

THE SEA URCHIN MODULE

I. SURVEY OF DESIGN PROBLEMS

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OUTLINE

The design and performance requirements for the Sea Urchin are surveyed and discussed.

I. Design Objectives

The design objectives of the Sea Urchin are constrained by two limiting factors. If we think of the Sea Urchin module as the equivalent in optical sensitivity of a phototube whose cathode has an area A , the design objective is to make A about one square meter. This corresponds to a threshold for triggering by light fluxes not exceeding 50 quanta/sq.m. Larger areas suffer from excessively high background rates, and smaller ones from a decrease in sensitivity.

The background is determined by the flux of K40 photons in the ocean. For standard "20-meter" water, that flux is 150 quanta/sq.cm.sec. (1), in the Cerenkov light within the water "pass band" extending from 400 to about 520 nm (see Fig. 1). If the effective area of the photon detector is one square meter, the incident photon flux is 1.5×10^6 /sec. If we assume a photocathode efficiency of 0.1, this yields a background rate of single-electron counts of 1.5×10^5 /sec. As shown elsewhere (2) this may be tolerable, provided the signal-induced PMT background of large pulses can be kept down to about 1% or less of the signal rate.

The economics of the DUMAND detector make it important to set as a design objective for the Sea Urchin module a maximum cost of \$1000. With this objective in mind, excessively expensive solutions can be rejected at an early stage. As a rough guide to the distribution of this sum, we can use the following table.

Table 1: Tentative Allocation of Sea Urchin Costs.

Item	Cost, \$
1. Spines	370.
2. Glass Sphere	50.
3. PMT	300.
4. Electronics	100.
5. Penetrations	100.
6. Spine Mounting Matrix	50.
7. Framework	30.
8. Buoyancy to achieve zero in-water weight	-

We have included the cost of sufficient buoyancy to achieve zero in-water weight for the module. Strictly speaking, this is not a module cost, but since it is a direct result of module design we include it. It has the effect of biasing the design toward larger spine diameters, since these have a greater toluene/glass ratio and are thus more buoyant.

III. The Central Glass Sphere.

The central sphere is a major component of the design. If the indices of refraction of the sphere and the spine match (near 1.51) the emerging light cone will contain over 80% of the light from each spine in a cone of half-angle 33 degrees. To keep this cone from expanding unduly, the space between the glass sphere and the concentric photocathode must be filled with a medium of the same (or larger) index of refraction. For simplicity, and to avoid reflection losses at the PMT surface, we assume the index constant from spine, through glass hemisphere, fluid coupling medium and PMT glass envelope. Then the PMT photocathode diameter should be close to one-half the glass sphere diameter (see Fig. 2). A 16-in glass sphere, a convenient size, thus allows an 8-in diameter hemispherical photocathode. In view of the observed attenuation lengths in spines, it is large enough to allow a sufficiently large number of spines to provide the necessary detection area.

Since the upper half of the sphere contains the transparent coupling fluid, it must be sealed off from the lower half, which contains the bottom half of the PMT and the electronics and penetrations. This seal must be made at the glass sphere envelope and at the PMT (see Fig. 2).

Power and signals may be transmitted through the sphere either by direct metallic conduction (via conductors in holes) or possibly through the glass. The small power requirement of the module (under 10 watts, certainly, and probably about two) makes it possible to consider using a radio-frequency power source capacitatively coupled through the glass as an alternative to penetrations. Signals, too, can be transmitted through the glass by optical means, thus avoiding penetrations. The advantages of avoiding penetrations are increased reliability, and possible lower cost. To secure these advantages, more detailed study of the real cost and reliability of both penetrations and of r-f power distribution must be made.

IV. Spine Sockets and Optical Contact.

How are the radiating spines to be supported in optical contact with the glass sphere? What sort of matrix must they be embedded in?

The required properties are somewhat contradictory. The matrix should conform to the surface of the sphere. If it is rigid, it will have to remain permanently in that position; it will consist of an overlay with sockets or holes into which the spines will be secured. This alternative, requiring the spines to be assembled in their final configuration, has not yet been explored. The spines are relatively fragile, and their weight in air not inconsiderable. Thus they may exert a considerable torque on their mountings, and may be susceptible to breakage for that reason. If there is a permanent supporting framework, this objection may be overcome.

Alternatively, the matrix overlaying the spherical surface may be flexible; it might consist (see Fig. 3) of a sandwich of foam rubber or similar material between layers of kevlar cloth, which could be cut into sectors joined at the center, allowing the entire matrix to be brought into a plane position, for introducing the spines into their sockets (see Fig. 4). If the spines were transported in this parallel position, the volume occupied by the module during transport would be considerably decreased. In operation, the spines would be opened up like the ribs of an umbrella, after deployment.

This system suffers from the drawback that the optical contact between the spines and the glass sphere is made after deployment, when nothing can be done about mismatches or errors. The matrix must be flexible enough to allow the spines to fold up into the parallel position, and rigid enough to support them when in position. This subject requires further investigation.

V. Support Framework.

This has the function of holding the spines firmly in place. It must of course be practically transparent. Present concepts envisage a radial set of spokes just below the diametral plane, supporting a circular rim at the "equator" of the hemisphere. There is also a "north pole" fastened to the glass sphere. Meridians of longitude connect the north pole and equator, at intervals; they are thin metal rods or strips. The space between these meridians can then be traversed by cords of strong material - e.g. nylon - that support the spines in place, and are secured to the framework. Fig. 5 shows such a system.

VI. Test and Auxiliary Equipment.

The test equipment needed will include light flashers, to test detector sensitivity; and probably various signals to perform various tests on the electronic functions. No serious thought has as yet been given to such problems.

4. OPACITY CALCULATION

The overall effectiveness of the Sea Urchin requires a knowledge of its total cross-section for incident light. This is described by a quantity we call the opacity, which is the fraction of the incident light that strikes a spine on its way through the array. The program CYL6X deals with the fate of light that

strikes a spine; the opacity program tells us what fraction of the geometric cross-section of the module is effective.

The geometric shape of the array is a hemisphere of radius r . The geometric cross-section in a direction normal to the diametral plane of the hemisphere is πr^2 , and in the direction at right angles that, half as much. The opacity has been calculated in both directions in a Monte Carlo program written by U. Camerini. Table 2 is a synopsis of the results, calculated for three different spine diameters, and for three different assumed values of the packing fraction (defined as the fraction of the area of the glass sphere housing the PMT which is actually covered by the spines.) The maximum possible packing fraction would be the area of a circle divided by that of the square enclosing it, or $\pi/4 = 0.68$. The effective areas are plotted in Fig. 6 vs the geometrical cross-section for all three sizes, and for two values of the packing fraction.

TABLE 2. Opacity of Sea Urchin Modules.
The geometrical cross-section is given for each spine length.

Spine Radius cm	Spine Length, cm, = (Geometrical area	100	200	300	400	
		3.14	12.56	28.27	50.26	m ²)

A. Packing Fraction 0.70

1. Light normal to diametral plane (incident from top)

1.27 (1"D.)	0.710	0.521	0.412	0.342
0.63 (1/2"D.)	0.866	0.713	0.603	0.522
0.32 (1/4"D.)	0.955	0.866	0.783	0.713

2. Light parallel to diametral plane (side view). Values here are referred to the same cross-section as above, even though from the side the cross-section is only half as great. The maximum value possible is thus 0.5

1.27	0.430	0.356	0.302	0.262
0.63	0.477	0.433	0.392	0.357
0.32	0.493	0.476	0.454	0.433

B. Packing Fraction 0.60

1. Light normal to plane (from top).

1.27	0.668	0.478	0.374	0.307
0.63	0.837	0.672	0.560	0.480
0.32	0.939	0.837	0.747	0.672

2. Light incident from side.

1.27	0.417	0.336	0.280	0.240
0.63	0.468	0.419	0.373	0.336
0.32	0.493	0.470	0.444	0.418

C. Packing Fraction 0.50

1. Light normal to plane (from top).

1.27	0.614	0.429	0.330	0.215
0.63	0.779	0.622	0.509	0.431
0.32	0.920	0.799	0.700	0.622

2. Light from side

1.27	0.398	0.310	0.254	0.215
0.63	0.458	0.399	0.350	0.311
0.32	0.487	0.459	0.428	0.399

VII. Effect of Spine Diameter on Buoyancy Requirements.

The larger the diameter of the spine, the greater is the ratio of toluene weight to glass weight, since these vary respectively as the volume and the area. Since the glass is denser than water and the toluene lighter, the buoyancy

cy of the spine increases with diameter. The cost of buoyancy was estimated in the 1978 workshop at about \$4/kg (3), when in the form of glass spheres, the cheapest possible source. Fig. 7 shows a comparison of the buoyancy of a module (including only the spines) for two choices that have about the same optical effective area: 1" diameter spines with a packing fraction 0.7, and 1/2" spines with a packing fraction 0.5. The 1" spines are 3.5m long, the 1/2" spines 3.0m. The difference in buoyancy is significant; it amounts to about \$200 worth per module. That is why we have included it in the parameters listed in table 1. It is worth noting that one gallon of toluene, costing about \$1.60, contributes \$2.04 worth (.51 kg.) of buoyancy.

VIII. Pressure Tolerance of Spines.

Since toluene compresses about 2.5% under 500 atmospheres pressure, the glass spines must be so designed as to permit this compression; the alternative would be to make them thick enough to withstand the pressure, thus adding much weight. In order for this to be possible the volume of the spine must be capable of compressing. Two possible ways of achieving this have been suggested, but there has been time to test neither of them as yet. One relies on the existence of a rubberlike material immune to attack by toluene, called "Viton", made by DuPont; it is supposed to be the only material with such properties. The other is based on the use of a lubricating grease called Molykote FS-3421, also alleged to be impervious to attack by toluene. Methods of using these materials are indicated in Fig. 8. Both of these materials are expensive, and satisfactory designs at reasonable cost are not yet available.

REFERENCES

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2. See, e.g., A. Roberts, "Trigger Logic and PMT Background Rates in DUMAND", Proc. 1980 DUMAND Signal Processing Workshop, A. Roberts, ed. Hawaii DUMAND Center, Honolulu, HI., 1980.
3. W. J. Nordell and R. H. Knapp, "Structural Response of the DUMAND Sensor Strings", DUMAND 1978, Vol. 3, G. Wilkins, ed., p. 67.

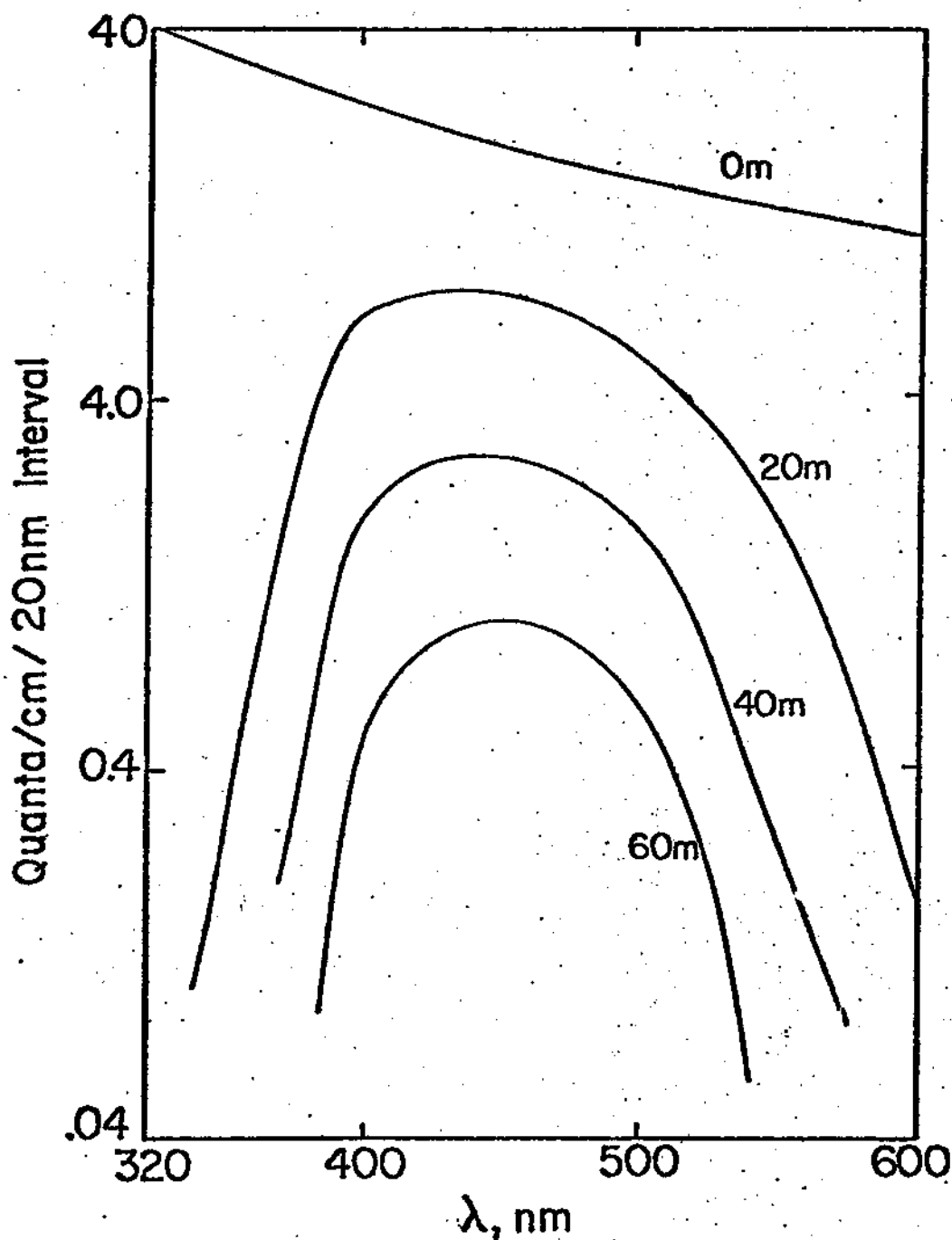


Fig. 1. Cerenkov spectrum of a minimum-ionizing particle in the ocean. curves are labelled by the length of water traversed: 0m signifies the emitted spectrum, with its well-known $1/\lambda$ dependence. The water is assumed to have an attenuation length of 20m at 440 nm. The resultant spectra reflect the "window" centered at 440 nm.

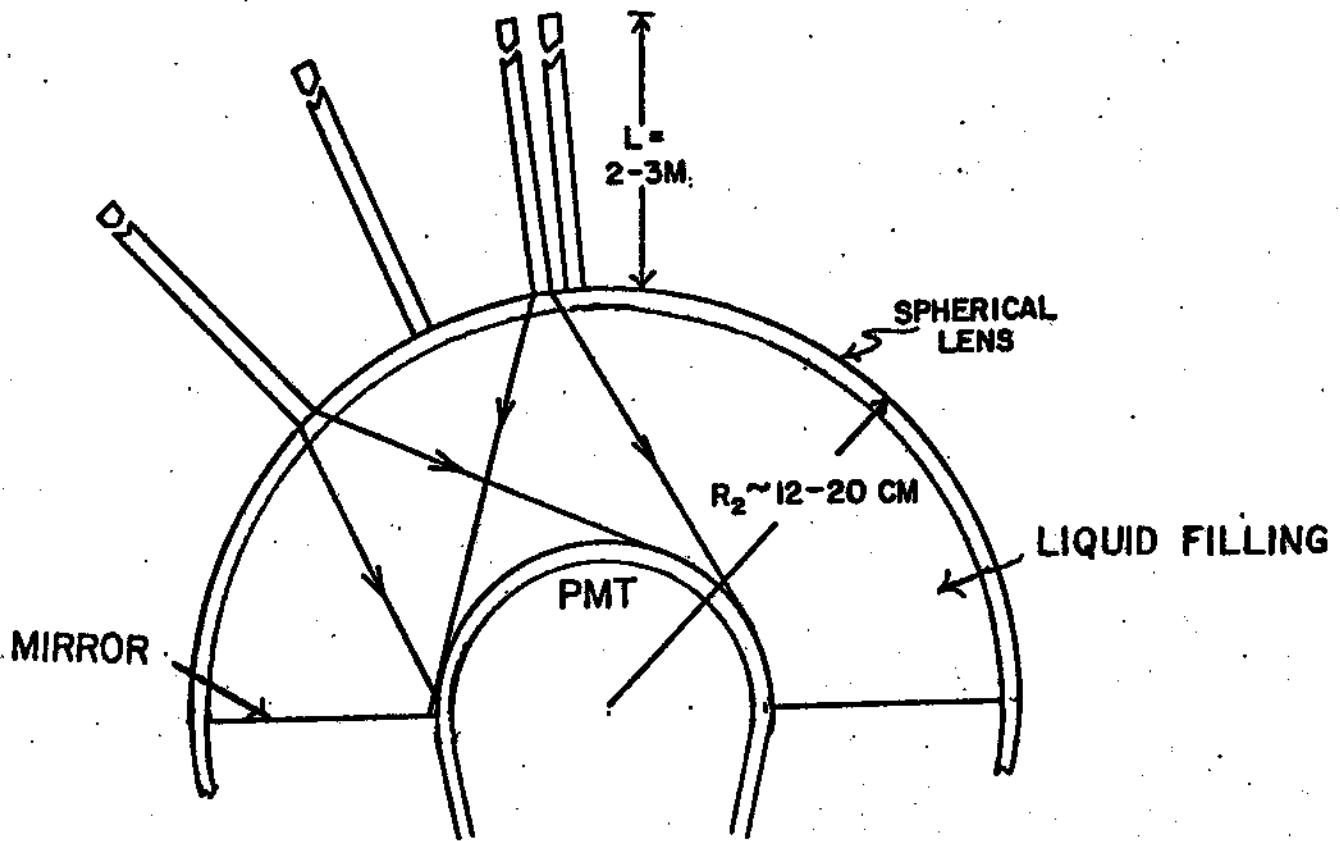


Figure 2, Sea Urchin Cerenkov detector module. A hemispherical "hard lens", about 15-20 cm in radius, sustains the ocean pressure of 600 atmospheres, and the lens liquid and PMT are at atmospheric pressure; the PMT need not then withstand high pressure. The emerging cone of internally reflected light 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.

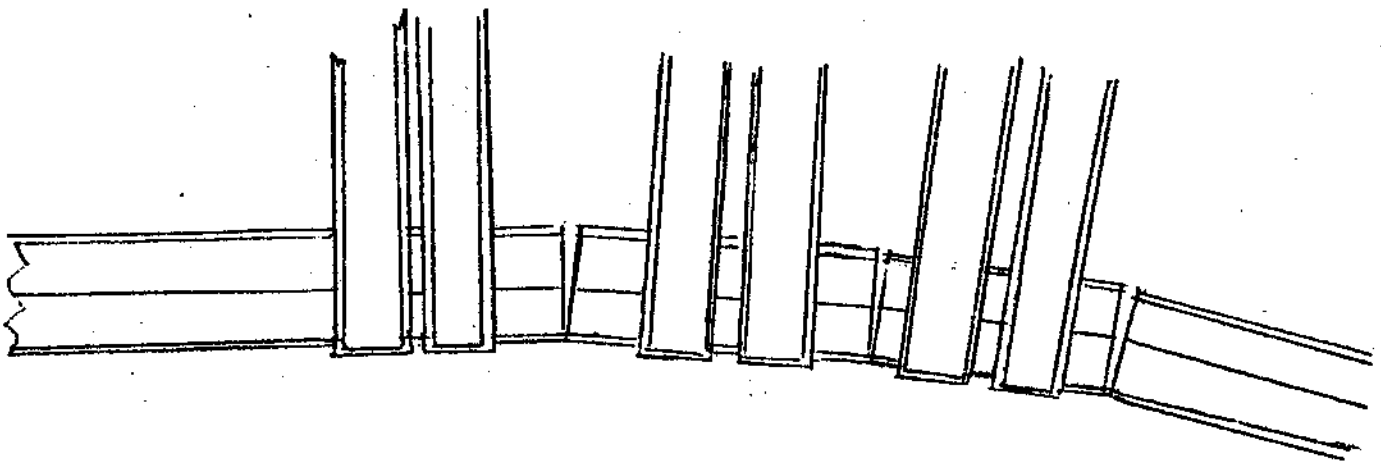


Fig. 3. Double-layer sandwich of foam rubber between sheets of Kevlar, with the top layer and rubber filling split to allow the sandwich to conform to a spherical surface. A few spines are shown mounted in holes in the sandwich.

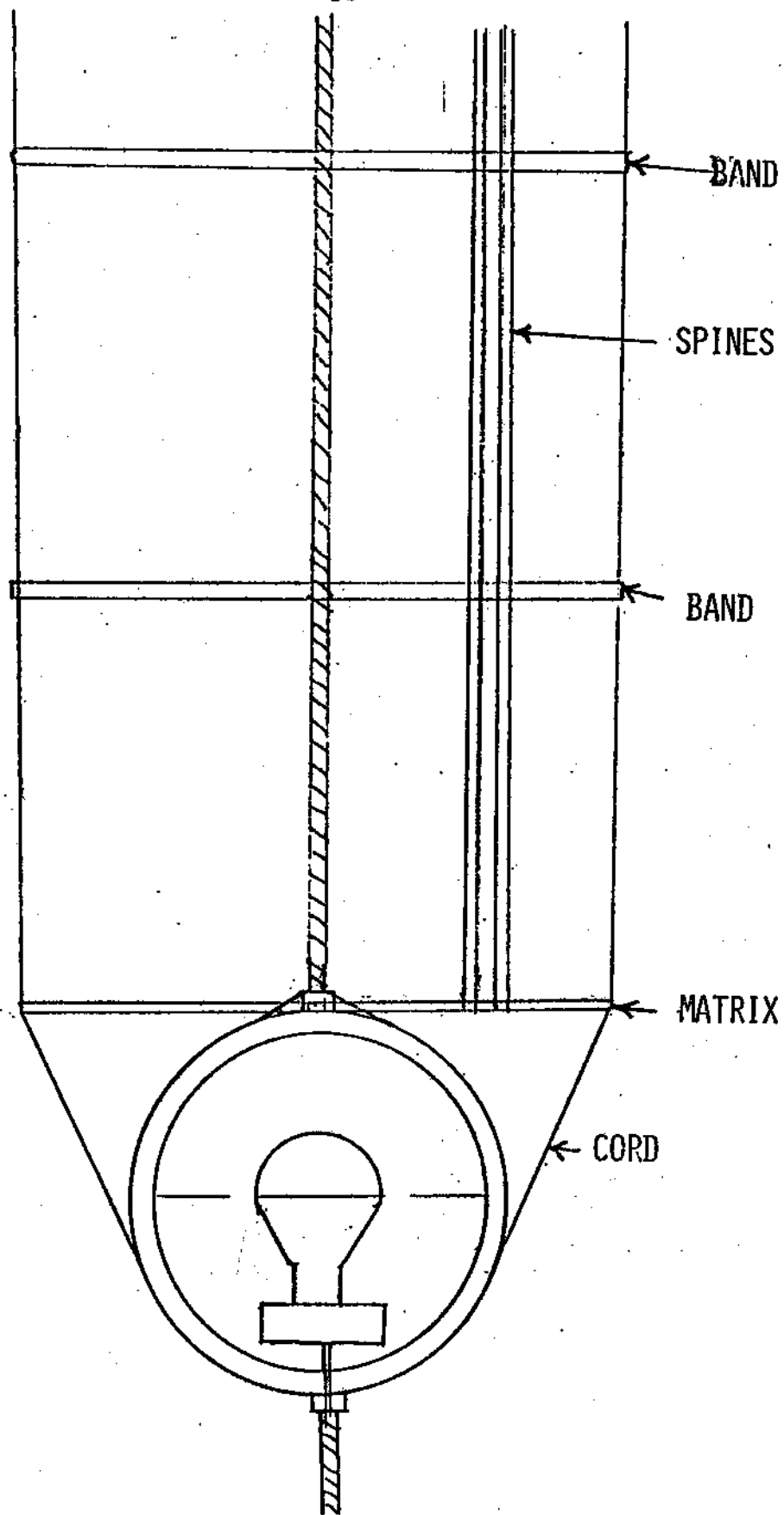


Fig. 4. Schematic of a glass sphere, attached to its cable, in position for transport. The spine-holding matrix has been extended into a plane position for transport. Only two spines are shown; but all are parallel to the cable. Two of the cords that will pull the spines into operating position are shown. The bands that secure the spines for transportation are still in place.

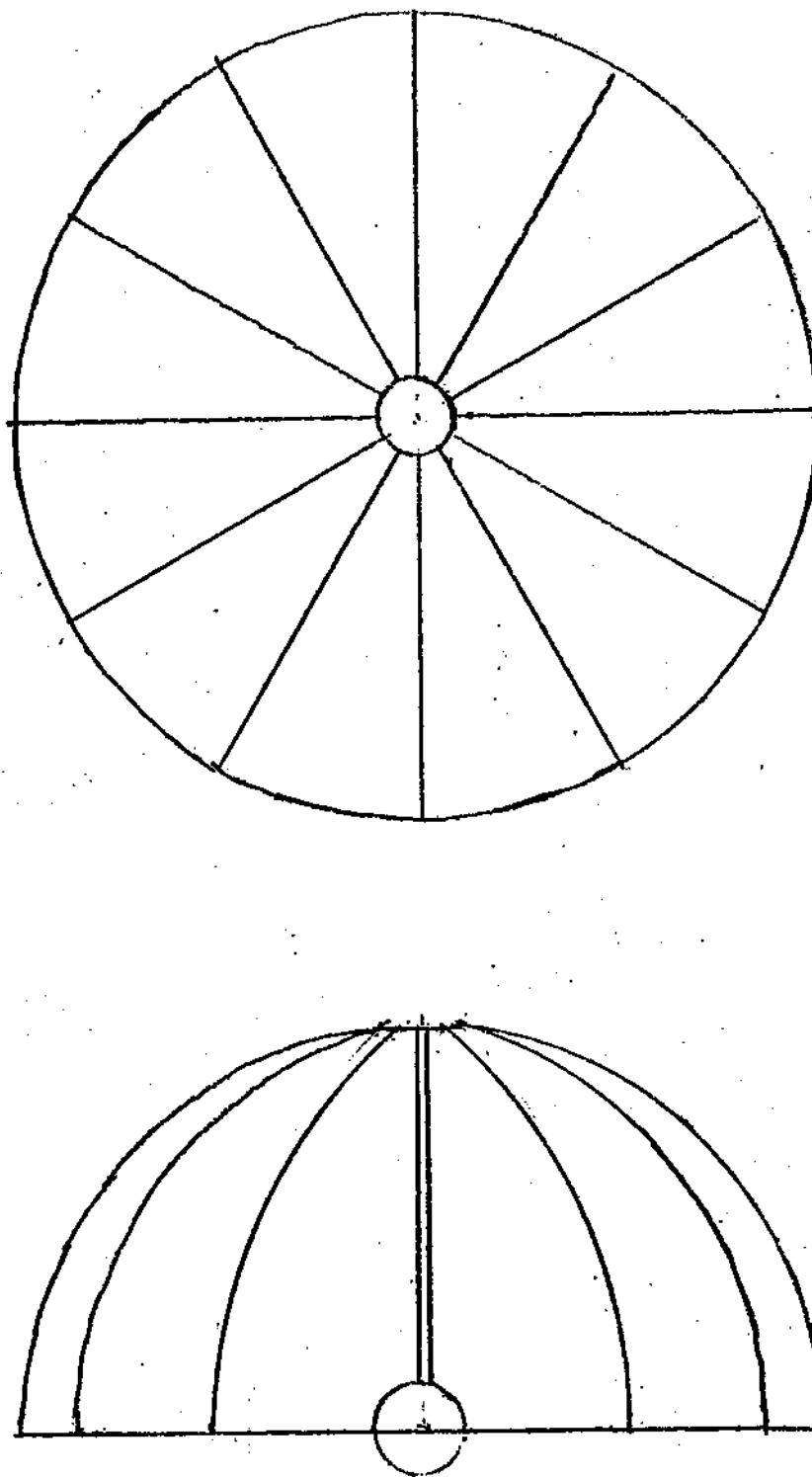


Fig. 5. Sketch of mechanical support frame for spines. An array of spokes in the equatorial plane of the glass sphere connects to an equatorial ring. A "North Pole" from the pole of the sphere is a rigid rod that supports flexible "meridians of longitude" to which would be fastened cords to support individual spines in position.

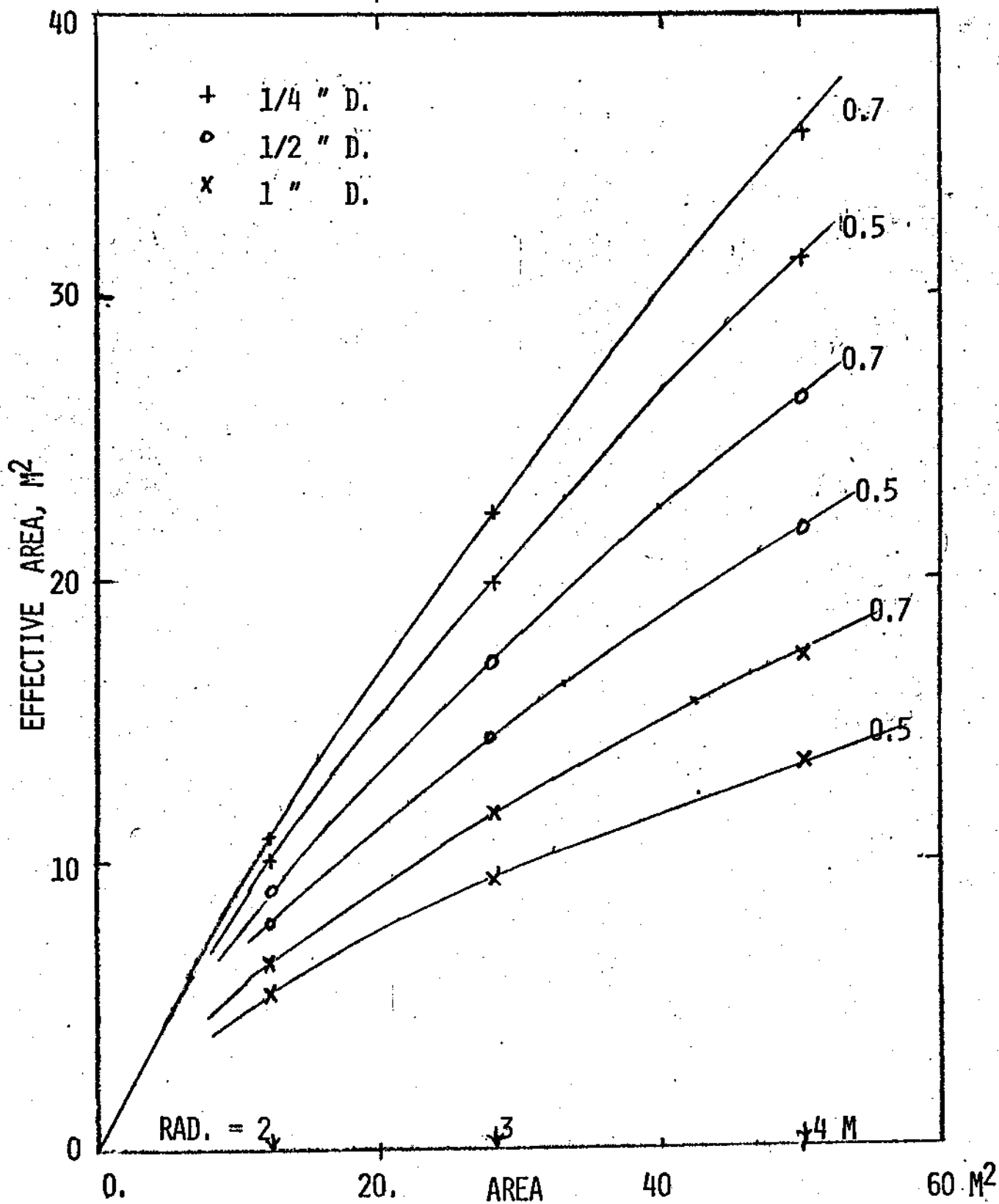


Fig. 6. Plot of the effective area of the Sea Urchin array vs. geometrical area, as a function of spine diameter and Packing Fraction (the fraction of the glass sphere area occupied by the spines.) The areas corresponding to spine radii of 2 to 4 meters are marked.

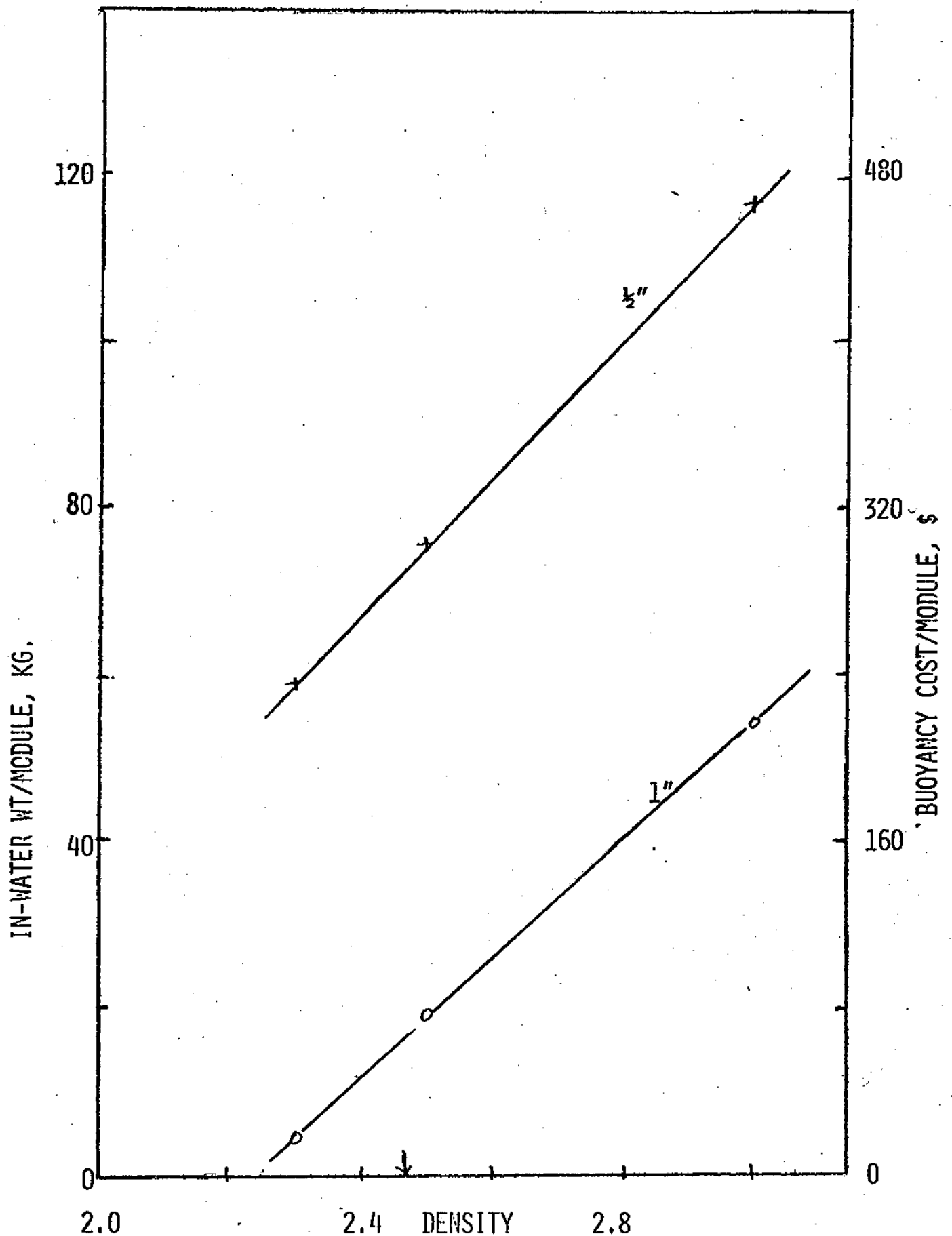


Fig. 7. The in-water weight per module of the spines only, for the two cases discussed in the text: 1/2 " spines 3m long, P.F. 0.5; and 1" spines 3.5m long, with p.F. 0.7. These have essentially equivalent optical areas; but they differ widely in buoyancy. The 1/2" spine needs \$200 more for buoyancy per module. The abscissa is the density of the glass used. For soda-lime glass the value is 2.47; for pyrex 2.26.

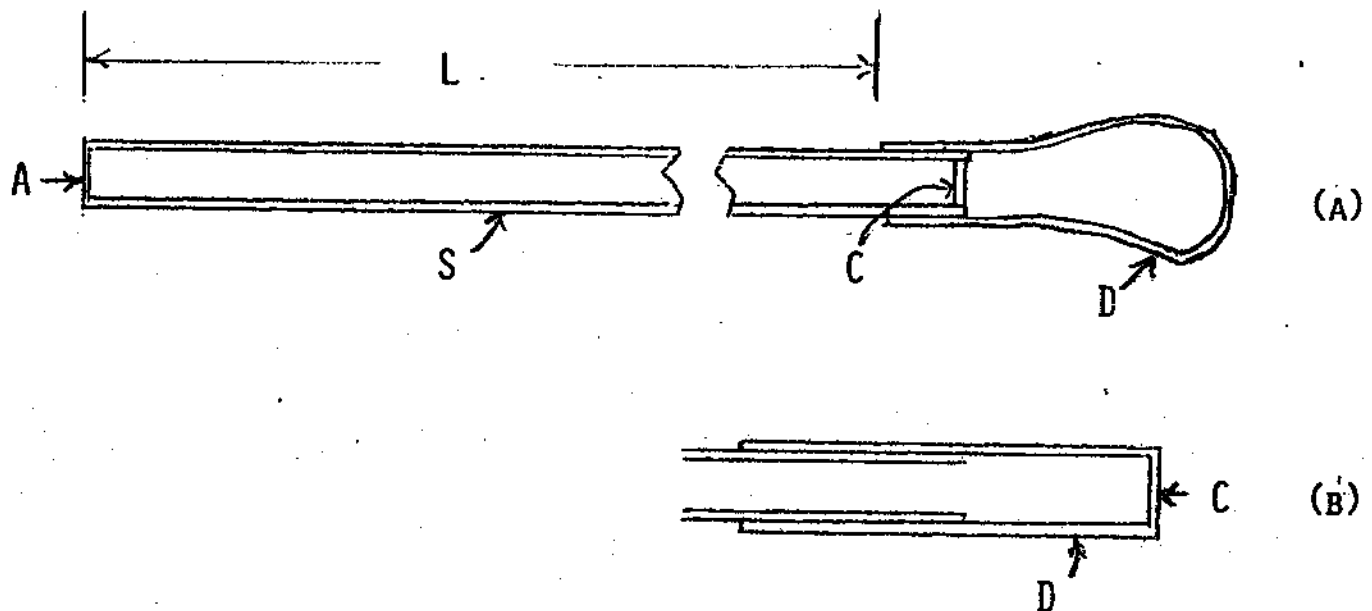


Fig. 8. Construction details of a single glass spine. S is the glass tube, 10 - 12 ft. long, probably near 1" in diameter. At one end, a glass seal A is flat enough to allow the light to be emitted into the glass sphere in optical contact; however, it need not be optically flat. At the other end, two possibilities are shown. Termination (a) has a seal C similar to A, but with a small aperture in it. Optically it is a reflecting termination; but it communicates with the small chamber enclosed by the finger-shaped elastomer D, which is glued to the glass tube at E, after filling with the fluorescent liquid. The elastomer D is compatible with the solvent; if the latter is toluene, it is made of "Viton". The purpose of D is to equalize the external and internal pressures as the spine is lowered in the ocean and the toluene compressed by 2.5% at 500 atmospheres.

The alternative seal at (b) is simpler. It uses a well-fitting sliding seal between the short glass endpiece D and the main tube. D has an end seal C, like the main tube, but this one is reflecting. The sliding seal is lubricated and sealed by an inert grease not attacked by toluene or seawater; Dow-Corning Molykote is reputed to be such a grease. It may be necessary to provide an elastomeric boot to seal the junction, if the grease cannot be relied upon; in that case the alternative solution may be preferred. The costs and efficacies of these terminations are as yet unknown.