RADIOISOTOPIC
SAND TRACER STUDY
POINT CONCEPTION, CALIFORNIA

PRELIMINARY REPORT ON ACCOMPLISHMENTS
JULY 1966 — JUNE 1968

by

David B. Duane and Charles W. Judge

MISCELLANEOUS PAPER NO. 2-69
MAY 1969

U. S. ARMY, CORPS OF ENGINEERS
COASTAL ENGINEERING
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ABSTRACT

The purpose of the Radioisotopic Sand Tracer (RIST) study is to develop and use radioactive tracer methods for research in sand movement and littoral processes. Research objectives include determination of suitable radioactive isotopes, development of mobile and stationary radiation detectors, and development of suitable handling and survey programs. Concurrent with these objectives, studies of sediment transport around the Point Conception headland and of the mechanics of littoral transport are being conducted. Methods developed by this program have direct application to engineering design of such works as harbor development and beach erosion prevention, and quasi-military application such as the location of radioactive or other toxic materials.

To date, sand grains indigenous to the study area have been labeled with xenon-133 which does not adversely affect the hydraulic properties of the sand. Various devices and methods of employing the tagged sand have been studied. A mobile detector system using cesium iodide crystals and housed in a "ball" towed behind an amphibious vehicle detects the quantity and areas of radiation. Computer programs have been developed to correct and plot radiation data.

A field test of equipment and principles at Cape Kennedy, Florida, was successful. Additional field tests were at Surf and Point Conception, California. These tests included isotope distribution, sediment analysis, offshore profiles, and oceanic and atmospheric environment monitoring. In addition, model tests were conducted in the Shore Processes Test Basin at the Coastal Engineering Research Center (CERC) to compare high and low specific activity xenon, and to study beach development and movement under the controlled conditions of a hydraulic laboratory.

The data density is sufficient to support tentative conclusions regarding offshore sediment movement in the Point Conception area. Additional field tests will extend the survey from the beach through the surf zone. In addition, development of instruments and field programs will continue in order to permit their routine use by technicians and field crews.

FOREWORD

For 35 years the U. S. Army Corps of Engineers' Coastal Engineering Research Center (CERC) and its predecessor, the Beach Erosion Board, have been studying coastal phenomena. While interest at CERC extends from wave generation in the deep ocean to the original source of sediment at the headwaters of streams in the high mountains, the practical limitation of its work is the coastal area. The coastal area can be considered to extend from the bluffs or sand dunes immediately landward from the present position of the shoreline to water depths representing the outer limit of bottom material movement by wave action.

The overall direction of the RIST study program rests with CERC. The program was initiated by N.E. Taney, formerly of the CERC staff, with the full cooperation and assistance of G. Magin, Jr., formerly with the Division of Isotopes Development, U. S. Atomic Energy Commission. Since November 1966, responsibility for the program direction has rested with D. B. Duane who succeeded N. E. Taney as Chief of the Geology Branch. This report was prepared by D. B.Duane and C. W. Judge under the general supervision of G. M. Watts, Chief of the Engineering Development Division.

This report was prepared as part of Contract AT (49-11)-2988 (as modified) between the Atomic Energy Commission and CERC. Other participants in this continuing multi-agency study are the Oak Ridge National Laboratories of the Atomic Energy Commission; U. S. Navy Pacific Missile Range; U. S. Air Force (Western Test Range, First Strategic Aerospace Division); U. S. Army Corps of Engineers Los Angeles District office; NASA (Nuclear Systems and Space Power Division) and the State of California (Department of Water Resources).

The authors wish to thank P. J. Mellinger and O. M. Bizzell of the Division of Isotope Development, Atomic Energy Commission; F. N. Case, E. H. Acree, and H. R. Brashear of the Oak Ridge National laboratory; T. B. Kerr of the Nuclear Systems and Space Power Division, National Aeronautics and Space Administration; R. R. Baray of the First Strategic Aerospace Division, Vandenberg Air Force Base; M. M. Richman, U. S. Air Force Western Test Range, Vandenberg Air Force Base; Colonel W. H. Lee, U. S. Air Force Eastern Test Range, Patrick Air Force Base; E. Rhodes, U. S. Navy Pacific Missile Range, Point Mugu, California; R. Angelos of the Department of Water Resources, State of California; and Colonel James Irvine, Jr., Corps of Engineers Western Area Office, Vandenberg Air Force Base. Appreciation is particularly expressed to J. M. Bittner, T. A. Bertin, and the various field crews and technical personnel of the Los Angeles District without whose cooperation this project would not have been possible.

At the time of publication, Lieutenant Colonel Myron Dow Snoke was Director of CERC; Joseph M. Caldwell was Technical Director.

NOTE: Comments on this paper are invited. Discussion will be published in the next issue of the CERC Bulletin.

This report is published under authority of Public Law 166, 79th Congress, approved July 31, 1945, as supplemented by Public Law 172, 88th Congress, approved November 7, 1963.

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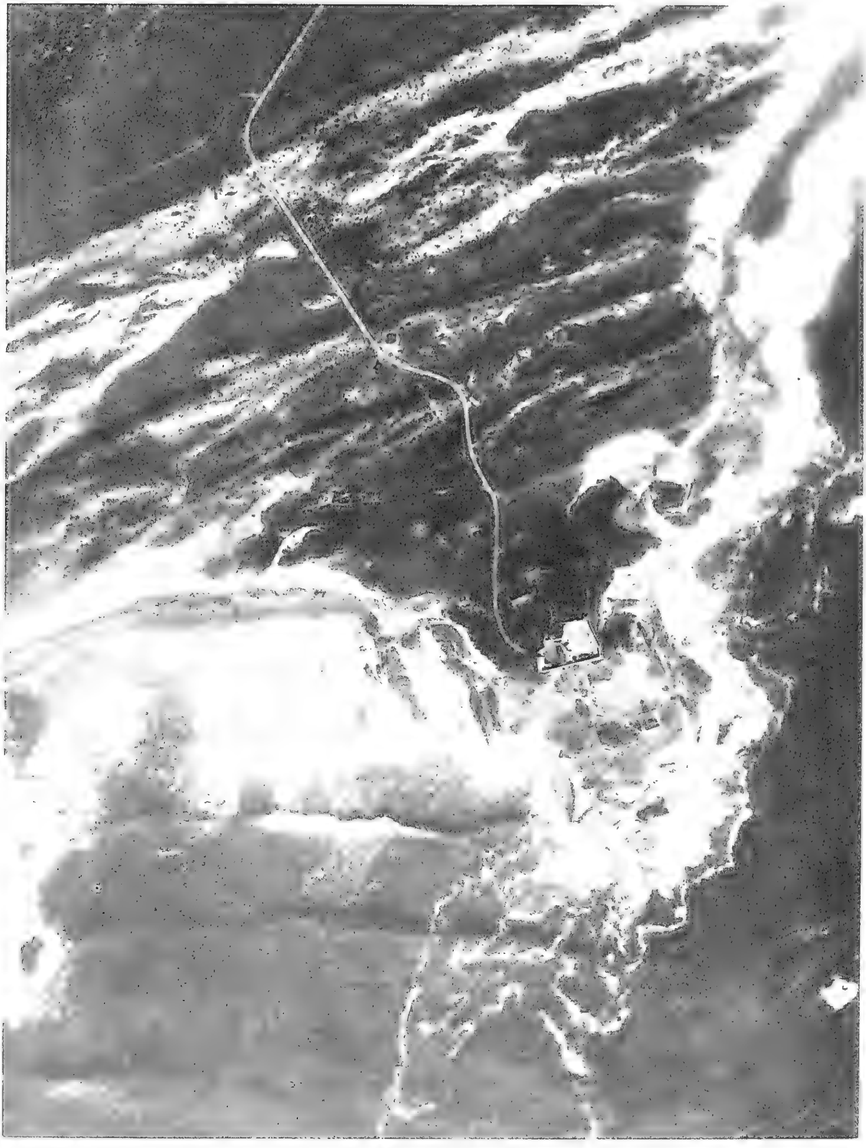


Figure 1. Point Conception, California
Vertical Aerial View from 10,000 feet.

RADIOISOTOPIC SAND TRACER STUDY, POINT CONCEPTION, CALIFORNIA

Preliminary Report on Accomplishments
July 1966 - June 1968

Section I. PROGRAM

1. Introduction

In 1966 the U. S. Army Corps of Engineers' Coastal Engineering Research Center in cooperation with the Atomic Energy Commission, initiated a 3-year Radioisotopic Sand Tracer Investigation of Littoral Transport around Point Conception, California. Program objectives may be summarized as: a) a study and selection of suitable radioisotope(s); b) development of radiation detection equipment capable of operating in the beach and marine environment to depths of 100 feet; and c) trace movement of tagged sand in a coastal zone. A major part of the development of hardware and tagging techniques has been performed by AEC's Oak Ridge National Laboratory at Oak Ridge, Tennessee. Other direct participants in the study are U. S. Navy, U. S. Air Force, Corps of Engineers District Office in Los Angeles, National Aeronautics and Space Administration, and the State of California. Recognizing the potential, broader geographic applications of this 3-year minimum research and development program, the rather ponderous official title has been shortened to Radioisotopic Sand Tracer Study with the acronym RIST.

Sediment in the littoral environment moves in response to various complex processes. In the nearshore zone (that zone extending from the water line to the limit of nearshore currents at about 50-foot depths) waves approaching at an angle generate currents that move in response to the direction of wave approach. Because more than one wave train may impinge upon the shore at the same time, more than one current direction and velocity maxima may exist. Further, in any given wave a water particle circumscribes a circular or elliptical orbit for which two additional velocity maxima exist opposed by 180 degrees. These and other factors enter into the problem, and may be classified as *force and response* elements. Examples of force elements are wave height and period, angle of wave approach, and stage of the tide; several response elements are particle size distribution of the sediments, density of the particles, and bottom and beach slope. The interaction of the force and response elements causes a continual action and reaction effect. Problems of the littoral zone, therefore, are concerned with many factors which may vary widely and which interact with each other singly and in combination in a most complicated manner.

The responses to the expenditure of energy by waves, currents, and other forces upon a sandy coast are erosion and transportation of the sedimentary particles. Because many of the shores of the United States and the world are sandy, investigators at CERC and other laboratories have studied sediment transport both in the laboratory and in the field. Generally, such studies are made along a long, straight beach in order to simplify the experiment. A much more complicated situation exists where the shoreline undergoes a radical change in orientation. Point Conception, California, is a geographic example of this condition. (See Figure 2).

Point Conception and Government Point (as well as Point Arguello and Pedernales Point to the north) are rocky promontories which extend seaward from the general alignment of the shore. The shore is backed by a sheer bluff rising approximately two hundred feet above the sea. The nearshore bottom is rock interspersed with sandy areas. Part of the nearshore bottom area appears to be swept free of sandy sediments; also extensive kelp beds present in the area are generally indicative of a rocky bottom. From general knowledge of the processes functioning in the area, the littoral drift has been assumed by earlier investigators to move from the north toward Point Conception and eastward away from it.

Very little is known concerning littoral transport in the vicinity of headlands or other supposed barriers to littoral drift, and Point Conception is no exception. If the sedimentary particles comprising this littoral drift do, in fact, move around the headland, the mechanics of movement are unknown. Lateral movement could occur in shallow or deep water or by a series of traverses essentially normal to the shore.

2. Scope and Objectives

The purpose of the Radioisotopic Sand Tracer Study (RIST) is to develop and utilize radioactive tracer methods for research into sand movement and littoral processes. Research objective include determination of suitable radioisotopes, development of mobile and stationary radiation detectors, and development of suitable radioisotope handling and survey programs. In conjunction with these objectives, studies of sediment transport around the Point Conception headland and of the mechanics of littoral transport are being conducted.

Development of suitable methods for using radioactive tracers in littoral transport studies required the accomplishment of the following specific objectives:

a. Study and selection of isotopes possessing a 4- to 20-day half-life, which emit γ radiation with energy peaks of the different isotopes sufficiently separated to permit detector discrimination in the field. In addition, it is desirable that the isotope be biologically inert.

b. Study of the isotopes selected to determine suitability of labeling technique and compatability with the sediment being labeled.

c. Design of a submersible radiation detection system using scintillation detectors. At present, the system monitors a single isotope but eventually there will be a need for concurrent quantitative detection and measurement of at least two, and possibly four, isotopes.

d. Choice of the appropriate gamma pulse-height analyzer system. The program requires a system with the capability to discriminate between two to four gamma energy peaks. When using multiple isotopes or discriminating multiple energy peaks, the measurements must be essentially simultaneous and yet be statistically significant.

e. Design and construction of a vehicle on which the detector(s) can be mounted. The vehicle must be suitable for use in highly turbulent water and in areas that are rocky or otherwise present a very rough surface.

f. Development of a safety program with provision for a safety officer, and the determination of suitable safe methods of handling and emplacing the isotope.

g. Design of the field experiments.

A number of agencies have an interest in one or several of the program objectives. Besides CERC, two other offices of the Corps of Engineers, the U. S. Army Engineer Division, South Pacific (SPD), and the U. S. Army Engineer District, Los Angeles (SPL), are participating in this program. The requirements of both of the above offices concern shore-protection structures along the coast. Basic information concerning the direction, path, and quantity of material moving in the littoral zone is needed for inproved functional design. For example, a harbor of refuge will be needed somewhere along the coast between Point Conception and Santa Barbara, California, probably near Gaviota. To properly design such a protected harbor, it is necessary to know the littoral sediment transport pattern in the area. The transport pattern would have an important effect upon the determination of the annual costs of maintaining adequate navigation depths in the channel which, in turn, would be dependent upon the location at which the sediments approach close to shore. If the drift were close to shore west from Gaviota, the material could shoal the channel.

Another Federal agency, Headquarters, First Strategic Aerospace Division (SAC) at Vandenberg Air Force Base, is participating in this program. Their objectives are quite different from those of the Corps of Engineers. The Air Force objectives are influenced by the geographical location and the mission of Vandenberg Air Force Base. The southeasterly limit of Air Force interest is controlled by the firing envelope (range safety limit) which reaches approximately to Santa Barbara; therefore, Vandenberg Air Force Base has requirements along the entire reach of shore between Point Sal and Santa Barbara. The Air Force is concerned about possible missile aborts (failures) which could cause contamination of water and sediments by exotic fuels. Since several of these exotic fuels are harmful to public safety, it is very important to determine whether contaminated sediments would reach areas available and freely accessible to the public. The Air Force is also interested in the location and construction of a harbor for military craft.

Figure 2. Map showing Point Conception, California, study area.

The National Aeronautics and Space Administration (NASA) has interests along the coastline and at greater depths in the Santa Barbara Channel. NASA systems to be fired from Vandenberg launch sites will carry power sources fueled by radioactive materials and toxic fuels of the booster, and early aborts on the pad or over the sea might create hazards. The hazards are essentially the same as those described earlier under Air Force objectives. Of additional concern to NASA is the possibility of an abort and the subsequent injection of hazardous material into the funnel-like Santa Barbara Channel, in which water depths exceed 2,000 feet. It may be that the configuration of this channel could cause a concentration of the hazardous material and its possible rapid transport to the beaches of the area.

The Atomic Energy Commission and its Oak Ridge National Laboratories are very interested in finding and developing beneficial uses for radioisotopes. Often this involves development of new and unique equipment for accomplishing a particular task. They assist in developing the application of radioisotopes to accomplish public benefit objectives of the other participating agencies and concur in these objectives.

The Department of Water Resources of the State of California has expressed great interest in the program in the context of the Department's awareness of the serious problems of beach erosion. The Department has taken aggressive measures to ensure the orderly development and use of the California shoreline areas as well as their protection and restoration. The State, in cooperation with the Corps of Engineers, has been actively engaged in beach-erosion control activities since 1946. The California Department of Water Resources is now conducting a comprehensive investigation of all aspects of sediment transport from watersheds for beach nourishment including the delineation of the areas where sediments are being produced under present conditions and anticipated future developments. The Department will also determine sources and physical characteristics of suitable material for artificial nourishment from inland sand sources. Because the assessment of beach-eorsion problems and subsequent engineering solutions are predicated upon accurate measurements of direction and rate of alongshore transport, the need for the proposed tracer study and for the collection and evaluation of littoral drift data is fully recognized.

Pleasure boating is expanding rapidly in California. New facilities, harbors, and harbors of refuge are required to satisfy this rapidly growing interest. The isotopic tracer program would provide valuable data toward the design considerations for these harbors.

Fundamental to all of these objectives is the investigation of sediment transport. Because previous effort has been expended on the long-straight beach and because of the importance of "filling in" data from an unknown area, investigation of the mechanics of littoral material movement near and around a headland was proposed. The scientific research objectives may be summarized as follows:

a. Development of techniques to determine whether sedimentary particles moving as littoral drift do or do not pass around a major headland.

b. If the particles do pass around the headland, determination of path or paths.

c. A quantitative or semiquantitative determination of onshore-offshore transport and of possible "deep water" alongshore transport and the relative importance of each.

d. Determination of seasonal changes in rate, direction, and distance of littoral transport in the study area.

e. Investigation of the average velocity of transport along a long straight beach and in the vicinity of a headland.

f. Investigation of the quantification of rate of littoral transport.

g. Investigation of the fundamental mechanics of sediment transport.

From this summary it may be seen that all but two of the major objectives stated by the sponsoring agencies can and should be satisfied by the series of experiments which have been and will be conducted by this program. The exceptions which do not appear clear at present concern the quantification of rate of littoral drift and the determination of seasonal changes. Tools and technology evolved during this program should permit the collection of the type of data necessary to meet the interests of all participants.

3. Previous Research

Research in littoral processes has been done in the prototype and the laboratory. The standard research technique is to hold all parameters constant but one, to vary that one, and to measure the response. It has been found, however, that the laboratory technique is not fully applicable to the prototype. The complex interplay among force and response elements, and the continuous feedback so generated is of extreme significance to the investigation of sediment transport phenomena. For this reason it is most important to transfer this research from the laboratory to the sea.

A major problem associated with studying sediment transport in the prototype has been the inability to fasten a satisfactory label on the sedimentary particles. During the past decade two identification methods - radioisotopic tracers and fluorescent tracers - have become available and have proved most useful. Unfortunately, the use of fluorescent tracers requires that physical samples of the bottom materials be secured and minutely examined in order to detect the presence of labeled particles. Also, fluorescent tracers can undergo chemical and physical degradation and therefore become lost from view. Adequately sampling extensive oceanic areas would be expensive in itself; the large number of samples resulting from each survey would prove unwieldy and expensive to analyze. This requirement for fluorescent tracer studies led to a very important advantage for radioactive tracers. Because detecting systems are capable of monitoring the presence of radioactive isotopes on the ocean floor as the system is moving, large areas may be investigated. For these reasons radioisotopic labeling of sediments provides a feasible and practical method of working in the ocean without the disadvantages inherent in laboratory procedures.

In addition to fluorescent tracers, some work on the use of naturally occurring radioactive materials as littoral tracers has been done, particularly at the University of California, Berkeley. Huston (1963) provides a good review of this work. In general, the method is similar to heavy-mineral tracing in littoral drift studies. Mineral sources must be identified; samples must be taken and analyzed in the laboratory to determine what quantities of the mineral are present.

An enormous amount of experimental work has been done with both radioactive and fluorescent tracers to determine sediment travel paths in the vicinity of engineering or navigation projects. Generally the approach has been to make an injection of the labeled material at point A and to follow its movement to some resting place at point B. In addition, several attempts have been made to quantify the volume of material moving per unit of time along a given reach of shoreline.

Of the various sediment tracers, glass, ground to an appropriate size distribution and labeled by an incorporated radioactive isotope, has been the most used. The method of preparation preferred by most investigators is to incorporate an inactive isotope as the label in the glass and activate it by irradiation in a nuclear reactor just prior to use. In addition, natural sediment materials have been labeled with sorbed (adsorbed or absorbed) isotopes by investigators interested in closer simulation of the native sediment. Sorbed labels also have the advantage of facilitating the preparation of large amounts of tracer. Disadvantages of sorbed labels for sand tracing are the nonuniformity of sorption on different minerals and the labeling amount being proportional to surface areas rather than mass.

A number of radioactive labels have been investigated and used. Svasek and Engel (1961) report on the use of scadium-46 in sedimentation studies near the entrance to Rotterdam waterway, Netherlands. Campbell, et al, (1967) report on the use of silt tagged with copper-64 to study channel silting at Port Hunter, Newcastle, Australia. Sato, et al, (1961) and Kato, et al, (1963) report on the use of radioactive glass "sand" using various labels to study sediment movement along various sections of the Japanese Coast. For studying movement along the California Coast, Inman and Chamberlain (1959) used quartz sands (with natural phosphorus impurities) which had been subjected to slow neutron irradiation to produce phosphorus-32. To detect the radioactivity, sediment samples were collected and used to expose film plates. Cummins (1964) and Ingram, et al, (1965) report on U.S. Army Engineer Waterways Experiment Station tracer tests using glass particles tagged with gold-198 at Cape Fear River, North Carolina, and Galveston Harbor, Texas, respectively. Krone (1960a) reports on the use of radioisotope tracers to study sedimentation in San

Francisco Bay. Krone's report also provides an excellent review of techniques and considerations in radioisotope tracing. In addition to the many field studies, some model work in the laboratory has been done (Lean and Crickmore (1963) and Taney (1962)).

Most investigators used bundles of Geiger-Muller detectors mounted on a sled, or drag. These detectors are large, rugged, and low in cost, but they have measurement efficiencies of only about 1 percent. Other investigators used scintillation detectors which have smaller active volumes, but can be very efficient. In some cases, samples were taken and autoradiographs made to provide a quantitative measure of sand tracer. The value of taking sediment samples and laboratory determination of label is limited by the number and size of the samples that can be taken, and by the delay between sampling and analysis.

The primary work accomplished to date in the vicinity of Point Conception was done by Trask (1952, 1955). He studied the minerals present in the stream sediments both north and east of Point Conception and found that augite was present only in streams north of the Point. Because augite was found to the east of Point Conception and because it could not have been supplied by the local streams, he concluded that sediments do indeed pass around the supposed barrier, the Point Conception complex.

The information available to Trask, unfortunately, was incomplete. No offshore samples were secured to the north and west of Point Conception to determine whether augite was or was not present in those areas. If augite did occur on the Continental Shelf to the north and west of Point Conception as well as offshore east and south, then it would not be a unique mineral species useful as a natural tracer. In fact, the possibility of an offshore source of sand containing augite was eliminated on the then held belief that sediments do not migrate toward the shore. Another factor not fully considered is the difference of size parameters on each side of the headland. Trask reported these differences, but failed to realize that another source area could be the cause.

Bowen and Inman (1966), partly based on the previous work by Trask (1955), concluded that sediment moved around the Point Conception complex. They also estimated the rate of drift at various locations around the Point. Mineralogy, sedimentation, and transport in the area around Pillar Point (northern California) were studied by Sayles (1965). He concluded that the sands were locally derived and that there was no net, long-term littoral transport of sand in this area. Similarly, Cherry (1965) concluded that Point Reyes and Bodega Head are barriers to longshore transport. The geology and oceanic environment offshore of Point Conception (San Miguel Gap) is discussed by Wright (1967). Lampietta (1964) reports on the Ocean Science and Engineering, Inc. study of beach configuration from Pismo to St. Augustin, California. Profiles 9 and 10 of that study are in the area of Surf, California, and profiles 12-14 cover the area near Point Conception. Other studies of California sediments have been made by Emery (1954) and Cooper (1967).

Section II. ISOTOPES SELECTION, TAGGING TECHNIQUES AND INSTRUMENTS

1. Studies of Isotopes and Tagging

Three criteria - health physics, gamma energy sufficient to be detected, and the engineering behavior of tagged sand - were emphasized in the search for isotopes and tagging techniques suitable for sand tracing. Consideration of health physics made low energy radiation, and isotopes that are chemically inert and biologically inactive, desirable. The radioisotope must have a sufficiently high energy gamma ray to permit easy measurement through an overburden of water and untagged sand. Consideration of the engineering behavior of tagged sand called for a new labeling process, one that definitely did not alter the "hydraulic characteristics" of the sand and yet ensured no loss of the radionuclide to the environment. To gain true scientific results from a sediment tracing experiment in a fluid environment, it is imperative that the tagged particle of sand have the same "hydraulic behavior" after tagging as before. It is also necessary to be sure that detected radiation belongs to the tagged particle and does not represent a radioactive veneer broken off from the particle.

A solution to shortcomings of labeling procedures presently in use and described by other studies would be to develop a technique that uses sand indigenous to a particular area, uses no external coating, and does not alter grain hydraulic characteristics. Diffusion of gas into a solid offers this solution. Krypton, in a process described by Chleck (1963) can be diffused at high temperature and pressure into solid materials. However, krypton's long (10-year) halflife made it generally unsuitable, except perhaps for special applications in tracing studies. Seeking other possible gases, personnel at Oak Ridge National Laboratory (ORNL) developed a process (xenonation) similar to kryptonation whereby a related gas, xenon-133, is diffused into a solid, in this case, a sand particle.

The study indicated xenon had numerous suitable characteristics. In terms of radiation exposure to personnel, xenon is easy to handle. Also, it is biologically inactive. From an engineering standpoint, the suitable halflife (5.27 days) and the labeling process, which required no external coating to natural sand, overrode the initial detection and instrumentation problems posed by the low energy (.08 million electron volts) gamma radiation. Consequently, xenon was selected for exclusive use in the initial phases of the program.

Tests conducted in the CERC Petrology Laboratory indicated xenonation did not alter the specific gravity of sand, nor does it alter grain hydraulic characteristics. By measuring the time required for sand grains to settle through a column of water, it is possible to test their "hydraulic characteristics", i.e., determine the sediment size distributional characteristics in the fluid medium. Replicate analyses of xenonated and non-xenonated sand from several different locations show only minor differences in the settling curves and consequent statistical parameters.

These differences are well within the limits of experimental error. Figure 3 shows several curves of settling-tube data and data obtained by standard seiving techniques.

Xenonation differs from kryptonation in that the former occurs at low pressure. High temperature of the process causes vaporizing of any carbonate contained in the sand, and thus adversely affects the labeling process. Consequently, the carbonate fraction must be removed by acid leaching before labeling. Therefore, xenonation is not a suitable technique where the dominant mineral constituent of sand is a carbonate. Carbonate-free sand is heated to approximately 900° C in a specially designed furnace containing an atmosphere of xenon-133. After cooling with liquid Nitrogen (N_2), the sand is removed and packaged for shipment to the test site. Due to desorption of xenon from sand, initial batches of labeled sand had an effective halflife of 2.7 days. However, recent improvements in the technique show that the effective halflife of xenonated sand is now 5 days, nearly identical to that of the gas itself. Labeling of sand with this technique is a function of the mass of the particle rather than the surface area.

Labeling is presently limited to a batch of about 40 liters (approximately 100 pounds) per day. Details of the process are presented in the ORNL report in Appendix C. Though the process occurs at high temperature, it does not affect the shape of grains (Figure 4), but has changed the color of the sand to ash-gray.

Other labeling techniques provide greater choice of isotopes, use of which may ultimately be required to meet RIST program goals. Artificially manufactured sand has been used as a tracer (Sato, 1962; Taney, 1962; Ingram, et al, 1965). However, such a process requires placing an element suitable for activation in a silica melt, maintaining specific gravity near that of quartz, crushing the solid mass, resizing it to match size distributional characteristics of sand in the test environment, and then shipping it to a reactor for activation. In special cases, where the mineralogy is suitable, it is possible to activate a naturally occurring impurity in quartz thereby permitting the use of sand indigenous to the test site (Inman and Chamberlain, 1959). Another possible technique is to place desired activity on the external surface of the grains and then seal it by the addition of an inert, abrasive-resistant coating.

Because these techniques may modify the specific gravity, size, shape, and roughness of discrete particles, it is possible that the hydraulic characteristics of the grains would be changed leaving results of an experiment in some doubt. The U. S. Naval Radiological Defense Laboratory (NRDL), San Francisco, has developed a means of coating sand grains by a water-glass procedure. Under contract to this RIST study, personnel at NRDL conducted experiments on the leaching and abrasion of beach sands tagged with barium-140, lanthanum-140, and chromium-51 by the NRDL water-glass procedure. These particular isotopes, with varying

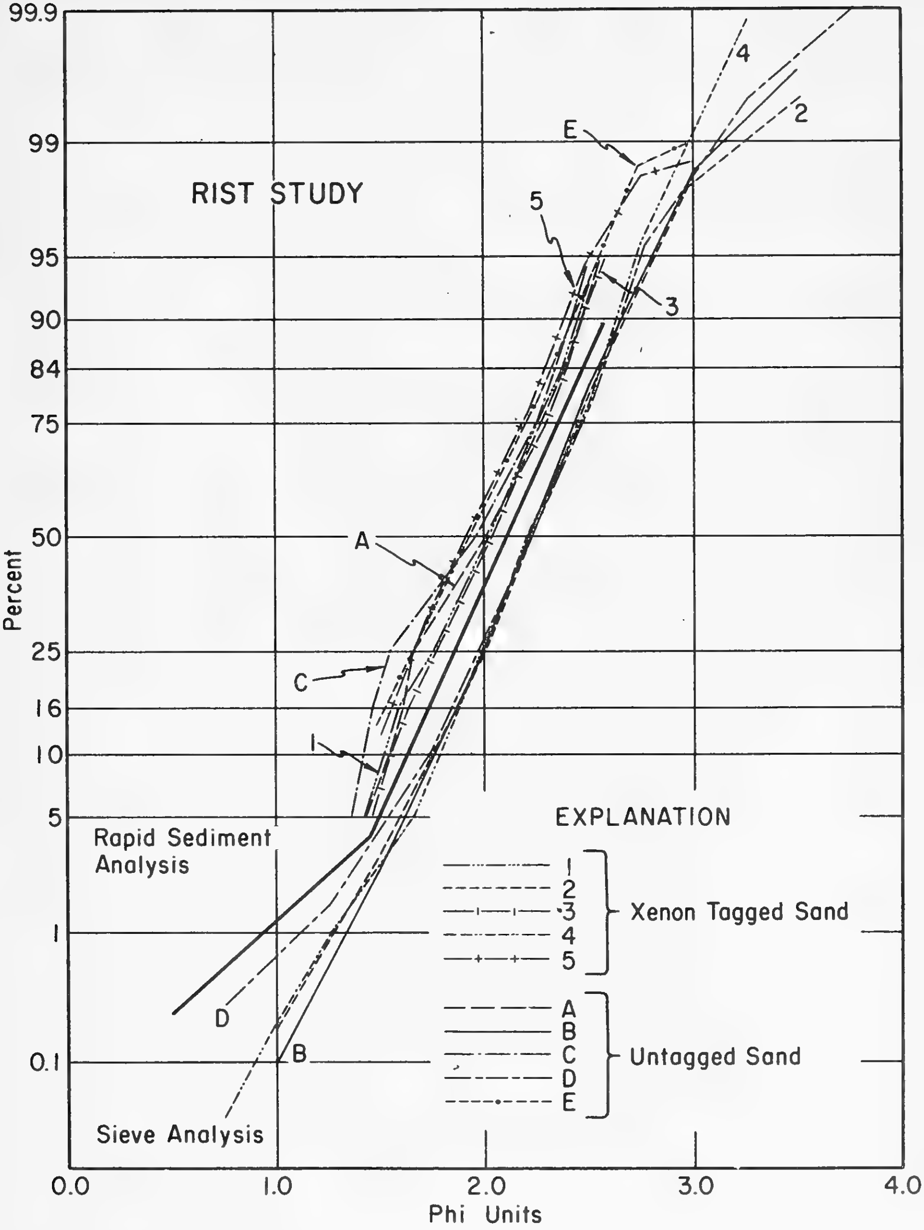
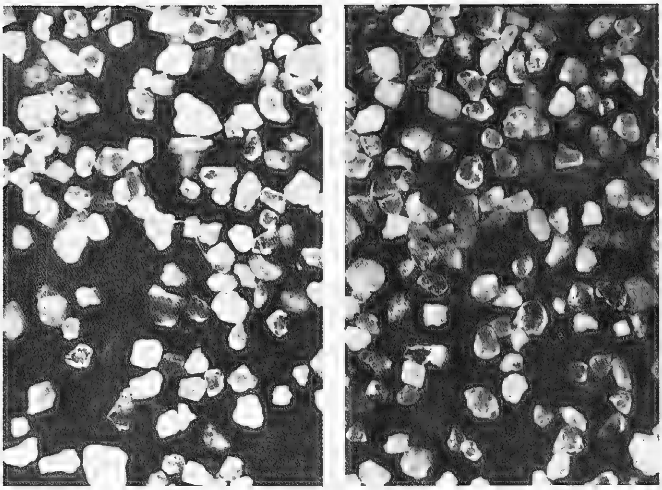


Figure 3. Sieve analysis and rapid sediment analyzer data



UNTREATED SAND XENONATED SAND

Figure 4. Comparison of xenonated sand with untreated sand from the same area, mean size 2.0 phi (0.25mm)

halflives and energy (Table I), while not yet used in the program, have potential application in multiple isotope studies, or at other places where their particular characteristics might be desirable.

TABLE I

Isotopes Considered for Use in the Study, Showing Halflives and Energy

Element	Halflife	Energy (million electron volts)	Abundance
Gold-198	64.8 hours	.41	96%
Barium-140	12.8 days	.54	25%
Lanthanum-140	40.2 hours	1.6	95%
Xenon-133	5.27 days	.081	35%
Krypton-85	10.76 years	.52	0.4%
Chromium-51	27.8 days	.32	9%

The NRDL studies (see Appendix A) indicated that loss by leaching and abrasion of barium-140, lanthanum-140, and chromium-51 from sand labeled with the NRDL water-glass technique is of small magnitude (1 to 4 percent). Some modifications in the size of particles are indicated by the NRDL data but the differences are minor and are probably within the limits of experimental error. Results of tests in the CERC laboratory, using samples supplied by NRDL, lead to the same conclusion, although there is more spread in the data than with xenonated sand.

NRDL also conducted experiments on loss of xenon from xenonated sand due to leaching and abrasion. Results of that study indicated approximately 3 to 5 percent of xenon was lost. Recent tests carried out by ORNL personnel indicate loss of xenon is negligible; possibly reflecting the improvement in labeling since the NRDL experiments.

2. Injection Devices

An apparatus capable of placing sand on the bottom in deep water, or in the relatively shallow water of the breaker zone, was required. Systems used in previous studies were designed primarily for point source injections and were unsatisfactory for working in a surf zone or for placing labeled sand in a line source. A suitably designed apparatus should be able to make injections in the surf zone and deeper water, inject line sources and point sources, and also provide radiation shielding.

The initial device used in the RIST study was a cylindrical hopper with pump and hoses (Figure 5) designed to emplace a slurry of labeled sand on the marine bottom, either as a point source or line source. Tests of the apparatus at ORNL and at the April 1967 Cape Kennedy field tests were successful. However, during the first injection of the June 1967 test at Surf, California, the sand bridged above the orifice and would not discharge. The device required that sand in the hopper remain dry,

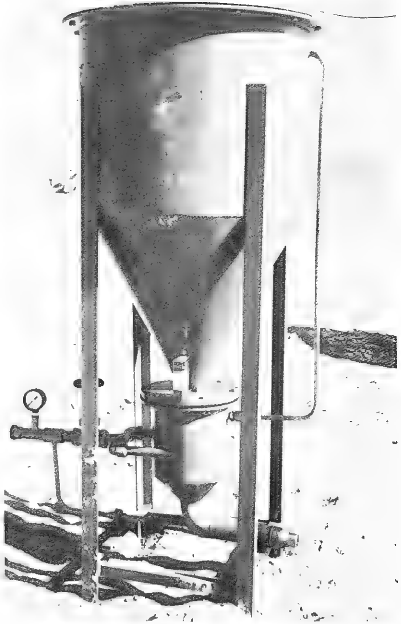


Figure 5. Cylindrical Hopper for emplacing tagged sand.

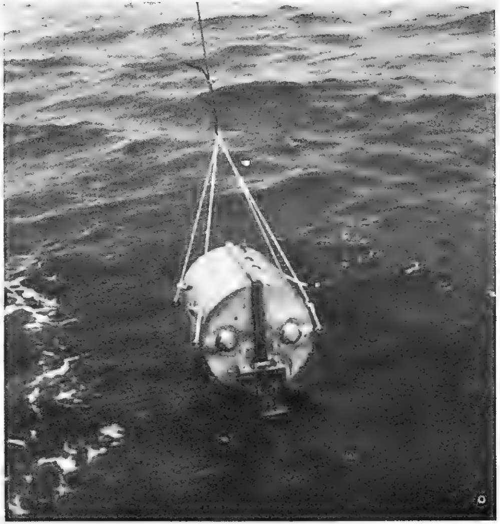


Figure 6. Clamshell Device for emplacing tagged sand.

since wet sand would not flow. During a second injection the apparatus did work reasonably well, and the sand was pumped to the bottom. A third injection was made without the apparatus.

It was recognized that the hopper had serious faults, and another device was designed and built for use in the December 1967 tests in the Point Conception area. This apparatus resembles a clamshell bucket (Figure 6). However, it works in reverse: loaded with labeled sand and closed at the surface, it is lowered to the bottom where a lever-spring mechanism opens the bucket upon contact with the bottom. On two of three occasions, scuba divers had to manipulate the jaws of the clamshell in order to completely open them. With a capacity of 40 liters, it proved effective for placing sand as a point source in water seaward of the breaker zone.

3. Mobile Detector

Labeled sediment used in tracing experiments can be studied by making on-site measurements or by collecting samples from the environment which are later analyzed in a laboratory. The latter technique is laborious and time consuming, and could involve problems of radiation exposure. On-site measurements minimize radiation exposure problems and provide data rapidly. Ability to quickly know of the presence or absence of labeled material is an aid in surveying.

On-site measurements can be made by holding a scintillation counter or Geiger-Müller tube against the sediment and obtaining discrete readings. Such a technique is usually employed in laboratory experiments, and was used in the experiment reported in Section III. Distances and areas involved in most field operations require a mobile detector system with continuous readout of data. Other investigators have reported the use of sled-mounted detectors (Krone, 1960b; Ingram, et al, 1965; Rakoczi, 1963). Such a device has been used with some success in estuaries and protected harbors, although even in these environments the sled has tipped over, disrupting the surveys. Such a system would likely be unstable in the surf zone, and would be totally unsuitable in rocky areas. Both conditions exist in the Point Conception study area. The ability to work in surf or topographically rough areas is required for the program to have general application. A ball-like device that would roll along the offshore marine bottom, through the surf zone, and up on the beach was designed and built by ORNL (see Appendix C). The shape of the detector vehicle resembles a cylinder with rounded ends (Figure 7).

The outer housing of the detector vehicle is constructed of a steel latticework covered by expanded metal reinforced at the bearing surface by stainless steel rods. This design prevents loose stones and other debris from entering the ball and possibly damaging the four 2 x 2-inch cesium iodide crystals housed inside the "ball" (Figure 8). The open latticework permits gamma energy emitted from the radionuclide to penetrate to the crystals. At the present time, all detectors are operated to see only one isotope (or gamma ray energy) over an area of approximately 2 square feet. The detector housing, suspended from the axle of

Figure 7. Field operations at Surf, California, June 1967. In foreground are mobile detector vehicle ("ball") and LARC-V with instrument shelter. In background is DUKW vehicle used in support of operations.

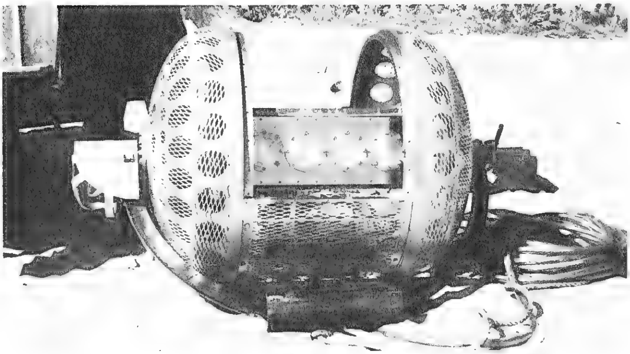


Figure 8. Detector vehicle with part of bearing surface removed to permit servicing. Shown are the detector housing and the ports for the detector crystals (not yet in place).

the ball, contains photomultiplier tubes, preamplifiers, and attendant circuitry. Coaxial cable for the detector circuitry exits from one end of the axle, and is then attached to the wire tow cable. As presently designed and constructed, the detector vehicle has a depth limit of 200 feet.

Limited tests of the rolling characteristics of the ball conducted at ORNL indicated the design was suitable. Turbidity of the Atlantic Ocean off Cape Kennedy during the 1967 test precluded observation of the deep water by project scientists using self-contained underwater breathing apparatus, but its ability to track and operate in the shallow-water surf was observed to be satisfactory. General operation of the vehicle in 30 feet of water during the 1967 test at Surf, California, was observed to be satisfactory by the project scientist, using scuba. Nevertheless, it was desired to obtain specific engineering data on the hydrodynamic performance of the vehicle to learn the limit of survey speeds and possible means of improving the design. Under contract to the RIST study, the U. S. Naval Ship Research and Development Center (NSRDC), formerly the David Taylor Model Basin, undertook a program to test the vehicle under a variety of conditions, most especially under a variety of towing speeds and cable lengths.

The NSRDC tests indicated that at 4 knots (6.75 feet per second) and the cable length usually employed (200 feet), the vehicle maintained bottom contact in the water depths normally surveyed (less than 60 feet) and would do so to a depth of 80 feet. All field tests so far have operated at a speed of approximately 2 knots (3.35 feet per second). Details of the test are contained in the NSRDC report attached as Appendix B. The recommendation of the test program to use oceanographic-type electromechanical tow cable in future tests is being followed.

4. On-board Data Collection System

Electrical signals from the four detectors mounted in the ball are carried to a signal mixer on the towing vehicle and then to a 400-channel analyzer (Figure 9). The analyzer is capable of operating in two modes: multi-scaler and pulse-height.

Normal surveying mode is "multi-scaler" whereby the analyzer operates as 400 individual counters; each counter stores signals from the detectors according to a preset time interval (0.01, 0.1, 1.0, or 10.0 seconds), selected by the operator. At the end of the appropriate time interval the counting sequence is terminated, and data must be cleared before the sequence is restarted. Assurance that the detected radiation comes from the labeling isotope is ensured by use of the pulse-height mode. This mode uses all 400 channels to analyze the energy spectrum of the radiation being observed. Data accumulated in either mode is printed out on a teleprinter and on punched paper tape as binary coded decimal. Radiation data can also be displayed on an oscilloscope in the analyzer unit. The scope is of particular value in calibration procedures and when operating in the pulse-height mode.

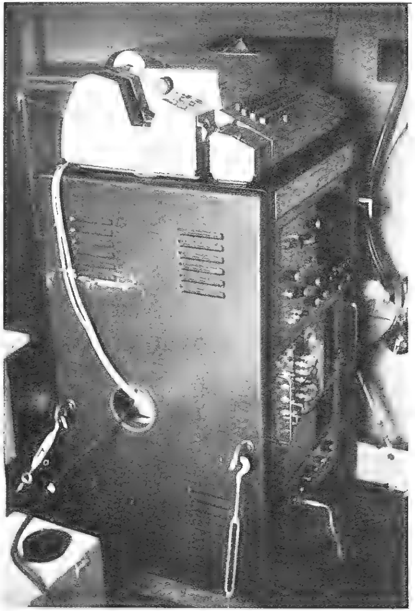


Figure 9. 400-Channel Pulse-Height Analyzer and Recorder with Teleprinter. The analyzer contains an oscilloscope for visual monitoring and spectrum display.

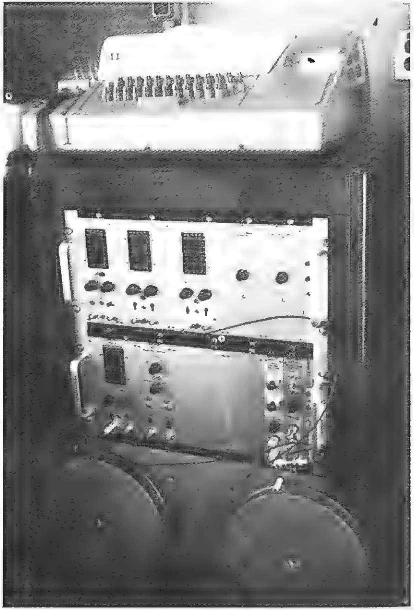


Figure 10. On-Board Programmed Interrogator. Photo shows readout, BCD tape reels and teleprinter.

By means of a programmed interrogator (Figure 10), other data pertinent to surveying are coordinated with the radiation data and read into the data display which is both real time and punched paper tape. Presently this additional data consists of time and line sequence data and navigational data (distance to the vessel from two known shore points). Concurrently with reading of above data it is possible to look at the pulse height or the energy distribution of the isotope being detected.

5. Field Support Equipment

Tracing littoral transport requires a vessel capable of operating through the surf zone where the greatest rate of sediment movement occurs. Military amphibious vehicles are ideally suited for such operations. During initial field tests at Cape Kennedy, and subsequently at Vandenberg AFB in June 1967, a LARC-V was used to tow the underwater detection vehicle and carry personnel and equipment (Figure 7, page 16). Later, when more comprehensive field experiments required a hoisting device, more electronic equipment, a larger power generator, and more working space for personnel, the need developed for a larger craft. The U. S. Army Mobility Equipment Command met this need by lending the Los Angeles District a LARC-XV.

The LARC-XV is a diesel-powered amphibious transport vehicle designed to carry cargo from offshore supply vessels to beach or inland staging areas (Figure 11). Normally operated by a 2-man crew, the LARC-XV has a cargo capacity of 15 tons, and can move on water at speeds up to 8 knots. Maximum land speed is around 30 miles per hour. Maximum dimensions are 45 feet long, 16 feet high and 14 1/2 feet wide, making long-range land

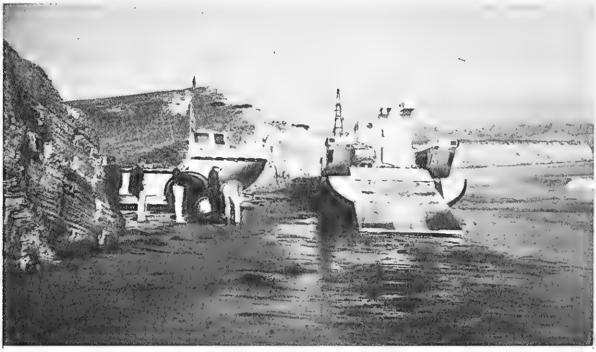


Figure 11. LARC Amphibious Vehicles. LARC XV is on right with loading ramp in lowered position; LARC V is on left. Note back-up detector vehicle carried on deck of LARC XV.

transport difficult. A flush cargo deck and hydraulically actuated ramp provide convenient access for personnel and wheeled-equipment. The LARC-XV is capable of negotiating breakers 10 feet high either onto or off the beach. With a fuel capacity of 360 gallons, it has a marine consumption rate of approximately 30 gallons per hour.

The LARC-V has become a standard amphibious vehicle, and its availability for radioisotopic tracing operations is fairly well assured. The LARC-XV, however, has had limited production and distribution, and might not be available for project-oriented searches when and where it is needed. It is judged that at the end of the present program, instrumentation will be refined to a highly transportable package that will permit operations aboard the smaller LARC-V or similar vessel. Actually, where environmental conditions are not severe and a hoisting device is not necessary, the present on-board instrument shelter will function on a LARC-V.

The Marine Corps Landing Force Development Center at Camp Pendleton, California, furnished a driver to instruct the crew in operation and maintenance of the amphibious vehicles.

The search operation requires a constant knowledge of the searcher's position. To save time and money, an accurate, fast position-finder is needed to determine the position of the radiation detector as it is towed behind the survey vessel. Transit and alidade techniques are slow, requiring two or more operators, and are not easily used with computers. The various radar navigational devices normally used by ships are not accurate enough to locate the surface craft within a few feet. Without precision, the search director could unknowingly miss hundreds of square feet of test area.

Without high-resolution positioning data, the configuration of dispersal patterns could not be accurately defined.

The Cubic Autotape System was evaluated as the most suitable navigational system available for the RIST study. The Autotape is a compact transistorized system which employs microwaves along the radio line of sight to establish ranges (distances) to the surface craft from shore-based responders. The system simultaneously measures the distance between each of the two responders and the boat-borne interrogator through a phase comparison of modulated frequencies. With a range of 30 miles, it has a resolution of 1 meter. The responders are battery-operated and can be left unattended while in operation.

For the RIST study, normal land surveying procedures are used to establish responder sites on major and minor coastal promontories. Distances between adjacent responders vary from 1,000 to 3,000 feet depending upon accessibility and their alinement with the search area.

Aboard the surface craft, the 2-range interrogator visually displays the distances to the responders in meters (Figure 12). The position of

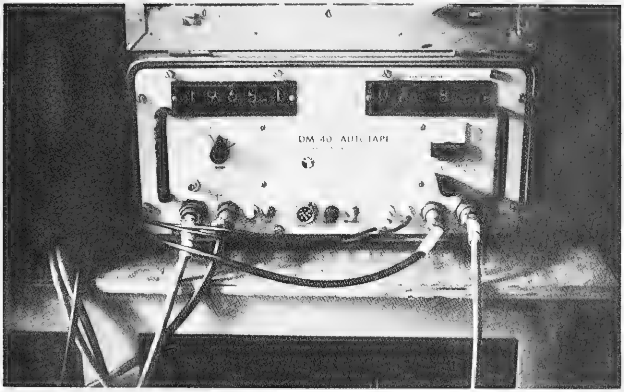


Figure 12. DM-40 Cubic Autotape Interrogator.
Direct digital readout is in meters.

the vessel is easily determined on a plotting board by intersecting arcs struck by the ranges scaled from the respective plotted responder sites. This manual method is used only as an aid in piloting the vessel. The Autotape is electrically coupled to the on-board analyzer of the mobile detection system for direct correlation of vehicle position with the parameters of time and count rate.

A knowledge of bottom topography is essential to a realistic analysis of littoral transport patterns. In addition, the operating depths should be known while towing the detector vehicle. Prior to the field tracer test, hydrographic and topographic surveys are conducted on ranges perpendicular to the shoreline. A transit operator with a portable radio occupies a point on shore and directs the vessel in on the range line. A second instrumentman, at a measured distance up or downcoast, plots the survey vessel's position using a plane table with an alidade on radio command from an operator on the boat. Depths are constantly recorded on the boat with a portable precision recording fathometer. Later the recorded depths are plotted on cross-section paper as a function of the distance from a baseline to form profiles of the sea bottom.

The heart (and most vulnerable part) of a fathometer is the transducer unit which is a 2-way energy conversion device. It transmits sonic energy waves (200 kilohertz) to the bottom and receives echoes of these waves reflected back from the bottom. The time lapse between transmission and reception, mainly a function of the distance the signal travels through the water, determines the water depth. Depths are visually displayed and recorded on electrosensitive paper. Calibrations are made for variations in water temperature, salinity and turbidity by measuring depths (at 10-foot increments) to a metal bar lowered below the boat. At the end of a day's run the chart running time is correlated with a tide curve for the same time period; depths are therefore corrected to a constant datum.

6. Computer Programs

Radiation measurements are made continuously as the mobile detector system is towed through the surf, along a beach, or along the ocean bottom offshore. Interpretation of the detected radioactivity depends upon the making of maps based on the collation and manipulation of data pertaining to position, observed radiation, and time. With a time-selection mode for data acquisition available at exponential increments of 10 (from 0.01 to 10.0) seconds, a large mass of data may be accumulated in a few hours. During a field test, surveying may go on several hours a day for several weeks, and computer processing is necessary to study and evaluate the collected data. Also, soon after the completion of a survey, plotting and posting of the survey is necessary to efficiently monitor the field operations. Initial field operations at Surf, California, relied on manual preparation of maps and subjective interpretation of data printed by the teletype of the on-board data acquisition system. Almost immediately it became evident that computer processing and plotting must be employed in future operations. Therefore, CERC undertook the in-house development of a computer program that would quickly generate plots useful to continuing field operations. This program is called RAPLOT. Presently ORNL is developing a more sophisticated program for subsequent study and refinement of the radiation data. The data collected from various sensors are assembled by the on-board detector system and punched on 8-channel paper tape in American Standard Code for Information Interchange (ASCII code). At present there are six fields on each line (or card image) of tape containing the data given in Table II. The data on the paper tape is eventually translated to a Binary Coded Decimal (BCD) magnetic tape for use in the RAPLOT program so that it will be compatible with most general purpose computers.

In addition to the basic field data, some further information, called program control parameters, must be fed into RAPLOT. These parameters supply the location of the shore beacons and the injection site, background radiation count, halflife of the isotope, and length of the cable on which the detector was towed. Also supplied are options controlling the format of the plots generated and a legend for the plots.

The program control cards contain the California Lambert Coordinates of the shore beacons. The data input tape contains the distance to each beacon for each fix. By the Cosine Law, this can be translated into distance in terms of a rectangular coordinate system.

$$DX1 = (DB^2 + D1^2 - D2^2)/\ 2\ DB$$

$$DY1 = \sqrt{D1^2 - DX1^2}$$

D1 is distance from the upcoast radar beacon, D2 is distance from the downcoast radar beacon, DB is the distance between the two beacons,

TABLE II

Data Format for Punched Paper Tape Input to *RAPLOT* Program

Field	Item	Definition
1	Line number	Increases sequentially with each line of data unless manually reset.
2	Time	Based upon time accumulation mode, cumulative unless manually reset.
3	Radiation count	Pulse from differential discriminator accumulated for time between lines only (automatically reset at each printing).
4	Beacon 1	Distance in tenths of meters from the upcoast fixed shore beacon, automatically changed at each line.
5	Beacon 2	Distance in tenths of meters from the downcoast fixed shore beacon, automatically changed at each line.
6	Spare	Reserved for a second radiation channel in a 2-isotope test.

DX1 is distance of the fix from the upcoast beacon in a direction parallel to a line intersecting the two beacons, and DY1 is distance of the fix from the upcoast beacon in a direction normal to a line intersecting the two beacons. These coordinates may be rotated and translated to give the Lambert Coordinates of each fix:

$$\mathrm{NCOORD} = \mathrm{DX1}\ \mathrm{SIN}\ \theta + \mathrm{DY1}\ \mathrm{COS}\ \theta + \mathrm{NORTH}$$

$$\mathrm{ECOORD} = \mathrm{DX1}\ \mathrm{COS}\ \theta - \mathrm{DY1}\ \mathrm{SIN}\ \theta + \mathrm{EAST}$$

θ is the angle of rotation of the coordinate system, NORTH and EAST are the Lambert Coordinates of the upcoast radar beacon, and NCOORD and ECOORD are the coordinates of the fix. Experience indicates that the distances to the radar beacons may be erroneous as often as 5% of the time, therefore, the program checks for errors by determining whether the absolute value of the difference between sequential radar beacon distances would indicate a boat speed greater than 4 knots, the known maximum speed of the survey vessel. If an error is detected, it is corrected by linear interpolation between valid radar beacon fixes.

Fixes give the position of the survey vessel at the time of each fix. To plot the radiation values correctly, one must know the location of the detector vehicle somewhere behind the vessel at the end of its cable. This position is estimated by extrapolating backward along the path of the vessel. Assuming a position for the detector vehicle at the beginning of the survey, the position of the detector at each fix is computed by linear interpolation from the present position of the vessel to the last computed position of the detector. The distance the detector lies astern of the survey vessel depends on the distance from radar mast to the stern post, where the cable is attached, and on the horizontal component of the cable which is a function of water depth. Because present field operations are conducted in very shallow water, or at nearly the same water depth, a constant depth value is used.

Before processing through RAPLOT, each set of data is visually scanned and an estimated background count is determined and entered on the data control card. The count is used to set an upper and lower bound on the range of background radiation. All counts between these bounds are averaged to obtain the mean background count. Background is subtracted from the radiation value of each fix, and the remainder (if greater than zero) is corrected for decay since the time of injection.

$$CC = NC\ (e^{\lambda t})$$

$$\text{where } \lambda = \frac{\text{natural log of 2 } (0.693)}{T_{1/2}}$$

CC is the corrected count, NC is the net count (observed radiation value less background), t is the elapsed time from the injection to the count, and $T_{1/2}$ is the isotope halflife in hours.

The output from RAPLOT is in two forms. The first is a printed output which gives all of the values of the control parameters used to control the computation of the data and the flow of the program. Also included are some summary statistics on the radiation values and the position of the center of the radioactive material (analogous to the center of gravity of a mass). The final part of the printout is a list of the fixes, which gives the fix number, the coordinates of the fix in the California Lambert Coordinate Grid and the corrected radiation value.

The second type of output consists of maps drawn off-line on a plotter driven by a plot tape generated by RAPLOT. There are three types of maps. The first is a plot of the trackline followed by the survey vessel. The second is a plot of uncorrected radiation values. The third shows the radiation values corrected for background count and decay since injection. The two radiation maps plot the fixes after they have been corrected for the distance that the detector is towed astern of the survey vessel. The choice of which maps to produce, as well as scale and format, is controlled by values fed in on the plot control card. A Fortran V source language listing of the RAPLOT program is found in Appendix D.

Position of the detector is computed at each fix time by linear interpolation from the present position of the survey vessel to the last computed position of the detector:

$$YD_n = YV_n - \frac{CABLE\ (YV_n - YD_{n-1})}{\sqrt{(YV_n - YD_{n-1})^2 + (XV_n - XD_{n-1})^2}}$$

$$XD_n = XV_n - \frac{CABLE\ XV_n - XD_{n-1})}{\sqrt{(YV_n - YD_{n-1})^2 + (XV_n - XD_{n-1})^2}}$$

where XD and YD are the coordinates of the detector and XV and YV are the coordinates of the vessel. "CABLE" is the horizontal distance the detector lies astern of the survey vessel.

Also printed on the third map type is the centroid of the detected radioactive material, which is located by the coordinates $\overline{X}$, $\overline{Y}$, where:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i \quad CC_i}{\sum_{i=1}^{n} CC_i}$$

$$\overline{Y} = \frac{\sum_{i=1}^{n} Y_i \quad CC_i}{\sum_{i=1}^{n} CC_i}$$

X_i and Y_i are the coordinates of each fix in the survey; CC_i is the corrected radiation count at each fix and n is the number of fixes.

Section III. FIELD AND LABORATORY TESTS

1. General Program Design

General program design involves a By-Product Material License from AEC, scheduling and planning field operations to coincide with ORNL reactor shut-down schedule, and selection of a season when wave climate will permit operations on the beach, through the surf, and offshore.

Although the use of xenon-133 tends to minimize radiation hazards, certain radiation safety precautions are required. Greater precaution is necessary when isotopes with a higher radiation output, such as gold-198, krypton-85, or chromium-51, are used. Appropriate AEC regulations were observed at all times. Application for the required AEC By-Product Material License is made on Form AEC-313. The license is obtained from AEC with the concurrence of the State concerned.

Personnel involved in the experiment were supplied with radiation dosimeters or ORNL film badges. These indicators were checked by the Program Health Physicist who maintained records of cumulative dosage on all personnel exposed to radiation hazards. Upon completion of a test, Cumulative Exposure Form DD-1141 was completed and provided to the Safety Office at the permanent duty station of the individual participant. In all the operations to date, no one has received a significant exposure to radiation.

To ensure safe operations during the test, full-scale rehearsals of all field procedures (particularly transport, mixing and injection of the tracer) were conducted prior to working with radiated sand. Following rehearsals, the Program Health Physicist presented a lecture on general radiological safety procedures to participating personnel.

The temporary storage areas for the radioactive sand were marked in accordance with AEC regulations; access to the areas was controlled. Similarly, once the radioactive sand was emplaced, the beach test area was marked and access controlled.

The tagged sand was injected under water, either as a line or a point source, by use of either the mixer-hopper or the clamshell device (see Section II). Safe transfer of the sand from the shipping package to the sand hopper was ensured by positive gasketed flange connections between the shipping container and the injection equipment. Personnel making the transfer, or otherwise handling the tagged sand, wore protective clothing. Use of the clamshell device, which is self-shielding, greatly simplified handling procedures.

Personnel, equipment, and the survey area were monitored throughout the test to locate areas where radioactive sand might have accumulated. If necessary, equipment (including shipping containers) was decontaminated, to acceptable radiation limits, generally by washing.

Tagged sand is prepared at ORNL, using sand indigenous to the survey area. At the present time, radioactive xenon (xenon-133) is manufactured only at the time of reactor shutdown and is then available for sand labeling (see Section II). In order to minimize radioactive decay of the isotope, field tests must be scheduled at times immediately following periods of reactor shutdown (approximately once a month). Immediately after tagging, the sand is taken as quickly as possible by common carrier (usually airlines) to the test area.

Prior to actual field tests with radioisotopic tracers, certain field studies are necessary to provide a background of data against which future measurements may be compared, and to provide design data for future testing. In addition, the information collected supplements radiation surveys for determining sediment movement patterns.

Base lines were established and hydrographic profiles were completed along various ranges perpendicular to the beach at Surf and around Point Conception to provide data concerning the initial conditions of the beach and nearshore bottom. Samples of sediments were collected along the profiles at the following locations +12', +6', +3', MLLW, -6', -12', -18, -24, -30', and -50' depths. These samples were analyzed at CERC for standard size parameters. (Future studies of the heavy mineral fractions are planned.) In addition, scuba divers made an inspection of the bottom character.

Aerial photographs of the coastline from Surf, around Point Conception, to Gaviota were taken to complement the surveys. These photographs and the hydrographic surveys were correlated to the USC&GS boat sheets (field survey plots) for the area.

Just prior to the tracing survey, the navigation system was set up using the previously established base line and the background radiation of the area was then surveyed. All radiation surveys were conducted by towing the mobile detector "ball" behind the amphibious vehicle (see Section II).

As soon as practicable after emplacing the tagged sand, an initial radiation survey was conducted. Radiation was then surveyed on successive days to define the development and changes in movement patterns. Collected data were corrected for radioactive decay and background, and plotted as isoactivity contour maps.

Sea, swell, and weather conditions were monitored throughout the California tests to aid in determining the relation of sediment movement to oceanographic conditions. In addition to forecasts and visual observations, a wave gage installed at Platform "Henry" near Point Conception was used to monitor wave conditions for the Point Conception sites. Future tests will also employ current direction and velocity meters emplaced in the immediate study area.

2. Cape Kennedy, Florida, April 1967

The April 1967 field operation conducted at Cape Kennedy with the assistance of the Air Force Eastern Test Range was fundamentally a test of tracing equipment. Primary objectives were to test the operational characteristics of all equipment and the conceptual framework of the program in the marine environment. Because the emphasis of this phase of the program was on these primary objectives, the geographic and scientific scope of the program were limited.

With the concurrence of the Air Force, the site selected for this test was on the north side of the Cape where the beach is wide enough to provide easy entrance and exit even at high tide. No rock outcrops on the beach nor on the marine bottom. The offshore slope is gradual to a depth of approximately 40 feet, the limit of the sounding records.

Sediments comprising the bottom at the depth of injection (30 feet) were small shell fragments; beaches were predominantly quartz sand. Winds occurring during the test were light; sea and swell never exceeded 2 feet.

Since the sand labeled with xenon was quartz sand from California, some problems might have developed with the "deep" water test. However, none did, and all other environmental parameters were nearly perfect for the objectives of the test. When assembled and mounted in the amphibious vehicle (LARC V), instruments were tested on the beach to determine the tracking characteristics of the detector vehicle and the ability of the detectors and analyzer system to see xenonated sand placed on a known section of the beach (Figure 13). Following this sequence the system was

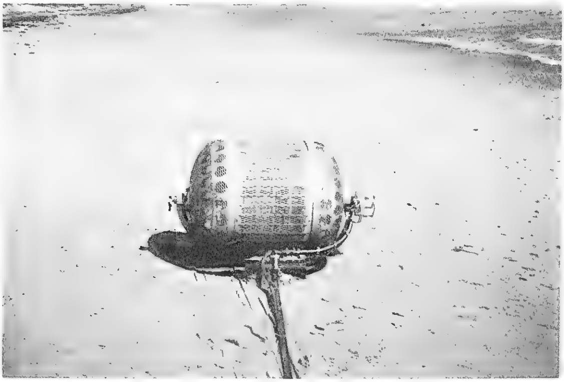


Figure 13. Detector vehicle at Cape Kennedy, Florida. On the beach the detector vehicle followed a true course behind the towing vehicle. When underway, the towing tongue is elevated and does not plow along the beach. See Figure B-1 in Appendix B.

towed into and through the surf zone to "deep" (30 feet) water for background radiation measurements. Turbidity of the water precluded observation of the detector by scuba divers in "deep" water, but satisfactory ability to track and operate in the surf was observed.

An offshore test area, 100 by 300 feet, was laid out nearly parallel to the beach, and marked by buoys. Using scuba, project scientists placed 1 liter (about 2 pounds) of sand tagged with 30 millicuries of xenon-133 on the ocean bottom in the center of the test area. When removed from its carrier and placed on the bottom, the sand was observed to spread out and to fall into the interstices between the small shell fragments comprising the bottom. Prior to termination of the survey, the sand was detected and followed by random search for approximately 1 hour over an area somewhat larger than the buoyed zone and at right angles to it.

Objectives of the test were met. The various mechanical and electronic components operated satisfactorily, and the LARC V amphibious vehicle proved to be superior to the small DUKW vehicles which were originally considered. Xenon could be detected in the marine environment. Counts were obtained that were several orders of magnitude above background.

Because no navigation system was employed in this test, nor any attempt made to monitor environmental parameters or components, no scientific significance is attached to the results regarding sediment transport.

The on-board data collection system was intermittently subjected to wetting by spray even though waves and surf were light. It became immediately evident that it would be necessary to have the on-board systems completely housed in a watertight instrument shelter.

3. Surf, California (Vandenberg Air Force Base), June 1967

As the objective of the Cape Kennedy test was to prove the conceptual framework of the program, the objectives of the first California test were to nurture all phases of the program to a completely operational level, and to test the instruments and field techniques in an environment harsher than that in Florida.

Scheduling of the test included the selection of a period during the remainder of the fiscal year when atmospheric and oceanic conditions would permit maximum time in the field, and then the coordination and scheduling of xenon-133 manufacture and sand tagging within the time selected for the field effort. To reach an operational level (the prime objective) required

a. coordination of xenon-133 manufacture, sand tagging and transcontinental air-freight shipping schedules to minimize decay;
b. coordination (between the field crew and host participant) of movement and storage of tagged sand at the study site;

c. instruction and training of field crews;

d. installation of instruments and equipment on amphibious vehicles;

e. perfection of field survey techniques to meet project requirements and environmental conditions; and

f. the full use of a precise and accurate navigation system.

Secondary objectives for this test were to gather scientific data and determine the quantity and activity level of tagged sand necessary for tracing activities.

The site selected for this phase of the study was near Surf, California. Location of this site, in relation to those sites studied at Point Conception, is shown in Figure 14. This site near Surf is a long straight beach on the Vandenberg Air Force Base property (Figure 15). The beach trends approximately 15° NE - 195° SW; landward is a row of dunes. Behind the dunes are a marsh and lake which constitute a part of the mouth and flood plain of the Santa Ynez River. While the Santa Ynez River is normally blocked from draining into the Pacific Ocean, it occasionally cuts through the dunes to the ocean following heavy rains as shown in Figure 15.

To the north of Surf, the Upper Monterey Formation outcrops along the shore and forms a rocky beach area with associated kelp in the vicinity of Purisima Point (Figure 16). Consisting of hard, laminated, siliceous shale, cherty shale, and diatomite, the Upper Monterey Formation is also highly jointed; large blocks of the formation are strewn about on the ocean bottom in the vicinity of the promontory.

At Surf, the beach contours tend to follow the coastline irregularly (Figure 17). The bottom consists mostly of fine and medium sand with a few rocky areas. Profiles in the survey area at Surf have a bottom slope (α) of approximately 0.01 (see Figures 18 through 20).

The beach and nearshore sediments at Surf, California, are fine to medium grained, light brownish gray (2.5Y6/2 Munsell color code) quartz sand. Medium grained (1ϕ-2ϕ) sand occurs on the beach and offshore to depths of 6 to 12 feet. Fine (2ϕ-3ϕ) sands occur from the 12-foot depth to the limits of the survey (50 feet). Along a given range, sand size decreases progressively seaward. Also the average particle size for a range (average of samples from MLLW to -50 feet) tends to increase southward from 2.3ϕ (.203 mm) at range 157 to 1.9ϕ (.26 mm) at range 170. Detailed granulometric analyses are given in Appendix E.

Composition of the sand is 70 to 80 percent subangular quartz grains (roundness 0.4, sphericity 0.8) with the remainder composed of metamorphics, heavy minerals, and small amounts of shell material. The opaque heavy minerals are smaller and more well-rounded than other material. Echinoid (sand dollar) fragments are plentiful at the 30-foot depth, particularly on Ranges 157, 160-165, and 167 but are rare at other depths. The 24-foot depth sample on Range 155 is composed almost entirely of echinoid spines.

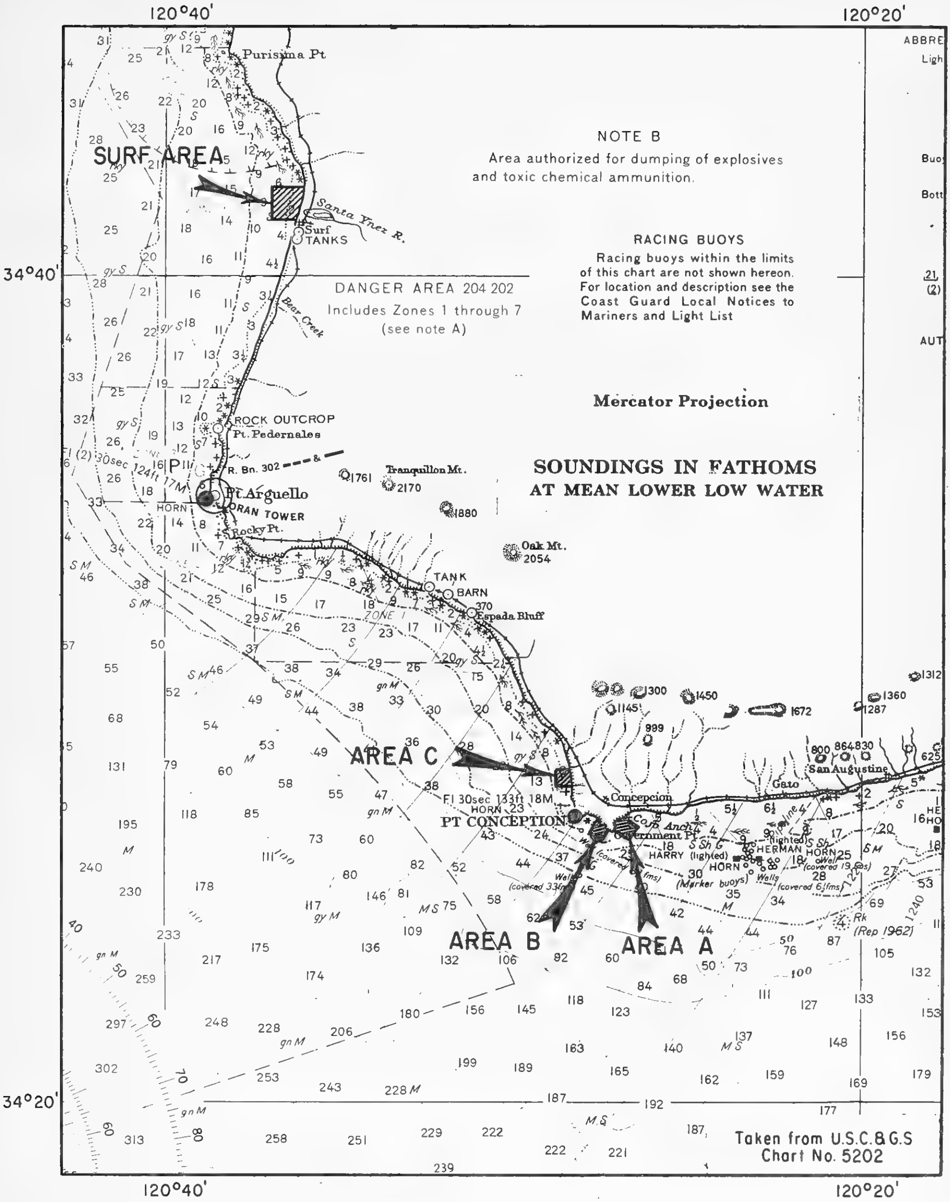


Figure 14. Chart of Point Arguello - Point Conception Area, showing location of test sites

Figure 15. Aerial view of Surf, California. Star indicates approximate location of injection site. At the time of the photo, the Santa Ynez River had sufficient flow to break through to the sea.

Figure 16. Beach at Surf, California. View is northward toward Purisima Point and shows the change from sandy beach to rocky shore.

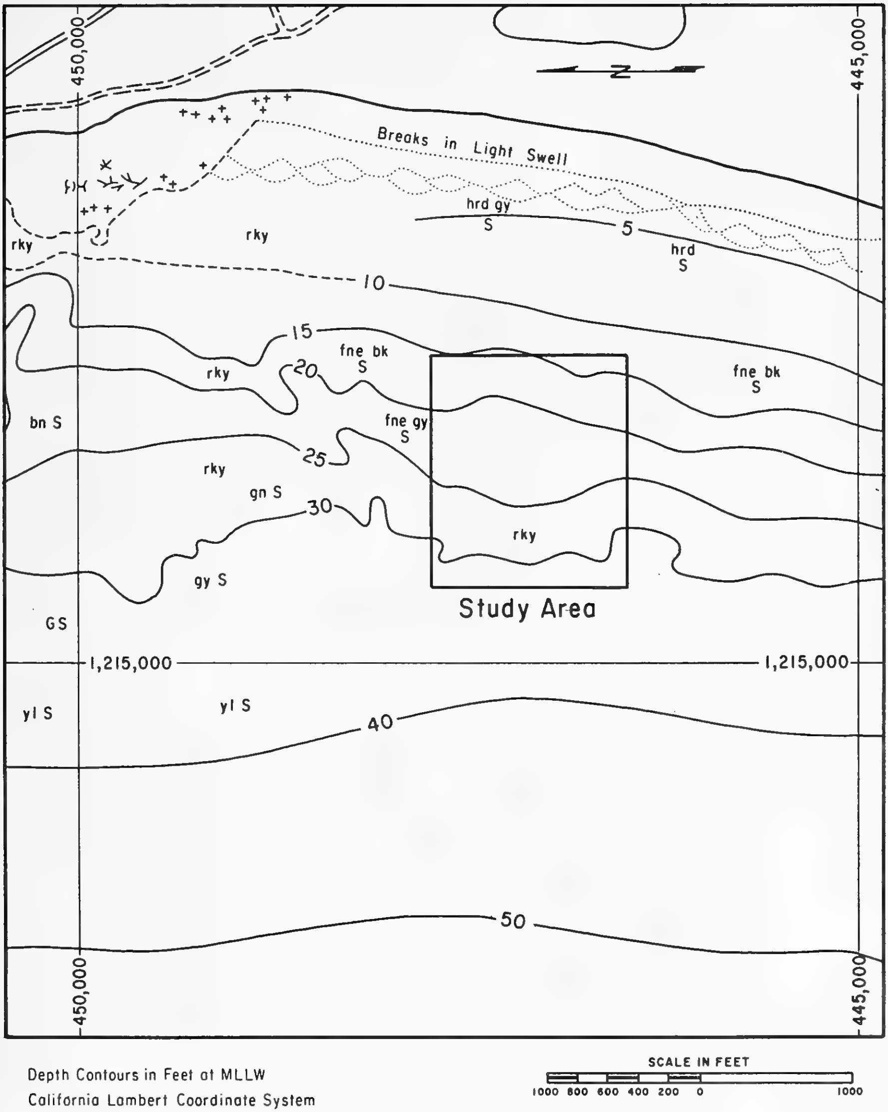


Figure 17. Bathymetric Chart - Surf, California, Vandenberg Air Force Base

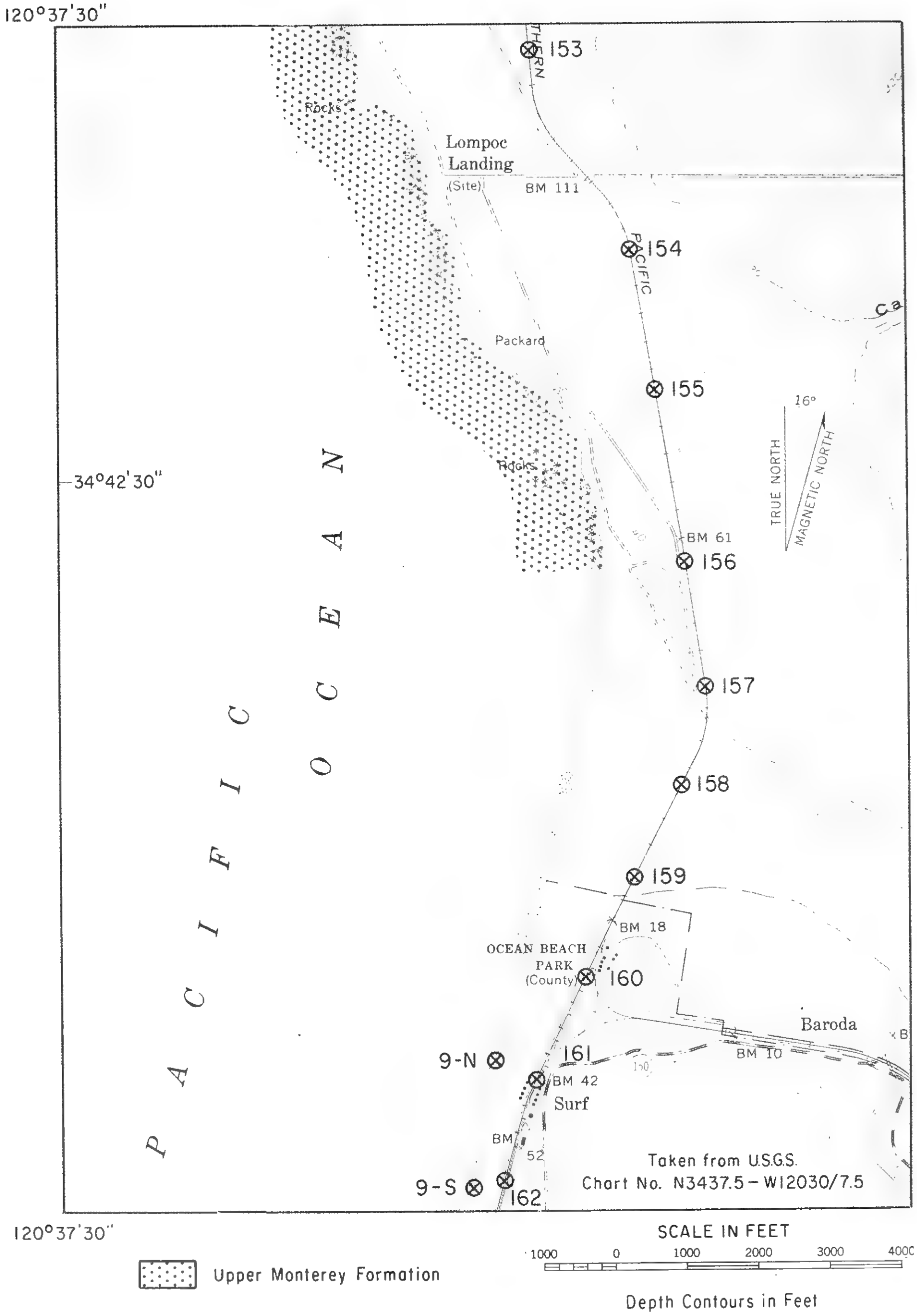
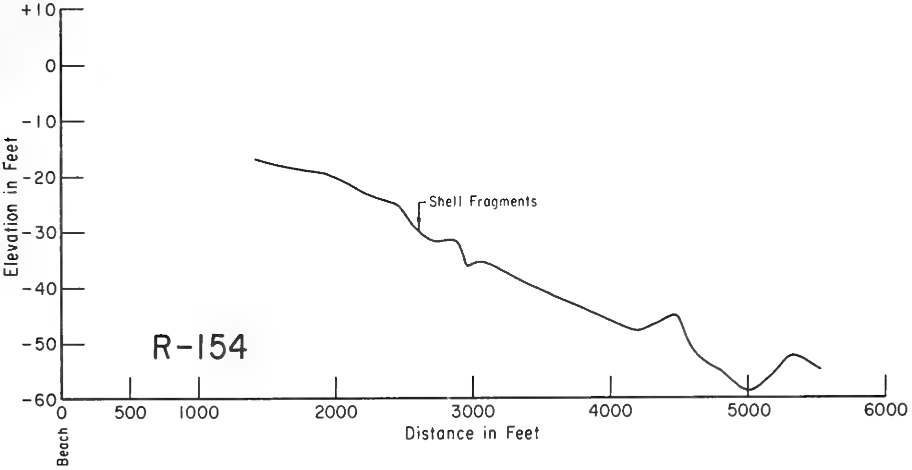


Figure 18. Index of Profiles - Surf, California



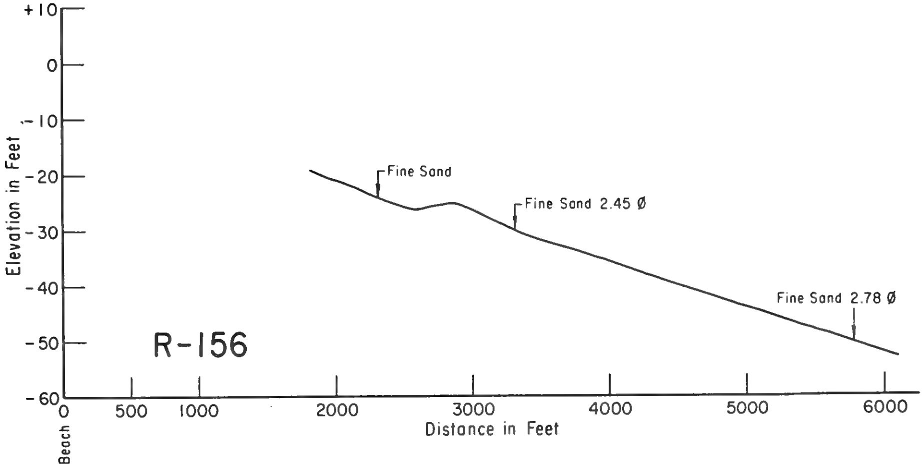


Figure 19. Beach Profiles 154 and 156, Surf, California

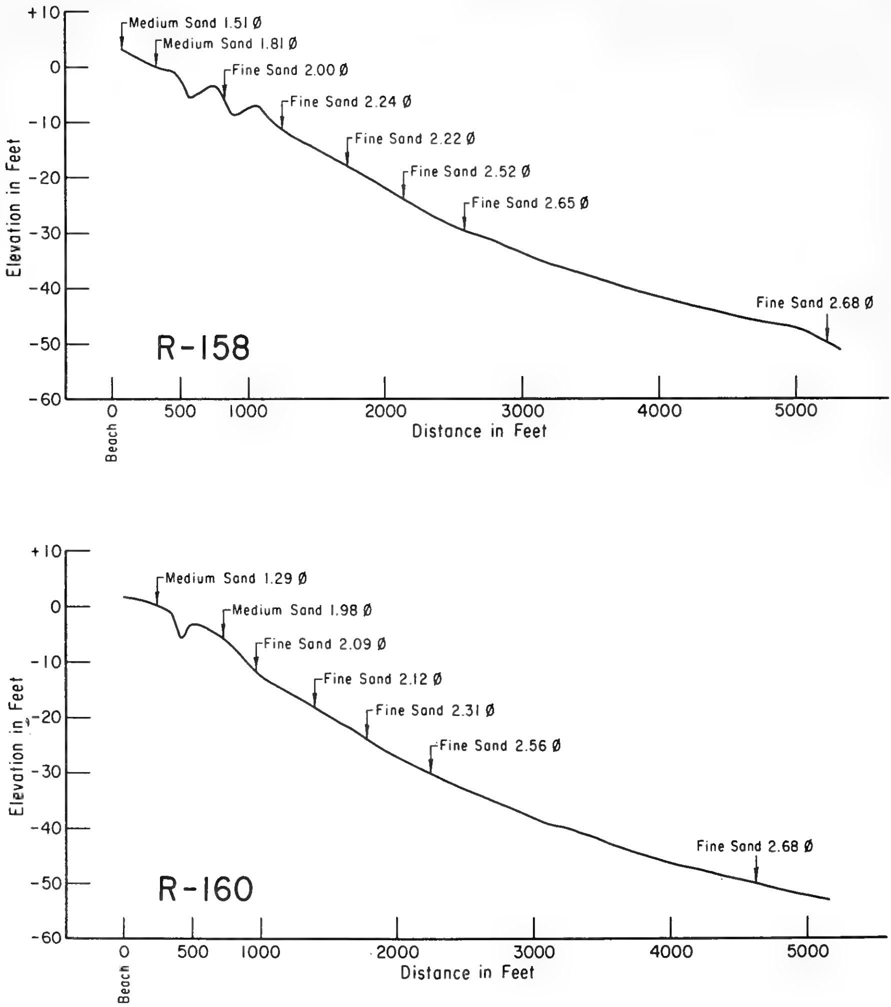


Figure 20. Beach Profiles 158 and 160, Surf, California

During the period of the test (21-23 June 1967), sea conditions at Surf, California, averaged 3 to 4 feet from the northwest. Deepwater waves (swells) averaged 7 to 8 feet from the northwest (305°) and had an average period of 10 seconds. (See Figures 21 and 22.) Based on these conditions, the bottom orbital velocity (U_m) was calculated by:

$$U_m = \pi\, H/T \sinh Kd$$

where H = wave height

T = wave period

d = depth of water

$k = 2\pi/L$

L = wave length

and found to be 109.6 centimeters per second for the 30-foot water depth. This value was believed to be more than sufficient to cause sediment movement considering that from Hjülstrom's curve a velocity of 18 centimeters per second is required to suspend particles of 2.0ϕ (.25 millimeters), the mean particle diameter of injected sand at this site. It should be noted that the average grain size at 30 feet is 2.65ϕ (.16 millimeters), which would require a velocity of 21 centimeters per second for suspension. Following the approach used by Bagnold (1947) and Vernon (1965), the sediment migration rate was calculated as 1/3 the water drift velocity ($\overline{u}$) where:

$$\overline{u} = \frac{5}{4} \left(\frac{H}{2d}\right)^2 C \text{ when } d<L$$

and in which $\overline{u}$ = water drift velocity along seabed

C = wave velocity

Based on oceanographic conditions for the period 21-23 June 1967, the sediment movement rate (1/3 $\overline{u}$) was determined to be 7.7 centimeters per second (910 feet per hour).

For the test at Surf, three large injections were made offshore in approximately 30-foot depth:

Date	Amount	Activity
13 June	80 liters	4.5 curies
20 June	40 liters	0.45 curies
21 June	40 liters	0.25 curies

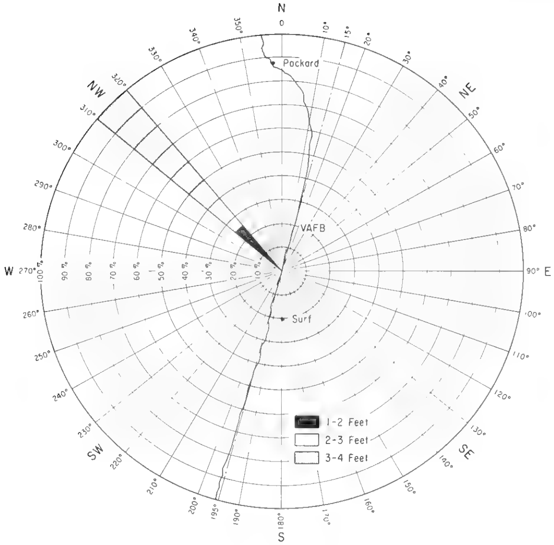
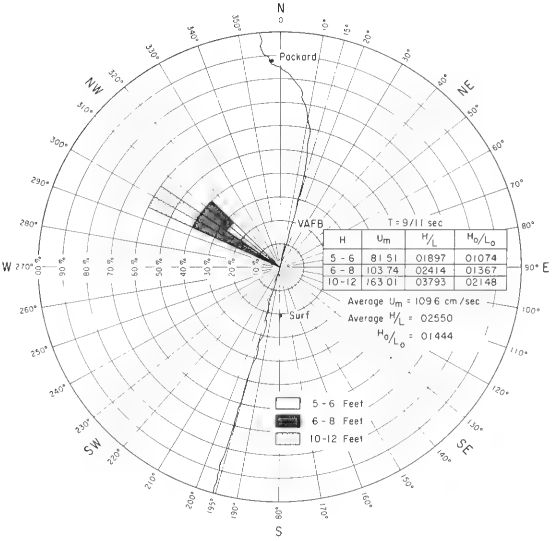


Figure 21. Average sea conditions, Surf, California 21-23 June 1967



T = 9/11 sec

H	U_m	H/L	H_o/L_o
5 - 6	81 51	01897	01074
6 - 8	103 74	02414	01367
10-12	163 01	03793	02148

Average U_m = 109 6 cm/sec

Average H/L = 02550

H_o/L_o = 01444

Figure 22. Average wave (swell) conditions, Surf, California 21-23 June 1967

Because of problems with the sand injection system on 13 June, the sand was injected from the ocean surface. It was never positively located again.

Prior to injection on 20 June, the operation of the injection system was observed underwater using scuba, and the procedures were somewhat modified. During the same period the detector vehicle was also observed underwater and its tracking characteristics under slow speed (4-6 feet per second) noted. Injection of 40 liters of xenonated sand on 20 June was made as a line source. It was tracked intermittently for 2 days but no intelligible interpretation of the dispersal pattern could be made.

Utilizing experience gained during the preceding days, the xenonated sand injected on 21 June was placed directly on the bottom as a point source. It was traced for 2 days before field operations ended on 23 June. Figures 23 through 25 show the isoactivity contours corrected for background and decay and illustrate the dispersal pattern for this test. From these drawings it is not possible to make accurate determinations of the rate of littoral drift, therefore the observed rate of tracer movement cannot be compared with the rate of sediment movement computed from the oceanographic parameters. However, it may be inferred that at this depth (30 feet) and under existing wave conditions, the bulk of the sediment was seaward of the equilibrium (null) point and moved offshore toward the northwest. However, bottom current data was not available, and based on the dispersal pattern, it might be concluded that, during the test, the bottom current was flowing offshore to the northwest. Ingle (1966), using fluorescent tracers, noted a somewhat analogous pattern at an injection site (in 15 feet) near San Diego, and postulated a counter-flowing bottom current.

While, from a scientific standpoint, it would have been beneficial to continue tracing the sediment movement, the primary objectives of the program had been achieved. It was found that the sediment could be traced for a period of days in an environment harsher than that experienced in Florida, and field techniques had been brought to a fully operational level.

4. Point Conception, California, November-December 1967

The Point Conception - Government Point complex represents a sharp change in the orientation of the California coastline (Figure 14). Point Conception and Government Point are both rocky promontories which extend seaward from the general alignment of the coast (Figure 26). Bluffs and extensive rocky areas on the bottom made this area more difficult to work in than previous areas.

This test represented an attempt to meet nearly all of the objectives previously defined (see Section I). It provided additional knowledge of operating characteristics of the equipment in the coastal environment, and basic information which can be used to improve field procedures. In order

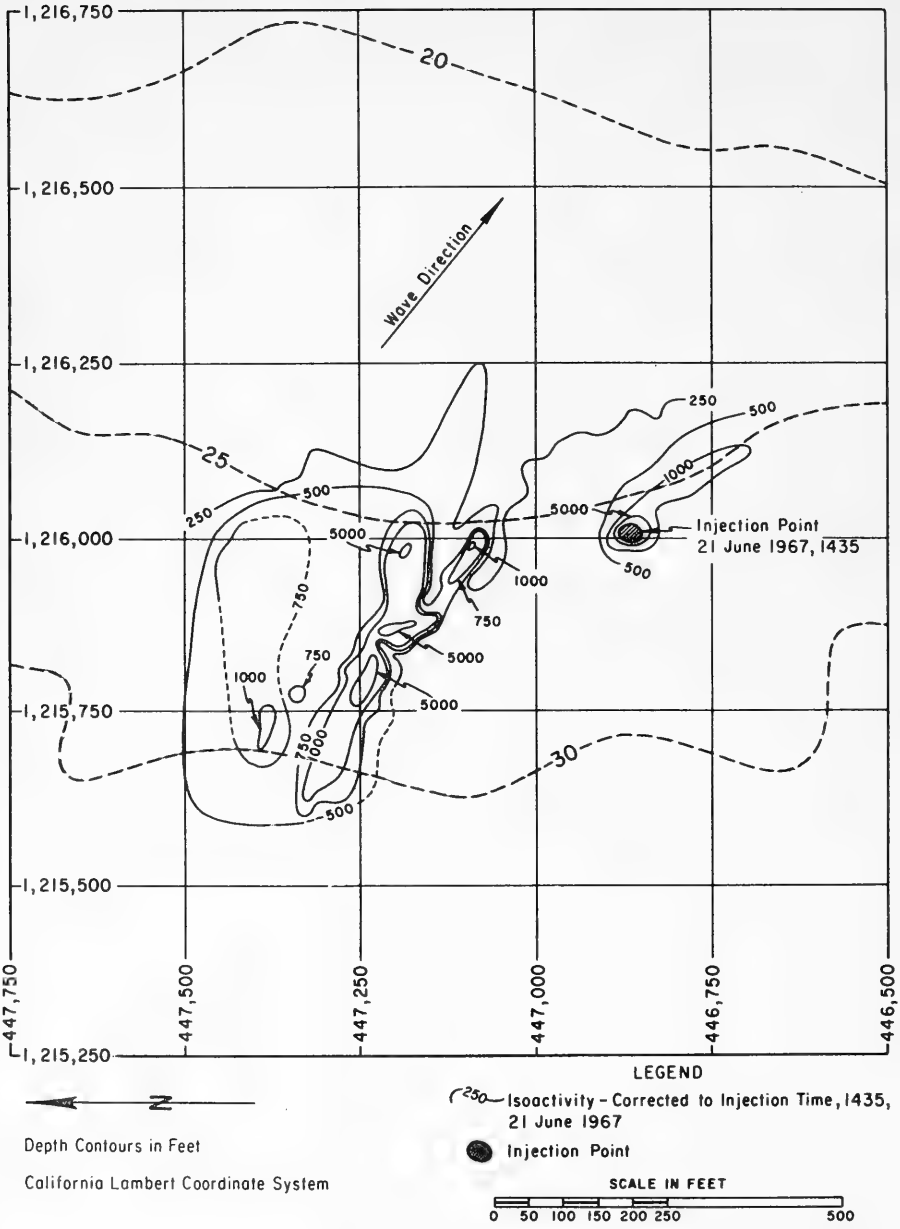


Figure 23. Sediment dispersion, Surf, California, study area 21 June 1967

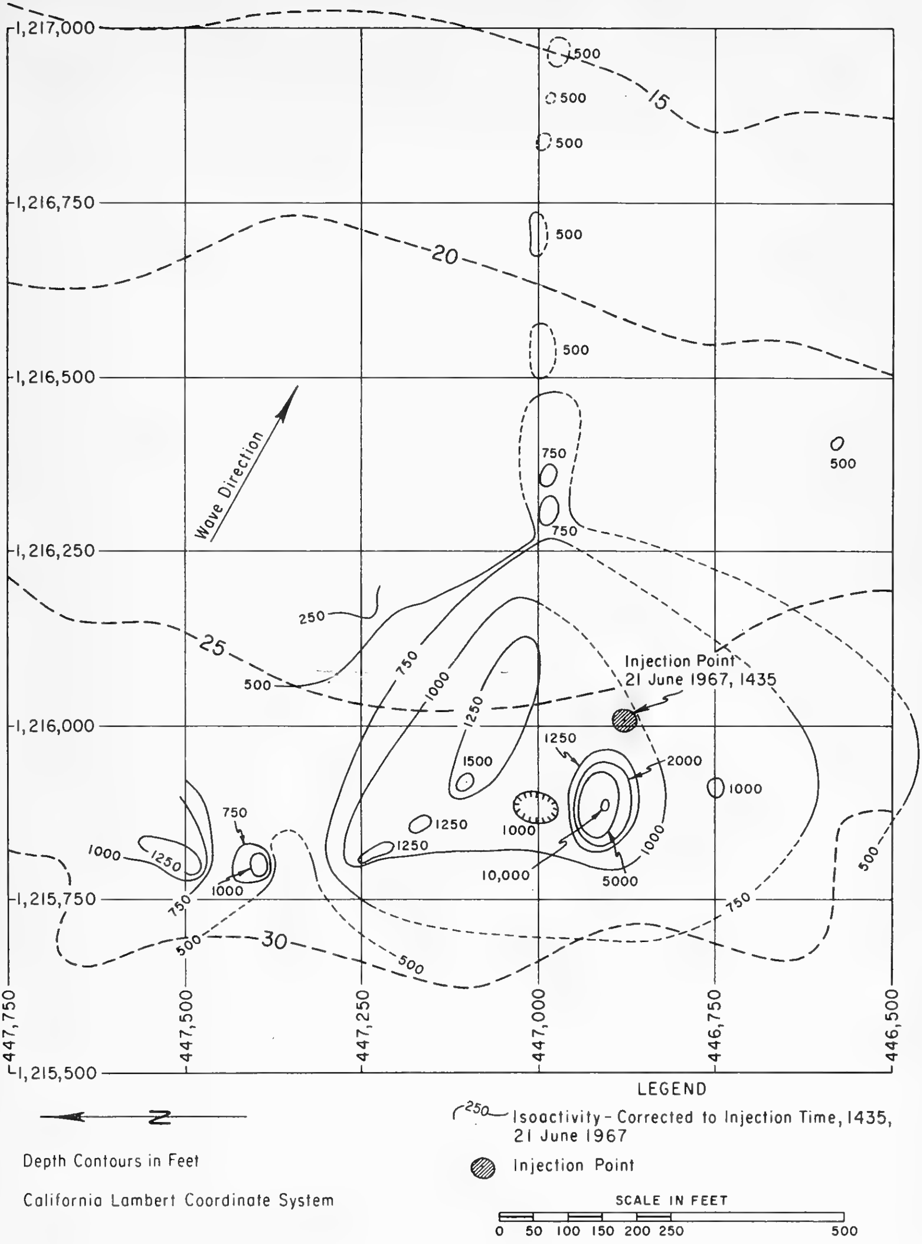


Figure 24. Sediment dispersion, Surf, California, study area 22 June 1967

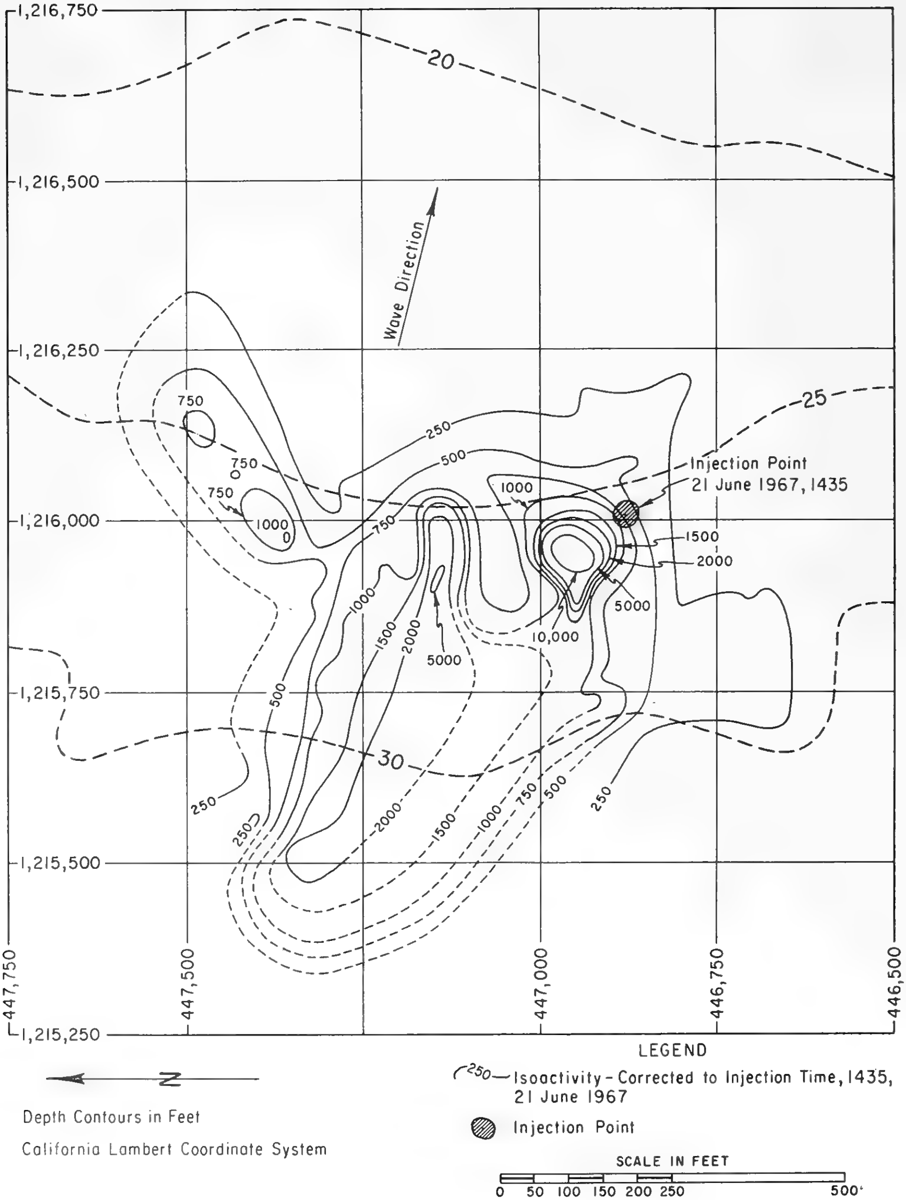


Figure 25. Sediment dispersion, Surf, California, study area
23 June 1967

Figure 26. Point Conception, California.
Vertical view from 10,000 feet

to test capabilities of meeting military or quasi-military objectives, a two-day program was conducted in the Point Sal area following the sand tracing operations.

In order to define the mechanics of littoral transport and trace sediment movement around Point Conception, three survey areas were selected: Area C north of Point Conception at Black Canyon; Area B between Point Conception and Government Point, and Area A to the east of Government Point at Cojo Anchorage (see Figure 27). At each site a point injection was made in approximately 30 feet of water. It was judged that by sequentially monitoring three sites it would be possible to integrate the results and thus ascertain the track of sediment movement in the vicinity of Point Conception.

The areas around Point Conception (C, B, and A) are marked by sea cliffs extending as high as 200 feet above a narrow beach. (See Figures 28 to 33.) North of Point Conception and east of Government Point, the Sisquoc Formation is exposed along these cliffs. The Sisquoc Formation consists of impure diatomite, diatomaceous shale, and pure laminated diatomite. The Upper Monterey Formation, composed of hard laminated platy siliceous shale, cherty shale, and diatomaceous lenses, outcrops along the shore cliffs between Point Conception and Government Point. At Areas A and C, the long narrow beaches at the base of the cliffs are occasionally interrupted by ledges and other rock outcrops. Between Point Conception and Government Point (Area B) are several pocket beaches.

General orientation of the coastline changes from a north-south direction north of Point Conception to an east-west direction east of Government Point, along the Santa Barbara Channel. The coastline trends are: Area C approximately 353°N-173°S; Area B approximately 293°W-134°SE; and Area A approximately 60°NE-240°SW (because of the bay configuration). Bathymetric contours in these areas tend to follow the general coastline with no prominent features (Figures 34 through 36). However, scuba divers inspecting the bottom in Area B, found an abrupt ledge approximately 5 feet high occurring at a depth of approximately 20 feet. Without a hoist or winch, such a feature would stop entry to the beach by the towed detector vehicle.

The offshore bottom at Area C is generally sandy with scattered boulders and outcrops. Immediately north and south of the area are extremely rocky areas with associated kelp beds. Nearshore at Area B, the bottom is rocky with sand pockets; farther offshore fine sand becomes more prevalent. The bottom at Area A is predominately sand with some rock and kelp. Bathymetric profiles of these areas are shown in Figure 37.

Sediments at the 30-foot depth near Area C consist of light brownish gray (2.5Y6/2 Munsell color code), fine grained quartz sand. The sand is composed of 85 to 90 percent subangular quartz grains (roundness 0.4 - 0.5, sphericity 0.7). Metamorphics and heavy minerals with minor amounts of

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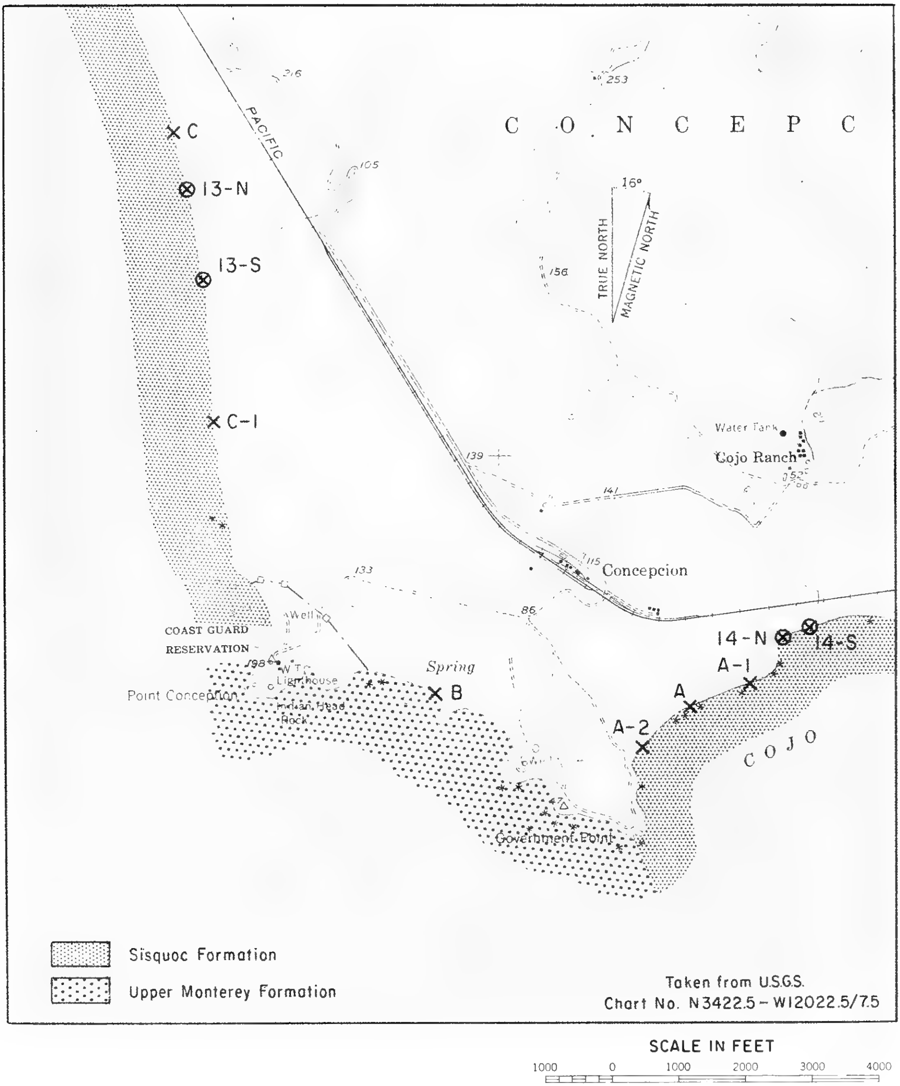


Figure 27. Index of Profiles for Point Conception area

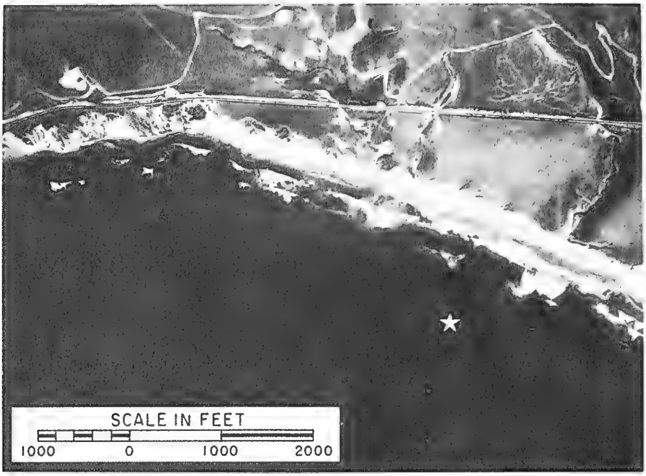


Figure 28. Vertical view of Area C at Point Conception. Star indicates approximate location of injection point.

Figure 29. View southward along beach at Area C. Point Conception is in background. Injection point near approximate center of photo.

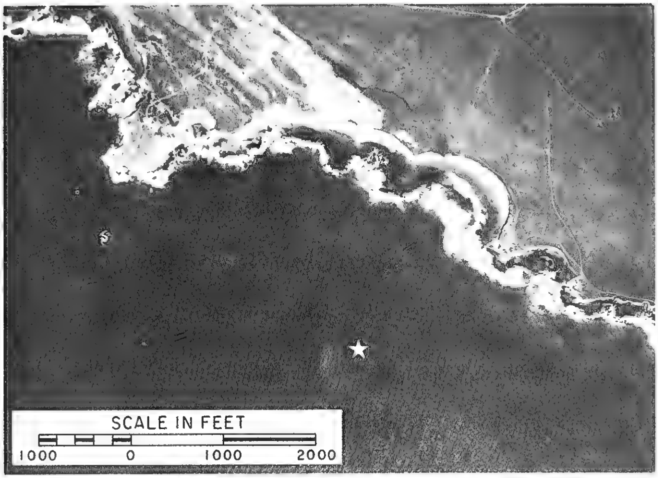


Figure 30. Vertical view of Area B at Point Conception. Star marks injection point.

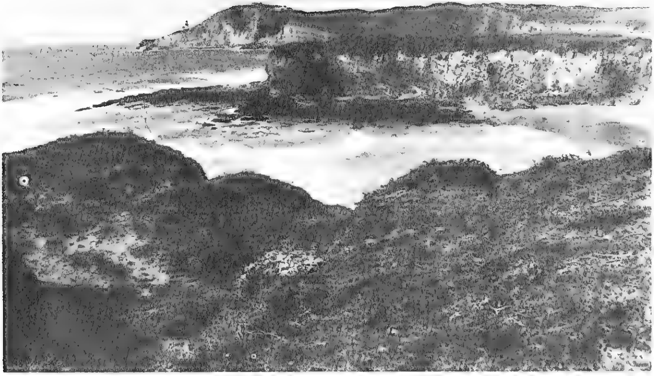
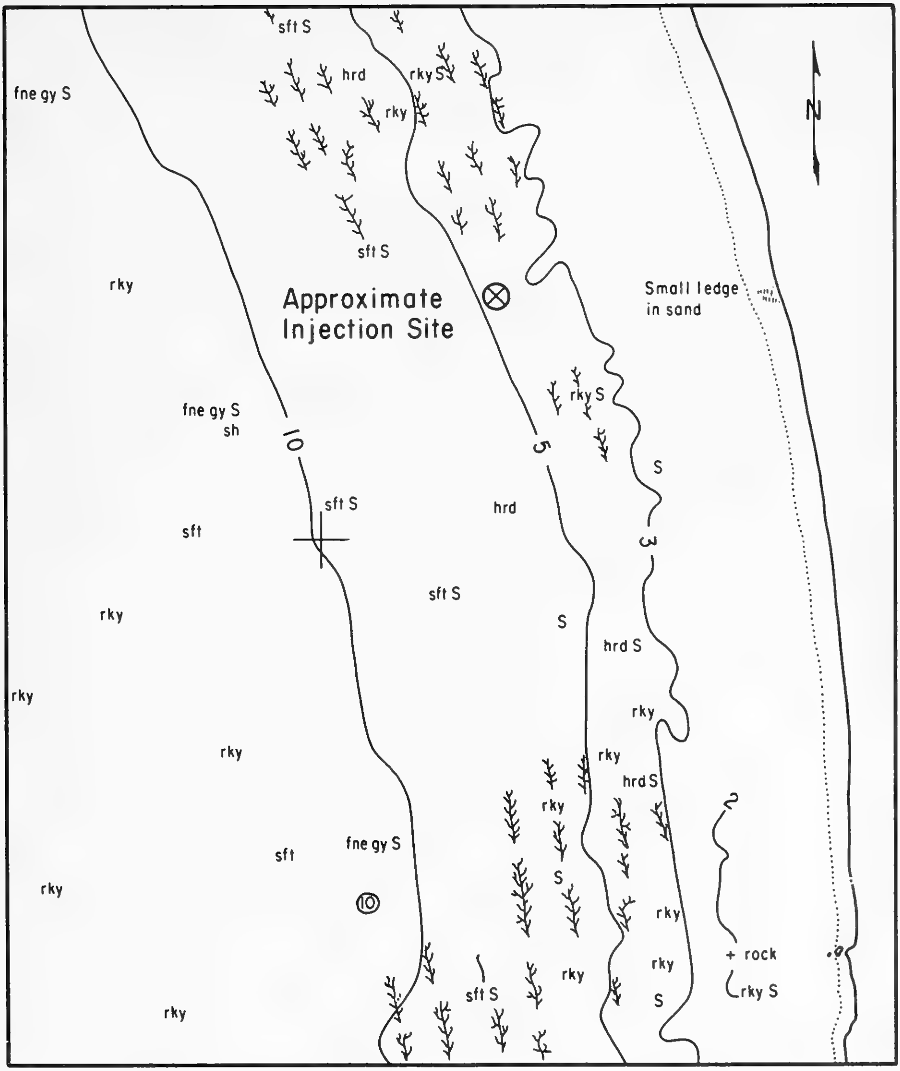


Figure 31. Beach at Area B, Point Conception, view northwest.

Figure 32. Vertical view of Area A, Cojo Anchorage at Point Conception. Star marks location of injection.

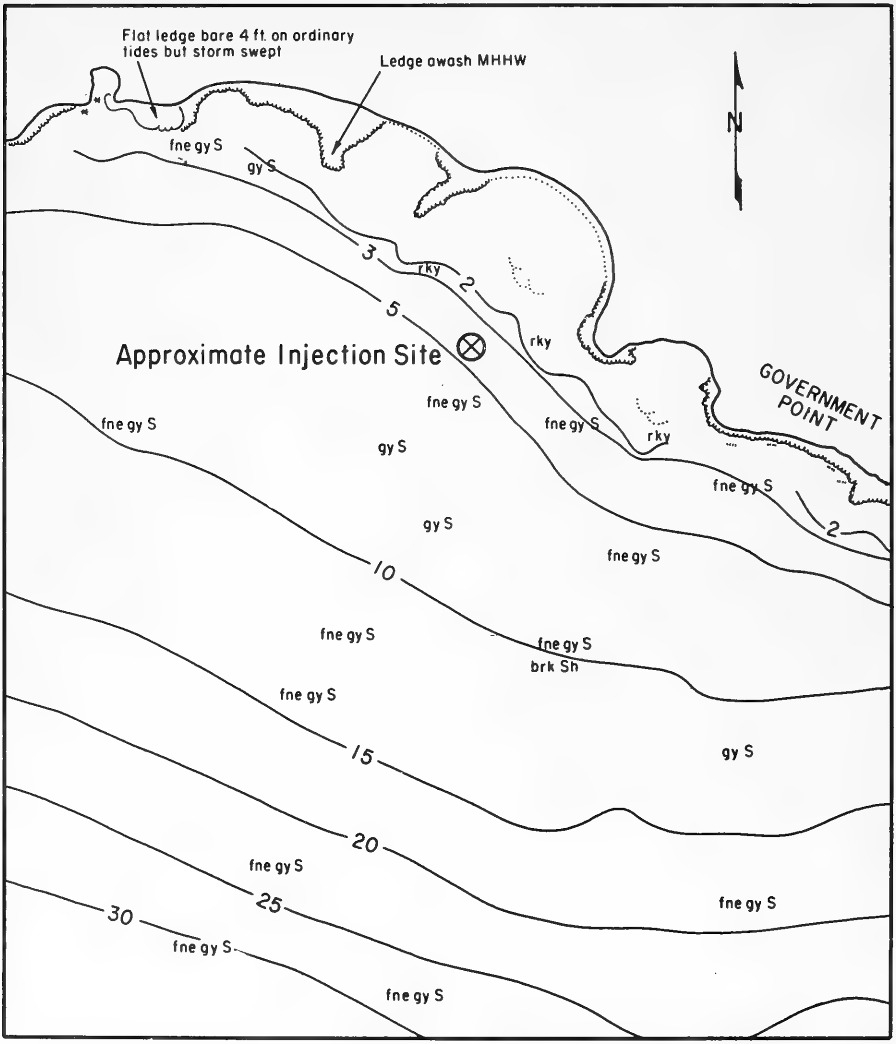
Figure 33. Beach at Area A, view eastward toward Santa Barbara. Note ledges formed by outcropping Miocene sedimentary rocks.



Taken from U.S.C.&G.S. Hydrographic Survey No. 5508 Boat Sheet

Depth Contours in Fathoms at MLLW

Figure 34. Bathymetric Chart, Point Conception - Area C.

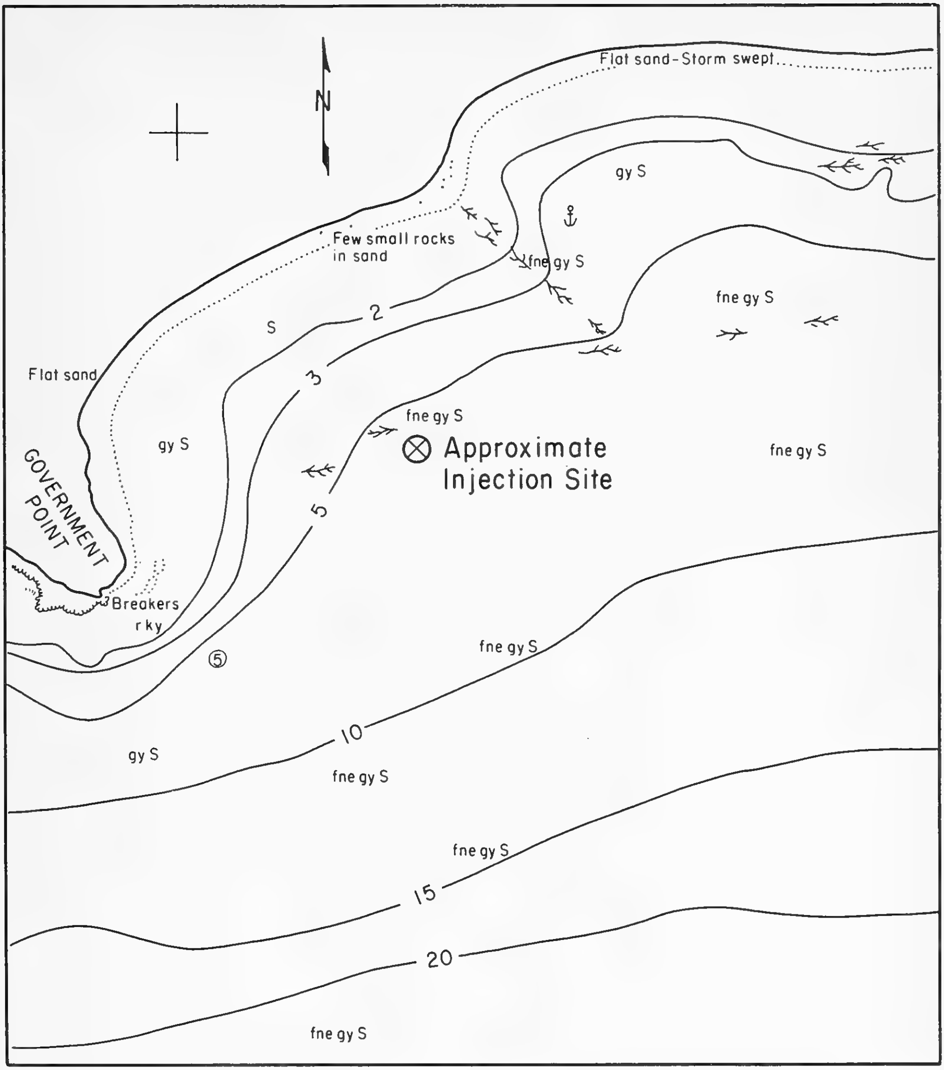


Taken from U.S.C. & G.S. Hydrographic Survey No. 5627 Boat Sheet

Depth Contours in Fathoms at MLLW

SCALE IN FEET
1000 800 600 400 200 0 1000

Figure 35. Bathymetric Chart, Point Conception - Area B



Taken from U.S.C.&G.S. Hydrographic Survey No. 5627 Boat Sheet

Depth Contours in Fathoms at MLLW

Figure 36. Bathymetric Chart, Point Conception - Area A.

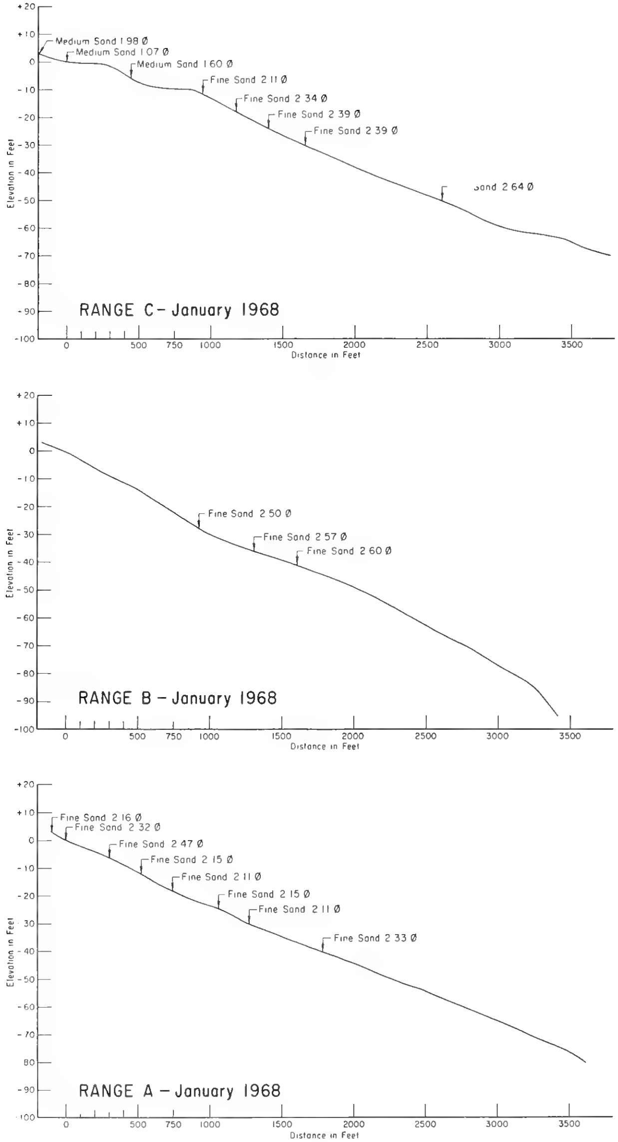


Figure 37. Beach Profiles, Point Conception, California

shell comprise the remainder. The average of the mean grain size for samples at 30 feet in Area C is 2.5ϕ (.176 millimeters).

Sediments at the 30-foot depth near Area B consist of light brownish gray (2.5Y6/2), fine grained quartz sand. The sand is composed of approximately 85 percent subangular to angular quartz grains (roundness 0.3, sphericity 0.7). The remainder (about 15 percent) is composed of metamorphics and heavy minerals with minor traces of shell. Average grain size for samples in this area is 2.56ϕ (.173 millimeters).

Sediments at the 30-foot depth near Area A consists of olive gray (5Y5/2), fine grained quartz sand. The sand is composed of 80 to 90 percent angular quartz grains (roundness 0.2, sphericity 0.7). The remainder is composed of 10 to 20 percent metamorphics and heavy minerals. The average grain size for samples at 30-foot depths in this area is 2.3ϕ (.203 millimeters). In Area A, a marked decrease in size is noted eastward along the 30-foot depth contour. A more detailed analysis of sediments in these areas (C, B, and A) is given in Appendix E.

In the spring and summer, brisk north and northwest winds are common along the west coast of the United States. These winds serve to drive the southward-flowing California Current close inshore along the California Coast. During the fall and winter, a north-directed surface current, the Davidson Current or California Countercurrent, develops inshore off Lower California, Mexico, and may extend to 45°N (Wright, 1967). Since this includes the latitudes of the present study, these currents could affect patterns of sediment movement, although such an effect has not yet been demonstrated.

Average wave conditions for survey periods are given in Table III along with computations for bottom orbital velocity and calculated sediment migration rate. Figures 38 through 43 illustrate these wave conditions. From Table III it may be seen that the bottom orbital velocity is sufficient to place sand in suspension and thus induce sand movement. It is then approximated that the sand should move forward at the rates given by 1/3 the wave drift veloctiy ($\overline{u}$) (Bagnold, 1947) and(Vernon, 1965). Sediment transport values for each of the areas around Point Conception are summarized by Table III. Velocities required for transport of the average particle are derived from Hjülstrom's suspension curve given in Heezen and Hollister (1964). An approximation of the average bottom current based on grain size is given using the method described by Wilde (1965) where $U = w/\alpha$ in which U = bottom current, w = settling velocity of mean grain, and α is the bottom slope.

TABLE III

Summary of Environmental Parameters for Water Depth of 30 Feet at Point Conception, California, November-December 1967

ITEM	AREA C Black Canyon	AREA B Government Point	AREA A Cojo Anchorage
Average Mean Grain Size	2.51ϕ (.17mm)	2.5ϕ (.175mm)	2.3ϕ (.203mm)
Suspension Velocity*	20 cm/sec	20 cm/sec	19 cm/sec
Bottom Slope (α) (Vertical Rise/ Horizontal Distance)	0.0264	0.0259	0.0209
Average Bottom Current $U = w/\alpha$**	43 cm/sec	32 cm/sec	57 cm/sec
Average Sea	2 feet NW WNW	2 feet NW-W	2 feet W
Average Swell	3-5 feet WSW-W	3-5 feet WSW	3 feet WSW
Bottom Orbital Velocity U_m	55 cm/sec	56 cm/sec	46 cm/sec
Sediment Migration $\overline{u}/3$***	2.1 cm/sec	2.4 cm/sec	1.2 cm/sec

* Hjülstrum (Heezen and Hollister)
** Wilde
*** Vernon ($\overline{u}$ = wave drift velocity)

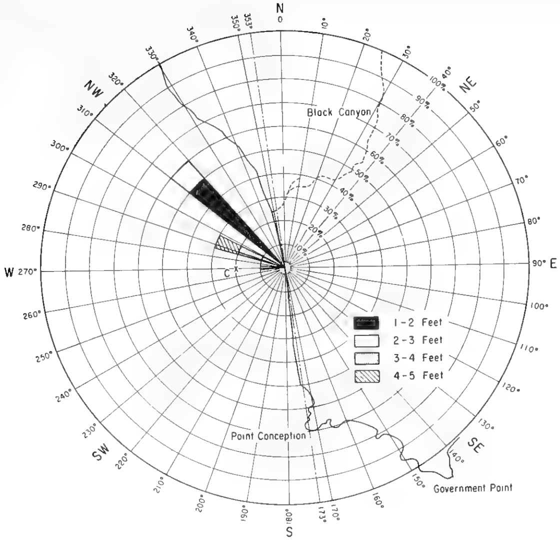
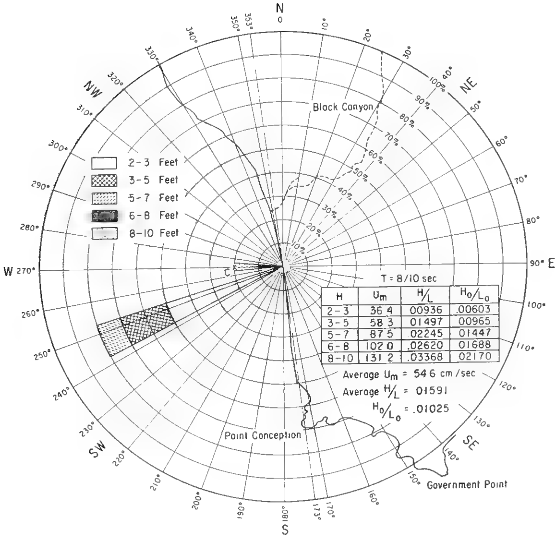


Figure 38. Average sea conditions, Area C



T = 8/10 sec

H	U_m	H/L	H_0/L_0
2-3	36 4	00936	.00603
3-5	58 3	01497	00965
5-7	87 5	.02245	01447
6-8	102 0	.02620	01688
8-10	131 2	.03368	02170

Average U_m = 54 6 cm/sec

Average H/L = 01591

H_0/L_0 = .01025

Figure 39. Average wave (swell) conditions, Area C

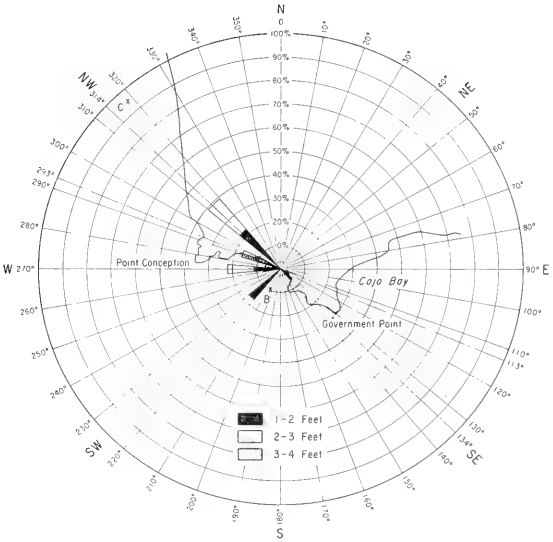
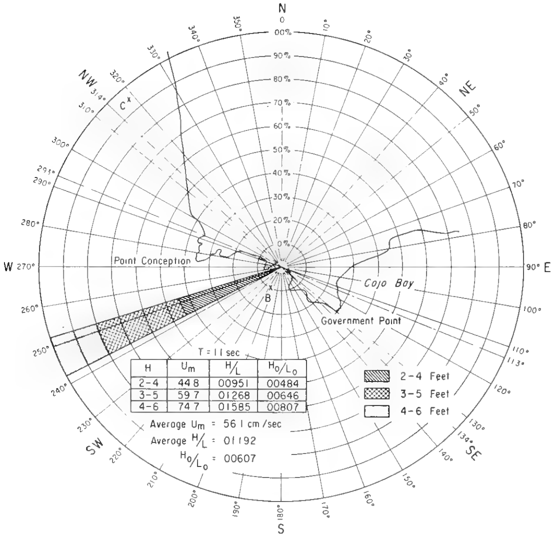


Figure 40. Average sea conditions, Area B



T = 11 sec

H	U_m	H/L	H_0/L_0
2-4	44 8	00951	00484
3-5	59 7	01268	00646
4-6	74 7	01585	00807

Average U_m = 56 1 cm /sec

Average H/L = 01192

H_0/L_0 = 00607

Figure 41. Average wave (swell) conditions, Area B

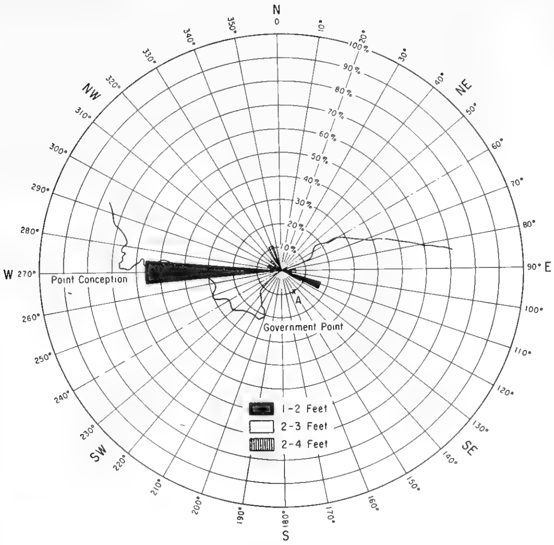
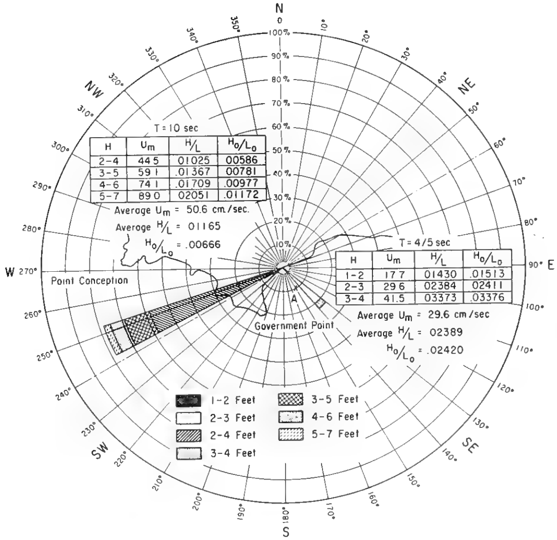


Figure 42. Average sea conditions, Area A



T = 10 sec

H	U_m	H/L	H_0/L_0
2-4	44.5	.01025	.00586
3-5	59.1	.01367	.00781
4-6	74.1	.01709	.00977
5-7	89.0	.02051	.01172

Average U_m = 50.6 cm./sec.
Average H/L = .01165
H_0/L_0 = .00666

T = 4/5 sec

H	U_m	H/L	H_0/L_0
1-2	17.7	.01430	.01513
2-3	29.6	.02384	.02411
3-4	41.5	.03373	.03376

Average U_m = 29.6 cm/sec
Average H/L = .02389
H_0/L_0 = .02420

Figure 43. Average wave (swell) conditions, Area A

Field operations were conducted from 15 November to 10 December 1967 in the Point Conception complex. Actual injection and tracing operations took place from 1 December to 10 December 1967. Information pertinent to injection operations is summarized by Table IV below.

TABLE IV

Summary of Injection Operations, Point Conception

Injection Number	Injection Date	Injection Area	Injection Depth	Tagged Sand (liters)	Total Activity Xe-133 (millicuries)
1	1 Dec 67	A	30 feet	40	1,200
2	2 Dec 67	C	30 feet	40	800
3	7 Dec 67	B	30 feet	40	600
4	10 Dec 67	A	Surf Zone	1	120

The actual data on sediment characteristics and observed wave conditions at the study sites were used to compute the parameters summarized in Table III. These parameters indicate sediment on the marine bottom at each of the 3 injection sites should have moved during the course of field operation. Significant (twice background) corrected radiation and survey tracks of the towed detector vehicle are shown by Figures 44 through 50. An approximation (or estimate) of the general direction of movement may be obtained by comparing the centroid of radiation values to the initial injection location. These directions (for a depth of 30 feet) are summarized as follows:

Area C: from point of injection toward the SW to NW

Area B: from point of injection toward the ESE to SE

Area A: from point of injection toward the SSW to SE.

Precise monitoring of the injection in the surf zone on 10 December 1967 was not attempted. For this test a small quantity of tagged sand was placed in the surf zone and an attempt made to follow it with the detector. This test demonstrated the capability of working in the surf zone; and this capability will be utilized in future tests.

Results of the Point Conception tests indicate that under the conditions extant during tracing activities in December 1967, the rate of

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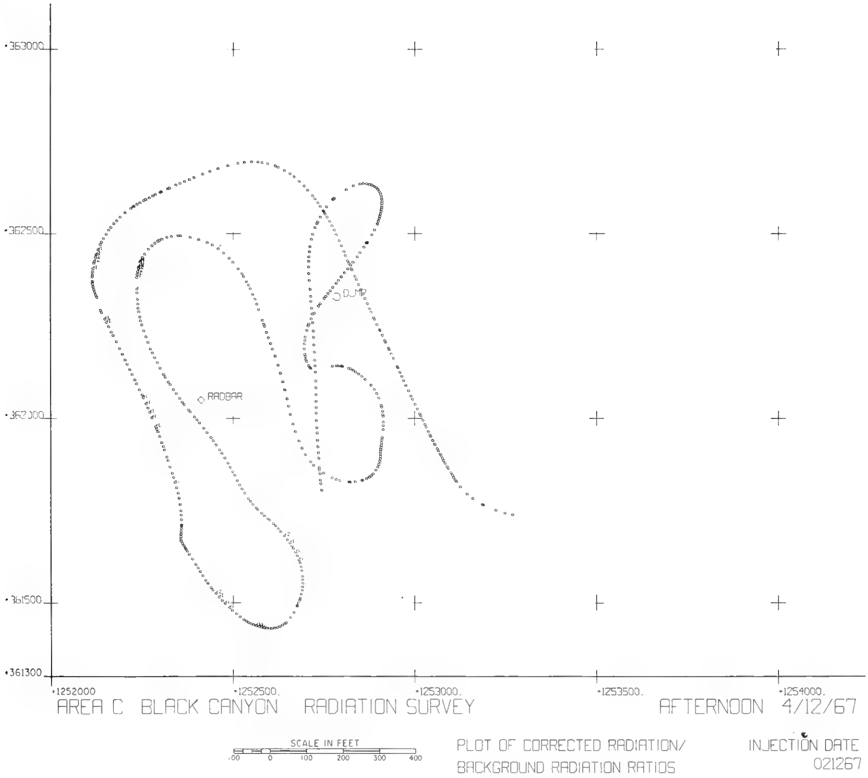


Figure 44. Radiation Survey, Area C, 4 December 1967

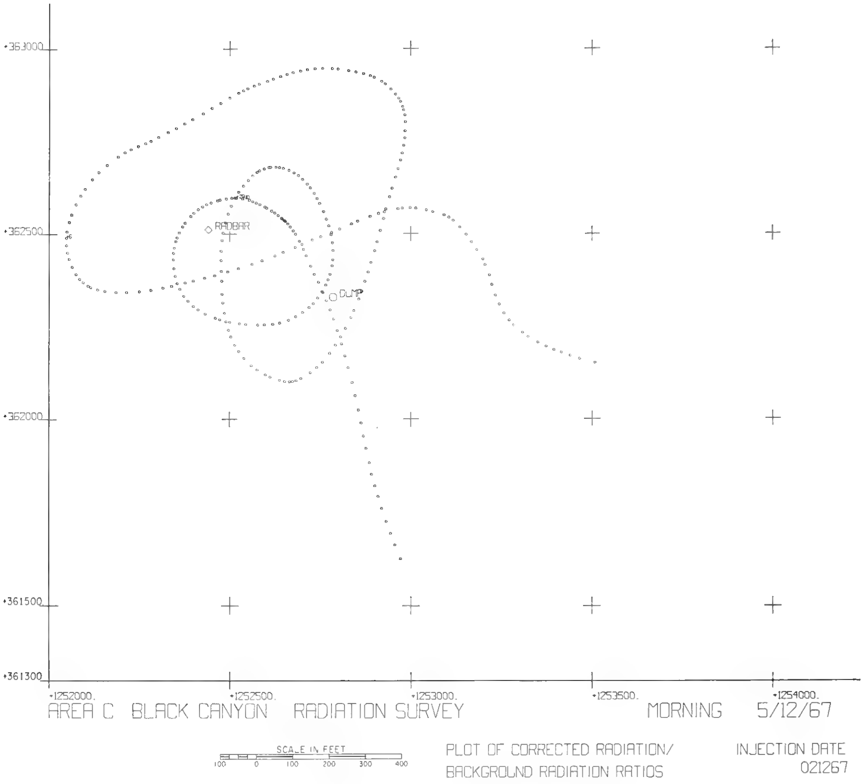


Figure 45. Radiation Survey, Area C, 5 December 1967

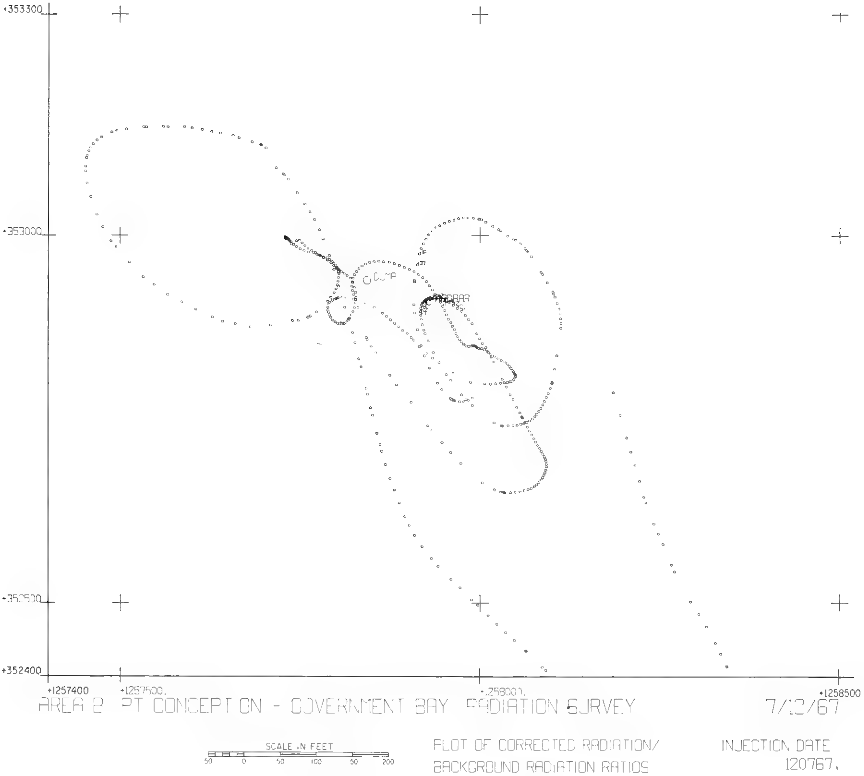


Figure 46. Radiation Survey, Area B, 7 December 1967

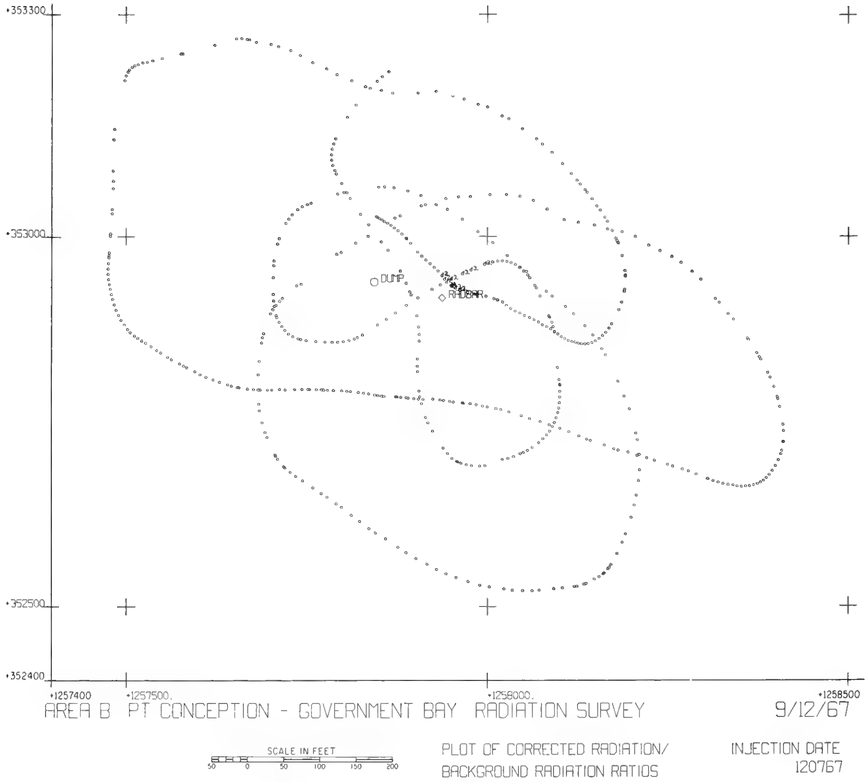


Figure 47. Radiation Survey, Area B, 9 December 1967

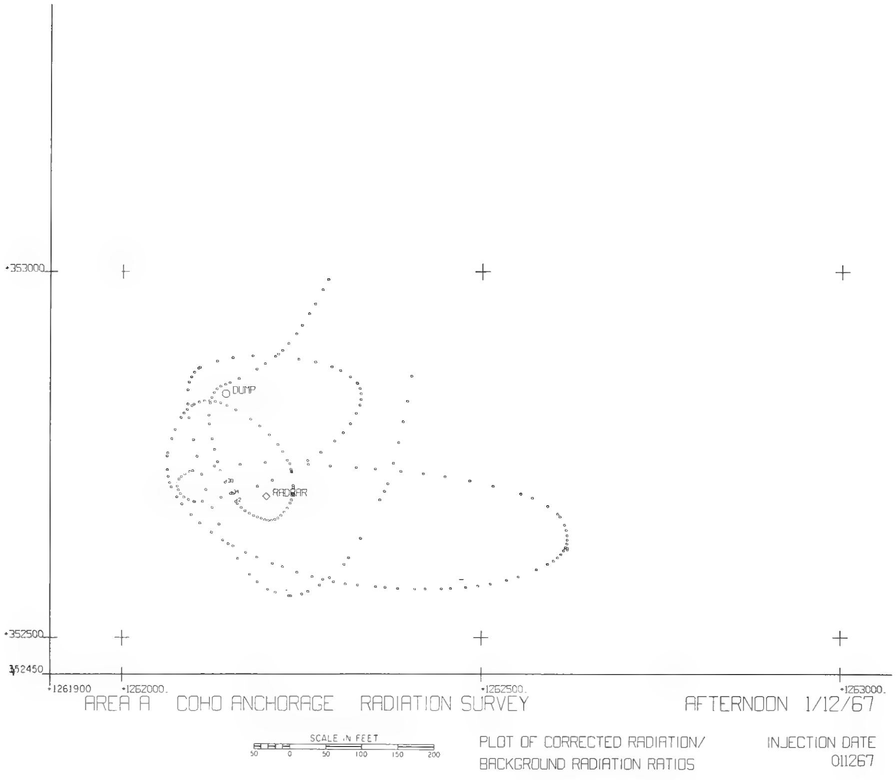


Figure 48. Radiation Survey, Area A, 1 December 1967

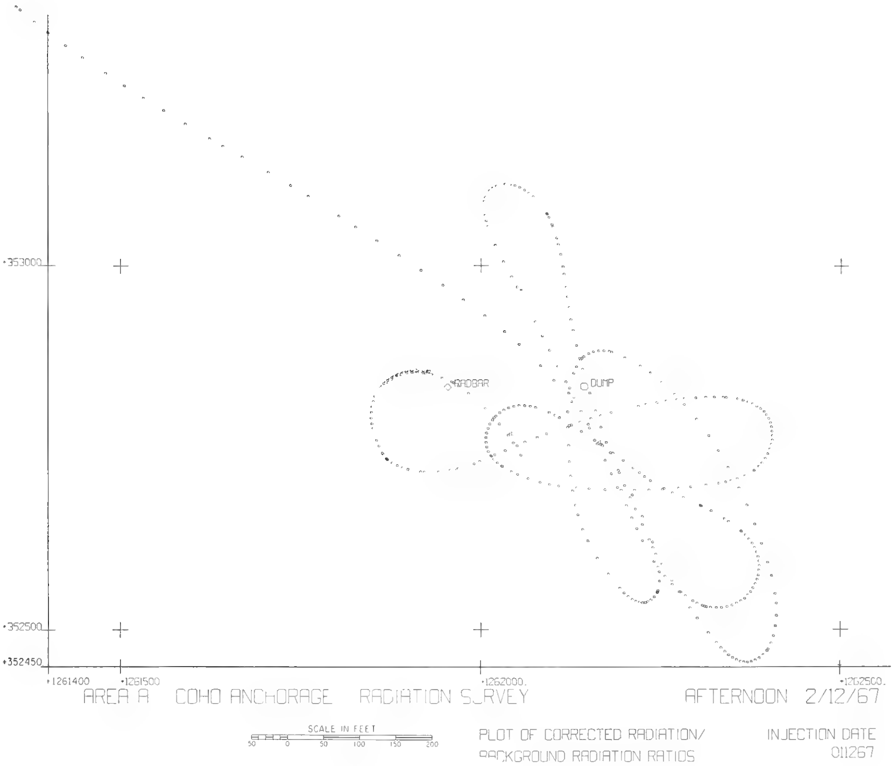


Figure 49. Radiation Survey, Area A, 2 December 1967

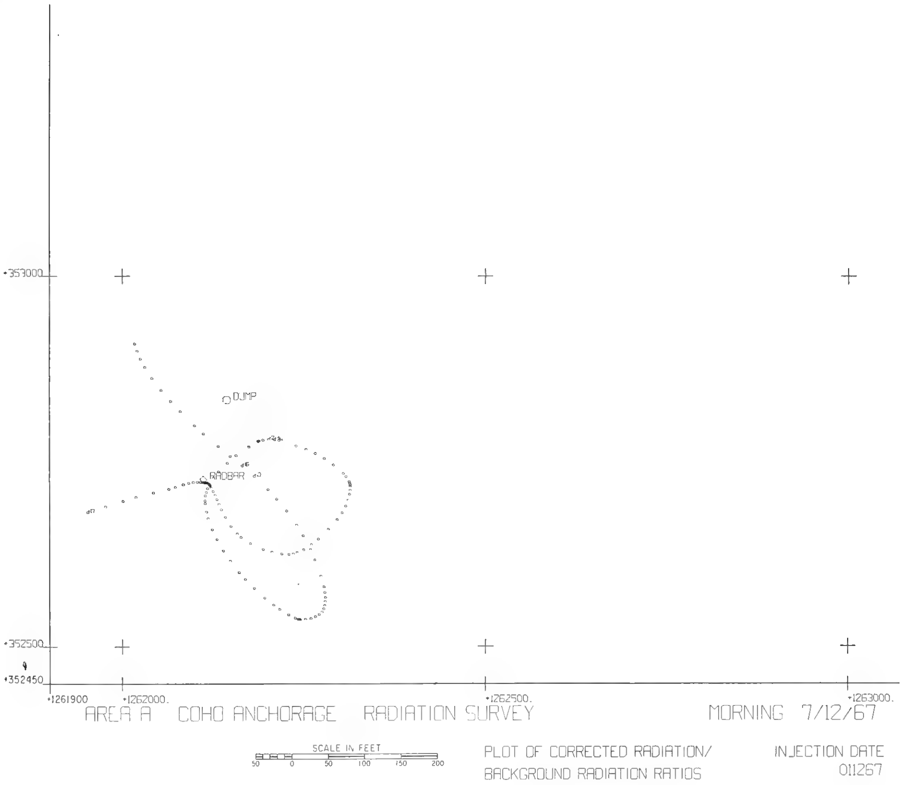


Figure 50. Radiation Survey, Area A, 7 December 1967

sediment movement was very slow and possibly no significant movement occurred. However, the paucity of data does not provide any real basis for determining whether sand does or does not move around Point Conception. Knowledge to that effect, and the manner in which it occurs, if it does indeed occur, must wait for subsequent programs. Intangible success accrued through additional knowledge of operating characteristics of the equipment in the oceanographic and coastal environment, as well as basic information which can be incorporated in future field tests.

Not enough data points are available to more precisely define dispersal patterns. Any of four factors may have caused or contributed to this difficulty:

1. rapid dispersion and dilution of the radioactive sand beyond the limits of detection (1 microcurie over 1 square foot);

2. failure to disperse or very slow rate of tagged-sand dispersion;

3. burial of the tagged sand; or

4. too widely spaced tracking, in terms of the rate of movement and volume of sand, especially if the sand remained in a small area.

Field procedures are designed so that monitoring begins nearly simultaneously with injection to guard against "losing" the sand as a result of rapid dispersion. Experience at Cape Kennedy and at Surf indicates the procedure is sound. Scuba divers, in the water at the time of each injection, observed a bottom surge associated with wave passage. By means of dye releases on the bottom, a unidirectional current of approximately 15 cm/sec (0.5 ft/sec) was measured at each location of dye placement; too rapid dispersion of the labeled sand is therefore unlikely. Although it appears unlikely, there is a possibility that labeled sand was gradually removed from the point source and was consequently diluted beyond the level of detectability. Computations of the supposed rate of sediment motion are imprecise and subject to wide latitude of values. Therefore, while data in Table III indicate the sand should move, it is conceivable that actual conditions on the sea floor precluded movement or that movement was relatively slow. Burial by unlabeled sand could mask the presence of labeled sand. The limiting depth of burial for detecting xenonated sand is approximately 6 centimeters. Divers reported ripple marks on the bottom in the three study sites; amplitudes in excess of 1.0 centimeter were only infrequently noted. The wave lengths of the ripples were such that all labeled sand would not be buried. Oceanic conditions indicated that a blanket burial was not probable. If the rate of dispersal was low, it is quite possible that the search tracks were too widely spaced. On-board plotting of the vessel track was done to preclude such a possibility, but proved to be a relatively imprecise technique. It is judged that the paucity of significant (twice background) radiation data is due to a combination of relatively slow movement of tagged sand and the wide track spacing.

It was recognized that the Point Conception area would be a difficult place to work, therefore, backup detection equipment and a much improved on-board instrument shelter were built for this test. While the radiation data collection system worked well, some problems developed. Bouncing of the detector "ball" as it was towed over the rock outcrops on the beach and offshore bottom caused gain shift and noise in the detectors which necessitated frequent adjustments to the recording instruments. in addition, breaks occurred in the Tygon covering for the cable and allowed water to penetrate the high voltage lines to the detector. The backup detector was utilized during this program so that it could continue to the planned completion stage.

5. CERC Shore Processes Test Basin, May 1968

Small quantities of labeled sediment are generally simpler to work with than are large quantities. Logistics and radiation safety are simpler. An excellent way to compare high and low specific activity sand would be a laboratory experiment under controlled conditions that permitted duplication of factors. Such a test at CERC compared results obtained using a large quantity of low specific activity sand with those obtained using a smaller quantity of high specific activity xenonated sand. Total activity remained equal in both instances. Limited test data on beach development and littoral movement under controlled conditions were also obtained. The test proved the suitability of xenonated sand for laboratory experiments in beach and nearshore processes.

Tests were conducted in a flume 68 feet long and 10 feet wide, constructed in the north part of the CERC Shore Processes Test Basin. The initial beach configuration for each test was essentially a plane beach with a 1:10 slope. The sand was a well-sorted medium quartz sand with an average mean size of 1.87ϕ (.27mm) and a standard deviation of 0.42.

Waves were 0.4 foot high with a period of 1.9 seconds. Each test (low specific activity and high specific activity) comprised a total of 22 minutes of wave action. Each test was interrupted after 3 minutes and again after 9 minutes of total wave action to measure changes in beach morphology and radioactivity distribution. The bathymetry of the beach face after 22 minutes of wave action is shown by Figure 51 and the profiles are shown by Figure 52.

When manufactured on 26 April 1968, the low specific activity sand had a specific activity of 5.28 microcuries per cubic centimeter; the high specific activity sand had a specific activity of 520 microcuries per cubic centimeter. On 29 April, about 1 liter of low specific activity xenonated sand was emplaced at 0.5-foot intervals, approximating a line source, from stations -1 through +8 along range 5; approximately 50 milliliters per interval was used.

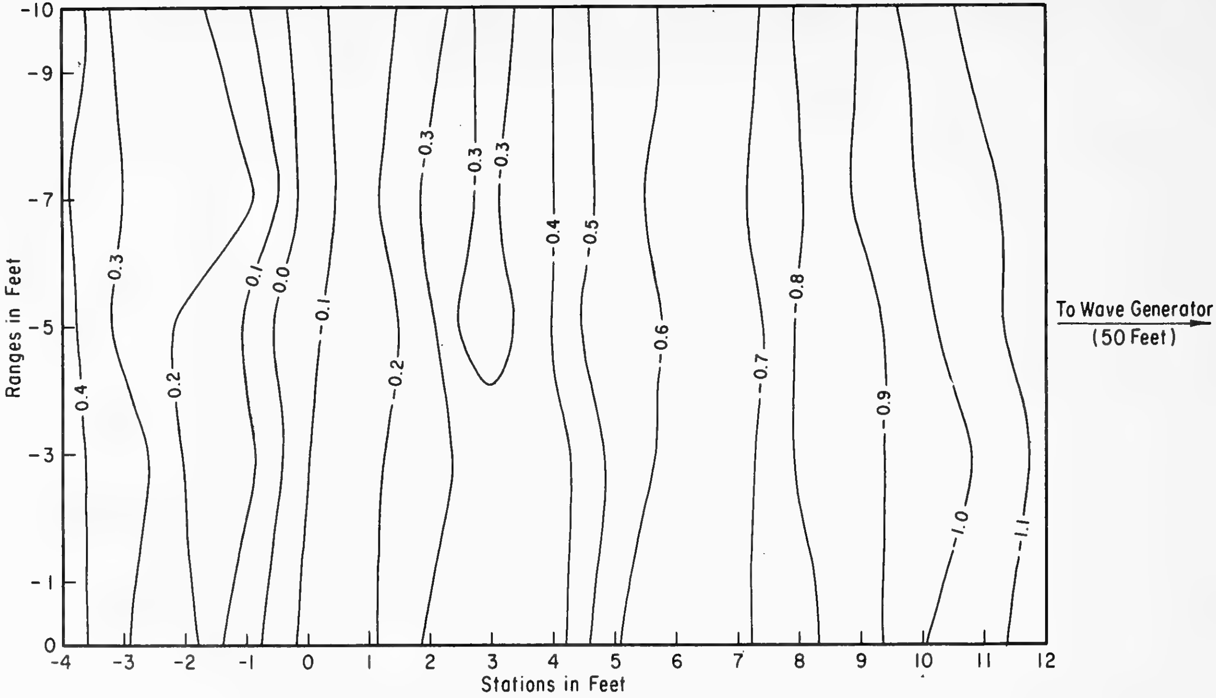
Following this test the radioactive sand was removed and the beach face was rebuilt. On 3 May, about 10 cubic centimeters of high specific activity xenonated sand was emplaced at the same 0.5-foot intervals from station -1 through +8 along range 5. To keep total activity the same as in the previous test, 0.5 cubic centimeters per interval was used.

Radiation and bathymetric surveys of the basin were made after 3, 9, and 22 minutes of total wave action. Radioactivity distribution was monitored at 1-foot intervals along ranges 1, 3, 5, 7, and 9, using a hand-held scintillation counter with a 3 by 3-inch sodium iodide crystal. Figure 53 illustrates the distributions obtained with low and high specific activity sand, following 22 minutes of wave action. A comparison of these distribution plots indicates results with high specific activity sand were nearly identical to those with low specific activity. The radiation distribution plots (and the profiles) demonstrate the tendency of the radioactive sand to orient in bands parallel to the shoreline and to accumulate and move down the left (range 9) side of the basin following the route of return water flow.

An attempt was made to determine depth of mixing at the conclusion of each test by taking cores and wrapping them with polaroid radiographic film; however, the level of activity was insufficient to expose the film even though it remained wrapped around the core for approximately 35 days.

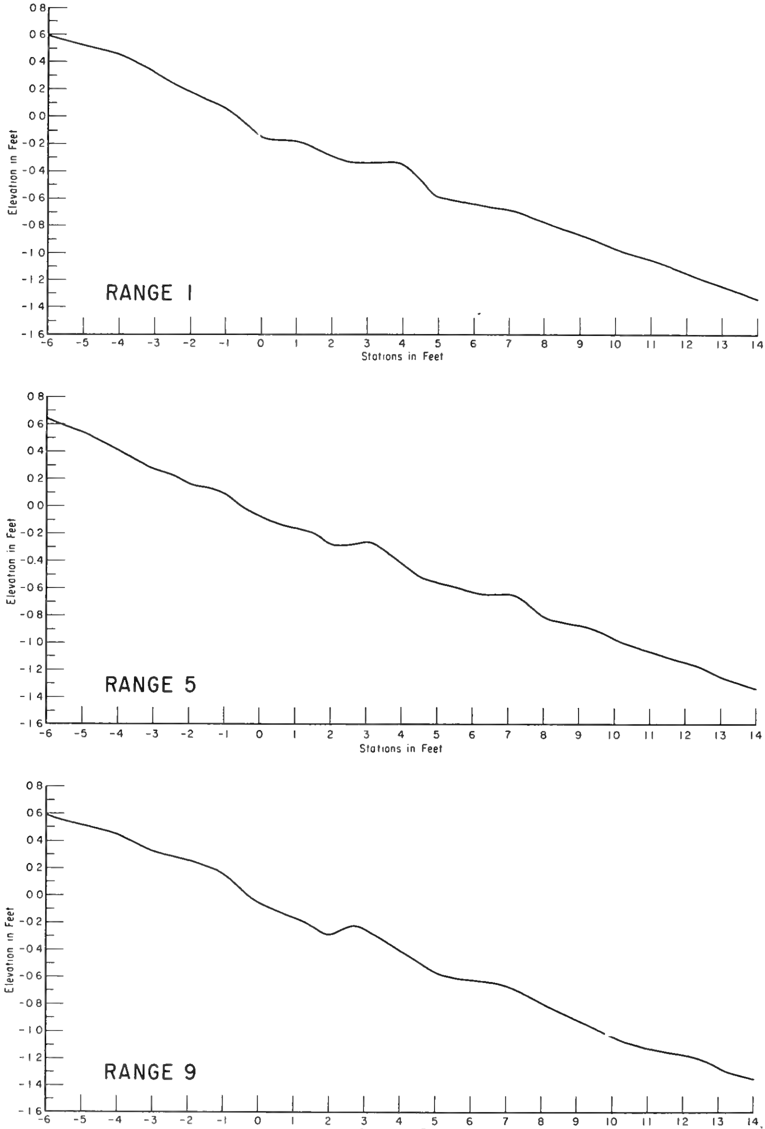
The distribution patterns obtained using high and low specific activity sand indicated that the use of a smaller quantity of high specific activity sand made no significant difference, at least so long as total activity remained the same. Results of the Shore Processes Test Basin tests confirmed that xenonated sand is ideal for laboratory tests involving sedimentation and beach processes.

To better determine the necessary frequency of data points (and hence serve as a guide for field programs), additional computer plots using a Lourier transform series were made on the data from Run 3 (22 minutes total wave action) of the low specific activity test. One plot used only even stations and another used only odd stations (every other station was omitted). A third plot was made omitting all data for range 5. As shown by Figures 54 and 55, all three plots exhibit patterns very similar to that of the complete data set. From this it may be concluded that from 20 to 50 percent fewer data points may be used to give significant results.



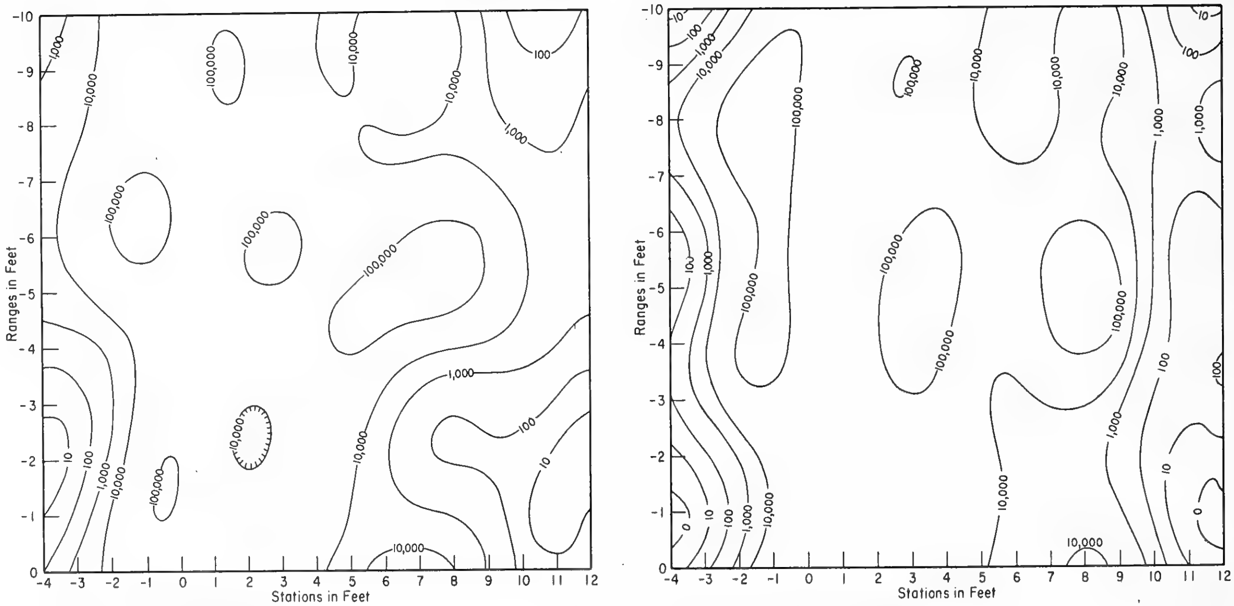
Low Specific Activity Xenon, Run 3,
22 Minutes Total Wave Action

Figure 51. Bathymetric Map - CERC Shore Processes Test Basin



Low Activity Xenon
Run 3 (22 Minutes Total)

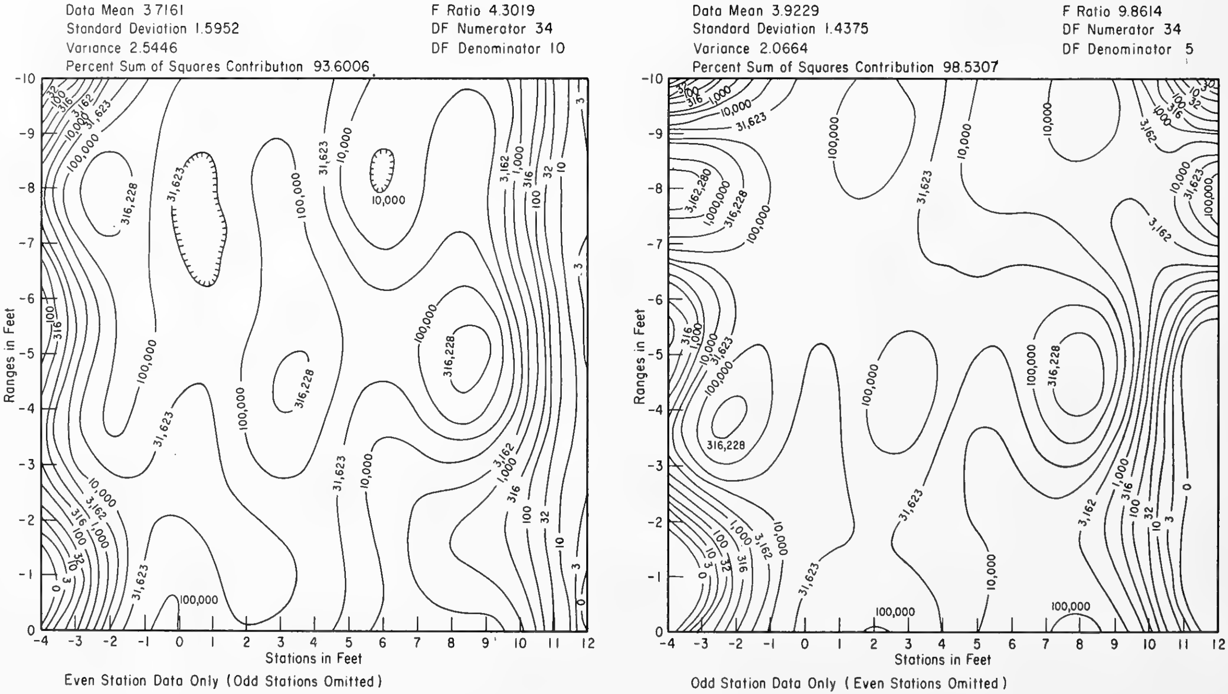
Figure 52. Beach Profiles, CERC Shore Processes Test Basin



High Specific Activity Xenon Tracer
Run 3 (22 Minutes) 7 May 1968

Low Specific Activity Xenon Tracer
Run 3 (22 Minutes) 1 May 1968

Figure 53. Radiation Surveys, CERC Shore Processes Test Basin



Data Mean 3.7161
Standard Deviation 1.5952
Variance 2.5446
Percent Sum of Squares Contribution 93.6006

F Ratio 4.3019
DF Numerator 34
DF Denominator 10

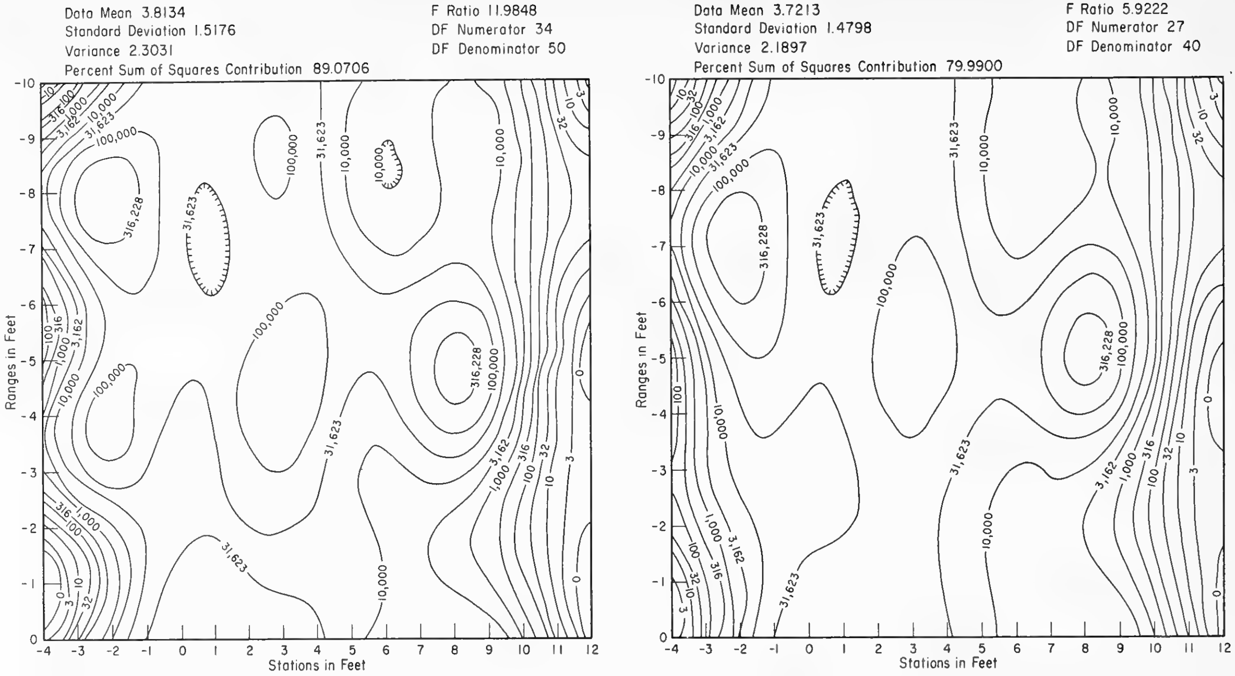
Even Station Data Only (Odd Stations Omitted)

Data Mean 3.9229
Standard Deviation 1.4375
Variance 2.0664
Percent Sum of Squares Contribution 98.5307

F Ratio 9.8614
DF Numerator 34
DF Denominator 5

Odd Station Data Only (Even Stations Omitted)

Figure 54. Data Omission Study, Radiation Surveys



Complete Data Set

Range 5 Data Deleted

Figure 55. Data Omission Study, Radiation Surveys

Section IV. PROGRAM SUMMARY

1. Hardware and Program Development

Xenon-133 is the only isotope used to date. This biologically inactive isotope is diffused into the quartz sand grains at high temperature and low pressure. Tests indicate that this process does not affect the hydraulic characteristics of the grain. As indicated by studies at NRDL, there is little loss of xenon due to leaching and abrasion. Because of degassing, the halflife of tagged particles used in early studies was 2.7 days as opposed to 5.3 days for xenon-133. However, this problem has been nearly eliminated and the halflife for the tagged particle is now approximately 5.0 days.

An apparatus capable of placing the tagged sand on the bottom in deep water or in relatively shallow water of the breaker zone was required. The initial device was a cylindrical hopper which could be used to emplace a slurry of tagged sand as either a point source or line source. However, the sand clogged on occasion when it got wet in the hopper. A springloaded clamshell device which opened upon contacting the bottom proved effective for placing sand as a point source.

The detection system consists of an on-board data collection system and a towed ball-like device which houses four cesium iodide crystals (scintillation detectors). Tests indicate that this ball design will track well at speeds up to 5 knots with the present cable configuration. As built, the device works to depths of 200 feet (about 6 atmospheres). Electrical signals from the detectors are carried to a signal mixer on the towing vehicle and then to a 400-channel analyzer. By means of a program interrogator, other data pertinent to surveying are coordinated with the radiation data and read into the data display.

Tagged sand is traced by towing the detector ball behind an amphibious vehicle. Navigational control uses a navigation system which provides direct readout of distance in meters from two responder beacons at established shore points. Position information and radiation data are printed out simultaneously. Soundings are taken with a precision fathometer located on board the amphibious vehicle.

Computer programs have been developed for processing the raw field data. Radioactivity data is corrected for background and decay; position data is corrected to indicate the location of the ball behind the amphibious vehicle. These data are subsequently read into memory, and an additional program plots and posts the corrected data. Isoactivity contour maps (trend surface) of gridded data may be made by a Fourier transform program.

2. Radiation Safety

Because xenon-133 has a relatively soft radiation and is biologically inert, hazards connected with its use are minimal. For example, a person could have lain one week on the sand used in the Shore Processes Test Basin tests (5.2 millicuries total activity per test) without exceeding the AEC permissible whole body dosage. As shown in Appendix F, only minimal radiation exposure was received by personnel handling or otherwise close to the activity in any RIST experiment.

Although the use of xenon-133 tends to minimize hazards, certain safety precautions are nevertheless required. Personnel were supplied with ORNL film badges or dosimeters, and cumulative radiation exposure records were kept. Full-scale rehearsals of all procedures were conducted prior to working with radiated sand. Test and storage areas were marked in accordance with AEC regulations, and access to these areas was controlled. Injection devices were used for emplacing the sand. Personnel handling tagged sand wore protective clothing. Personnel, equipment, and the survey area were monitored throughout the test to locate possible contamination.

3. Field and Laboratory Tests

The preliminary Cape Kennedy field test proved the engineering design of the detector, the analyzer system, and the sand tagging process, as well as the conceptual framework of the program. The test at Surf demonstrated that the sediment could be traced for a period of days in an environment harsher than Florida, and field techniques were brought to a fully operational level. As a bonus to this test, sediment dispersal patterns for the area were derived. For a depth of 30 feet, these patterns indicate an offshore movement toward the northwest. The test at Point Conception worked toward accomplishing nearly all of the objectives of the program. Although there was not enough significant data to define dispersal patterns, some tentative approximations of direction of movement were obtained. Despite the paucity of definitive data, these field tests were successful in that they provided additional knowledge of operating characteristics of the equipment and basic information which can be used to improve field procedures. The test in the CERC Shore Processes Test Basin showed that the use of a small quantity of high specific activity xenonated sand made no significant difference from the distribution patterns obtained using a larger quantity of low specific activity sand (same total activity). A data omission study indicated that somewhat fewer data points may be used to give significant results.

Section V. FUTURE OBJECTIVES

While much has been accomplished to date within the context of the original 3-year research and development program, objectives in several categories remain to be met. Some are merely refinements of existing capabilities; others represent major goals. Both classes are categorized and summarized as follows:

a. Isotopes: Seek other isotopes suitable for tagging by a technique analogous to xenonation; study field use of isotope(s) other than xenon; and provide for detection and analysis of multiple isotopes for use in study of depth of sand burial.

b. Instrumentation and Computer Programs: Develop *in situ* stationary detectors to serve as monitors of sand movement; modify existing detector and on-board analyzer system to simultaneously detect and record multiple isotopes; provide for use of oceanographic cable; automate and digitize water depth data; and refine computer programs for analysis and treatment of radiation data.

c. Sediment Movement: Improve field surveying to increase collection of data points for maps; design and conduct programs for other coastal sectors in the study area; extend the surveys through the surf zone and beach face; use multiple isotopes; define more precisely the mechanics and movement (including, if possible, quantification) of sediment in the Point Conception area; and determine the effect of sediment burial.

To be able to predict the course of sediment movement and annual volume will provide for improved engineering design of coastal structures and subsequent economy of maintenance. Basic techniques and technology are now at the point where the RIST system can be considered an operational tool for determining direction of sediment movement. However, improvements and refinements of the system will continue only through use. Improvements must continue to a point where the program can be operated by a greater percentage of technicians than is now possible. Not until then will the techniques and technology developed be fully and widely applicable to engineering and scientific studies.

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APPENDIX A

Part 1. Leaching and Abrasion Studies on Beach Sands Tagged with Radionuclides by the NRDL Water-Glass Procedure.

Part 2. Xenotated Sand: Leaching and Abrasion Studies.

Part 3. Bibliography on Radiotracer-Tagging Sand and Sediments for Study of Mass Transport in Fluvial and Marine Environments.

PART 1

LEACHING AND ABRASION STUDIES ON BEACH SANDS TAGGED WITH RADIONUCLIDES BY THE NRDL WATER-GLASS PROCEDURE

INTRODUCTION

The investigations being conducted at Point Conception, California by the U. S. Army Coastal Engineering Research Center and associated agencies are for the purpose of studying littoral transport of beach materials past coastal promontories. Initially, sand labeled with radioactive Xe-133 is being used to trace the littoral migration of the beach materials. The xenonation technique for labeling the sand was developed at Oak Ridge National Laboratory* and is similar to the familiar Kryptonation technique (Carden, 1966), a technique by which Kr-85 is diffused at high temperatures and pressures into solid materials. Other radioisotopes, such as Ba-La-140 and Cr-51, will be utilized (perhaps simultaneously, so that several particle sizes can be followed in the same experiment) for labeling the sand in subsequent investigations at Point Conception. If these latter nuclides are to be used successfully for tracing sand, suitable labeling techniques are necessary to prevent the radioactive nuclides from leaching or abrading away from the sand during the experiment. The objective of the investigation reported in this paper is to determine whether a tagging procedure developed at NRDL some years ago could be utilized for sealing the radioactive nuclides Ba-La-140 and Cr-51 into the sand.

The NRDL water-glass technique was developed to produce a fallout simulant for evaluation of counter-measures for recovering military and civil sites contaminated by radioactive fallout. The simulant consisted of Monterey sand labeled with Ba-La-140 activity (Owen and Sartor 1963). Briefly, the procedure (Crew, 1965) involved spraying the desired activity on sand which was being rotated inside a concrete mixer. During the mixing the sand was dried by direction of a blast of hot air into the mixer. Next, a solution of sodium silicate (water glass) was sprayed on the sand and the sand was dried as before with hot air. Then the labeled sand was fired for an hour at 1900°F (1030°C). The fused water-glass coating on the sand provided an effective seal for retarding the desorption of the radioactivity into fresh water (i.e. from firehoses or rain) in the type of field experiment for which it was developed.

To determine whether the NRDL sealing technique could be extended to the Point Conception project, laboratory experiments were designed to measure the release of activity from tagged sand to the environment by (1) the simple static leaching action of sea water and (2) the combination of sea-water leaching and the mutual abrasive action of the sand particles as would be experienced in the surf zone. The results of such studies with both Ba-La-140 and Cr-51 are summarized below.

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* F. N. Case and E. H. Acree, ORNL, personal communication

EXPERIMENTAL

The sand was tagged in 100-gram lots for the laboratory experiments. The sand was placed in a 16-ounce screw-cap bottle and the desired radioactivity, in 2.25 milliliters of distilled water, was added dropwise to the sand. The activity level of the added radionuclide per 100 grams of sand varied from 3 to 5 million counts per minute. The bottle was capped, and sand and radioactivity were thoroughly mixed by rolling the bottle on a jar mill for one hour. The moist sand was then dried in an oven at 130-140°C. Then 2.25 milliliters of a 50-50 mixture of water and 40-42 Baumé sodium silicate solution was added dropwise to the sand. Contents of the bottle were mixed on the jar mill for one hour, and then the coated sand was dried in the oven as before. After this, the dried sand was placed in a porcelain casserole and fired for one hour at 1900°F (1030-1040°C).

About 5-6 grams of the tagged sand was weighed into a 15 by 125-millimeter test tube. This (standard) sand sample was radioassayed each time aliquots of supernates were assayed in the static leaching and the abrasion tests; it served as a standard for calculating the quantity of radioactivity removed in those tests.

For the static leaching study, 40 grams of the tagged sand was placed in an 8-ounce screw-cap bottle along with 100 milliliters of sea water. On the first day of the leaching study, 0.5-milliliter aliquots of the supernate were removed and radioassayed 1, 2, and 6 hours after the sea water had been added to the sand. During the following 12 to 14 days, a daily aliquot was removed and radioassayed. Then the experiment was terminated. Before each aliquot was removed, the contents of the bottle were stirred thoroughly and then allowed to settle for 5 minutes.

For the abrasion studies, 40 grams of the tagged sand was placed in a 500-milliliter bottle along with 100 milliliters of sea water. The bottle was agitated in a Parr Pressure Reaction Apparatus. Aliquots (0.5 milliliter) were obtained and assayed just as those for the leaching experiment. As the abrasion experiment proceeded, a suspension developed in the supernate. This suspension was quite stable. Therefore, the radioassay included this suspended material.

Commercial Monterey sand was used for pilot studies. After procedures had been tested, sands from the Point Conception test site were utilized. The Point Conception sands were provided by Mr. Joseph H. Bittner of the Los Angeles District, Corps of Engineers. The various Point Conception sands are designated according to their geographical and beach locations.

Because the tagging procedure could materially alter the size of sand particles, the sand-size distributions, at various stages of the tagging procedure and after the abrasion experiment, were checked with a mechanically operated sieving device. In all cases the sieving lasted for 15 minutes. The sieving results obtained are not to be interpreted as definitive studies in sand-size distributions. They were made simply to provide an order-of-magnitude estimate of the effects of coating, firing, and abrasion on the size of the particles. Small, unavoidable weight losses of the sand sample occurred as the tagging, sieving, and abrasion routine developed. Sources of these weight losses were the inability to transfer quantitatively the coated sand from the sodium silicate mixing bottle to the porcelain casserole, losses due to the high temperature firing of the sand (carbonate decomposition), changes in the sorbed moisture on the sand, and losses in removing the smaller sand fraction from sieves and weighing containers because of the electrostatic charge developed on the particles during the sieving. Since most of the material losses were cumulative, the sieving routine was varied from experiment to experiment so that the number of sieving operations in any one experiment (and therefore also the total weight-loss error) was minimized. The total loss caused by the sources listed above varied from 2.5 to 4.5 grams per 100 grams sand.

The pre-tagging sieving results for Monterey sand and the various Point Conception sands are given in Table A-I. Several Point Conception samples consisted chiefly of coarse gravel and pebbles up to 1 1/2 inches in diameter. Because the coarse material would tend to bias results when 100-gram sand samples were used in the experiments, only material that passed through an 833-micron sieve was retained for the experiments. Another objection to the retention of the coarse material was the excessive grinding action that would be produced in the limited confines of the 500-milliliter abrasion vessel. Such results would be similar to those obtained with grinding pebbles in a ball mill, and would be much more severe than those likely to be experienced under test conditions. The arbitrary imposition of an upper limit to the particle size does not in any way invalidate the results obtained, because the objective of the investigation was the integrity of the silicate coating under reasonable experimental conditions and not the particle size distribution of the sand. Furthermore, on a weight basis, the smaller fractions are the more important because the specific activity of a particle increases inversely as its size. Also the smaller fractions will be the most important ones in the field since they will travel the farthest from the deposition site in a given time.

The new size distribution data obtained after the removal of the coarse material are shown in Table A-II.

RESULTS

Study No. 1 - Monterey Sand - A pilot study was made with Monterey sand. This study was made for scaling down the established procedure for concrete-mixer size batches of tagged sand to 100-gram laboratory size batches. The study was made also for providing a standard tagged sand for comparison with the Point Conception sands to be studied later. The Monterey sand was tagged with Ba-La-140 radioactivity. The leaching and abrasion experiments extended over 12 days, approximately one half-life of the activity. After 12 days about 1 percent of the activity had leached off the sand in the static tests, and about 3.8 percent of the activity had abraded away from the sand in the abrasion study.

Study No. 2 - Surf No. 2, MLLW Sand - In this study, the Point Conception sand was treated with dilute hydrocholric acid (HCl) prior to the tagging with Ba-La-140 activity. The purpose of the HCl leach was to remove sea shells and other carbonate minerals from the sand. The HCl was added in small portions to the sand (which was covered with water) until gas evolution ceased. The sand was washed thoroughly with distilled water, and then dried before initiation of the tagging procedure. The mass-size and activity-size distributions of the sample during the various stages of the study are given in Table A-III. The HCl leaching and the firing losses are also given. The table includes the mass-size distribution of the original sand sample, of the sample after the HCl treatment, and of the sample after it had been tagged, coated, and fired at 1900°F. Also included are the distribution of the activity on the tagged sample and the mass-size distribution of the sand at the termination of the abrasion studies. Leaching and abrasion data were collected for 12 days. The results for the leaching experiment showed that 1.1 percent of the activity was lost to the aqueous phase. For the abrasion experiment the figure was 4.2 percent.

Study No. 3 - Surf No. 2, MLLW Sand - This study was terminated by an accident early in the course of the experiment. The experiment was repeated as Study No. 4.

Study No. 4 - Surf No. 2, MLLW Sand - The purpose of this study was to determine the effect of the carbonate minerals in the Point Conception sand on the sealing of the tagged sand. Therefore, the carbonates were not removed by the preliminary HCl leach. The high temperature at which the water glass is fired decomposes the carbonate minerals. As in the previous study, the mass-size and activity-size distributions at various stages of the study are given in Table A-IV. After 12 days of static leaching, 4.8 percent of the activity was in the aqueous phase. The comparable value for the abrasion experiment was 15.8 percent. These results clearly indicate that the presence of carbonate mineral decomposition products (basic oxides) in the sand adversely affects the sealing quality of the water-glass tagging procedure.

Study No. 5 - Bear Creek No. 1, +5 Sand - This study was made to check the water-glass procedure with one other Point Conception sand. This particular sand was selected because of its fine, uniform appearance. The carbonates were removed before the sand was tagged with Ba-La-140 activity. The size and activity data are given in Table A-V. After 12 days of static leaching, approximately 0.6 percent of the radioactivity had escaped into the aqueous phase. For the abrasion experiment, 0.9 percent of the radioactivity was in the aqueous phase.

Study No. 6 - Monterey Sand - This study was made to determine whether Revlon nail enamel, No. 61, had adequate sealing properties for retaining radioactivity under the conditions described in the previous studies.

(If successful, this material could have been used to seal activity on dolomite type sands.) The experiment was discontinued after 24 hours because of poor results. In the static leaching experiment, 26 percent of the activity was lost to the aqueous environment. About 60 percent of the activity was abraded away in the 24 hours.

Study No. 7 - Monterey Sand - In this experiment the firing temperature for the water-glass technique was reduced from 1030° to 500°C. The seal at the lower temperature was inferior to that obtained at 1030°C. After 24 hours, 8 percent of the activity had leached away in the static test and 16.4 percent of the activity had been lost in the abrasion experiment.

Study No. 8 - Bear Creek No. 1, +5 Sand - The sand was tagged with Cr-51 radioactivity by the water-glass procedure. Approximately 1 percent of the activity was leached from the tagged sand in the static test and 1.3 percent was in the aqueous phase due to abrasion. The experiment extended over 14 days. No sieving data were taken.

Sieving Experiment with Bear Creek No. 1, +5 Sand - An examination of the size-distribution data obtained with Surf No. 2, MLLW sand in the original form shows a considerable variation in the results (cf. first row of data, Tables A-III and A-IV). Initially this was attributed to poor sampling, probably caused by size fractionation of unknown origin. For a test of this thesis, Bear Creek No. 1, +5 sand was thoroughly mixed for 15 minutes in a jar mill. Two 100-gram samples then were removed and each was mechanically sieved for 15 minutes. The sieving results are given in Table A-VI. These results should also be compared with the results of the item designated "original" in Table A-V. Apparently mass-size variations up to 5 absolute percent, which is larger than had been anticipated, are to be expected.

FUTURE PLANS

Leaching and abrasion experiments for xenonated sand, supplied by Oak Ridge National Laboratory, have been completed. The results obtained will be incorporated in a subsequent report. A bibliography on sand-tagging techniques has been completed in rough draft, and will be reported shortly.

CONCLUSION

The NRDL procedure for sealing radioactivity to soils can be extended to beach sands, provided carbonate minerals are absent or may be removed. Over a 12-day period, about 1 percent of the radioactivity is removed by static leaching processes, and from 1 percent to 4 percent of the activity may be abraded away from the tagged sand. Losses of this small magnitude are no cause for concern. It is inconceivable that they would either jeopardize the results of the operation or constitute a health hazard. These results apply to Ba-La-140 and Cr-51 activities. Presumably any radioactive element that is not vaporized at the firing temperature (1900°F) can be used for tagging refractory sands.

TABLE A-1

Mass-Size Distribution of Various Sand Samples as Received
(Percent by weight)*

Sample	Total Weight g	% >1680 µ	% 833-1680 µ	% 420-833 µ	% 295-420 µ	% 210-295 µ	% 149-210 µ	% 88-149 µ	% <88 µ
Monterey Sand	99.89	None	None	8.77	88.87	2.16	.19	.01	None
Surf No. 1, +5	523.5	.36	1.18	12.30	33.57	41.09	10.31	1.14	.04
Surf No. 2, MLLW	604.	17.80	2.81	13.12	24.56	30.39	9.83	1.44	.02
Surf No. 3, -5	672.5	11.38	2.16	12.12	24.48	33.68	12.99	3.14	.04
Bear Creek No. 1, +5	485.5	None	None	1.47	21.53	61.59	13.18	2.10	.02
Bear Creek No. 2, MLLW	788.5	6.47	1.36	7.25	21.68	46.95	13.50	2.74	.07
Bear Creek No. 3, -5	603.5	2.88	1.03	5.70	22.51	50.41	13.91	3.49	.07
Lompoc Landing No. 1, +5	648.	41.13	36.26	21.45	.92	.09	.01	.01	.004
Lompoc Landing No. 2, MLLW	604.5	86.88	10.07	2.83	.29	.05	.01	.002	.0002
Lompoc Landing No. 3, -5	646.5	6.73	5.03	39.63	32.62	11.93	1.22	2.55	.30

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* These percentages, as well as those in subsequent tables, do not always add up to 100% because they were calculated on the basis of original sample weights. Subsequent losses or partial drying of fractions account for the deviations noted.

TABLE A-II

Mass-Size Distribution of Various Sand Samples for Particles Under 833 Microns*
(Percent by weight)

Sample	% 420-833 μ	% 295-420 μ	% 210-295 μ	% 149-210 μ	% 88-149 μ	% <88 μ
Monterey Sand	8.77	88.87	2.16	.19	.01	None
Surf No. 1, +5	12.49	34.08	41.71	10.47	1.16	.04
Surf No. 2, MLLW	16.48	30.86	38.18	12.35	1.81	.04
Surf No. 3, -5	14.05	28.38	39.04	15.06	3.64	.05
Bear Creek No. 1, +5	1.47	21.53	61.59	13.18	2.10	.02
Bear Creek No. 2, MLLW	7.87	23.53	50.96	14.65	2.98	.07
Bear Creek No. 3, -5	5.93	23.40	52.41	14.46	3.63	.07
Lompoc Landing No. 1, +5	95.41	4.08	.39	.065	.04	.017
Lompoc Landing No. 2, MLLW	88.87	9.20	1.52	.32	.08	.008
Lompoc Landing No. 3, -5	44.78	36.85	13.48	1.38	2.88	.34

*Calculated from data of Table A-I

TABLE A-III

Mass-Size and Activity-Size Distribution of Sand at VArious Stages of Study No. 2 (Percent by weight or activity)

Sample Stage	% 420-833 μ	% 295-420 μ	% 210-295 μ	% 149-210 μ	% 88-149 μ	% <88 μ
Original [1]	16.48	30.86	38.18	12.35	1.81	.04
After HCl leach (2.98% weight loss)	16.48 [2]	31.49[2]	39.24[2]	10.84[2]	1.75[2]	.21[2]
Coated and fired (1.87% weight loss)	16.28[2]	33.67[2]	37.37[2]	10.68[2]	1.85[2]	.14[2]
Coated and fired (activity)[3]	(15.15)	(26.90)	(38.88)	(13.73)	(3.80)	(1.53)
Abrasion residue	15.26	29.96	38.81	13.08	2.47	.41

TABLE A-IV

Mass-Size and Activity-Size Distribution of Sand at Various Stages of Study No. 4 (Percent by weight or activity)

Sample Stage	% 420-833 μ	% 295-420 μ	% 210-295 μ	% 149-210 μ	% 88-149 μ	% <88 μ
Original [1]	19.31	33.22	36.27	9.81	1.36	.02
Coated and fired (1.96% weight loss)	19.71[2]	34.04[2]	35.46[2]	9.37[2]	1.30[2]	.12[2]
Abrasion residue	22.81	33.62	33.46	8.82	..93	.36
Abrasion residue (activity) [3]	(19.18)	(21.44)	(39.12)	(15.52)	(3.07)	(1.70)

1. Surf No. 2, MLLW sample. Compare Tables A-III and A-IV. See sieving experiment in text for explanation.
2. Percent of depleted sample.
3. Numbers in parentheses refer to activity-size distributions. All others refer to mass-size distributions.

TABLE A-V

Mass-Size and Activity-Size Distribution of Sand at Various Stages of Study No. 5 (Percent by weight or activity)

Sample Stage	% 420-833 μ	% 295-420 μ	% 210-295 μ	% 149-210 μ	% 88-149 μ	% <88 μ
Original [1]	1.27	18.91	62.26	15.14	2.41	.01
After HCl leach (2.37% weight loss)	1.26[2]	18.28[2]	62.24[2]	15.51[2]	2.65[2]	.07[2]
Coated and fired (0.29% weight loss)	1.42	20.20	60.20	15.40	2.70	.09
Abrasion residue	1.18	20.74	59.12	16.74	2.10	.11
Abrasion residue (activity) [3]	(.66)	(9.82)	(46.40)	(33.08)	(9.63)	(.48)

1. Bear Creek No. 1, +5 sample.
2. Percent of depleted sample.
3. Numbers in parentheses refer to activity-size distributions. All others refer to mass-size distributions.

TABLE A-VI

Mass-Size Distributions Obtained by Sequentially Sieving Two Bear Creek No. 1, +5 Samples (Percent by weight)

Experiment Number	% 420-833 μ	% 295-420 μ	% 210-295 μ	% 149-210 μ	% 88-149 μ	% <88 μ
1.	2.23	23.92	60.54	11.63	1.66	.01
2.	1.60	19.72	63.61	13.01	2.09	.01
Original from Table A-V	1.27	18.91	62.26	15.14	2.41	.01

PART 2

XENONATED SAND: LEACHING AND ABRASION STUDIES

INTRODUCTION

The U. S. Army Coastal Engineering Research Center and associated agencies are studying littoral transport of beach materials past coastal promontories at Point Conception, California. Sand labeled with radioactive nuclides is used to trace the littoral migration of the beach materials. The first injection of sand labeled with radioactive Xe-133 occurred in June 1967. The technique for labeling sand with Xe-133 was developed at Oak Ridge National Laboratory (F. N. Case and E. H. Acree, Oak Ridge National Laboratory, personal communication) and is similar to the familiar kryptonation technique (Carder, 1966), in which Kr-85 is diffused at high temperatures and pressures into solids. The depth of penetration of Kr-85 into the host solid is 10^3 to 10^5 Å. Kryptonated solids remain stable (no outgassing) with time at room temperature, barring surface reactions such as oxidation or hydration of the host solid. Although similar behavior is anticipated for xenonated solids, due allowance must be made for the enhanced size of the xenon atom over that of krypton, because the labeling mechanism for both techniques depends on the entrapment of the noble gas in the interstitial spaces and structural voids of the host solid. The objective of the investigations reported in this paper is to determine whether outgassing of Xe-133 will occur when xenonated sand is subjected to conditions prevailing at the water-sand interface of a marine environment.

Laboratory experiments were designed to determine whether outgassing of Xe-133 from xenonated sand occurred. The experiments were similar to those that were used to test the integrity of the Naval Radiological Defense Laboratory (NRDL) water-glass technique for labeling sand with radioisotopes (Appendix A, Part 1). Static water tests were made to determine the effect of water in causing outgassing of the xenonated sand, and abrasion tests were made to determine the radioactivity loss caused by the mutual abrasive action of the sand particles as would be experienced in the surf zone.

EXPERIMENTAL

At ambient temperatures and pressures zenon is a gas with a characteristic valence of zero. This property necessitates the use of a closed system for investigation of the outgassing of Xe-133 from zenonated sand. A desirable apparatus for this study would utilize all-glass construction with provisions for sample agitation and for removal of outgassed Xe at desired intervals. However, limitations on time and funding precluded the possibility of constructing and testing such an apparatus. In place of this apparatus simple experiments were prepared in 25-milliliter screw-cap vials. The vials were sealed with polyethylene gaskets seated in the caps. Six static experiments and six abrasion experiments were prepared with these containers in the investigation of the outgassing of Xe-133 from the sand as a function of time.

Five grams (5.00 g) of xenonated sand were weighed into each vial. Next the vial was filled completely with distilled water. The amount of water added was measured with a burette. Then the caps were secured, and for insurance of a seal, the vials were inverted until they were radioassayed. The vials used in the abrasion experiments were placed in a Parr agitation apparatus in an inverted position. They were agitated in this position until they were assayed. A calibration standard was prepared at the same time as the experiments. The standard consisted of 6.0787 grams of the dry xenonated sand in a 15 by 125-millimeter test tube. The tube was not sealed. The standard was radioassayed each time aliquots of supernate from the vials were assayed. A semilogarithmic plot of the count rate of the standard vs. the time showed that, from 28 to 436 hours, it decayed with a halflife of 5.29 days. The good agreement with the published Xe-133 halflife (5.27 days) indicates that no loss of Xe-133 occurred by escape into the atmosphere during this time. Zero time for all experiments was set at the time the vials were filled with water.

At various times after the experiment began, supernates from a static experimental vial and from an agitated vial were radioassayed for the presence of outgassed Xe-133. A 4-milliliter aliquot was removed from the vial and radioassayed as quickly as possible. (Rate of loss of Xe-133 from an aliquot was determined in a collateral experiment.) The assay was made with a Sodium Iodide (NaI) (Tl-activated) crystal scintillation well counter. The vials were discarded after the assay. The time selected for a radioassay did not follow a set pattern. The time was determined more by the results of the previous assay and by the desire to extract as much information as possible from the results than by any other consideration. Altogether the time lapse for all the experiments extended over about two Xe-133 halflives (i.e., 10 days).

The xenonated sand was provided by Mr. F. N. Case of Oak Ridge National Laboratory (ORNL). Carbonates had been removed at ORNL prior to xenonation. Because of a misunderstanding, the sand was not received until the middle of May 1967. Thus only one batch of sand was available for experimental purposes.

RESULTS AND DISCUSSION

The pertinent data for both sets of the outgassing experiments are shown in Table A-VII. The data include the time lapse from zero to assay time, the total activity of the sand standard, the activity (calculated from the specific activity of the standard and the activity lost to the water) of the sand in the vial after exposure, the volume of water required to fill the vial, the total activity (calculated) of Xe-133 in the aqueous phase, and the percent of outgassed Xe-133. The calculated activities (all corrected for background) were for the times indicated in the first column.

After 28 hours the amount of Xe-133 outgassed from the sand in the static experiment corresponded to 3.5 percent of the amount remaining in the sand. After 219.5 hours the figure had increased to 5.5 percent.

TABLE A-VII

Outgassing of Xe-133 from 5.00-gram Samples of Xenonated Sand

Time (hr)	Sample No.	Standard Activity[a] (c/m)	Sand Activity[a] After Leaching (c/m)	Water (ml)	Water Activity[a] In Total Volume (c/m)	Xe Outgassed (%)
			A. Effect of Leaching			
28	1S	589,300	468,300	22.85	16,475	3.52
51	2S	519,000	409,500	23.02	17,771	4.34
75.5	3S	456,600	358,800	23.20	17,238	4.80
99.5	4S	399,400	311,900	23.20	16,866	5.41
195.5	5S	234,900	182,700	22.90	10,534	5.75
219.5	6S	205,400	160,200	23.20	8,862	5.54
			B. Effect of Abrasion and Leaching			
28	6A	589,300	464,500	23.45	20,448	4.41
51	5A	519,000	406,700	23.44	20,557	5.05
75.5	4A	456,600	355,700	23.22	20,108	5.65
99.5	3A	399,400	311,100	23.00	17,779	5.72
195.5	2A	234,900	183,100	23.10	10,254	5.60
219.5	1A	205,400	159,000	22.50	10,035	6.31

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[a] Activity at time indicated in first column.

Comparable figures for the abrasion experiments were 4.4 percent and 6.3 percent, respectively. In an attempt to improve the accuracy of the measurements, distilled water was used in the static outgassing and abrasion experiments because Xe is more soluble in distilled water than in sea water (Wood and Caputi, 1966). Because the vials were filled completely with water, dead spaces were avoided and the outgassed Xe remained in solution until the vials were opened for assay. About two minutes elapsed from the time a vial was opened until an aliquot was inserted into the counter for radioassay. It is assumed that a negligible amount of xenon was lost from the aliquot during this time because of the extremely low concentration of the xenon in the solution. However, in an attempt to provide an estimate of the rate of xenon escape from the aliquot as well as to show that the Xe-133 detected in the aliquot was the result of outgassing and not due to a fine suspension of sand in the supernate, the activity of the aliquots from experiments 6S and 1A was followed for 119 hours after separation, with the containers open to the atmostphere continuously. These data are shown in Table A-VIII. The results are given as the fraction of activity remaining in the aliquots after various time lapses. In 2.5 hours about 39 percent of the dissolved Xe-133 escaped from the aliquot from the static experiment and 24 percent from the abrasion-experiment aliquot. In both cases the rate of escape of xenon from solution is much greater than the rate of radioactive decay. The results show that, although 24 to 39 percent of the xenon escapes from the solution in 2.5 hours, prompt aliquoting and counting reduces this loss to a reasonable figure. Further support for this conclusion was obtained from another experiment in which 10 percent of the xenon escaped from the 1S aliquot in 30 minutes. It is estimated that the error due to xenon escape from the aliquots prior to radioassay is less than 1 percent of the outgassed xenon.* The results thus substantiate the findings that Xenon-133 is outgassed from the xenonated sand.

CONCLUSION

The experimental results show that Xenon-133 is slowly released from xenonated sand in the presence of water. The amount of Xe-133 lost from the xenonated sand to the aqueous phase was relatively small (about 3 to 5 percent). There was little difference between the static-experimental results and the abrasion-experimental results. Comparable results obtained with sands tagged with Ba-La-140 and Cr-51 by the NRDL waterglass technique were 1 percent for the static leaching experiments and 4 percent for the abrasion experiments (Appendix A, Part 1).

When an aliquot of the supernate from a leaching or abrasion experiment was left open to the atmosphere, the dissolved Xe-133 gas escaped into the atmosphere. This proved that the gas was dissolved in the aqueous phase and was not contained in sand suspended in the water.

The results show that the outgassing of Xe-133 from the treated sand need not be of concern either as a health hazard or with respect to the usefulness of Xe-133 as a tracer for the investigation of sand transport.

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* The outgassing results shown in Table A-VII tend to substantiate this estimate (plateau effect at later times).

TABLE A-VIII

Escape and Decay of Outgassed Xe-133 from Water

Time (hr)	6S Aliquot Activity[a] (c/m/4 ml)	6S Aliquot decay[a] (c/m/4 ml) calculated	6S Retained Activity[a] (fraction)	1A Aliquot Activity[a] (c/m/4 ml)	1A Aliquot decay[a] (c/m/4 ml) calculated	1A Retained Activity[a] (fraction)
0	1,527	1,527	1	1,779	1,779	1
2.5	931	1,506	.62	1,349	1,755	.77
23.5	115	1,342	.086	637	1,564	.41
47	38	1,180	.032	127	1,375	.092
119	4	796	.005	19	927	.020

[a] At time indicated in first column.

PART 3

BIBLIOGRAPHY ON RADIOTRACER-TAGGING SAND AND SEDIMENTS FOR STUDY OF MASS TRANSPORT IN FLUVIAL AND MARINE ENVIRONMENTS

INTRODUCTION

This bibliography was prepared for the U. S. Army Coastal Engineering Research Center as background material for the planning of future projects related to the transport around Point Conception, California, of sand labeled with radioisotopes. The list deals with the tracing of mass transport in rivers and along coastlines by such means.

The criterion for the sources was that they provide information on techniques for tagging sands and sediments with radioactivity. However, some of the sources may not be relevant because they were selected on the basis of incomplete information. Most of them were available only as abstracts or as references in related literature. Because of this restricted availability of many of the original sources (progress reports, journals with limited circulation, etc.), citations of abstracts, etc., are included in addition to those of the original sources. Thus the user of this bibliography has more information upon which to decide whether the original source would satisfy a specific need. The unavailability of the original literature and the effort to include as much information as was available in each case have led to a non-standard format in the final presentation.

SOURCES

The main sources of information were *Chemical Abstracts* from 1 January 1937 (vol. 31) through 30 June 1967 (vol. 66) and *Nuclear Science Abstracts* from 1 January 1948 through 30 June 1967. The monography by Ingle, *The Movement of Beach Sand: An Analysis Using Fluorescent Grains*, (Ref. 41) was also a rich source of material. The year 1937, that of the earliest *Chemical Abstracts* surveyed, is significant only in that the 4th Decennial Index of *Chemical Abstracts* encompasses the period 1937-46. The year 1946 is significant in that it is the year in which radioisotopes became available on a large scale. It is doubtful that any significant work related to sand-tagging with radioactivity was performed prior to this time.

Key or index words under which information in *Chemical Abstracts* was sought were: (1) isotopes and (2) sand. The indexes of volumes 64 and 65 were not available at the time the literature search was made. For these years all titles under the following sections were checked:

(1) Nuclear Phenomena
(2) Nuclear Technology
(3) Apparatus, Plant Equipment and Unit Operations and Processes
(4) Ceramics
(5) Mineralogical and Geological Chemistry
(6) Petroleum, Petroleum Derivatives and Related Products.

The following key items were checked in *Nuclear Science Abstracts:*

(1) oceanography
(2) radioisotopes
(3) sand
(4) tracer techniques (general, engineering, geology, hydrology, and oceanography).

All references derived from Ingle's monograph are indicated by the notation "Reference 41."

Some ninety-four citations are included in the bibliography. Citations 1 through 87 are arranged alphabetically in order of the senior author's names. It was not possible to obtain the titles of citations 88 through 91, and these are presented as a separate group. Citations 92 through 94 are given without authors, having been obtained from secondary sources (as references in other citations).

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APPENDIX B

Towing Characteristics of an Underwater Radiation Detector Vehicle

(USNSRDC)

NOTE: This report represents an independent study and the results of an investigation generated by the objectives of the RIST study.

TOWING CHARACTERISTICS OF AN UNDERWATER RADIATION DETECTOR VEHICLE

INTRODUCTION

Appendix B is a report of an investigation to evaluate the required hydrodynamic performance of the detector vehicle. The investigation was made for the Coastal Engineering Research Center (CERC) by the Naval Ship Research and Development Center (NSRDC). The program included towing the vehicle at speeds up to 6 knots in three modes as follows: (a) in a suspended attitude, (b) in a survey attitude (rolling on basin floor), and (c) using various cable lengths with additional weight on the vehicle. The cable tension, cable angle, and tracking attitude were observed for each towing mode.

This report contains a description of the detector vehicle and test procedures, presents the results of the towing tests and observations of the vehicle towing attitude, gives predictions of the cable configurations assumed by the towcable, and makes recommendations for modifications.

DESCRIPTION OF VEHICLE

The detector vehicle furnished by CERC to NSRDC for the tests is shown in Figure B-1. The vehicle, designed to roll along the bottom in its survey attitude, consists of a cylindrical housing made of expanded metal reinforced on its rolling surface with stainless steel rods. The detection mechanism and electronics assembly, which is pendulous, is attached to a shaft through the housing that provides protection for the assembly. A tow bail is attached at each end of the shaft and provides for a single-point towcable attachment. The electrical cables for the detection equipment exit from one end of the shaft, are attached along the tow bail to the towcable attachment, and then are married to a 1/4-inch-diameter wire rope towcable. Physical characteristics of the detector are listed in Table B-I.

TABLE B-I

Physical Characteristics of Detector Vehicle and Towcable

Overall width, inches	50
Overall diameter, inches	30
Housing width, inches	42
Height, inches	30
Distance from center shaft to towpoint, inches	32
Model weight in air, pounds	505
Model weight in fresh water, pounds	410
Towcable weight per foot in air, pounds	0.6
Towcable weight per foot in fresh water, pounds	0.4

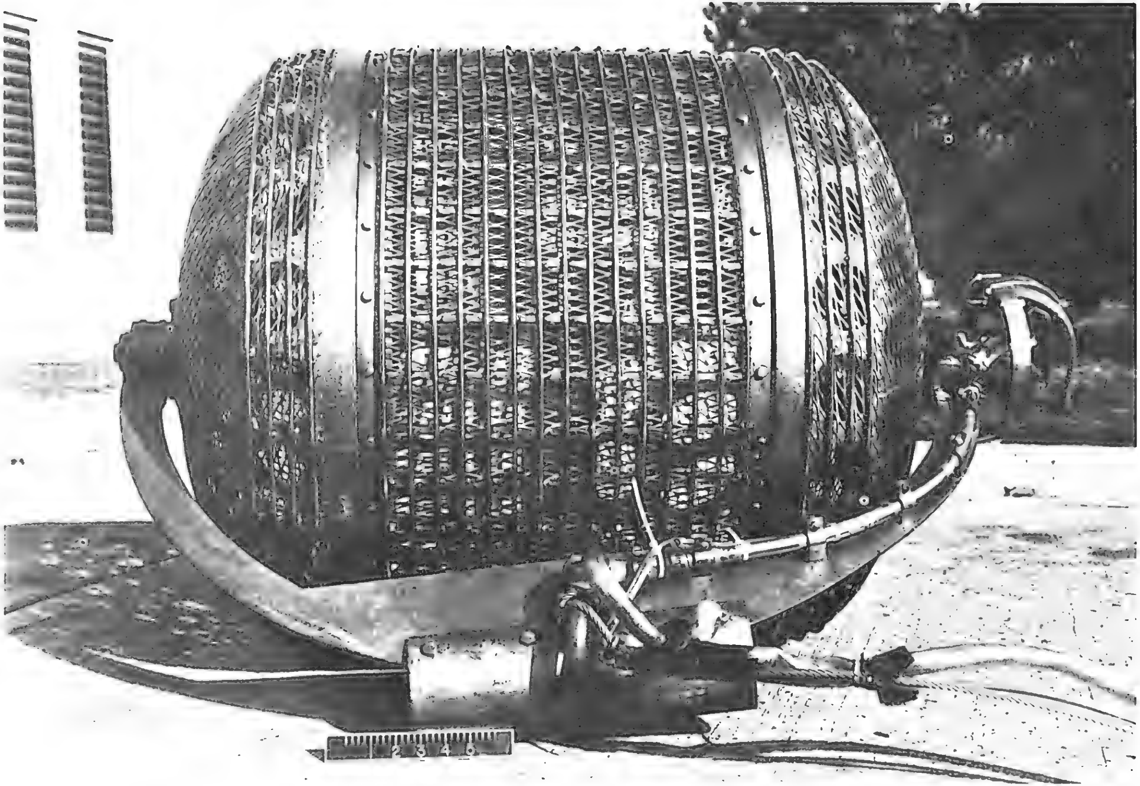


Figure B-1. Radiation - Detector Vehicle

TEST APPARATUS AND PROCEDURES

The towing tests were conducted in the high-speed basin of the David Taylor Model Basin. Instrumentation used for the tests consisted of a pendulum angle indicator mounted to the tow bail to measure its angular attitude, a 1200-pound-capacity tension gage to measure tension in the towcable at the detector vehicle, and a pendulum angle indicator to measure the towcable angle at the point where the towcable was attached to the towing carriage. The tension gage was connected between the body and the towcable, and the signal leads from both the angle indicator and tension gage were married to the towcable and connected to a strip chart recorder on the carriage.

For the first series of tests, the detector vehicle was towed in the suspended mode on a 12.5-foot length of cable in the deepwater portion of the basin at speeds from 0 to 6 knots in 1-knot increments. The tension in the towcable at the detector and the angular attitudes of the towcable both at the detector and at the towing carriage were measured, and the towing behavior of the detector vehicle was observed.

In tests to determine the tracking behavior of the detector and the maximum towing speed for the detector to remain in a survey attitude (on the bottom), the detector was towed on cable lengths of 12.5, 25, and 50 feet of cable at speeds up to 6 knots. The angle and tension values were monitored for each speed and cable length while observations were made of the tracking and lift-off behavior. These tests were made in the shallow-water portion (10 feet deep) of the high-speed basin.

In the tests to determine the effect additional weight has on the tracking behavior and maximum survey speed, approximately 100 pounds of sheet lead were added around the detector mechanism. The detector vehicle was towed on 12.5 and 25 feet of cable at speeds up to 6 knots in the shallow portion of the high-speed basin. The angular attitude and towcable tensions were monitored for each speed and cable length, and observations were made of the vehicle towing and tracking behavior.

TOWING BEHAVIOR

The detector vehicle, in the suspended mode, towed steadily at each speed up to 6 knots. There were no apparent oscillations, and the vehicle towed directly aft of the towpoint with no yawing attitude. When the vehicle was in its survey attitude on the 12.5-, 25-, and 50-foot cable lengths, it tracked directly aft of the towpoint with no yaw. The expanded metal housing rolled along the bottom for all speeds up to about 3.5 knots on the 12.5-foot cable, about 4.0 knots on the 25-foot cable, and about 4.5 knots on the 50-foot cable. When the vehicle lost contact with the bottom, it would cease to rotate. The addition of approximately 100 pounds of weight in the vehicle did not produce the desired increase in rolling speed (speed at which the vehicle would leave the bottom) but had no adverse effects on the tracking behavior.

TOWCABLE TENSIONS AND ANGLES

The cable tensions measured at the detector vehicle as a function of speed are shown in Figure B-2 for the vehicle in the suspended condition on 12.5 feet of cable and in the survey condition of 12.5, 25, and 50 feet of cable. As shown by the figure, the tensions for the survey condition are less than the tensions for the suspended condition for all speeds less than 3.4 knots for the 12.5-foot cable, 4.0 knots for the 25-foot cable and 4.3 knots for the 50-foot cable. When the tension in the survey condition equaled the tensions in suspended condition, the vehicle lost contact with the bottom. This was substantiated by observations made during the tests. However, there occurred in the suspended condition a tension difference for each speed as a function of towcable length. This difference is attributed to an increase in vehicle drag due to proximity of the vehicle to the bottom of the basin.

The cable angle at the detector vehicle and at the towing carriage are shown in Figure B-3 for the suspended condition. The cable angles obtained when the vehicle was towed in the survey condition are not shown since they are of no practical value.

PREDICTION TECHNIQUE AND CONFIGURATIONS

Cable configurations were predicted using the computer program described by Cuthill (1964). The program is based on the theory of Pode (1951) and the following conditions and assumptions:

1. All calculations are for standard sea conditions (45° North Latitude, 3.5 percent salinity, and 59° Fahrenheit.
2. A mean cable diameter of 1.0 inch is used for the cable. The towcable consists of two bundles of electrical conductors and a 0.25-inch-diameter wire rope.
3. The weight of the cable per unit length in water is 0.4 pounds per foot.
4. The drag coefficient for the cable when perpendicular to the stream is 3.0. The assumed coefficient is based on iterative calculations to fit computed angle predictions to the measured cable angle data. The coefficient is higher than that used for single cables, but this can be expected because of the multi-cylindrical shapes in close proximity to each other and because of the vibrations associated with unfaired towcables.
5. The ratio of drag per unit length of cable when parallel to the stream to the drag per unit length of cable when perpendicular to the stream is 0.02.

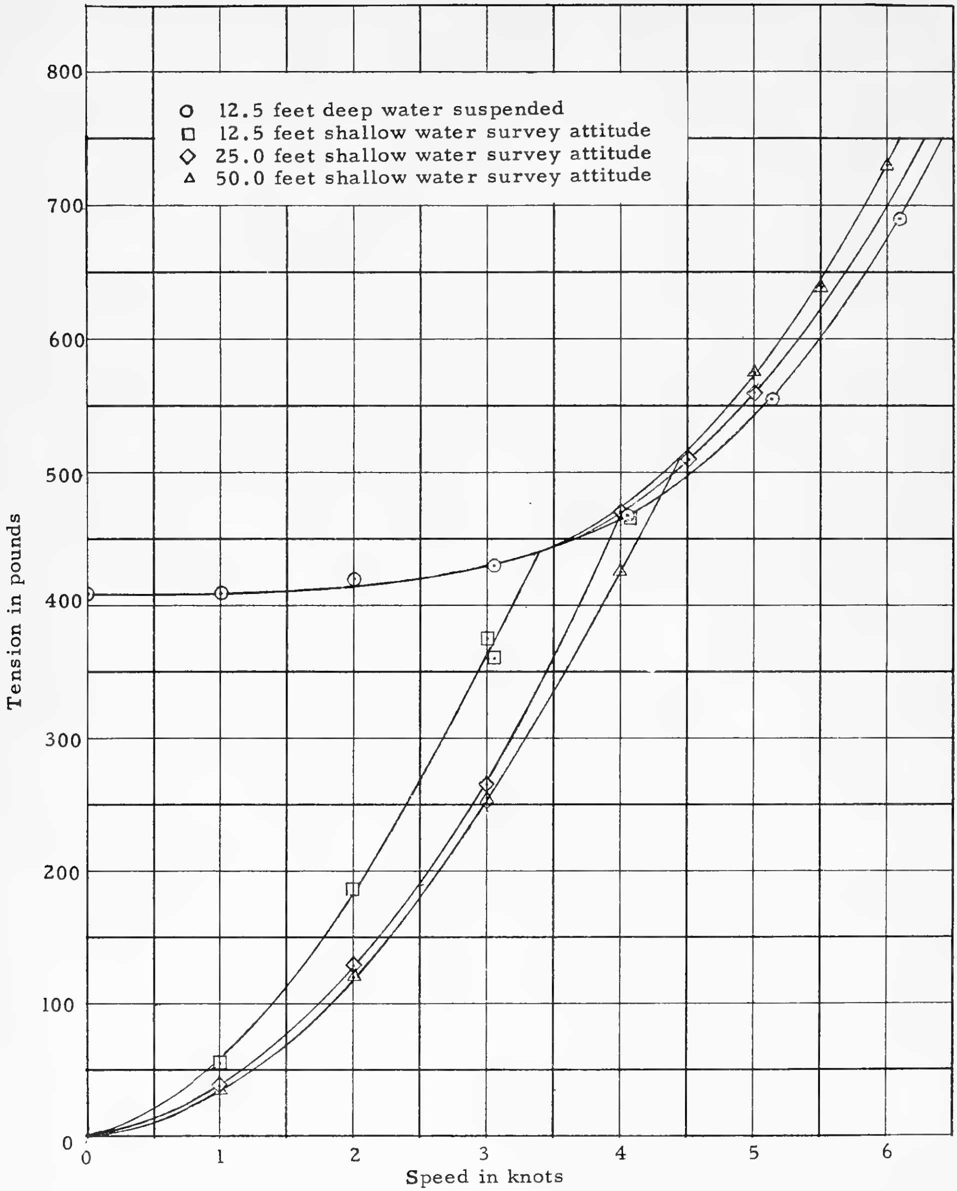


Figure B-2. Cable Tension at the Detector Vehicle (Data are for conditions without 100-pound added weight)

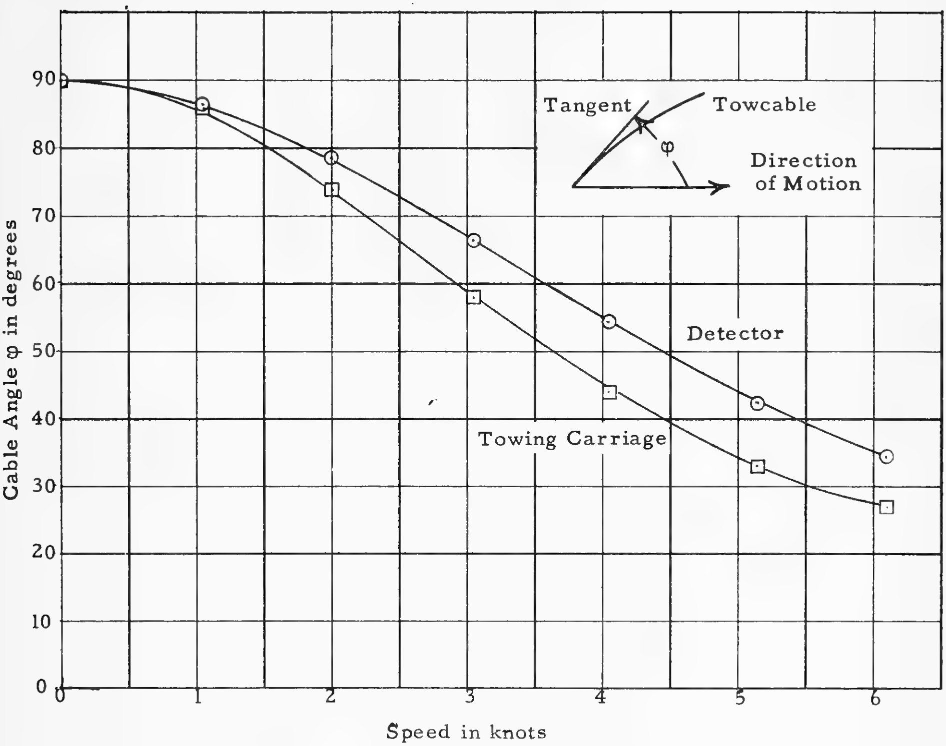


Figure B-3. Cable Angles at Detector and Towing Carriage for the 12.5-foot Cable

The computations were made for speeds from 1 to 6 knots and cable lengths up to 240 feet. The resulting predictions are presented in Figure B-4 as depth of detector as a function of cable length in the water for speeds of 1 to 6 knots and in Figure B-5 as tension at the ship as a function of cable length in the water.

Figure B-4 may be used as a guide to determine the minimum amount of cable that must be used to reach a desired depth for a particular survey speed. Figure B-5 may be used as a guide to determine the strength of cable required for a particular survey speed.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the towing tests, the following are concluded:

1. The detector vehicle has good tracking characteristics for all speeds up to 6 knots.
2. The detector housing will not rotate unless in contact with the bottom.
3. At the design survey speed of 4 knots and a cable scope of 200 feet, the detector will maintain bottom contact in water depths down to 80 feet. At an increased speed of 6 knots, contact is maintained at depths down to 55 feet.
4. The addition of approximately 100 pounds of weight will neither effectively increase the bottom contact capability nor impair the tracking characterisitcs of the vehicle.

In using the CERC towcable during survey operations, one obvious modification is recommended. The present towcable, consisting of a 1/4-inch wire rope and two plastic tubes containing the electrical leads, should be replaced by an electro-mechanical towcable. This modified cable might be constructed of two reverse lays of steel wire wrapped around a core containing the necessary electrical conductors. This arrangement should simplify handling, reduce the drag on the towcable, increase the depth capability for a shorter length of cable, and make the electrical bundles less susceptible to wear.

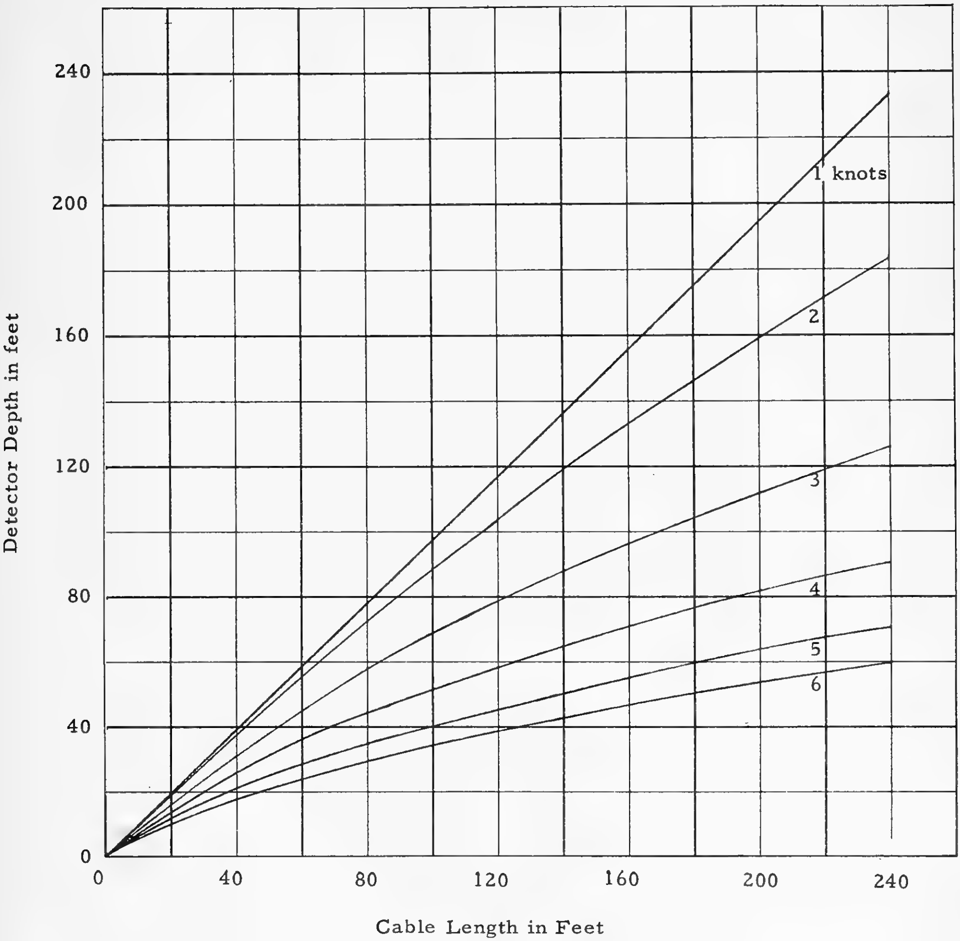


Figure B-4. Minimum Required Cable Length as a Function of Detector Depth for Various Speeds

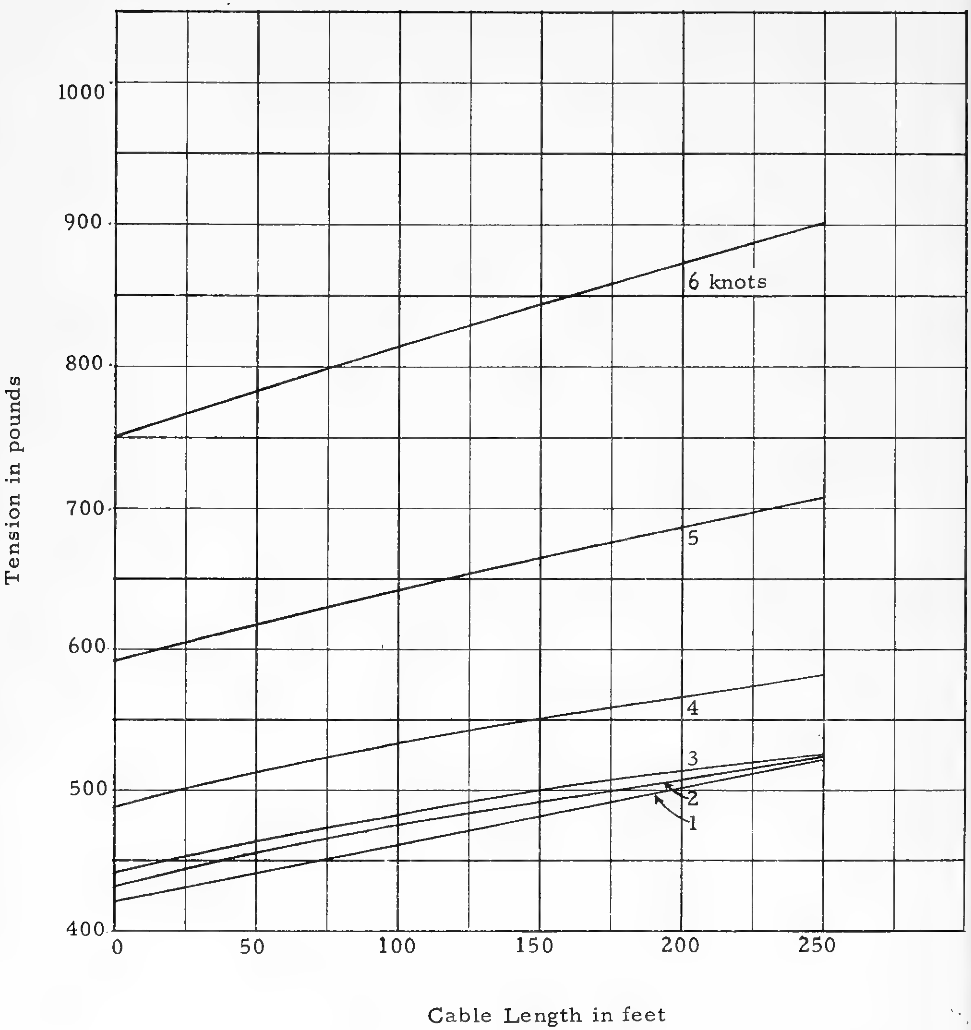


Figure B-5. Tension at Towing Ship as a Function of Cable Cable Length for Various Speeds

APPENDIX C

RIST STATUS REPORT

by

ISOTOPES DEVELOPMENT CENTER

OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENNESSEE
Operated by UNION CARBIDE CORPORATION for the
U. S. ATOMIC ENERGY COMMISSION

Contract No. W-7405-eng-26 ORNL-4341

RADIOISOTOPIC SAND TRACER STUDY (RIST)
STATUS REPORT FOR MAY 1966 - APRIL 1968

E. H. Acree, H. R. Brashear, F. N. Case, and N. H. Cutshall

ABSTRACT

The Radioisotopic Sand Tracer Study (RIST) was initiated in May 1966 as a multiagency cooperative effort to develop technology and survey equipment for sediment transport studies with the objective of determining direction and amount of sand movement. To prove the system effective a test was planned to determine how sand moves around a headland where a change in beach direction occurs on either side of the headland. The first two years of the work done at ORNL consisted primarily in developing equipment and techniques for studying sand transport in the littoral zone. Field operations to evaluate the equipment and to develop more effective procedures were conducted at Cape Kennedy, Florida, at Surf, California, and at Point Conception, California. In these tests sand tagged with ^{133}Xe was released on the ocean floor in the study area at a depth of 30 ft. The dispersion and transport of the labeled sand were observed with cesium iodide detectors contained in a specially designed detector transport vehicle (ORNL Underwater Survey System). The detector assembly was towed through the ocean by an amphibious vessel. Charts of the isoactivity contours were prepared from some of the data to estimate direction and velocity of sand transport.

INTRODUCTION

The Radioisotopic Sand Tracer Study (RIST) was initiated in May 1966, and the work reported here covers a two-year period. The study is continuing and as additional field tests are made, the data will be reported. The program objective was to develop technology and survey equipment to obtain data from a dynamic system that could be used to obtain a reasonably accurate description of sediment transport in the littoral zone. These techniques, when fully developed, are expected to find use in other sediment transport systems involving waterways and inland lakes.

The specific requirements to accomplish this development were to

1. develop a survey system that can be reliably operated in the field and have a high degree of versatility relative to environmental variables and choice of radionuclides,
2. evaluate various radionuclides to determine those that are useful in sediment transport experiments from the standpoint of cost, physical properties, availability, and hazard,
3. demonstrate the utility of the system under field conditions,
4. develop a technique for determination of sand burial,
5. develop suitable tagging procedures for radionuclides considered to be useful in sediment transport studies,
6. correlate sand transport with wave and current variables.

The multiagency study, involving the U. S. Atomic Energy Commission, Department of the Army, Department of the Navy, Department of the Air Force, National Aeronautics and Space Administration, and the State of California, receives technical support from the Oak Ridge National Laboratory and the Coastal Engineering Research Center, with direct assistance from the Pacific Missile Range, Western Test Range, First Strategic Aerospace Division, Corps of Engineers for Los Angeles District, Nuclear Systems and Space Power Division, and Department of Water Resources. Overall direction of the project rests with the Corps of Engineers Coastal Engineering Research Center. The Isotopes Development Center has been responsible for

1. designing, fabricating, and testing of a submersible detection system and appropriate analyzer system,
2. assisting in the selection of applicable radioisotopes,
3. developing processes for labeling sand with radionuclides,
4. developing a radiological safety program.

During this two-year period the major effort was directed toward development of equipment and techniques for studying sediment transport in the littoral zone (from shore line to water depths of 30 to 50 ft). Three field tests were conducted to evaluate equipment performance and the effectiveness of measuring and recording procedures: one at Cape Kennedy, Florida, one at Surf, California, and one at Point Conception, California. Instruments and methods were modified after each operation. In order to show the rationale of the development of survey instruments and techniques, the field tests are reported in chronological order.

Several methods have been used to study sand movements. Fluorescent dyes tagged onto sand grains have been used extensively, and most of the information concerning sediment transport has been obtained with this method. There are, however, fundamental difficulties that limit the utility of fluorescent tags in obtaining meaningful data from dynamic systems such as the ocean. Perhaps the most serious are the limited number of samples that can be obtained after injection of the tagged sand and the inability to predict sampling points.

Naturally occurring minerals have been utilized as indicators of sand transport; however, unless the source of the mineral is well defined and known to be the exclusive source, the data obtained are often misleading. With radioisotope tracers, which have been used to a lesser extent, useful studies of sand transport have been made in laboratory flumes and wave basins, but definitive information can come only from field tests (See Addendum C-1)

Field testing is divided into three major efforts: preparing and dispensing the tracer in a test area, which are discussed elsewhere, surveying the test area, and treating the data. Both radioactive and fluorescent tracing systems have common problems relative to data treatment. Radioisotope tracing does, however, offer considerable advantage over the fluorescent tracing during sampling since in situ measurements are made and a large number of data points can be obtained. In addition, readout data are available to assist in the determination of sample points, and thus one is able to follow the progress of the transport system on a real-time basis. A number of radionuclides were considered for use in sediment transport studies, and the half-life, energy of the radiation, biological hazard, and tagging method specific to various elements were evaluated. While no single radionuclide was found to meet all the requirements that would make it ideal for all tracing experiments, primary consideration was given to those radioisotopes that have a low biological hazard. This characteristic was especially important during the early phases of the field testing when data could be collected to serve as a basis for determining the concentration or dilution of tagged sand that may occur during tracing studies. Also, radiation exposure to be expected could be determined. Such data could then be used to determine hazards associated with the use of other radionuclides in tagging sediment.

After tagged sand has been placed in the ocean, as a point source or as a line source, surveys are made to determine transport. This is done either by collecting grab samples and taking them to a laboratory for counting or by making the measurements on the ocean floor. Since the in situ measurement yields data rapidly, it was considered to be the more promising method for gathering information for littoral transport studies.

Selecting the Radioisotope

Some of the nuclear properties considered in selecting the radioisotope for further evaluation were half-life, type of radiation, and radiation energy.

Neutron-deficient radioisotopes, because of their low production yields, and radioisotopes with half-lives of less than 2 days or greater than 15 days were arbitrarily excluded. Table C-1 presents some of the data that were used for making the initial selection. Three of the radioisotopes, ^{140}Ba-^{140}La, ^{198}Au, and ^{133}Xe, were of special interest because of their nuclear properties.

Table C-1. Comparative Data on Radioisotopes

Isotope	Half-Life, days	Principal Gamma Radiation,[a] MeV	Maximum Permissible Burden[b] (Man), μCi	Comparative Uptake (Fish), relative units
^{131}Ba	12	0.496 (48%) 0.124 (28%)	50	3
^{140}Ba-^{140}La	12.8	1.596 (96%)	4	3
^{131}I	8.05	0.364 (82%)	0.7	2
^{111}Ag	7.5	0.247 (1%) 0.342 (6%)	20	1
^{133}Xe	5.2	0.081 (37%)	c	0
^{198}Au	2.7	0.412 (95%)	30	1

[a] C. M. Lederer, J. M. Holland, and I. Perlman, Table of Isotopes, 6th ed., Wiley, New York, 1967.
[b] Handbook No. 69, U. S. Dept. of Commerce, National Bureau of Standards, July 5, 1959.
[c] No retention.

Barium-140—lanthanum-140 had been used for sand tracing, and techniques for tagging sand had been developed by the Naval Radiological Defense Laboratory. However, this radionuclide has two disadvantages: (1) The excessively high energy gamma rays (1.6 MeV) make handling and radiation exposure control difficult. (2) Tagging sand with ^{140}Ba-^{140}La consists of coating the surface of the sand grains with sodium silicate containing the radionuclide, and initially it was not known whether or not this would affect the hydraulic properties of the sand (later experiments indicated that little, if any, adverse effect resulted from this labeling technique).

Gold-198 has also been used on various projects, but the evaluation of the ^{198}Au-labeled materials has been very limited. Leaching rates, efficiency of tagging, and actual labeling procedures are not described in detail. Also, it was believed that the half-life of this nuclide (2.7 d) would limit tracing experiments to one week or less. However, ^{198}Au was maintained high on the list of useful isotopes since it can be prepared in large quantities at a relatively low cost and the biological hazard is low (Table C-2). (In a later study, which will be reported separately, it

Table C-2. Comparison of Properties of Several Radionuclides for Use in Sand Tagging

	Xenon-133	Krypton	Gold-198-199	Chromium-51
Half-life	5.2 d	10.27 y	^{198}Au: 2.7 d ^{19} Au: 3.14 d	27.8 d
Useful radiation and yield	0.081-MeV gamma; 100%	0.5-MeV gamma; 0.37%	^{198}Au: 0.4; 100% ^{199}Au: 0.15;100%	0.32-MeV gamma; 8%
Detection efficiency, 2-in. sodium iodide crystal, through 1 in. H_2O normalized to ^{133}Xe	1	0.06	8	0.6
Efficiency of tagging method relative to useful gamma output using 1000-Ci radionuclide feed in tagging procedure	1 Ci/40 liters of sand	0.0036 Ci/40 liters of sand	800 Ci/liter of sand; no limit on size of sand batch	64 Ci/liter of sand; no limit on size of sand batch
Use characteristics	Biologically inert; excellent for ~2-week experiment; no dispensing problem	Biologically inert; potential hazard due to long half-life; minor dispensing problems	Relatively biologically inert; excellent for 1-week experiments; dispensing problem	Concentrated in biological systems; moderate hazard 30-60 days; dispensing problem
Availability	Adequate	Adequate	Unlimited	Adequate

was found that under the influence of high waves the transport of sediment is rapid and that useful data can be obtained within the time available before decay of the radionuclide seriously reduces the radiation available for detection.)

Because ^{133}Xe is biologically inert and has a half-life of 5.27 d, it met most of our criteria for sand-tracing experiments. However, the low-energy (80-keV) gamma radiation required that the detector system have a high degree of sensitivity and imposed the limitation that only tagged sand moving at or near the surface of a sand column could be detected. On the other hand, the use of low-energy gamma radiation reduced the handling and dispensing problems as far as radiation exposure to personnel is concerned. Tagging procedures were developed (Addendum C-1) to adsorb ^{133}Xe onto sand.

Evaluation of ^{133}Xe-Tagged Sand

Since sand tagged with a rare gas loses activity, due to diffusion as well as to decay of the ^{133}Xe ($T_{1/2}$ = 5.27 d), data derived through use of ^{133}Xe-tagged sand must be corrected to an "effective half-life." Test samples prepared by the foregoing procedure were counted over a period of several days and there was little incremental loss (over decay) (Fig. C-1) Experiments also showed that no loss of activity could be attributed to leaching by seawater (Table C-3). In a test of labeling uniformity, random quantities of tagged sand were counted and compared on the basis of the quantity of sorbed ^{133}Xe versus the quantity of sand (Table C-4). Although the uniformity was fair, the radiation counts from the samples varied from high to low by a factor of 3.

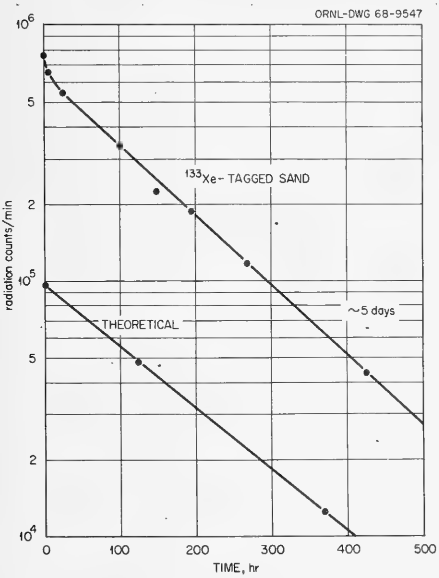


Fig. C-1. Apparent Half-Life of ^{133}Xe-Tagged Sand

Subsequent tests have shown that specific minerals in sand do not tag with the same efficiency. This causes the individual sand grains to vary with respect to the quantity of ^{133}Xe that is adsorbed.

Samples were also tagged, separated into particle-size fractions, weighed, and counted to determine whether those fractions making up the bulk of the sand contained the bulk of the ^{133}Xe. As shown in Fig. C-2, the correlation between size distribution and xenon sorption is good. The slight tailing off of the large particles is probably due to specific minerals that tend to concentrate in the large-particle fractions.

Table C-3. Seawater Leach Test on ^{133}Xe-Tagged Sand

Leach Time, hr	Activity, counts/min Control	Activity, counts/min Test	Ratio, control/test
		Test No. 1	
Beginning	0.9×10^5	1.47×10^5	0.67
72	0.58×10^5	0.89×10^5	0.65
96	0.53×10^5	0.79×10^5	0.67
		Test No. 2	
Beginning	4.2×10^4	3.4×10^4	1.3
48	2.7×10^4	3.2×10^4	1.2
120	1.3×10^4	1.1×10^4	1.2
		Test No. 3	
Beginning	3.9×10^4	3.7×10^4	1.1
48	2.5×10^4	2.2×10^4	1.1
120	1.2×10^4	1.1×10^4	1.1

Table C-4. Uniformity Test on ^{133}Xe-Tagged Sand

Sample	Weight of Sand, mg	Activity: Counts per sec[a]	Activity: Counts per mg of sand
1	71.7	1634	1140
2	52.8	1746	1650
3	96.9	1108	570
4	24.3	534	1100
5	62.3	1774	1400
6	51.7	1334	1290
7	43.6	670	770
8	55.0	1430	1300
9	42.4	1512	1780
10	53.1	648	610

[a] Based on total counts for 50-sec period.

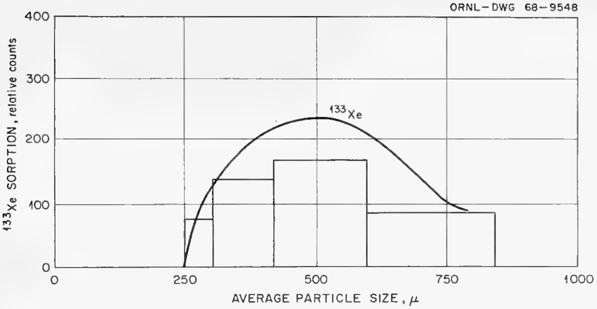


Fig. C-2. ^{133}Xe Sorption vs Particle-Size Distribution

ORNL UNDERWATER SURVEY SYSTEM

Since most of the surveying required to measure the dispersion and transport of tagged sand occurs in the surf zone, the detector system was designed to operate in breakers as well as in deep water. Sleds have been used as vehicles for transporting detectors along the bottom. Because sleds are easily tipped in turbulent water and are subject to snagging on underwater obstruction such as rock ledges and large rocks, an open mesh steel ball was designed for use as the detector vehicle (Fig. C-3). This

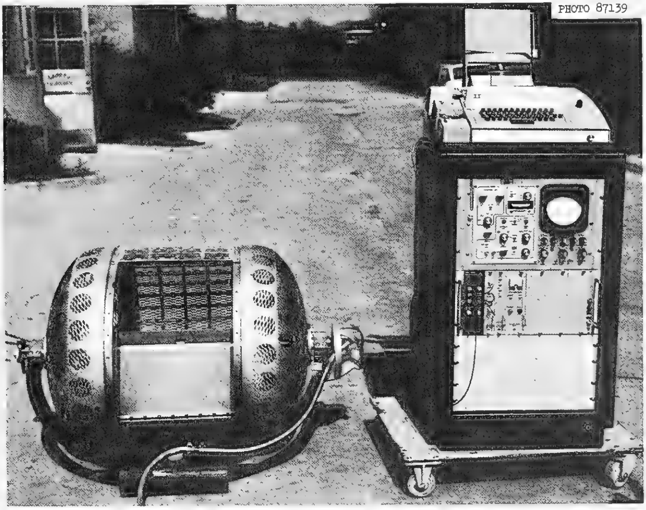


Fig. C-3. Radiation Detection System

ball contains the radiation detectors and is towed behind an amphibious vessel on a 150-ft-long cable. Operating characteristics were found to be excellent in very rough surf and moderatly rocky bottom conditions. While the detector ball is unaffected by heavy surf, early surveys parallel to the beach were limited by the ability of the tow vessel to operate broadside to the breakers. Survey tracks were made from ~45° to 90° to the beach face to overcome this problem.

The radiation measuring equipment shown in Fig.C-3 is an underwater mobile system that can be rolled along the ocean floor, efficiently detect the 80-keV gamma rays from ^{133}Xe, and operate on the beach, in the surf zone, and in the ocean to depths of 200 ft.

Detector System

The detector system consists of four 2- by 2-in. sodium-activated cesium iodide crystals housed in 0.030-in.-thick anodized aluminum cans. These cans are mounted in a 1/2-in.-thick stainless steel plate that forms the bottom section of a sealed chamber attached to the axle of the ball. As the ball rotates on the stationary axle, the detectors remain oriented toward the surface over which the ball moves. Since the canned crystals are exposed to the water pressure, a 1/2-in.-thick Plexiglas light pipe is used as a pressure barrier (see Fig.C-4.) Photomultiplier tubes and preamplifiers are mounted in the detector chamber and are thus protected from the water and pressure.

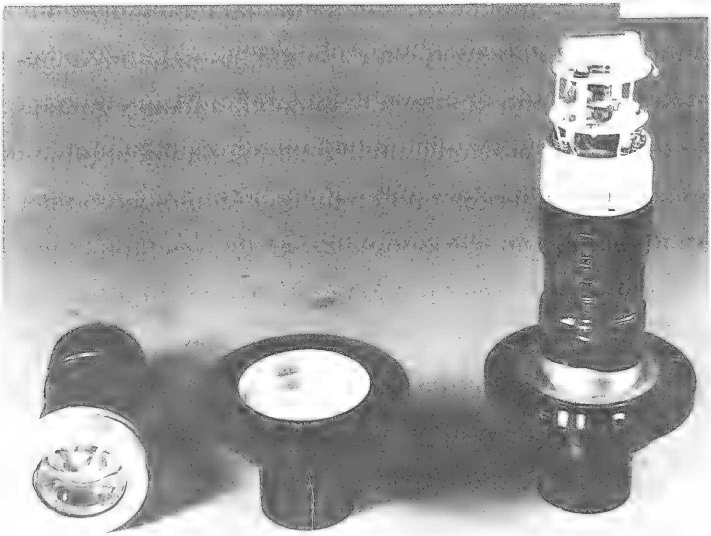


Fig. C-4. Underwater Detector Component

The photomultiplier tubes (RCA-6655A) operate with a negative voltage of 700 to 900 V. This 200-V range permits gain adjustment of the tubes so that the responses from all four of the detectors will be equal. The tubes are 2 in. in diameter and have ten stages. The preamplifiers (one for each tube) consist of three emitter-followers in cascade. The preamplifier output is matched in a 50-ohm coaxial cable (RG-174-u) which carries both the positive 24-V dc power to the preamplifiers and the output voltage pulses from the preamplifiers. These pulses are transmitted to a mixer on board the tow vessel. The single output pulse from the mixer is fed to the amplifier of the multichannel analyzer (PIP-400).

The sides of the cylinder used to transport the detector assembly are fabricated with rectangular steel bars to form an open lattice with a minimum of shielding of the detector crystals. This allows the 80-keV gamma and a fraction of the 30-keV x-ray from ^{133}Xe to reach the detectors, which are positioned approximately 2 in. from the surface over which the cylindrical ball travels. The entire device is covered with expanded metal to exclude stones and other debris and to provide mechanical protection (Addendum C-4).

The detector housing is weighted with lead to maintain the detectors in a vertical position (see Addendum C-5 for description of the device that indicates the position of the detector assembly). At a speed of 3 mph, however, the forward motion of the rolling device causes the detector housing to be ~5° off-center toward the back. Since the count rates are a direct function of geometry, an experiment was designed to determine the difference between the count rates obtained when the detector housing was in the vertical position and when it was off-center. The following results were obtained for three variations from vertical:

0°	910 counts/sec
5°	880 counts/sec
10°	800 counts/sec

The difference of 30 counts/sec or ~3% for an angle of 5° (normal operating angle) indicates that the count rate is not appreciably affected by an off-center movement of the detector housing.

The towing characteristics of the detector assembly were determined by the Naval Ship Research and Development Center, Tests proved that with a tow cable 200 ft long the detector assembly was stable and remained on the bottom at a depth of up to 80 ft at a speed of up to 6.7 fps. Changing the length of the cable will modify the speed at which the assembly can be towed and still remain on the bottom. It was also established that the assembly would remain in the survey position (detectors pointed toward the bottom) even when it was pulled rapidly through the water column. However, the tow cable and the plastic tube containing the conductor cables oscillated, and it was evident that the conductor cables would be damaged if they were towed rapidly through the water for long periods of time.

Data Collection System

Individual signals from the four detectors are fed through cables to the surface vessel and into a mixer. A differential discriminator sorts the proper signals and feeds a multichannel analyzer (PIP-400) (see Fig.C-3) that can operate in a pulse-height mode or in a multiscaler mode (normal operating mode for survey is the multiscaler). This system stores counts from the detector for a time set by the operator. The possible accumulation times are 10, 1, 0.1, and 0.01 sec. The information can be displayed on an oscilloscope, typed out on a teletype unit, or punched on a tape.

In the multiscaler mode the analyzer operates as 400 individual counters. A counter stores the signals from the detectors for the time set by the operator. The analyzer automatically changes from counter to counter according to the preset time intervals. With a data accumulation time of 10 sec, an uninterrupted survey can be conducted for 4000 sec, or approximately 65 min. At the end of the period the data must be typed and punched on tape, which requires approximately 4.5 min. With this system the starting time as well as the position coordinates must be logged. All data must be correlated with the time and position log.

CAPE KENNEDY FIELD OPERATION (APRIL 1967)

Purpose

The operation was conducted in the beach area adjacent to Cape Kennedy, Florida, and was the initial field trial for the ORNL Underwater Survey System. The major objective was to check the operating characteristics of the detector system and the towing characteristics of the cylindrical detector housing.

Operational Procedure

A 1.45-kg batch of sand that had been tagged with 30 mCi of ^{133}Xe by the techniques described in Addendum C-2 was used. Scuba divers placed the sand within a 3-ft-dia area at a water depth of 30 ft, approximately one-half mile off the Florida coast. The underwater detector was towed through the area by an amphibious vessel (LARC V). No navigation system was used, and no established search pattern was followed. The purpose was merely to determine whether the detectors could detect the ^{133}Xe-tagged sand that had been placed on the ocean bottom. Initial passes through the injection area showed no activity. The search was expanded, and the tagged sand was detected approximately 100 yards from its original injection area.

A device to inject 40-liter batches of sand onto the ocean bottom was tested for shipboard operation. Sand placed in a hopper was flushed from the hopper through a 1-in. hose that reached to the ocean bottom in about 30 ft of water. A pump with a flow rate of 12 gpm was used to supply salt water to the injection system, and no difficulty was experienced in transferring sand from the hopper to the bottom.

Observations

The underwater detector system appeared to be very stable in the surf zone, and broadside breakers had little effect on its tracking ability. The 80-keV gamma rays from the ^{133}Xe-tagged sand were detected with reasonable efficiency; counts in the tens of thousands per second were observed. The system was stable, and all detectors functioned properly. No malfunctions were observed in the sand-pumping device. The sea conditions were mild, with ocean swells ~1 ft high. The tagged sand appeared to be in patches that formed a pattern. Liberal interpretation (since the survey was very limited) of the data revealed a series of waves running perpendicular to the beach. No significance was placed on this interpretation in regard to sand transport mechanisms.

Alterations Indicated by Test

Since it was known that large rocks are located near the area selected for the next test (Surf, California), it was decided to utilize a weak link in the tow cable so that the link would break if the detector assembly became lodged in the rocks. Breaking of the link would allow additional tow cable to play out and thus give the LARC operator time to stop. Also, it was recognized that sea conditions would be less favorable at Point Conception, California (the last test), and plans were formulated to provide a metal cabin shelter for the instruments, as well as for housing all the on-board equipment, to afford some protection from ocean spray.

SURF FIELD OPERATION (JUNE 1967)

Purpose

The operation at Surf, California, was a full-scale sand-tracing experiment conducted in order to test all developmental components and to establish operational techniques for handling 58-kg quantities of tagged sand. This area was chosen because all access is controlled by the U. S. Air Force and because future requirements at Vandenberg Air Force Base indicate a need for additional information concerning sand transport in the area.

Operational Procedure

Considerable difficulty was experienced in making the first 116-kg injection. Tagged sand in the hopper of the injection device became wet with ocean spray and would not flow properly; therefore the sand was dumped into the water from the surface. Because of ocean currents this caused the sand to disperse over a large area, and only background radiation levels were detected. For the next injection the sand-pumping device was again used, but in a slightly different manner: the sand was pumped to the bottom in a water slurry. Here again, however, very little

^{133}Xe radiation was detected. These injections and the associated surveys were hampered by very large rocks. Therefore the third, and last, injection, which was placed on the ocean floor by scuba divers, was made in an area that was relatively free of rocks. This injection was successful, and surveys were made in the area for three consecutive days.

A radar navigation system was used in this survey. Navigational fixes were taken at 2-min intervals and the data were entered in a time log, as were the starting and stopping times of the analyzer. Recorded count levels were corrected for background and decay and then plotted.

Observations

The Surf operation established that ^{133}Xe-tagged sand can be traced for several days over relatively long distances. Charts of isoactivity contours (Fig.C-5)showed that the tagged sand from the last injection had been dispersed over an area approximately 600 by 1200 ft when surveillance ended (after 3 days). From all indications the batch could have been traced for a much longer period of time, perhaps up to ten days after release.

The detector system worked well. Tracking performance and towing stability were good; however, several changes in equipment and in operational procedures were indicated, such as better correlation of data. Analysis of the data showed areas that should have been covered more extensively and areas that required less coverage. Also, slight variations in the time log and in the recording of the starting and stopping times of the analyzer made it very difficult to analyze the data. Although some protection was afforded by a metal shelter available at the test site, it was evident that better protection would be required for the electronic instruments.

Alterations Indicated by Test

Following the Surf operation a system was designed and built to integrate and record location, time, and radiation data (see Fig. C-6). A real-time readout of typewritten and punched paper-tape records allowing instantaneous evaluation of results, as well as a more sophisticated analysis at a later time, was provided.

An instrument shelter was built (Fig. C-7)which incorporates enclosed motor generators and a complete forced-air handling system to keep the instruments dry. The instruments and the shelter are completely self-supporting.

Since it was recognized that the Point Conception area would be a very difficult area to survey because of extensive rock outcropping and severe surf conditions, backup equipment was built. A complete spare detector assembly was fabricated. The electronic equipment has been fabricated with enough flexibility to permit the interchanging of components. This feature ensures the accumulation of radiation data. For example, since each detector is an independent unit, one or all four can be operated at any given time. Two data-recording systems exist, and if the automatic data-correlation system should fail, data can be accumulated manually by using the multichannel analyzer.

ORNL-DWG 67-8504A

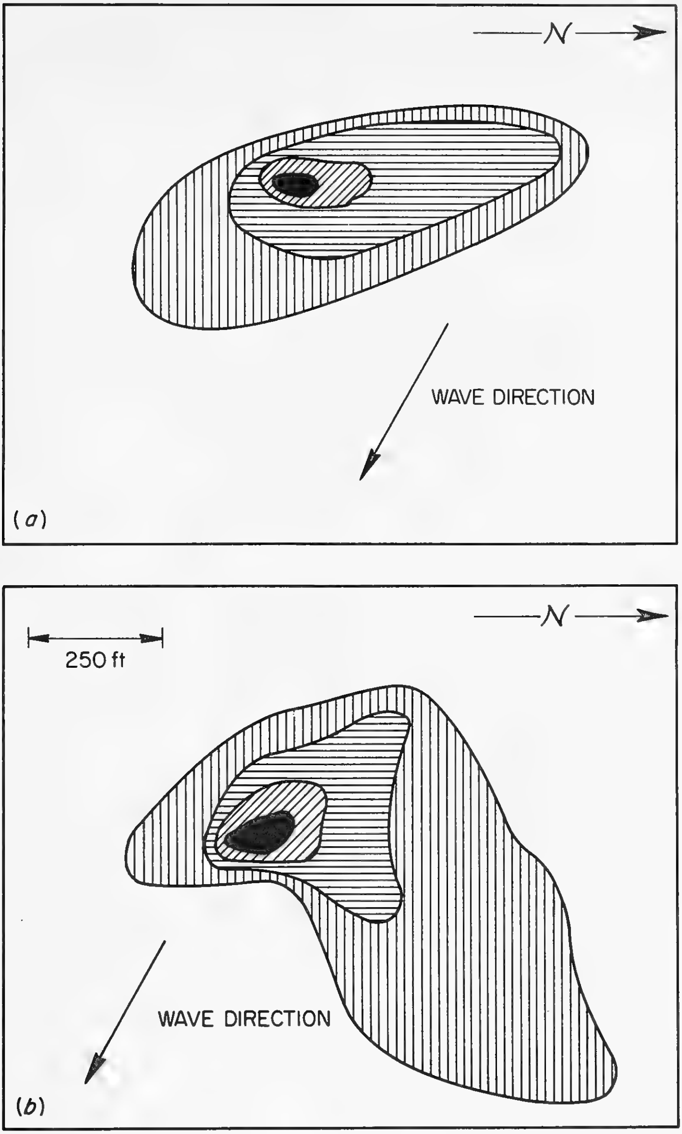


Figure C-5. Dispersion Pattern of ^{133}Xe-Tagged Sand. (a) 1 day after release of sand; (b) 2 days after release of sand.

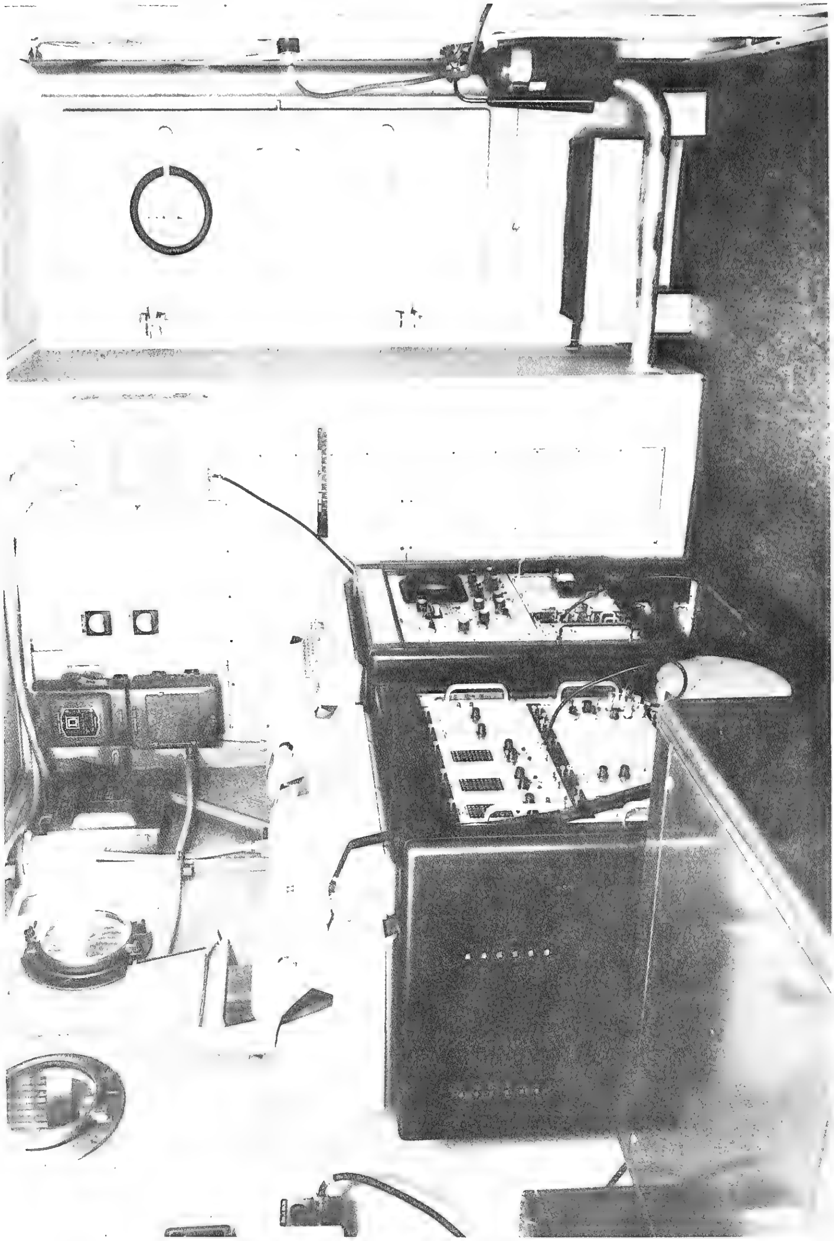


Figure C-6. Shipboard Data Collection System.

PHOTO 90192A

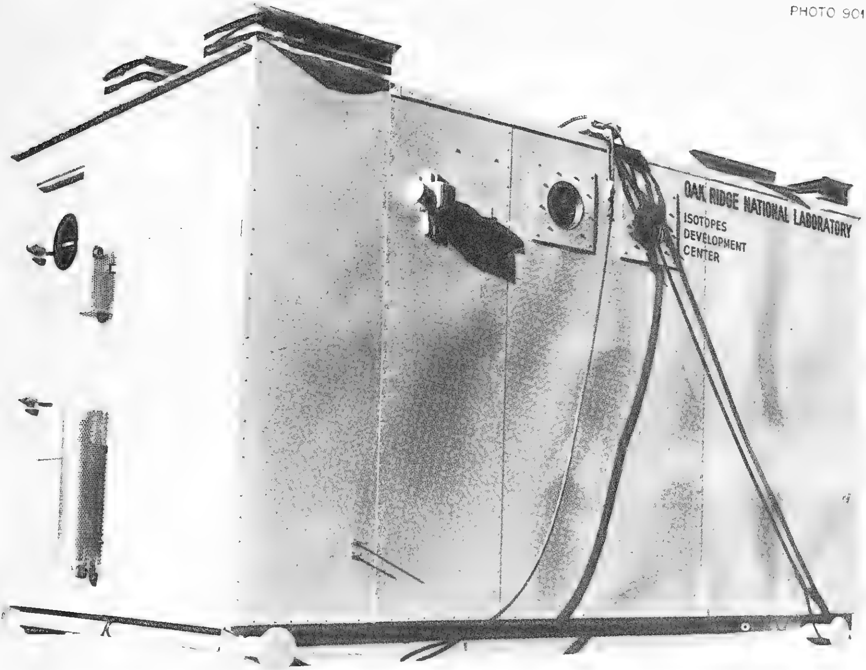


Figure C-7. Shelter for Shipboard Instrumentation.

A new sand-dispensing apparatus was built which operates on the clamshell principle (see Addendum C-6).

It was decided to make all future sand injections directly on the ocean floor, since even in shallow water sand released above the bottom spreads considerably before it settles to the bottom. Treatment of the data in this test indicates that the data should be manually plotted on board the survey vessel as they are collected. This is not considered to be an accurate display of data, but it will permit surveyors to change the survey pattern to yield maximum information.

POINT CONCEPTION FIELD OPERATION (DECEMBER 1967)

Purpose

The Point Conception experiment was designed to obtain information that could be used to answer the question: Does sand move around a headland (Point Conception)? By making three injections and determining the transport from one injection area to another, long-distance transport patterns could be determined in a relatively short time.

Operational Procedure

Injections were made at three locations: one northward of Point Conception, one on the Point, and one southward of the Point in ~30 ft of water. In each injection 40 liters of sand tagged with ~1.2 Ci of ^{133}Xe was used. The sand was placed on the bottom with the clamshell device, and surveys were made of all three sites by alternating from one site to the next.

The first injection was southward of the Point and all equipment functioned properly except the detectors, which required frequent calibration. This calibration problem was due to gain shift, which resulted from severe vibrations caused by pulling the equipment across large rock outcrops. These outcrops made surveying extremely difficult.

The second injection was made northward of the Point, and survey conditions proved to be even more severe than those of the first injection.

The third injection, which was delayed several times because of bad weather, was placed directly on the Point. Because of a large rock outcrop (~12 ft tall), the detector could not be pulled to the survey area from the beach but had to be lowered to the bottom from the survey vessel. This proved to be extremely difficult because the winch did not have adequate power to properly control the detector assembly, which weighs approximately 400 lb; however, the detector assembly was successfully placed on the bottom several times and surveys were accomplished.

A fourth batch, which consisted of only 1 liter of sand tagged with 200 mCi of ^{133}Xe, was placed in the breaker zone as a preliminary test to observe the dispersal rate that would be encountered in future tests planned for the surf zone.

Observations

All the injections were successful. The new data system worked well but the 10-sec collection period seemed to be too long. Rocks in the survey areas and the necessity of pulling the detector assembly from the beach to the area caused some difficulty with the detectors. Because of gain shift and noise, frequent adjustments were required, making it difficult to correlate radiation data on a day-to-day basis. Although survey areas were covered many times, very little radiation data were collected (see pages 59-65). Two explanations are possible: either the sand was buried or it was not transported. In the latter case, radiation detection would be obscured because it is virtually impossible to place the detector assembly directly on the injection point. In future tests an attempt will be made to determine which explanation is valid.

The preliminary test (fourth injection) for determining whether there would be any future problems associated with surf zone surveys went well. Initial conclusions are that the system can function in the surf zone.

Alterations Indicated by Test

Since sand transport is rapid in the surf area, the surveys need to be done in the shortest time period possible. Data will be useful only if the data collection period is short compared with the time required for the tracer pattern to develop. Our present accumulation period is 10 sec. Since the detector surveys a strip 2 ft wide, at a tow speed of 3 to 5 fps the radiation data are averaged over an area of 60 to 100 ft^2. We believe that this area is too large and are therefore modifying the system to print out every second. This will permit a larger survey in a much shorter time span. Models of experiments indicate that this survey time will be a definite improvement.

The photomultiplier tubes will be changed to high-shock-resistant tubes. An electromechanical cable will be purchased and adapted to the survey system. This cable will make it possible to use a power winch and drum to raise and lower the detector assembly. Slight modifications and additions will be made to accommodate multiple photopeaks.

ADDENDA C-1 to C-6

to

APPENDIX C

ADDENDUM C-1

Comparison of Tracing Methods

Fluorescent-Tagged Sand	Radioisotope-Tagged Sand	Stable-Tagged Sand Activation Analysis	Natural Minerals
Low cost; requires no special handling	Moderate to high cost; special handling and licensing	Moderate to high cost; requires no special handling	Low cost; requires no special handling
Sampling difficult; grab samples and limited numbers possible; no sample validity in field	Sampling easy; special equipment required; unlimited data potential; immediate indication of sample validity	Sampling difficult; grab samples, limited numbers; no sample validity in field	Sampling difficult; grab samples, limited numbers; characteristics of mineral may exhibit sorting and concentration not easily related to transport phenomena
Analysis required on individual samples; interference from natural background minerals	Analysis and sampling in situ	Analysis required; interference from natural background minerals	Analysis required on individual samples
Sampling slow, not possible to obtain good representation of dynamic system	Sampling fast; dynamic sampling in dynamic system	Sampling slow, not possible to obtain good representation of dynamic system	Sampling slow, not possible to obtain good representation of dynamic system
Related data difficult to correlate with samples	Samples easily correlated with other data	Related data difficult to correlate with samples	Related data difficult to correlate with samples
Results of test lag field sampling	Results of test rapid; initial evaluation ~24 hr	Results of test lag field test	Results of test lag field test

ADDENDUM C-1 (Cont.)

Comparison of Tracing Methods

Fluorescent-Tagged Sand	Radioisotope-Tagged Sand	Stable-Tagged Sand Activation Analysis	Natural Minerals
Core sampling required for burial information	In situ sampling possible for burial determination	Core sampling required for burial information	Core sampling required for burial information
Large quantities of tracer required	Small quantities of tracer required	Large quantities of tracer required	Source of mineral must be established and alternate sources must be absent
Total data collection necessary to obtain direction, speed, and quantity of sediment; transport believed to be highly uncertain due to limited sample potential and statistical requirements	Total data collection necessary to obtain direction, speed, and quantity of sediment; transport; possible as indicated by mathematical models and wave tank experiments	Total data collection necessary to obtain direction, speed, and quantity of sediment; transport believed to be highly uncertain due to limited sample potential and statistical requirements	Data limited to determination of direction and distance of transport
Public relations problems unlikely	Public relations problems exist (problem can be minimized with proper control)	Public relations problems unlikely	Public relations problems unlikely
Survey area may be contaminated for future tests	Rapid clearing of survey area with short half-life isotopes	Survey area may be contaminated for future tests	Not possible to assign time to transport information or retest area

ADDENDUM C-1 (Cont.)

Comparison of Tracing Methods

Fluorescent-Tagged Sand	Radioisotope-Tagged Sand	Stable-Tagged Sand Activation Analysis	Natural Minerals
Technique established and well developed	Technique demonstrated but not refined to the point of usefulness in obtaining engineering data; excellent potential for high utility	Technique demonstrated; sensitivity problems	Technique established and well developed

ADDENDUM C-2

Xenon-133 Tagging Procedure

Preparation of Sand

Sand from the test area which had been shipped to ORNL for treatment and labeling was screened with a 10 mesh screen to remove debris, washed with tap water, and covered with hydrochloric acid. The acid concentration was not critical but should be >6 N. The mixture was held in a well-ventilated area for ~24 hr and occasionally stirred, until all signs of a reaction with carbonates had ceased. After the sand was thoroughly washed to remove the acid and dried, it was ready for high-temperature tagging with ^{133}Xe.

Tagging Procedure

A 58-kg batch of prepared sand was loaded into a specially designed furnace (see Addendum C-3). The furnace was placed in a shielded cell equipped with manipulators, connected to a gas purification system (see Fig. C-8), and heated to 600°C. The gases evolved from the sand during heating were removed with a vacuum pump. At 600°C, pumping was discontinued (pressure is ~0.03 cm of Hg), and ^{133}Xe was admitted into the furnace. The furnace was further heated to 850°C (requires ~3 hr) and was then cooled, first to 150°C by circulating N_2 gas that had been cooled with liquid N_2 through the cooling coils, and then to ~80°C by water. The excess ^{133}Xe was recovered by pumping the gas mixture through traps cooled with liquid N_2. These traps recovered ^{133}Xe and allowed the bulk of the gas contaminants (N_2 and O_2) to pass through. The gas pressure in the furnace after ^{133}Xe addition was <1 cm of Hg. After the furnace was heated and cooled, the pressure was ~150 cm of Hg. The sand was removed and then packaged in gallon paint cans. With a ^{133}Xe concentration of 8 mCi/cm^3 in the gas phase, the sand will adsorb ~20 µCi of ^{133}Xe per gram of sand.

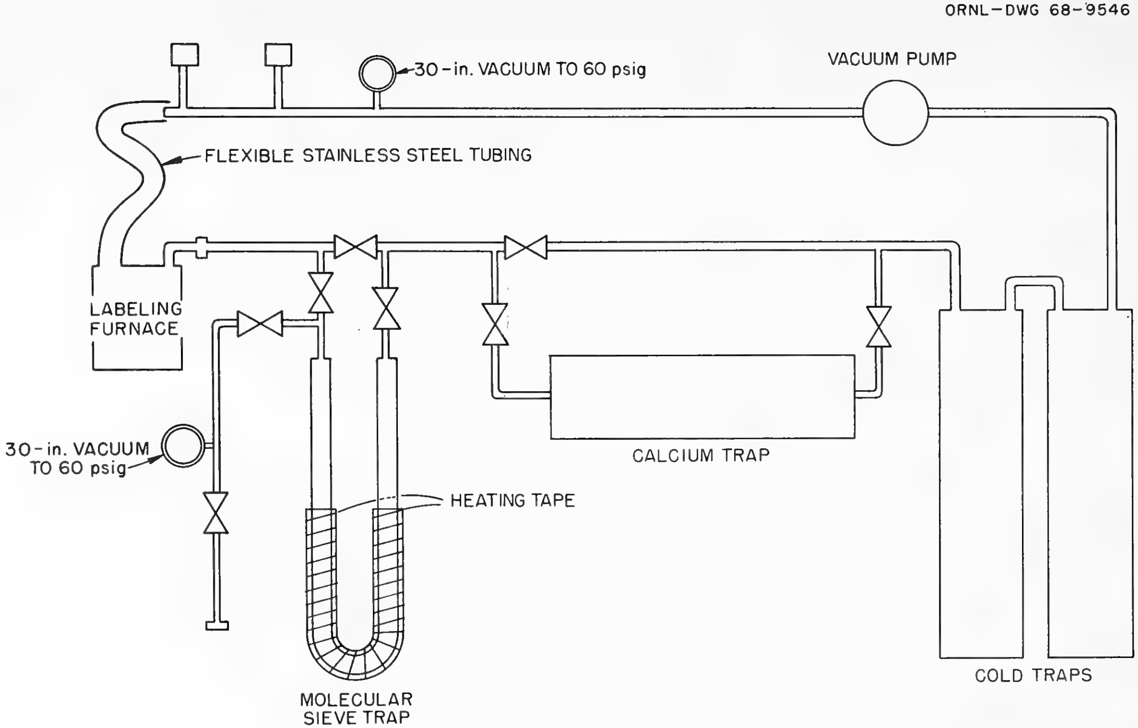


Figure C-8. ^{133}Xe Purification System

ADDENDUM C-3

Xenon-133 Tagging Furnace

The ^{133}Xe-tagging furnace, shown in Fig. C-9, was designed to tag 40 liters of sand. The basic unit is constructed of mild steel, contains eight heating elements (230-V, 1500-W Calrods) and eight cooling loops, and is insulated with fire brick and sheet asbestos. Two 30-amp 210-V Variacs are used to furnish power to the heating elements. These are enclosed in stainless steel to prevent corrosion and failure. Two calibrated thermocouples are used to monitor temperature in the center and side of the furnace. The maximum operating temperature for the furnace is 900°C.

A typical heating cycle with 40 liters of sand is as follows. The Variacs are set at 10 amp for 1 hr and are then raised to 20 amp for 3 hr. The final temperature is 850°C on the center thermocouple and 750°C on the outside thermocouple. The cooling cycle is started immediately, first with cooled N_2 gas (bubbled through liquid N_2) at a flow rate of 5 cfm for 1 1/2 hr and then with water cooling to reduce the temperature to 80°C (~2 hr).

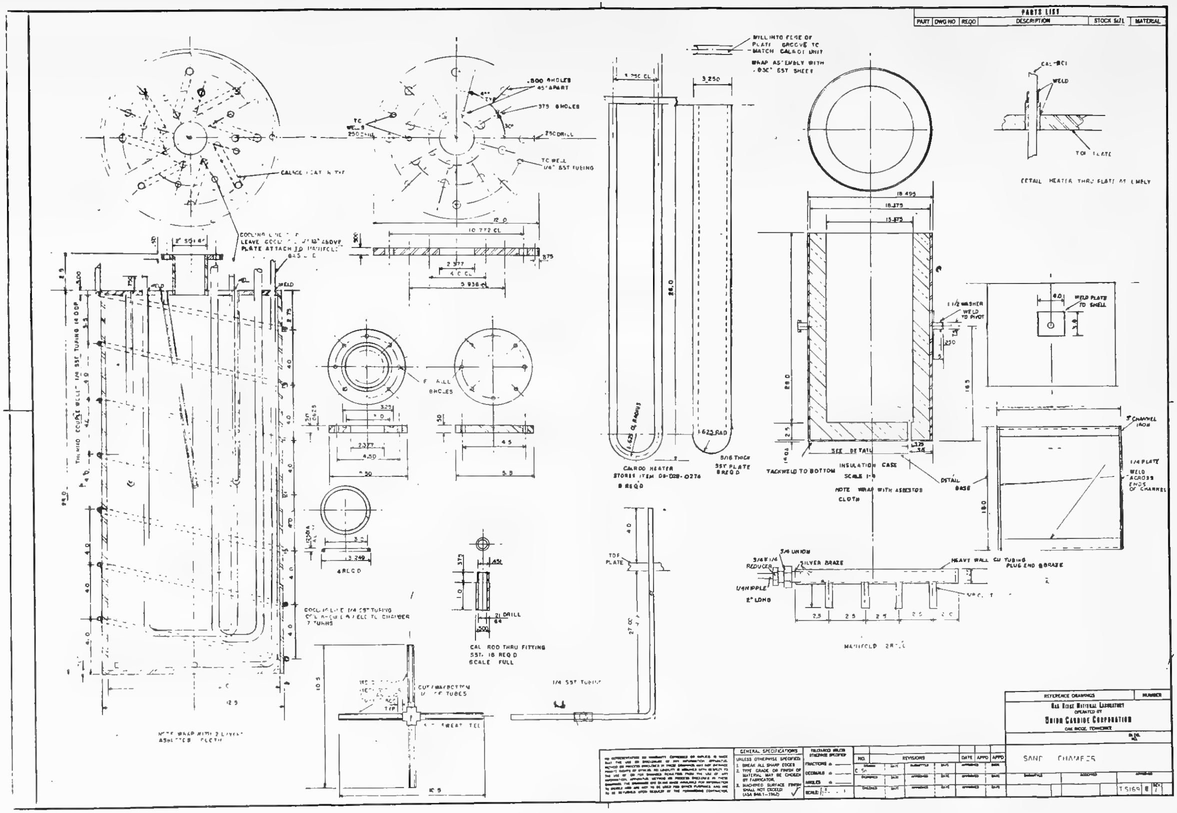


Figure C-9. ^{133}Xe-Tagging Furnace.

ADDENDUM C-4

Underwater Detector Assembly

The underwater detector assembly, shown in Figs. C-10 and C-11, is constructed of mild steel, except for the detector housing, which is constructed of stainless steel. The final assembly is plated with nickel (electroless process) to prevent excessive corrosion. Careful attention is given to axle and bearing tolerances because the detector housing must swing freely as a pendulum. A 1/2-in.-thick lead plate is used at the bottom of the detector housing to aid in holding the detectors in a vertical position. Conductor cables are passed through the hollow axle and around a towing torque. The cable entry is sealed with epoxy resin to prevent water from entering the detector housing.

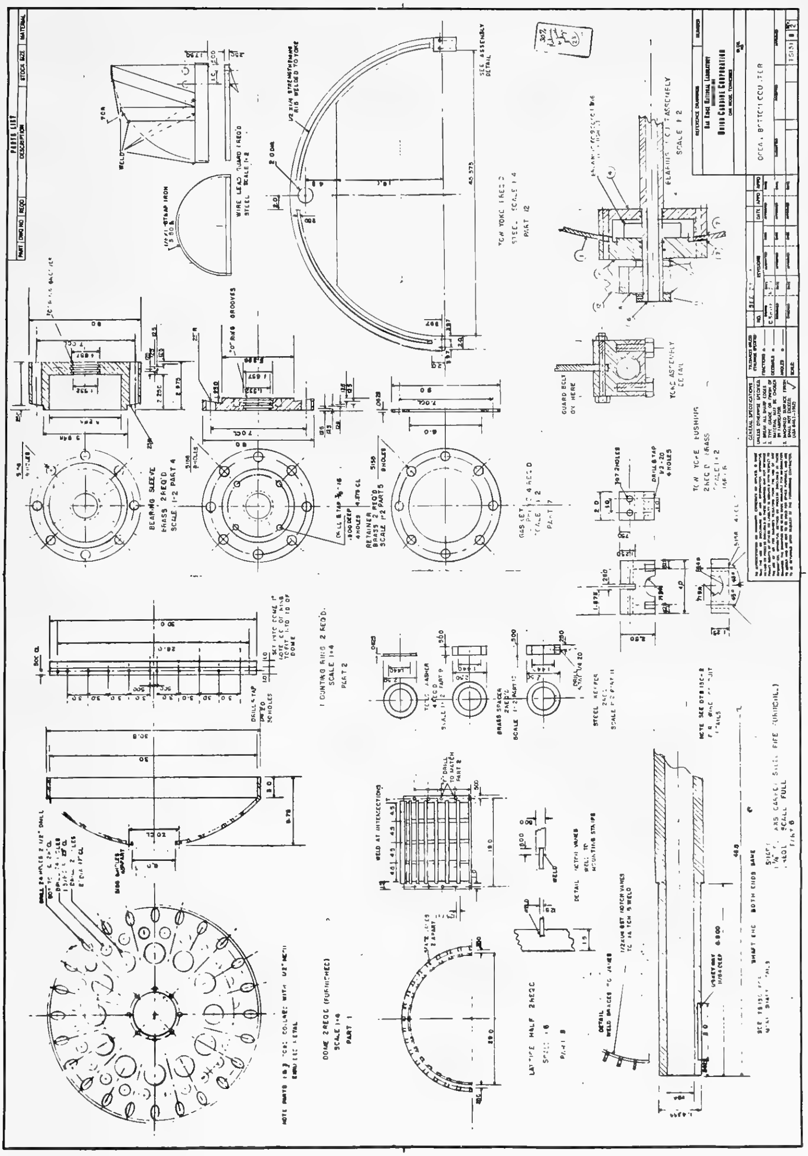


Figure C-10. Underwater Detector Assembly.

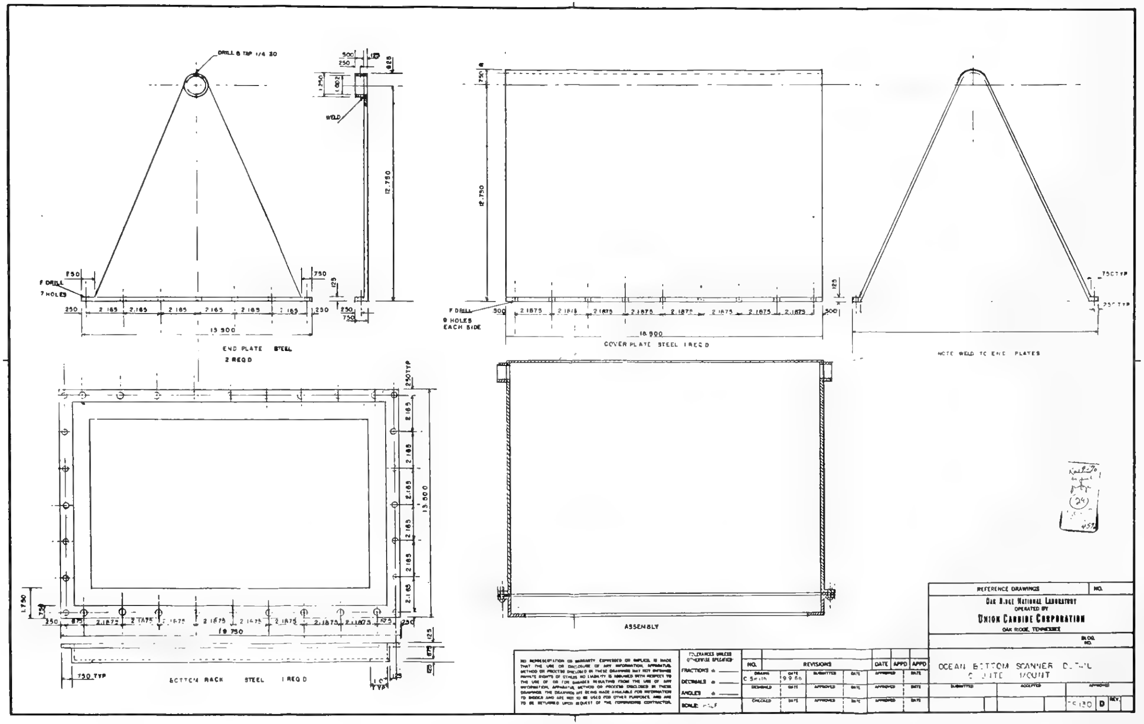
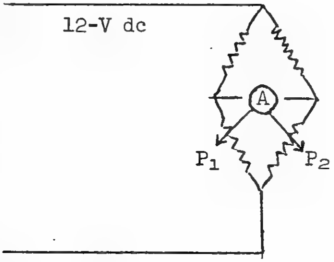


Figure C-11. Mounting for Underwater Detector Housing.

ADDENDUM C-5

Detector Position Indicator

The device shown in Fig. C-12 which is used to indicate the position of the detector housing, is located within the watertight detector housing and functions as a weighted pendulum. The pendulum is connected directly to a 3-turn 5000-ohm potentiometer by a small pinion gear. This potentiometer is connected to an identical potentiometer on board the vessel. The readout is shown in the following sketch:



With the detector housing in the vertical position the ammeter, A, is zeroed with the potentiometer, P_2. As the pendulum moves, it changes the potentiometer, P_1, which causes the ammeter pointer to move to the right or left. This ammeter is calibrated in degrees and reflects the position of the detector housing.

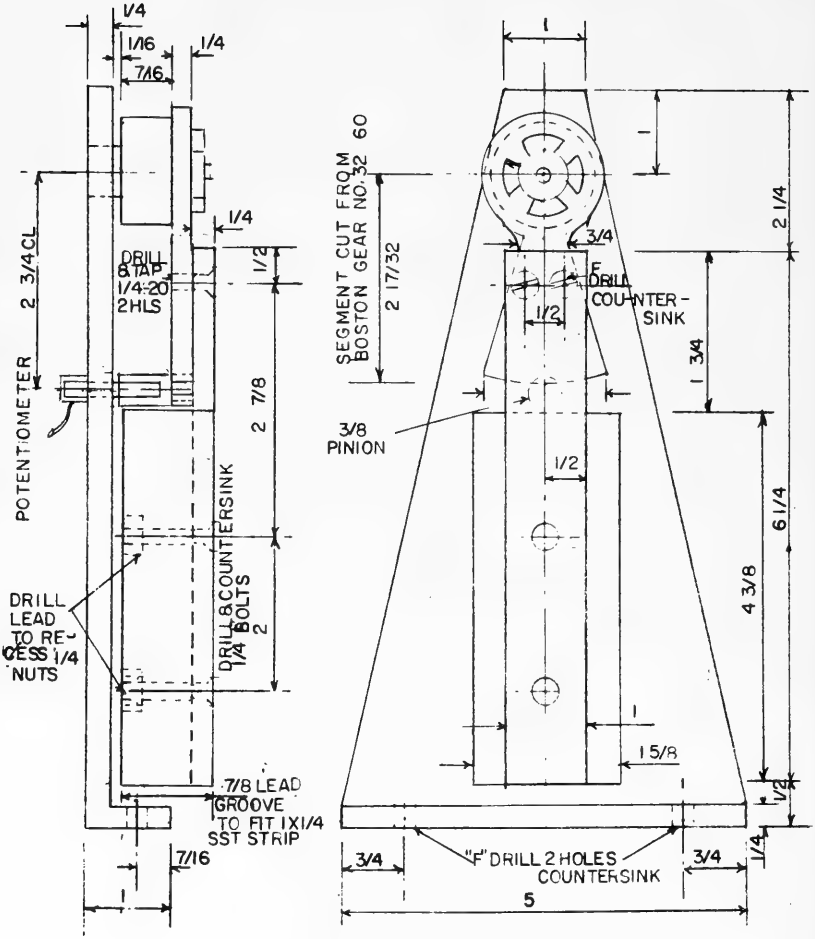


Figure C-12. Level Indicator for Detector Housing.

ADDENDUM C-6

Clamshell Dispensing Apparatus

The clamshell dispensing apparatus, shown in Fig. C-13, was designed to dispense 40 liters of sand on the ocean floor. The basic construction is 16-gage stainless steel. A bridle constructed of 1/4-in.-thick nylon rope is used to lower the apparatus to the ocean bottom. The length (~3 ft) of the bridle must be adjusted under load to ensure that a proper opening force exists. When the device is lowered and makes contact with the bottom, the latching pins are disengaged. The weight of the drum and contents causes the apparatus to open, releasing the sand. Two plugs located in one end of the device are used for filling. In order for the device to sink, three small plugs in the top of the device must be opened.

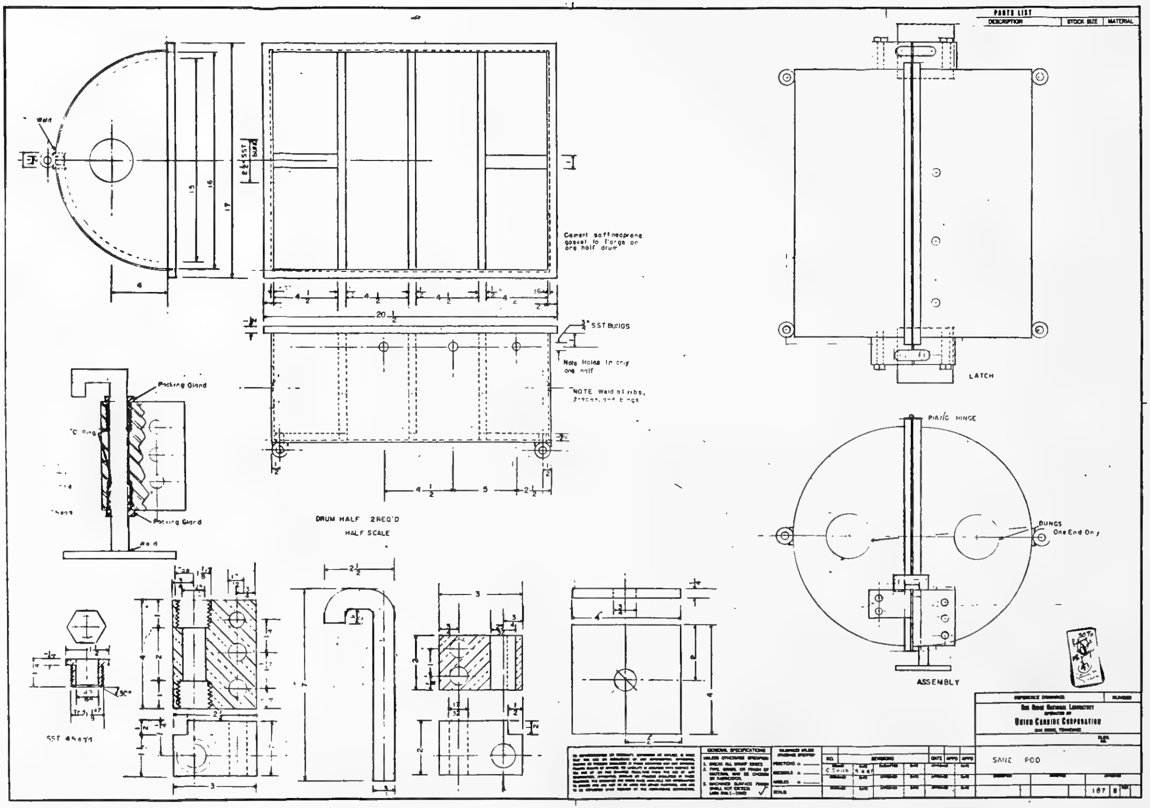


Figure C-13. Clamshell Dispensing Apparatus.

APPENDIX D

RADIATION DATA REDUCTION AND PLOTTING PROGRAM - RAPLOT

Prepared by

P. A. TURNER
Geology Branch
Engineering Development Division
Coastal Engineering Research Center

```
@ ELT RAPLOT,1,680724, 51042

C   TITLE -- RAPLOT
C     THE PURPOSE OF THIS PROGRAM IS TO REDUCE THE RADIOACTIVITY SURVEY
C   DATA FROM THE RIST PROJECT AND PLOT THE SURVEY ON A RENSON-LEHNER
C   INCREMENTAL PLOTTER.  THE FOLLOWING PLOTS ARE THE OUTPUT'
C        TRACKLINE FOLLOWED BY SURVEY VESSEL
C        PLOT OF UNCORRECTED RADIATION VALUES (BACKGROUND SURVEY)
C        SYMBOL PLOT OF RADIATION VALUES CORRECTED FOR BACKGROUND AND
C                  DECAY SINCE INJECTION TIME.
C   FORMAT AND ENTRIES ON DATA CONTROL CARD
C         COL  1- 6  MONTH,DAY AND YEAR OF SURVEY.
C         COL  8-10  CABLE LENGTH IN FEET, TO THE NEAREST FOOT.
C         COL 12-13  WATER DEPTH PLUS FREEBOARD IN FEET, TO THE NEAREST
C                          FOOT.
C         COL 15-16  DISTANCE FROM RADAR MAST TO CABLE STANCHION IN FEET
C                          TO NEAREST FOOT.
C         COL 18-23  BACKGROUND RADIATION COUNT.
```

```
000017     C          COL 25-28  TIME OF INJECTION IN HOURS AND MINUTES.
000018     C          COL 30-31  THE NUMBER OF DAYS SINCE THE INJECTION.
000019     C          COL 33-36  THE HALF LIFE OF THE RADIOACTIVE TRACER IN DAYS.
000020     C                         THE DECIMAL POINT MUST BE PUNCHED IN.
000021     C          COL 38-43  TIME WHEN THE TIMER WAS SET TO ZERO AND STARTED IN
000022     C                         HOURS, MINUTES AND SECONDS.
000023     C          COL 45-51  BEACON1 NORTH COORD /   LAMBERT COORDINATES OF
000024     C          COL 53-59  BEACON1  EAST COORD /   RADAR BEACONS TO THE NEAR-
000025     C          COL 60-67  BEACON2 NORTH COORD /   EST FOOT.  BEACON1 IS AL-
000026     C          COL 69-75  BEACON2  EAST COORD /   WAYS UP COAST.
000027     C          COL 76-78  THE NUMBER OF CARD IMAGES TO BE SKIPPED AT THE BE-
000028     C                         GINNING OF A DATA SET IN ORDER TO AVOID READING
000029     C                         IN SOME BAD DATA.
000030     C          COL 80     PUNCH T HERE ON THE LAST DATA SET
000031     C     FORMAT AND ENTRIES ON PLOT CONTROL CARD
000032     C          COL  1- 3  PLOT OPTION CONTROL.  TO USE, PUNCH THE NUMERAL 1
000033     C                     IN THE COLIMN INDICATED.
000034     C                     1 = PLOT TRACKLINE FOLLOWED BY SURVEY VESSEL.
```

```
000035        C                  2 = PLOT UNCORRECTED RADIATION VALUES.
000036        C                  3 = PLOT RADIATION VALUES CORRECTED FOR BACKGROUND
000037        C                    AND DECAY SINCE TIME ZERO.
000038        C                  4 = UNUSED. LEAVE BLANK.
000039        C       COL   5-14 MAP SCALE EXPRESSED IN UNITS PER INCH
000040        C       COL  16-17 OPTION 1 / USE WHEN SPOTTING DATA FOR EACH PLOT
000041        C       COL  18-19     ]     2 / OPTION.  USER CAN SPECIFY THAT EVERY NTH
000042        C       COL  20-21     ]     4 / POINT BE PLOTTED.  IF LEFT BLANK, THE
000043        C                            PROGRAM ASSUMES EVERY POINT IS TO BE
000044        C                            PLOTTED.
000045        C       COL  23-32 INTERVALS ON THE COORDINATE GRID AT WHICH TICK
000046        C                  MARKS WITH THE LAMBERT COORDINATES WILL BE POSTED.
000047        C                  IF FIELD IS LEFT BLANK, PROGRAM WILL ASSUME THAT
000048        C                  NO TICK MARKS ARE TO BE PLOTTED AND POSTED.
000049        C       COL  34-43 BEACON 1 / INJECTION SITE. DISTANCE IN METERS TO
000050        C       COL  45 54 BEACON 2 / THE NAMED BEACONS. IF FIELDS ARE LEFT
000051        C                            BLANK, SITE IS NOT PLOTTED.
000052        C       COL  56-61 DAY,MONTH AND YEAR THE SAND WAS INJECTED
```

```
C   FORMAT AND ENTRIES ON PLOT IDENTIFICATION CARD
C        COL  1-78  THIS FIELD WILL BE PLOTTED ON THE LOWER MARGIN OF
C                   THE MAP.
      COMMON NOPT(4),SCALE,NPLT(3), GRID,SITEN,SITEE,INDATE,LEGEND(13),
     1BEAC1N,BEAC1E,BEAC2N,BEAC2E,LINE,BKGRND,SNORTH,SFAST,NENTRY,NMAX,
     2NMIN,EMAX,EMIN
      REAL NORTH(3000), NCORD(3000), MBAR,NMAX,NMIN
      DIMENSION EAST(3000), RAD(3000), N MB R(3000), ECORD(3000),
     1TIME(3000), D(2,3000), DUMMY(14)
      LOGICAL JOBEND
      EQUIVALENCE (NCORD(1), D(1,1)), (ECORD(1), D(1,1501))
C
C   NTAPE IS THE NUMBER FOR THE INPUT TAPE CONTAINING THF SURVFY DATA
C
      NTAPE = 7
    6 FORMAT(1H1/)
C
C     READ IN DATA CONTROL CARD
```

```
C
    1 READ(5,3 ) HDATE,CABLE,DEPTH,BOAT,BKGRND,ZHR,ZMIN,DDAY,HLIFE,
     1SETIME,RMIN,SEC,BEAC1N,BEAC1E,BEAC2N,BEAC2E,ISKIP,JOBEND
    3 FORMAT(A6,F4.0,2F3.0,F7.0,1X,2F2.0,F3.0,F5.2,1X,3F2.0,4(1X,F7.0),
     1I3,L2)
C
C   READ IN PLOT CONTROL PARAMETERS
C
      READ(5,4)NOPT,SCALE,(NPLT(I),I=1,3),GRID,DUMP1,DUMP2,INDATE
    4 FORMAT(4I1  ,F10.0,1X,3I2,1X,F10.0,2(1X,F10.0),1X,A6)
      DO 502 I = 1,3
      IF (NPLT(I)) 501, 501, 502
  501 NPLT(I) = 1
  502 CONTINUE
C
C   READ IN PLOT LEGEND
C
      READ(5,5) LEGEND
```

```
    5 FORMAT(13A6)
      WRITE(6,250) (LEGEND(I),I=1,12), HDATE
      WRITE(6,9002) BEAC1N, BEAC1E, BEAC2N, BEAC2E
 9002 FORMAT(/5X,8HBEACON 1,F10.0,1HN,F10.0,1HE,5X,8HBEACON 2,F10.0,1HN,
     1F10.0,1HE//)
C
C     COMPUTE PROGRAM PARAMETERS FROM DATA CONTROL CARD ENTRIES
C
      SQDSTB = (BEAC2N -BEAC1N)**2 + (BEAC2E - BEAC1E)**2
      DISTB = SQRT(SQDSTB)
      WRITE(6,10) SQDSTB, DISTB
   10 FORMAT(5X,21HSQUARE DIST BETWEEN =,E16.8,5X,18HDISTANCE BETWEEN =,
     1F10.0)
      SINE = (BEAC2N - BEAC1N)/DISTB
      COSINE = (BEAC2E - BEAC1E)/DISTB
      WRITE(6,20) SINE,COSINE
   20 FORMAT(5X,6HSINE =,E16.8,5X,8HCOSINE =,E16.8)
      ZHR = ZHR + ZMIN/60. -DDAY*24.
```

```
      SETIME = SETIME + RMIN/60. + SEC/3600.
      CABLE = BOAT + SQRT(CABLE**2 - DEPTH**2)
      WRITE(6,30) ZHR, SETIME, CABLE
   30 FORMAT(5X,5HZHR =,F10.3,10X,8HSETIME =,F10.3,10X,7HCABLE =,F10.2)
      IF (HLIFE .GT. 0.0)  DECAY = ALOG(2.)/(HLIFE*24.)
      WRITE(6,35) BKGRND, HLIFE, DECAY
   35 FORMAT(5X,18HBACKGROUND COUNT =,F7.0,5X,21HHALFLIFE OF ISOTOPE =,
     1F7.2,4HDAYS,5X,14HDECAY FACTOR =,E16.8)
      WRITE(6,600) (NOPT(I),I = 1,3)
  600 FORMAT(// 40X,15HPLOTS GENERATED /10X,9HTRACKLINE,I5,10X,20HBACKGR
     1OUND RADIATION,I5,10X,19HCORRECTED RADIATION,I5)
C
C   COMPUTE COORDINATES OF THE INJECTION SITE FROM THE DISTANCES FROM
C   THE BEACONS
C
      IF(DUMP1) 340, 340, 300
  300 DUMP1 = DUMP1 * 3.28083
      DUMP2 = DUMP2 * 3.28083
```

```
      DX1 = (SQDSTB + DUMP1*DUMP1 - DUMP2*DUMP2)/(DISTR*2.)
      DY1 =  DUMP1*DUMP1 - DX1*DX1
      IF (DY1) 310, 310, 320
  310 SITEN = -999999.
      WRITE(6,315)
  315 FORMAT(5X, 51HBEACON RANGES FOR DUMP SITE COMPUTE IMAGINARY ROOT.)
      GO TO 340
  320 DY1 = -SQRT(DY1)
      SITEE = DX1*COSINE - DY1*SINE
      SITEN = DX1*SINE + DY1*COSINE
      DUMP1 = SITEN + BEAC1N
      DUMP2 = SITEE + BEAC1E
      WRITE(6,330) DUMP1, DUMP2
  330 FORMAT(10X,37HLAMBERT COORDINATES OF INJECTION SITE ,F10.0,1HN,
     1F10.0,1HE )
  340 N = 0
C
C     SKIP LEADING CARD IMAGES THAT CONTAIN RAD DATA.
```

```
C
      IF(ISKIP .GT. 0) READ(NTAPE,39) ((DUMMY(J),J=1,5),I=1,ISKIP)
   39 FORMAT( 5(A6,1X))
   40 N = N + 1
C
C    READ IN  ONE LINE OF RIST SURVEY DATA
C
      READ(NTAPE,50,END=100) NMBR(N),TIME(N),RAD(N),D(1,N),D(2,N)
   50 FORMAT(I6,F7.1,F7.0,2F7.1)
C
C     CONVERT DISTANCE TO THE BEACONS FROM METERS TO FFFT.
C
      D(1,N) = D(1,N) * 3.28083
      D(2,N) = D(2,N) * 3.28083
C
C    COMPUTE TIME OF FIX
C
      IF (N.GT. 1 .AND. TIME(N) .LE. 0.0) TIME(N) = TIMF(N-1) + 10.
```

```
      TIME(N) = SETIME + TIME(N)/3600.
      GO TO 40
  100 LINE = N - 1
      MSTOP = LINE - 1
C
C     CHECK DISTANCES TO RADAR BEACONS FOR ERRORS.  IF DISTANCE/TIME
C     FOR SUCCESSIVE BEACON RANGES INDICATE A SHIP SPEED .GT. 4 KNOTS,
C     RANGE IS IN ERROR.
C
      DO 400 I = 1,2
      DO 130 M = 1,MSTOP
      IF (D(I,M)) 130, 130, 110
  110 NSTART = M + 1
      DO 120 N = NSTART,LINE
      IF(ABS(D(I,N)-D(I,M)) - (TIME(N)-TIME(M))*25000.) 130, 130, 120
  120 D(I,N) = -1.
  130 CONTINUE
      DO 390 M = 1,MSTOP
```

```
      IF (D(I,M)) 140, 140, 390
  140 NSTART = M
C
C     CORRECT ERRONEOUS BEACON RANGES BY LINEAR INTERPOLATION (ON TIME)
C     BETWEEN NON-ERRONEOUS RANGES.
C
      DO 360 N = NSTART, LINE
      IF(D(I,N)) 360, 360, 150
  150 NSTOP = N - 1
      GO TO 370
  360 CONTINUE
  370 DTIME = TIME(NSTOP + 1) - TIME(NSTART - 1)
      DD1 = D(I,NSTOP+1) - D(I,NSTART-1)
      N = NSTART
  380 D(I,N) = D(I,NSTART-1) + DD1*(TIME(N)-TIME(NSTART-1))/DTIME
      N = N+ 1
      IF (N - NSTOP) 380, 380, 390
  390 CONTINUE
```

```
  400 CONTINUE
C
C   COMPUTE POSITION OF SHIP FROM DISTANCES FROM THE TWO BEACONS
C
      DO 430 N = 1, LINE
      DX1 = (SQDSTB + D(1,N)*D(1,N) - D(2,N)*D(2,N))/(DISTB*2.)
      DY1 = D(1,N)*D(1,N) - DX1*DX1
C
C     CHECK FOR IMAGINARY ROOT.
C
      IF (DY1) 410, 410, 420
  410 NORTH(N) = -999999.
      GO TO 430
  420 DY1 = - SQRT(DY1)
      EAST(N) = DX1*COSINE - DY1*SINE
      NORTH(N)= DX1*SINE + DY1*COSINE
  430 CONTINUE
C
```

```
C     REMOVE ANY FIXES THAT HAVE UNDETERMINED COORDINATES FROM THE DATA
C     FILE.
C
      N = 0
  435 N = N + 1
      IF(NORTH(N) + 999999.) 455, 440, 455
  440 MSTART = N
      MSTOP = LINE - 1
      IF (MSTOP-MSTART) 452, 445, 445
  445 DO 450 M = MSTART,MSTOP
      NORTH(M) = NORTH(M+1)
      EAST(M) = EAST(M+1)
      N MB R(M) = N MB R(M+1)
      TIME(M) = TIME(M+1)
  450 RAD(M) = RAD(M+1)
      N = N - 1
  452 LINE = LINE - 1
  455 IF(LINE - N) 460, 460, 435
```

```
C   460 CONTINUE
C
C     CALL SUBROUTINE FOR PLOTTING THE TRACK OF THE SURVEY VESSEL.
C
      NENTRY = 1
      IF(NOPT(1) .EQ. 1) CALL BENLEH(NORTH,EAST,NMBR)
C
C    APPLY A CORRECTION TO ALLOW FOR THE DISTANCE THE DETECTOR IS TOWED
C        ASTERN OF THE SURVEY SHIP.
C
      DNO = NORTH(1) - (NORTH(2) - NORTH(1))
      DEO =  EAST(1) - ( EAST(2) -  EAST(1))
      DENOM = SQRT((NORTH(1) - DNO)**2 + ( EAST(1) - DEO)**2)
      NCORD(1) = NORTH(1) - CABLE*(NORTH(1) - DNO)/ DENOM
      ECORD(1) =  EAST(1) - CABLE*( EAST(1) - DEO)/ DENOM
      DO 160  N = 2,LINE
      DENOM = SQRT((NORTH(N)-NCORD(N-1))**2 + (EAST(N)-ECORD(N-1))**2)
C
```

```
C        THE CORRECTION FOR THE DISTANCE BETWEEN VESSEL AND THE DETECTOR
C      IS EQUAL TO 'CABLE' UNLESS THE VESSEL IS LESS THAN 'CABLE' FEET
C      AWAY FROM THE LAST COMPUTED POSITION OF THE DETECTOR VEHICLE.  IN
C      THIS EVENT, THE CORRECTION IS EQUAL TO 95 PC. OF THF DISTANCE TO THE
C      LAST COMPUTED POSITION.
C
         IF(DENOM - CABLE) 154, 154, 152
  152 NCORD(N) = NORTH(N) - CABLE*(NORTH(N) - NCORD(N-1))/ DENOM
      ECORD(N) = EAST(N) - CABLE*(EAST(N) - ECORD(N-1))/DENOM
      GO TO 160
  154  TEST =      DENOM*.95
       NCORD(N) = NORTH(N) - TEST*(NORTH(N)-NCORD(N-1))/DENOM
       ECORD(N) = EAST(N) - TEST*(EAST(N)-ECORD(N-1))/DENOM
  160 CONTINUE
C
C      CALL THE SUBROUTINE FOR PLOTTING UNCORRECTED RADIATION VALUES
C
      NENTRY = 2
```

```
      IF(NOPT(2) .EQ. 1) CALL RADPLT(NCORD,ECORD,RAD)
C
C     COMPUTE THE MEAN AND STANDARD DEVIATION OF THE UNCORRECTED
C     RADIATION COUNTS.
C
      SUMRAD = 0.0
      SSQRAD = 0.0
      DO  162 N = 1,LINE
      SUMRAD = SUMRAD + RAD(N)
  162 SSQRAD = SSQRAD + RAD(N)*RAD(N)
      DLINE = FLOAT(LINE)
      STDRAD = SQRT((DLINE*SSQRAD - SUMRAD**2)/(DLINE*(DLINE-1.)))
      RADBAR = SUMRAD/DLINE
      WRITE(6,164) RADBAR, STDRAD
  164 FORMAT(//20X, 37HSUMMARY STATISTICS OF RADIATION COUNT / 25X,16HME
     1AN RADIATION =, F10.0/ 21X, 20HSTANDARD DEVIATION =,F10.0 )
      IF(NOPT(3) .NE. 1) GO TO 230
      SUMRAD = 0.0
```

```
      SNORTH = 0.0
       SEAST = 0.0
        SSQN = 0.0
        SSQE = 0.0
      DO 200  N = 1,LINE
C
C   CORRECT RADIATION VALUES FOR BACKGROUND AND FOR TIME-DECAY FACTOR
C
      RAD(N) = RAD(N) - BKGRND
      IF(RAD(N)) 170, 170, 180
  170 RAD(N) = 0.0
      GO TO 200
  180 RAD(N) = RAD(N)*EXP(DECAY*(TIME(N) -ZHR))
  190 SUMRAD = SUMRAD + RAD(N)
      SNORTH = SNORTH + NCORD(N)*RAD(N)
      SEAST  =  SEAST + ECORD(N)*RAD(N)
      SSQN   =   SSQN + NCORD(N)*NCORD(N)*RAD(N)
      SSQE   =   SSQE + ECORD(N)*ECORD(N)*RAD(N)
```

```
  200 CONTINUE
C
C   COMPUTE WEIGHTED MEAN AND STD. DEV. OF ACTIVITY LOCATION
C
      SDNRTH = SQRT((SUMRAD*SSQN - SNORTH**2)/(SUMRAD**2))
      SDEAST = SQRT((SUMRAD*SSQE - SEAST**2)/(SUMRAD**2))
      SNORTH = SNORTH/SUMRAD
      SEAST  = SEAST/SUMRAD
      NBAR = SNORTH + BEAC1N
      EBAR = SEAST  + BEAC1E
      WRITE(6,210) NBAR, EBAR, SDNRTH, SDEAST
  210 FORMAT(//20X,41HSUMMARY STATISTICS OF RADIATION LOCATION. /24X,
     111HNORTH COORD,10X,10HEAST COORD/16X,4HMEAN,5X,F10.0,10X,F10.0/11X
     2, 9HSTD. DEV.,5X,F10.0,10X,F10.0)
C
C   COMPUTE AND PRINT 95 PC. CONFIDENCE LIMITS OF MEAN RADIATION
C   LOCATION.
C
```

```
      RTSUM = SQRT(SUMRAD/BKGRND)
      CFIDN = 1.96 * SDNRTH / RTSUM
      CFIDE = 1.96 * SDEAST / RTSUM
      WRITE(6,220) CFIDN, CFIDE
  220 FORMAT(10X,10HCONFIDENCE /7X,13HLIMIT OF MEAN,5X,F10.0,10X,F10.0)
  230 NENTRY = 3
      IF(NOPT(3) .EQ. 1) CALL RADPLT(NCORD,ECORD,RAD)
      UH = NMAX + BEAC1N
      UL = NMIN + BEAC1N
      EH = EMAX + BEAC1E
      EL = EMIN + BEAC1E
      WRITE(6,222)  UH, EH
  222 FORMAT (//7X,13HMAXIMUM COORD,5X,F10.0,1HN,9X,F10.0,1HE)
      WRITE(6,224) UL, EL
  224 FORMAT (//7X,13HMINIMUM COORD,5X,F10.0,1HN,9X,F10.0,1HE//)
C
C     COMPUTE CALIFORNIA LAMBERT COORDINATES FOR SHIP POSITION.
C
```

```
      DO 225  N =1,LINE
         NCORD(N) = NCORD(N) + BEAC1N
  225 ECORD(N) = ECORD(N) + BEAC1E
C
C     WRITE OUT THE NUMBER, COORDINATES AND ACTIVITY OF EACH DATA POINT
C
         I1 = -150
         I2 = -100
         I3 = - 50
  240 I1 = I1 + 150
         I2 = I2 + 150
         I3 = I3 + 150
         WRITE(6,6)
         WRITE(6,250) LEGEND, HDATE
  250 FORMAT(10X,13A6,10X,A6)
         WRITE(6,260)
  260 FORMAT(119H0 NUMBER     N COORD     E COORD  ACTIVITY  NUMRER     N C
     1OORD     E COORD  ACTIVITY  NUMBER     NCOORD     E COORD  ACTIVITY).
```

```
      DO 270  N = 1,50
  270 WRITE(6,280)N MB R(I1+N),NCORD(I1+N),ECORD(I1+N),RAD(I1+N),N MB R(
     1I2+N),NCORD(I2+N),ECORD(I2+N),RAD(I2+N),N MB R(I3+N),NCORD(I3+N),
     2ECORD(I3+N),RAD(I3+N)
  280 FORMAT(3(I8,2F11.0,F10.0))
      IF(I3+50 - LINE ) 240, 290, 290
  290 CONTINUE
      WRITE(9) LEGEND,JOBEND,LINE
      WRITE(9) (NMBR(I), NCORD(I), ECORD(I), RAD(I), I=1,LINE)
      WRITE(6,6)
      IF (.NOT. JOBEND) GO TO 1
      END FILE 9
      STOP
      END
```

5. LIST CODE

APPENDIX E

SEDIMENT ANALYSIS TABLES

RANGE: 157 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.75	0.389	0.198	2.437

RANGE: 158 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.71	0.435	0.460	2.757
+ 6					
+ 3					
MLLW					
- 6	2.13	2.00	0.516	-0.164	2.974
-12	2.38	2.24	0.501	-0.066	2.989
-18	2.13	2.22	0.388	0.028	2.934
-24	2.63	2.52	0.372	0.532	3.706
-30	2.63	2.65	0.436	0.298	3.229
-50	2.63	2.68	0.429	0.284	3.114

RANGE: 159 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.61	0.383	0.704	3.760
+ 6	1.63	1.68	0.367	0.325	2.358
+ 3	1.63	1.53	0.440	0.147	2.122
MLLW	1.13	1.26	0.456	0.706	2.785
- 6	1.63	1.67	0.552	0.175	2.269
-12	2.13	2.16	0.525	-0.208	2.341
-18	2.13	2.03	0.515	0.008	2.111
-24	2.38	2.45	0.459	0.200	3.066
-30	2.63	2.70	0.399	0.082	2.573
-50	2.63	2.69	0.435	0.212	2.985

RANGE: 160 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	ϕ WORKING MEAN	ϕ MEAN	ϕ STND. DEV.	SKEWNESS	KURTOSIS
+12	1.38	1.42	0.389	0.651	2.859
+ 6	1.63	1.60	0.370	0.533	2.758
+ 3	1.13	1.30	0.410	0.872	3.204
MLLW	1.13	1.29	0.518	0.502	2.780
- 6	2.13	1.98	0.461	-0.086	2.336
-12	2.13	2.09	0.428	0.169	2.445
-18	2.13	2.12	0.453	0.130	2.492
	2.13	2.13	0.468	0.147	3.023
-24	2.38	2.31	0.437	0.041	3.008
-30	2.63	2.56	0.519	-0.302	2.654
-50	2.63	2.68	0.432	0.316	3.057

RANGE: 161 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	ϕ WORKING MEAN	ϕ MEAN	ϕ STND. DEV.	SKEWNESS	KURTOSIS
+12	1.88	1.83	0.337	0.369	2.446
+ 6	1.38	1.47	0.439	0.281	2.075
+ 3	1.38	1.43	0.497	0.289	2.104
	1.38	1.36	0.540	0.342	2.049
MLLW	1.63	1.76	0.420	0.204	2.210
- 6	1.88	1.78	0.552	0.457	2.907
-12	2.13	2.02	0.501	0.123	2.570
-18	1.88	2.00	0.509	0.147	2.403
-24	2.63	2.66	0.442	0.426	3.411
-30	2.63	2.64	0.446	-0.137	2.504
-50	2.63	2.67	0.456	0.256	2.819

RANGE: 162 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.64	0.385	0.428	2.475
	2.13	2.02	0.463	-1.557	5.001
+ 6	1.63	1.65	0.384	0.374	2.443
+ 3	1.38	1.48	0.446	0.575	2.894
MLLW	1.13	1.34	0.466	0.875	3.943
	1.13	1.30	0.443	0.713	3.007
	1.38	1.37	0.418	0.658	3.072
- 6	1.38	1.51	0.493	0.353	2.413
-12	2.13	2.11	0.519	-0.204	2.170
-18	1.88	1.97	0.483	0.140	2.790
-24	2.13	2.14	0.529	0.444	2.915
-30	2.63	2.70	0.438	-0.059	2.981
-50	2.63	2.73	0.432	0.183	3.039

RANGE: 163 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.38	1.47	0.393	0.554	2.769
+ 6	1.63	1.69	0.348	0.279	2.463
+ 3	1.38	1.40	0.516	0.733	3.951
MLLW	1.38	1.41	0.452	0.541	2.671
- 6	1.88	1.75	0.542	0.082	2.774
-12	2.13	2.19	0.491	0.192	3.072
-18	2.13	2.12	0.498	0.117	2.778
-24	2.38	2.44	0.487	0.558	3.820
-30	2.63	2.52	0.526	0.154	2.869
-50	2.63	2.65	0.425	0.194	2.605

RANGE: 164 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.38	1.43	0.378	0.530	2.904
+ 6	1.38	1.52	0.349	0.349	2.508
+ 3	1.38	1.43	0.392	0.497	2.566
MLLW	1.63	1.68	0.463	1.416	6.687
- 6	1.63	1.68	0.446	0.214	2.459
-12	1.88	1.92	0.521	0.130	2.793
-18	1.88	1.96	0.498	-0.132	2.530
-24	2.38	2.32	0.426	0.386	3.099
-30	2.63	2.67	0.420	-0.051	2.704
-50	2.63	2.75	0.431	0.292	3.270

RANGE: 165 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.69	0.390	0.327	2.487
+ 6	1.63	1.65	0.355	0.399	2.733
+ 3	1.63	1.56	0.549	0.566	3.993
MLLW	1.88	1.75	0.428	0.167	2.104
- 6	1.63	1.61	0.477	0.343	2.424
-12	2.13	2.04	0.546	-0.086	2.012
-18	2.13	1.99	0.509	0.397	3.518
-24	2.13	2.17	0.486	0.213	2.564
-30	2.63	2.65	0.473	0.089	3.289
-50	2.63	2.68	0.436	-0.027	2.486

RANGE: 167 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.64	0.355	0.289	2.392
+ 6	1.63	1.52	0.395	0.103	2.575
+ 3	1.13	1.27	0.464	0.569	2.565
MLLW	1.13	1.24	0.483	0.437	2.372
- 6	1.88	1.87	0.476	0.125	2.108
-12	1.88	1.94	0.530	0.161	2.235
-18	1.88	1.91	0.546	0.285	2.211
-24	2.13	2.23	0.571	0.108	2.622
-30	2.63	2.63	0.511	-0.213	2.925
-50	2.63	2.71	0.424	0.002	2.599

RANGE: 168 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.59	0.362	0.288	2.583
+ 6	1.63	1.55	0.387	0.299	2.464
+ 3	1.38	1.42	0.414	0.636	2.696
MLLW	1.13	1.23	0.431	0.758	3.363
- 6	1.63	1.77	0.450	0.358	2.419
-12	1.63	1.69	0.502	0.441	2.576
-18	1.88	1.91	0.489	0.271	2.526
-24	2.38	2.31	0.481	0.226	2.657
-30	2.63	2.57	0.532	-0.115	2.638
-50	2.88	2.73	0.446	0.142	3.202

RANGE: 170 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.64	0.416	1.224	5.999
+ 6	1.38	1.33	0.367	0.827	3.651
+ 3	1.38	1.33	0.426	0.594	2.824
MLLW	1.38	1.33	0.424	0.354	2.538
- 6	1.88	1.86	0.450	0.299	3.021
-12	1.63	1.56	0.621	0.262	2.379
-18	2.38	2.23	0.500	-0.113	2.389
-24	2.38	2.31	0.487	0.251	2.868
-30	2.63	2.64	0.434	0.076	2.494
-50	1.88	2.03	0.592	0.317	2.297

RANGE: 171 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
- 6	1.63	1.75	0.427	0.404	2.622
-12	1.88	1.81	0.532	0.192	2.293
-18	1.63	1.67	0.444	0.481	2.755
-24	1.88	1.94	0.452	0.337	2.824
-30	2.63	2.52	0.472	0.172	2.789
-50	2.88	2.77	0.404	-0.268	2.629

RANGE: 172 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.57	0.371	0.135	2.575
+ 6	1.38	1.46	0.380	0.477	2.634
+ 3	1.38	1.40	0.391	0.782	4.170
MLLW	1.13	1.24	0.404	0.636	2.932

RANGE: 174 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.38	1.53	0.368	0.687	4.123
+ 6	1.38	1.42	0.341	0.616	3.024
+ 3					
MLLW	1.13	1.20	0.398	0.979	4.007

RANGE: 175 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.55	0.385	0.339	2.509
+ 6	1.63	1.67	0.368	0.410	2.524
+ 3	1.63	1.61	0.396	0.276	2.397
MLLW	1.13	1.33	0.437	0.630	2.680

RANGE: 176 Survey Date: May 1967 AREA: Surf

STATION DEPTH IN FEET	Ø WORKING MEAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.63	1.53	0.353	0.335	2.672
+ 6	1.38	1.34	0.398	0.447	2.828
+ 3	1.38	1.44	0.403	0.742	3.390
MLLW	1.13	1.12	0.457	0.407	2.438

RANGE: 156 Survey Date: June 1968 AREA: Surf

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.51	1.53	.44	.24	2.25
+ 6	1.60	1.61	.42	.13	2.35
+ 3	1.58	1.61	.48	.19	1.94
MLLW	1.16	1.33	.58	.40	2.29
- 6	1.91	1.90	.39	.06	2.37
-12					
-18	2.38	2.37	.38	.26	3.47
-24	2.42	2.39	.43	-.02	2.36
-30	2.37	2.33	.46	-.24	2.52
-50	2.66	2.64	.39	.03	2.65

RANGE: 157 Survey Date: June 1968 AREA: Surf

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.57	1.60	.43	.33	2.23
+ 6	2.00	1.96	.35	-.13	2.15
+ 3	1.38	1.49	.43	.74	2.78
MLLW	-.01	.16	.87	.72	2.72
- 6	1.64	1.68	.49	.23	2.19
-12	2.26	2.17	.48	-.38	2.43
-18	2.25	2.20	.45	-.27	2.60
-24	2.50	2.48	.34	-.01	2.55
-30	2.44	2.43	.41	.20	2.76
-50	2.71	2.71	.40	.24	3.11

RANGE: 158 Survey Date: June 1968 AREA: Surf

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.73	1.75	.38	.18	2.27
+ 6	1.92	1.94	.33	.17	2.28
+ 3	1.31	1.41	.41	.84	3.18
MLLW	1.18	1.27	.39	1.11	3.94
- 6	1.63	1.67	.46	.22	2.14
	1.65	1.69	.46	.30	2.39
-12	2.26	2.26	.44	.42	3.81
-18	2.05	2.03	.46	.09	2.35
-24	2.47	2.43	.45	.04	2.57
-30	2.66	2.63	.36	-.18	2.44
-50	2.69	2.67	.40	.16	2.99

RANGE: 159 Survey Date: June 1968 AREA: Surf

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.69	1.71	.38	.34	2.36
+ 6	1.81	1.81	.37	.14	2.24
+ 3	1.37	1.43	.41	.61	2.77
MLLW	1.19	1.25	.45	.46	2.46
- 6	1.50	1.50	.45	.29	2.31
-12	2.06	2.02	.48	-.17	2.29
-18	2.00	2.00	.49	.09	2.18
-24	2.28	2.27	.50	.07	2.45
-30	2.72	2.70	.36	-.09	2.64
-50	2.69	2.67	.44	.06	2.69

RANGE: 160 Survey Date: June 1968 AREA: Surf

STATION	Ø	Ø	Ø		
DEPTH IN FEET	MEDIAN	MEAN	STND. DEV.	SKEWNESS	KURTOSIS
+12	1.71	1.70	.39	.18	2.17
+ 6	1.67	1.73	.37	.43	2.41
+ 3	1.51	1.57	.41	1.48	6.96
MLLW	1.07	1.19	.44	.72	2.73
- 6	1.50	1.56	.51	.44	2.26
-12	1.61	1.61	.58	.07	2.25
-18	2.35	2.29	.47	-.37	2.32
-24	2.40	2.36	.46	.01	2.23
-30	2.67	2.64	.43	-.09	2.26
-50	2.79	2.77	.44	-.06	2.57

RANGE: 9 N Survey Date: June 1968 AREA: Surf

STATION	Ø	Ø	Ø		
DEPTH IN FEET	MEDIAN	MEAN	STND. DEV.	SKEWNESS	KURTOSIS
+12	1.29	1.37	.40	.57	2.47
+ 6	1.42	1.48	.39	.44	2.25
+ 3	1.31	1.39	.40	.58	2.49
MLLW	1.13	1.21	.46	.72	2.95
-6	1.36	1.42	.37	.55	2.62
-12	2.22	2.19	.44	-.09	2.21
-18	1.78	1.78	.62	.10	2.07
-24	2.19	2.19	.51	.25	2.29
-30	2.66	2.62	.45	-.25	2.54
-50	2.67	2.66	.41	.03	2.48

RANGE: C　　Survey Date: June 1968　　AREA: C

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.67	1.68	.36	.25	2.39
+ 6	1.04	1.10	.81	.05	1.83
+ 3	2.03	1.98	.42	-.16	2.16
MLLW	1.21	1.07	1.04	-.39	2.11
- 6	1.66	1.60	.70	-.64	3.17
-12	2.13	2.11	.43	.04	2.21
-18	2.37	2.34	.40	-.09	2.19
-24	2.44	2.39	.38	-.31	2.44
-30	2.45	2.39	.45	-.42	2.92
-50	2.69	2.64	.35	-.27	2.52

RANGE: 13 N　　Survey Date: June 1968　　AREA: C

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.62	1.64	.40	.17	2.27
+ 6	1.59	1.59	.66	-1.24	6.32
+ 3	1.90	1.81	.62	-1.27	5.91
MLLW	1.75	1.78	.44	.22	2.38
- 6	1.12	1.15	.69	-.12	2.59
-12	2.03	2.00	.47	.03	2.30
-18	1.84	1.82	.49	-.01	2.32
-24	2.07	2.03	.49	.08	2.11
-30	2.44	2.42	.39	-.05	2.43
-50	2.62	2.59	.39	-.03	2.50

RANGE: 13 S Survey Date: June 1968 AREA: C

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.37	1.46	.47	.39	2.21
+ 6	1.73	1.75	.36	.19	2.47
+ 3	1.68	1.69	.43	.21	2.16
MLLW	1.61	1.64	.39	.34	2.18
- 6	1.52	1.43	.65	-1.12	4.96
-12	2.23	2.21	.45	-.26	2.63
-18	2.08	2.03	.50	-.08	2.13
-24	2.42	2.38	.41	-.21	2.48
-30	2.57	2.54	.35	-.13	2.45
-50	2.63	2.57	.43	-.40	2.49

RANGE: C-1 Survey Date: June 1968 AREA: C

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.23	1.34	.45	.59	2.32
+ 6	1.74	1.73	.44	.00	2.12
+ 3	1.58	1.54	.62	-.49	3.13
MLLW	1.51	1.55	.58	.10	2.17
- 6	1.74	1.75	.41	.24	2.12
-12					
-18	2.21	2.17	.45	-.11	2.07
-24	2.35	2.33	.39	-.07	2.17
-30	2.49	2.48	.36	.04	2.39
-50	2.48	2.37	.55	-1.82	7.74

RANGE: A-2 Survey Date: June 1968 AREA: A

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	1.96	1.96	.31	.20	2.29
+ 6	1.99	1.98	.39	.11	2.12
+ 3	2.28	2.26	.34	-.13	2.19
MLLW	2.44	2.41	.36	-.20	2.28
-6	2.16	2.15	.41	.05	2.35
-12	1.96	1.96	.42	.04	2.38
-18	2.09	2.06	.48	-.08	2.38
-24	1.97	1.98	.43	.21	2.03
-30	1.96	1.91	.53	-.12	2.05
-50					

RANGE: A Survey Date: June 1968 AREA: A

STATION DEPTH IN FEET	Ø MEDIAN	Ø MEAN	Ø STND. DEV.	SKEWNESS	KURTOSIS
+12	.68	.83	1.19	.10	1.35
+ 6	1.83	1.85	.39	.28	2.26
+ 3	2.16	2.16	.34	-.02	2.38
MLLW	2.34	2.32	.34	-.18	2.52
- 6	2.53	2.47	.40	-.20	2.28
-12	2.24	2.15	.60	-.20	2.02
-18	2.15	2.11	.51	-.14	2.18
-24	2.15	2.15	.48	-.10	2.30
-30	2.12	2.11	.45	.10	2.16
-50	2.38	2.33	.41	-.18	2.16

RANGE: A-1 Survey Date: June 1968 AREA: A

STATION DEPTH IN FEET	ϕ MEDIAN	ϕ MEAN	ϕ STND. DEV.	SKEWNESS	KURTOSIS
+12	1.33	1.25	1.13	.11	2.06
+ 6	2.00	2.02	.35	.04	2.31
+ 3	2.34	2.34	.28	.02	2.19
MLLW	2.25	2.19	.37	-.46	2.57
- 6					
-12					
-18					
-24	2.64	2.60	.35	-.28	2.52
-30	2.62	2.57	.45	-.25	2.53
-50	2.39	2.35	.41	-.12	2.11

RANGE: 14 N Survey Date: June 1968 AREA: A

STATION DEPTH IN FEET	ϕ MEDIAN	ϕ MEAN	ϕ STND. DEV.	SKEWNESS	KURTOSIS
+12	1.83	1.85	.36	.41	2.52
+ 6	2.31	2.26	.31	-.23	2.25
+ 3	2.29	2.27	.32	-.17	2.28
MLLW	2.41	2.38	.36	-.25	2.45
- 6	2.00	1.99	.48	.08	2.25
-12	2.50	2.44	.38	-.28	2.24
-18	2.53	2.32	.81	-2.22	8.21
-24	2.58	2.55	.42	-.11	2.52
-30	2.72	2.68	.33	-.35	2.72
-50	2.70	2.67	.32	-.20	2.72

APPENDIX F

RADIATION EXPOSURE RECORD

Units are shown in Millirems (Mrem)

NAME	Cape Kennedy		Surf (VAFB)		Pt Conception		CERC SPTB	
	D_S	D_C	D_S	D_C	D_S	D_C	D_S	D_C
E. H. Acree	0	0	<50	<50	60	60	0	0
H. R. Brashear	NP	NP	NP	NP	70	50	NP	NP
T. Burtin	NP	NP	NP	NP	50	40	NP	NP
F. N. Case	NP	NP	NP	NP	60	40	NP	NP
N. H. Cutshall	NP	NP	<50	<50	40	30	NP	NP
D. B. Duane	0	0	<50	<50	60	60	0	0
C. J. Galvin	NP	NP	NP	NP	NP	NP	0	0
C. W. Judge	NP	NP	NP	NP	NP	NP	0	0
R. O. Stafford	NP	NP	NP	NP	NP	NP	0	0
J. G. Tingler	NP	NP	NP	NP	NP	NP	0	0

NP - Indicates no participation

D_S - Skin dosage in Mrem

D_C - Cumulative dosage in Mrem

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Coastal Engineering Research Center (CERC)
Corps of Engineers, Department of the Army
Washington, D. C.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
RADIOISOTOPIC SAND TRACER STUDY, POINT CONCEPTION, CALIFORNIA
Preliminary report on accomplishments July 1966 to June 1968

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(First name, middle initial, last name)*
David B. Duane
Charles W. Judge

6. REPORT DATE
May 1969

7a. TOTAL NO. OF PAGES
194

7b. NO. OF REFS
36

8a. CONTRACT OR GRANT NO.
AT(49-11) - 2988 between Atomic Energy Commission and Coastal Engineering Research Center

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
Miscellaneous Paper 2-69

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The purpose of the study is to develop and use radioactive tracers for research in sand movement and littoral processes. Objectives include determination of suitable radioactive isotopes, development of radiation detectors, and development of handling and survey programs. Concurrent with these objectives, studies of sediment transport around the Point Conception headland and of the mechanics of littoral transport are being conducted. Methods developed by this program have direct application to engineering design of such works as harbor development and beach erosion prevention, and quasi-military application such as the location of radioactive or other toxic materials.

Sand grains indigenous to the study area have been labeled with xenon-133 which does not adversely affect the hydraulic properties of the sand. A mobile detector system using cesium iodide crystals and housed in a "ball" towed behind an amphibious vehicle detects quantity and areas of radiation. Computer programs correct and plot radiation data. A field test of equipment and principles at Cape Kennedy, Florida, was successful. Additional field tests were at Surf and Point Conception, California. These tests included isotope distribution, sediment analysis, offshore profiles, and oceanic and atmospheric environment monitoring. In addition, model tests were conducted at CERC to compare high and low specific activity xenon, and to study beach development and movement under the controlled conditions of a hydraulic laboratory.

Data density is sufficient to support tentative conclusions regarding offshore sediment movement in the Point Conception area. Additional field tests will extend the survey from the beach through the surf zone. Also, development of instruments and field programs will continue in order to permit routine use by technicians and field crews.

DD FORM 1 NOV 65 **1473** REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
radioisotopes						
radioactive isotopes						
xenon-133						
radiation detector						
radiation measuring instruments						
cesium iodide crystals						
sediment transport						
littoral transport						
littoral processes						
sediment analysis						
hydraulic models						
headlands						
beaches						
hydrographic surveys						
Point Conception, California						
Cape Kennedy, Florida						

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1. Radioisotopes
2. Sediment tracers
3. Littoral transport
4. Point Conception,
   California

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II Duane, D. B.
III Judge, C. W.

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