NOAA Technical Report OOE 1

A Submersible Physics Laboratory Experiment

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Office of Ocean Engineering

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Manned Undersea Science and Technology Office
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A Submersible Physics Laboratory Experiment

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National Oceanic & Atmospheric Administration

SUMMARY

In autumn 1976, I proposed to Edwin Link, Vice President, Harbor Branch Foundation, Inc., Ft. Pierce, Fla., that Harbor Branch/Johnson-Sealink (JSL) submersible be used to prepare on the ocean bottom, and then lock out, sensitive photographic emulsion stacks for the detection of cosmic-ray muons.* The ocean would serve as an homogeneous and isotropic filter, absorbing most cosmic-ray and other nuclear particles, except, for purpose of this experiment, the muons (or mu-mesons).

After a meeting at Harbor Branch in early 1977, President S. Johnson and E. Link agreed that the University of Washington/Western Washington University (U. of W./W.W.U.) experimenters (J. Lord and P. Kotzer) with NOAA/OOE/MUS&T (K. Stehling as scientist-monitor-observer) would be granted JSL time. Furthermore, Harbor Branch then proposed, designed, and built a unique ocean bottom-sitting receptacle or chamber (a modified JSL aft "sphere," unused), which they deployed in September 1977 off West End, Grand Bahama Island (lat. 26°41′4″N, long, 70°00′8″W).

During the week of Oct. 3, 1977, two emulsion stacks in glass cassettes** were prepared in the JSL and deployed, one at 1,000 ft (328 m) within the bottom chamber and one for reference at 400 ft (122 m).

In March 1978, the 400-ft cassette was retrieved and locked into the JSL, and the emulsions were developed in situ. The 1,000-ft emulsions were retrieved in October 1978. New experiments are being planned.

The following features highlight this unique experiment, which blends ocean engineering with high-energy physics:

1. A submersible was used as a minilab for preparing cosmic-ray detectors.
2. Lockout into a bottom chamber was achieved, at 1-atm. pressure.
3. The JSL crew remained, in one mission, for 12 hr at 1,080 ft with no adverse consequences.
4. A partnership between the NOAA and Harbor Branch, a not-for-profit foundation, was achieved, with the Harbor Branch contributing most of the technical and logistic support and equipment to the missions.
5. The University of Washington/Western Washington University scientists have already found evidence of new muon interactions.

* Mention of a particular item does not constitute endorsement by NOAA.

**9-in diameter glass spheres, manufactured by Benthos Corp., Falmouth, Mass. (fig. 1).

INTRODUCTION AND BACKGROUND

Since 1972, NOAA (OOE & MUS&T) and the University of Washington Physics Department, have been associated in the underwater detection and analysis of cosmic radiation flux. The reasons for operating underwater are:

a. The water is an isotropic and homogeneous medium that "filters" or absorbs many "stray," or unwanted hadrons* and leptons** which are filtered also by rock and soil as in a mine, but the filtering function of a heterogeneous overburden is ambiguous;

b. The natural radioactivity of seawater is much less than that present in deep mine shafts where various cosmic-ray detection experiments have been tried;

c. Water, from the nuclear interaction standpoint, is a hydrogen or proton "soup" wherein collision products are much easier to predict, discern, and analyze. The dissolved metallic and other ions do not materially affect this property of water;

d. The water itself can act as a detector (in a deep mine, tanks of water or other liquids are also used) with the high-energy cosmic-ray neutrinos producing muons by inelastic nuclear collisions, which in turn generate microscopic "Cerenkov" light flashes in the water, detectable with photomultipliers. Tracks made by the muons can be discerned in media such as a photographic emulsion as described herein.

The deeper the cosmic-ray detection device is placed in the ocean the greater is the filtering factor, with the stray particle density reduced almost linearly with depth increase. A 50-ft depth experiment shows an almost 10 percent decrease in unwanted particle background. At 400 ft one can expect trivial noise background, leaving mostly neutrino-generated muons to be detected by the photoemulsions.

The purpose, then, of past (1972-76) underwater (HYDROLAB-based) experiments, and those described in this paper has been to take advantage of the nuclear cosmic-ray related qualities of the ocean water mass by allowing the experimenter(s) to work in situ on the sea floor, rather than attempting to try an impractical alternative: lowering a prepared photoemulsion detector to the bottom from a surface vessel, a method that would yield an unacceptably surface-radiation-cluttered emulsion.

This report describes briefly the four elements that motivated or comprised the subject experiment:

Basic Physics which motivated the mission

Applied Physics, including particle detection, emulsion chemistry, calibration, and scanning

* Nucleons: e.g., protons, neutrons.

** Extranuclear particles: e.g., electrons.

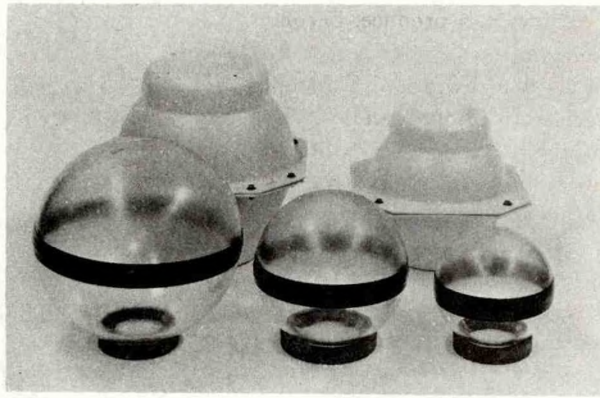

FIGURE 1.—Examples of Benthos glass spheres—protective "hard hats" in rear.

Engineering, including design and fabrication of supporting apparatus, use of a submersible† and a bottom lockout chamber.

Operations, including submersible dives, ship support, emulsion preparation, deployment, recovery, and development.

BASIC PHYSICS

It is believed that the phenomena of the universe are best understood in terms of the set of elementary particles that have been discovered and the four basic forces (gravitation, strong, electromagnetic, weak) which govern their dynamics. Each time a phenomenon involving higher energy particles has been investigated, new insights (and often new particles and laws) into the structure of our world have been discovered. Recently, the study of neutrino reactions at accelerators has produced evidence that may lead to a synthesis of two of the great laws of physics—quantum electrodynamics and weak interactions; in addition, the existence of charmed quarks as well as the standard three quarks has been implicated.

A particularly rich field of investigation has been that of cosmic radiation. The highest energy cosmic-rays sofar detected have an energy of 4×10^{21} eV†† (electron volts) or 40 billion times greater than the highest energy particle produced at the Fermi National Accelerator.

Two features of cosmic radiation make it a particularly important field. First, it provides a guidepost to the nature of physical laws at energies far greater than

† The submersible (JSL) was modified slightly to permit lock-on to the bottom chamber.

†† The energy accrued by an electron while traversing a 1-Volt field/cm. A flea jumping to 10 cm generates about 0.6×10^{14} eV.

machines can produce. Second, study of the composition and energy spectra of primary cosmic rays can be used to learn about astrophysical processes in the formation of stars and star systems. The roles played by the elementary particles, particularly the neutrino, are thought to be crucial in the evolutionary developments of the universe.

The nature of the ultra high-energy (over 10^{15} eV) primary cosmic rays is being studied in the "Fly's Eye" experiment of the University of Utah. This experiment is capable of determining if the higher energy cosmic rays are neutrinos. Another experiment has indicated that the primary cosmic radiation may be an admixture of magnetic monopoles and protons. (There are no other experiments supporting this result as yet.)

A major effort by a group of scientists is being expended on the proposal for a deep undersea neutrino observatory, which is now in its early, conceptual stages. Knowledge of the lower-energy cosmic-ray muon background is of central importance to this experiment. One purpose of the described experiment is to study the low-energy radiations and its composition underwater as it may relate to background in proposed designs of deep undersea neutrino observatories.

Among the possible detectors considered, nuclear track sensitive photographic emulsion was chosen for the following reasons:

a. The nuclear emulsion is simple, compact, and can be prepared anywhere, even in the confines of a submersible. A particle penetrating into the dense emulsion has a high probability of colliding with nuclei; hence, there is a good chance that the emulsion will show interesting events, including scattering, disintegrations, and even the formation of new particles. From the moment it is manufactured, an emulsion begins to collect random particle tracks from cosmic rays (and terrestrial radioactivity, if any). It is true that by the time the film is developed it is difficult to disentangle separate events and impossible to tell when the various tracks were made. Moreover, it takes tedious scanning under a high-power microscope to find the tracks at all. However, unlike emulsion records from nuclear accelerator or high-altitude balloon exposures, undersea nuclear events are relatively infrequent (and there is little background "noise").

b. They give unprecedented resolution in the arrival angle of the cosmic-ray particle. When this information is coupled with the uniform overburden, one may derive considerable information about muons in the trans-accelerator energy region.

c. It is possible to measure a totally unexplored (except for the π^0) region of particle lifetimes (10^{-11} to 10^{-16} s).* No other detector has the capability of producing measurements in this time range, yet recent theories unifying the weak and electromagnetic interactions may indicate a new class of particles in this area.

d. In contrast to electronic counter systems, nuclear track-sensitive photographic emulsion measures the particles directly, with no "pile up" problem; therefore, relatively lower noise limits accrue.

e. The nuclear emulsion detector can search for particles between the energy levels of the natural radiation background and the lower limit (usually 20 MeV) set by Cerenkov, scintillation, and other counters.

f. Being passive, nuclear track-sensitive photographic emulsion requires no maintenance or power for operation.

Data Sought From Nuclear Track-Sensitive Detectors

The initial experiments have concentrated on the determination of the flux of the low-energy component of the undersea cosmic radiation including the hadrons. The study of the hadronic component yields information regarding the photonuclear interaction and perhaps other processes due to unkown radiation components as postulated to explain "Cowan events" and Lande "neutrino" bursts. The following is a discussion of measurements of important parameters of the undersea cosmic radiation that can be determined by the use of nuclear track-sensitive detectors and associated arrays.

Range-Flux and Angular Distribution Measurements of Underseas Muons—The uniform nature of the absorbing medium in these experiments will make it possible to obtain very accurate information on the flux of cosmic-ray particles as a function of depth in water. Particularly interesting would be a check of the absolute flux determinations by Allkofer, which show that at energies from 1 to 50 billion electron-Volts (GeV), the long-accepted flux values were about 25 percent too low. Measurements of the angular distribution bears in an important way on the existence of the intermediate vector bosons in the study of the weak interactions.

The primary cosmic radiation greater than 2×10^{12} eV energy would create the postulated intermediate vector bosons** (which have a mass of 58 GeV according to the Weinberg-Salam Theory). The radiation is

* π^0 = pi-meson or pion, a neutral particle (in this case).

** $W^{\pm}$.

believed to produce muons in the following interactions:

1. $p + p \rightarrow w^+ + n + p$

$$w^+ \rightarrow \mu^+ + \nu_\mu$$

ν = neutrino
p = proton
μ = muon
ν_μ = muon-neutrino (only neutrino that produces muons)

2. $p + n \rightarrow w^- + p + p$

$$w^- \rightarrow \mu^- + \nu_{\bar{\mu}}$$

—The prompt decay of the $w^\pm$ compared to π and K* decay would produce excess of high-energy muons at large zenith angles.

Intensity of Stopping Muons—This measurement bears directly on the origin of the x-processes.** The intensity of stopping muons will be measured in the emulsion stacks described later. In the experimental data from underground measurement, there are extremely large differences in the intensity of muons measured by different observers. Since each measurement is taken in an underground room of different dimensions, the fraction of muons contributed by the decay of pions would be expected to show wide variations. The observations in this experiment are made in uniform containers (i.e., emulsion stacks) so that geometry will be the same in each case. In addition, the medium (water) is uniform (fig. 2).

Underground and Underwater Hadronic Cascades—An underground experiment near Turin, Italy, showed an anomalously high intensity of stopping muons that has led to speculation about the characteristics of the hadronic contamination of the underground muon "beam." In a model proposed by Keuffel, this excess of stopping muons is the result of energetic hadronic cascades produced by fast muons in their interactions with the rock nuclei. Analogous with the degradation of energy in an extensive air shower, these underground hadronic cascades have as a constituent of their final products, slow nearly isotropic pions that could decay into muons and result in the observed excess. To get agreement with the Turin results, Keuffel's model requires either an increase in the photonuclear cross section or the postulation of some new process. In view of the above observation of Keuffel and those of Raman Murthy in India, it is clear that there is a great need for more direct visual

*K=Kaon or K-meson.

** μ's created by neutral particles.

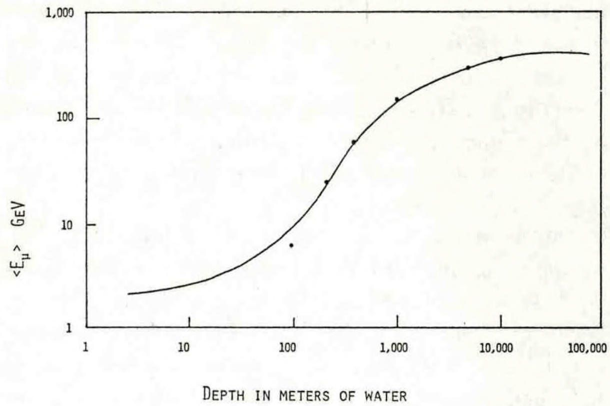

FIGURE 2.—Variation of muon energy with depth of water penetration.

observation of and detailed information about the nature of the hadronic cascade under water.

The large size of the emulsion stack † permits tracing or following all tracks produced by a muon—which originate from a star and either interact within or leave the scanning volume (fig. 3). In this way, it will be possible to classify the nuclear cascades for multiplicity of (1) protons, (2) fast pions, and (3) slow pions, as a function of depth. This will give a better understanding of the importance of pions of moderate and low energies to muon and neutrino experiments.

At a depth of 305 m, the stack is expected to accumulate, in a 1-yr exposure, 34 stopping muons, 2 stopping pions, 4 neutron stars, about 10 recoil protons (from fast neutrons) and 1 to 3 muon photonuclear stars (figs. 4 and 5).

The Anomalous Neutral Component of Cowan—The purpose is to determine if the strange events of Cowan are due to hadronic cascades. The emulsion stacks used in the proposed research program will be searched for stopping muons. It will be possible to follow back a certain fraction of muons and see if they might have been produced in the emulsion by a neutral radiation of the type described by Cowan. There would be about one such Cowan-type event for each 10 cm^3 of emulsion exposed for 1 yr. If Cowan's rates are correct, one should find about 40 events in the stacks exposed in these experiments.

However, there are no **firm** expectations for finding Cowan events: The chain of circumstances that would produce an unambiguous Cowan "signature" is too serendipitous and too subtle to permit either firm prediction or clear recognition of this phenomenon.

† About 400 cm^3 of emulsion for each emplacement described here vs. about 70 cm^3 for the earlier HYDROLAB experiments.

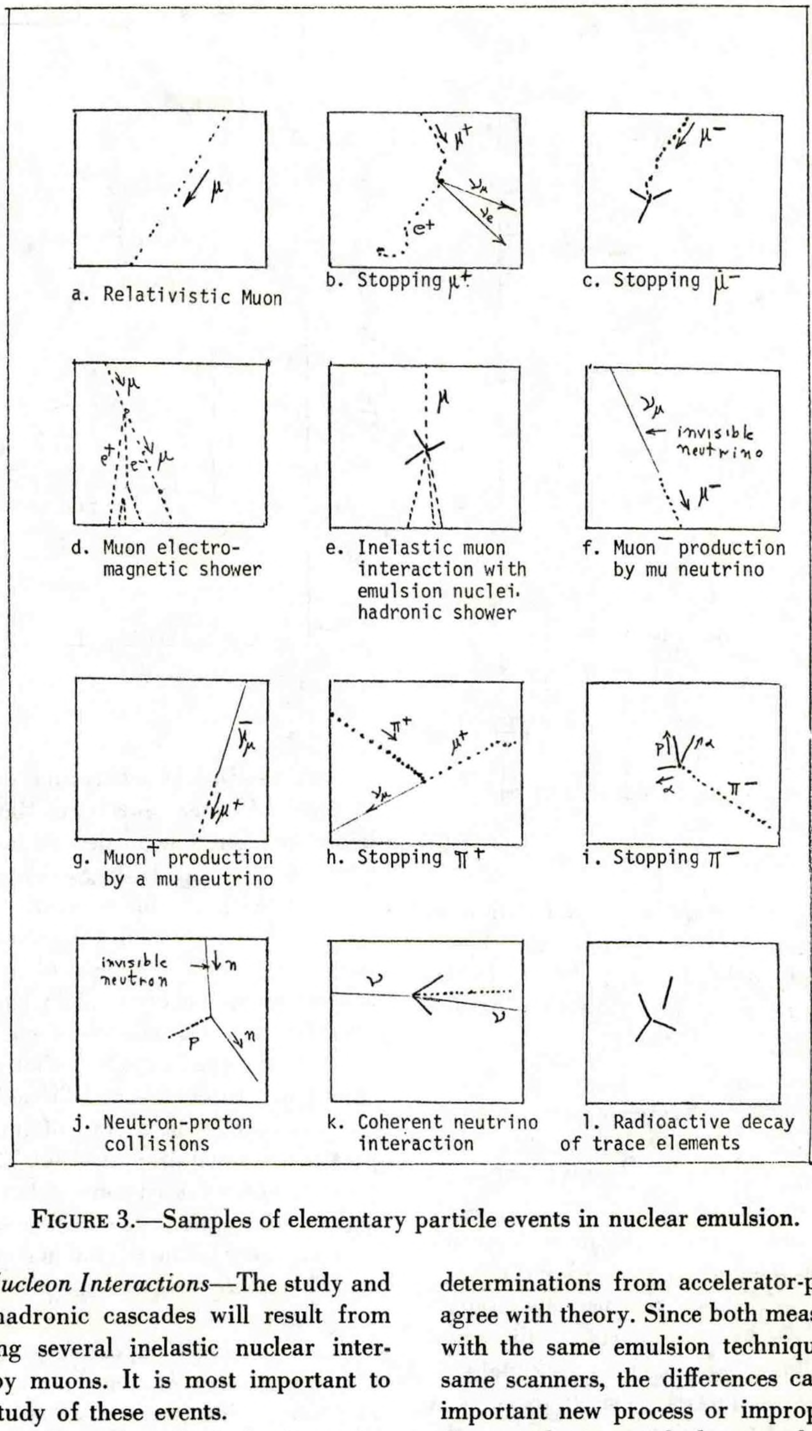

FIGURE 3.—Samples of elementary particle events in nuclear emulsion.

Inelastic Muon-Nucleon Interactions—The study and understanding of hadronic cascades will result from the scanners finding several inelastic nuclear interactions produced by muons. It is most important to make a thorough study of these events.

The observations of Cottrell on the inelastic scattering of muons showed a wide discrepancy between theory and experiment. As a matter of fact, all experimental cosmic-ray observations to date show a major departure from the calculations of quantum electrodynamics (which is the best theory available to date). This is especially puzzling since the measurements of Cottrell were compared directly with corresponding determinations from accelerator-produced muons that agree with theory. Since both measurements were made with the same emulsion technique as well as by the same scanners, the differences can only be due to an important new process or improper understanding of the contributions of hadrons to the underground muon "beam."

It is hoped to use the muon events found in the present study of hadronic cascades to test the theory of inelastic muon interactions. The experiment will, in this case, make it possible to subtract out the contributions of pions and other contaminants to the scattering.

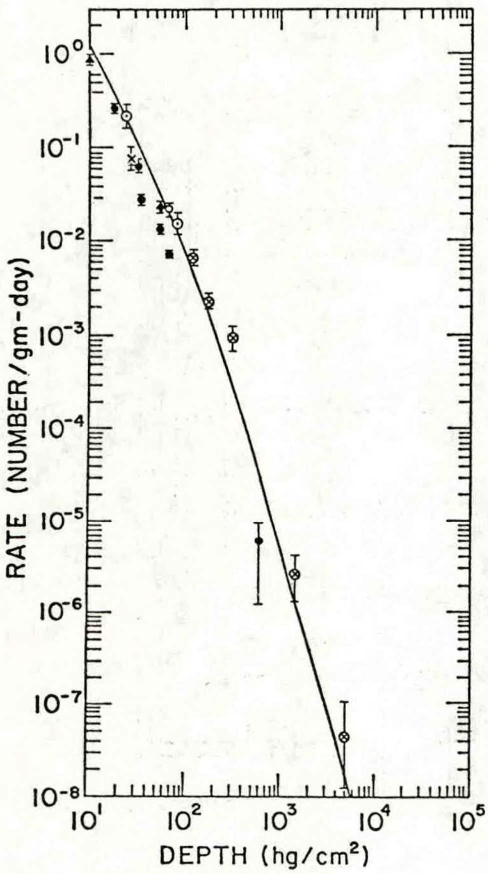

FIGURE 4.—Rate of muon stopping as a function of depth of water penetrated. + George and Evans (1950), ▲ Barton and Slade (1965), ○ Short (1963), ● Baschiera et al. (1970). Solid curve is calculated rate of stopping.

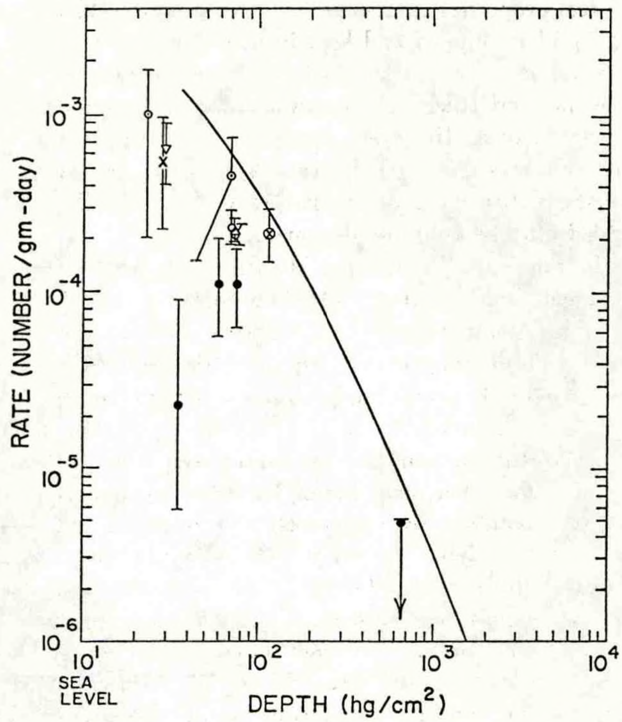

FIGURE 5.—Rate of positive ion stopping as a function of depth of water penetrated. Rates not corrected for losses of pions due to decays in Flight near the detector. ○ Short (1963), ▲ Barton and Slade (1965). Solid curve due to Keuffel et al. (1972).

APPLIED PHYSICS

Emulsion Preparation and Development Procedures

The key and crucial procedure in these missions, and that which makes them unprecedented and unique, is the preparation, *under water*, of the photographic emulsions at NTP*. The heating, pouring, gelling, and hardening of the liquid emulsion is essentially a physical-chemical process that is sensitive to ambient pressure, humidity, and temperature, and which may be prejudiced by marked increases from NTP and "average" relative humidity (RH) of, say, 50 percent.

When an emulsion pouring attempt was made in the "La Chalupa"** habitat, some years ago, the emulsion would not gel properly. This was, after some analysis, traced to the high ambient (3 atm) pressure and, to a lesser extent, the 80°F (26°C) temperature and high humidity. For the missions described in this paper, it was hoped, and expected, that the aft-submersible-compartment would be at NTP and less than 50 percent RH. Actually, while P was, of course, 1 atm, the temperature hovered around 20°C. The RH was above 50 percent, which caused some difficulties with the gelling and especially the drying of the emulsions.

A summary of the operational procedures and emulsion characteristics follows, with the detailed sequences appended:

a. Emulsion Composition and Properties.

The University of Washington, a pioneer in the use of photographic cosmic-ray detection, has been using a liquid, collodial silver halide (AgBr) solution made in England (ILFORD 1G5).

The IG5 was used in past HYDROLAB experiments and in the 400-ft (120-m) cassette mission described in this report. For the 1,000-ft (330-m) deployment, however, a Kodak NTB-3 emulsion was used—its first underwater application. The NTB-3 is still experimental; however, its physical and photo-

* Normal (i.e., "room") temperature and 1 atm pressure.

** An underwater habitat/lab deployed off Puerto Rico.

chemical properties seem superior to those of the IG5. The liquid is shipped and kept in plastic bottles until ready for use. The substance is, of course, subjected to cosmic, and other, radiation flux from the moment of manufacture. However, the exposed microscopic trails or tracks left by the traversing particles are not permanent (as in a dried plate), but are quickly blended into the fluid and disappear.

b. Emulsion Preparation, Coating, Drying, Development, and Scanning*—A Minisequence:

1. About 500 cm^3 of IG5 and NTB-3 emulsion were transferred into the JOHNSON-SEA-LINK dive chamber after being preheated to around 40°C.
2. The four bottles were poured out, one after the other, onto the eight, 5- by 5-in almost optically flat glass plates or pellicles that were lying (four at a time) on an aluminum chilled flat table or plate. The yellowish liquid was allowed to spread evenly over each plate, which had its edges blocked by chrome-plated brass "dikes"** to prevent the emulsion from running off the plates.

The emulsion thickness had to be 400 μm thick. This was attained by pouring out a (previously) accurately weighed volume from each metered bottle. After about one-half hour the material had gelled sufficiently to permit the pellicles to be placed, stacked vertically, into the electrically heated drying "oven" (fig. 6). The plates were separated by about ½ cm, permitting the blower-forced warm air at 28°C (86°F) to pass over and between them and then through a desiccator bed to keep the chamber's RH at 30 percent, assuming an ambient RH of 60 percent.

Laboratory tests had shown a drying time of about 5 hr, but, due to higher than expected humidity (about 80 percent) in the submersible compartment and the resultant inability of the drying chamber to hold its own RH below 30 percent, the emulsion drying and hardening time lengthened to 8 hr. for the first deployment mission and 6½ hr. for the second, resulting in total JOHNSON-SEA-LINK bottom times of 11 and 9½ hr, respectively.

Once dry, the pellicles were packaged, deployed, and left on the ocean bottom (described under "operations").

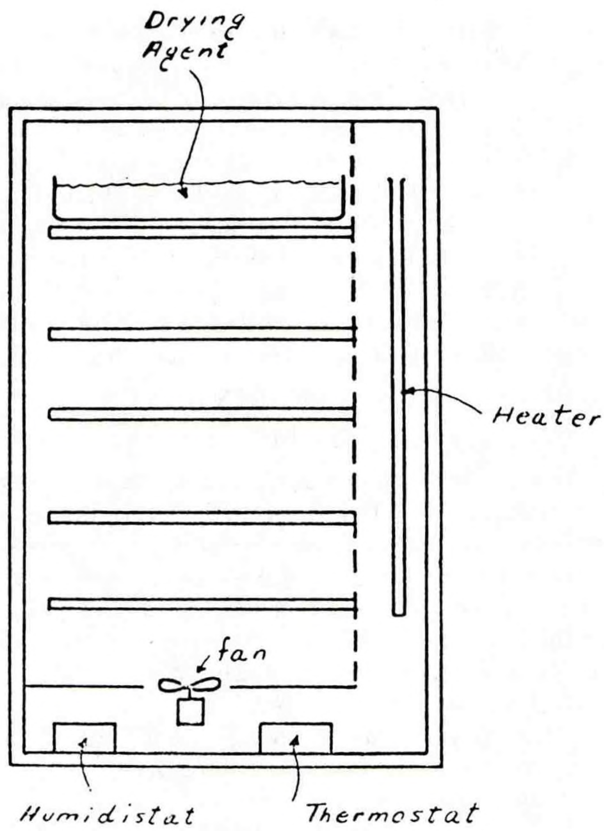

FIGURE 6.—Simplified sketch of nuclear track-sensitive emulsion drying "oven", and cut-away profile.

Retrieval of the 400-ft (120-m) cassette (also described under "operations") was followed by development and "fixing" of the pellicles. This process follows fairly conventional photographic practice with a sequence of development, stopping, and fixing immersions in reducing chemical solutions contained in special trays designed and built by Harbor Branch. Strict temperature control was maintained, and development was accomplished in less than 5 hr for a total mission time of about 8 hr. The chemicals had been previously screened, evaluated, and cleared regarding toxicity within the JOHNSON-SEA-LINK's chamber's atmosphere. The pellicles were dried within the JOHNSON-SEA-LINK, repackaged, and shipped to the University of Washington physics laboratory for further fixing before analysis. The analysis consists of scanning the emulsions (which are, by now, translucent) with near-field, or sometimes phase-contrast microscopes. This scanning is a tedious procedure requiring above-average

* The sequence applies to both (400-ft and 1,000-ft) deployments and the 400-ft recovery.

** Designed and made by Harbor Branch R. and D. personnel.

eye resolution and a trained perception for the subtle manifestations of muon (and other particle) tracks within the reduced silver/gel colloid. Not only must the initial track (which may be only a fraction of a millimeter long) be detected, but its trail through the emulsion, into the next one (if the particle has penetrated that far) must be traced. Most importantly—and this helps to identify the particle—collision processes (if any) must be noted and angles of the "debris" trail must be measured (fig. 7).

ENGINEERING

Apparatus Used (Nonmarine)

Most of the apparatus used for the emulsion work was designed and built by the Harbor Branch Research and Development staff. The versatility and general quality and innovation demonstrated were exceptional. The missions were successful because of this.

The following is a list of major equipment that was designed and built for the experiment:

1. Emulsion drying chamber (fig. 6).
2. Leveling aluminum chilling "table" with heat transfer fins and cooling bath (fig. 8).
3. Desiccator cassette.
4. Emulsion storage heater box.
5. Four stainless steel bins or tanks, 5-liter capacity each, fabricated by Harbor Branch, were used for the developing and soaking cycles during the 400-ft retrieval mission. One tank was thermostatically controlled at 24°C. (fig. 9).

Major Marine Facilities and Equipment Used

October 1–7, 1977 Mission I, and March 14–16, 1978 Mission II

1. JOHNSON-SEA-LINK No. 2 (fig. 10); crush depth 6,000 ft (1800m) gross weight 23,000 lb.*
2. October 19, 1977/only—The SEA-DIVER surface support ship; 100 ft (31 m) long, 270 long ton displacement.

2A. March 19, 1978/only—The RV JOHNSON surface support ship; 123 ft (37.5 m) long, 350 long ton displacement.

3. An ocean-bottom deployed lockout or transfer chamber (fig. 10), suggested, designed, built, and deployed at 1,080 ft (333 m) by Harbor Branch. Emplaced September 1977.
4. Winching and hoisting gear for the submersible and bottom chamber (fig. 12).

*A bottom mating flange and split "O" ring were added for lock-on, as were two guide "cones" for directing the vehicle on to 2 guide bars affixed to the bottom "cosmic chamber."

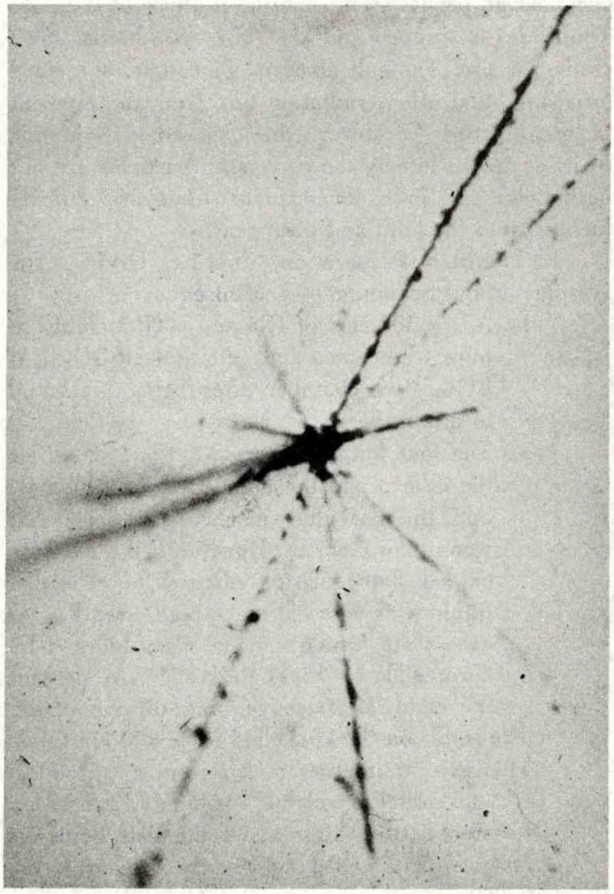

FIGURE 7.—Track of a collision between a muon and a proton in an emulsion exposed in HYDROLAB.

5. Laboratory and mechanical/hydraulic working space and equipment aboard both surface support ships.
6. Appropriate sonar and Loran C locator equipment.

OPERATIONS

The sequence of field operations for the October 1977 and March 1978 missions was about the same, with these differences:

1. Kotzer/Stehling/Roesch—Harbor Branch diver and submersible technician, do "dry-run" of emulsion operations inside the JOHNSON-SEA-LINK, in the Harbor Branch shop, a day or two before departure to the test site.
2. The JOHNSON-SEA-LINK (fig. 10A) was hoisted and lowered by a specially designed crane on the support vessel.

Harbor Branch ship operators were very adept and experienced at handling the JOHNSON-SEA-LINK

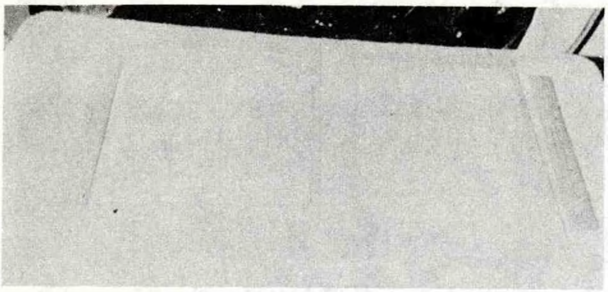

FIGURE 8.—Liquid emulsion poured on a chilled glass plate (pellicle) surrounded with chrome-brass dikes.

(JSL), even in fairly rough seas, and few difficulties in retrieving the JSL were encountered during the March mission. The surface support ship was rolling and pitching in moderate seas while the JSL was suspended in midair.

Diving Procedures

After several shallow water test dives and a trial rendezvous with the bottom chamber, the chamber was deployed at 1,080 ft. with a sonic "pinger" attached for location by the JSL. The location was also noted from Loran C coordinates.

During all muon missions, the JSL would dive in the general area of the chamber's location. Each time, via active JSL sonar and signals from the chamber's pinger, the vehicle homed in on, and located, the chamber. This process required from 45 min to 1½ hr depending on equipment performance, above-average currents (about ⅓ kt), etc.

The pilot then maneuvered the JSL on top of the chamber and settled on it, guided by two locator rods. This tricky operation took about 15 min. The JSL had previously removed a plexiglas lid from the chamber, using the manipulator to place the lid next to the chamber for later replacement.

The JSL finally settled or nestled on the chamber, guided during the actual mating by three wedge-shaped guide fins that prevented lateral movement during contact of the JSL and chamber's flanges (fig. 13).

When the pilot concluded that the JSL had, in fact, made contact and that the grooved "O" ring of the JSL's flange was sitting correctly upon the bottom chamber (b.c.), he directed R. Roesch, in the rear, to achieve an atmospheric seal by relieving the water pressure in the chamber by opening a valve connected to the JSL hatch manway. The valve was connected to a one-quarter inch relief line that ran to an atmospheric-pressure "holding" tank (later, directly into the JSL aft-end chamber's bilge). When the valve was

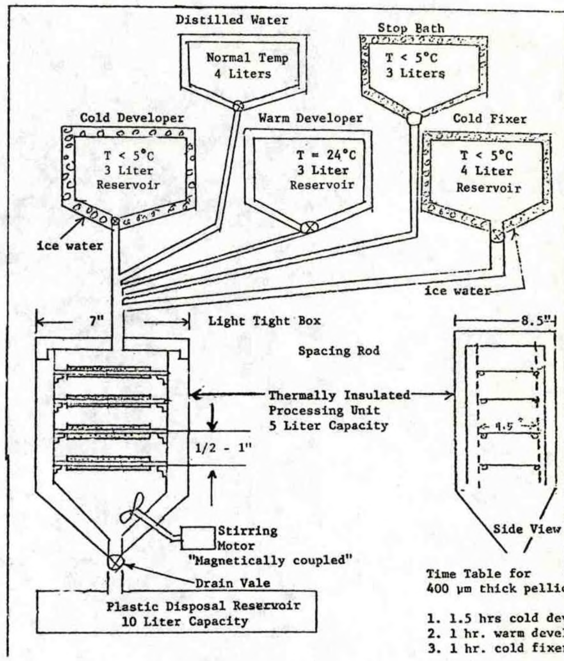

FIGURE 9.—Processing tanks used for nuclear emulsions during a retrieval mission.

opened, a loud "thump" could be heard as the pressure in the bottom chamber went to 1 atm, with about a quart of water spraying into the tank (or bilge).

The valve was then closed and the depth gages were watched; any increase in depth (from "O" on the gage) meant a leak. None occurred, and when the pilot was satisfied with the system's integrity and sealing he directed the rear bottom hatch to be opened. Roesch and Kotzer then lowered the packaged glass sphere into the b.c. For the actual emplacement within the b.c. at the 1,000-ft depth, the sphere was anchored to a weight and floated upward from its own buoyancy. For the 400-ft mission, the sphere was also locked into the b.c., but then removed by the manipulator and transported to the preselected 400-ft site.

Beginning in March 1978, three successive dives were made for recovery of the 400-ft (120-m) sphere and emulsion development at 1,000 ft. Sea conditions were moderately rough, but the RV JOHNSON, once it was approximately over the b.c. area as located by Loran C coordinates, launched the JOHNSON-SEA-LINK with little difficulty. However, the physical discomfort of the JSL crew increased the longer JSL was bobbing on the surface and it was a great physical relief to dive into quiet subsurface water.

There was no immediate location of the 400-ft package, although the b.c. was located despite a slight current and a seemingly unusual turbidity.

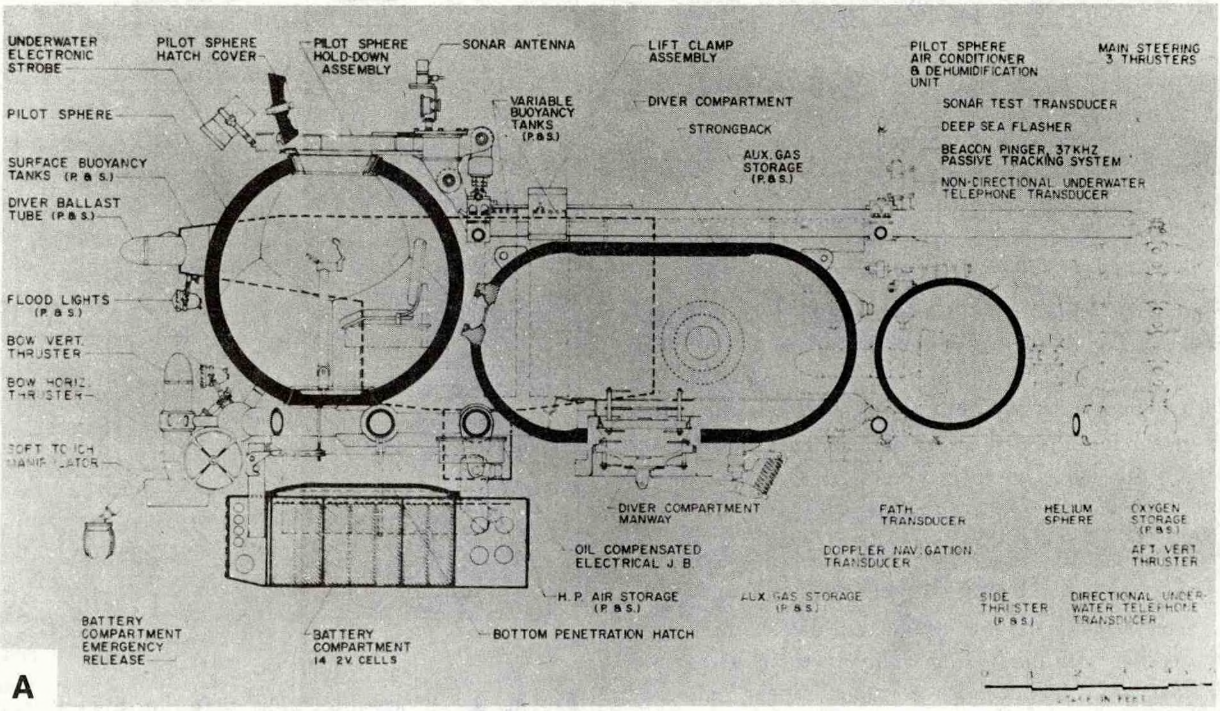

FIGURE 10.—The JOHNSON-SEA-LINK shown A) in cut-away profile, B) at aft end of the R/V JOHNSON surface-support ship, C) in bottom hatch detail, and D) specifications and operating characteristics.

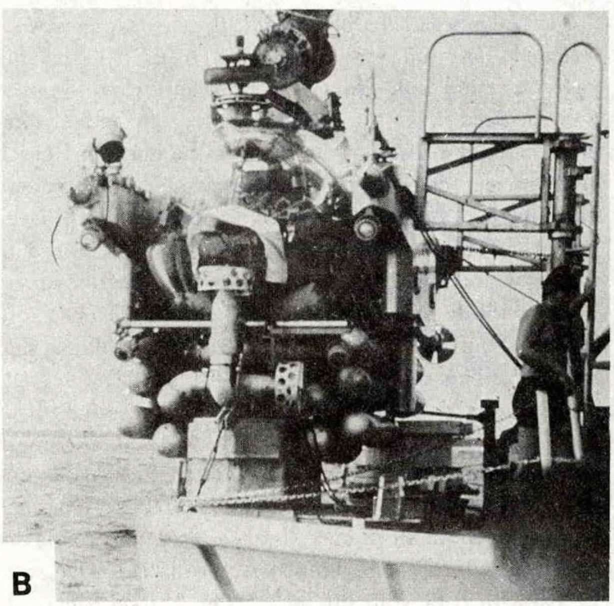

FIGURE 10.—(continued)

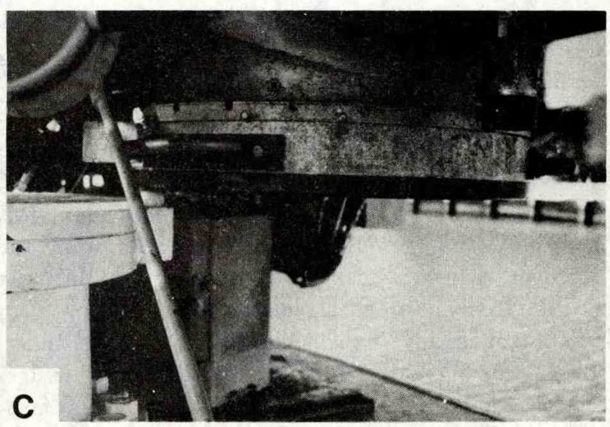

FIGURE 10.—(continued)

The next day, a second dive located the 400-ft sphere (although its "pinger" had quit), because of its proximity to an overturned bus whose position relative to the b.c. had been mapped. A back-vector from the b.c. put the JSL on course. The sphere was grabbed by the manipulator, and the JSL returned to the b.c. and dropped in the sphere.

On the third day the emulsion cassette sphere was retrieved from the b.c. and the film package was found intact although a bit of water (about 50 cc) was found

JOHNSON-SEA-LINK I & II

Specifications*

DIMENSIONS

Overall

Length	22' - 10"
Beam	7' - 11"
Height	10' - 7"
Draft	7' - 6"
Gross Weight	23,000 lbs.

Pilot Sphere

Outside Diameter	66"
Inside Diameter	58"
Thickness	4"
Internal Volume	59 cu. ft.
Hatch Clear Opening	18" diameter
Material	Acrylic Plexiglas Grade "G" Annealed

Diver Compartment

Length	8'
Outside Diameter	59½"
Internal Diameter	53"
Hatch Clear Opening	20" diameter
Material	Aluminum Alloy 5456
Internal Pressure	Test pressure 1,000 psi Operating pressure 670 psi

*Specifications apply to both submersibles, since they differ only in minor respects.

OPERATING CHARACTERISTICS

Depth	
Operating Depth	1,000'
ABS Classification Depth	1,000'
Test Depth	2,000'
Crush Depth	6,000'
Speed	
Cruise	3/4 knots
Maximum	1 3/4 knots
Life Support	
Endurance	480 man-hours (20 man-days)
Carbon Dioxide Scrubbers	
Pilot Sphere	Harbor Branch Foundation
Diver Compartment	Lindbergh-Hammer
Emergency Breathing Masks	
Pilot Sphere	Two
Diver Compartment	Two
Metabolic Oxygen Bleed	
Oxygen Analyzer	
Pilot Sphere	One Analyzer, One Remote Meter from Diver Compartment
Diver Compartment	One Oxygen Monitor
Carbon Dioxide Monitors	
Pilot Sphere	One Carbon Dioxide Monitor, One Analyzer, One Remote Meter from Diver Compartment
Diver Compartment	One Monitor, One Analyzer
Emergency Life Support-Rebreathers	
Pilot Sphere	Two
Diver Compartment	Two
Power	
Oil Compensated Lead Acid Battery	32 KWH @ 28 VDC
Inverter	117 VAC @ 2.5 amps 60 HZ

Equipment on Board

- Six Function Manipulator
- Sonar
- Doppler Navigation
- Underwater Telephone
- VHF Transceiver
- Zenon Short Arc Light
- Flood and Spot Lights
- Emergency Location and Rescue Buoy
- Deep Sea Still, Movie and Video Camera Systems
- Video Tape Recorder
- Fail Safe Drop Lock Sub Release System
- Adjustable Equipment Arm
- Diver Self-Contained Rebreathing Apparatus

Optional Equipment

- Cable Cutter
- Line Cutter
- Rotenone Dispenser
- Sea Hook
- Corer

D

FIGURE 10.—(continued)

in the sphere. It was probably condensed moisture trapped in the sphere and also exuded from the pellicles. The film pellicles were unwrapped from their lightproof covering and then developed and "stopped" in about 3 hr. A minor incident enlivened this mission: the defunct sonic pinger on the cassette, with 1,000-ft (330 m) water apparently trapped in its batteries, "exploded" a few seconds after it reached atmospheric pressure in the after chamber. The two crew members were lightly spattered with chemicals, zinc, etc., but no eyes were damaged because crewmembers both had been looking away at the moment. They will wear safety glasses next time, although no such pinger will again be used.

CONCLUSIONS

In general, the missions were accomplished successfully with only trival mechanical, electrical, or hydraulic problems.

The b.c., built at considerable expense by Harbor Branch, was a brilliant innovation that permitted dry lockout at atmospheric pressure. It can be used to 2,000 ft. (660 m) or more; as deep as the JSL can go, in fact.

Other experiments, physics, biology, and the like, can be accommodated. The b.c. can be retrieved at will for inspection and cleaning. However, after 6 mo down, no corrosion or coatings were noticed and not much may ever accumulate because of the relatively sterile ambience and the very little free O_2 available to produce corrosion.

New and otherwise unobtainable high-energy physics and cosmic ray data can be obtained with undersea experiments of this kind.

Glass spheres, as experiment apparatus (emulsions in this case, and perhaps photomultiplier or solid

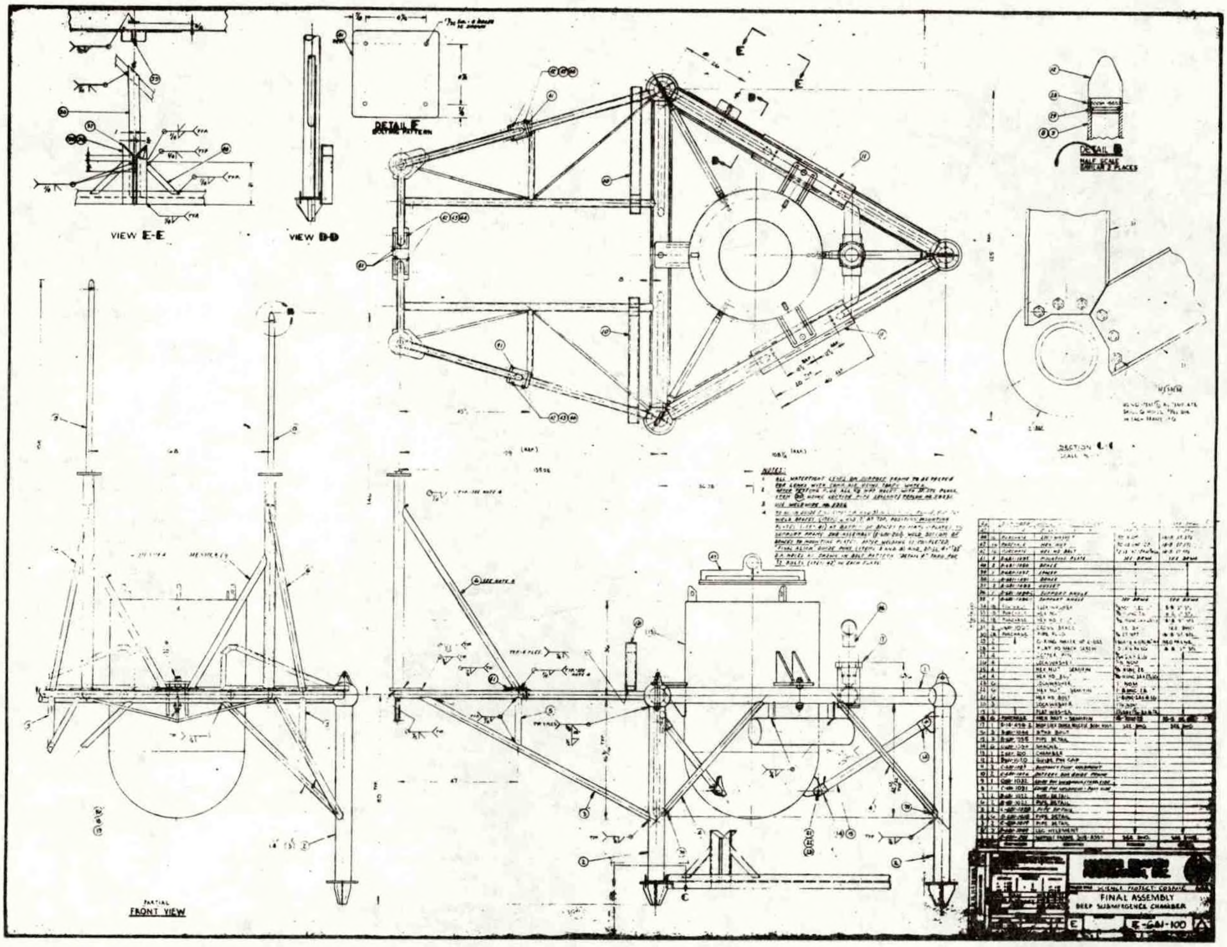

FIGURE 11—Detail drawings of the Harbor Branch deep submergence, lockout transfer chamber.

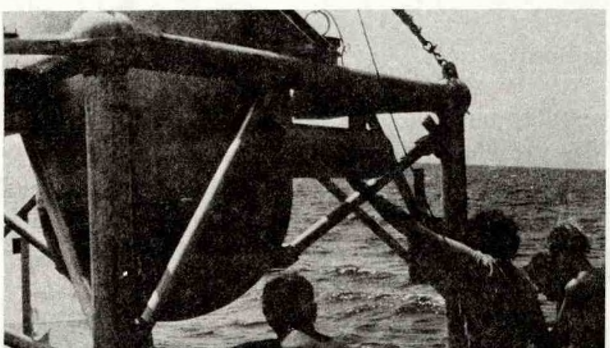

FIGURE 12.—Winching and hoisting gear lowering lockout transfer chamber into ocean.

state detectors in the future) are relatively inexpensive, reliable and convenient "pressure vessels" for deep ocean work.

Other (besides University of Washington/Western Washington University) U.S. and foreign physics groups noting the success of the NOAA/University of Washington/Western University (and now Harbor Branch Foundation) missions are beginning to consider deeper ocean deployment of large arrays of photoelectric and even acoustic cosmic ray (neutrino) detectors. However, the small-scale experiments described here, and their probable electronic successors, fill a valuable niche in the panoply of possible cosmic radiation sensing techniques.

The NOAA/University of Washington/Western Washington University/Harbor Branch Foundation association has been successful and mutually productive. The Harbor Branch Foundation have invested large funds in these missions and the engineering support work. The NOAA funding contribution to Harbor Branch Foundation, while growing, has been —and still is—relatively modest with Harbor Branch Foundation still providing the largest fraction of each mission support.

The use of the JOHNSON-SEA-LINK for the purpose described herein is an example of an undersea laboratory application.

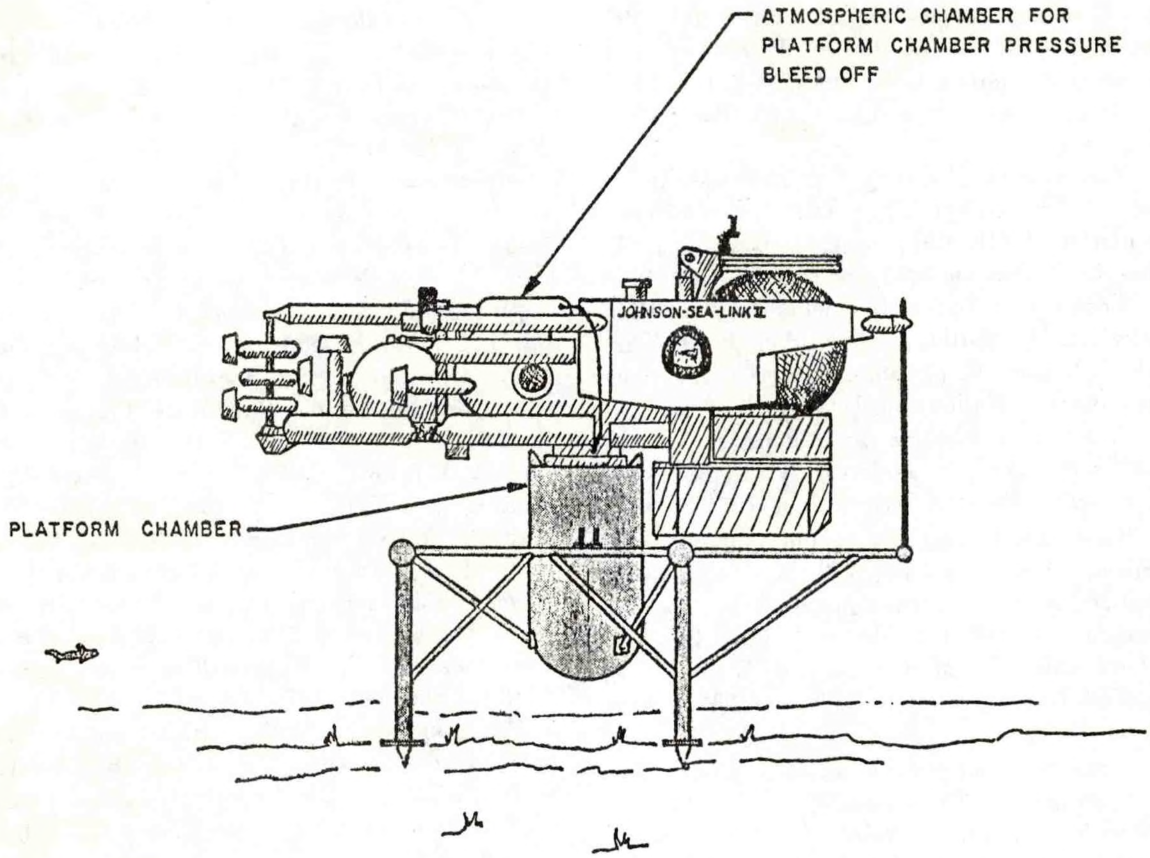

FIGURE 13.—Schematic of sub and platform chamber for dry transfer of pellicle plates.

BIBLIOGRAPHY

1. "Electromagnetic Interactions of 5–50 GeV/c Cosmic Ray Muons with Electrons", P. Kotzer, University of Washington *Dissertation*, 1964.

2. "Positive Excess of Shower Producing Cosmic-Ray Particles", S. H. Neddermeyer, S. Curtis, P. Kotzer, *Bulletin of the American Physicial Society*, 7, 1962.

3. "Muon-Electron Interactions at High Energies", P. Kotzer and S. H. Neddermeyer, *Bulletin of the American Physical Society*, 7, (463), 1962.

4. "Muon-Negation Interactions at High Four-Momentum Transfers", P. Kotzer and S. H. Neddermeyer, *Bulletin of the American Physical Society*, 10, (80), 1965.

5. "Scattering of Cosmic-Ray Muons on Electrons", P. Kotzer and S. H. Neddermeyer, *Bulletin of the American Physical Society*, 12, 1967.

6. *Abstract* for Presentation to American Physical Society Meeting, Washington, D.C., on "Observations on Cosmic Ray Quark Like Tracks in a Cloud Chamber in a Magnetic Field". 1971.

7. "Proton-Tungston Nuclear Collisions at 200 GeV", J. R. Florian, L. B. Kirkpatrick, J. J. Lord, J. Martin, R. E. Gibbs, Peter Kotzer, R. Piserchio (1973), *A.I.P. Conference Proceedings No. 3, Particles and Fields Subseries No. 2* (1973), Vanderbuilt University, Nashville, Tenn.

8. "Underwater Cosmic Rays", P. Kotzer and Jere J. Lord (1973), *Hydrolab. Journal*, 1, (2), July 1973.

9. "Cosmic-Ray Nuclear Interactions Over 5 Tev and Comparison with Scaling", J. W. Martin, J. R. Florian, Robert E. Gibbs, Peter Kotzer, J. J. Lord. (1973), *Proceedings of the 13th International Conference on Cosmic Rays*, Denver, Colo.

10. "Cosmic-Ray Muons Underwater", S. Anderson, J. J. Lord, and Peter Kotzer. (1973). *Proceedings of the 13th International Conference on Cosmic Rays*, Denver, Colo.

11. "Proton Interactions in Heavy Nuclei at 200 GeV", J. R. Florian, L. B. Kirkpatrick, J. J. Lord, J. Martin, R. E. Gibbs, P. Kotzer, R. Piserchio. Paper—*A.I.P. Division of Particles and Fields, 1973 Meeting*, Berkeley, Calif.

12. "Changing Composition of Cosmic Ray Primaries in the TeV Energy Range", P. Kotzer, S. N. Anderson, J. R. Florian, L. D. Kirkpatrick, J. J. Lord, J. W. Martin, *A.I.P. Division of Cosmic Rays,* 1973, Tucson, Ariz.

13. "Composition of Cosmic Ray Primaries at Energies > 1 TeV/Nucleon", P. Kotzer, S. N. Anderson, J. R. Florian, L. D. Kirkpatrick. J. J. Lord, J. W. Martin, *A.I.P. Division of Cosmic Rays,* April 1974

14. "Cosmic Ray Nuclear Interactions at Very High Energies", J. W. Martin, J. R. Florian, L. D. Kirkpatrick, J. J. Lord, R. E. Gibbs, P. Kotzer, *American Physical Society,* Washington, D.C., April 1974

15. "Neutron Production by Muons at Various Depths Underwater", S. Anderson, P. Kotzer, J. J. Lord, *American Physical Society,* June 1974

16. "Interaction of 300 GeV Protons with Tungsten and Silver," Abstract submitted for the *Fall meeting of the Division of Particles and Fields of the American Physical Society, 1975.* J. R. Florian, L. D. Kirkpatrick, J. J. Lord and J. W. Martin, Univ. of Wash., R. E. Gibbs, East Washington State College and P. Kotzer, Fairhaven College.

17. "Absorption and Interactions of the Cosmic Ray Muon Beam in Great Thicknesses of Matter," Abstract submitted for the *Annual Meeting of The American Physical Society, Anaheim, California, Jan-Feb 1975,* S. Anderson, P. Kotzer and J. J. Lord Unievrsity of Washington, Seattle.

18. "Slow Muons and Other Associated, Locally Produced Particle Fluxes at 60 Meters Underwater" P. Kotzer, S. Anderson, J. J. Lord, K. Stehling, *Proceedings of the 14th International Cosmic Ray Conference 1975,* Max Planck Institut Für Extraterrestrische Physik, München, Germany.

19. "Anomalous Stopping Particles at Great Depths Underground" P. Kotzer, S. Anderson, J. J. Lord, *Proceedings of the 14th IUPAP International Cosmic Ray Conference 1975,* Max Planck Institut Für Extraterestrische Physik, München, Germany.

20. "*Proceeding of the 1975 Summer Workshop on Neutrino Interactions in the Ocean Depths and on Oceanographic Physics and on Marine Engineering,* twenty four contributions, 317 pages, Western Washington State College, 1976, P. Kotzer, editor.

21. "Design Parameters of Large Scale Underseas Supernova Neutrino Detectors" P. Kotzer, D. Davisson, J. J. Lord, S. Neddermeyer, K. Stehling, *Bulletin of the American Physical Society,* April 1976.

22 "Residue Cosmic Ray Muon Fluxes at Great Depths Underground", P. Kotzer, S. Anderson, R. Lindsay, J. J. Lord, *Bulletin of the American Physical Society,* April 1976.

23. "DUMAND as a Supernova Neutrino Detector", P. Kotzer, J. Lord, F. Reines, *Proceedings of the 1975 Summer Workshop on Neutrino Interactions in the Ocean Depths and on Oceanographic Physics and on Marine Engineering, Western Washington State University,* Bellingham, 1976.

24. "Long Range Alpha Particles and Correlation with Superheavy Nuclei" P. Kotzer, R. Lindsay, S. Anderson, J. J. Lord, S. Neddermeyer *Paper presented at the Annual Meeting of the APS/AAPT.* Chicago, Ill., 7-10 February 1977.

25. "Neutrino Detection in an Undersea Habitat", Kurt R. Stehling, *Sea Technology,* December 1973.

26. "Man and the Atom in the Ocean", Kurt R. Stehling, *NOAA Magazine,* Vol. 5, No. 1, January 1975.

27. "Keeping a Watery Eye on the Universe", Kurt R. Stehling, *NOAA Magazine,* Vol. 7, No. 2, April 1977.

28. "Manned Submersible Study Cosmic Radiation Deep in the Sea", Robert S. Jones, Peter Kotzer, *Sea Technology,* March 1978.

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