		1003.2	40	35	170	15
1600	1800' overcast	15		1001.6	40	36	160	10
1700	1000' overcast	10	Light rain	1000.8	39	37	160	10

November 13, 1971 (D+7); Solar Radiation Total 102 Langleys; 24-Hour Precipitation Trace

0800	1500' scattered 2500' broken	15		988.2	32	24	250	22G32
0900	1500' scattered 2500' broken	25		988.4	33	22	240	24G32
1000	1500' scattered 2500' broken	10		988.7	33	24	250	18G28
1100	1500' scattered 2500' broken	25		988.4	34	23	250	20G30
1200	2500' broken	25		988.4	34	23	250	18G28
1300	2500' broken	35		987.6	37	21	240	20G30
1400	2500' scattered	35		987.4	37	23	240	20G30
1500	600' overcast	2	Very light snow	987.6	37	32	240	20G30
1600	1500' scattered 2500' broken	7		987.0	36	29	250	20G30
1700	2500' overcast	7		987.4	36	29	250	20G30

(a) Clear = <0.1 sky cover; scattered = 0.1-<0.6 sky cover; broken = 0.6-0.9 sky cover; overcast = >0.9 sky cover; obscured = 1.0 sky hidden by precipitation or obstruction to vision (fog).

(b) Correct wind direction can be obtained by adding 20-30 deg to value given.

(c) The notations 24G35, etc., mean average wind speed of 24 knots, with gusts up to 35 knots.

APPENDIX C

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS OF THE CANNIKIN SITE

Data from the U.S. Geological Survey, Denver, Colorado

APPENDIX C

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS OF THE CANNIKIN SITE

by

U.S. Geological Survey

Introduction

The U.S. Geological Survey (USGS) of the Department of the Interior has principal responsibility for defining and interpreting the geologic and hydrologic environment of underground nuclear explosions.

Most of the geologic and hydrologic investigations on Amchitka were directed toward preparation for and completion of Milrow in 1969 and Cannikin in 1971.

Definition of the Geologic Environment

Geologic investigations enhanced by aerial photography, an infrared survey, an aeromagnetic survey, gravity surveys, and marine geophysical surveys were completed and evaluated prior to Milrow in 1969. Further studies in preparation for Cannikin included studies of the tectonics of the Aleutian arc and marine-terrace studies which were completed to provide background information to aid in assessing the possibility of triggering large earthquakes and tsunamis.

Site Selection and Evaluation

The working point for Cannikin was selected on the basis of depth, predicted suitability of rock for chambering, and minimal water inflow.

Geologic and Tectonic Effects of Nuclear Explosions

Explosion-produced geologic and tectonic effects were predicted and documented for both Milrow and Cannikin. These included such effects as fractured rock, collapse sinks, ground deformation, and fault movement.

Geologic effects of Cannikin were similar to those of Milrow but of anticipated larger magnitude. Cliff spall along the Bering coast was greater than anticipated and is estimated to be some 25,000 cubic meters of rock and turf. The Bering coastline was uplifted 0.25 to 1.1 m (0.8 to 3.5 ft) along about 2 km (1-1/4 miles) of coastline nearest to the site.

Nearly all visible geologic effects were confined between two east-trending faults which are 760 m (2,500 ft) south and 1,068 m (3,500 ft) north of the site. The northern fault was offset at the surface a maximum of 60 cm (2 ft) vertically along 460 m (1,500 ft) of strike at shot time. The south fault was offset a maximum of 60 cm vertically along about 1,430 m (4,700 ft) of strike. Most of the movement on the latter fault did not occur until the collapse sink was formed. Precise surveys show that a line 2 km (1 1/4 miles) long trending northeast across SZ extended 1.2 m (4 ft).

Calculated strains decrease with slant distance from SZ as the minus 3 power out to a distance of 6 km (3.7 miles). At that distance the strain was 2×10^{-5}, about the limit of detection for the method used. Principal strains show northeast-southwest extension.

The collapse sink appears from preliminary surveys to have an oval shape about 915 by 1,270 m (3,000 by 4,500 ft) in diameter with a maximum depth of about 20 m (50-60 ft). It is asymmetrical in that the maximum subsidence is 366 m (1,200 ft) east-southeast of SZ. Subsidence at SZ was only 5 m (16 ft). The asymmetry of the collapse sink is probably related to geologic structure. The chimney appears to have stoped upward normal to the dip of the beds. When the chimney reached the surface, the bedrock dropped as discrete blocks broken along small faults and joints. Some of these fractures were offset as much as 3 m (10 ft).

Definition of the Hydrologic Environment

Groundwater studies were designed to determine (1) the groundwater flow system, (2) the chemical and radiochemical quality of water, (3) the hydraulic characteristics of specific rock units and intervals, and (4) the acceptability of sites selected for emplacement holes.

Automatic continuous-recording gages were installed on five streams to determine the base flow of the streams and to measure storm runoff. These gages were also used to monitor effects of the underground tests on the stream flow. Streams selected for gaging stations include streams that drain the Milrow and Cannikin test sites and one area between the two sites. Water levels were monitored in 28 holes on the Island to evaluate changes in water level, both natural and man-made.

Precipitation records were acquired by two automatic precipitation gages and daily precipitation records were collected at the air terminal.

Hydrologic Effects of Explosions

The hydrologic effects of Cannikin were similar to those of Milrow. At both sites flow of the streams draining the site was reduced. This was caused by capture of part of the stream flow by collapse of the sinks. Another effect of the tests is the creation of a cone of depression in the groundwater in the chimney area.

After Cannikin the discharge of White Alice Creek, which drains the test site, was reduced to about 4 percent of normal. It is estimated that the Cannikin chimney will be filled in about 9 months by the return flow of the groundwater toward the chimney and the addition of surface runoff. At that time the closed depression formed by the sink will start to fill and form a lake as much as 6 m (20 ft) deep. Only after the chimney and lake fill will White Alice Creek resume normal discharge.

Long-Term Hydrologic Monitoring Program

A long-term hydrologic monitoring program was established on Amchitka in 1967. As part of the monitoring program a water-sampling network was established. The

sampling network of 60 stations presently includes 23 lake, 15 stream, 5 seep and spring, 7 well, 1 precipitation, and 9 ocean water-sampling locations. Samples from these locations are analyzed routinely for chemical constituents and to establish radiological background levels of tritium and of gross alpha and gross beta contents.

Sampling frequency immediately after Cannikin has been bimonthly, and will be quarterly after the end of the first year. Starting approximately 1-1/2 years after the event, sampling will be on an annual basis. Current analyses show no measurable increase in radioactivity over preshot data.

The Cannikin reentry hole has been developed as a hydrologic monitoring hole. Water samples will be obtained from various levels in the chimney to determine the distribution of radioactivity with time, and the water level will be monitored to determine the rate of chimney filling.

All samples collected after Cannikin will be analyzed for tritium using the liquid scintillation method with a lower limit of about 200 tritium units (TU). All samples will be analyzed for gross alpha, and gross beta/gamma. Any sample collected from critical or suspect areas or that contains greater than background concentrations of gross alpha or gross beta/gamma will be reanalyzed using low-level tritium techniques with a lower limit of about 20 TU. The samples also will be analyzed for specific radionuclides including strontium 90 to differentiate the source of the radioactivity from worldwide fallout.

Routine reports of the long-term monitoring results will be prepared annually, and prompt, special reports will be prepared if above-background concentrations of event-related radioactivity are found.

APPENDIX D

PHOTOGRAMMETRY

APPENDIX D

PHOTOGRAMMETRY

Approximately 5000 aerial photographs were taken over Amchitka prior to and after Cannikin by a BCL photogrammetrist. The photographs were taken to support all bioenvironmental studies and other contractors of AEC-NVOO, such as USGS. An Alloutte III helicopter provided a suitable platform for two Fairchild K-17B aerial cameras (9-1/2 by 9-1/2-inch film format). Intensive oblique and vertical photographic coverage with color film* and infrared color film** was obtained for the areas within 3-km radii around Cannikin and Milrow SZ, and the portion of the Island lying between these sites. Additional but less intensive coverage was obtained for that portion of the Island extending from Cannikin northwestward to about D Site (Figure D-1). The total area covered by this aerial photography is approximately 80 km^2.

Photographs were taken up to 2 days before testtime, and photo missions were resumed on D-day. The large-format photography lends itself readily to a precise comparison of terrain and nearshore features, pre- and posttest. It clearly reveals changes in lakes (e.g., fissures in lake bottoms and changes in water level), and the creation of new lakes and ponds. It shows rock falls and tundra slides around the Bering Sea and Pacific Ocean coastal cliffs in sufficient detail to permit good estimation of volumes of material displaced. Cracks and scarps in the inland terrain around SZ can be measured, and caved portions of stream banks and turbidity in nearshore marine waters are clearly delineated. The photography is detailed and extensive enough to be used for systematic evaluation of Cannikin-related changes in the terrain and nearshore features. It has been indexed and keyed to 1:25,000 Army Map Service map sheets # 2023 I NW, 2024 III NE, 2024 III SE, and 2024 II SW. Some 1500 frames have been copied on 35-mm slides for quick reference and side-by-side comparison of photographic data.

Specifically, the following photographic coverage was obtained between August 31 and November 12, 1971:

- The area within 3-km radius of Cannikin and Milrow SZ and the area in between (Oblique infrared color and vertical color imagery; average photographic scale – 1:4000).
- The sea cliffs and sea stacks on the Bering and Pacific Coast (Oblique infrared color and color imagery; average photographic scale – 1:1000).
- Test lakes within 3.5-km radius of Cannikin SZ (Vertical color and oblique infrared color imagery; average photographic scale – 1:1000).
- Three streams within 4-km radius of Cannikin SZ (Vertical color and oblique infrared color imagery; average photographic scale – 1:1000).

* Ektachrome color film, Kodak Type SO-397.

** Infrared color film, Kodak Type 8443.

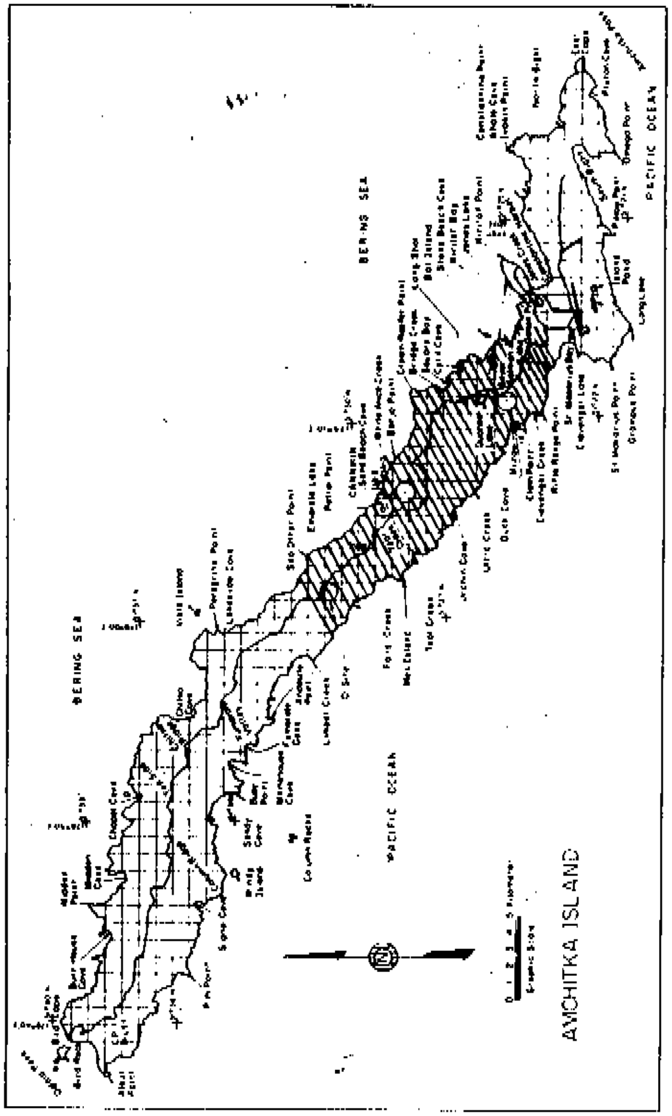

FIGURE D-1. APPROXIMATE AREA (HATCHED) OF CANNIKIN/MILROW-RELATED AERIAL PHOTOGRAPHIC COVERAGE

- Six plant-ecology transects within 8.5-km radius of Cannikin SZ (Vertical color and oblique infrared color, average photographic scale – 1:2000).
- Peregrine falcon eyries and bald eagle nesting sites within 10-km radius of Cannikin SZ (Oblique color imagery; average photographic scale – 1:500).
- Portions of Bering Sea and Pacific Ocean coastlines within 8-km radius of Cannikin SZ during low tides (Vertical infrared color imagery; average photographic scale – 1:1500).
- SZ area within 1.5 km (Vertical color, oblique color and infrared color imagery, average photographic scale – 1:4000).

In addition to the large-format photographic coverage, about 750 color or infrared color, 35-mm and 70 mm photographs were taken of selected features.

APPENDIX E

AMCHITKA BIOENVIRONMENTAL PUBLICATIONS

APPENDIX E

AMCHITKA BIOENVIRONMENTAL PUBLICATIONS

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APPENDIX F

ORGANIZATIONS AND INDIVIDUALS PARTICIPATING IN THE AMCHITKA BIOENVIRONMENTAL STUDIES

APPENDIX F

ORGANIZATIONS AND INDIVIDUALS PARTICIPATING IN THE AMCHITKA BIOENVIRONMENTAL STUDIES

(Also given is the period of time principal participants have been involved with the studies.)

General Program Planning and Coordination

Battelle's Columbus Laboratories

Dr. R. S. Davidson (Program Director)	July 1, 1967-present
***Dr. J. B. Kirkwood (Technical Coordinator)	January 1, 1968-present
Dr. D. E. Bell	July 1, 1967-September, 1971
**Mr. R. G. Fuller	
***Mr. I. M. Mercier	

Photogrammetry

Battelle's Columbus Laboratories

***Mr. J. G. Stephan (Principal Investigator)	January 1, 1968-present
***Mr. I. M. Mercier	

Sea Otter Response to Overpressure

Battelle's Columbus Laboratories

*Dr. R. A. Wright (Principal Investigator)	January 1, 1968-July 1, 1971
*Mr. W. H. Allton	
***Mr. I. M. Mercier	

With assistance from

***Mr. K. Schneider, State of Alaska, Department of Fish and Game
***Mr. C. E. Abegglen, U. S. Bureau of Sports Fisheries and Wildlife
***Mr. B. Cater, U. S. Bureau of Sports Fisheries and Wildlife
*Mr. L. W. Sowl, U. S. Bureau of Sports Fisheries and Wildlife

Sea Otter Abundance

U. S. Bureau of Sports Fisheries and Wildlife

Mr. D. L. Spencer (Principal Investigator)	July, 1968-December, 1968
***Mr. B. Cater	
*Mr. L. W. Sowl	

*Personnel involved in the Milrow testtime studies during the period from September 1 through November 30, 1969.
**Personnel involved in Cannikin testtime studies during the period August 15 through December 20, 1971.
***Personnel involved in both Milrow testtime studies (September 1 through November 30, 1969) and Cannikin testtime studies (August 15 through December 20, 1971).

Sea Otter Behavior Studies

University of Arizona — October, 1970-present
- Dr. N. Smith (Principal Investigator)
- **Mr. J. A. Estes

Sea Otter Mortality Studies

Battelle's Columbus Laboratories
- *Mr. W. H. Allton (Principal Investigator) — January 1, 1968-July 1, 1971

With assistance from

- Mr. J. Hakala, U. S. Bureau of Sports Fisheries and Wildlife
- *Mr. L. W. Sowl, U. S. Bureau of Sports Fisheries and Wildlife

University of Arizona
- ** Mr. J. A. Estes (Principal Investigator) — October, 1970-present

U. S. Public Health Service
- **Dr. R. Rausch (Conducted Autopsies) — November, 1971-present

Oceanography

U. S. Bureau of Commerical Fisheries (Presently National Marine Fisheries Service)
- Dr. Bruce McAlister (Principal Investigator) July, 1968-June 30, 1969
- Mr. R. C. Clark, Jr.
- Mr. D. Day
- Mr. W. J. Ingraham
- Mr. J. Larrance
- Mr. C. Mahnken

Marine Ecology and Oceanography

University of Washington, Fisheries Research Institute
- Dr. R. L. Burgner (Principal Investigator) — July, 1967-present
- **Dr. R. Nakatani (Principal Investigator) — July, 1971-present
- Mr. E. A. Best
- Mr. R. A. Bishop
- Dr. K. K. Chew
- **Mr. M. B. Dell
- Mr. P. J. Eldridge
- ***Mr. L. G. Gilbertson
- Mrs. G. M. Harbert
- *Mr. D. K. Holmberg
- ***Mr. J. S. Isakson
- Mr. K. S. Kimura
- ***Mr. P. A. Lebednik
- ***Dr. O. A. Mathisen

*Personnel involved in the Milrow testtime studies during the period from September 1 through November 30, 1969.
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Marine Ecology and Oceanography (Continued)

- Mr. D. L. Mayer
- Dr. R. E. Norris
- ***Mr. C. E. O'Clair
- Dr. R. I. Paine
- Mr. J. F. Palmisano
- Mrs. M. M. Peck
- Mr. K. Robertson
- Dr. E. O. Salo
- Mr. R. L. Schneider
- ***Mr. C. A. Simenstad
- ***Mr. P. N. Slattery
- ***Mr. G. J. Tutmark
- Mr. F. C. Weinmann
- Dr. M. J. Wynne

Subtidal Biological Studies

National Marine Fisheries Service
- ***Mr. T. R. Merrell (Principal Investigator) — September, 1969-present
- ***Mr. L. Barr
- **Mr. R. Budke
- **Mr. R. Dewey
- *Mr. R. Ellis
- *Mr. W. Heard
- *Mr. J. Helle
- **Dr. D. Hoopes
- ***Mr. R. Williamson

Freshwater Ecology

Utah State University
- Dr. J. M. Neuhold (Principal Investigator) — July 1, 1968-July 1, 1971
- ***Dr. W. T. Helm (Principal Investigator since July, 1971) — July 1, 1968-present
- Mr. J. Palmisano
- ***Mr. R. Valdez

The Ohio State University
- *Dr. D. D. Koob (Principal Investigator) — July 1, 1968-June 30, 1970
- Mr. K. R. Gordon
- Mr. J. D. Youger

Battelle's Columbus Laboratories
- **Dr. T. J. Birch (Principal Investigator) — July 1, 1970-present
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- **Mr. P. S. Mohler
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Geomorphology

The Ohio State University
***Dr. K. R. Everett (Principal Investigator) January, 1968-present

Plant Ecology

University of Tennessee
Dr. E. E. C. Clebsch (Principal Investigator) September, 1967-present
***Dr. C. C. Amundsen (Principal Investigator since July 1, 1970) September, 1968-present

Avian Ecology

Smithsonian Institution
***Dr. F. S. L. Williamson (Principal Investigator) January, 1968-present
***Mr. W. B. Emison
Mr. R. E. Johnson

With assistance from

Dr. D. W. Johnson, University of Florida
Dr. C. G. Yarbrough, University of Florida
***Dr. C. M. White, Brigham Young University (formerly of Cornell University)
Dr. H. E. Childs (Consultant to Battelle from Cerritos College)

Terrestrial Invertebrates

University of Tennessee
Dr. R. R. Schmoller (Principal Investigator) June, 1969-June, 1970

Revegetation Studies

Battelle's Columbus Laboratories
Dr. H. E. Kazmaier (Principal Investigator) January, 1968-July, 1968

University of Alaska
Dr. W. Mitchell (Principal Investigator)

Ground Shock and Overpressure

Sandia Corporation
***Dr. M. L. Merritt (Principal Investigator) July, 1967-present

Source-Term Predictions (Radionuclide and Physical Shock)

Battelle's Columbus Laboratories
Mr. R. A. Ewing (Principal Investigator) January, 1968-present
Mr. J. E. Howes, Jr.
Dr. G. E. Raines
Dr. J. R. Vogt

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***Personnel involved in both Milrow testtime studies (September 1 through November 30, 1969) and Cannikin testtime studies (August 15 through December 20, 1971).

Chemical and Radiochemical Analyses

Battelle's Columbus Laboratories
Dr. G. E. Raines (Principal Investigator) January, 1968-present
Dr. J. R. Vogt

University of Washington
Dr. A. H. Seymour (Principal Investigator) January, 1968-present
Dr. E. Held
**Mr. R. Eagle
***Mr. J. S. Isakson

Mathematical Simulation Studies

Battelle's Columbus Laboratories
Dr. G. E. Raines (Principal Investigator) January, 1968-present
Dr. S. G. Bloom

Research Observations and Coordination for the U. S. Department of the Interior

Bureau of Sports Fisheries and Wildlife
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Research Observations and Coordination for the U. S. Department of Commerce

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