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F I E L D E X A M I N A T I O N O F D E L B U O Y

Trip Report to University of Puerto Rico Marine Research Station at Mayaguez on behalf of Office of Science Advisor

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S U M M A R Y

Under an original grant from NOAH, proof of principle was accomplished for DELBUOY system. Under the sponsorship of AID Office of Science Advisor, this has been extended to demonstrate desalted water piped to the beach. Additionally, actual transfer of technology has been demonstrated, as evidenced by complete underwater installation of latest DELBUOY by two indigenous Puerto Rican fishermen.

After tracing progress of DELBUOY researchers in producing fresh water, a digest of present program status is presented. This is preceded by a description of the marine research faculty available at subcontractor University of Puerto Rico, and is followed by an analysis of future research needs and costs before DELBUOY can become a production reality for LDC environments.

As a result of interest expressed by S&T/EY management, University of Delaware Marine Sciences staff expect to prepare a proposal for follow-on research, to be submitted together with final report. As explained in text, production of potable water was not a primary research aim for University Delaware researchers. However, because of its importance to AID, author has specifically arranged for inclusion of data on potable water production in upcoming final report.

INTRODUCTION

As a subcontractor under the University of Delaware grant, the University of Puerto Rico has supplied facilities and personnel to field-test and service DELBUOY.

In an initial interview with Dr. Manuel Hernandez-Avilla, who heads the University of Puerto Rico Marine Sciences College and Experiment Station, it was evident that Dean Hernandez is a DELBUOY enthusiast. He believes that, once materials problems are solved, this system can be "done on a bigger scale." During our conference he limited his scope to Latin America, but immediately named Antigua, Montserrat, St. John, St. Croix, St. Thomas, plus South American coastal cities in general and even the South coast of Puerto Rico. He confirmed having drunk desalted water from DELBUOY some 7 to 8 months ago, from an operating system which he personally observed underwater.

This list of Countries obviously does not include the innumerable coastal sites throughout the South Pacific Ocean, Asia, the Indian Ocean and the coasts of Africa. Preliminary interest expressed by S&T/EY, Office of Energy in a recent University of Delaware AID briefing will prompt researchers to elaborate these application sites--with rich wave fields and corresponding potable water needs--for consideration of further research.

UNIVERSITY OF PUERTO RICO MARINES SCIENCES RESUME

An initial observation on the University of Puerto Rico Marine Sciences program and research faculty is in order. Assistant Dean John Kubaryk briefed author on fact that UPR marine Sciences has the only PhD program on campus, with 24 full professors, 22 of which hold the PhD degree and two the M.S. degree. Dean Hernandez heads not only this faculty, but the Sea Grant Program as well. UPR is one of the earliest Land-Grant institutions, dating to circa 1918. Like the University of Delaware, it is both a Land-Grant and Sea Grant College.

On the research staff of UPR Marine Sciences are the following scientists:

1-Chemical Oceanographer
1-Geological Oceanographer
2-Physical Oceanographers
20-Biological Oceanographers (consisting of 4 fresh water Aquaculturists, a Parasitologist, an Ichthyologist, a Planktologist, a Mariculturist, and various Fisheries Biologists).

Relations with the University of Delaware have been in existence since the mid-1970's, with student and professor exchanges. Additionally, Dr. Hernandez and other professors have served on Delaware PhD committees, and vice versa.

It is apparent that Dr. Kubaryk is much impressed with the ability of Hernandez to sell people on his ideas.

Logistically, UPR Marine Sciences operates both from laboratories at the University in Mayaguez, and from a field station at Isla Maguey a short distance off of Parguera . From here, power boats are dispatched to transport divers (or observers) to the present DELBUOY site at Media Luna reef (or Turramote reef at an earlier period.)

It is worthy to note that the University of Puerto Rico carries a lower overhead than the University of Delaware, which may be relevant to future DELBUOY research.

PRESENT STATUS OF DELBUOY PROGRAM

Where does the DELBUOY program stand at this point in time? It would appear that the current system (Pump #4, under new nomenclature, or System #10 from start of program) qualifies as a workable prototype. This statement is based both on the production of fresh water to Media Luna reef, and the fact that it rode out a severe storm rated above design capabilities.

Principal Investigator Dr. C. M. Pleass considers it a "tremendous tribute" that this latest system survived the tropical storm designated "Klaus", from November 2 to 7. More conservatively, Dive Officer George Mitcheson (with whom Author spent most of his time during this field trip) considers it "encouraging" that this pump survived during such "appalling" weather. A Red Flag Condition was evidenced by whitecaps in the inner harbor, with boats forbidden to leave dock, and five to seven foot waves (design capability 3-foot waves), at sea. Several buoys have been lost in past storms of no greater severity. It should be noted that wave energy is proportional to the square of wave height, so that a 5-foot wave carries 2.8 times the energy of a 3-foot wave (design standard), or 16 times the energy of 1 1/4-foot wave, such as prevailed during the calm following "Klaus."

A few more words are in order on this storm and its aftermath. On November 8, after the storm had ended, UPR researchers attached the reverse osmosis module to DELBUOY. Fresh water production commenced from that date to present, according to Dr. Pleass, without interruption. However, from November 10 through 13, a dead calm prevailed, with only 5 g.p.d. produced on average. Then, on November 14 (during my field visit), wave action began to pick up, although average wave height from November 14 - 20 is reported at only 1 1/4-feet. This is very small versus design height of 3-feet, representing only 17 per cent as much energy content. An average production of 5 g.p.h. has been reported since November 14, corresponding to such average 1 1/4-foot wave height.

In view of these figures, Dr. Pleass regards the average (reported) production of 5 g.p.h. at 1 1/4 -foot average wave height as "pleasantly surprising efficiency," since calculated flow would be only 1.8 g.p.h. under these conditions.

This storm and its aftermath illustrate the extreme ranges possible with an apparatus such as DELBUOY, ranging from 400 g.p.d. with storm waves (up to 7-feet high) and downward to only 5 gallons per day in a flat sea. A reasonable conclusion would be that actual DELBUOY installations in LDCs could serve to replenish reservoir inventories, but could not be depended upon for a steady, high-level flow.

In terms of components, or subsystems, Mitcheson rates himself as "happy" with the pump rod and gland seals ("finally"), as well as with the accumulator, the check valves, and the quality of input water. A problem with a cracked piston head disturbs Mitcheson, who feels (privately) that such materials problems should be worked out in the Delaware laboratories before going to the expense of field installation and experimentation.

Mitcheson acknowledges the need for sea time to prove the system as a whole. He did not, prior to my visit as Program Manager, recognize the importance AID/SCI attaches to the demonstration of desalted water piped to shore, despite admonitions to the offices of Dr. Pleass and Assistant Doug Hicks. However, this point is now clear and all are agreed to document as much fresh water flow as possible, given suitable sea states and funds left in the University of Puerto Rico subcontract (which is not much out of original $10,000 grant).

In my opinion, in addition to the demonstration of fresh water production capability, one of the real accomplishments of this project has been technology transfer. Thus, two Puerto Rican fishermen with but halting English, completely installed the last system (Pump #4) by themselves, albeit under the watchful eye of Supervisor George Mitcheson. It appears plain that this accomplishment can be reproduced elsewhere.

A specific suggestion to Dr. Pleass by myself was to incorporate a Time to Failure Analysis of field data, as a prime measurement of project progress. This Dr. Pleass has agreed with as desirable and will attempt such analysis following his present preoccupation with summarizing data for actual fresh water production by DELBUOY.

A last minute telephone check with University of Puerto Rico's Mitcheson revealed (November 28) that system is still producing fresh water, despite waves of only 1 1/4-feet average height. Over the past seven (7) days, 400 gallons of desalted water have been collected, at a quality of 0.112% NACl and a brine discharge of 600 p.s.i. (This salinity goes up with decreasing pressure, being 0.16% at 500 p.s.i., when wave height is at a minimum).

FRESH WATER PRODUCTION ACCOMPLISHED

It was obvious, from the discussions held with Diving Officer George Mitcheson, that fresh water production has definitely not been the chief goal in past field testing. Indeed, without the urging of AID, such data might never have been collected in any quantity, since the main thrust has been development, debugging and proving of components. Thus, most recently attention has been directed to such factors as condition of piston rod and head (a breakage problem); how self-sealing surfaces (water lubricated) have performed; and deterioration of wire tethers and return springs on pump.

This research-oriented attitude is understandable, first because individual components have given such problems in development (especially the pump) and, secondly, because fresh water production can be inferred by the mere achievement of a brine discharge pressure in the 600 to 800 p.s.i. range. In other words, reverse osmosis technology is State-of-the-Art, and calibration curves (supplied by DuPont) give fresh water flow rates as a function of applied pressure. Consequently, much high-pressure sea water and/or desalted water is claimed to have been wasted to sea or on land. Even at present, any amount over 30 gallons is automatically siphoned off and dumped, although it is first measured for cumulative flow at Media Luna reef.

Even so, is there available evidence that fresh water has in fact been produced by the DELBUOY apparatus? Yes there is. First, fresh water was produced at Turramote reef during the period Summer 1983 to Fall 1983. This, in fact is one of the longest periods during which this device has run without system failure. At first, high-pressure (600-800 p.s.i.) salt water was pumped to land, where it was passed through a land-based R.O. unit for closer observation. A total of sixteen (16) fresh water production days were recorded during July of this period, the longest run being eleven (11) days at 250 g.p.d. powered by 3-foot waves. These days are considered especially significant, since they correspond to the design standard (3-feet) for wave energy. Another 5 days at 200 g.p.d. were recorded, divided between January and March 1983, during the period high pressure water was piped to the R.O. unit on the beach. Thereafter, the reverse osmosis unit was relocated underwater. During this latter period, a weekly sample of approximately 20 min. duration was collected in plastic bags. This system lost its buoys in a November 1983 storm, which ended this series of experiments.

Fresh water was not again produced until the Horizons Communications filming, in Spring 1984, and then only for a single day. No pipeline was involved, but water was reportedly pumped to the surface and sampled by participants in boats. One of these observers was Janine M.H. Selendy, who is co-Chairman and President of Horizons Communications, and a qualified diver. I contacted Ms. Selendy personally by telephone to confirm that she had both seen the pump working underwater and sampled the fresh water at the surface shortly thereafter. Her Chief Photographer, Stan Waterman of "Jaws" fame, also confirmed to me that he had observed the pump working underwater, but he did not sample the water produced.

Two additional systems were installed during the period June to August 1984, variations of the Horizons system, with the brine discharge pressures ranging from 530 to 650 p.s.i. For Pump #3 (new numbering system), 55 gallons of fresh water were collected in 7 hours, during the third day and into the fourth day. Actually, the rate was lower during the first two days, while the line was being purged of sea water. Although the apparatus ran for nine days total, only during six days was the R.O. module installed. This extrapolates to 98 g.p.d. average for the six "functional days" with reverse osmosis unit attached, but 192 g.p.d. during the last two days only. During this time, waves averaged 2-feet in height, ranging up to 3-feet, and salinity was rated as "good" (less than 500 p.p.m., based on a single measurement).

As noted earlier, water production is proportional to the square of wave height. During the period November 10 through 12, a condition of dead calm prevailed, following tropical storm "Klaus," and production averaged only 5 gallons per day. Commencing November 14, the sea state began to pick up again, according to Principal Investigator Dr. Pleass, with waves averaging 1 1/4-feet, rated as very small versus the design height (3-feet) and "Very unusual for a tropical trade-wind belt," per Chief Diver George Mitcheson. Normally, Mitcheson advises, this much water is collected in 1/2-hour (e.g., 5 gal. in 37 min. @ 600-650 p.s.i.), with salinity level of less than 0.01% NaCl. From November 14 to November 20, the flow has picked up to an average of 5 g.p.h., states Pleass. He also notes a steady improvement in salinity since the storm, observing that efficiency of desalting increases with wave height, with less efficient desalting at a low sea state.

~~My own observations of the DELBUOY Pump #4 installation were~~ conducted during a field trip to Puerto Rico November 12 to 16, during a period of relative calm following this major tropical storm. As a result of such unusually calm weather, it was possible to detect actual water production only by priming the plastic pipeline and observing a small but continuous discharge.

This was in addition to observations of cumulative flow as registered by a Republic flow meter (20 gallons cited above).

This is the water which I sampled for taste, at Media Luna Reef during the abovementioned period. To be sure, the presence of salinity was still detectable, although this was explained by Mitcheson as resulting from the use of Sodium Bisulfite to disinfect (de-alginate) the reverse osmosis unit. A sample of this water, brought from Media Luna, is available for tasting by those interested. Certainly, it is potable and was refreshing to us as swimmers (Mitcheson, Padillo and myself), but purer water has been reported from past experiments with DELBUOY.

As reported earlier, one additional observer saw the operation of DELBUOY underseas, and sampled the water produced, namely Dr. Manuel Hernandez-Avilla, Dean of Marine Sciences at University of Puerto Rico. In fact, Dr. Hernandez states he observed the system "two or three times", and drank product water "seven or eight months ago" (approximately March-April 1984).

FOLLOW-ON RESEARCH CONTRACT TO BE SOLICITED

When asked the rhetorical question, "What would you do if you were boss of this project?", George Mitcheson replied substantially that he would not presently be confident to take the system to an LDC. It must first be "demonstrable" (i.e., repeatable), in his words. He would want first to demonstrate two(2) systems of present configuration for 1/2-year each, over an elapsed time of one year minimum from this point.

This is an interesting contrast to Dr. Pleass, who opts for 20 system-years as his minimum, before proving the system to his satisfaction.

Mitcheson would want to produce a "number" of "frozen design" systems (borrowing our terminology) before going overseas, utilizing these in a cluster of six(6) units producing 1,200 g.p.d. He would then want to bring a responsible LDC engineer to observe operation of this system. Thereafter, an LDC demonstration should commence with a single, small system--to teach locals how to operate and maintain same. This would be followed by a larger cluster once technology is adequately transferred.

Mitcheson feels that results should not be based on one system alone, however satisfactory, and that two system operating one-half year each are "better" than one system operating a full year. A 1,200 gallon per day system could provide back-up water for a small community and furnish some irrigation water, George Mitcheson believes.

In my own mind, I can visualize an overall development program for DELBUOY--patterned after my experience in the aerospace industry--about as follows:

Phase I - Basic research (proof of principle accomplished under NOAH Sea Grant)

Phase II - Applications research (fresh water production, components development, technology transfer accomplished under SCI grant)

Phase III - LDC prototype (200 g.p.d. "frozen design" demonstrated in LDC)

Phase IV - LDC full-system prototype (1,200 g.p.d. demonstrated in LDC)

Phase V - Pre-production/production models (private enterprise sponsor)

What would be needed in resources to accomplish Phases III and IV? First of all, the following facilities have been required to date:

1-System designer/fabricator (presently Dr. Pleass/Doug Hicks)
1-Field person (presently George Mitcheson)
1-Machine shop (could be in Puerto Rico, at University and/or Ponce, instead of Delaware)
2-Local assistants (presently two Fishermen, Godo and Marcos)

In the opinion of George Mitcheson, one professional full-time--with access to an adequate machine shop and local assistants--could accomplish this total job.

These observations are added not only in conclusion to this field trip, but also because S&T/EY management has expressed interest in possible follow-on funding of DELBUOY. Acting on this encouragement, University of Delaware is expected to submit a proposal for additional research in the near future, as a part of its final report. As a result of author's field trip and by express arrangement, this final report will contain field documentation of fresh water produced as a result of grant from Office of Science Advisor.

WHAT WILL DELBUY COST?

What will a program of LDC demonstration of DELBUOY (Phases III and IV) cost? As a ball-park guess, George Mitcheson estimates $100,000, including salaries. This appears low to the author, unless all investigators are stationed at Puerto Rico and carry the lower University of Puerto Rico overhead and salaries, as compared to the University of Delaware. Comparing salary costs, for example, a Professor at UPR would command $22,000 to $24,000 per annum, compared to an estimated $30,000 to $50,000 per year for Delaware. A Post-Doctoral researcher at UPR would draw $18,000 per annum, while local assistants (e.g., Godo Padilla or Marcos Rosada) would earn less than $10,000 per year and be required only 1/3 time (2 dives/week to check pump).

One way to look at development costs is to consider the apparent cost of prototypes versus the calculated cost. Thus, Dr. Pleass has maintained in his writings that $2,500 per copy would be a reasonable estimate for a DELBUOY of 200 - 250 g.p.d. capacity, once fully developed. A useful analogy may be drawn to the aerospace industry, where the research prototype (for a new missile, engine, guidance system, etc.) precedes the production model at an order-or-magnitude greater cost.

In the case of DELBUOY, the average prototype cost has been approximately $16,600 ($166,528 divided by approximately 10 systems to date) or roughly six to seven times the projected production cost. A production cost of $2,500 per copy could be achieved only after perfecting a production prototype and considerable "learning curve" experience.

This is in line with a different type of estimate provided to author by a Pan American Health Organization (PAHO) technical specialist, Fred Rieff. He examined the DELBUOY concept and interviewed Dr. Pleass independently at my request in May 1984. Rieff advises that a figure of ten (10) times projected (budget) R&D cost is not unusual to achieve an operational prototype for marine-related hardware.

Although the latest DELBUOY configuration is a fully operational prototype, it has still not been proven in a developing country environment. (Puerto Rico is much better equipped than the average LDC, as witness the high quality machine shops, boat service, and stature of the Marine Sciences faculty/researchers). Moreover, DELBUOY has not been demonstrated at higher capacities, such as a cluster of 6 to produce

1,200 g.p.d. instead of 200 gallons. Once such designs are "frozen", a Phase V and actual production experience could possibly provide the benefits of the learning curve to reduce unit costs to the $2,500 level per 200 g.p.d. module. This might be accomplished under private sector funding, if the results of an expanded Phases III and IV proved economically attractive.

In my opinion, to accomplish Phases III and IV under AID auspices would require a further program at least equal to the Office of Science advisor effort to date, namely $166,528. In fact, it could be more realistic to assume this much for each of phases III and IV.

Some economies are possible, however. These figures might be pared down if more effort were picked up by the University of Puerto Rico, instead of University of Delaware.

Despite difficulties encountered, much has been accomplished under the Office of Science Advisor grant to the Universities of Delaware and Puerto Rico. At this stage of development, additional funding could be money well spent.

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