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DUMAND Note 80-11

PROPOSED 1980 DUMAND STANDARD ARRAY

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Abstract

A revised standard array is proposed. Its ground plan is a rhomboid of area 0.866 km2, 1000m on a side, with 21 rows of 21 strings each, with 15 modules per string. With a spacing of 50m between elements, this yields a volume of 0.60 km3. The total number of modules is now 6615, as compared with 22,698. Although area and volume are reduced by a factor of 2, the total cost is now estimated as under $20M, as compared with $89M for the 1978 standard array.

The standard 1978 DUMAND array has for two years been the basis for all DUMAND computations, calculations, and experimental designs. Such a standard is essential; otherwise there is no way that different parts of the project can be sure they are talking about the same thing. Physics capabilities, deployment, engineering, signal processing, module design, all depend upon the same concept as to what DUMAND stands for. To distinguish the full-scale 1978 DUMAND array from subsequent considerations of smaller or "mini-DUMANDS", it has been denominated DUMAND G, the G standing for Gigaton. In point of fact, the area of DUMAND G is 1.8 km2 and the enclosed volume 1.22 km3. Fig. 1 from the original description of the array(1) is a diagram of it.

Several considerations have been leading us in the direction of redefining the standard array. First, the cost of DUMAND G was originally estimated , in 1978 dollars, as $89M(2). Subsequent improvements in module design have radically increased the module sensitivity and reduced the cost of the individual optical module ; and improvements in the method of deployment have decreased the estimated cost of deployment, so that a revised overall cost for DUMAND G is now $55M.

Now, however, new factors have made their appearance, and their effects must be taken into account. They include a reconsideration of the priorities of the experiments planned, and some new results of Monte Carlo calculations. Taken together, these factors lead us to propose a new standard DUMAND, to be called DUMAND G2, to replace DUMAND G as the full-scale model.

First, we describe the new DUMAND G2, explain the steps leading to its proposal and then compare its characteristics with those of DUMAND G.

In the hexagonal floor plan of DUMAND G (Fig. 1), there are three legs, each with 20 rows of 21 strings, making a total of 60 x 21 strings, plus one more at the center to make 1261. Each string has 18 modules, so the total number of modules is 22,698.

In DUMAND G2, (see Fig. 2) only one of these three legs is retained, leaving a rhomboidal array of 21 rows of 21 strings, each with 15 modules. This yields a total of 6615 modules. The spacing is increased from 40 to 50 meters. This makes the rhombus 1000 meters on a side. The 50-meter spacing gives the array a vertical height of 700m, so that the volume becomes 0.60 km3 and the area 0.866 km2.

Table 1 lists the dimensions and costs of DUMAND G and DUMAND G2.

TABLE 1

Two sets of costs for DUMAND G are given. The first is the original estimate(3); the second, in parentheses, shows the savings from changing the detector module to Sea Urchin, and a deployment method revised as described in Ref. (3).

ARRAY Property	DUMAND G	COST $M	DUMAND G2	COST $M
No. of Modules	61x20x18= 22,698	53.(23)	21x21x15= 6615	6.6
Spacing, m.	40.		50.	
Area, km2	1.8		0.866	
Volume, km3	1.22		0.60	
Fiducial vol.,km3 (for neutrino interactions)	0.61		0.28	
Cables		7.8		3.1
Floats		2.0		0.6
String and row Module Assembly		10.		4.
Deployment		15.(10.)		3.5
Shore cable, Computer		1.0		1.0
Navigational aids		0.7		0.3
	TOTAL	89.5(54.5)		19.1

There are three major reasons for the reduction that brings the projected cost, in 1980 dollars, to under $20M. They are:

1. The development of a more sensitive, less expensive individual detector module, the Sea Urchin. The sensitivity is improved by a factor of about 4, the cost decreased about a factor of 2, by current estimates.

2. The Monte Carlo studies of the effects of varying the array spacing on the efficiency of detection and the measurement precision.

3. The changing of priorities on measurements to be made with the array, which place a lower priority on high-energy physics investigations of neutrino interactions in the 1-10 TeV region. This allows increased spacing with less disadvantage.

SEA URCHIN

Sea Urchin has been described in a preliminary fashion in previous papers(4-5). Fig. 3 shows a sketch of the module, and Fig. 4 a diagram indicating the internal structure.

The major advantages of Sea Urchin are:

A. Reduction in cost. The module uses inexpensive materials, and only a single phototube of 8" diameter. The production of a sensor whose effective cross-section approaches a square meter, which uses only one 8" phototube is an unusual feat, and is due to the perfect match between the phase space of the light emitted by each of the spines, and the collecting area of the PMT photocathode. No other detector so far proposed has that property.

B. Increased sensitivity. The sensitivity of a complete unit has not yet been tested, but assuming a high quantum efficiency for the wavelength shifter used, an overall sensitivity of 50 quanta/m2 for producing a 3-electron trigger appears to be attainable; this is about a factor 4 better than the 1978 module.

The disadvantages:

A. Greatly increased fragility. Should the spines be eventually made, as presently intended, of glass tubing filled with a solution of wavelength shifter in an organic solvent like toluene or styrene, this will constitute the most serious drawback to the design.

B. Much more complicated construction. Somewhere between 500 and 1500 individual spines must be individually fabricated, and assembled in optical contact with the glass pressure sphere containing the PMT and electronics. The fragility of the Sea Urchin also demands a rethinking of the module packaging and deployment problems.

DEPLOYMENT OF A SEA URCHIN STRING

The original concept of Sea Urchin preparation for deployment involved mounting the spines in a flexible matrix. Then, for deployment purposes, one end of the spines - the end not in contact with the glass sphere - could be gathered up into a closely-packed cylinder, not much greater in diameter than the glass pressure sphere, and then opened out, like a flower, into place after the string had been deployed to its final position. Although this appears to be a technically feasible solution, it has the undesirable feature that the all-important optical contact between the spines and the glass sphere must be made at the bottom of the ocean, under remote control, where nothing can be done easily to remedy any faults that may occur.

Searching for a better way, we have come up with the notion of the "submarine convoy" which we now describe.

Consider the unit of deployment, the 1000-meter long "row", to which 21 strings are attached, 50 meters apart. The Sea Urchin module is a 6m-diameter hemisphere, and there are 15 to a string. If these are housed in a cylinder 6m in diameter, they will fit into a 50m-long container. Then these containers can all be attached to the row structure longitudinally, giving a train of oversized railroad tank cars. If the row is designed as a framework to carry these units, and articulated between them, this should make a structure capable of being towed in the ocean, at least in reasonably calm conditions. The problems of lowering to the bottom, aligning it parallel to the other rows, staking down, and releasing the strings from the containers are as before, except that the individual containers are larger than they were. Fig. 5 shows a sketch of the individual string module (submarine), and Fig. 6 a diagram of the row, or "submarine convoy".

The scheme just presented is certainly not the only possible one. Alternatives need to be explored. Major improvements in the concept can be expected from further studies of sensor packing efficiency and specific deployment techniques.

Packing Efficiency. The packing mode shown in figure 5 requires a unique axial section for each Sea Urchin hemisphere. All lengths are additive, so that 15 3-meter-radius modules have an axial length of 50 meters per string — 1050 meters per 21-string plane.

This concept assumes that axial sensor lengths are not shared. Yet, anyone who has packaged sea urchins knows that N urchins occupy much less space than N times the volume of a single animal, since the total cross-section of the spines is independent of the animal's radius. In the context of Fig. 5, some shortening of each sensor string container can be achieved if alternate sensors are reversed to allow a nesting effect. At least a 50% length reduction should be possible, if the module spines can be protected and isolated. A water-soluble packing might be used to furnish this isolation.

Deployment Techniques. It is reasonable to assume that the transport length of a sensor plane module can be resuced to about 500 meters (only 1.5 times the length of an aircraft carrier). During transport to the DUMAND site, this length should have a horizontal configuration; e.g., towed in a submerged mode with individual sensor-string containers held near the surface by spar buoys (3).

On the other hand, transport from the ocean surface at the DUMAND site to the seafloor should be accomplished with the sensor plane modules arranged vertically. This can be done by attaching one end of the transport train to a drill string, sequentially cutting the transport buoys (starting from the opposite end) until the train is hanging vertically, then lowering that train to the seafloor. Distribution of the sensor string containers then follows the logic described by Schlosser et al.(3)

With a lower deployment cost (and higher risk), the vertically hanging sensor plane train might simply be dropped from the surface to a staging area near the DUMAND site. The surface handling drill string need then be lowered only once, and could reposition all previously dropped sensor plane modules.

ARRAY CAPABILITIES

The change from the 1978 Standard Array to the 1980 one reduces the total number of modules from 22,698 to 6615. This decrease, by a factor of 3.4, only produces a decrease in area (in plan view) from 1.80 to 0.866 km2, a factor of 2.1; and in volume by a factor of 2. Factors of 2 in counting rate are rarely crucial in any experiment; and we have achieved a reduction in cost by a factor of 4.5, from \$89M to less than \$20M. This reduction in cost may be crucial in achieving the acceptance of DUMAND. What it accomplishes is to move the project from comparison with a large accelerator improvement program, such as the Fermilab energy doubler, to a comparison with an individual detector project, such as a colliding-beam target-region detector. This is a comparison we welcome; if we cannot successfully withstand it, the cost has not yet been sufficiently reduced.

Why not a further reduction? We have attempted one; if we go down to an array of the order of 2000 modules, the volume of the array will fall below the value at which a significant fiducial volume for neutrino interactions remains. For this purpose we define the fiducial volume of the array as that remaining after a 100m shell is removed from all surfaces, to serve as an anticoincidence blanket. Clearly, when the array shrinks to a 200m cube, the fiducial volume vanishes. The fiducial volume so defined is of importance primarily for the study of neutrino interactions, for which it is necessary not only to recognize the interaction as due to a neutral particle, but to observe the outgoing muon, and also to measure its energy if the dynamics of the interaction are to be observed. The following table, for cubical arrays for simplicity, shows the relevant numbers for various small arrays. For reasonable neutrino interaction studies in the 1 TeV range and above, a volume of 0.2km3 appears minimal.

Table 2. Small Arrays. For convenience they are cubical.

Edge of Cube m.	Area km2	Total vol. km3	Fiducial Vol.,km3	No. of Modules (50 m spacing)
200	0.04	0.008	0	64
300	0.09	0.027	0.001	216
400	0.16	0.064	0.008	512
600	0.36	0.22	0.064	1728

Arrays of this size, while useful for other purposes (especially those for which area is the significant parameter), are not as useful for neutrino interaction studies.

RESULTS OF MONTE CARLO STUDIES

Monte Carlo studies, presently being carried on by Prof. V. Stenger (6-8), have so far shown that, retaining the assumption of a 20m attenuation length for average Cerenkov light in water, it is possible to increase the spacing between elements without seriously degrading the performance of the array. What suffers is the efficiency of detecting muons in the 1 TeV region in an individual module; but the fact that many modules are exposed to the trajectory means that the overall detection efficiency suffers little until the individual module efficiency becomes quite low. This is one advantage of large arrays. It is not yet clear that 50 meters is the optimal choice; it depends upon how various factors are weighted. It is obviously a critical parameter; if we could go to 66.7m spacing, a cubic km array would require only 4096 modules. Thus the values shown above are perhaps still not the best we can do. They mAy perhaps be improved, either as a result of further Monte Carlo studies, or if it should turn out that the transparency of the water at the site is better than has been assumed (there is some preliminary evidence that this may be the case.) However, we have already reached the point where the module cost is less than a third of the total cost; it may not pay to decrease the number much further, but rather to try to deploy them more inexpensively, and utilize any additional gains to increase the detector array volume.

June 25, 1980

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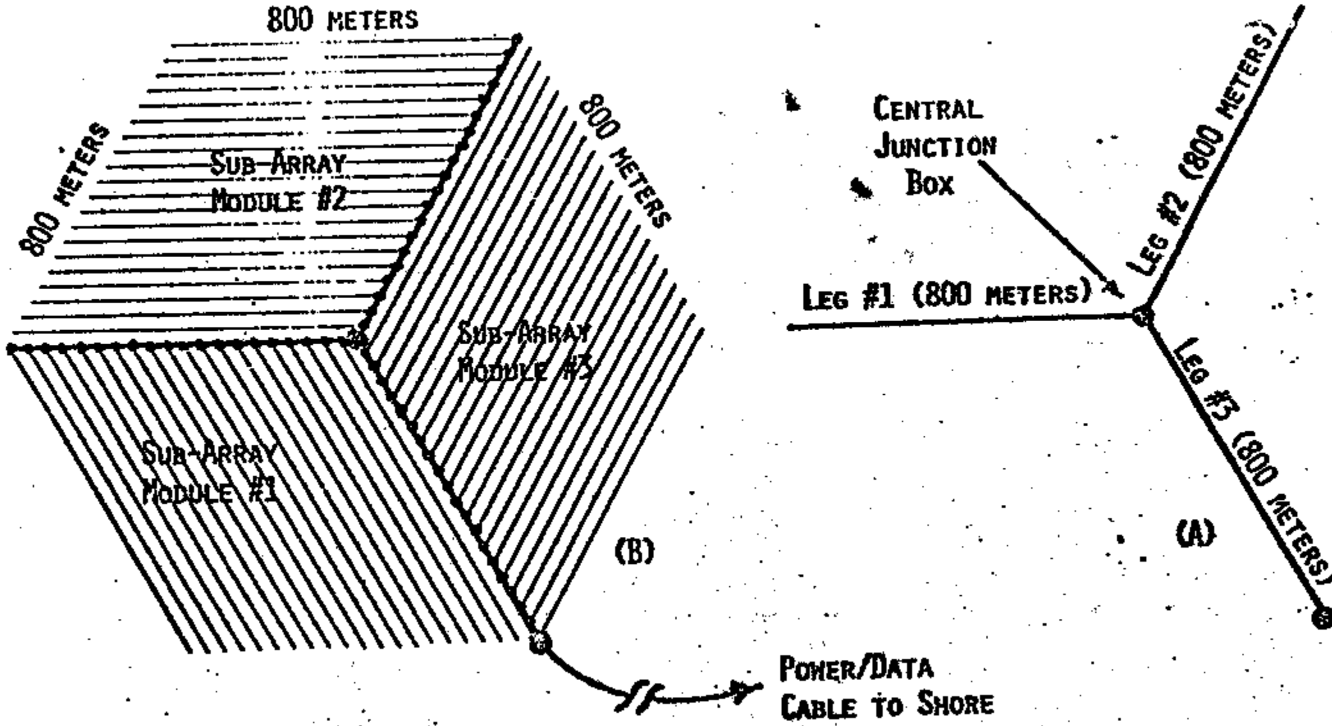

FIGURE IA. PLAN VIEW OF THE 1978 DESIGN MODEL OF THE DUMAND OPTICAL ARRAY.

SKETCH (A): THE 3 PRIMARY, INTRA-ARRAY, POWER/DATA, SUPPORT CABLES.

SKETCH (B): ADDS THE 60 INTERCONNECTING CABLES WHICH SUPPORT THE ARRAY'S 1261 VERTICAL OPTICAL SENSOR STRINGS.

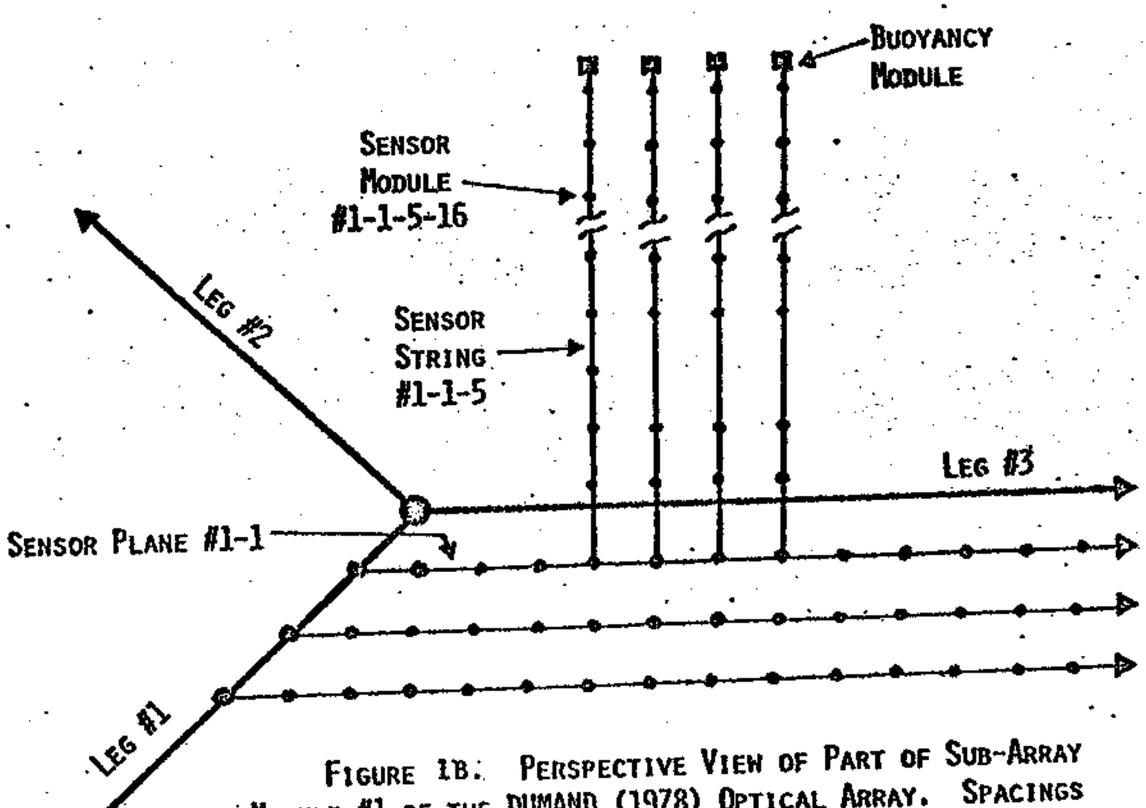

FIGURE IB. PERSPECTIVE VIEW OF PART OF SUB-ARRAY MODULE #1 OF THE DUMAND (1978) OPTICAL ARRAY. SPACINGS ARE 40 METERS BETWEEN SENSOR PLANES AND SENSOR STRINGS, AND 36.6 METERS BETWEEN CENTERS OF THE SENSOR MODULES. THE BUOYANCY MODULES FLOAT 673 METERS ABOVE THE SEAFLOOR.

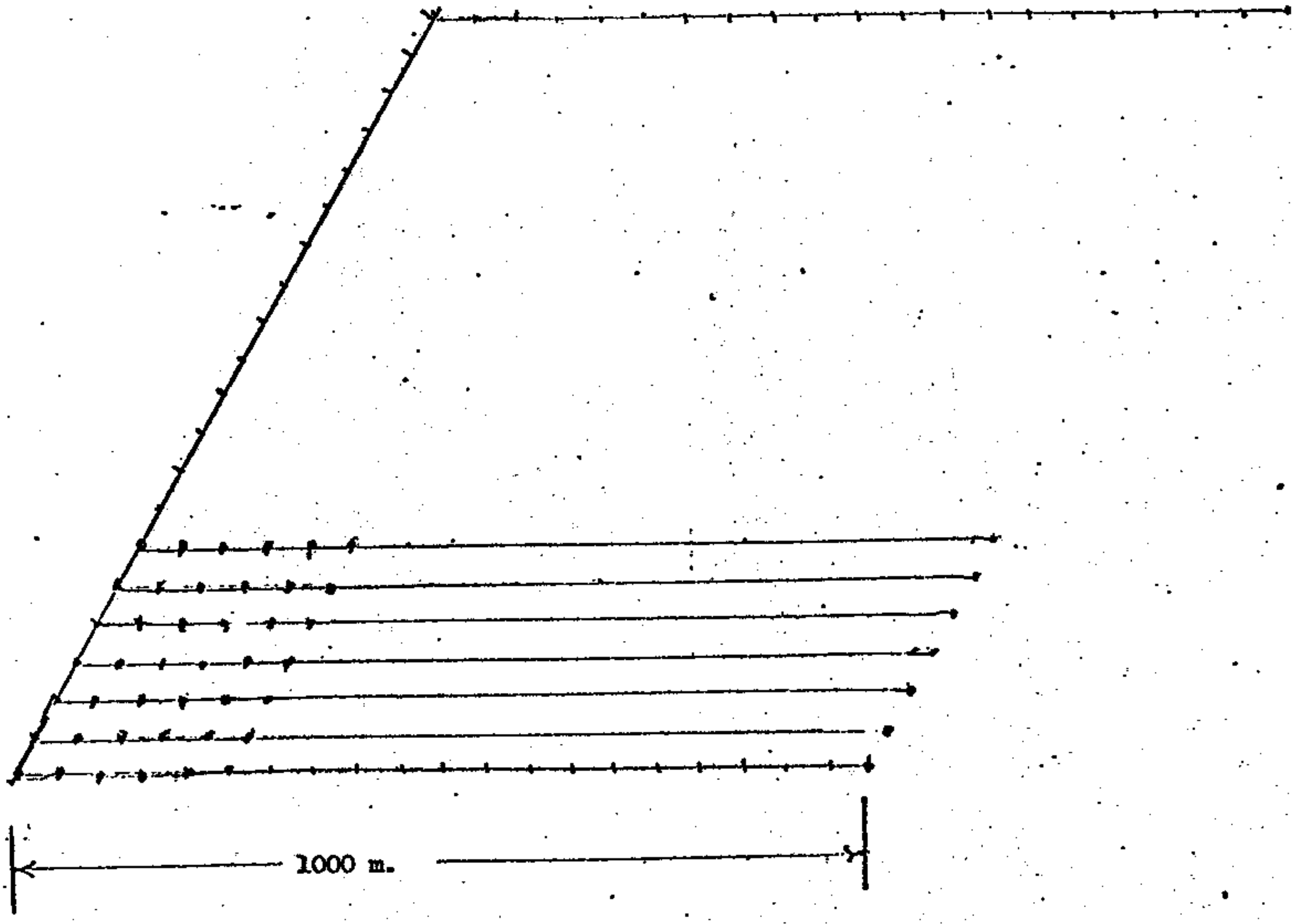

Fig. 2. Ground plan of DUMAND 2G, showing rhomboidal layout of 21 rows of 21 strings each in a close-packed hexagonal array. Dots show string locations. Spacing is 50m.

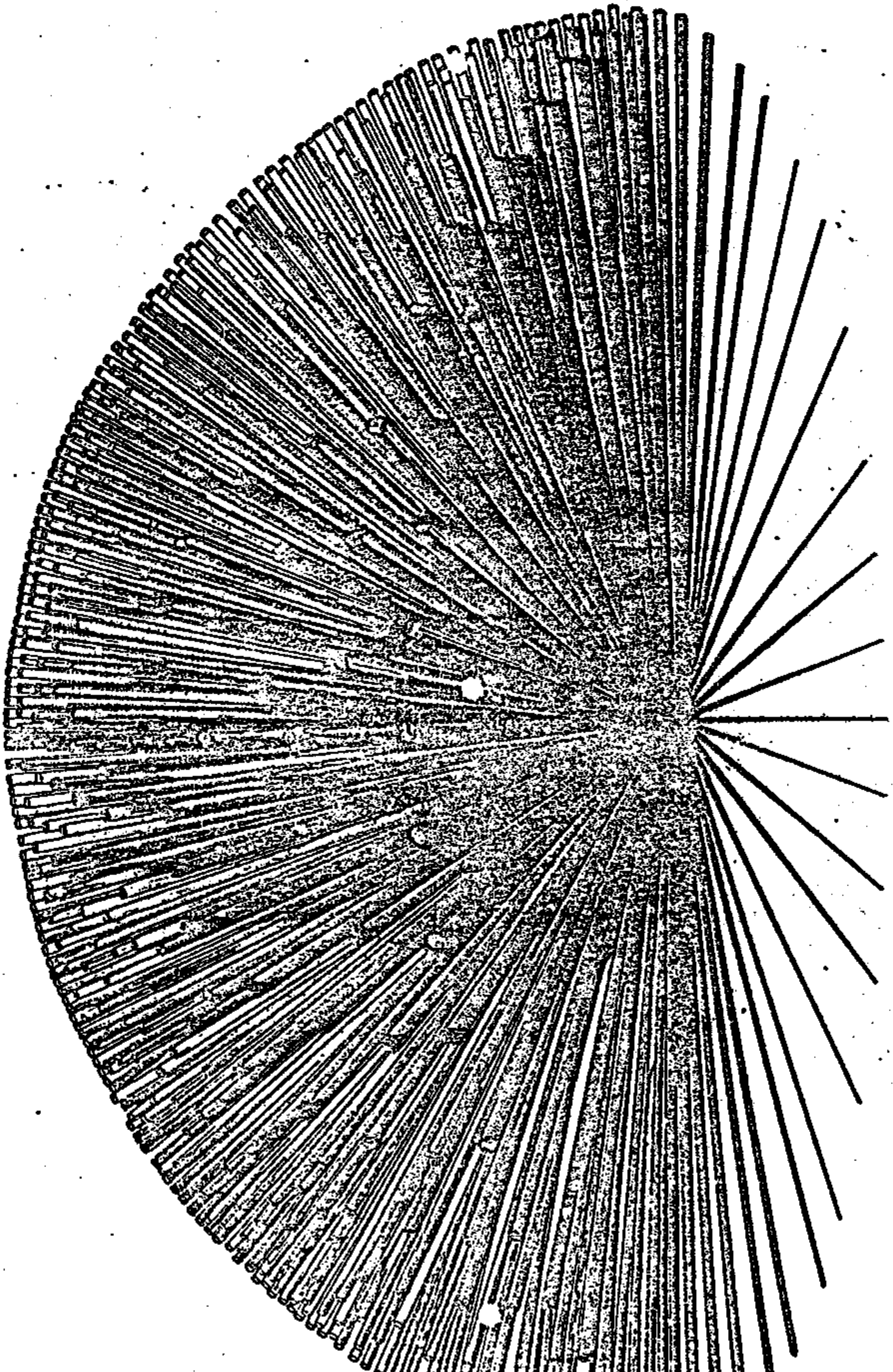

FIG. 3. Sea Urchin - artist's conception.

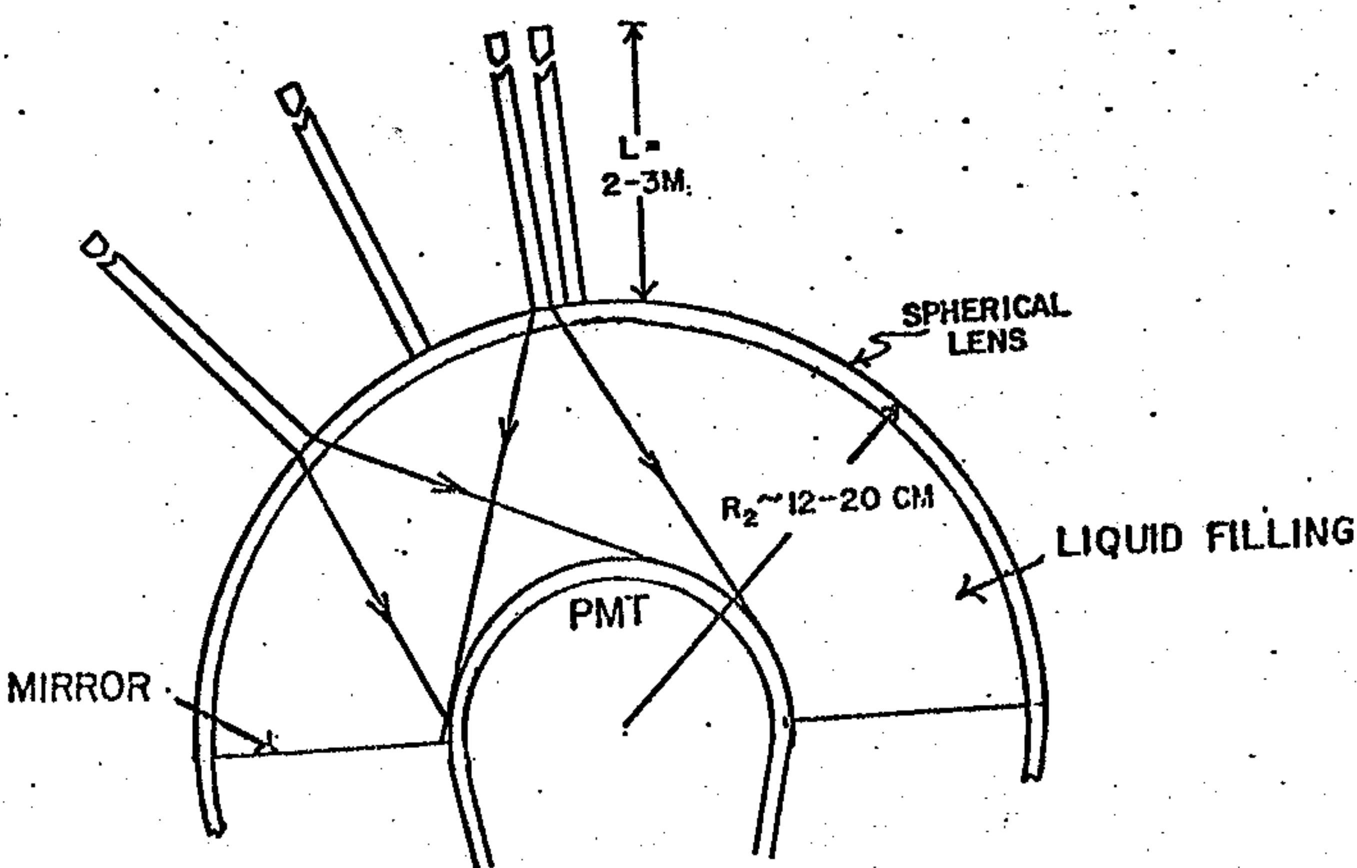

Figure 4. Sea Urchin Cerenkov detector module. A hemispherical "hard lens", about 15-20 cm in radius, sustains the ocean pressure of 600 atmospheres, and the lens liquid and PMT are at atmospheric pressure; the PMT need not then withstand high pressure. The emerging cone of internally reflected light from each WLS tube has an angular width Θ, and the PMT radius and lens radius are arranged so that the cone is entirely intercepted by the PMT cathode, thus effecting a perfect phase-space match from the PMT to all WLS tubes. The WLS solvent (toluene), the glass of the lens and the PMT, and the lens filling will all have the same index of refraction (1.51). The WLS elements consist of tubes about 3m long (more if the light attenuation is small enough) and about 2cm in diameter, radially attached to the spherical lens surface; hence the name sea urchin.

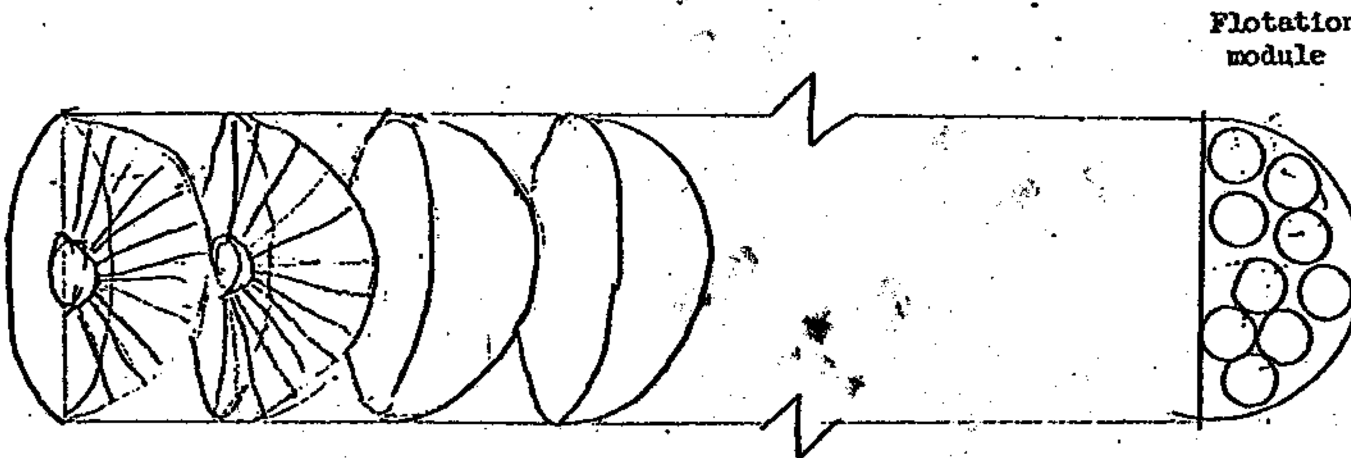

Fig. 5. The "Submarine" string container. Fifteen hemispherical Sea Urchin modules are packed as closely as possible into a sealed, sterile container 6m in diameter and 50m long, both to avoid contamination and to protect the fragile modules.

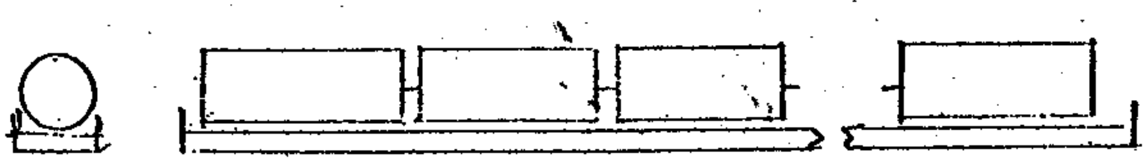

Fig. 6. "Submarine Convoy", a possible way of connecting all 21 strings in a single row to a framework, making an assembly resembling a long freight train that could be readily towed. Flexibility must be incorporated, either through articulation or inherent flexibility. If the entire row can thus be pre-assembled and tested before deployment, it can b~ connected to the feeder leg with a single connector. Lowering to the sea-floor presents a problem.