UNDERWATER GAMMA RADIATION DETECTION SYSTEM

Final Report
for
A Research Project Sponsored by the

American Electric Power Service Corporation

University Account No. 30544

October, 1970

Phillip A. Plato
Dale E. Gelskey
G. Hoyt Whipple

The University of Michigan
Department of Environmental & Industrial Health
Radiological Health Group
Ann Arbor, Michigan

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont'd.)

INTRODUCTION

Purpose of the Project

There are many environmental media which may be sampled as part of a radiological survey of a nuclear facility. One medium sampled regularly in most radiological surveillance programs is sediment. Many sediments are able to retain large amounts of radionuclides that would otherwise remain dissolved or suspended in low concentrations in water. Suspended particles and biological organisms may remove radionuclides from water and eventually settle to the bottom. If sediment were the final resting place for radionuclides which find their way to the bottom of large bodies of water little attention might be given to sediment as a sampling medium. However, many benthic and filter feeding organisms remove radionuclides from sediment as part of their digestive processes. These organisms may in turn be eaten by man directly or be eaten by larger organisms which are consumed by man. Thus, sediment is a link in some food chains to man; a link which retains radionuclides that are potentially hazardous to man. The need to measure both qualitatively and quantitatively the radionuclides present in sediment is apparent.

Radiological measurements of sediment have been made for years. The conventional procedure involves collecting grab samples of sediment using some type of dredging device, transporting the samples to a laboratory for oven drying, and obtaining a gamma ray spectrum for each sediment sample using a multichannel analyzer. The spectra are then analyzed for radionuclides present in the samples. The disadvantages of this procedure include:

1. Using a dredging device disturbs the sediment sample from its natural condition. Disturbances occur when different layers of sediment are combined to form one homogeneous sample and when some of the fine clay particles (the chemically active fraction of the sediment) are lost in bringing the sample to the surface of the water.
2. A relatively small area is sampled even if large numbers of samples are collected. There is a finite probability of not sampling a highly radioactive area. There is no way of knowing whether a representative set of samples has been obtained.
3. The sensitivity for measuring radioisotopes present in grab samples of sediment is low due to self adsorption which limits the volume of sediment that can be counted in the laboratory.
4. A long lag time usually exists from the time a sample is collected until it is analyzed. If some samples show more radioactivity than others a second trip to the field may be required to collect additional samples in the area with the greater radioactivity.

These four disadvantages can be reduced or eliminated if the collection and analysis steps are combined by taking the equipment into the field and analyzing the undisturbed sediment.

A letter dated November 27, 1968, from Mr. C. F. Pantske, Assistant Secretary of the Interior to Mr. H. L. Price, Director of Regulations, U.S. Atomic Energy Commission concerning the construction permit for the Donald C. Cook Nuclear Power Plant, stated:

> "Although we recognize the difficulty involved in trying to obtain reproducible results from samples of loose sand, there are methods other than the taking of sediment cores. For example, it is possible to measure radioactivity associated with sediments _in situ_ by the use of an underwater probe."

The letter referred to work done by Jennings (reviewed in the next section of this report) which involved placing a watertight sodium iodide detector above undisturbed sediment. While Jenning's approach minimized the last three disadvantages listed above, it still resulted in sampling a relatively small area of sediment.

The purpose of this investigation was to develop and test a device which could measure radioactivity while moving over large areas of undisturbed sediment. In a letter dated March 27, 1969, from Mr. Paul Dragoumis, Assistant Vice President, American Electric Service Corporation, to Dr. G. Hoyt Whipple, Professor of Radiological Health, University of Michigan, Mr. Dragoumis stated that:

> ".... extraction of bottom samples for survey purposes ought to be abandoned in favor of putting a traveling detector into (Lake Michigan) for direct measurement purposes."

The letter authorized a $25,000 grant to the University of Michigan, Department of Environmental Health, for the purpose of developing and testing such a detector primarily for Lake Michigan, but which would be applicable to any body of water. The budget included funds for equipment, supplies, travel, and a fellowship to support a graduate student who would work on the project. The project was to be completed by September, 1970.

Historical Background

Underwater probes for measuring gamma radiation in water were used as early as 1955.[1] A scintillation probe was designed and built at Hanford, Washington, for continuous monitoring of gross gamma radioactivity in the Pacific Ocean. The detector (a plastic phosphor 3 inches in diameter and 30 inches long), circuitry, and batteries were encased in a 7 foot long stainless steel housing, and towed underwater behing a Coast Guard research vessel.

A publication describing an underwater gamma ray detection system appeared in 1960 by G. K. Riel,[2] who measured the concentration of radioisotopes in waters surrounding several nuclear power reactors and in the Pacific and Atlantic oceans. The gamma ray detector was a sodium iodide thallium activated crystal.

Two sled-mounted scintillation probes were used in the early 1960s for gamma radiation tracer studies. In 1961 W. W. Sayre and D. W. Hubbel used a sled-mounted probe to investigate the dispersion of radioactive labled sand in the North Loup River in Nebraska.[3] In 1962 the Sanitary and Hydraulic Engineering Laboratories of the University of California used a sled-mounted probe to examine the movement of radioactive labeled sediment entering the San Francisco Bay.[4]

In 1965 D. Jennings mounted a scintillation probe to a tripod and used the device to detect gamma ray emitting fission products in situ in Columbia River sediments.[5] This device allowed Jennings to measure radionuclides qualitatively and quantitatively in sediments but could only be positioned over one location at a time. To analyze another area the tripod had to be raised from the bottom, transported to a new location, and then positioned over the new site.

Final Results

By September 1, 1970, an underwater probe had been designed, built, calibrated, and field tested under a grant from the American Electric Power Service Corporation to the University of Michigan, Department of Environmental Health. The probe travels above the bottom sediments and measures qualitatively and quantitatively the radioactive content of the sediment. The radiation detector is housed in a large high flotation tire which rolls across the lake bottom with minimal disturbance to the sediment. The tire was used successfully on very rocky bottoms, on bottoms consisting of hard packed sand, silt, and clay, and on very loosely packed bottoms. The detector is connected by an electrical cable to the analyzing equipment located aboard a boat. The electronic equipment can be placed aboard an 18 foot outboard boat for work in shallow water or aboard a large ship for work in deep water.

The analyzing equipment consists of a gamma ray spectrometer and auxillary components which permit the operator to identify the radionuclides present in the sediment over which the tire containing the detector is rolling. The spectra are stored on punched paper tape for quantitative analyses at a later time. The operator can evaluate immediately the radioactivity present in the sediment over which the tire is rolling. This evaluation can be used to direct the detector to a new location or to stop the detector for an extended measurement at a particular location.

DESCRIPTION OF THE SYSTEM

Figure 1 shows a block diagram of the system designed to permit *in situ* gamma radiation measurements of sediment. The detector consists of a right circular cylindrical sodium iodide crystal 10 cm thick by 12 cm in diameter. The crystal is connected optically to a 12 cm diameter photomultiplier tube. The high output phototube eliminates the need for signal amplification at the detector and drives the signal through 500 meters of co-axial cable. The cable carries both the 1800 volts necessary to drive the phototube and the output voltage pulses from the phototube. An aluminum pressure vessel is used to protect the crystal, phototube, and voltage divider against water, pressure

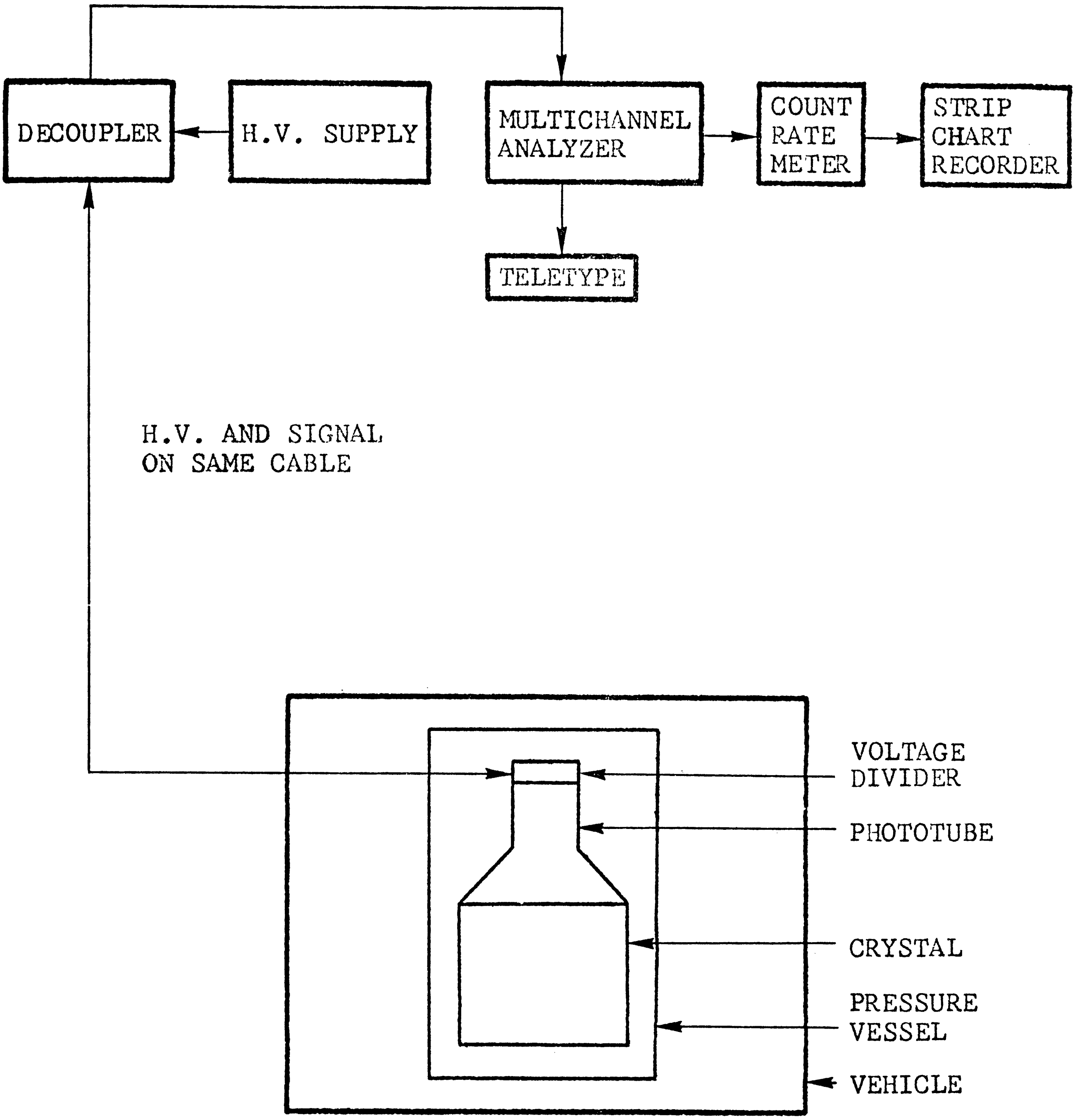

FIGURE 1

BLOCK DIAGRAM OF UNDERWATER
GAMMA RADIATION DETECTOR

and thermal and physical shock. The vessel is designed to withstand pressures encountered in water depths up to 350 meters. Figure 12 in the Appendix shows a detailed drawing of the pressure vessel and its contents. Gamma ray transmission characteristics for the aluminum used in fabricating the pressure vessel are shown in Figure 13.

A vehicle was necessary to transport the detector over bottom sediments while being towed by a boat. The towed vehicle was required to:

1. Hold the detector at a constant distance from the bottom.
2. Move with ease over hard packed sand and loosely packed mud.
3. Move over or around submerged obstacles.
4. Disturb the sediment as little as possible.
5. Protect the detector from physical shock.

A sled was the first attempt at a towed vehicle. Scuba divers found that the sled satisfied only requirement #4 listed above. The sled was replaced by a high flotation rubber tire which appeared to satisfy all of the requirements listed above. A drain plug is located on each of the tire's two steel side rims. When the tire is to be used the drain plugs are removed and the tire is lowered to the lake bottom. Figure 2 demonstrates the method used to position the aluminum pressure vessel inside the tire. The vessel is mounted pendulously between the axle which connects the tire's two steel side rims. As the tire rotates about the stationary axle, the detector remains in a vertical position. The cable which transmits the signals from the detector to the boat enters the tire through a hollow axle and connects to the detector. The semicirular tow bar deflects the tire

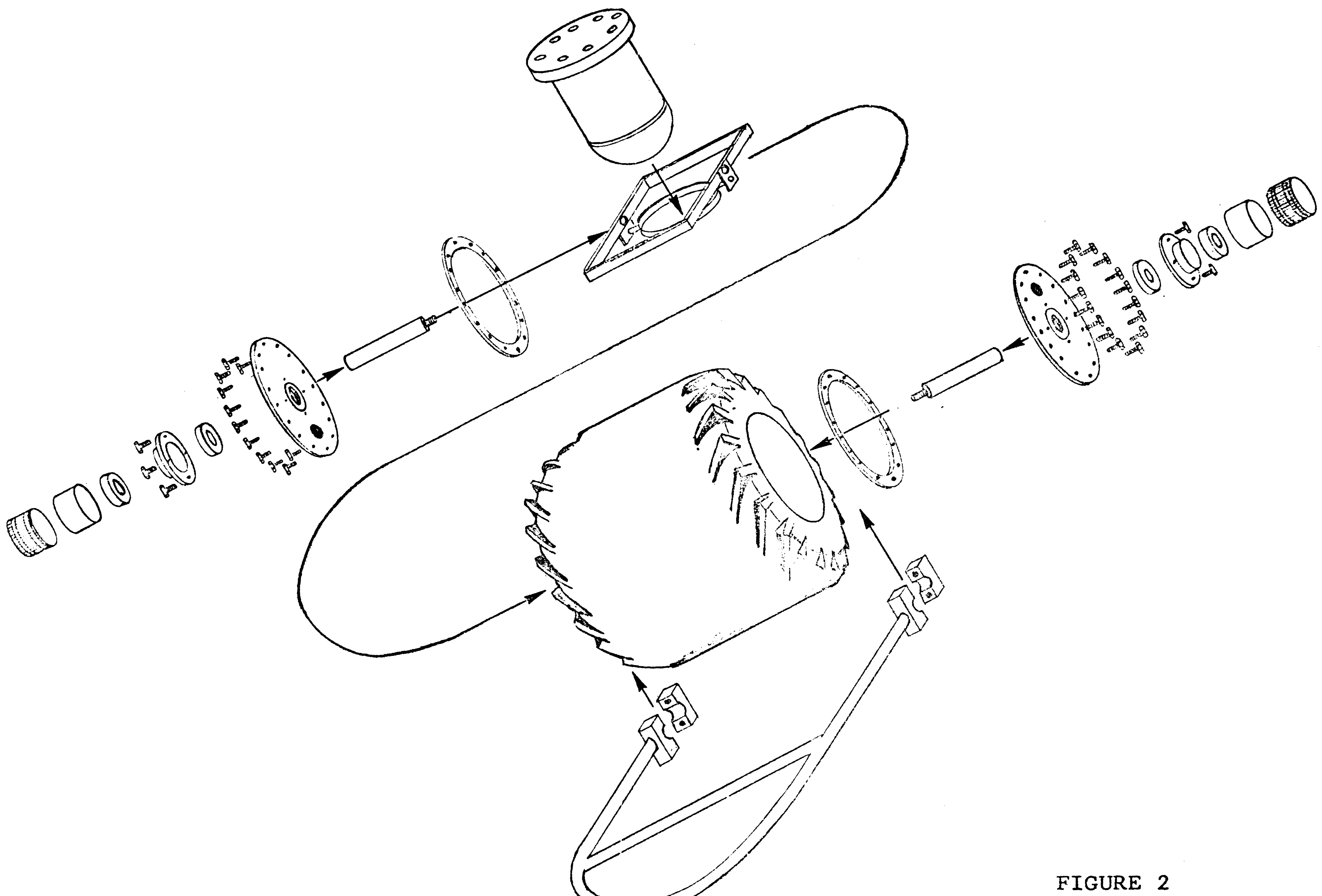

FIGURE 2

PRODUCTION DRAWING SHOWING UNDERWATER GAMMA RADIATION DETECTOR ASSEMBLY around obstacles protruding upward from the bottom.

A high voltage power supply, shown in Figure 1, supplies 1800 volts required for the photomultiplier tube. The decoupler is used to separate the 1800 volts supplied to the phototube from the variable (up to 10 millivolts) signal coming from the phototube. Figure 14 in the Appendix shows a circuit diagram of the decoupler and voltage divider string.

A 256 channel pulse height analyzer, shown in Figure 1, is used to store the signals coming from the photomultiplier tube. Pulses from the photomultiplier tube are recorded in two ways. A count rate meter gives the gross gamma count rate from the multichannel analyzer. A low level discriminator is used to filter out low energy pulses such as noise, therefore the count rate meter can be made sensitive to small changes in gamma ray produced pulses. A strip chart recorder records the count rate as a function of time. The operator uses the strip chart record to detect subtle changes in the gamma ray activity as the detector is traveling above the sediment.

A teletype unit records each gamma ray spectrum on typewritten paper and on punched paper tape. The data on the punched paper tape can be transferred easily to a reel of magnetic tape which acts as a permanent file for up to 3000 spectra.

A computer program called GRAPH can be used to graph any of the spectra present on the magnetic tape reel. A spectrum analysis computer program called NASA can be used to analyze any of the spectra present on the magnetic reel, for specific radioisotopes.

Figure 3 shows a photograph of the equipment used to construct the underwater gamma radiation detection system. Table 4 in the Appendix contains a complete list of the equipment and the cost of each item.

CALIBRATION OF THE DETECTOR

Calibration Considerations

Qualitative determination of radionuclides present in sediment can be made by bringing the detector close to the bottom so that a statistically significant gamma ray spectrum is obtained. Quantitative determination requires a calibration of the detector.

A quantitative calibration requires that known quantities of the radioisotopes present in sediment be measured by the detector under conditions identical to those encountered in the field. Sediment spectra taken in the field then can be compared to the complete set of standard reference spectra for quantitative analyses of the field spectra.

A spectrum analysis computer program which uses the least squares method has been developed by Dr. J. I. Trombka of the Goddard Space Flight Center. A copy of this program was obtained from Dr. Trombka and revised substantially to fit the needs of this project. The program is called NASA after its original sponsor.

The NASA program is designed to receive a library of standard reference spectra. The standard spectra are linear arrays of numbers with dimensions of uCi/meter^2, which produced

FIGURE 3. EQUIPMENT USED IN THE UNDERWATER GAMMA RADIATION DETECTION SYSTEM.

each of the library spectra must be known. The program receives a sample field spectrum and determines how much of each of the library standards is present in the sample spectrum.

The NASA program constructs a spectrum from the library reference spectra to match a sediment spectrum taken in the field. The final results given by the NASA program for each sediment spectrum are a graph of the spectrum and one data sheet which contains the activities of each of the library references that are present in the sediment spectrum. The graph of the sediment spectrum is used for a visual check of the presence of radioisotopes not represented in reference library of the NASA computer program.

The calibration of the detector required that the field counting geometry be duplicated in the laboratory. It was assumed that radioisotopes deposited on sediment from nuclear weapons tests or from waste discharges from nuclear facilities would become layered on the surface of the sediment. Since man-made radioisotopes are the radioisotopes of prime concern in an environmental surveillance program, the detector was calibrated for a counting geometry approximating an infinite plane source. Standard reference spectra were made with plane sources placed beneath the detector. Therefore, all quantitative analyses of sediment spectra taken in the field are reported as activity per unit area equivalent to the plane sources used in the calibration geometry.

Calibration Procedure

The surace area over which the detector can measure gamma rays depends upon the height of the detector above the sediment and the energy of the gamma rays. It was assumed (and verified by field observations) that the high flotation tire would hold the detector at a constant distance above the sediment.

The underwater gamma ray detector system was calibrated in the laboratory using a twelve foot diameter, four foot deep, plastic swimming pool. About seven inches of sand were distributed uniformly on the bottom of the pool to simulate a lake bottom.

In order to determine the effective area over which the detector can measure gamma radiation, Tygon tubing (0.50 inch OD, 0.25 inch ID) was first coiled into a 30 cm diameter plane on top of the sand in the pool. The ends of the coiled Tygon tubing were placed in a reservoir of Cs-137. A pump was used to keep the cesium solution moving continuously through the Tygon tubing.

The detector, mounted inside the tire, was placed over the coiled tubing, and a gamma ray spectrum was obtained. The integrated count rate under the Cs-137 photopeak was measured. The diameter of the coiled Tygon tubing was increased to 40 cm, by adding turns of tubing to the coil, and again the integrated count rate under the photopeak was measured. The 40 cm diameter coil resulted in a count rate greater than that measured with the 30 cm diameter coil. The diameter of the Tygon coil was increased by adding further turns of tubing to the coil until no further increase in the integrated count rate under the photopeak occurred. Figure 4 shows the resulting graph of activity versus coil diameter. Figure 4 shows that a coil diameter greater than 70 cm contributes no additional counts to the photopeak. Thus, 70 cm was taken to be the diameter of the effective area over which the detector is sensitive.

The tygon tubing was then arranged in a rectangle 100 cm by 100 cm. This geometry was favored over a circle because there was a minimum diameter in which tubing could be coiled. The rectangular geometry resulted in a uniform plane source beneath the detector.

The use of the NASA least squares spectrum analysis computer program requires a reference spectrum for each radioisotope that may be present in a sample spectrum. Radioisotopes detected in the sediments of Lake Michigan from previous work included naturally occurring potassium-40 and radium-226 in equilibrium with its daughters. Cesium-137 from nuclear weapons fallout is detectable over large areas of Lake Michigan sediment.[6] The Big Rock Nuclear Power Reactor at Charlevoix, Michigan, is known to release significant amounts of zinc-65, manganese-54, cobalt-58, and cobalt-60. It was decided tc calibrate the underwater gamma ray detection system for these seven radioisotopes.

Calibration for Cs-137 was done by filling the reservoir on the side of the pool with a solution containing Cs-137 and pumping the solution through the Tygon tubing located beneath

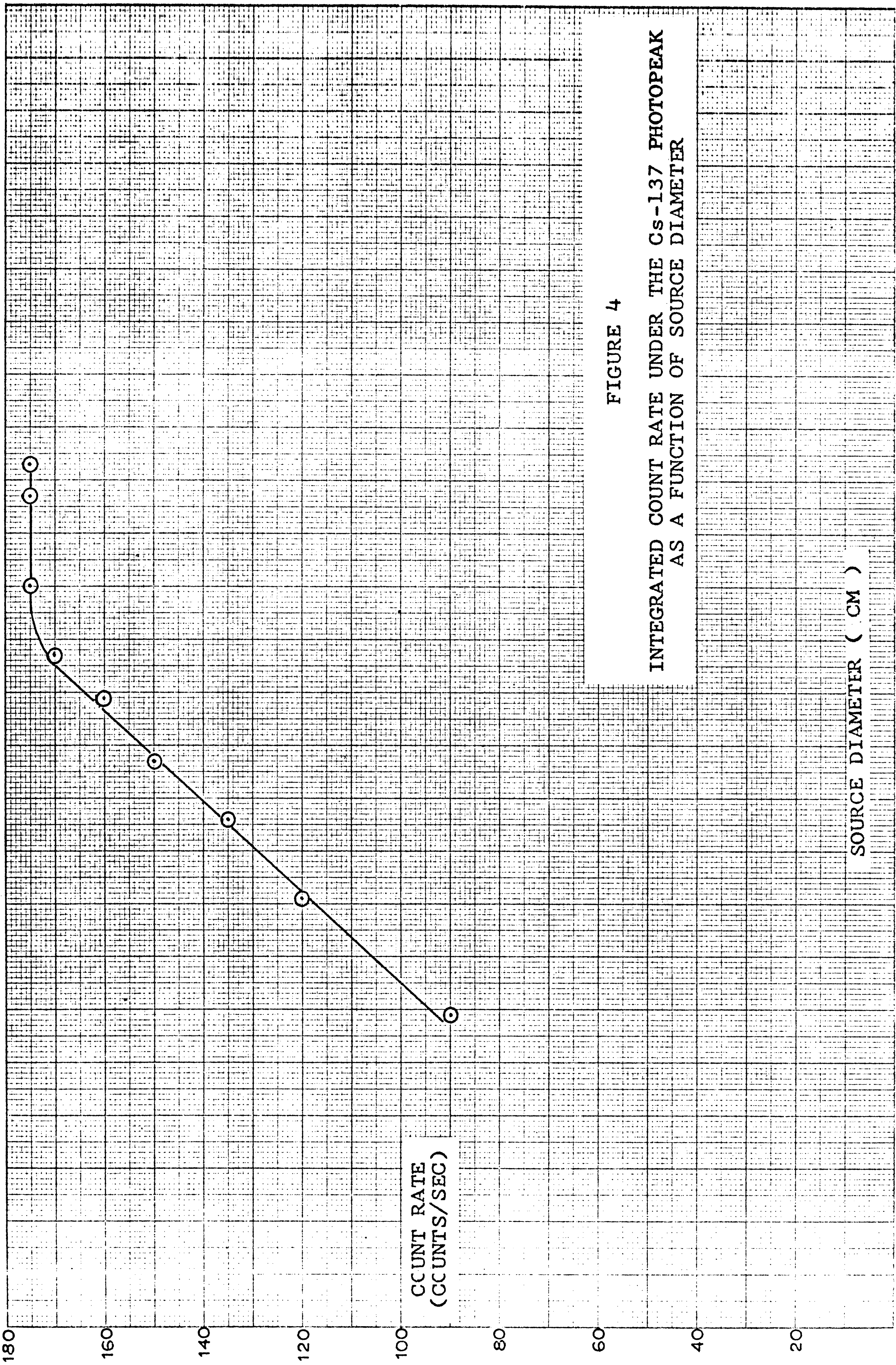

FIGURE 4

INTEGRATED COUNT RATE UNDER THE Cs-137 PHOTOPEAK AS A FUNCTION OF SOURCE DIAMETER the detector. The activity of the Cs-137 in the solution was increased until a dead time of two percent was reached with the gamma ray spectrometer. This activity was sufficient to produce a statistically valid spectrum within a relatively short counting time. The Cs-137 present in the Tygon tubing was counted for 200 seconds, and the resulting Cs-137 reference spectrum was recorded on punched paper tape. Three one milliliter aliquots were removed from the reservoir and evaporated to dryness on two inch diameter planchets. The planchets were counted on a previously calibrated gamma ray spectrometer system, and the NASA computer program was used to measure the Cs-137 activity present on each of the planchets. The average of these three activities was used as the activity per milliliter of solution in the reservoir and in the Tygon tubing. The volume of the Cs-137 solution in the Tygon tubing within the 70 cm effective area of the detector was calculated to be 884 milliliters. Thus, the activity, in units of microcuries per square meter, used to generate the Cs-137 reference spectrum was determined. The same procedure was used for Zn-65, Mn-54, Co-58, and Co-60.

A known weight of potassium chloride was dissolved in a known volume of 0.5 normal hydrochloric acid to produce a known activity per unit volume of potassium-40. A K-40 spectrum was obtained for a calculated activity in units of microcuries per square meter.

Radium-226 is a difficult radioisotope to calibrate since sealed sources must be used with time allowed for equilibrium to be reached.

A reference spectrum of Ra-226 plus daughters is required for the NASA program since the resulting photopeaks are observed regularly in sediment spectra. However, the exact activity of Ra-226 plus daughters present in sediment is of little interest in environmental monitoring of nuclear facilities. It was decided, therefore, to produce a radium-226 reference spectrum by placing one millicurie of Ra-226 plus daughters contained in a flame sealed ampule close enough to the detector to produce a reference spectrum. The activity used to produce this reference spectrum was called arbitrarily, a "radium unit". The NASA computer program can give the relative number of radium units present in a sediment spectrum.

FIELD EXPERIENCE

Trip No. 1

July 9-11, 1969

Grand Haven, Michigan

The detector was mounted on a sled for a field test in Lake Michigan and the electronic equipment was placed aboard the University's 50 foot ship R/V MYSIS. To determine the effect of water in attenuating gamma rays from the sediment, the detector was placed directly on the lake bottom and several ten second gross gamma counts were taken. The detector was then positioned at 3, 5, 7 inches and 10 feet above the bottom and several ten second gross gamma counts were taken at each height interval. The water depth was about 20 feet. Figure 5

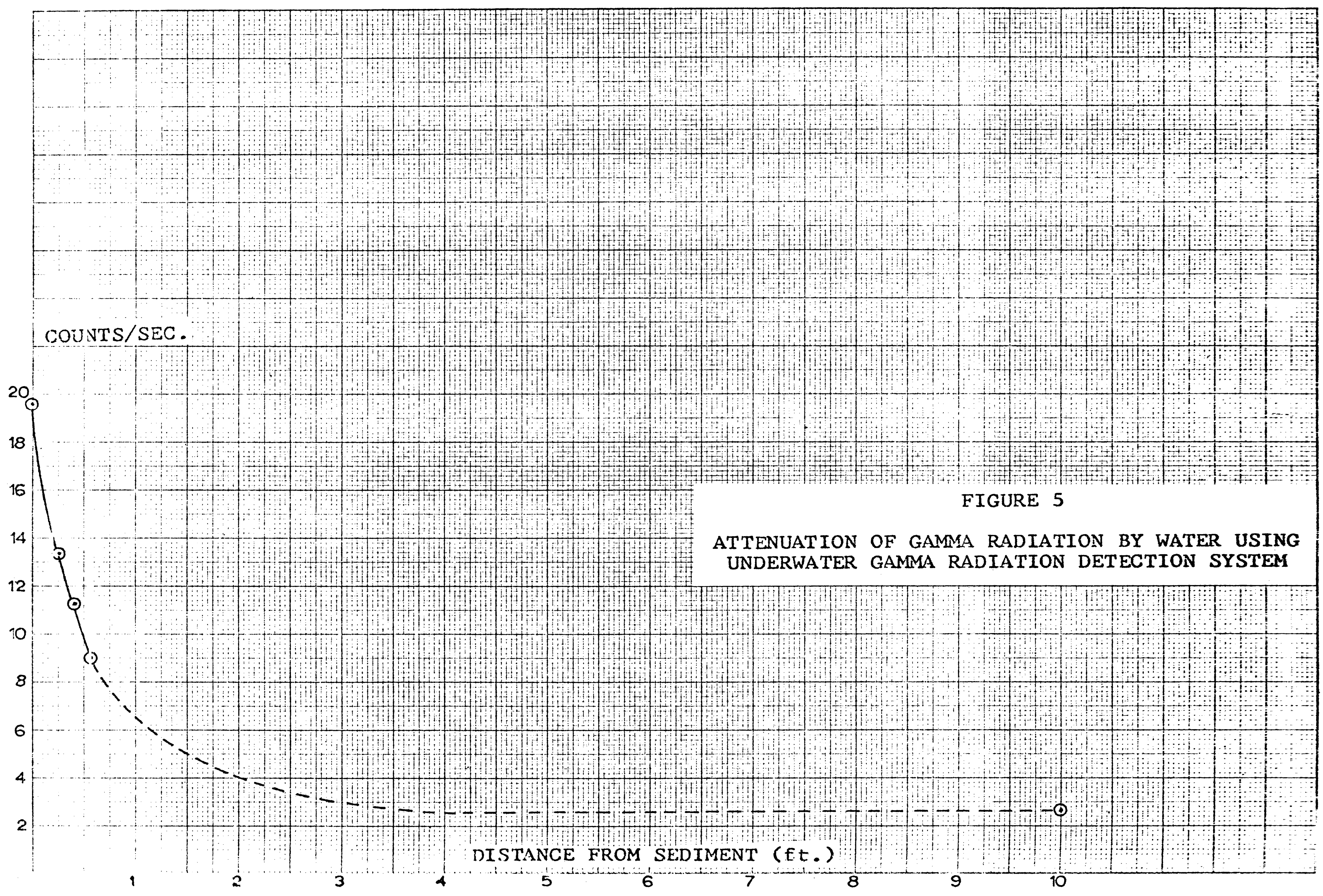

FIGURE 5

ATTENUATION OF GAMMA RADIATION BY WATER USING UNDERWATER GAMMA RADIATION DETECTION SYSTEM shows the attenuating effect of the water. This rather crude experiment emphasized the need for keeping the distance between the detector and the bottom as small and as constant as possible. The detector was mounted on the sled two inches above the bottom. The sled was towed parallel to shore past the mouth of the Grand River. The gross gamma activity was higher at the mouth of the river than on either side of the mouth. Grab samples of the sediment taken along the path of the sled showed that the Grand River had deposited a layer of organic sludge over the hard packed sand of Lake Michigan. This test showed the value of gross gamma activity as an indication of radioactivity changes in sediment.

<u>Trip No. 2</u>

July 29 - August 2, 1969

Tobermory, Ontario

The clear water of the Georgian Bay presented an opportunity to observe the dynamic behavior of the sled used in Trip No. 1. A skiff was used to pull the sled across the bottom of a bay approximately 15 feet deep while scuba divers observed the behavior of the sled.

The bottom of the bay was sand, some partially buried tree trunks and a few large rocks. The sled frequently became lodged against large rocks or tree trunks. It was decided to abandon the sled as a vehicle for the detector.

Trip No. 3

August 6-8, 1969

Charlevoix, Michigan

The probe was lowered over the side of the R/V MYSIS without the sled. The detector was placed on the bottom at a point approximately half a mile from the Big Rock Point Nuclear Power Plant, and later at a second point about 5 miles from the Plant. The spectra showed several man-made radionuclides in the sediment near the Plant, but only natural radionuclides in the sediment five miles from the plant.

Trip No. 4

May, 1970

Monroe, Michigan

By May, 1970, the system was complete including the high flotation tire. Laboratory tests indicated that all the components were working as expected and it was decided to field test the system around the Enrico Fermi Nuclear Power Plant. Three trips were made to the Plant during May. None of these trips was successful in the sense that each time various problems prevented the taking of even one gamma ray spectrum of the sediments in the area. However, a great deal of experience was gained in the art of using the detection system in the field. This experience proved invaluable once the technical problems were eliminated.

A Chevrolet Carryall was used to transport all of the equipment including the tire to the Fermi Plant. An 18 foot Boston Whaler boat with a 55 horse power outboard motor was pulled behind the Carryall to the Plant. The boat was used at the Plant to carry the electronic equipment together with three people and to tow the detector across the bottom. Since much of the river and lagoon around the Plant was very shallow, the use of a small boat was essential.

During the first two trips to the Fermi Plant an intermittent short-circuiting problem was noticed in the electrical cable used to carry high voltage to the detector and return pulses from the photomultiplier tube. This shorting caused an avalanche of noise pulses which obliterated the gamma ray spectra that otherwise would have been recorded. The shorting problem did not occur in the laboratory. Many alterations were made, but the problem was not eliminated. The third trip to the Fermi Plant ended when the propeller of the outboard motor severed the electrical cable.

<u>Trip No. 5</u>

May 22, 1970

Brighton, Michigan

In an effort to isolate the shorting problem it was decided that conditions aboard a boat could be simulated by setting up the electronic equipment inside the Chevrolet Carryall and pulling the tire containing the detector behind the truck across land. It is easier to stop a truck and look for problems than to stop a boat. The day was spent pulling the detector around a vacant field without encountering the shorting problem. It was discovered that the system could be used to measure radioactivity on land as well as in sediment.

Many gamma ray spectra were taken which showed naturally occurring potassium-40 and radium-226 plus daughters. A point source of cobalt-60 was buried at depths up to 30 centimeters in the ground. As the detector rolled over the buried source a sharp increase in the gross gamma count rate was observed. The time during which the detector was near the buried source was too short for cobalt-60 to be seen in the gamma spectra. This emphasized the need to detect subtle changes in activity that would go unnoticed if only gamma ray spectra were taken.

Trip No. 6

June 15, 1970

Pinckney, Michigan

To this date the tire had not been observed rolling across bottom sediments as had been done with the sled. It was decided to observe the dynamic characteristics of the tire rolling on the bottom under less than ideal conditions. The tire, without its associated electronic equipment, was taken to North Lake, one of the lakes located in the Pinckney Recreation Area near Ann Arbor, Michigan. Scuba divers observed the tire as it was pulled across the lake bottom. The bottom sediment was a thick (greater than one meter) oozy organic substance. The sled which was used previous to the tire would have buried itself completely in the soft sediment. The tire rode over this sediment with little trouble due to the large surface area of the tire in contact with the sediment. It was discovered, however, that any air left in the tire causes it to ride unevenly across the bottom. It was also noticed that even though a large plume of sediment was kicked up behind the rolling tire the sediment in front of and under the tire remained relatively undisturbed.

Trip No. 7

July 18- 6, 1970

Charlevoix, Michigan

The electronic equipment was placed aboard the R/V MYSIS for testing in Little Traverse Bay near the Big Rock Point Nuclear Power Plant. Figure 6 shows the tire being prepared for towing near the Plant. The system was complete although not calibrated.

Throughout most of the field trip the electrical shorting problem occurred frequently enough to prevent any spectra from being obtained. It finally was discovered that the problem was associated with the underwater splices in the electrical co-axial cable. There was not a water tight separation between the center wire and the surrounding ground wire in the cable. The two wires were separated electrically using electrical tape. However, water could get into the ground wire through small breaks in the outer rubber surface of the cable. Water seeped through the electrical tape at the splice and caused an intermittent short. The problem was solved by putting a water tight splice around the center wire and a second water tight splice around the surrounding ground wire. This provided a water tight seal

FIGURE 6. UNDERWATER GAMMA RADIATION DETECTION SYSTEM BEING PREPARED FOR FIELD WORK NEAR BIG ROCK NUCLEAR POWER PLANT.

between the two wires and resulted in flawless operation of the underwater detector during the last two days of the trip.

Figure 7 shows where spectra were taken on July 24, 1970. The discriminator for the integrating count rate meter was set very low. Since a large fraction of all of the pulses entering the spectrometer are low energy (less than 0.4 MeV) the gross gamma count rate was constant throughout the day and of little help in identifying areas of high and low activities.

Figure 8 shows where spectra were taken on July 25, 1970. The discriminator for the integrating count rate meter was increased from the previous day so that energy pulses less than 0.40 MeV were not included in the gross gamma count. These low energy pulses, however, were allowed to pass into the memory of the spectrometer. This made the count rate meter sensitive to changes in the gross gamma activity representing primary gamma rays.

Table 1 shows a compilation of the information obtained from the spectra taken on July 24-25. The only radioisotopes observed in the spectra were cesium-137, potassium-40, and radium-226 in equilibrium with its daughters. T ble 1 shows that the detector exhibited excellent gain stability throughout the four hours it was underwater each day.

Many of the spectra showed large, well-defined Cs-137 and K-40 peaks. Figure 9 contains a typical spectrum together with the gross gamma activity recorded simultaneously with the spectrum. Figures 7 and 8 and Table 1 indicate that the spectra

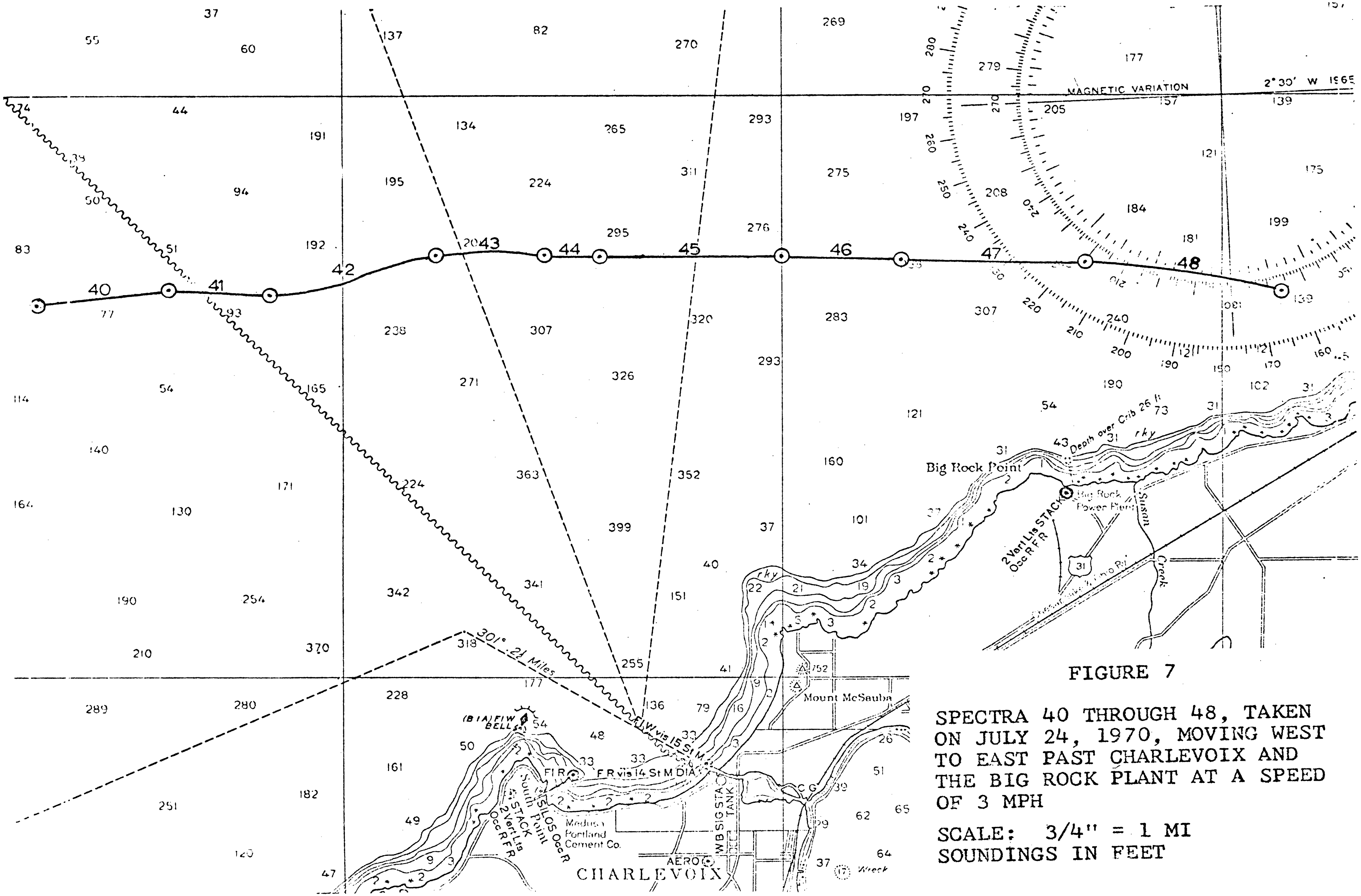

FIGURE 7

SPECTRA 40 THROUGH 48, TAKEN ON JULY 24, 1970, MOVING WEST TO EAST PAST CHARLEVOIX AND THE BIG ROCK PLANT AT A SPEED OF 3 MPH

SCALE: 3/4" = 1 MI
SOUNDINGS IN FEET

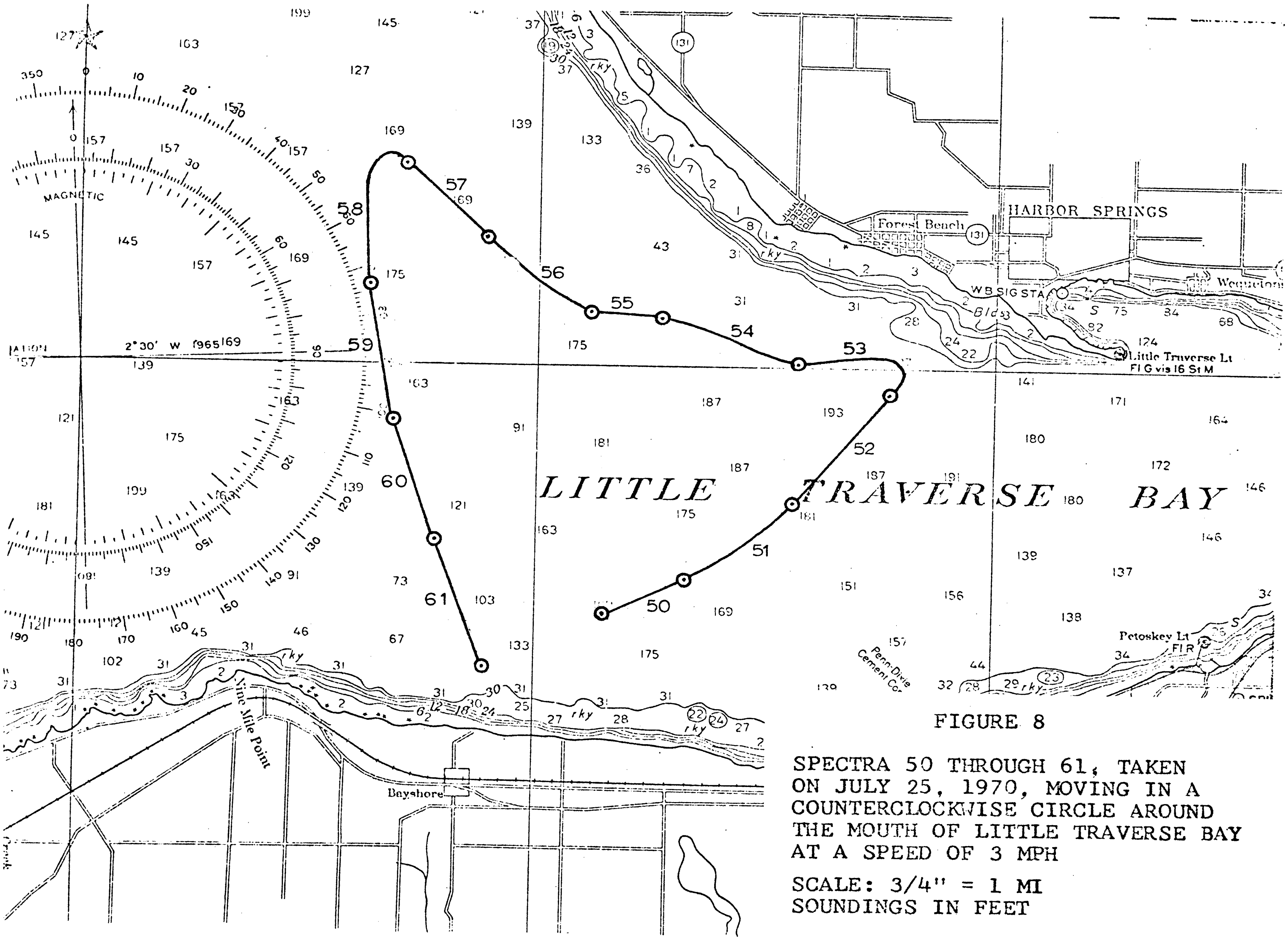

FIGURE 8

SPECTRA 50 THROUGH 61, TAKEN ON JULY 25, 1970, MOVING IN A COUNTERCLOCKWISE CIRCLE AROUND THE MOUTH OF LITTLE TRAVERSE BAY AT A SPEED OF 3 MPH

SCALE: 3/4" = 1 MI
SOUNDINGS IN FEET

TABLE 1

Results of Gamma Ray Spectra Taken Around the Big Rock Nuclear Power Plant

Spectrum Number	Cesium-137 Energy Peak (MeV)	Cesium-137 Activity (uCi/m^2)	Potassium-40 Energy Peak (MeV)	Potassium-40 Activity (uCi/m^2)
40*	-	0	1.46	90.1
41*	-	0	1.46	104
42	-	0	1.46	65.4
43	-	0	1.47	77.7
44	-	0	1.47	66.1
45	0.67	.045	1.47	45.8
46	0.67	.073	1.47	69.8
47	0.68	.101	1.47	70.2
48	0.67	.186	1.47	56.4
50	0.66	.854	1.44	55.7
51	0.66	1.68	1.45	65.9
52	0.67	1.30	1.46	71.6
53*	0.67	1.16	1.47	126
54*	-	0	1.47	128
55*	-	0	1.47	121
56*	-	0	1.47	111
57*	-	0	1.45	122
58	-	0	1.45	116
59	-	0	1.46	114
60	-	0	1.45	112
61	-	0	1.45	114

*Ra-226 detected in these spectra.

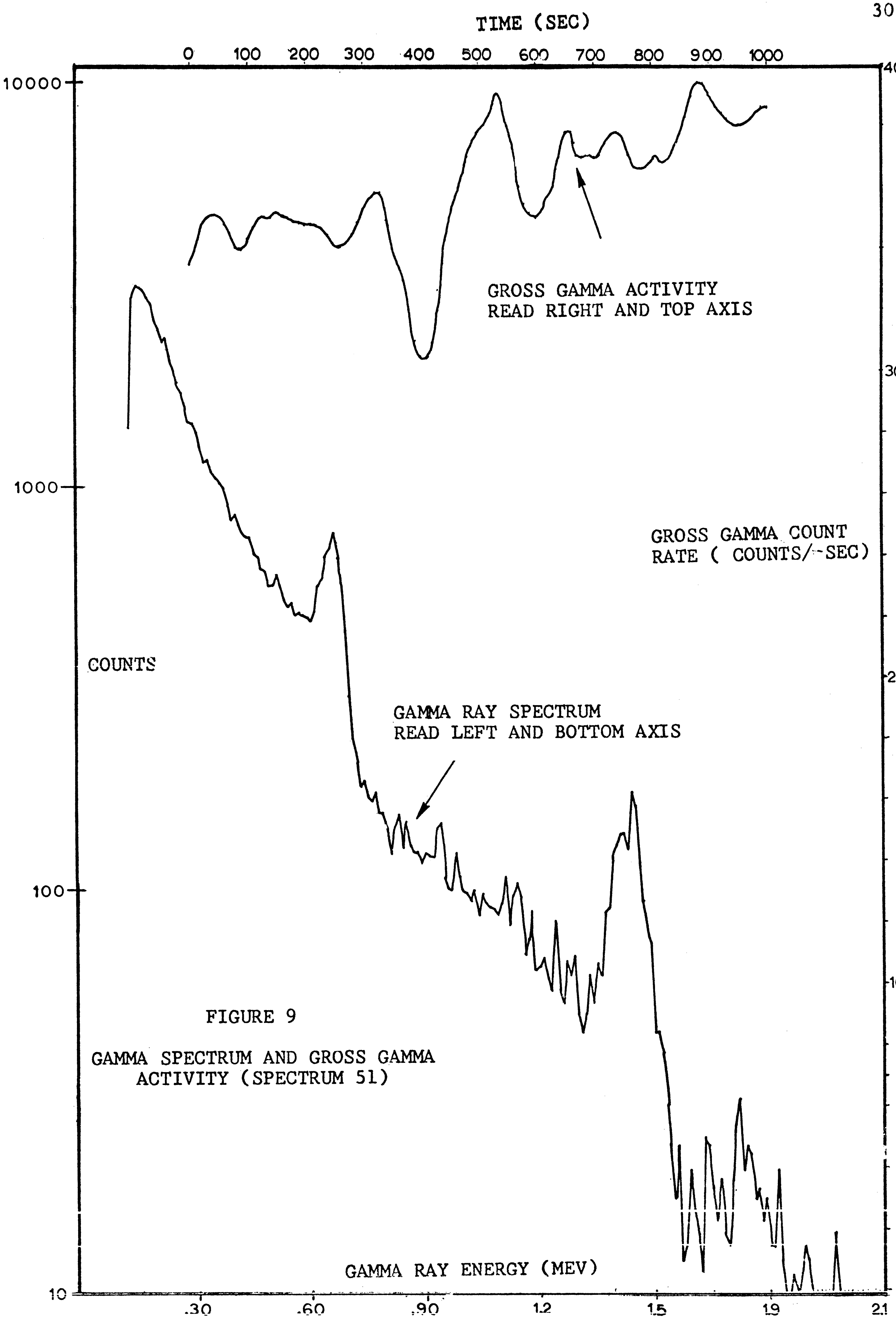

FIGURE 9

GAMMA SPECTRUM AND GROSS GAMMA ACTIVITY (SPECTRUM 51) taken on deep sediments showed detectable amounts of Cs-137. It is likely that the fine silt and clay particles tend to remove dissolved ions from the water and to settle in the deeper areas. The Cs-137 seen in the spectra could have come from the Big Rock Nuclear Power Plant or from nuclear weapons tests. Two factors point to the latter explanation. First, no other radioisotopes were observed that could have come from the Plant. Second, grab samples of sediment taken at fifty locations around Lake Michigan show significant amounts of Cs-137 uniformly distributed throughout the Lake.[6]

As spectrum No. 54 was about to be completed on July 25, the count rate increased rapidly from about 40 to about 70 counts per second. Since this appeared to indicate a "hot spot" the ship stopped and a grab sample of sediment was taken. This sample, unlike any of the other grab samples taken in the area, contained small managanese nodules. The source of the radioactivity which caused the count rate meter to show an increase in activity was Ra-226. It is possible that conditions that cause manganese to precipitate and form concentrated nodules also cause radium to precipitate. This is supported by the fact that higher than average amounts of Ra-226 were detected where manganese nodules were found. It therefore may be possible to map the location of manganese deposits in Lake Michigan using the gamma probe.

The bottom terrain around Charlevoix is very rugged; depths drop to 300 feet within a quarter of a mile in some places. The tire in which the probe is mounted performed very well even in such rugged areas. Once the tire apparently flipped over. This was noted by a sudden drop in the gross gamma count rate which indicated that the detector was off the bottom. The problem was corrected easily by raising the tire about a foot off the bottom and then letting it fall to its normal towing position.

At the end of the day on July 21, the probe was brought toward the surface for recovery. The MYSIS was pitching and rolling on large swells. This caused the probe to bounce at the end of the tow cable. When the probe was about 20 feet from the surface of the water, the swivel hook on the tow bar broke and the probe fell about 150 feet to the bottom. A marker buoy had been attached to the tow bar at the beginning of the run and marked the spot where the probe landed. The MYSIS returned to the marker buoy on the following day with a grappling hook, 300 feet of rope, a small outboard motor boat, and two scuba divers. The probe was snagged with the grappling hook and raised to a depth of 100 feet where the divers were able to secure a steel cable on the tow bar. After recovering the probe it was dismantled to check for damage. Except for the broken swivel pin no damage was found.

<u>Trip No. 8</u>

October 4-8, 1970

South Haven, Michigan

The tested and calibrated underwater gamma ray detection system was taken to South Haven for a preoperational survey around the Palisades Nuclear Power Plant. An air valve had been installed in one of the side plates of the tire which could be used to inflate the tire to approximately 2 psig. At this pressure the tire remained rigid while passing over moderately rough land surfaces. The inflated tire could be pulled over land behind a Carryall containing the electronic equipment and a small gasoline powered generator.

The first day was spent measuring radioactivity present on a fourty acre pasture of the Sherman Dairy Farm. The farm is located approximately ten miles north of the Palisades Plant and is one of three dairy farms from which the Plant receives milk samples as part of an environmental surveillance program. Potassium-40 and radium-226 and its daughters were observed in all the spectra taken on the Sherman Farm. Spectra taken in one corner of the pasture showed detectable amounts of cesium-137.

Two days were spent aboard the R/V MYSIS measuring radioactivity present in bottom sediments near the Palisades Plant. Four passes were made parallel to the shoreline, each running from four miles north to four miles south of the Plant. Figure 10 shows where the spectra were taken, and Table 2 shows the data obtained.

Trip No. 9

October 9-11, 1970

Benton Harbor, Michigan

The same survey pattern used to measure the radioactivity present in sediment near the Palisades Plant was used at the

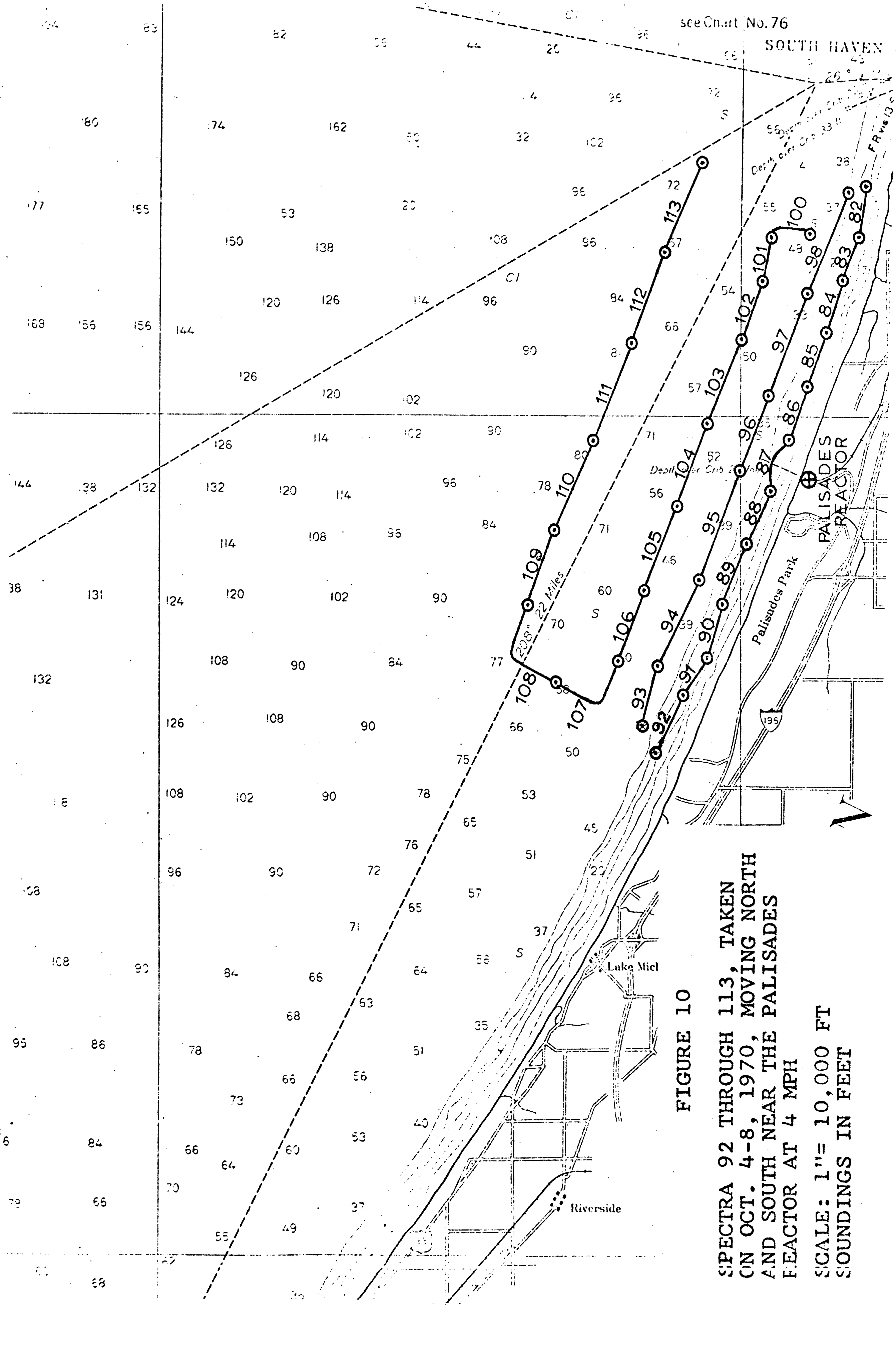

FIGURE 10

SPECTRA 92 THROUGH 113, TAKEN ON OCT. 4-8, 1970, MOVING NORTH AND SOUTH NEAR THE PALISADES REACTOR AT 4 MPH

SCALE: 1"= 10,000 FT
SOUNDINGS IN FEET

TABLE 2

Results of Gamma Ray Spectra Taken Around
Palisades Nuclear Power Plant

Spectrum Number	Potassium-40 Activity (uCi/m^2)
82	141
83	184
84	178
85	171
86	165
87	166
88	162
89	149
90	146
91	142
92	156
93	154
94	136
95	140
96	125
97	133
98	188
100	147
101	117
102	136
103	107
104	96
105	115
106	125
107	128
108	116
109	101
110	112
111	102
112	90
113	108

*K-40 was the only radioisotope observed in these spectra.

Donald C. Cook Nuclear Power Plant. The Cook Plant is expected to become operational in approximately two years. Figure 11 shows where the spectra were taken near the Cook Plant, and Table 3 shows the data obtained.

CONCLUSIONS

An underwater gamma radiation probe has been built and tested. The detector component of the system is mounted inside a high flotation rubber tire which transports the detector over the sediment being analyzed. A pulse height analyzer produces a gamma ray spectrum while the detector is moving. The spectra are recorded on punched paper tape and analyzed with the aid of computer programs.

The detector has been calibrated to give a quantitative measurement of sediment activity for several radioisotopes. The predicted activities for a spectrum, in units of microcuries per square meter, represent activities averaged over the distance covered by the detector while the spectrum was being recorded. A count rate meter is used to measure the total gamma ray activity being measured by the detector at any given time. The gross gamma data are recorded continuously on a strip chart recorder. Subtle changes in the activity present in the sediment can be detected by observing the strip chart recorder.

A number of spectra were taken around Big Rock, Palisades, and Donald C. Cook Nuclear Power Plants. Radioactivity measurements also were made on a dairy farm with the electronic

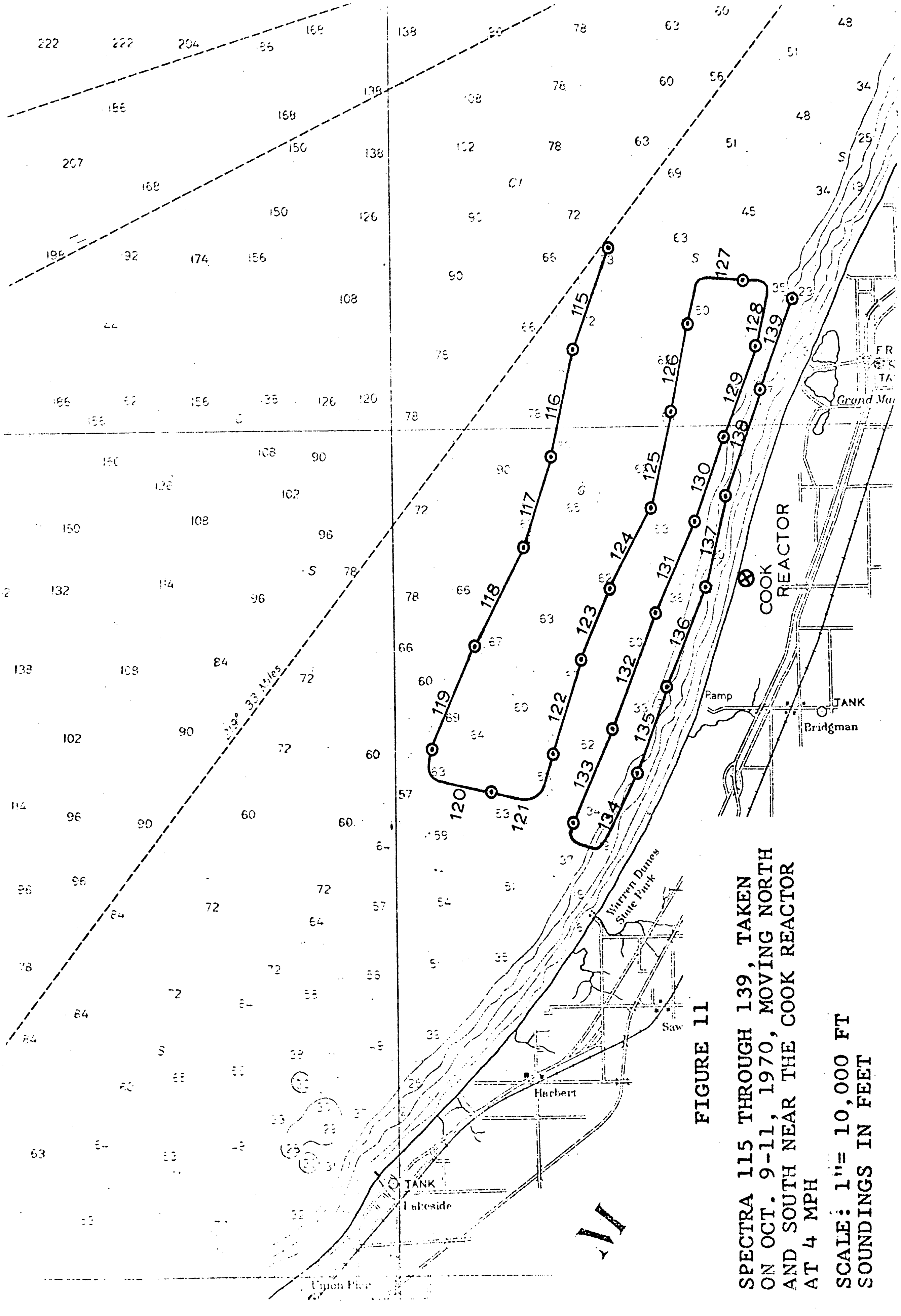

FIGURE 11

SPECTRA 115 THROUGH 139, TAKEN ON OCT. 9-11, 1970, MOVING NORTH AND SOUTH NEAR THE COOK REACTOR AT 4 MPH

SCALE: 1"= 10,000 FT
SOUNDINGS IN FEET

TABLE 3

Results of Gamma Ray Spectra Taken Around Donald C. Cook Nuclear Power Plant*

Spectrum Number	Potassium-40 Activity (uCi/m^2)
115	129
116	131
117	131
118	135
119	149
120	166
121	154
122	155
123	123
124	137
125	92
126	161
127	121
128	131
129	197
130	157
131	150
132	178
133	141
134	156
135	157
136	169
137	157
138	160
139	148

*K-40 was the only radioisotope observed in these spectra.

equipment mounted inside a truck. The probe system has proven itself to be valuable as a device for measuring qualitatively the radioisotopes present in bottom sediment and soil. The quantitative calibration procedure involves several assumptions which have not been investigated fully at this time. Further work will be done to improve the calibration of the probe.

The calibration of the probe was checked by comparing radioactivity measurements made with the probe to measurements made on grab samples of the same sediment measured by the probe. Three grab samples of sediment were taken in the vicinity of spectra 45, 46, 47 and 48 shown in Figure 7. These grab samples were analyzed by conventional laboratory procedures and found to contain 1.2, 3.1 and 1.5 picocuries per gram of cesium-137. The average value was 1.9 pCi/gram. The average cesium-137 activity in the sediment as determined from spectra 45, 46, 47 and 48 was 0.101 microcuries per square meter (see Table 1). If the assumption is made that all of the cesium-137 is layered in the upper three centimeters of the sediment and that the sediment has a density of 1.7 grams per cubic centimeter, the average cesium-137 activity measured by the probe is 1.9 pCi/gram.

ACKNOWLEDGEMENTS

The authors wish to state their gratitude to Dr. Gordon Riel of the Naval Ordnance Laboratory for his advice and suggestions during the initial period of this project, to Mr. Ed Michellena of the Department of Meteorology and Oceanography for his assistance with many of the electrical problems encountered, to Dr. A. P. Jacobson and Mr. Jeffrey Colvin of the Department of Environmental and Industrial Health, University of Michigan, for their assistance on several of our field trips, and to the American Electric Power Service Corporation for funding this project.

APPENDIX

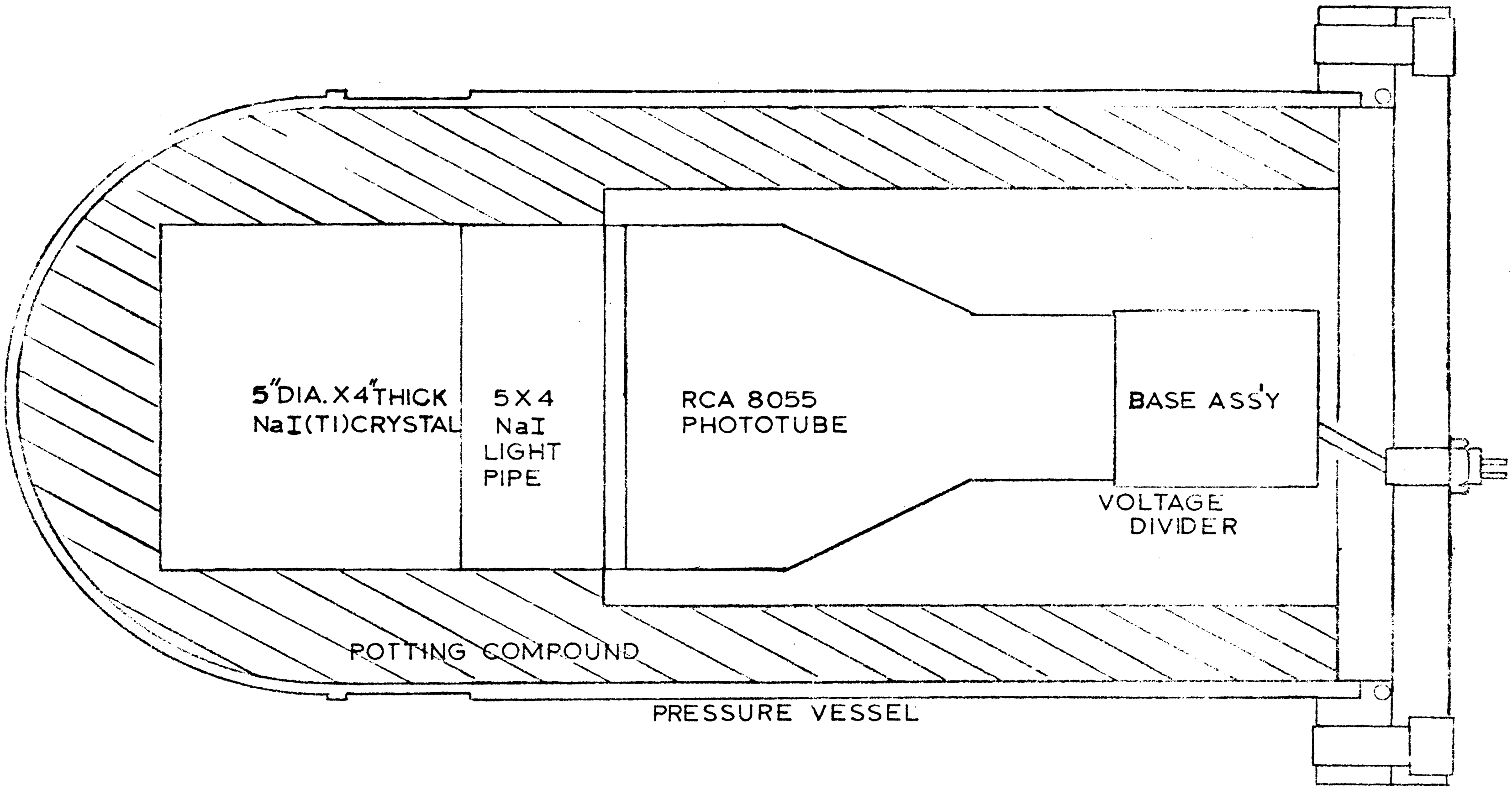

FIGURE 12

CROSS SECTION OF PRESSURE VESSEL

SCALE 3/8" = 1"

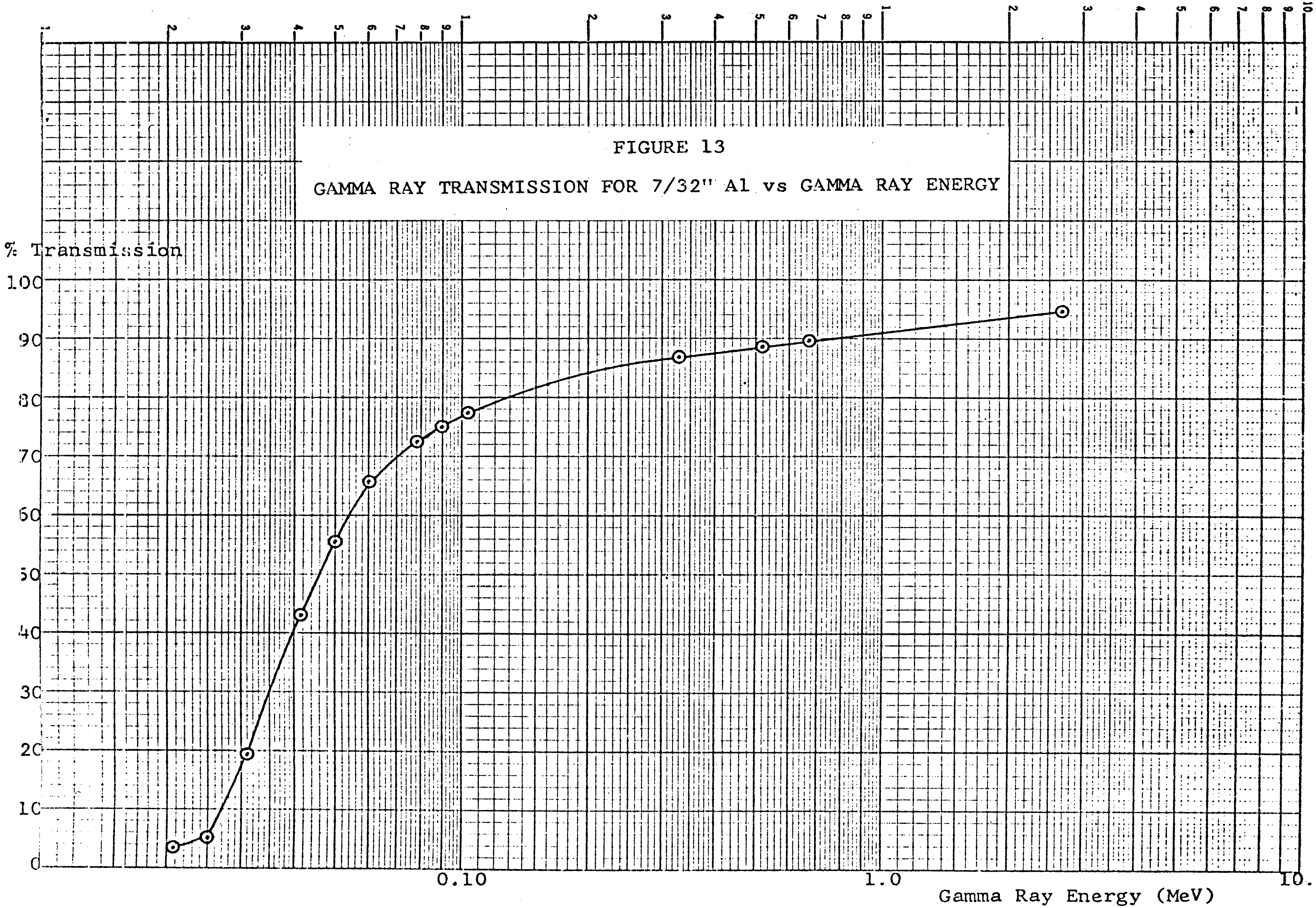

FIGURE 13

GAMMA RAY TRANSMISSION FOR 7/32" Al vs GAMMA RAY ENERGY

R = 100KΩ	R_5 = 39K	R_{10} = 39K	C_1 = 0.1μf 3KV
R_1 = 39K	R_6 = 39K	R_{11} = 90K	C_2 = 0.1μf 1KV
R_2 = 39K	R_7 = 39K	R_{12} = 93Ω	C_3 = 0.1μf 1KV
R_3 = 39K	R_8 = 39K	R_{13} = 1K	C_4 = 1.0μf 3KV
R_4 = 39K	R_9 = 39K	R_{14} = 100K	C_5 = 1.0μf 3KV

all resistors are ½ watt, 5%

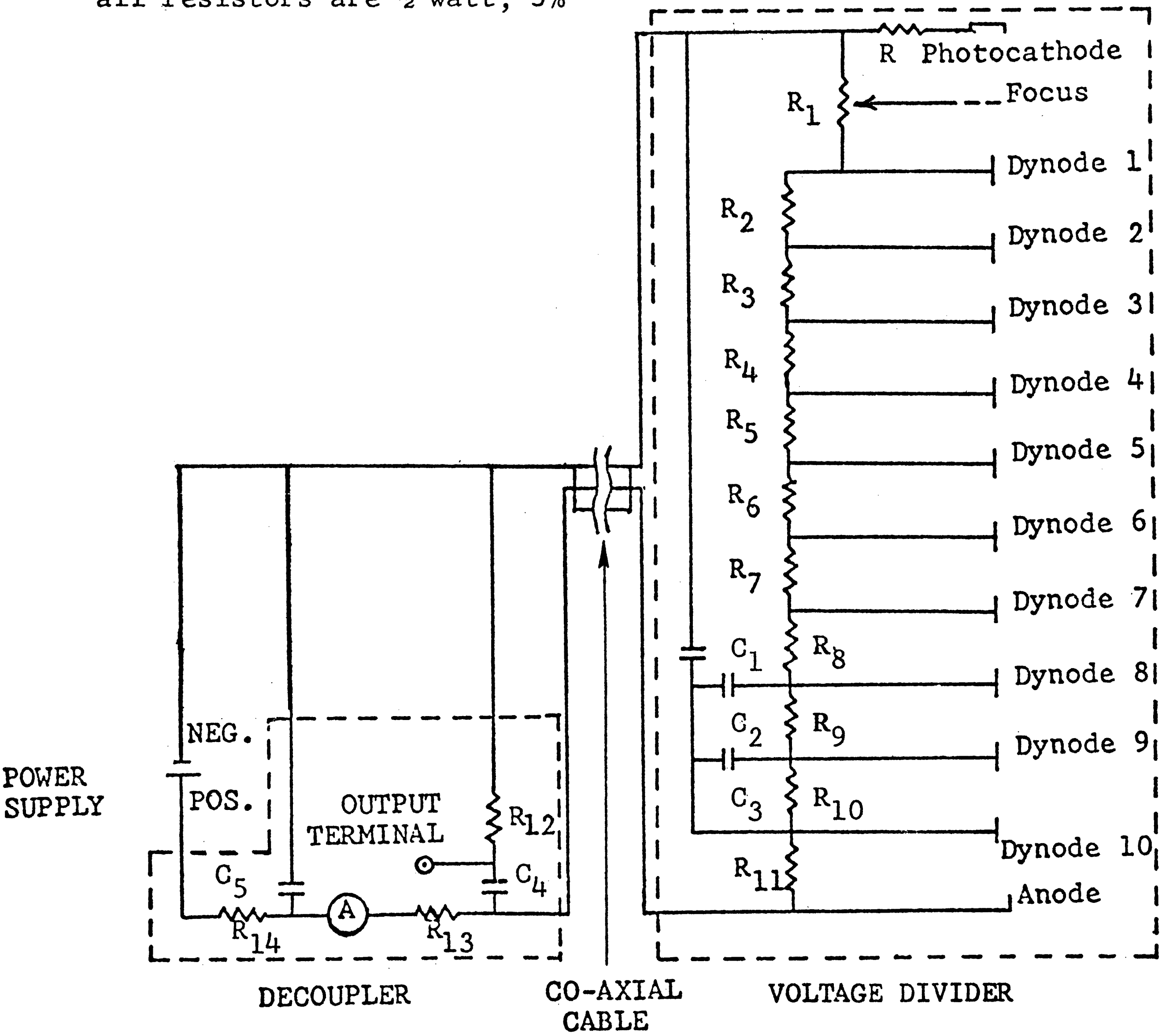

FIGURE 14

Underwater Gamma Ray Detector Circuit

TABLE 4

Equipment for Underwater Probe System

Detector (Harshaw) 5"x4" NaI crystal RCA 8055 photomultiplier tube Voltage divider string Design and fabrication of pressure vessel	$ 5,200
Pulse Height Analyzer (Nuclear Data) Model 1100 PHA, 256 channels Preamplifier, amplifier, discriminator Oscilloscope	4,715
Teletype (Western Electric) Model 33-TC-ASR	900
Count Rate Meter (Ortec) Model 441	295
Strip Chart Recorder (Leeds and Northrop) Speedomax H, Model S.	900
High Voltage Power Supply (John Fluke) Model 408B	665
Decoupler (Homemade)	50
Coaxial Cable (Belden) 1500 feet of type RG58U cable	160
Rubber Tire (Goodyear) Super Terra-Grip	1,500
Axle for tire (Homemade)	1,400
TOTAL	$ 15,785

REFERENCES

1. U.S. Atomic Energy Commission, Operation Troll, NYO-4656, March 1956.

2. Riel, G. K., Dolfis, J. P. and Simons, D. G. Underwater gamma ray spectrometers for monitoring environmental water at nuclear power stations. Nature 188:266, 1960

3. Sayre, W. W. and Hubbel, D. W. Transport of Radionuclides in fresh water: dispersal of bed sediments in transport of radionuclides in fresh water sediments, Report of a Working Meeting Held at the University of Texas, January 30-February 1, 1963. TID-7664.

4. Kaufman, W. J. and Klingerman, P. C. Nature and disposition of sediment sorbed radionuclides entering San Francisco Bay, Report of a Working Meeting Held at the University of Texas, January 30-February 1, 1963. TID-7664.

5. Jennings, D., Cutshall, N. and Osterberg, C. Radioactivity detection of gamma ray fission in sediments in situ, Science 148:948, 1965.

6. Golden, J. C., Plato, P. A. and Whipple, G. H. Lake Michigan environmental survey, Contract ORA-69-1599-Ll, The University of Michigan, Ann Arbor, Michigan. September 25, 1970.