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Summary Report on Progress at the Hawaii DUMAND Center

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This paper will attempt to summarize briefly technical developments in DUMAND during the last year. It will be concerned mainly with the Hawaii DUMAND Center, which started operation under the direction of Prof. V. Z. Peterson at the beginning of 1980, and has been the focus of DUMAND activity since then.

1. Development of Optical Sensors.

A considerable amount of work has been devoted to the development of a high-sensitivity sensor. This led to the development of Sea Urchin, described in detail in the accompanying paper MN6-6.

In addition work has been done (mainly by J. Learned) in aiding the development, both at EMI and at Hamamatsu, of a 13" hemispherical-cathode photomultiplier tube, whose sensitivity for axial light is about 1.5 photoelectrons collected in a flux of 100 quanta/m^2. This tube is expected to be of widespread use in DUMAND.

2. Monte Carlo Work on Array Design.

This work, of the highest importance to DUMAND, has been carried out mainly by V.J.Stenger and A. Roberts. The Monte Carlo programs can evaluate the response of any array, with sensors of prescribed sensitivity, to charged particles, cascades, multiple muons, and any other required events. To date, the programs have been used primarily to investigate the response of various array geometries and sensitivities to muons. Studies on the detection of electron neutrinos and of multiple muons are just getting started.

As a consequence of this work, it has been possible steadily to optimize parameters, and thus to reduce the cost and complexity of the DUMAND array. The MICRO array (1) started out as an exercise in deployment, with no thought of doing physics with it,since it was thought too small. However, Monte Carlo investigation showed it to be a good muon detector, with uniform sensor spacing of 50m, using Sea Urchin sensors. Very recently, further work on asymmetrically spaced arrays (see Sec. 7, below) has resulted in an array with strings 50m apart and sensors 25m apart along the strings (2). Table 1 shows the arrays currently under consideration. MINI is primarily intended for the detection of electron neutrinos.

3. Muon String.

As a first step toward putting an array into the ocean, and as an indispensible stage in testing and proving DUMAND concepts, the DUMAND group has started construction of a "muon string" of five sensors, to be deployed as a single string, with spacing between sensors of about 5 meters. This device and its capabilities are decribed at some length in the accompanying paper, MN6-3. In addition to providing irreplaceable operating experience in the ocean, the muon string will also provide useful data in muon physics, since it represents an effective area for muon detection of about 700 m^2.

As of March, the project has reached the construction phase, with computers, pressure housings, cable and considerable electronics on hand.

4. DUMAND Meetings.

Three major meetings were held during the year.

A. Signal Processing Workshop. - Held in Honolulu in February, it was attended by over 20 physicists and engineers, who discussed possible schemes for processing signals from a DUMAND array. The one they considered was the original 1978 DUMAND Standard array, with nearly 23000 sensors; it therefore posed the greatest possible difficulty of any array. Despite this, several feasible procedures were advanced. It became clear that fiber optics data transmission, both within the array, and between the array and shore, would be essential in minimizing the amount of underwater signal processing required. Data transmission by fiber optics is just coming into use, and all the engineering needed to provide practical underwater systems has not yet been done. Proceedings of the Workshop are available from the Hawaii DUMAND Center.

B. 1980 DUMAND Symposium/Workshop.

About 75 conferees from 9 countries attended the week-long symposium and 3-day workshop held at the Hawaii DUMAND Center in Honolulu July 24 - Aug. 2. The symposium was mainly concerned with the field of neutrino astrophysics, and it covered the entire range, including reports on neutrino oscillations and cosmological implications. There were also discussions of cosmic-ray and proton-decay experiments, including possible auxiliary arrays attached to DUMAND that would facilitate the interpretation of very high energy cosmic-ray events. There was also much discussion of possible DUMAND array designs, all in the small to medium range (less than 2000 sensors). Two new possible deployment procedures were suggested (they were explored in depth at the deployment workshop - see below). The usefulness of DUMAND in observing neutrino oscillations over a very wide range of distance and energy was stressed, as was its value in searching for anti-matter galaxies.

The Proceedings of the 1980 Symposium/Workshop have now been published, and are available from the Hawaii DUMAND Center.

C. DUMAND 1980 Deployment Workshop. - On Dec. 1-5, 1980, a DUMAND deployment workshop was held at the Scripps Institution in LaJolla, CA., with the cooperation of Scripps and the Naval Ocean Systems Center, San Diego. Two different sensors, called high- and low-sensitivity, respectively, were postulated. For the high-sensitivity sensor a choice between Sea Urchin and a hypothetical cylindrical PMT, as proposed by EMI, was allowed. The low-sensitivity sensor was a 13" EMI hemispherical-photocathode PMT. Arrays with both narrow (15m) and wide (50m) spacing were discussed.

The workshop proposed two alternative deployment procedures that appear both feasible and economical; they are known as the drill-ship and master-buoy methods (3). The Workshop achieved two advances in design of the greatest significance. First, with any array up to about 100 to 150 strings, the entire array can be hard-wired on the surface, with only the cable to shore emerging from it. No underwater connections need be made. This will allow complete testing and monitoring of the array before, during, and after deployment, and also during cable-laying. We estimate this to add at least an order of magnitude to the reliability of the array.

Second, the present deployment schemes do not require the services of an undersea work vehicle.

5. Use of DUMAND to Study VHE Primary Cosmic Rays.

The usefulness of DUMAND, considered as a detector of underwater multiple-muon events, in studying VHE cosmic-ray events, would be greatly enhanced by an auxiliary array at or near the surface, which would give information either on the atmospheric shower development, or on the surface density of electrons or of slow muons. For this purpose, some work has been done on possible auxiliary Fly's Eye installations (4), and on subsurface low-energy muon detectors (5). The recent deployment workshop considered the latter problem; and despite predictions that such arrays were not practical, it failed to rule them out (6). The subject therefore deserves further study.

6. Further Studies of Site Properties.

During the last year additional work on site studies (7,8) has included measurements of water transparency (by two different methods), current measurements over extended periods, and bottom profiling. Measurements by both methods indicate that the water transparency at the Keahole site, which is now preferred over the Maui site for logistic reasons, corresponds to an attenuation length of at least 25m, rather than the 20m we have been conservatively assuming. This allows the array spacing to go to 50m rather than 40m, with a major saving in the number of sensors needed. Current meters at both sites indicate negligible average currents, and no currents above 11 cm/sec, a readily tolerable value. Bottom profiles indicate a region of rubble near the slope to the big island that we must avoid. Measurements of this sort will continue and expand; in particular we need more information on biofouling, and long-term monitoring of ocean currents and optical properties.

7. Introduction of Asymmetric Arrays; Present Status.

Following the deployment workshop, which emphasized the difficulties of emplacing high-sensitivity large and clumsy sensors, it was found that asymmetric wide-spaced arrays (z sensor spacings not equal to x,y string spacings) can use low sensitivity sensors, without serious loss of detection efficiency. This work is described in Ref (2) and in the accompanying paper MN6-4.

This discovery has apparently removed the requirement for further development of high sensitivity sensors, and made it possible to propose arrays with effective volumes of 10^8 m^3 or more, well suited for muon physics and neutrino detection, to be constructed and deployed at a total cost of the order of \$5M. See Table 1.

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3. See A. Schlosser, and also F. Jones, Proc. 1980 DUMAND Deployment Workshop (in press).

4. "Air Shower Detector Systems for DUMAND. I. An Atmospheric Shower Detector for DUMAND." J. Elbert, DUMAND 1980, 1, p. 203

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6. G.D.Gilbert, S.D.Hultberg and A. Roberts, Proc. DUMAND 1980 Deployment Workshop, in press.

7."Optical Properties of the Keahole-DUMAND Site," by R. Zaneveld, DUMAND 1980, 1, p.1

8. "Long Baseline Measurements of Light Attenuation," by H. Bradner and G. Blackinton, DUMAND 1980, 1, p. 9.

Table 1. Arrays Now Under Study.

PROPERTY	MIDI	MINI	MICRO
Ground Plan	500x500m	150x150m	250x250m
String Spacing	50m	15m	50m
No. of Strings	121	121	36
Sensor	13" PMT	13" PMT	13" PMT
Vertical Spacing	25m	15m	25m
Vertical Ht.	500m	300m	500m
Sensors/string	21	21	21
Total No. of Sensors	2541	2541	756
Volume, Cu. M.	$1.25x10^8$	$6.7x10^6$	$3x10^7$
Array Radius, km	.25	.075	.125
Volume gain for Detection of 2-TeV neutrinos	6.15	22.2	12.5
Effective Vol. m^3	$.8x10^9$	$.15x10^9$	$.4x10^9$
Counting rate; muons from neutrinos of 200 GeV and above: Events/year	$5x10^4$	$1x10^4$	$3.x10^4$
Normalized Minimum Detectable Flux (MDF) Neutrinos/cm^2 sec MDF	$2.5x10^{-10}$	$1.5x10^{-9}$	$6x10^{-10}$
Angul. Accuracy, mr	5	12	15-50
Cost, estimated	$10-15M	$5-10M	$3.5-7M