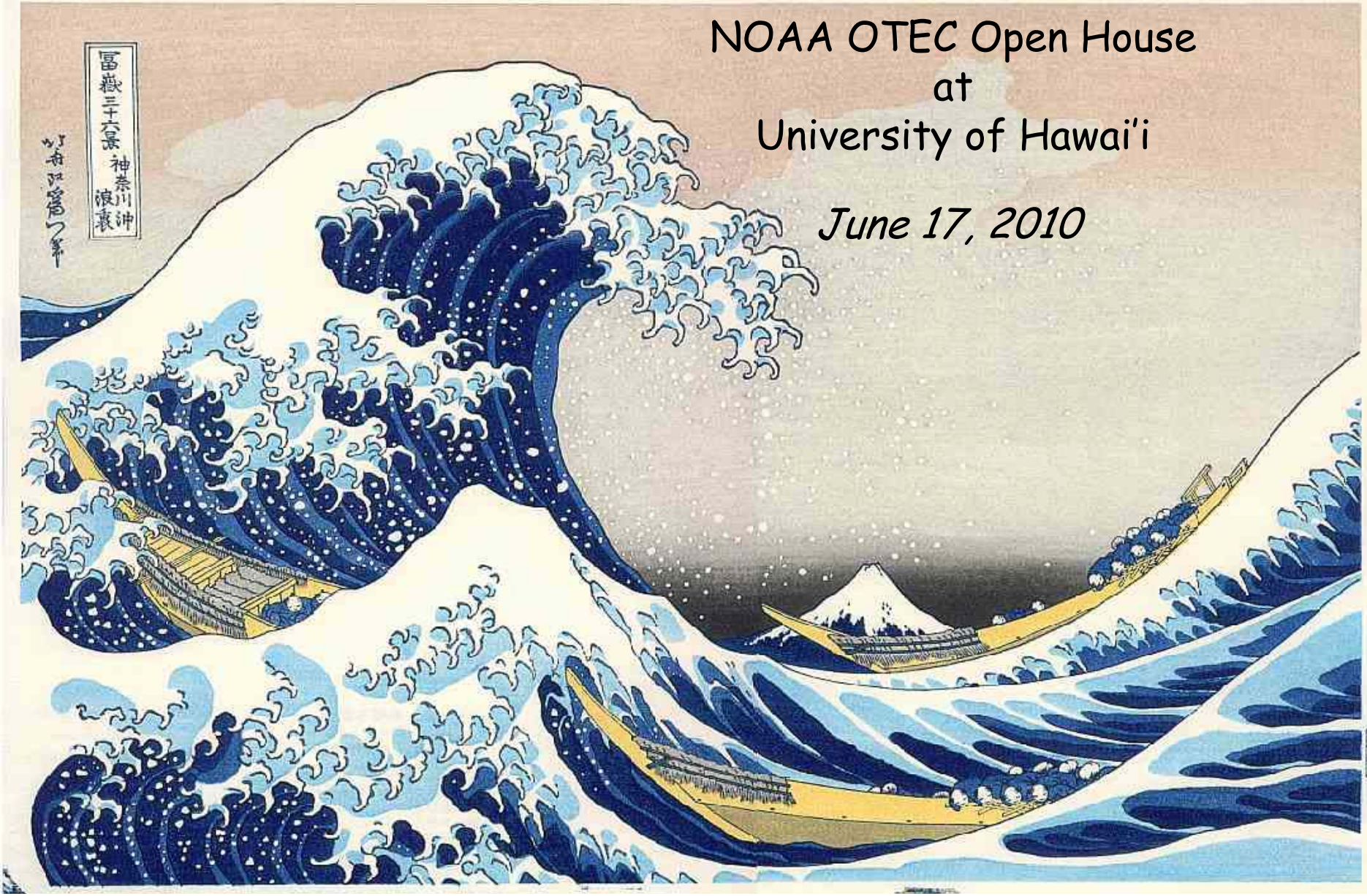


The Great Wave off Kanagawa
(Katsushika Hokusai, 1832)

Ocean Thermal Energy Conversion History

Mostly about USA

1980's to 1990's

and

bias towards Vega's Experience

Table of Contents

- Claude's off Brazil (30's)
- USA Revival (80's)
- Resource
- Floating Structures (Plantships)
- Bottom-Mounted Structures
- Model Basin Tests/ At-Sea Tests
- 210 kW OC-OTEC Experimental Plant
- Designs/ Lessons Learned/ EIA
- Economics/Updated Resource Data
- Revival (New Century)

OTEC PHYSICAL SYSTEMS GENERAL CHARACTERISTICS

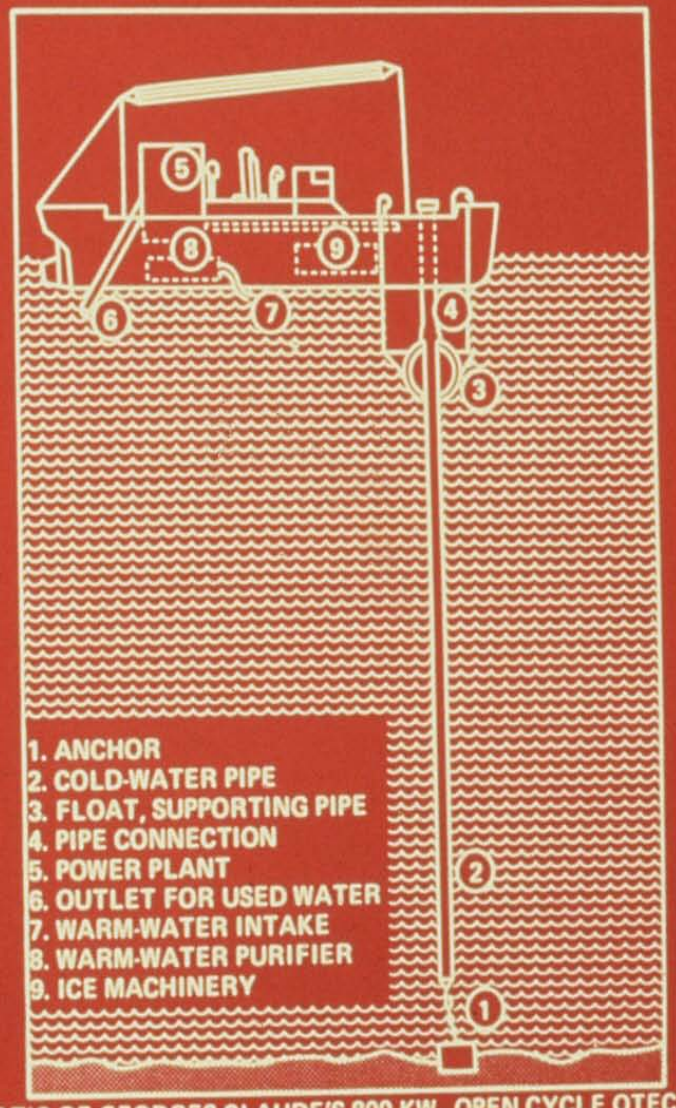
ENVIRONMENT
- WAVES
- CURRENTS
- WIND

PLATFORM
- ELASTIC MATERIALS
- ENVIRONMENTAL, CWP AND MOORING LOADS
- 6 DOE

GIMBALL
- 3 DOE

CWP
- ELASTIC/VISCOELASTIC MATERIALS
- 6 DOE
- ENVIRONMENTAL AND PLATFORM LOADS
- FLUID DAMPING
- FLUID-STRUCTURAL INTERACTIONS

BOTTOM
- FREE
- WEIGHTED
- FIXED



SCHEMATIC OF GEORGES CLAUDE'S 800 KW_e OPEN CYCLE OTEC PLANT

Claude's Off Rio de Janeiro (1933)

- Floating Ice Plant: 2.2 MW OC-OTEC to produce 2000 tonnes of Ice →CWP Installation failure *(no ocean engineers available)*

- Historical slide from Inventor is indicative of multiple engineering disciplines required for OTEC Plants

US Federal Government

(*Rephrasing late 70's to early 80's OTEC Mandate*)

By Year 2000 → 10^4 MW Installed

equivalent to 100 x 100 MW Plants

(Capital > $40 x 10^9)

Therefore,

<u>Must</u> implement optimized designs and industrial facilities for plantships producing OTEC electricity or other energy carriers to be delivered to shore…

US Federal Government OTEC Program (70's –80's)

- Aim → optimize all components for projected $40B cumulative capital by year 2000;
- Hindsight → should have used funds ($0.25 B) to build at least one "large" plant with off-the-shelve hardware…

US Federal Government OTEC Program

Analytical Work

↓

Designs

↓

Model Basin Tests

↓

At-Sea Tests

↓

?

Thermal Resource

Temperature Difference between Surface Water and 1,000 m Water (want > 20 °C) :

Yellow	18 to 20 °C
Orange	20 to 22 °C
Red	22 to 24 °C

LARGE SCALE DISTRIBUTION OF

OTEC THERMAL RESOURCE

ΔT(°C) BETWEEN SURFACE AND 1000 METER DEPTH

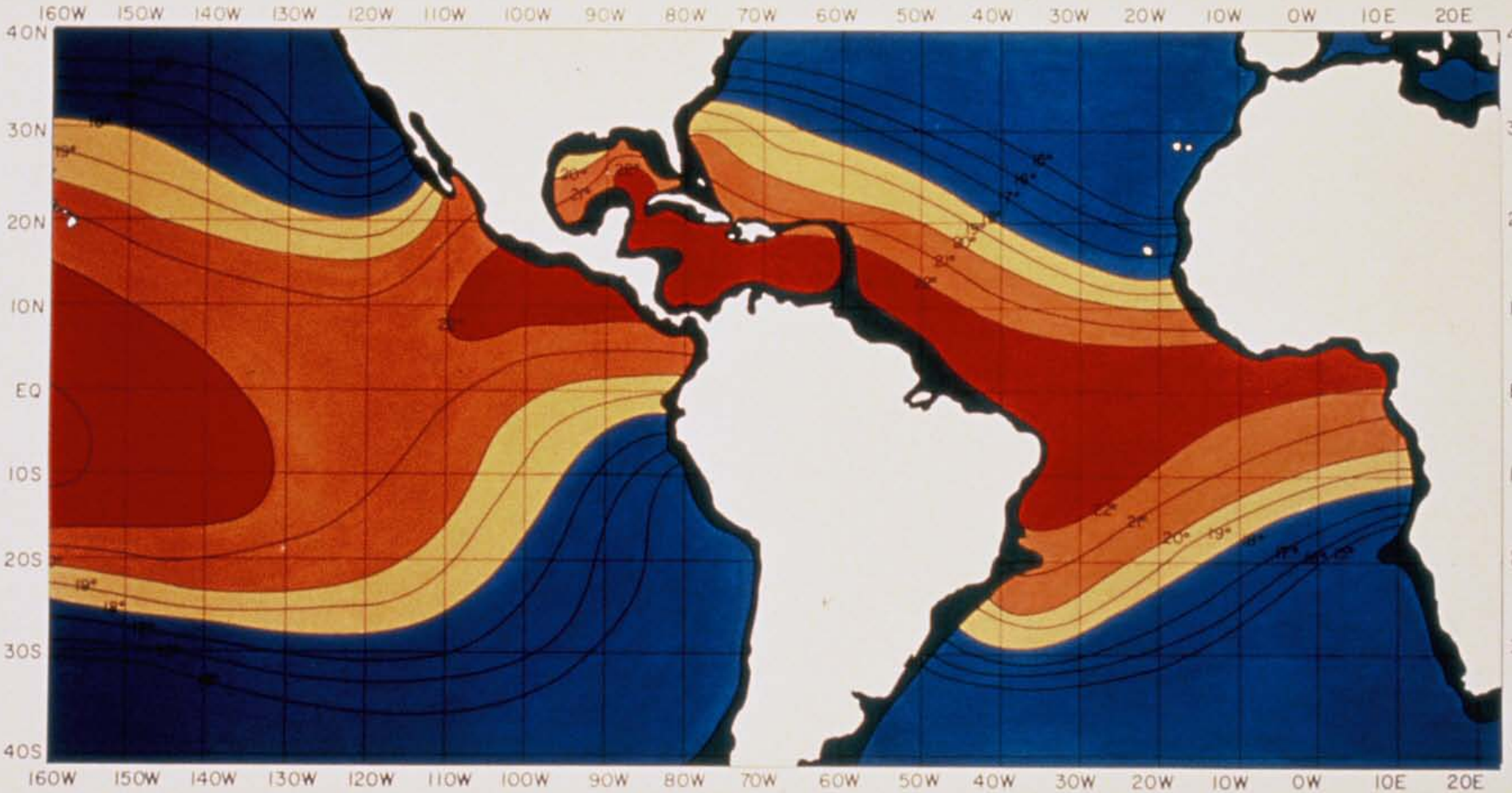


Figure 1A (Continued)

SCALE AND ACCURACY

Hawaii Ocean Thermal Resource: Truisms

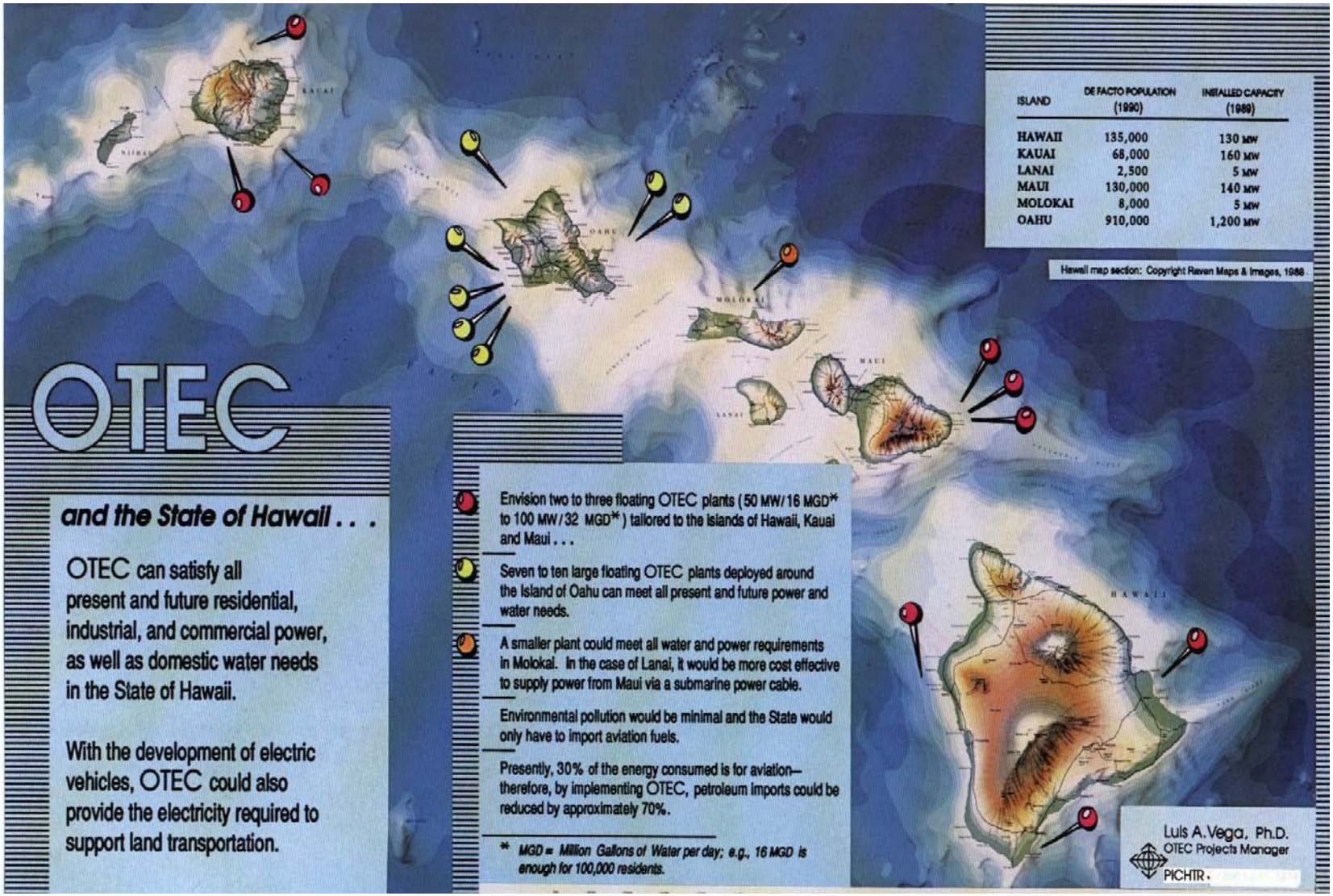
- OTEC plants <u>could supply all</u> the electricity and potable water consumed in the State, {but at what cost?}
- Only <u>indigenous renewable energy resource</u> that can provide a high degree of energy security to the State and in addition minimize green house gas emissions;
- Assessment also applicable to all US Island Territories.

Other Applications: AC

<u>Cold deep water as the chiller fluid in air conditioning (AC) systems</u>: load can be met using 1/10 of the energy required for conventional systems and with an investment payback period estimated at 3 to 4 years.

Energy Carriers

- OTEC <u>energy</u> could be transported via electrical, chemical, thermal and electrochemical <u>carriers</u>:
- Presently, *all yield costs higher than those estimated for the submarine power cable* *(< 400 km offshore).*



ISLAND	DE FACTO POPULATION (1990)	INSTALLED CAPACITY (1989)
HAWAII	135,000	130 MW
KAUAI	68,000	160 MW
LANAI	2,500	5 MW
MAUI	130,000	140 MW
MOLOKAI	8,000	5 MW
OAHU	910,000	1,200 MW

1990 Historical Data

Floating Platforms

- Several Platform Concepts (not shown: Tension Leg Platform, TLP)
- 40 MW APL Concrete Barge:

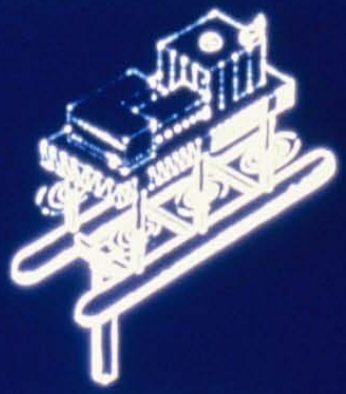
135 m (Length); 43 m (Beam); 31 m (Depth)

- LMSC Submerged Power Block

PLATFORM CONCEPTS

TANKER

SPAR



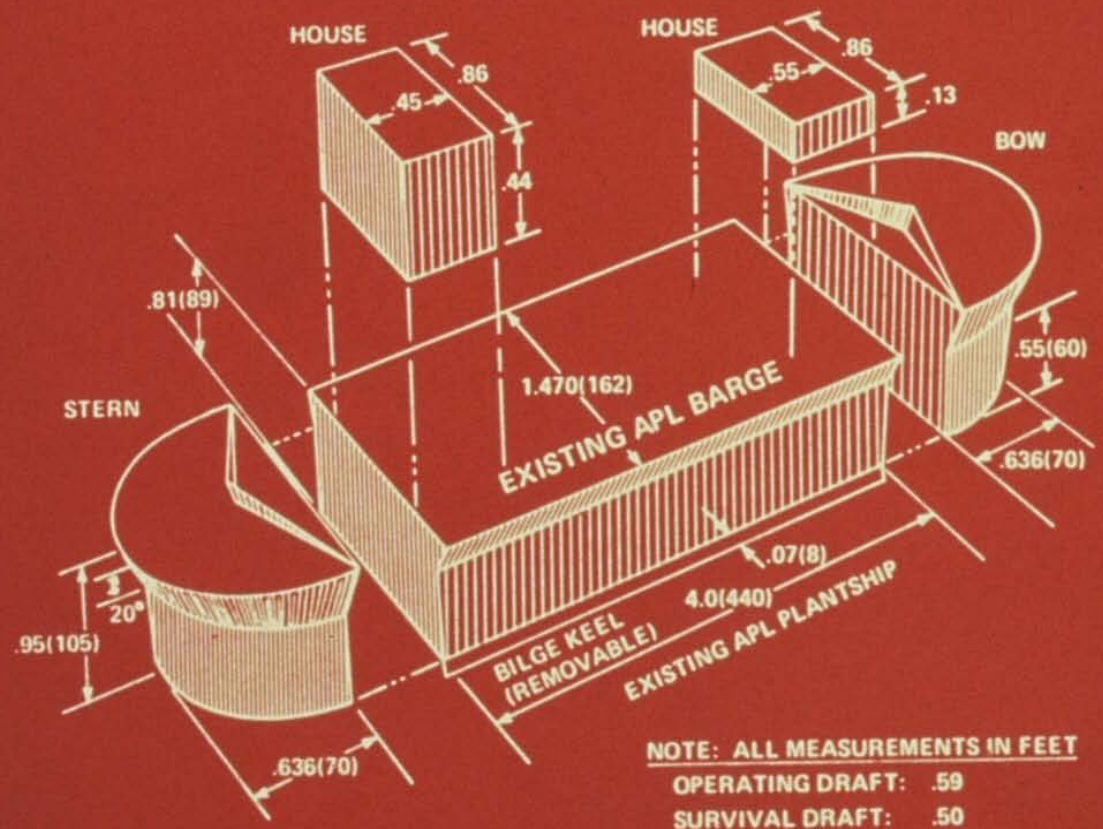
SEMI-SUBMERSIBLE

SUBMERSIBLE

DISC

TUNED SPHERE

PROPOSED SEAKEEPING IMPROVEMENTS FOR MODEL OF APL BARGE



1:110 SCALE MODEL

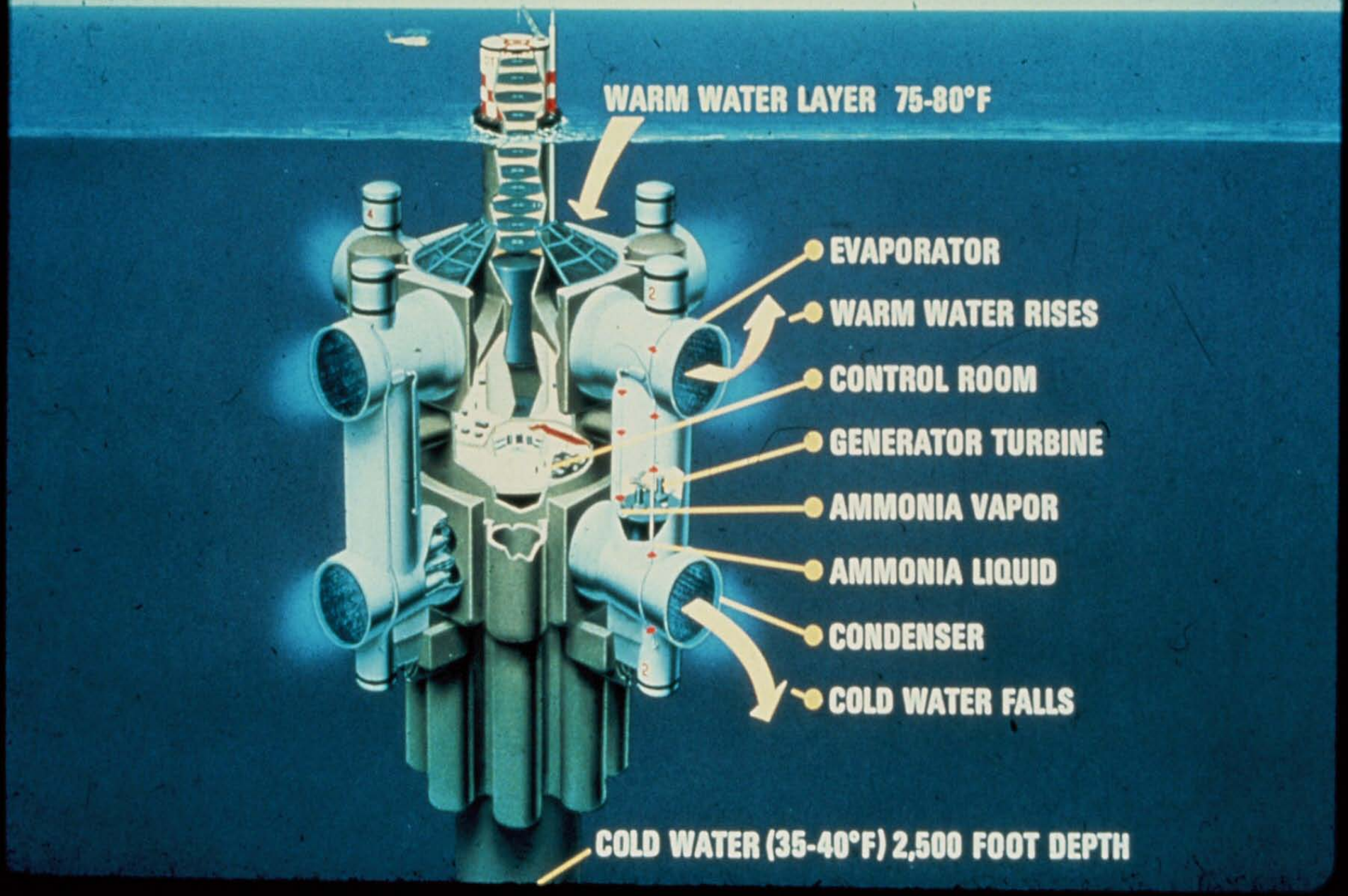
NOTE: ALL MEASUREMENTS IN FEET

	OPERATING DRAFT:	.59
	SURVIVAL DRAFT:	.50
	OPERATING Δ:	228 LBS
	SURVIVAL Δ:	193 LBS
W/O CWP	OPERATING KG:	.37
W/O CWP	SURVIVAL KG:	.394

MAJOR IMPROVEMENTS

1. INCREASE LENGTH FROM 440 TO 580 FT TO REDUCE PITCH MOTION
2. ADD BILGE KEELS TO REDUCE ROLL MOTION
3. CHANGE RECTANGULAR TO CIRCULAR SHAPED BOW AND STERN TO REDUCE WAVE SLAP
4. ADD FLARES AND SPOILERS TO REDUCE OVERTOPPING
5. INCREASE FREE BOARD AND DEPTH
6. REDUCE TRIM
7. REMOVE WARM WATER PODS TO AVOID WAVE FOCUS EFFECTS

Ocean Thermal Energy Conversion (OTEC)



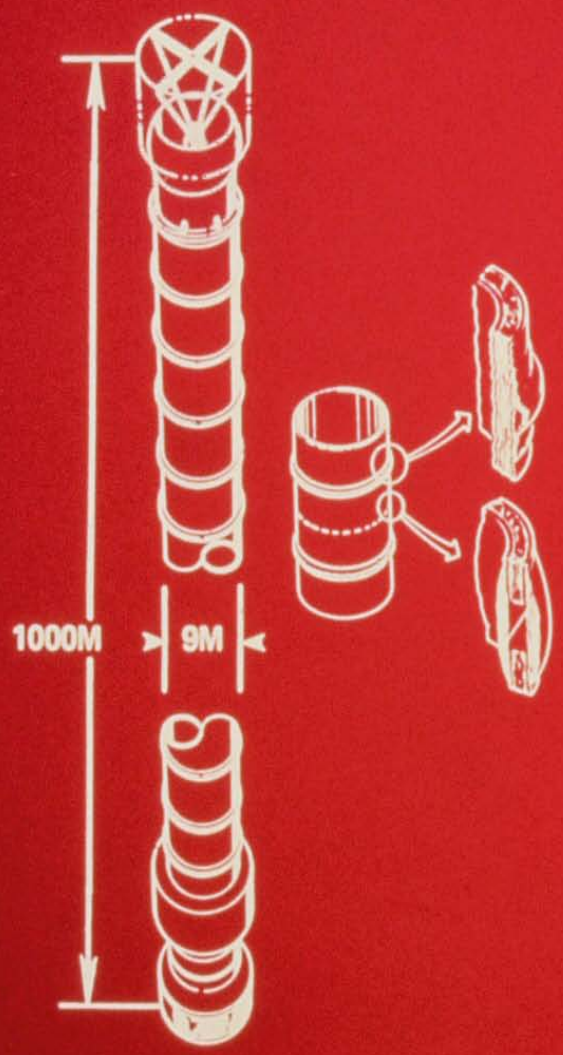
CWP for Floating Platforms

- FRP Sandwich
- HDPE Bundle
- Reinforced Elastomer
- Concrete Pipe (not shown)
- Soft Pipe with pumps at intake (not shown)

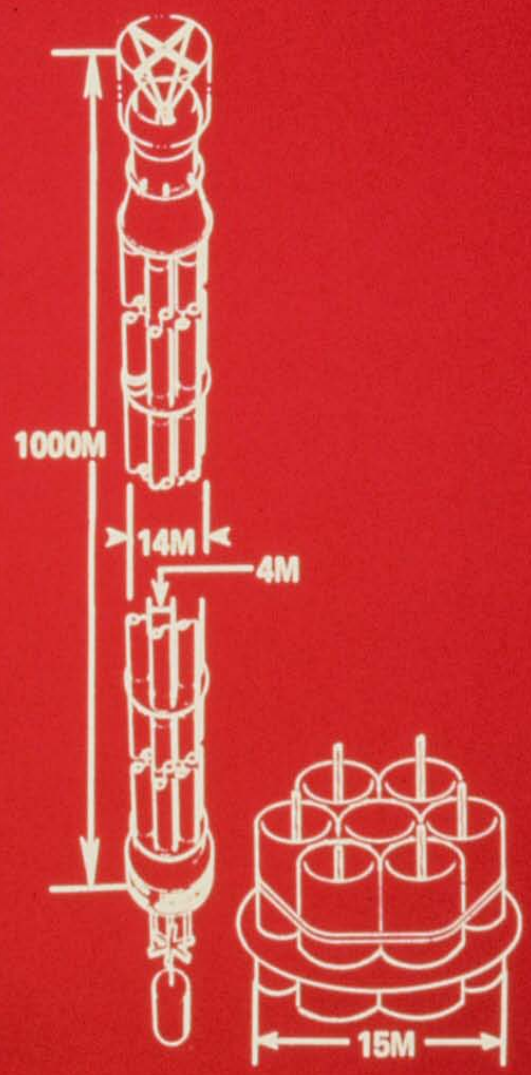
→ Need ~ 10 m i.d. for 100 MW

(FRP Sandwich Selected)

10/40 MW PLANT CWP DESIGNS



FRP SANDWICH



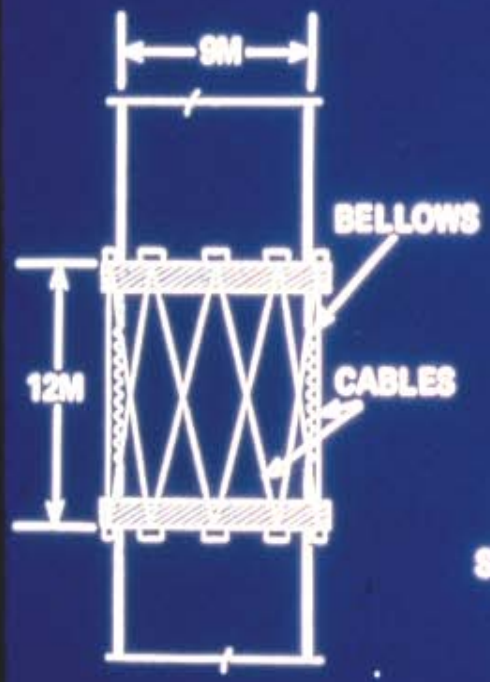
MULTIPLE POLYETHYLENE

ELASTOMER

Floating Structures

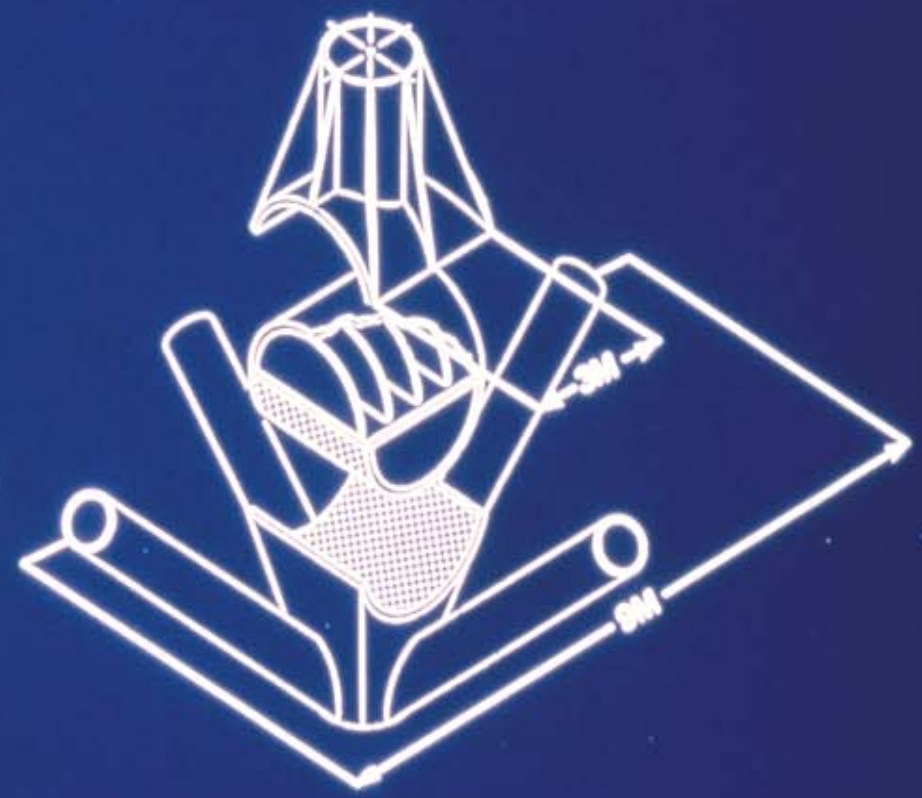
- CWP/Platform Attachment (Gimbals)
- Submarine Power Cable & Attachments

CWP/PLATFORM INTERFACE DESIGNS



CABLE

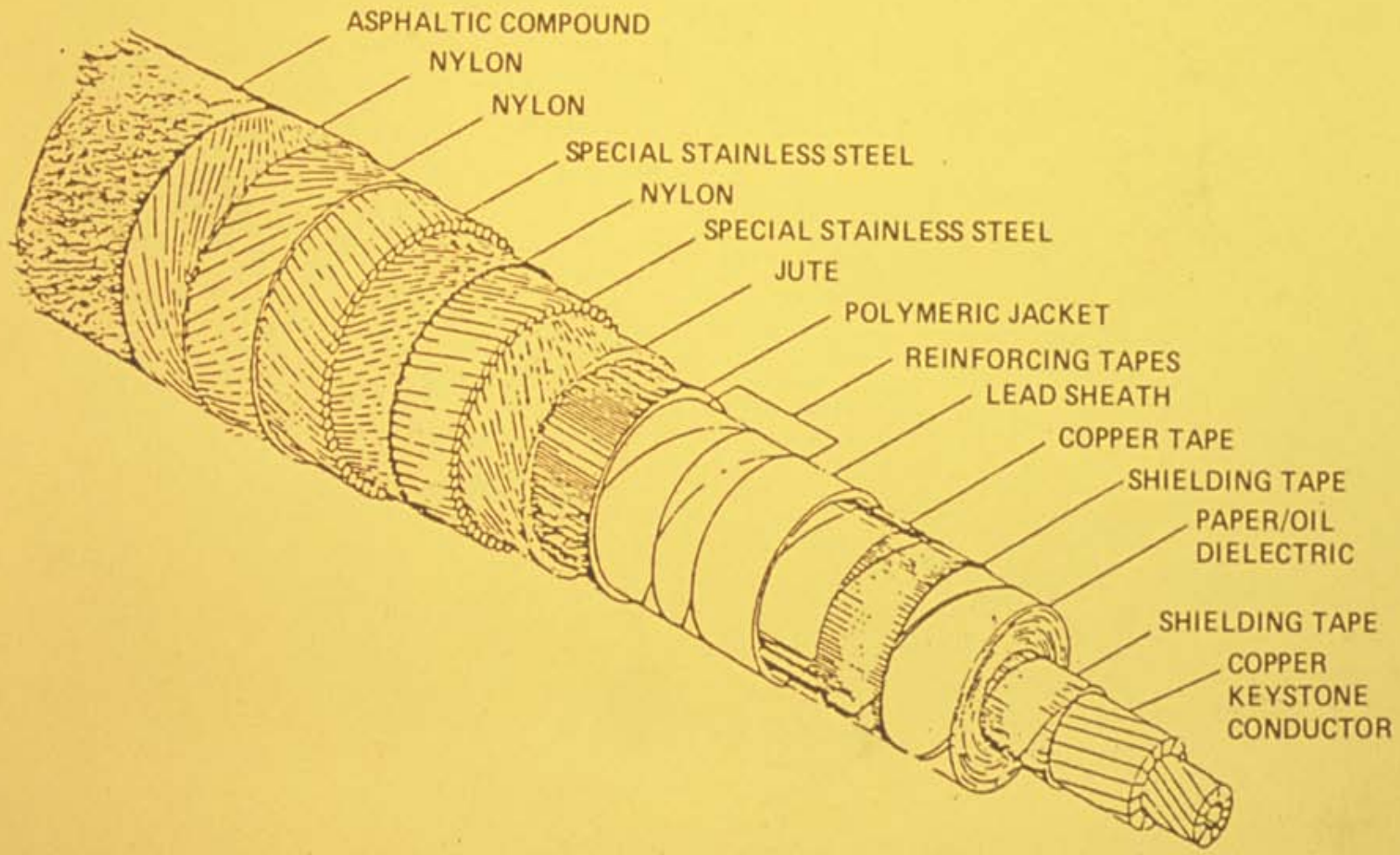
SPHERICAL UNIVERSAL JOINT



COMPRESSION BLOCK

SCOFF SELF-CONTAINED 138 KV 100 MW OTEC RISER CABLE

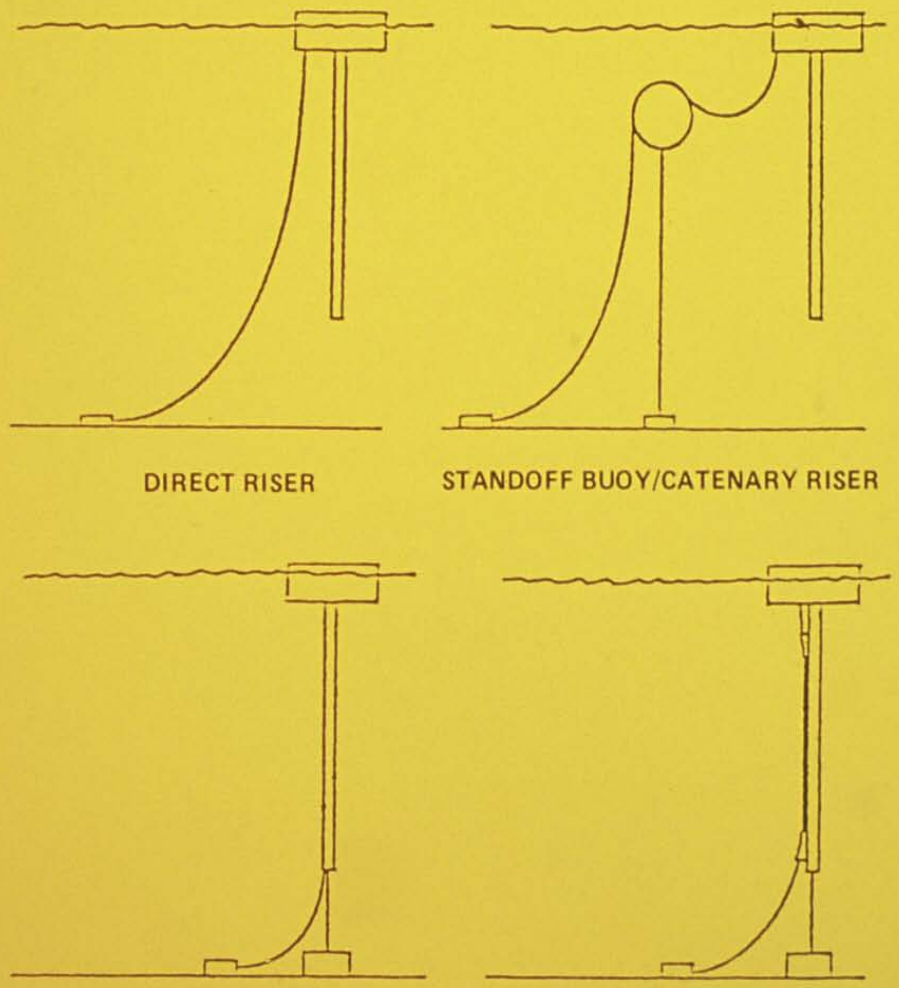
DESIGN 14



OTEC POWER TRANSMISSION RISER CABLE DEPLOYMENT SCHEMES

SIMPLEX

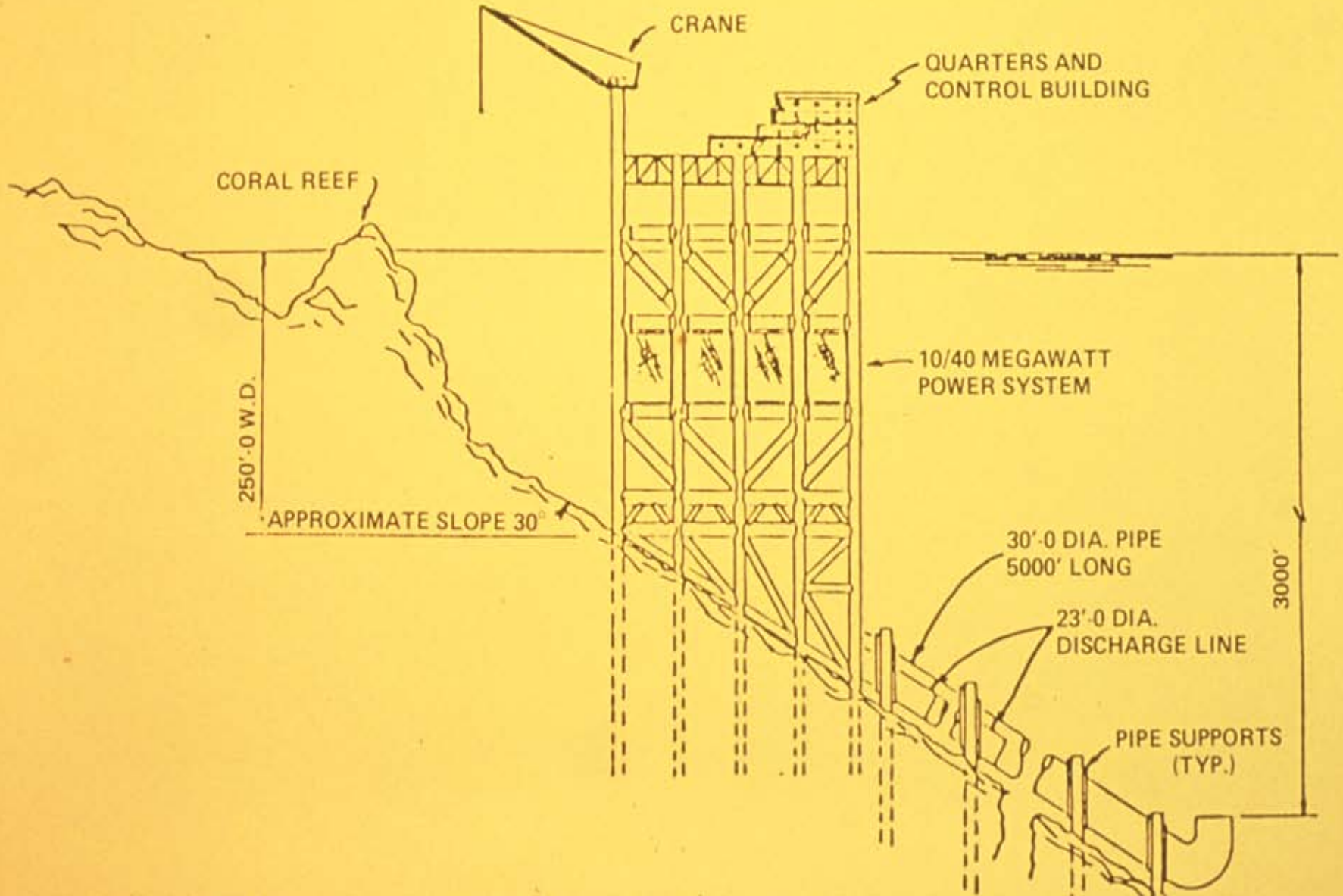
WIRE AND CABLE COMPANY



Bottom-Mounted Structures

- Fixed Towers
- Guyed Towers
- TLP not shown
- Causeway (connected to existing Power Plant)
- Cold Water Pipe Installation
- Tunneling (cold-water-conduit)

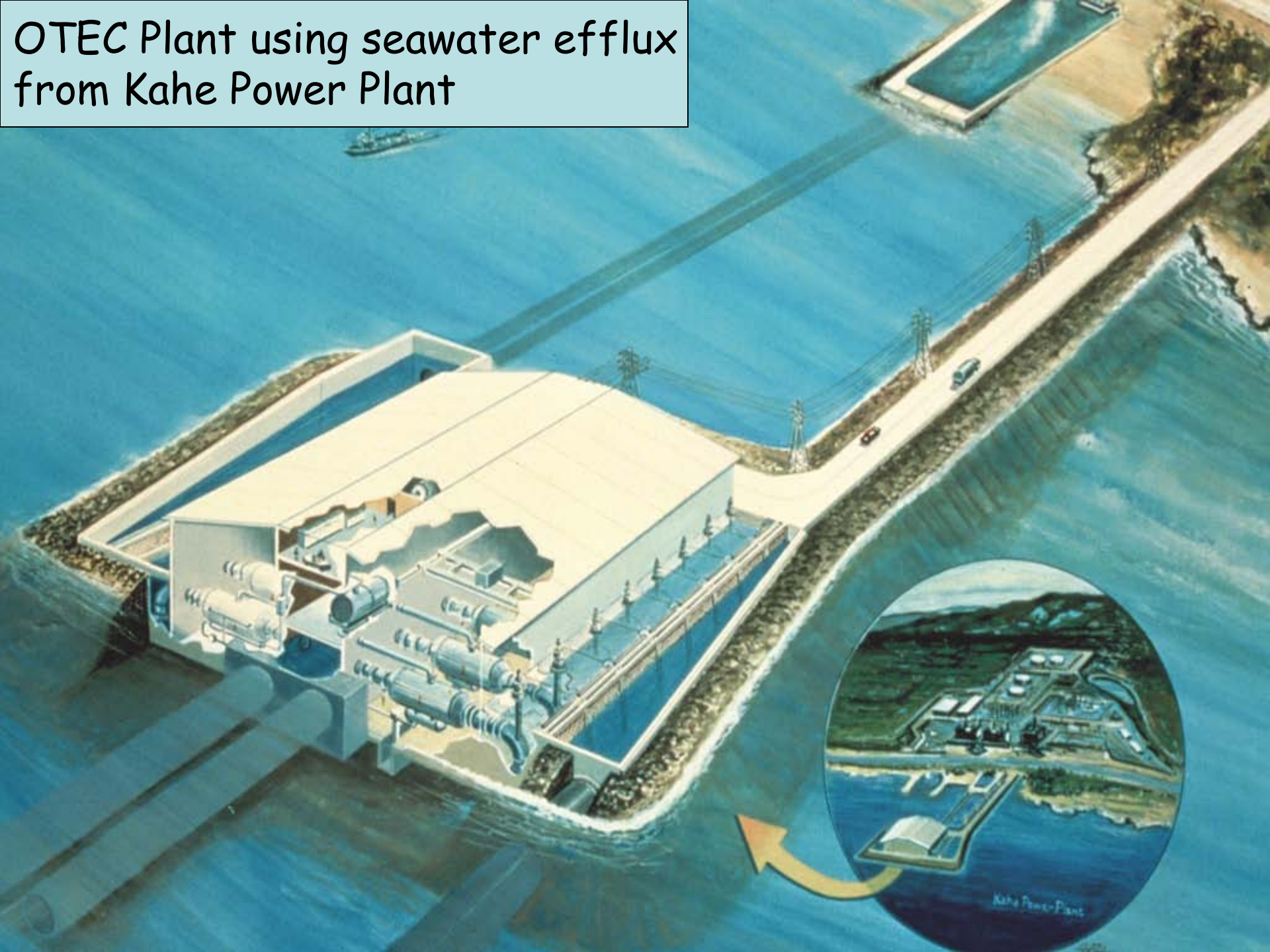
OTEC 10/40 MWe FIXED OFFSHORE TOWER POWER PLANT,
ARRANGEMENT DRAWING BY J. RAY McDERMOTT & COMPANY, INC. (6)



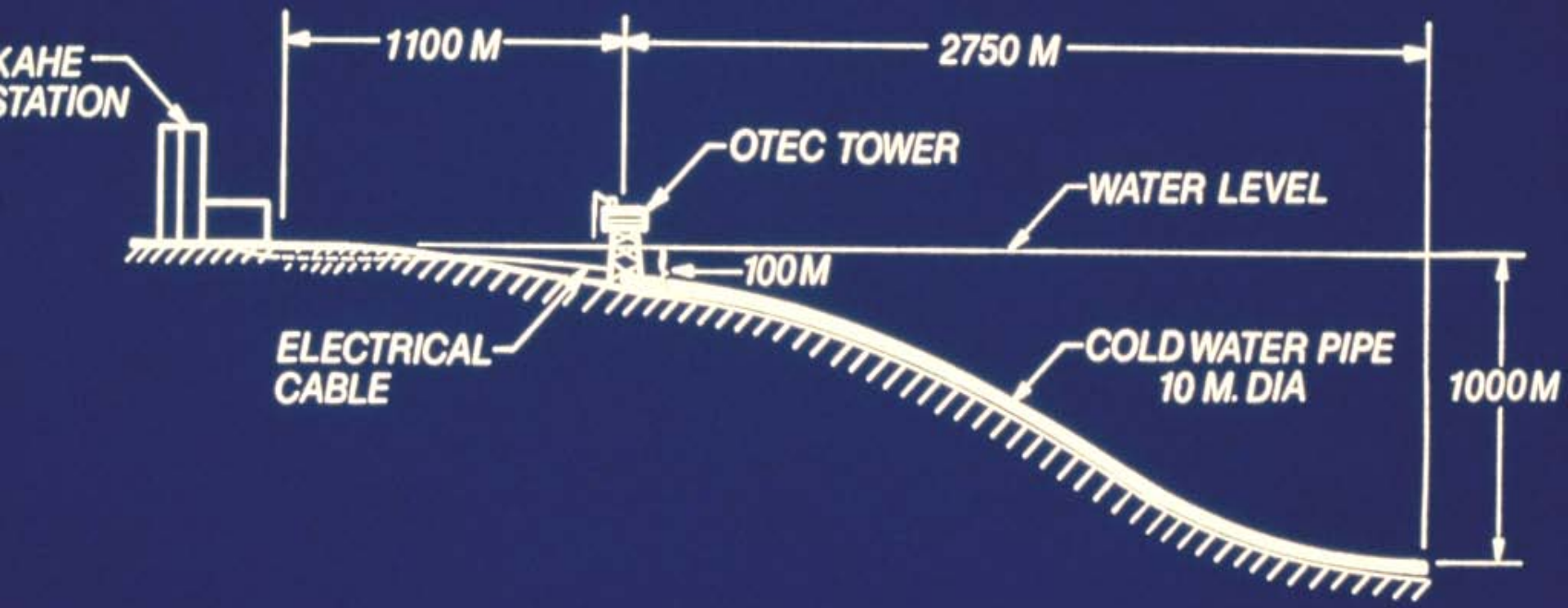
GE Design '80s

400 TO 800 MWe OTEC GUYED TOWER BY
J. RAY McDERMOTT & COMPANY, INC.

OTEC Plant using seawater efflux from Kahe Power Plant

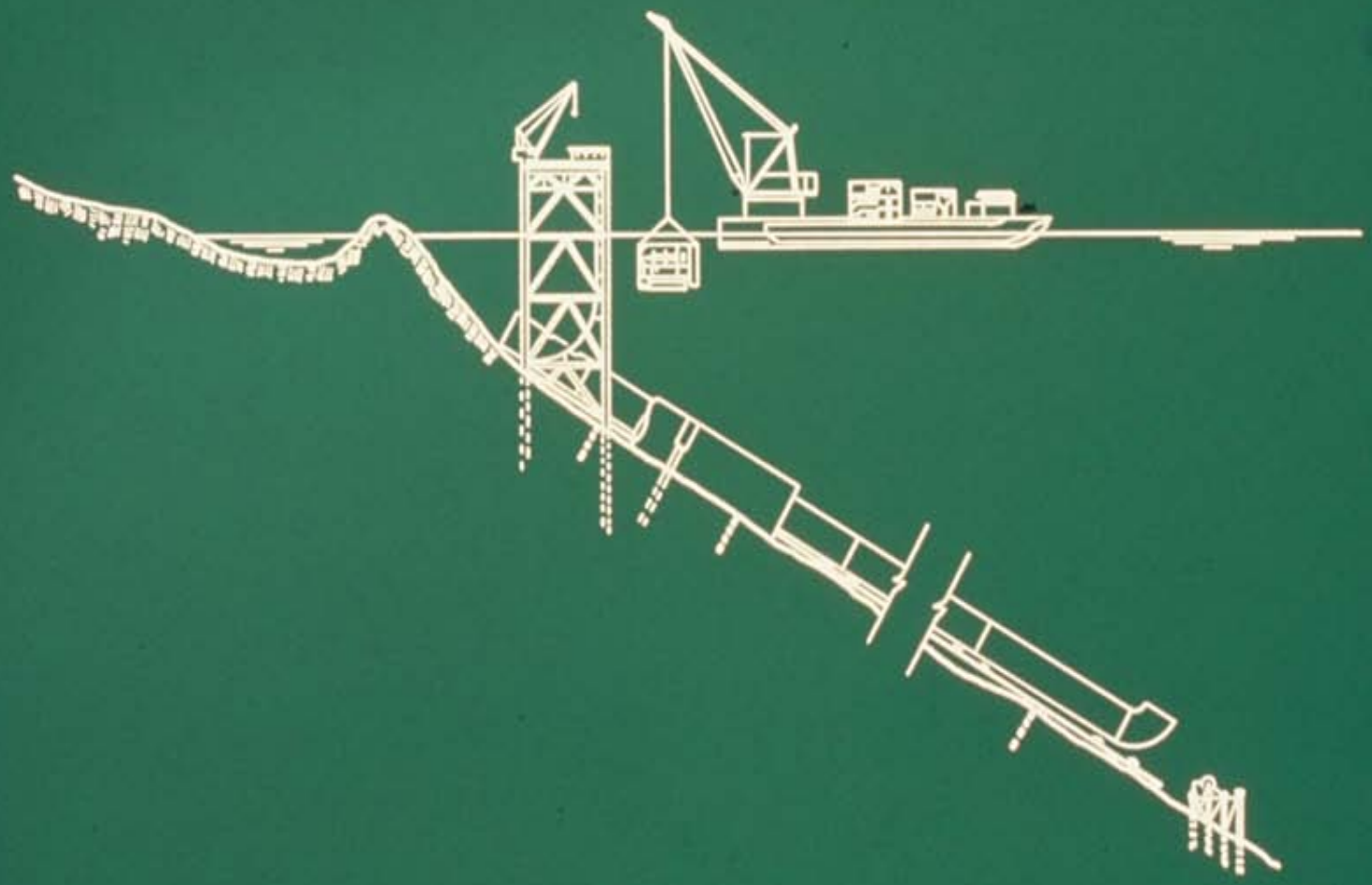


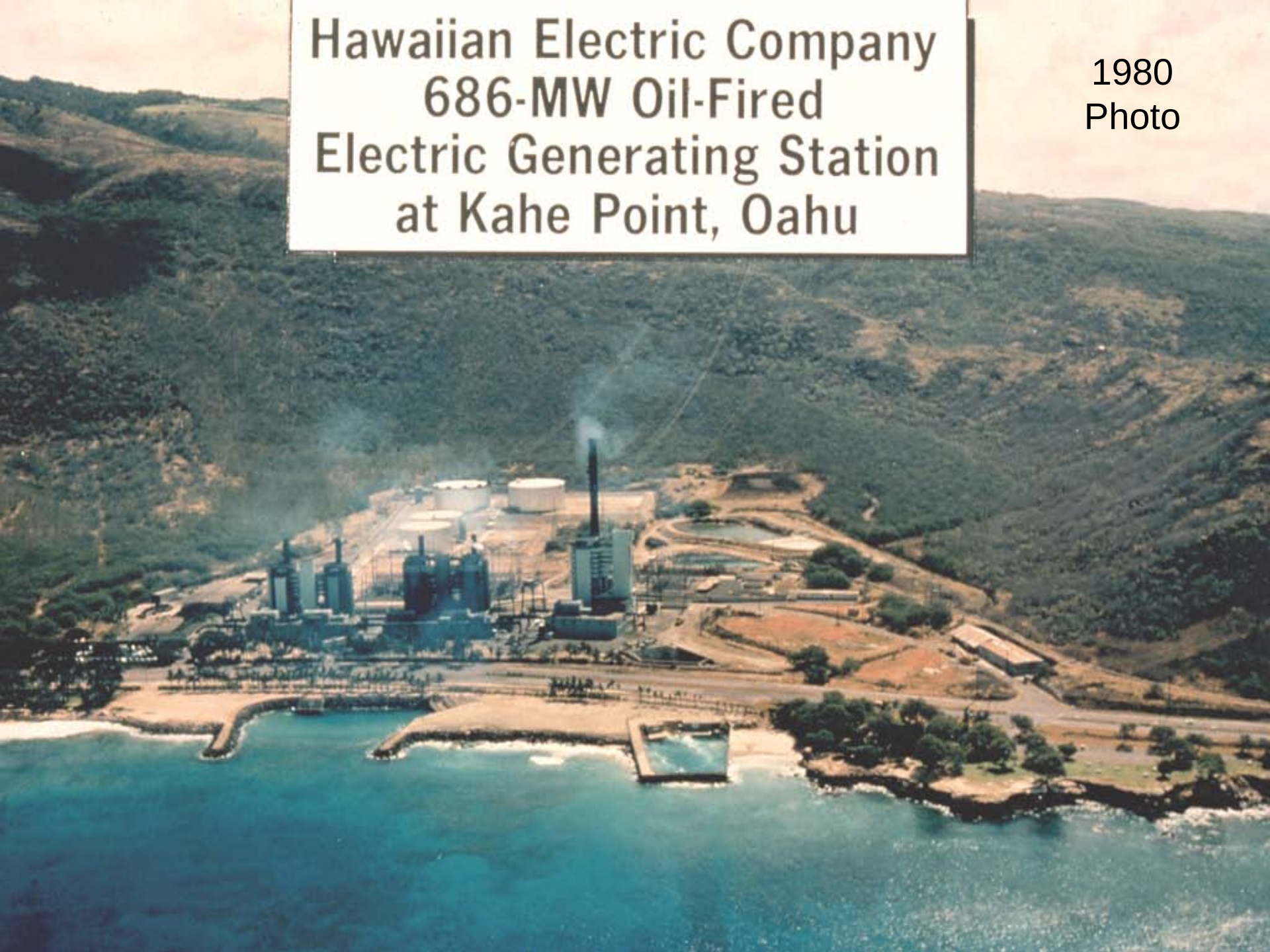
OTEC PILOT PLANT CONCEPT AT KAHE POINT, OAHU



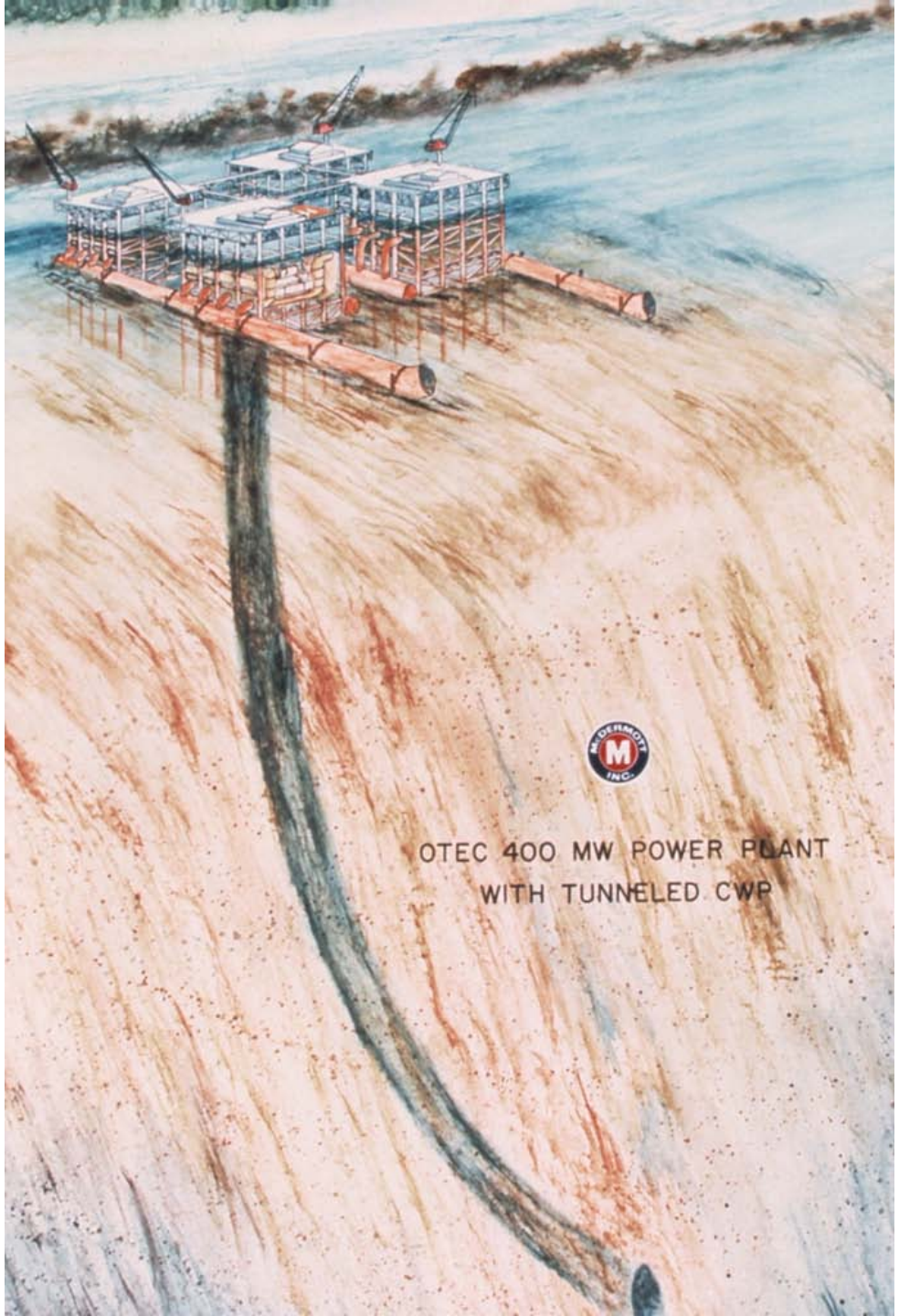
SHELF MOUNTED OTEC PLANT DEPLOYING MARINE RAILWAY

SHELF MOUNTED OTEC PLANT
CWP AND PLATFORM INSTALLATION COMPLETED, INSTALLING POWER PLANT




Hawaiian Electric Company
686-MW Oil-Fired
Electric Generating Station
at Kahe Point, Oahu

1980
Photo


OTEC 400 MW POWER PLANT
WITH TUNNELED CWP

NOAA Model Basin Tests

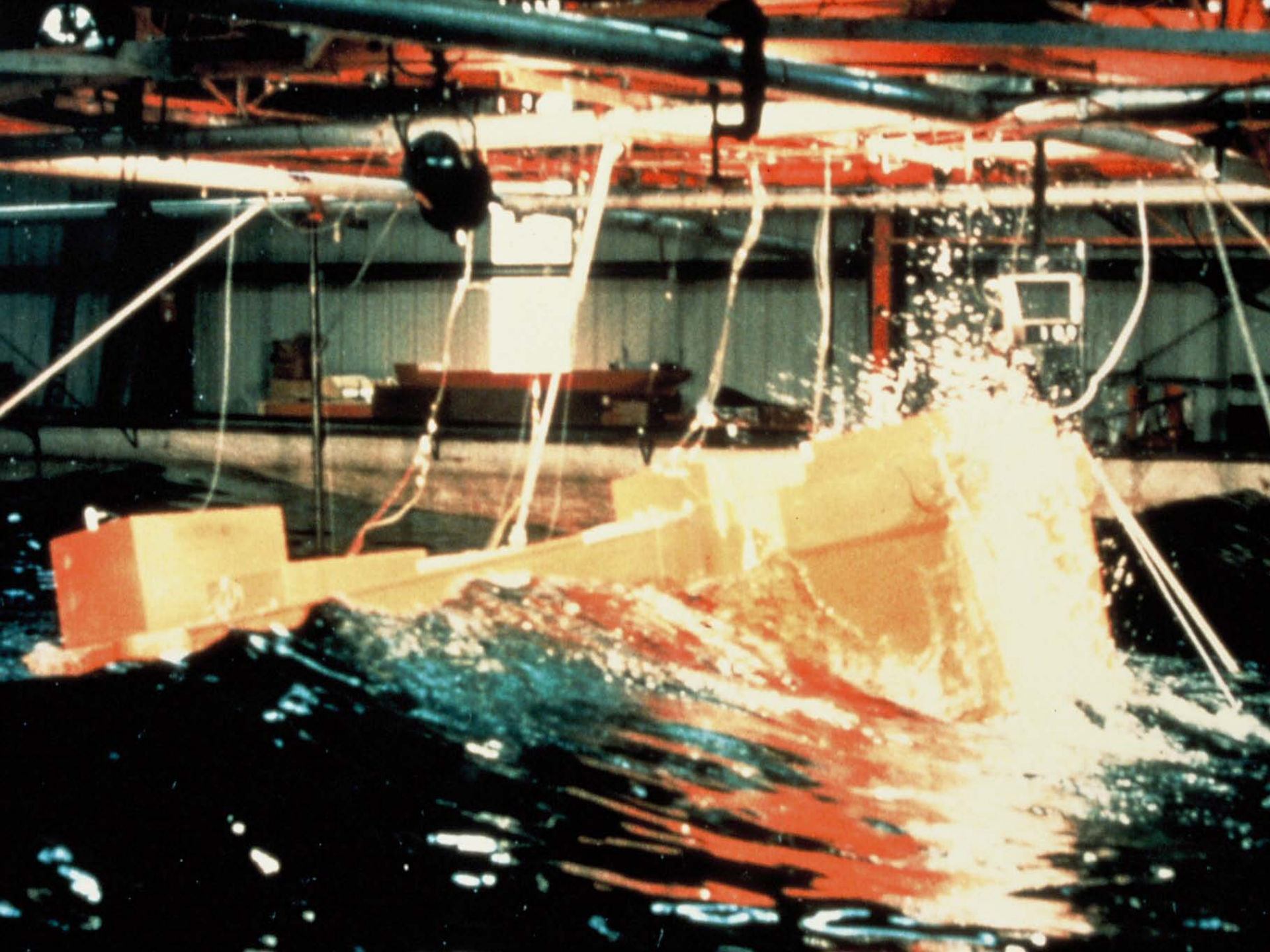
1/30th Scale Original

APL Plantship (concrete barge)

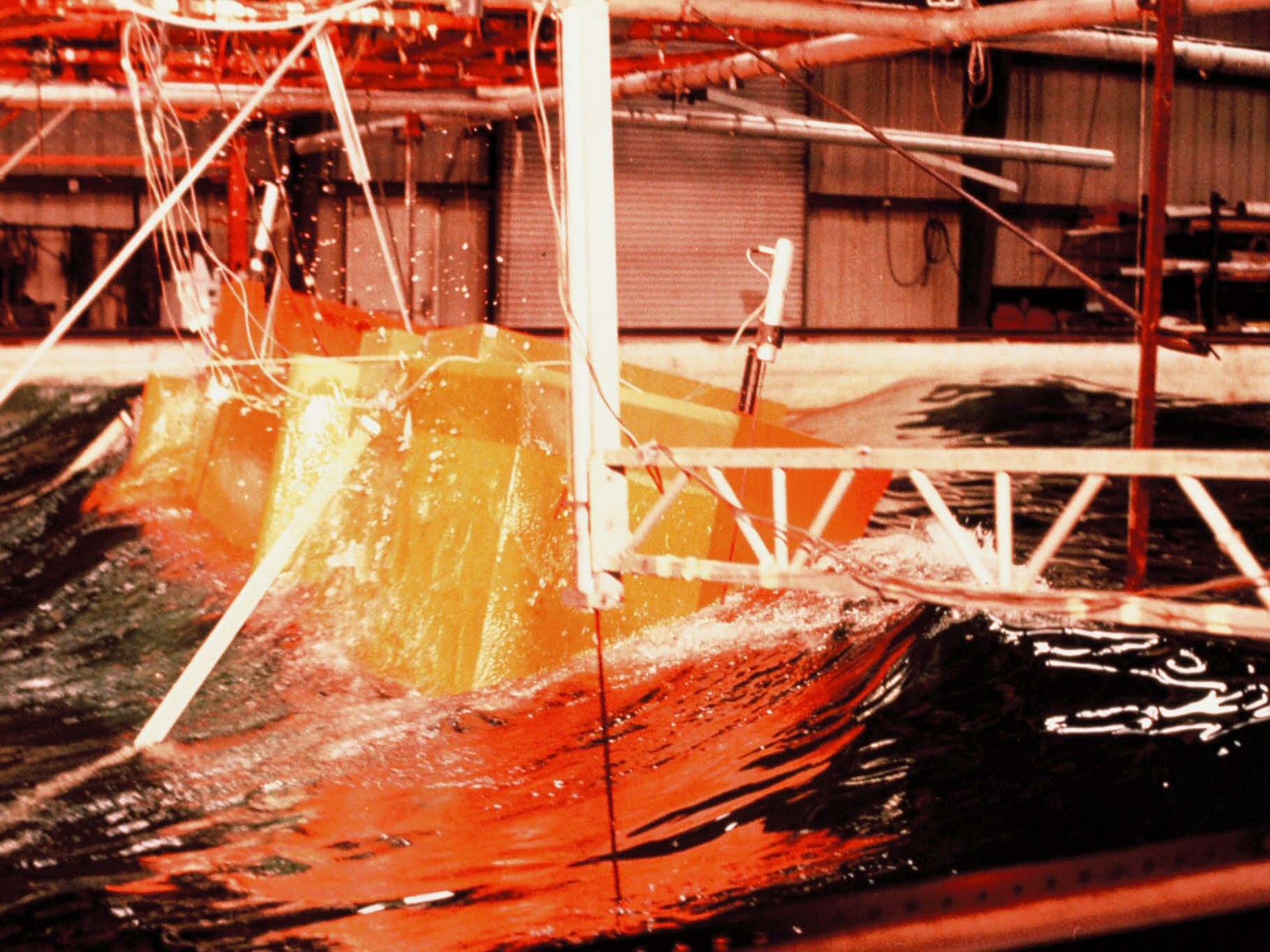
<u>Survival Seakeeping Tests</u>:

Head, Quartering and Beam

100th Year Storm Seas



104



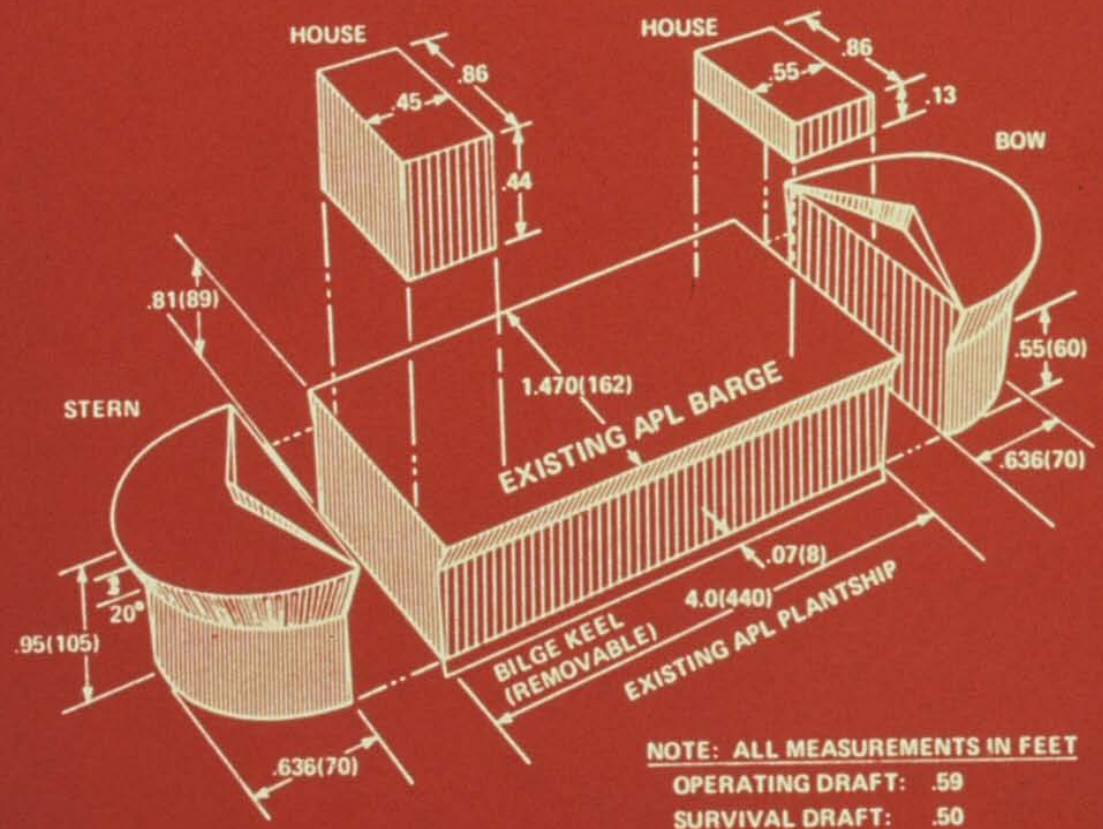
Model Basin Tests

NOAA:

1/110th Scale Modified APL Plantship

- Seakeeping; and,
- Cold Water Pipe Towing Tests

PROPOSED SEAKEEPING IMPROVEMENTS FOR MODEL OF APL BARGE



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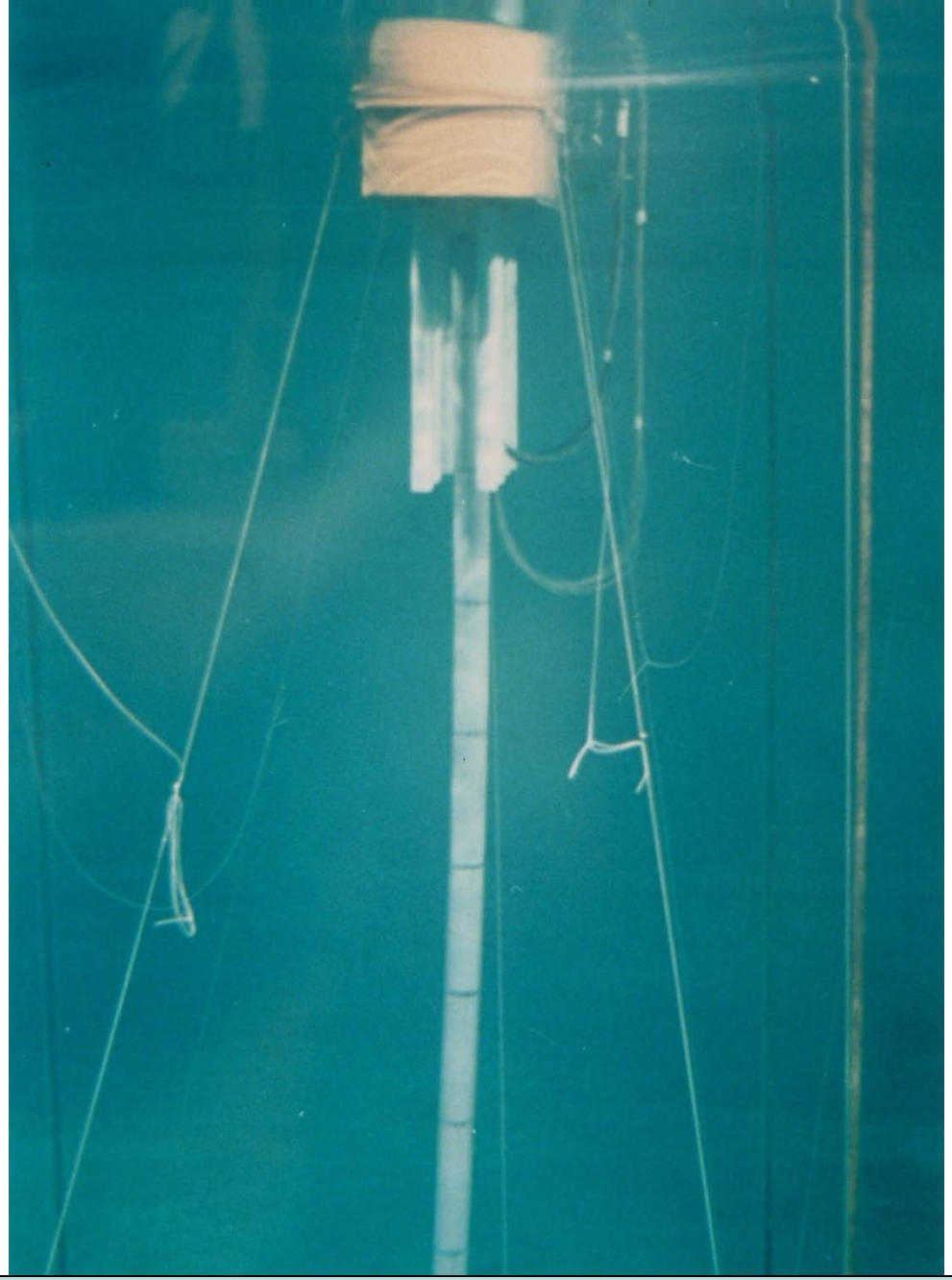
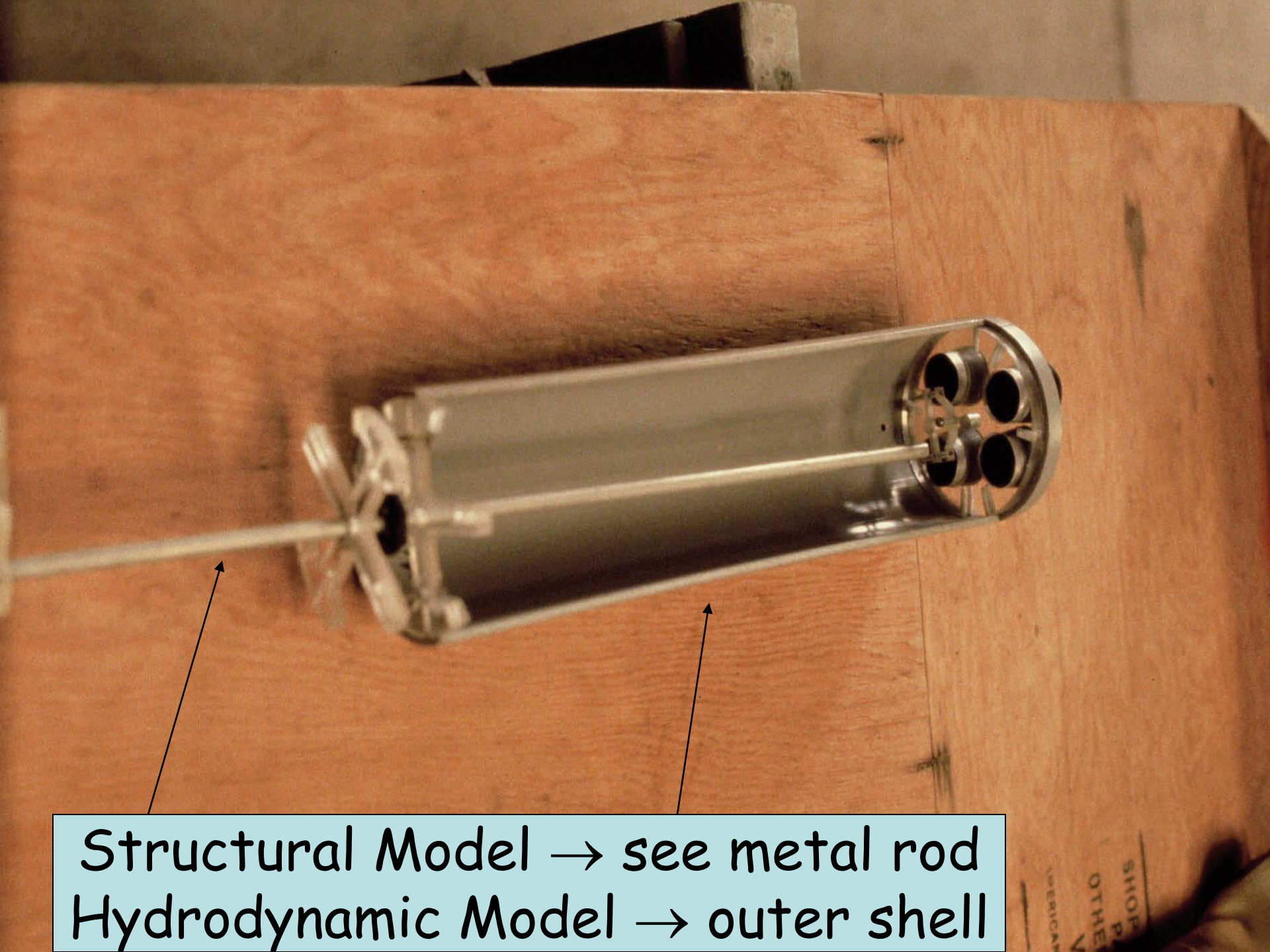
7. REMOVE WARM WATER PODS TO AVOID WAVE FOCUS EFFECTS

1/110th Scale Modified Plantship



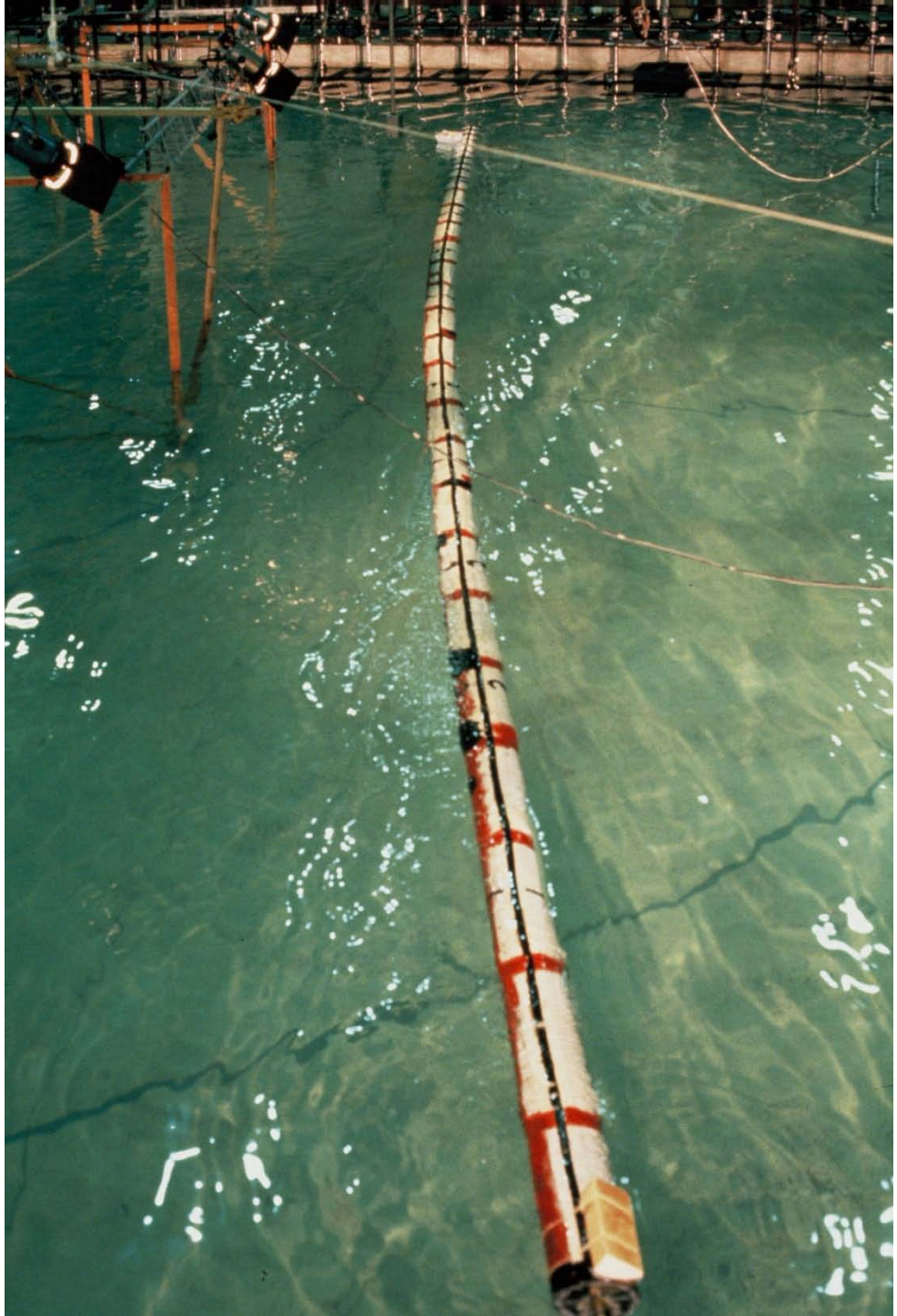
1/110th Scale Seakeeping Tests: Platform and CWP



Structural Model → see metal rod
Hydrodynamic Model → outer shell

1/110th Scale CWP Towing Tests (Head Seas)

Towing Tests
(Beam Seas)



At-Sea Tests

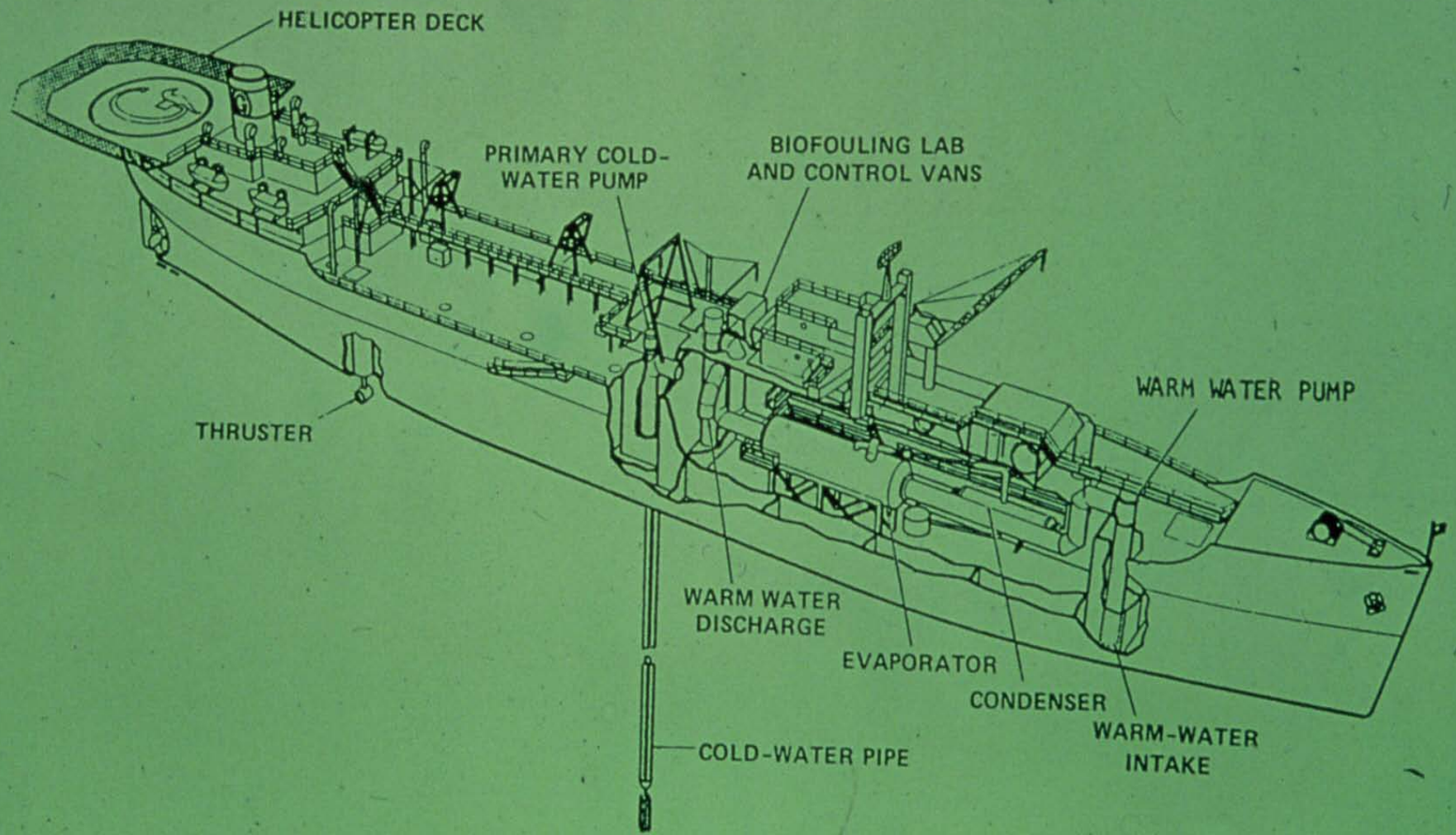
<u>DOE</u>

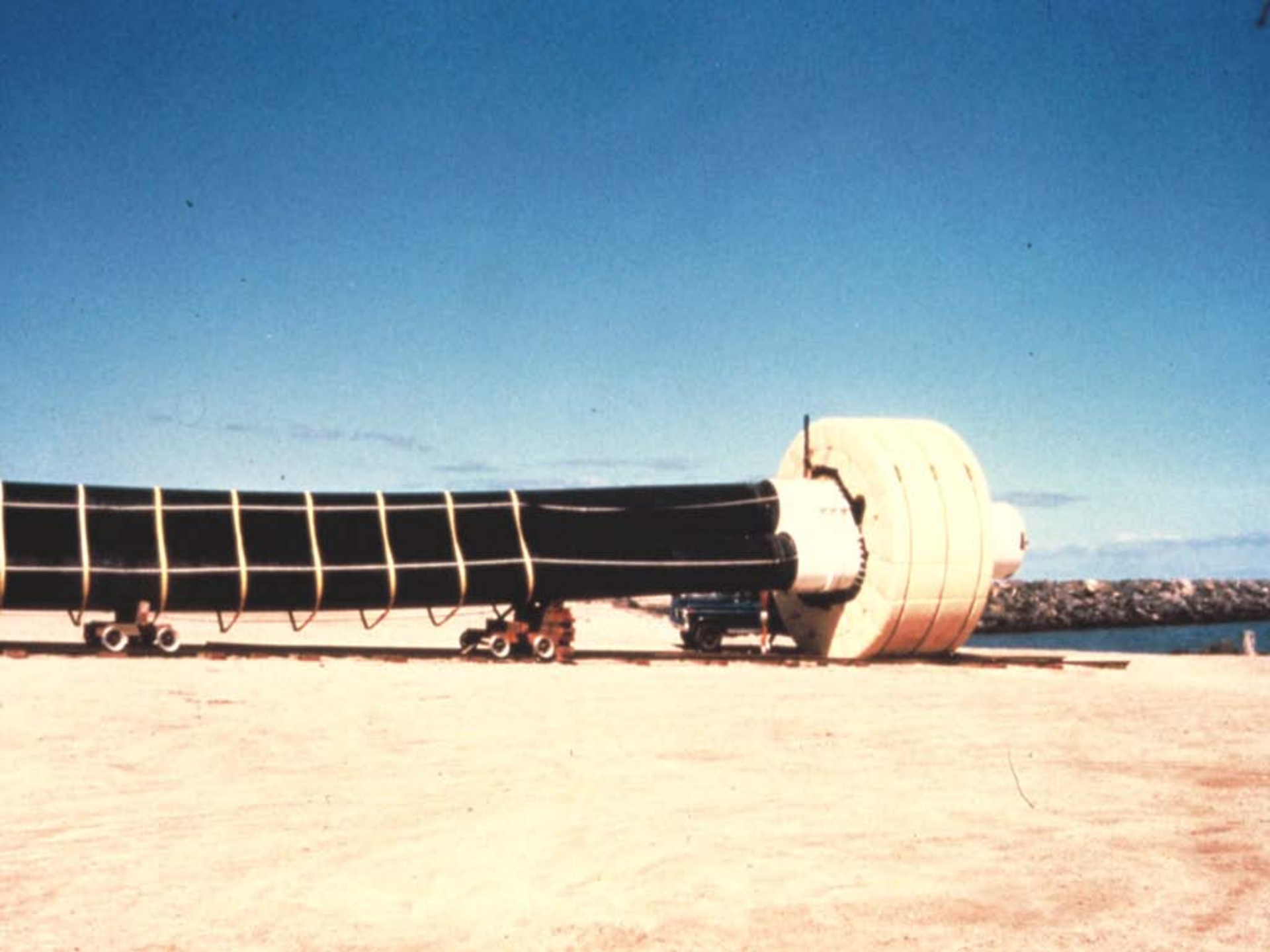
OTEC-1: "1 MW" Heat Exchanger's Tests (22,000 tonnes Tanker)

&

CWP bundle of 3 x 48" HDPE Pipes

ISOMETRIC CUTAWAY OF THE OTEC-1 TEST PLATFORM, A CONVERTED NAVY T-2 TANKER

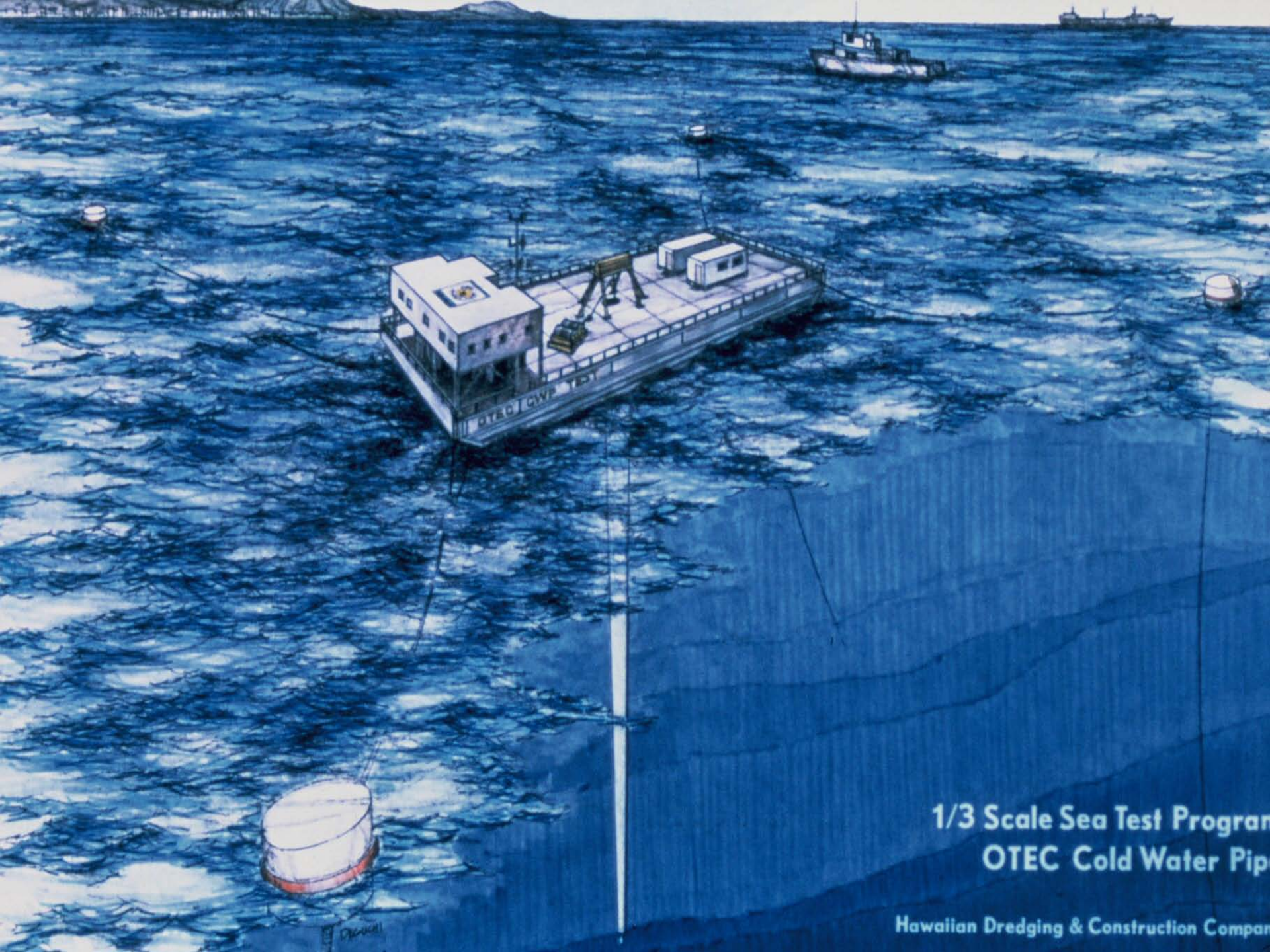


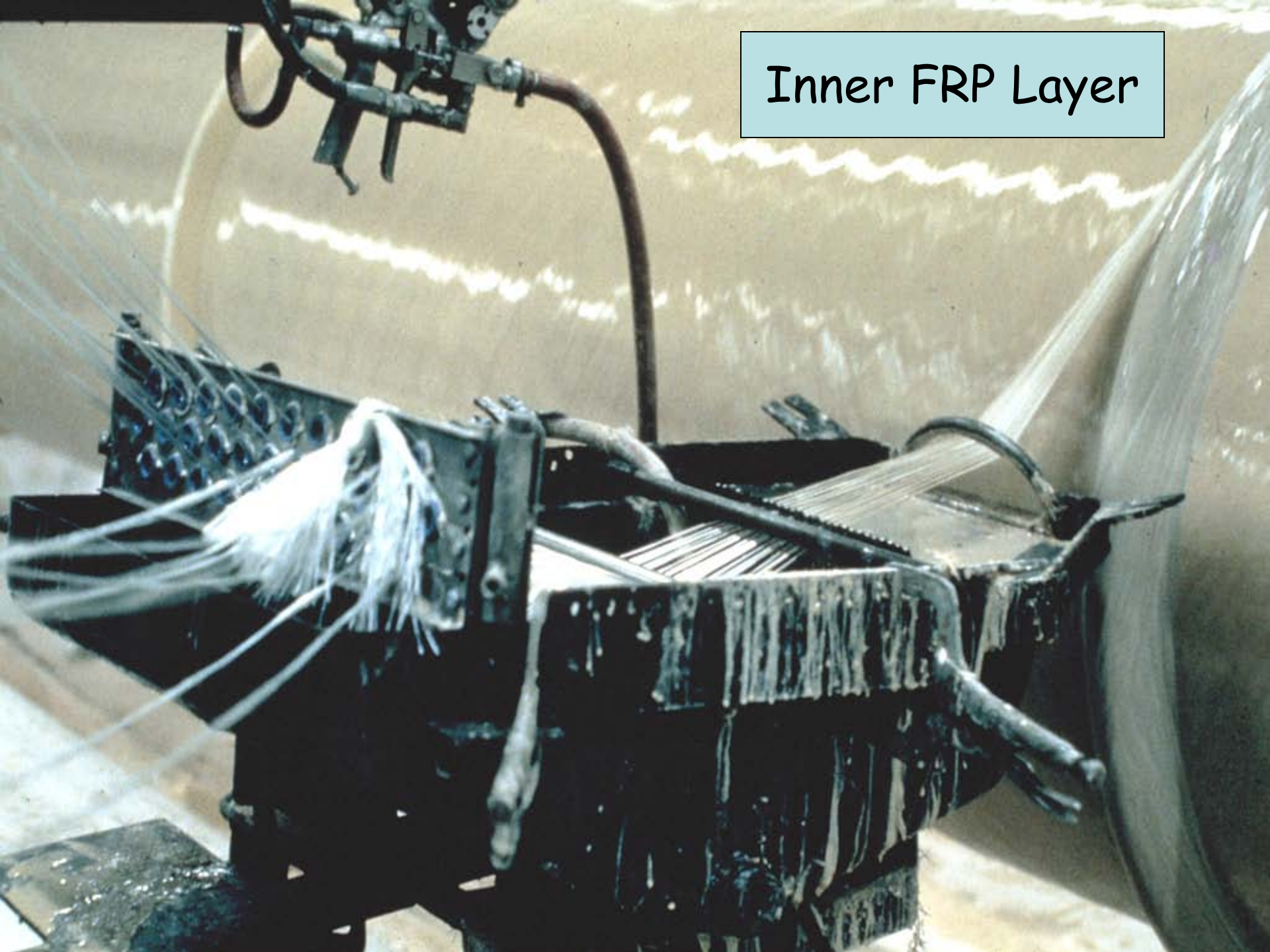


At-Sea Tests

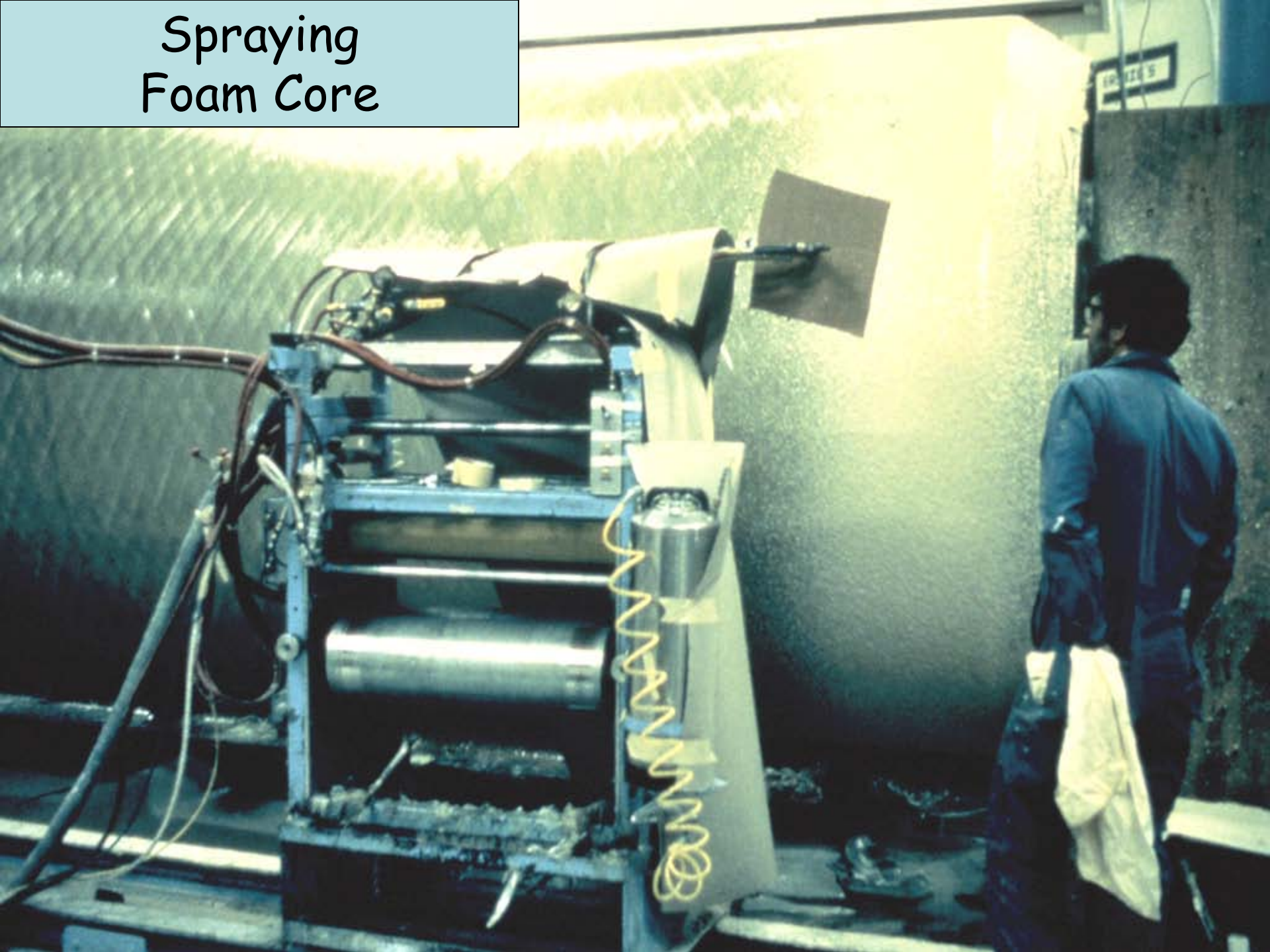
<u>NOAA</u>: 1/3 Scale Suspended Cold Water Pipe (CWP): *30' Diameter FRP-Sandwich Pipe*

[Test Director: Vega]


1/3 Scale Sea Test Progran
OTEC Cold Water Pip
Hawaiian Dredging & Construction Compar


Inner FRP Layer

Spraying Foam Core



Outer FRP Layer

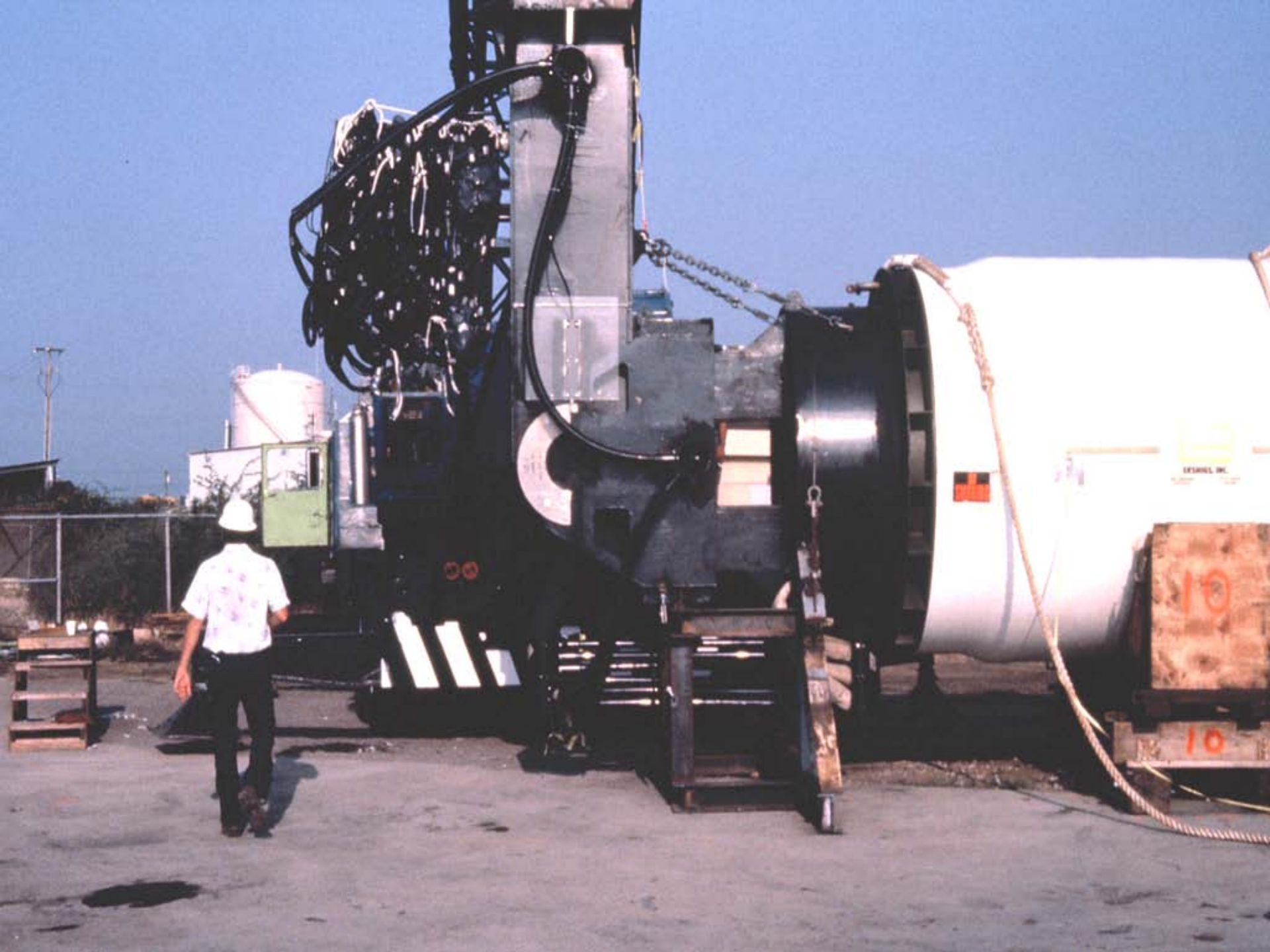
CWP:
FRP Sandwich
0.38" Laminates
1.3" core

CWP Launching Sequence

- 8′ Diameter x 40′ Sections butt-jointed into →

-80′ Lengths in Washington State for land/ocean transport to Hawaii

- Field-jointed into 400′ CWP


10
10

CWP Towing Sequence

"Flotilla" Towing Pipe to test site off Waikiki

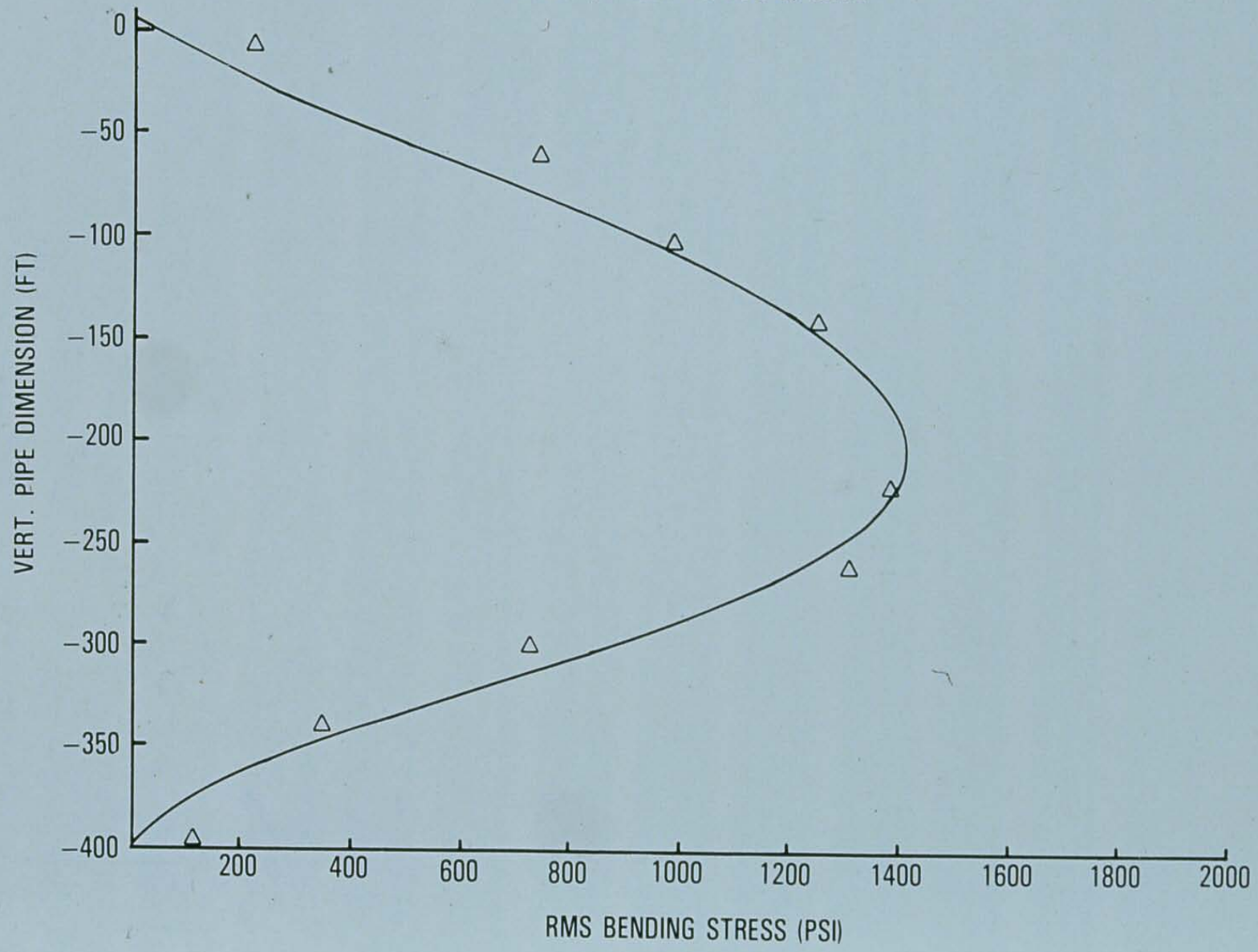
(N.B. numerous vessels involved)

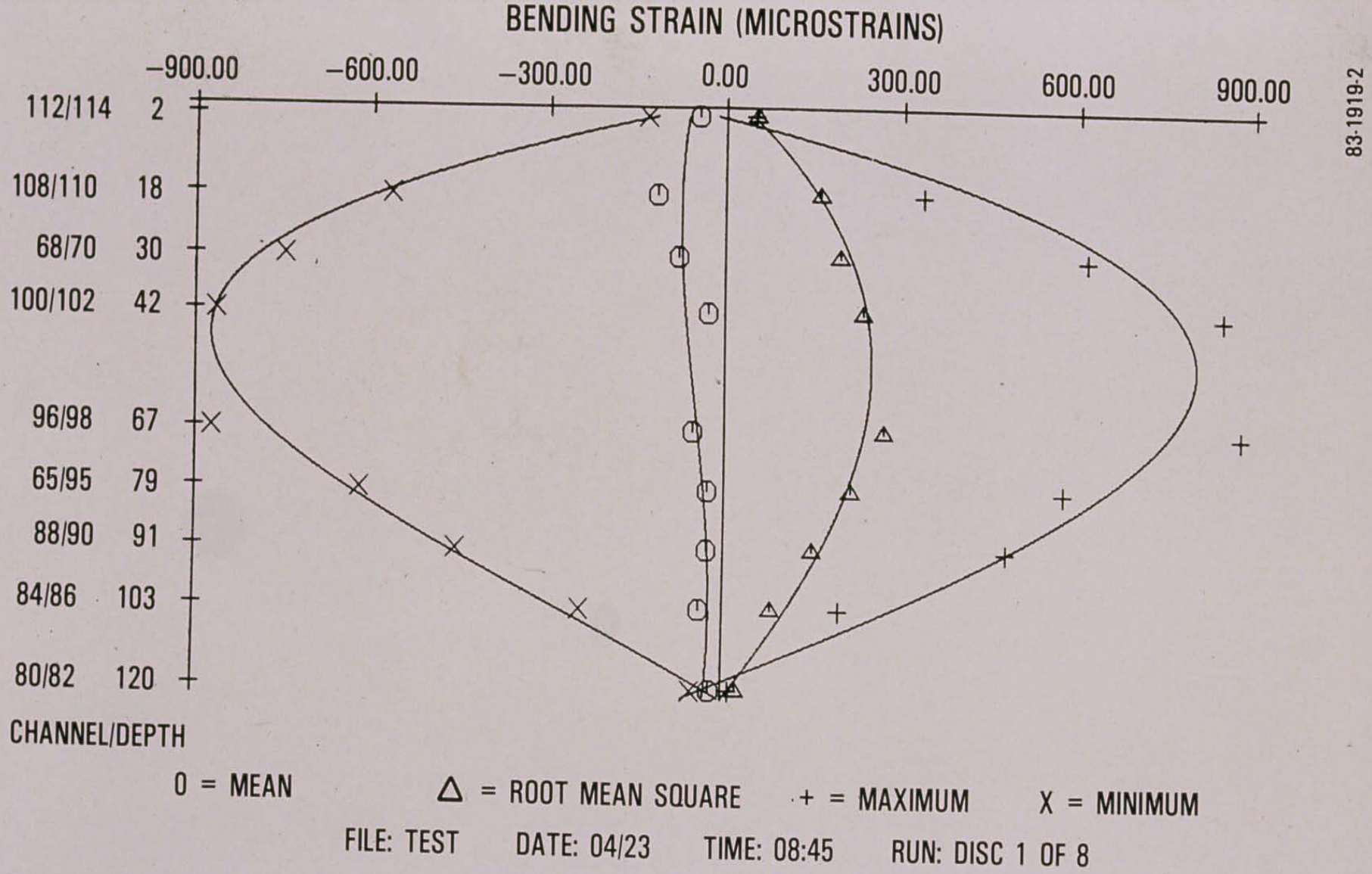
At-Sea Test Data Used to Validate Computer Model of CWP Structural Response

Nihous & Vega

OTEC AT-SEA TEST COLD WATER PIPE BENDING STRESS
COMPUTER PREDICTIONS VS AT-SEA TEST DATA

ROTECF, CASES VS RUN 3, 05/02





BENDING STRAIN DISTRIBUTION ALONG
THE COLD WATER PIPE

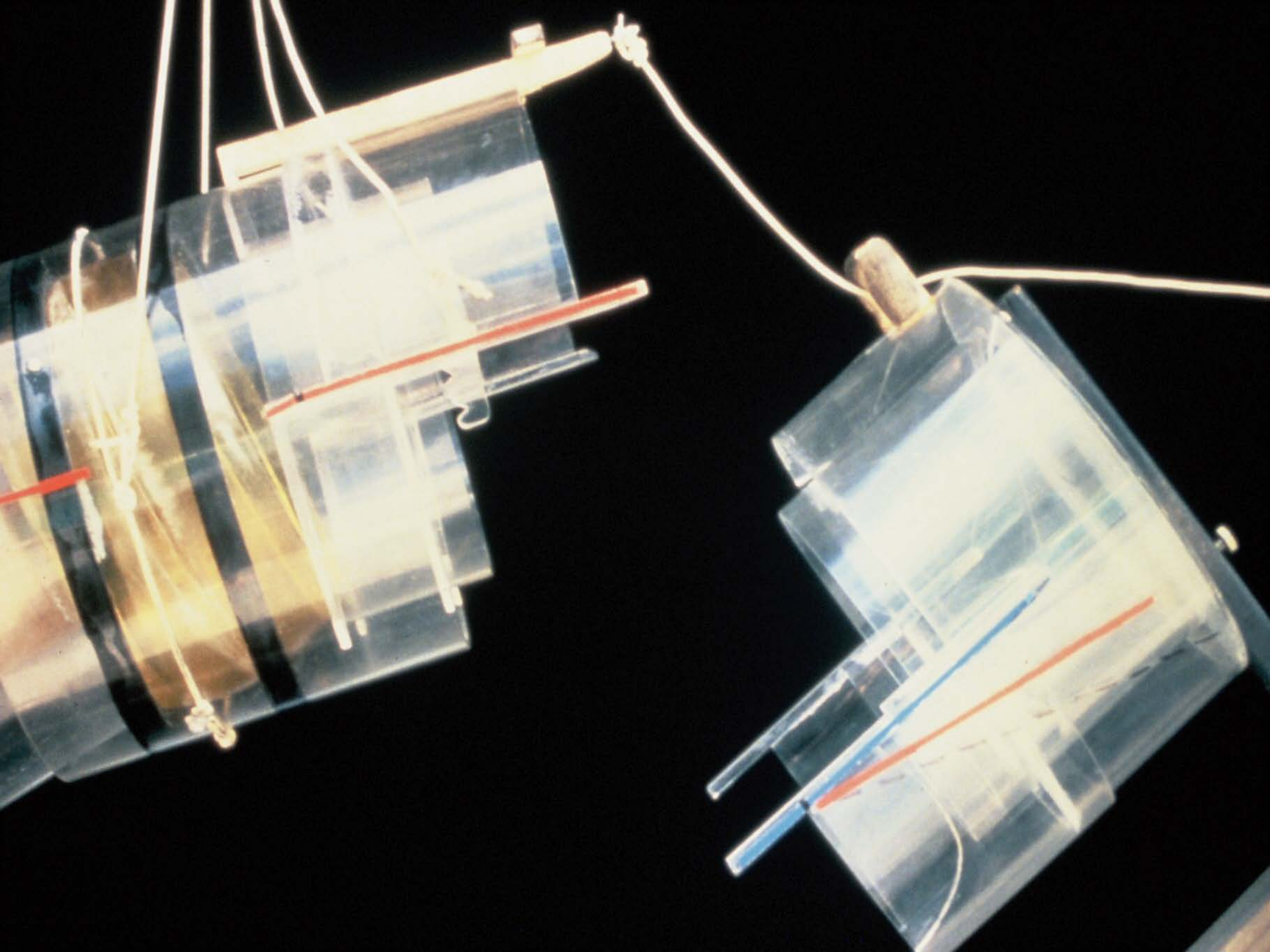
At-Sea Tests

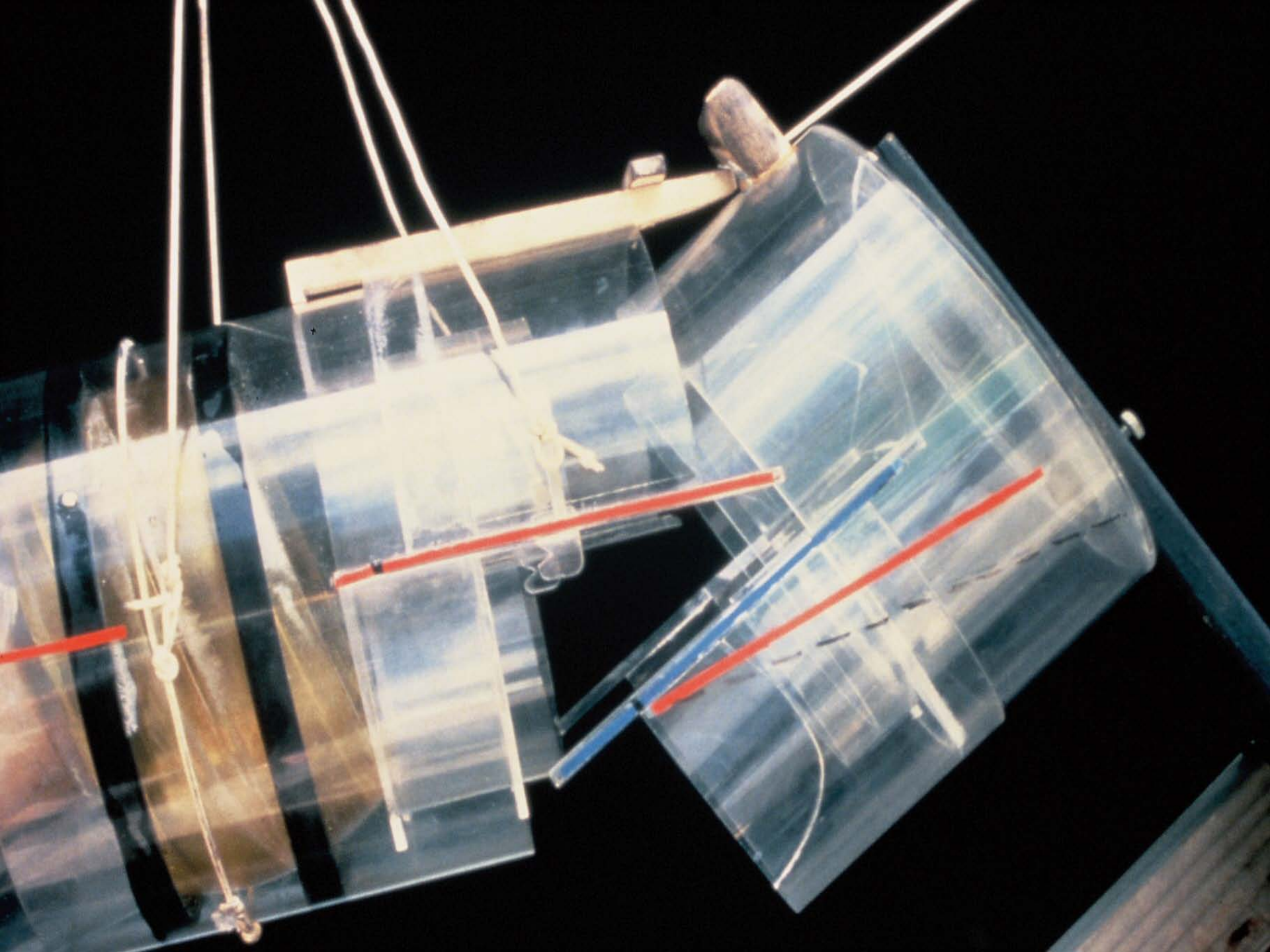
<u>NOAA</u>

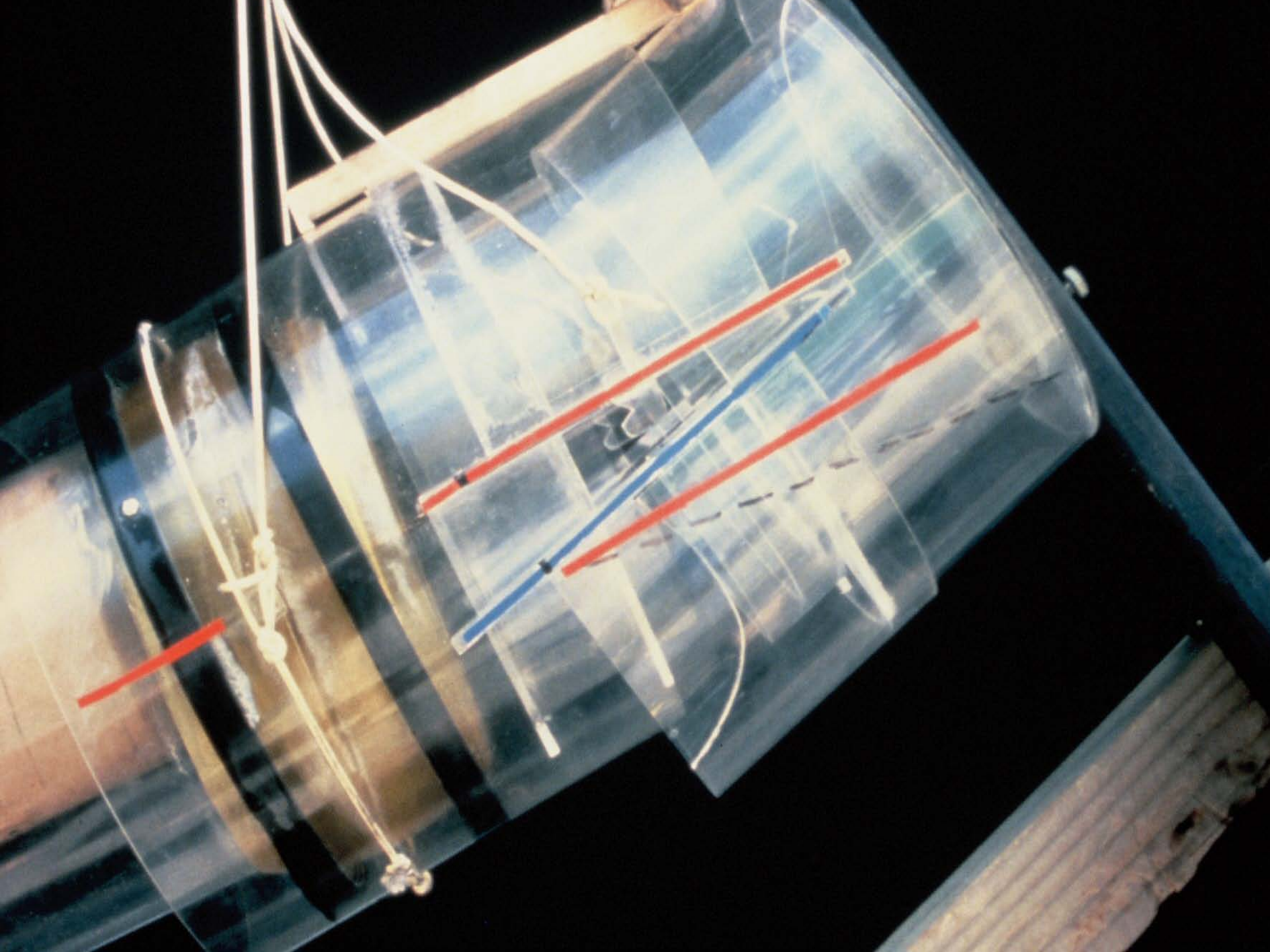
1/3 Scale Bottom-Mounted

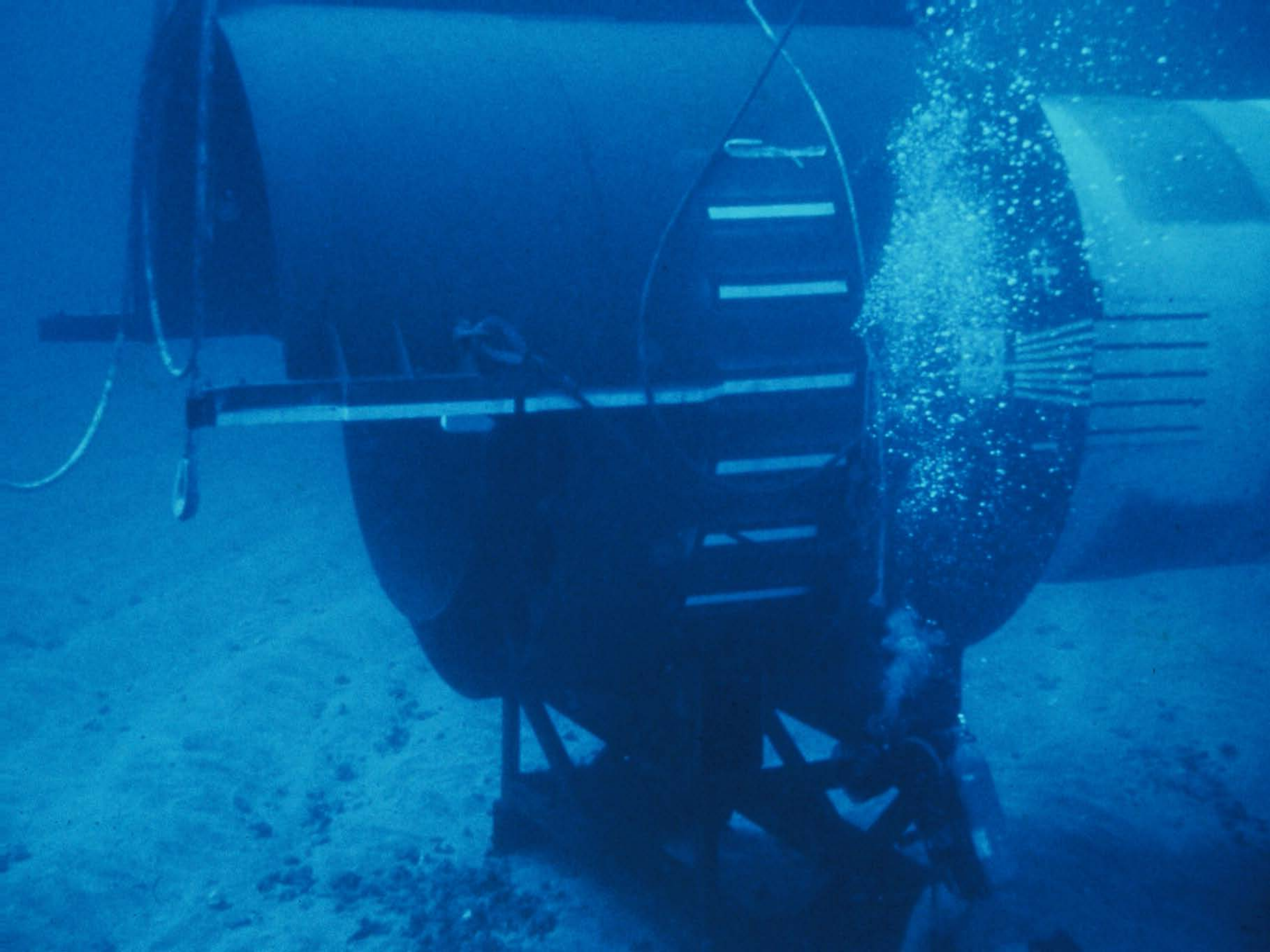
CWP Test:

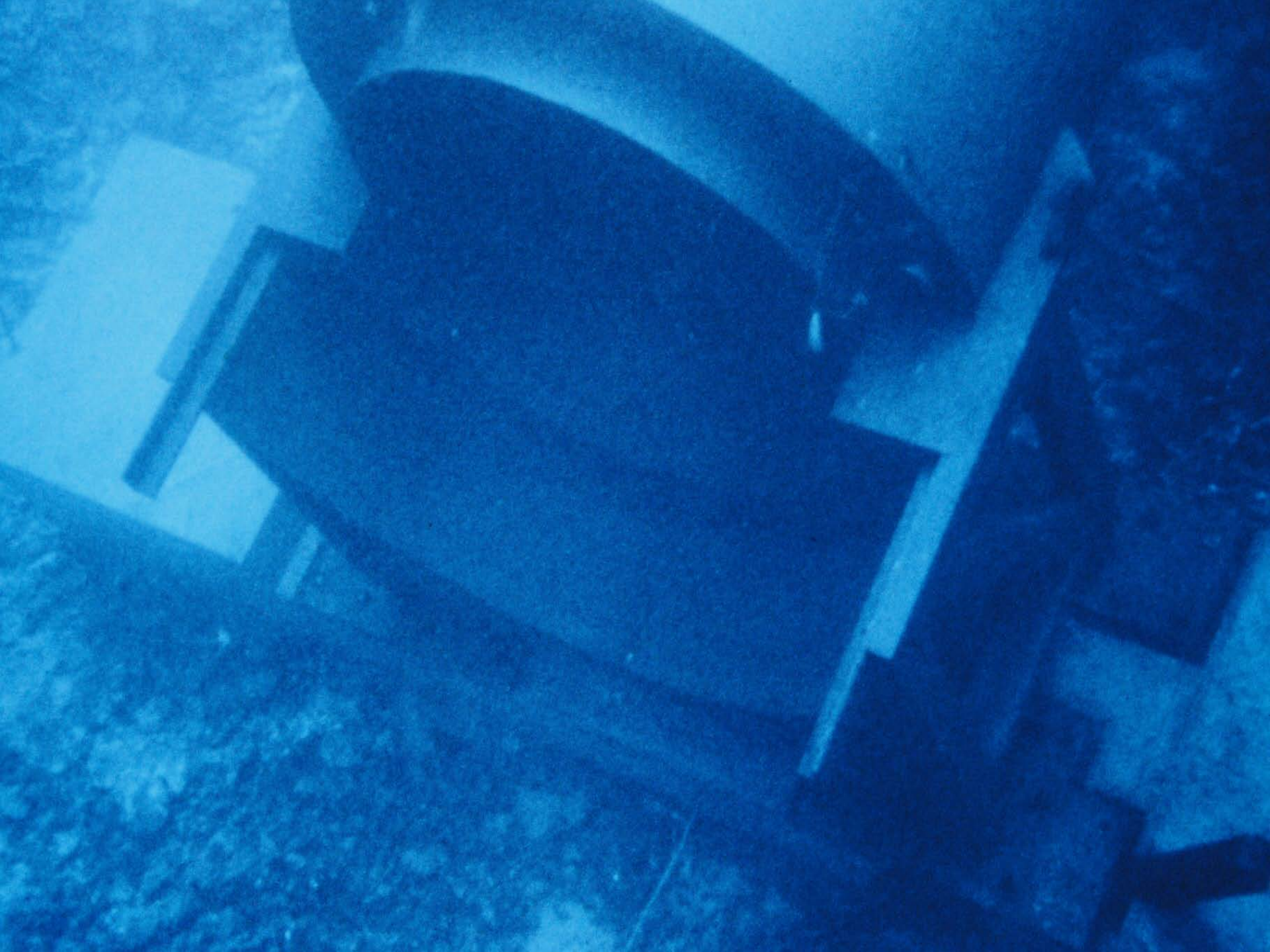
- First sequence shows MOE's plexiglass model used to train divers
- Second Sequence is actual deployment

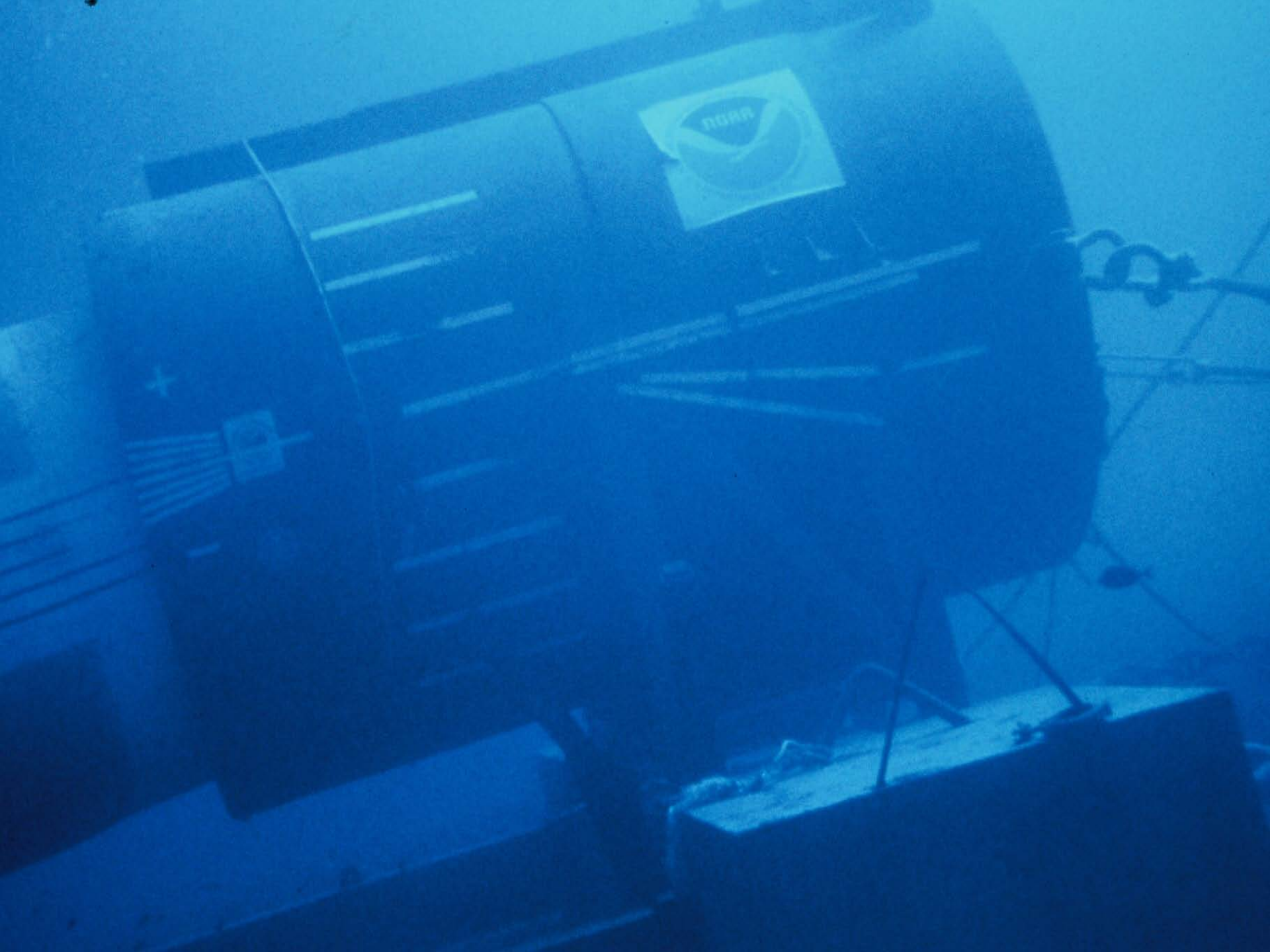


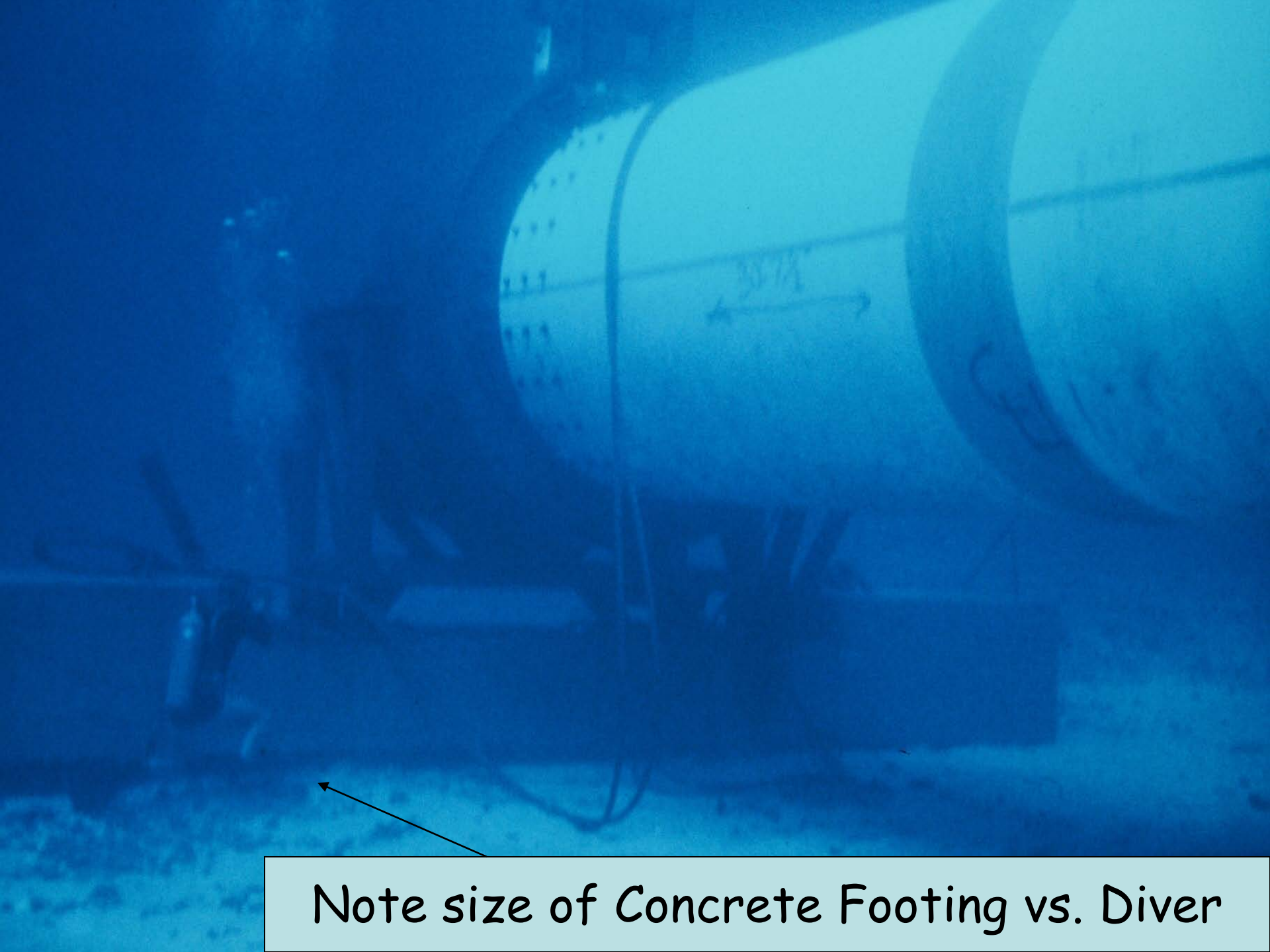




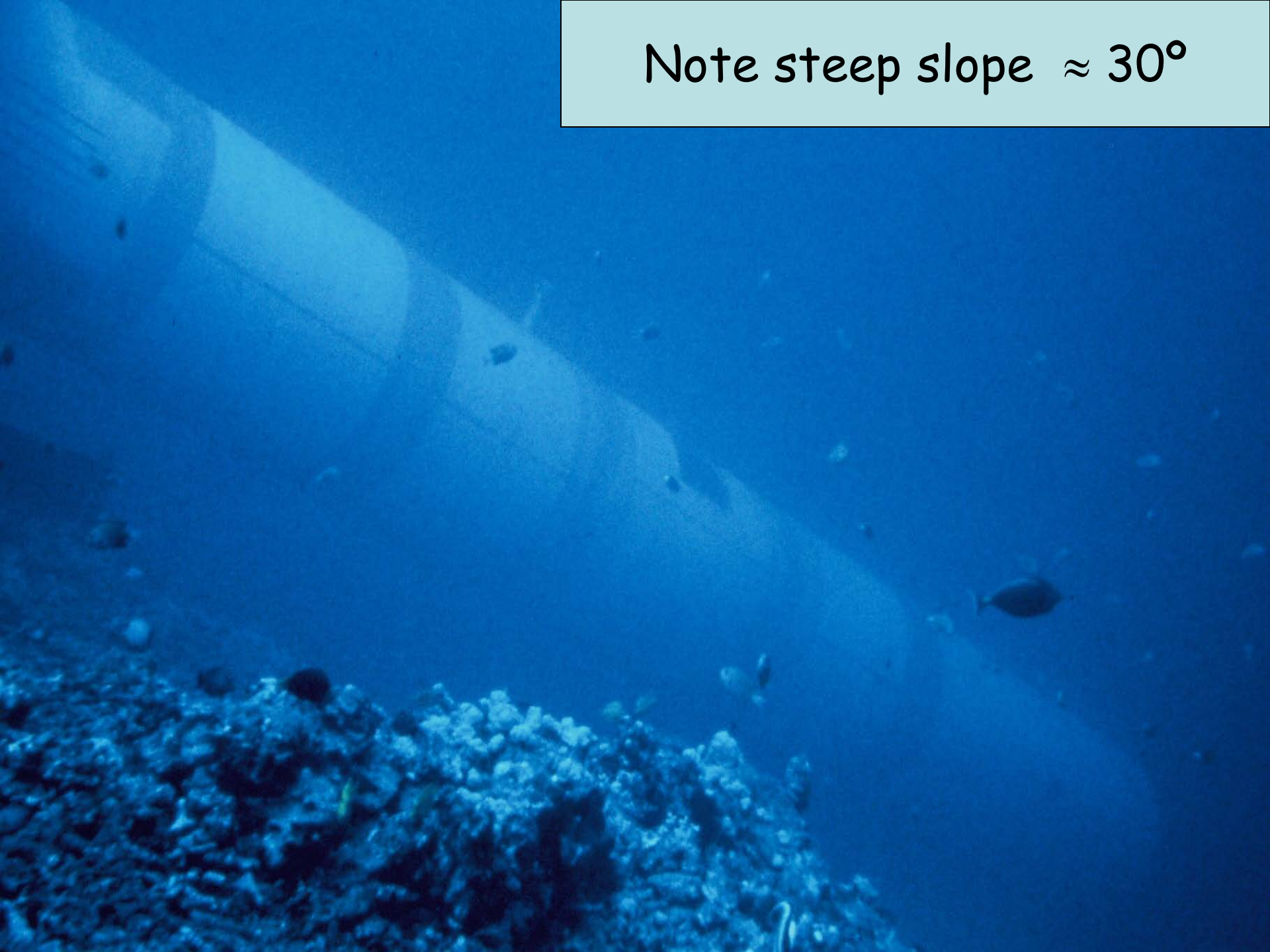




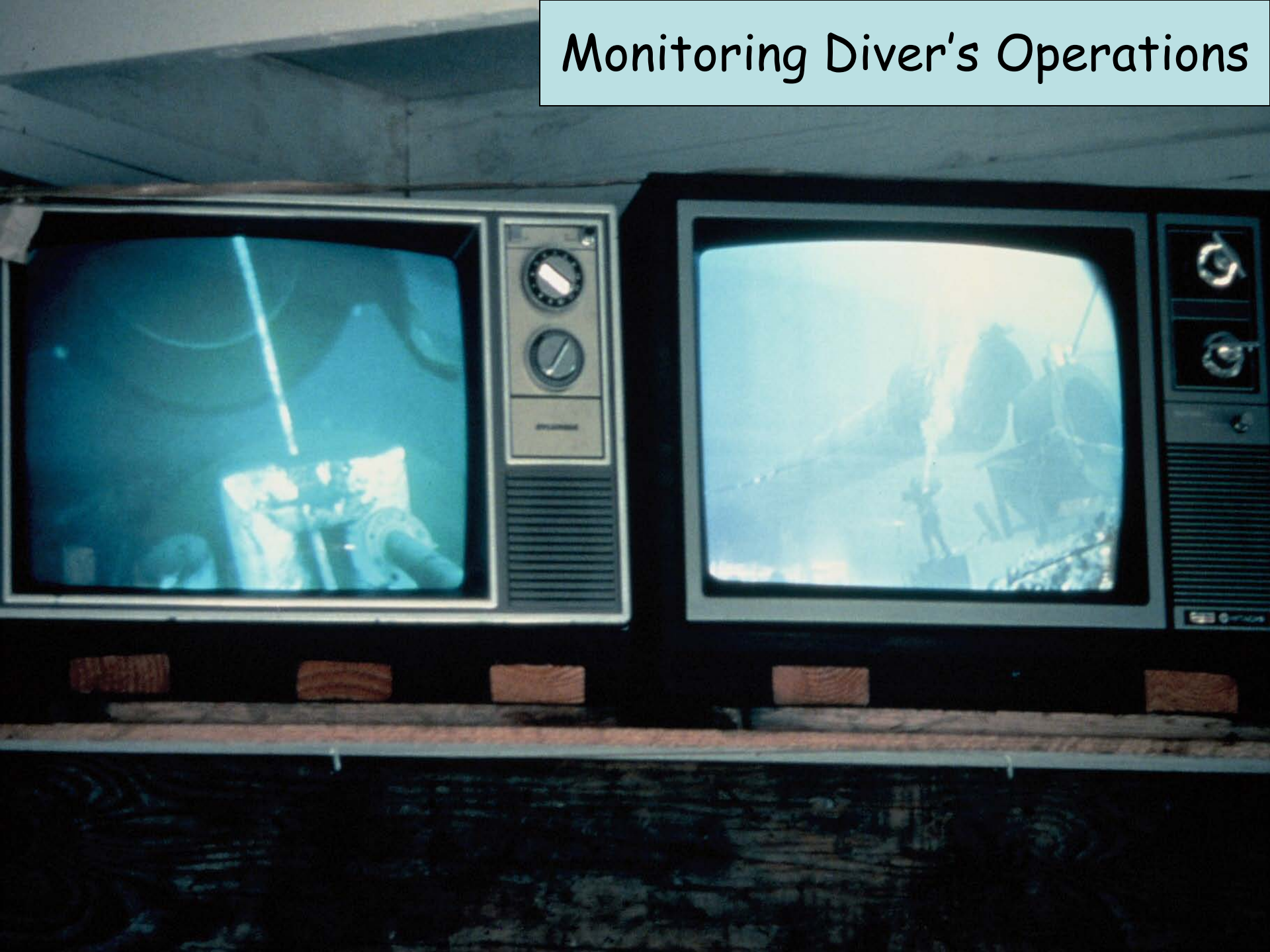

NOAA



Note size of Concrete Footing vs. Diver


Note steep slope ≈ 30°

Monitoring Diver's Operations



OC-OTEC Experimental Plants

DOE & SOH

<u>210 kW Experimental Apparatus</u>

- Concrete Vacuum Structure

  25' (dia.) x 31' Height (overall height: 43')

- Turbine

  10' dia. radial inlet; 7' dia. axial outlet

210 kWe (gross) OPEN-CYCLE OTEC EXPERIMENTAL APPARATUS FOR THE PRODUCTION OF ELECTRICITY & FRESH WATER

By

THE PACIFIC INTERNATIONAL CENTER
FOR HIGH TECHNOLOGY RESEARCH

With

- ABAM CONSULTING ENGINEERS
- BARBER-NICHOLS INC.
- HAROLD H. MIURA INC.
- MECHANICAL TECHNOLOGY, INC.
- THERMAL ENGINEERING CORPORATION

General Contractor

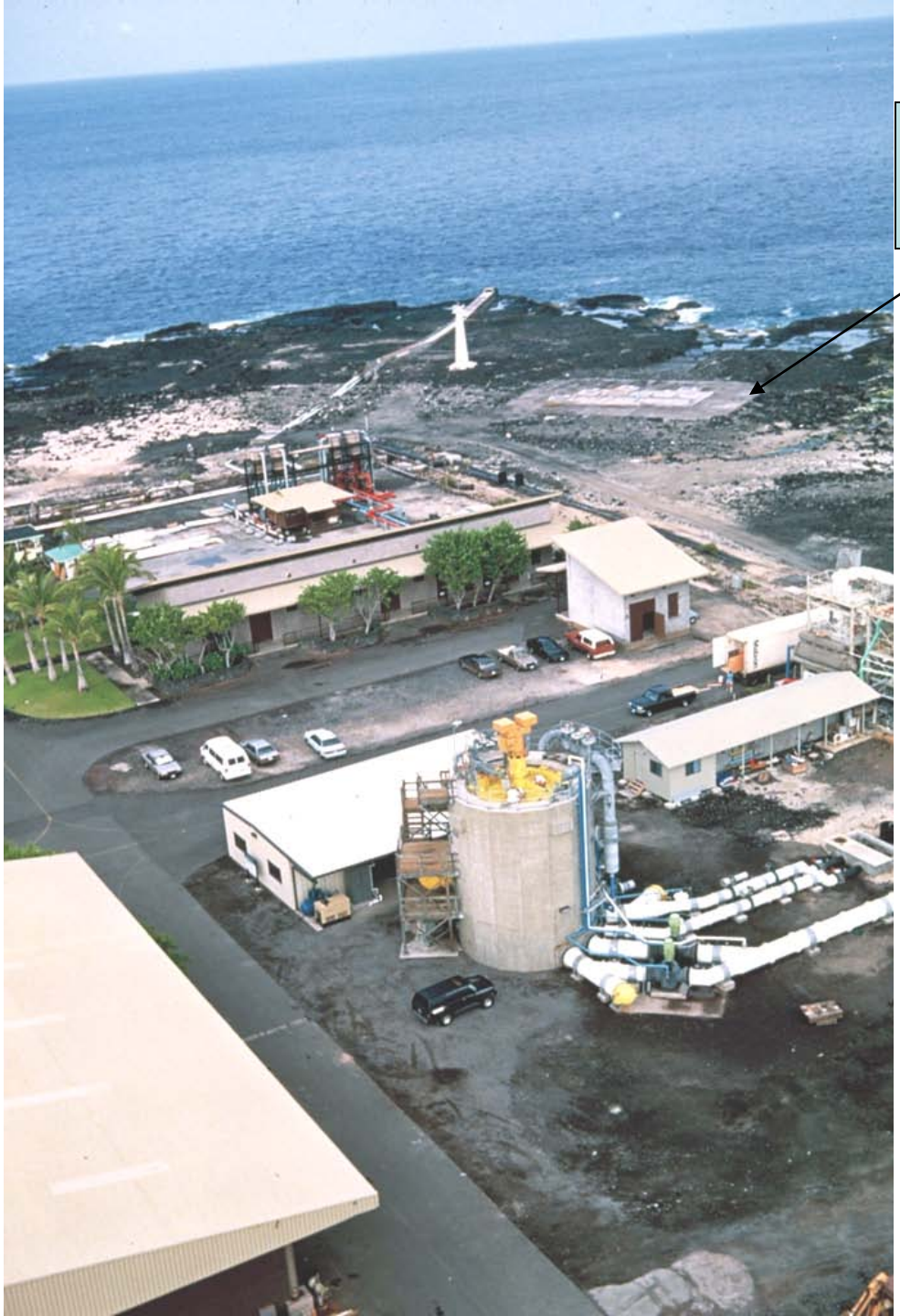
- ABREGO INC.

Sponsored by

- U.S. DEPARTMENT OF ENERGY / NREL
- STATE OF HAWAII / DBED

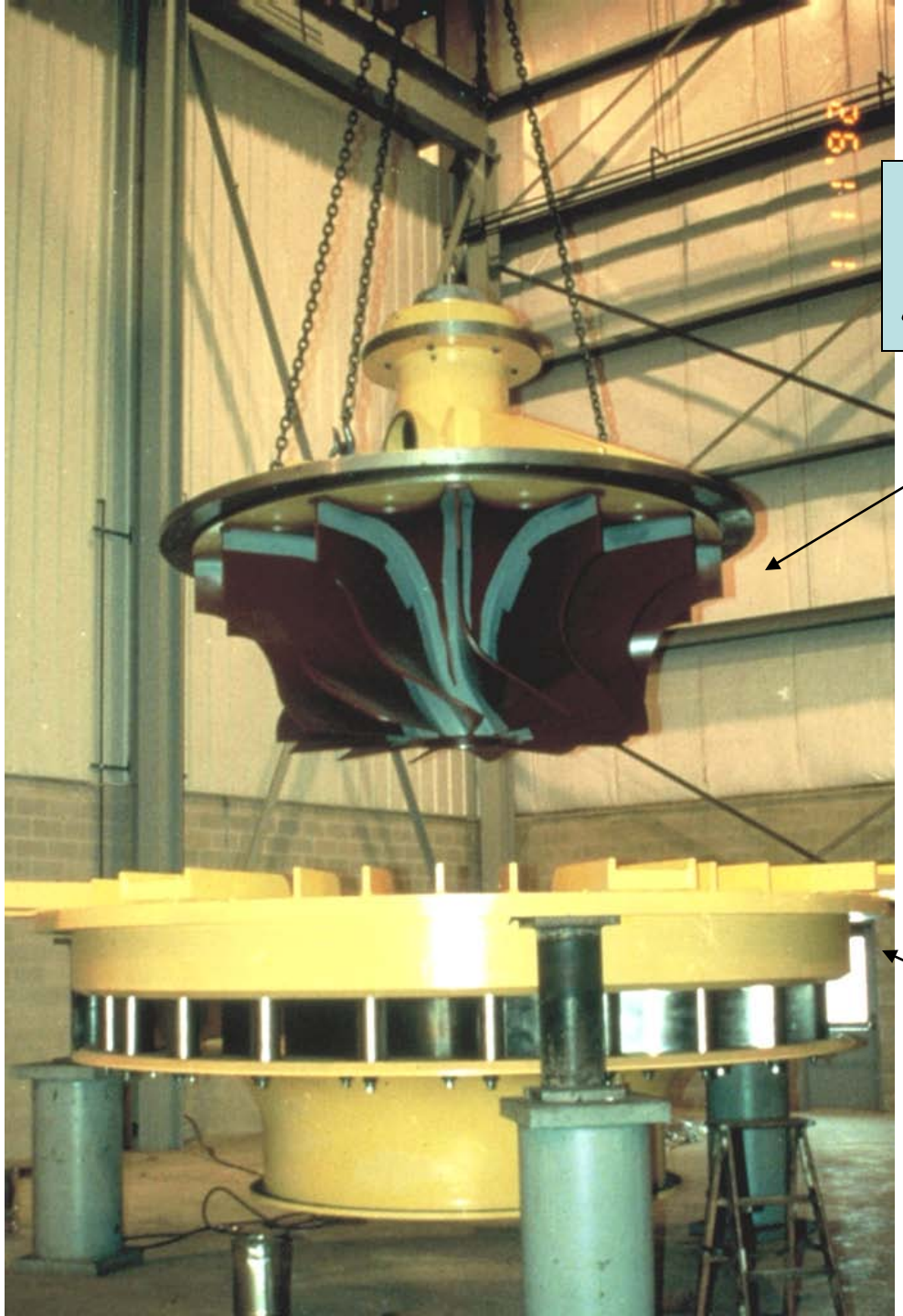
210 kW OC-OTEC Experimental Plant

(Vega et al: 1993-1998)


Pump Station

Waves Pounding Pump Station

OC-OTEC
Steam
Turbine



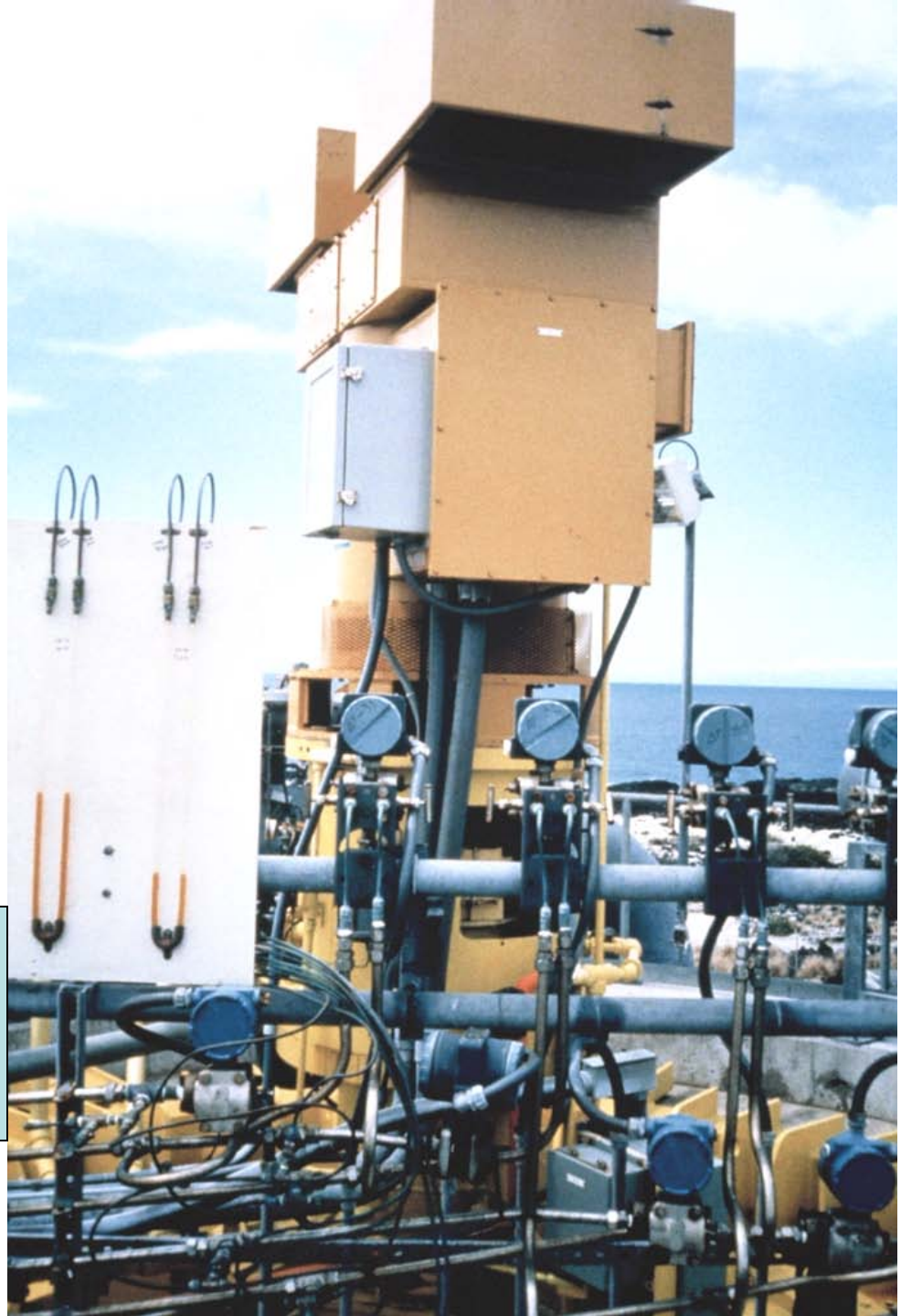
7’ dia.
Axial Outlet

10’ dia.
Radial Inlet

OC-OTEC Evaporator Spouts

Joe McCleskey

Electrical Generator



Joe Clarkson

Peter Shackelford

Desalinated Water Production

(Vega et al:'94-'98)

Surface Condenser: Steam Fins

Surface Condenser:
Extruded Water Channels

Control Room

Aluminum Corrosion Testing

- Argonne National Laboratory field tests at NELHA ('83-'87): *Evaluate Al as material for OTEC Heat Exchangers*
- Over 30-year life wall thickness ("t") losses
  - < 90 μm in evaporator; and,
  - < 200 μm in condenser; →

Aluminum Corrosion Testing

- Bare Al alloys, exposed to flowing seawater, exhibit two stages of uniform corrosion: (i) a relatively high rate over the first 200 days (mostly in surface seawater); (ii) followed by asymptotic limiting rates corresponding to annual "t" losses of < 3 **μm** (surface water) and 7 **μm** (deep water);

- Results are only applicable for seamless flow channels. For the condenser, brazed joints fabricated using commercial fluxes are not acceptable.

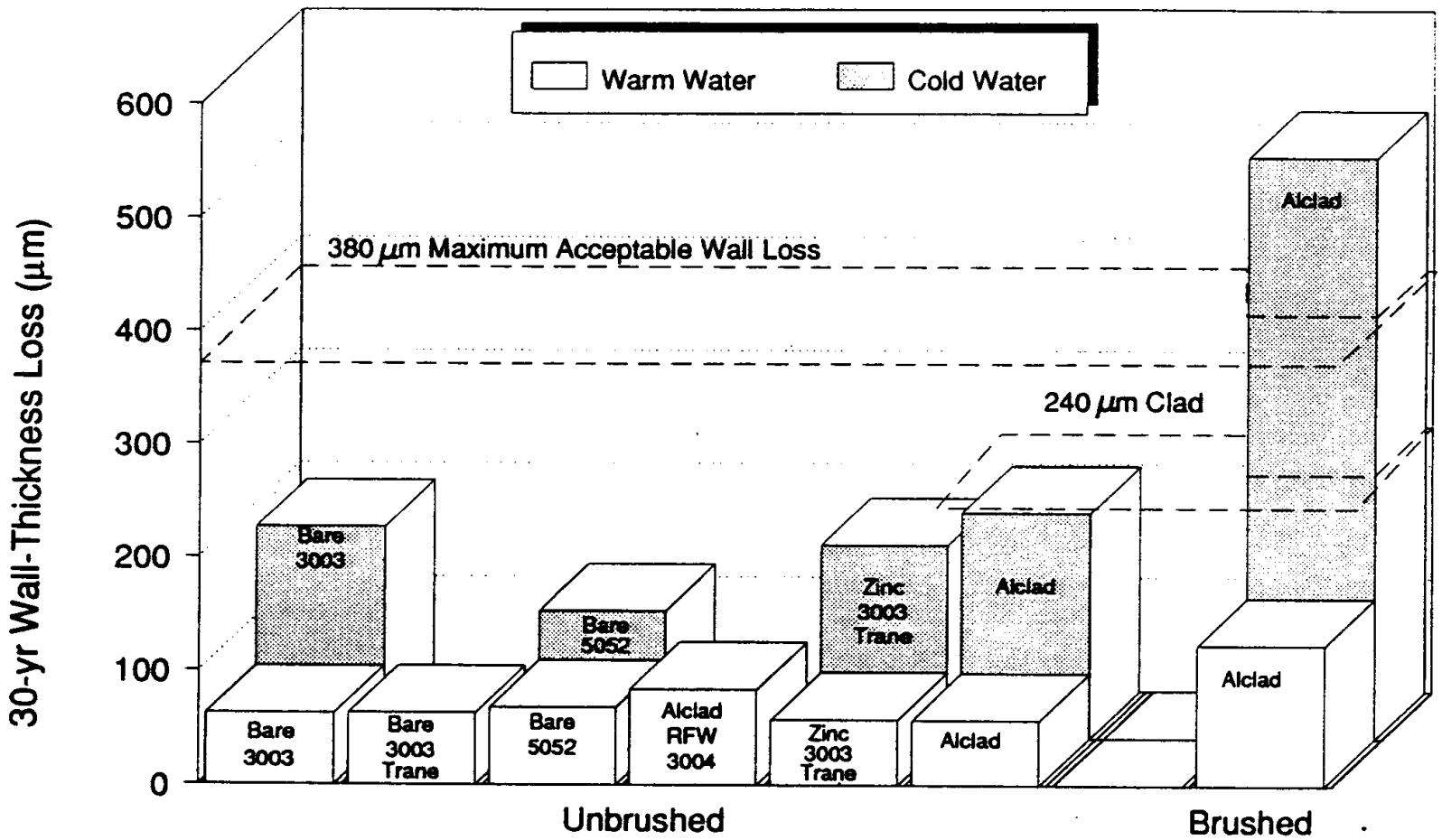


FIGURE S-1 Wall-Thickness Loss for Candidate Aluminum Alloys

Environment	Material	Comments	Conclusions
Warm Seawater	Bare Al-3003 Drawn or Brazed Elements	No pitting of drawn tubes; some pitting at joints of brazed elements.	Acceptable
	Bare Al-3003 Trane Extrusions	No pitting.	Acceptable
	Bare Al-5052 Drawn Tubes	No pitting.	Acceptable
	Alclad 3004 RFW Tubes	Small percent of sampling showed pitting, which was confined to cladding.	Acceptable
	Diffused-Zn Al-3003 Trane Extrusion	Shallow pitting, evidence of cathodic protection.	Acceptable
	Alclad Drawn Tubes	Infrequent, shallow pitting.	Acceptable
	Alclad Brushed Drawn Tubes	No pitting.	Acceptable
Cold Seawater	Bare Al-3003 Drawn Tubes	Some samples showed initiation of pitting.	Acceptable with caution
	Bare Al-5052 Drawn Tubes	No pitting.	Acceptable
	Diffused-Zn Al-3003 Trane Extrusion	Some samples showed pitting.	Acceptable with caution
	Alclad 3004 RFW Tubes	Pitting penetrated cladding; cathodic protection occurred.	Welding process adversely affects cladding.
	Alclad Drawn Tubes	Severe pitting. Cathodic protection occurred. Lost cladding.	Unacceptable
	Alclad Brushed Drawn Tubes	No severe pitting.	Acceptable

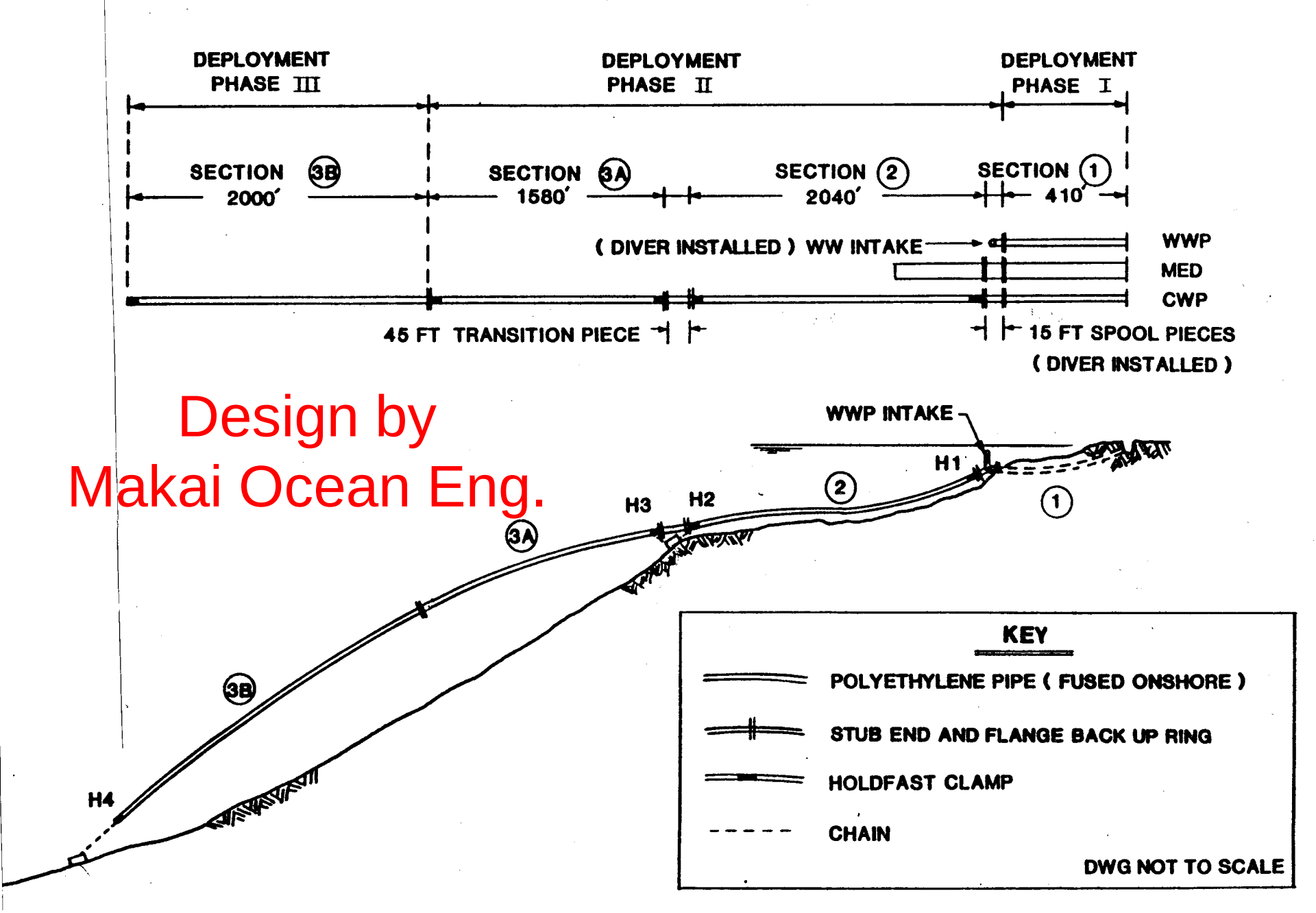
CWP for the 210 kW OC-OTEC

40" HDPE CWP

for the

210 kW Experimental Apparatus:

- Towing to site
- Intake at 670 m


DEPLOYMENT PHASE III
DEPLOYMENT PHASE II
DEPLOYMENT PHASE I
SECTION 3B 2000′
SECTION 3A 1580′
SECTION 2 2040′
SECTION 1 410′
(DIVER INSTALLED) WW INTAKE
WWP
MED
CWP
45 FT TRANSITION PIECE
15 FT SPOOL PIECES
(DIVER INSTALLED)
Design by
Makai Ocean Eng.
WWP INTAKE
H1
H2
H3
H4
2
1
3A
3B
KEY
POLYETHYLENE PIPE (FUSED ONSHORE)
STUB END AND FLANGE BACK UP RING
HOLDFAST CLAMP
CHAIN
DWG NOT TO SCALE

210 kW OC-OTEC Experimental Apparatus

OTEC World Records by Vega et al:

- Power production: 256 kW (24/7)

- Desalinated Water Production: 0.35 l/s (5.5 gpm)

CC-OTEC Experimental Plants

- 50 kW MiniOTEC (Lockheed, Hawaiian Dredging, State of Hawaii …)
- 100 kW Nauru Plant (Tokyo Electric et al)
- 50 kW Test Apparatus (PICHTR, HEI, SOH)

MiniOTEC
(1979)
50 kW CC-OTEC
MINI OTEC
YGN 70

Nauru (1982)

100 kW CC-OTEC

50 kW CC-OTEC (NH_3) Test Apparatus

(Vega et al: 1999)

Land Based OC-OTEC Plant for the Production of Electricity and Fresh Water

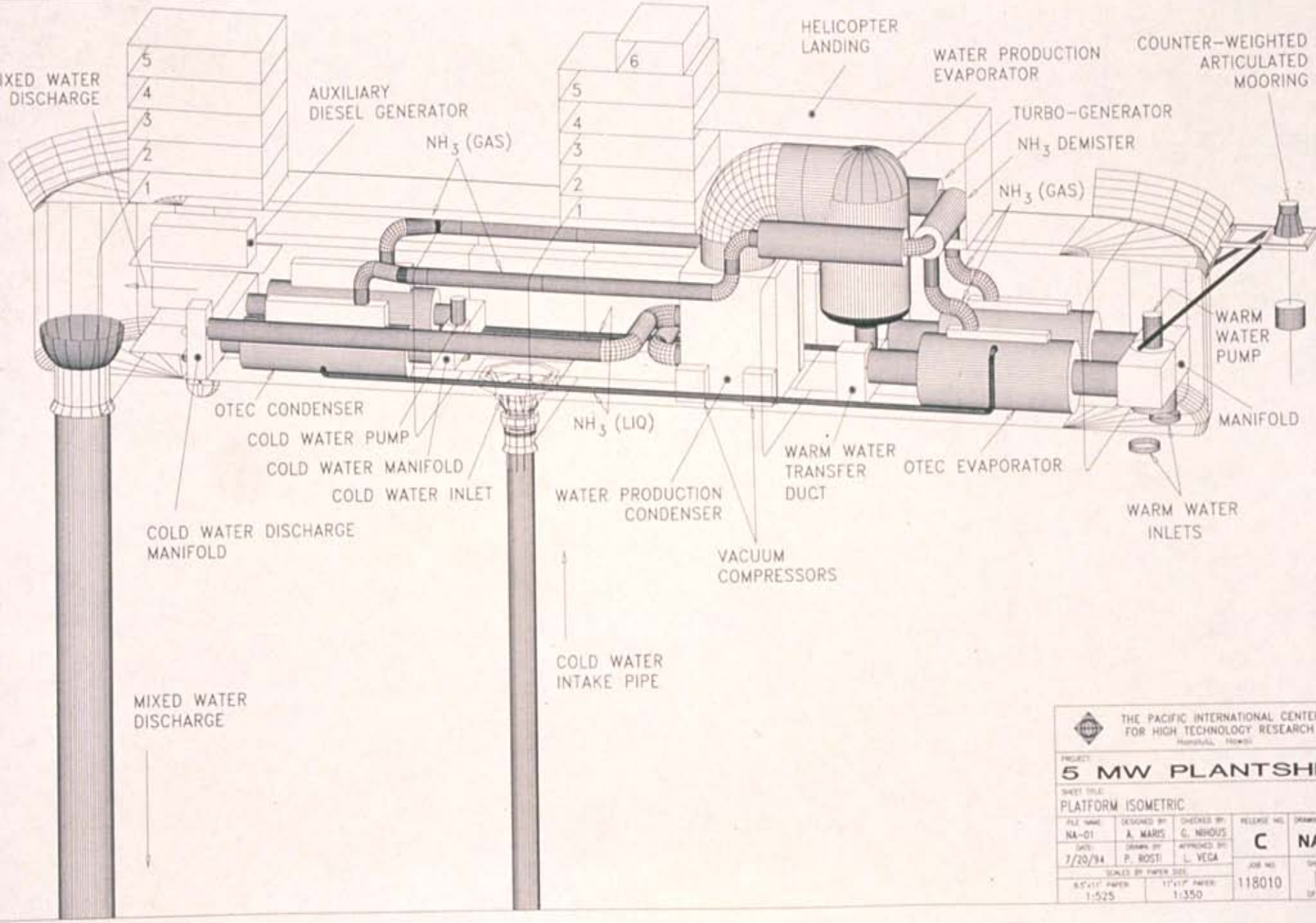
- 1.8 MW Gross Power for either:
  - 1.2 MW-net and 2,200 m^3/day; or,
  - 1.1 MW-net and 5,150 m^3/day

- Bottom-mounted CWP: 1.6 m HDPE Pipe

5 MW Pre-Commercial Plant Design

(1/5 Scale of 25 MW Module)

- 33,000 tonnes ship, 10 km Offshore
- CWP: 2.74 m id x 1000 m FRP Pipe
- Single Point Counterweight-Articulated-Mooring System includes power and desalinated water swivels for transmission to shore


MIXED WATER DISCHARGE
AUXILIARY DIESEL GENERATOR
NH_3 (GAS)
HELICOPTER LANDING
WATER PRODUCTION EVAPORATOR
COUNTER-WEIGHTED ARTICULATED MOORING
TURBO-GENERATOR
NH_3 DEMISTER
NH_3 (GAS)
WARM WATER PUMP
MANIFOLD
OTEC CONDENSER
COLD WATER PUMP
COLD WATER MANIFOLD
COLD WATER INLET
COLD WATER DISCHARGE MANIFOLD
NH_3 (LIQ)
WATER PRODUCTION CONDENSER
WARM WATER TRANSFER DUCT
OTEC EVAPORATOR
WARM WATER INLETS
VACUUM COMPRESSORS
COLD WATER INTAKE PIPE
MIXED WATER DISCHARGE
THE PACIFIC INTERNATIONAL CENTER FOR HIGH TECHNOLOGY RESEARCH
Honolulu, Hawaii
PROJECT
5 MW PLANTSH
SHEET TITLE
PLATFORM ISOMETRIC
FILE NAME NA-01
DESIGNED BY A. MARIS
CHECKED BY G. NIHOUS
RELEASE NO. C
DRAWING NA
DATE 7/20/94
DRAWN BY P. ROSTI
APPROVED BY L. VEGA
JOB NO. 118010
SCALES BY PAPER SIZE
8.5"x11" PAPER 1:525
17"x11" PAPER 1:350

Lessons Learned

- Life-Cycle Design
- Constructability
- System Integration
- Embellishing → Negative Consequences

Lessons Learned

Life-Cycle Design

e.g., locating a component in the water column might yield higher efficiencies but result in elaborate maintenance requirements and higher operational costs

Lessons Learned

Constructability

Can equipment be manufactured using commercially available practices and in existing factories?

Lessons Learned

System Integration

In addition to power block (HXs & T-G), OTEC includes seawater subsystems; dynamic positioning subsystems; and, submarine power cable

Lessons Learned

<u>Embellishment</u>

Has led to credibility barriers and unrealistic expectations…

Please stop it!

Environmental Impact Assessment (Lawrence Berkeley Lab.)

- OTEC <u>can be</u> an environmentally benign alternative for the production of electricity and desalinated water in tropical islands

- Potentially <u>detrimental effects</u> can be <u>mitigated</u> by proper design

Temp. Anomalies & Upwelling

Sustained flow of cold, nutrient-rich, bacteria-free deep ocean water could cause:

- sea surface temp. anomalies;
- biostimulation

<u>If and only if</u> resident times in the mixed layer; and, the euphotic zone are long enough

Euphotic Zone: Tropical Oceans

- The euphotic zone: layer in which there is sufficient light for photosynthesis;
- Conservative Definition: 1 % light-penetration depth (e.g., 120 m in Hawaii);
- Practical Definition: biological activity requires radiation levels of at least 10 % of the sea surface value (e.g., 60 m in Hawaii).

EIA

Can OTEC have an impact on the environment below the oceanic <u>mixed layer</u> (sea surface to ~ 100 m) and, therefore, long-term significance in the marine environment?

OTEC Return Water

- Mixed seawater returned at 60 m depth → dilution coefficient of 4 (i.e., 1 part OTEC effluent is mixed with 3 parts of the ambient seawater) → equilibrium (neutral buoyancy) depths below the mixed layer;

- Marine food web should be minimally affected and sea surface temperature anomalies should not be induced.

EIA: Construction

OTEC Construction phase:

- similar to construction of power plants; shipbuilding; and, offshore platforms;

EIA: Operations

- Unique to OTEC is the movement of seawater streams and the effect of passing such streams through the components before returning them to the ocean;
- Losses of inshore fish eggs and larvae, as well as juvenile fish, due to impingement and entrainment may reduce fish populations.

EIA: Operations

- CC-OTEC handling of <u>hazardous substances</u> is limited to the working fluid (NH_3) and the biocide (Cl_2, evaporator biofouling);
- None for OC-OTEC

EIA: Operations

- Use of Cl_2 and NH_3 similar to other human activities;

- If, for example, USA occupational health and safety regulations are followed, working fluid and biocide emissions from a plant should be too low to detect outside the plant site.

CO_2 Outgassing

- CO_2 out-gassing from the seawater used for the operation of an OC-OTEC plant is < 0.5% the amount released by fuel oil plants;

- The value is even lower in the case of a CC-OTEC plant.

What is known about OTEC Economics ?

- Economically competitive under certain "scenarios"

  (defined by fuel-and-water-costs) :

[Vega, 1992]

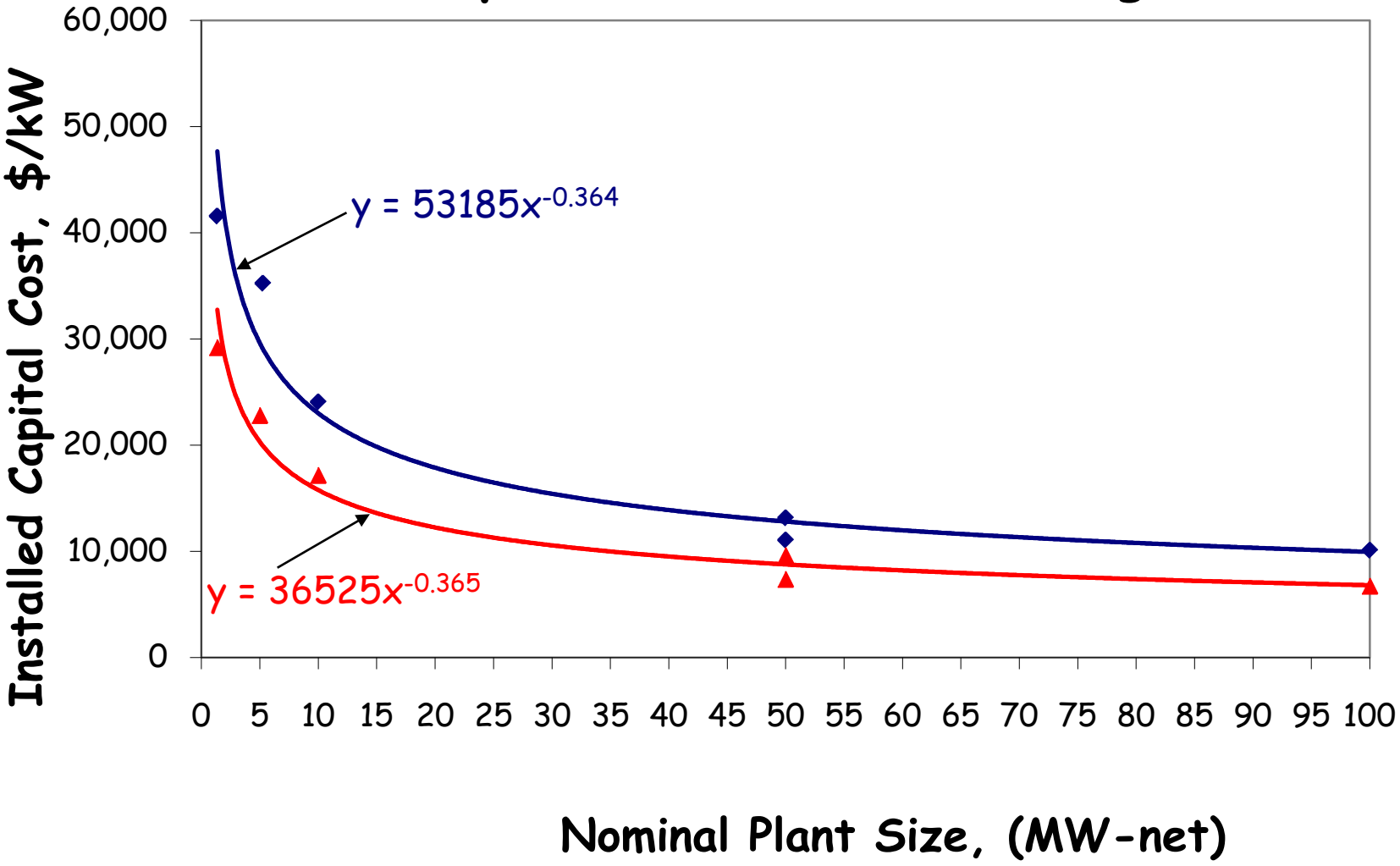
Nominal Size, MW	TYPE (After Eng. Dev.)	Scenario (by ~ 10th Plant)	Potential Sites
1	Land-Based OC-OTEC with 2nd Stage for Additional Water Production.	**Diesel: $45/barrel Water: $1.6/m^3**	Present Situation in Some Small Island States.
10	Same as Above.	**Fuel Oil: $30/barrel Water: $0.9/ m^3**	U.S. Pacific Insular Areas and other Island Nations.
50	Land-Based Hybrid CC-OTEC with 2nd Stage.	**$50/barrel $0.4/ m^3 or $30/barrel $0.8/ m^3**	Hawaii, **Puerto Rico** If fuel or water cost doubles.
50	Land-Based CC-OTEC	**$40/barrel**	Same as Above.
100	CC-OTEC Plantship	**$20/barrel**	Numerous sites

Fuel and Water Costs Required for Competitiveness (1990)

Economics Summary: Hawai'i (2007)

Because **OTEC is capital intensive** electricity **cost-competitiveness** if Size > **50 MW** & > **15-year Life-Cycle.**

1st Plant and 10th Plant
Capital Cost Estimates (Vega 2007)



Please Beware!!

Economy of Scale 10 vs. 100 MW →

- Power Block Cost of 100 MW plant is

  ~ 10 x 10 MW

- Seawater Subsystems & At-Sea Deployment of 100 MW is

  < 10 x 10 MW

- Staffing requirements constant

  100 MW = 10 MW

Cost of Electricity Production

COE ($/kWh) = CC + OMR&R

+ **Fuel** *(for OTEC zero)*

{- Environmental Credit}

CC = Capital Cost Amortization

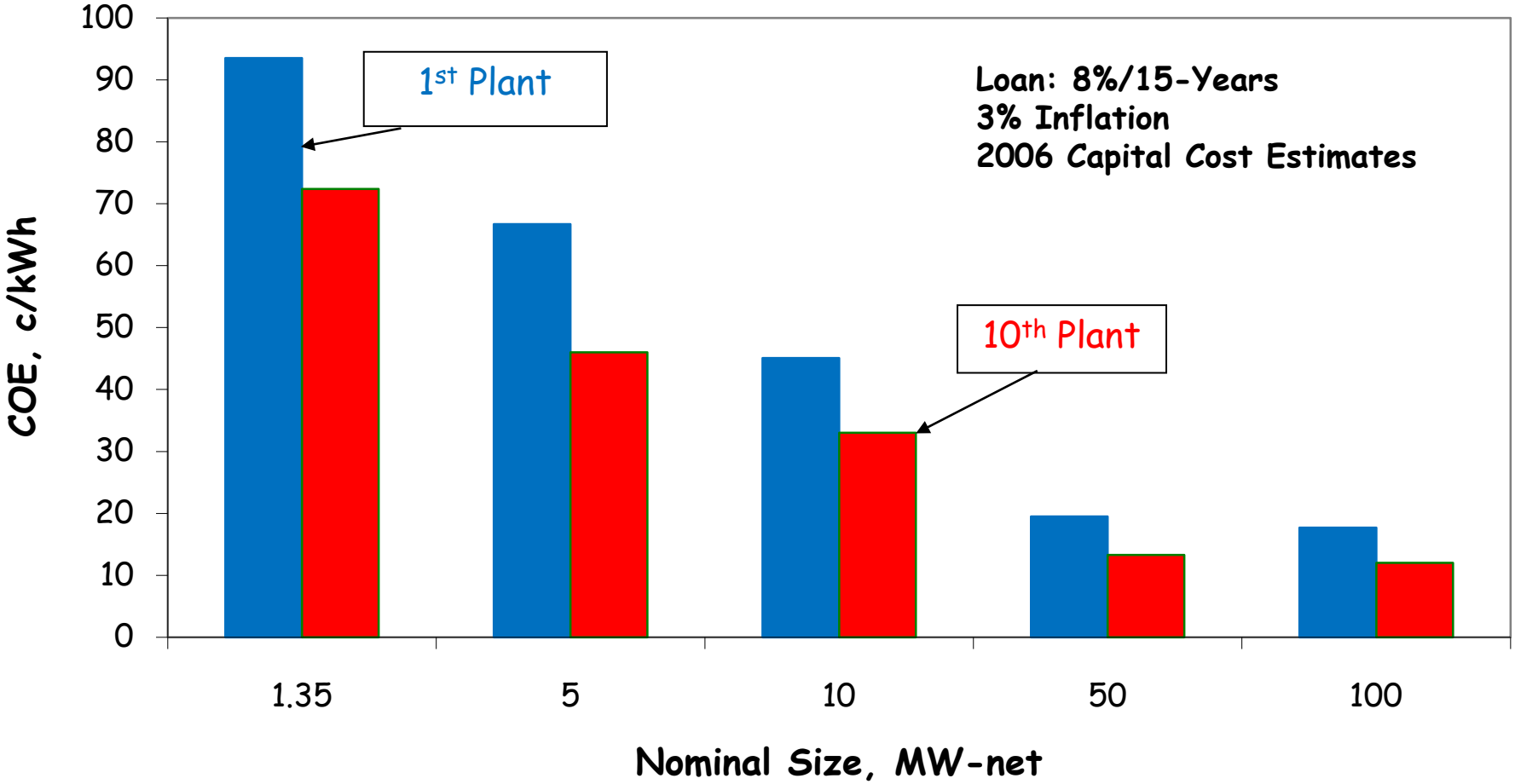
(N.B. much higher for OTEC)

OMR&R = Operations + Maintenance

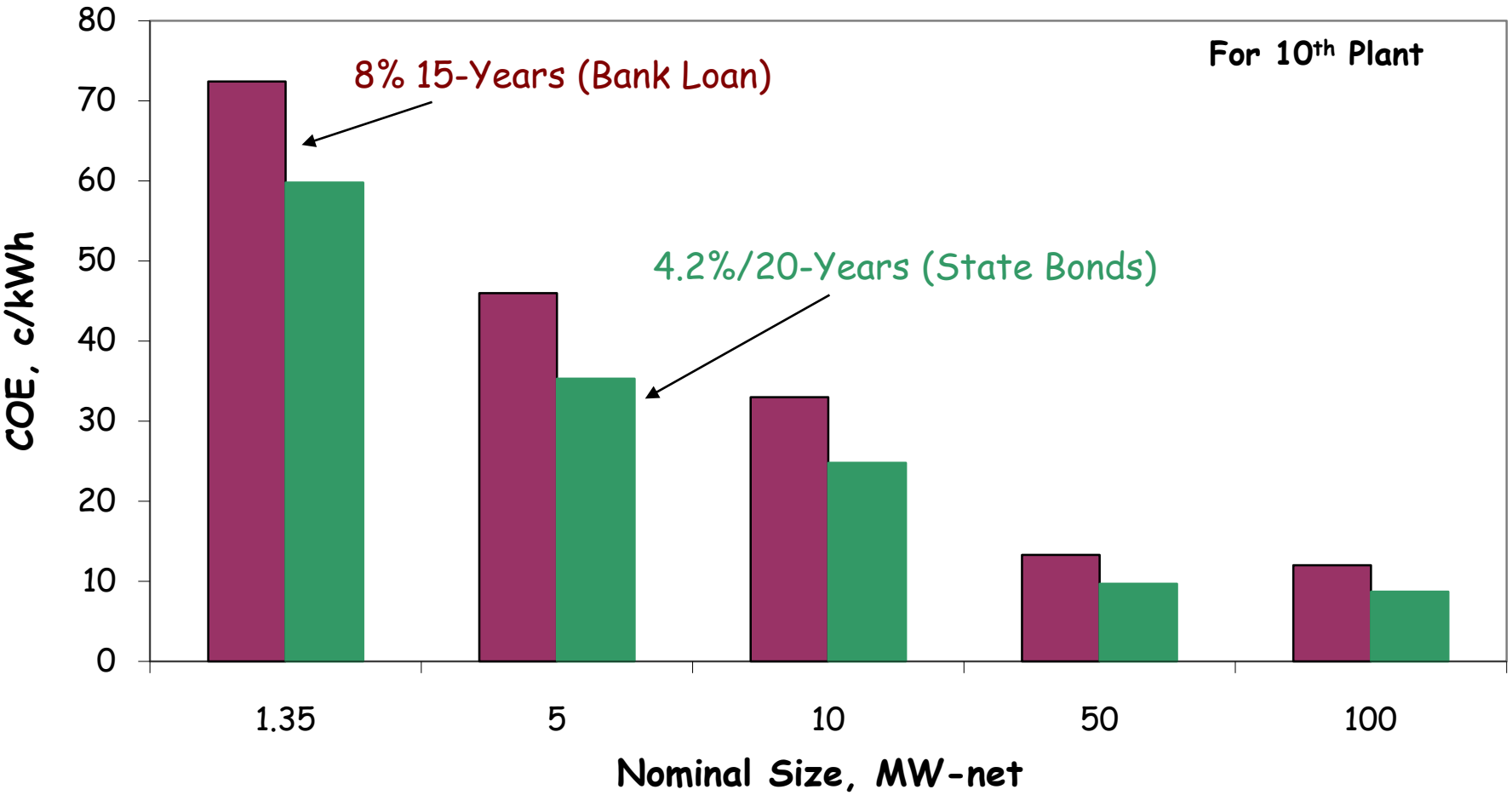
+ Repair + Replacement

Tariff = COE + Profit - Subsidy

Cost of Electricity Production for 1st Plant and 10th Plant
[COE = CC + OMR&R]



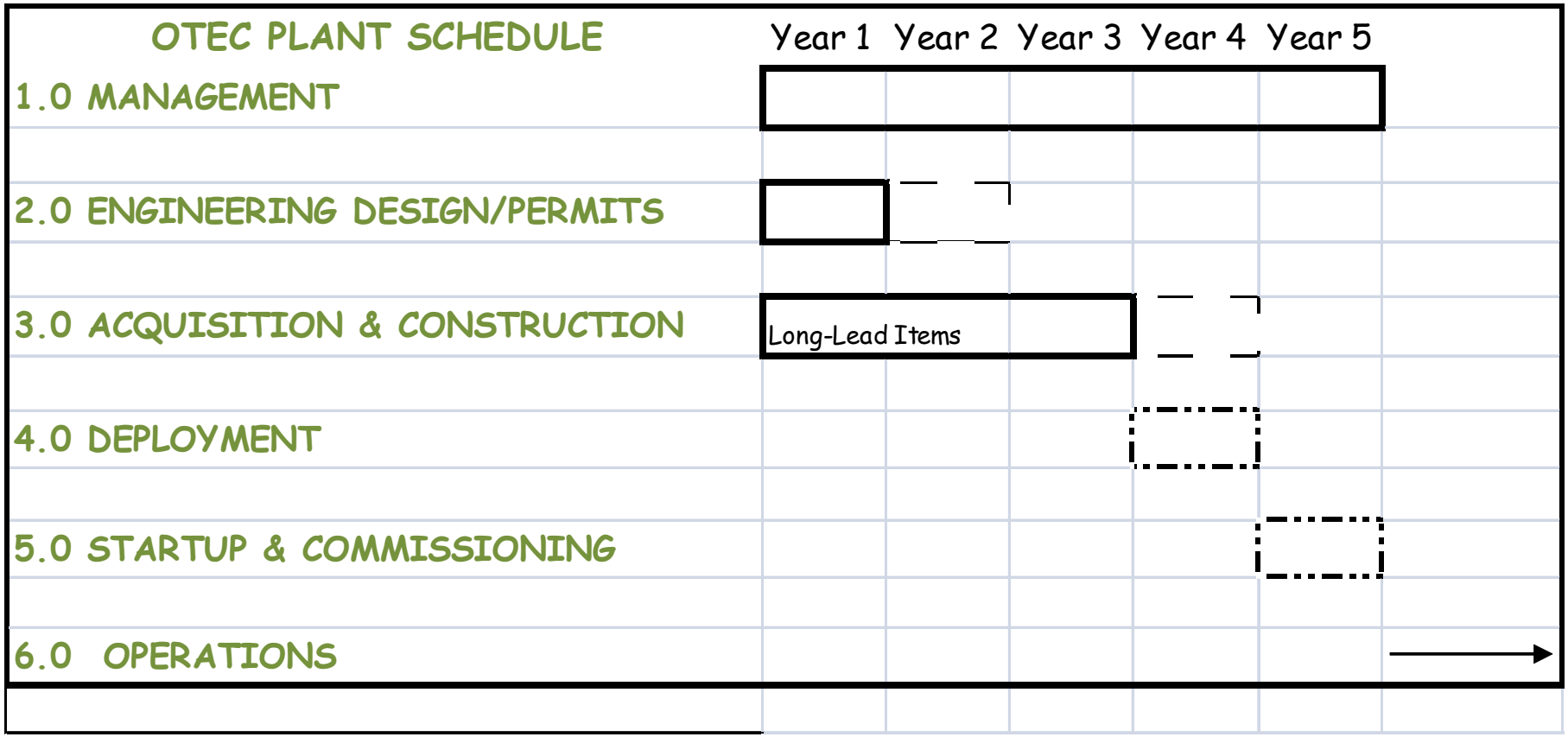
OTEC Cost of Electricity Production as a Function of Loan Term



Schedule

- Detailed-Engineering-Design ~ one-year; Permits ~ two-years;
- **Major components** are **long-lead-items**, requiring 12 to 24^{+} months for delivery, and are **available from established industry**;
- As much as **5-years** after-receipt-of-order (**ARO**) is required before delivering **electricity to grid**.

OTEC Plant Schedule



OTEC Resource Data

Gérard C. Nihous
Dept. of Ocean and Resources Engineering
University of Hawaii

- A change of 1 C in ΔT roughly leads to a change of 15% in $P_{net.}$

- Around Hawaii, ΔT can be mapped from daily HYCOM+NCODA data (1/12 resolution) since late June 2007.

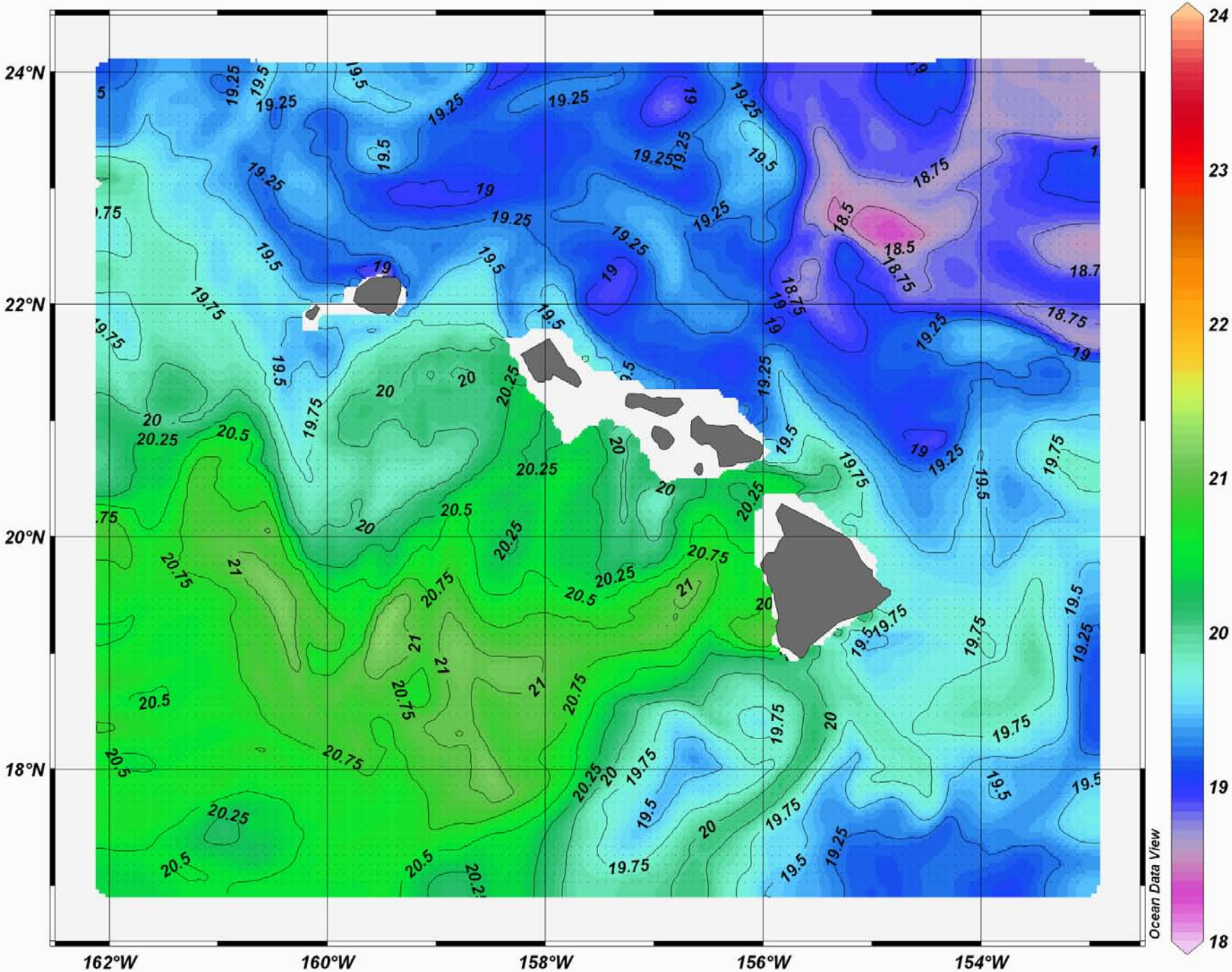
- Examples for ΔT defined between 20 m and 1000 m water depths:

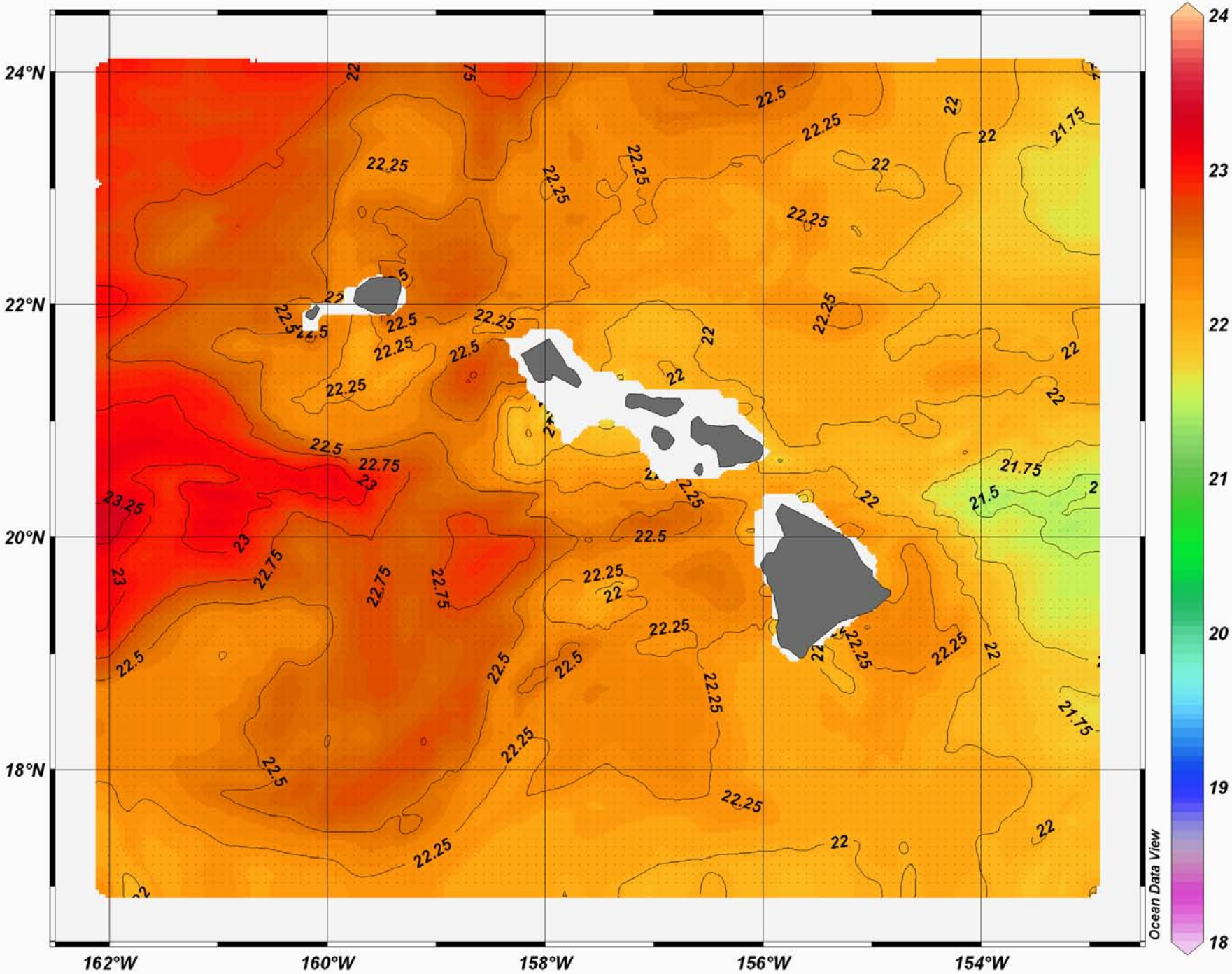
  - Feb. 1st ‘08 (‘cool season’ snapshot)

  - Oct. 1st ‘08 (‘warm season’ snapshot)

  - Aug. ‘08 & Feb ‘09

    (spatial and temporal variability)


24°N
22°N
20°N
18°N
162°W
160°W
158°W
156°W
154°W
24
23
22
21
20
19
18
Ocean Data View


24°N
22°N
20°N
18°N
162°W
160°W
158°W
156°W
154°W
24
23
22
21
20
19
18
Ocean Data View

H_2 or NH_3 OTEC Plantships

Nihous & Vega

Plantships

- Floating platforms housing hydrogen or ammonia plants operated with 100 MW of OTEC-generated electricity have been conceptualized;
- These plantships, deployed throughout the tropical oceans, could provide a significant source of energy in the form of liquid hydrogen or ammonia;

DP Plantship

- A 285,000-tonne ship-shaped vessel is first proposed. It provides deck space for the OTEC plant, H_2 or NH_3 plant, storage, and crew quarters;
- A length of 250 m and a beam of 60 m are sufficient to accommodate five seawater sumps; operational draught is 20 m; 4 x 3000 hp thrusters permit grazing at 0.5 knots and maneuvering capability;

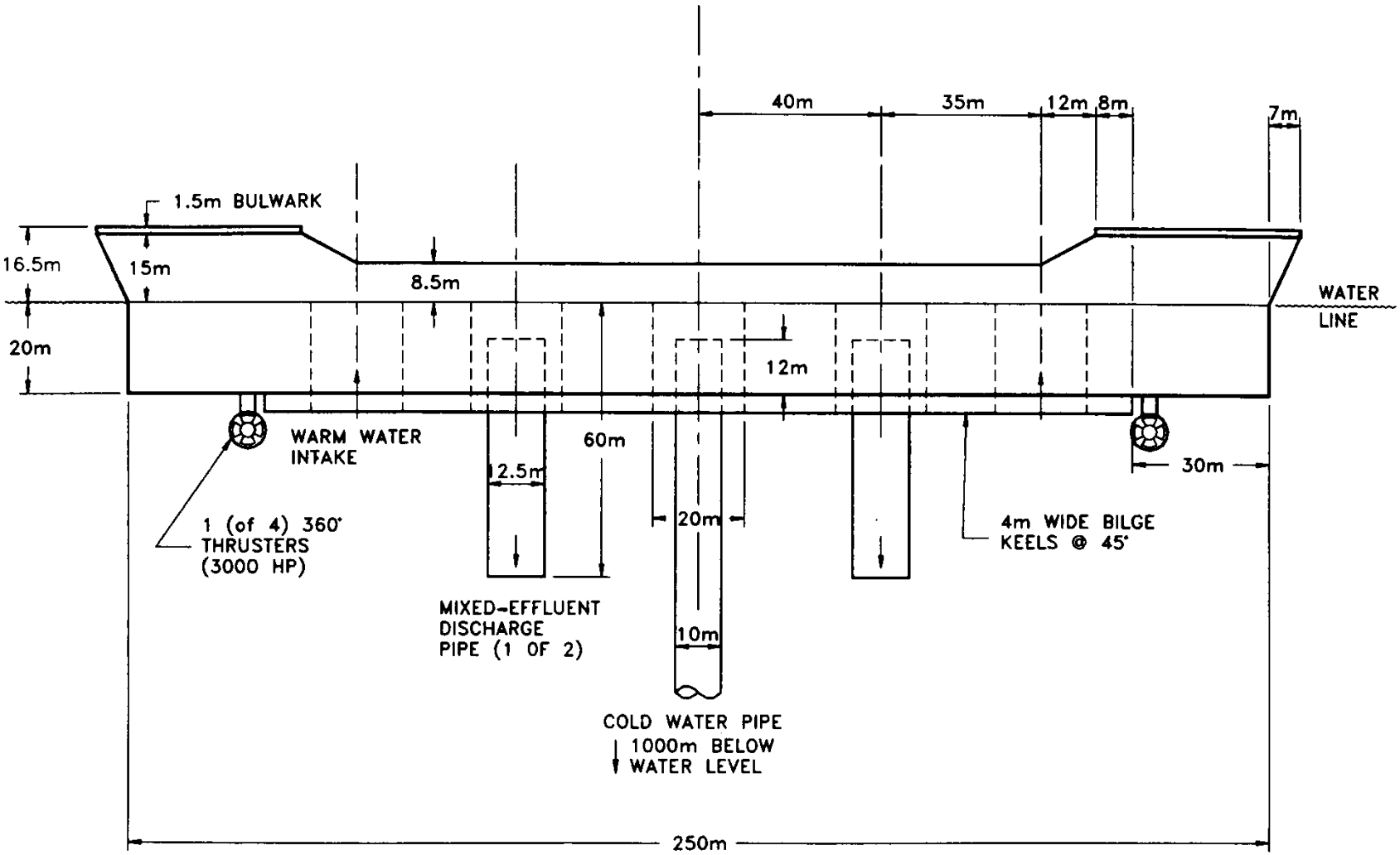


Fig. 1. Baseline conceptual design for the 100 MW OTEC-hydrogen plantships (side view).

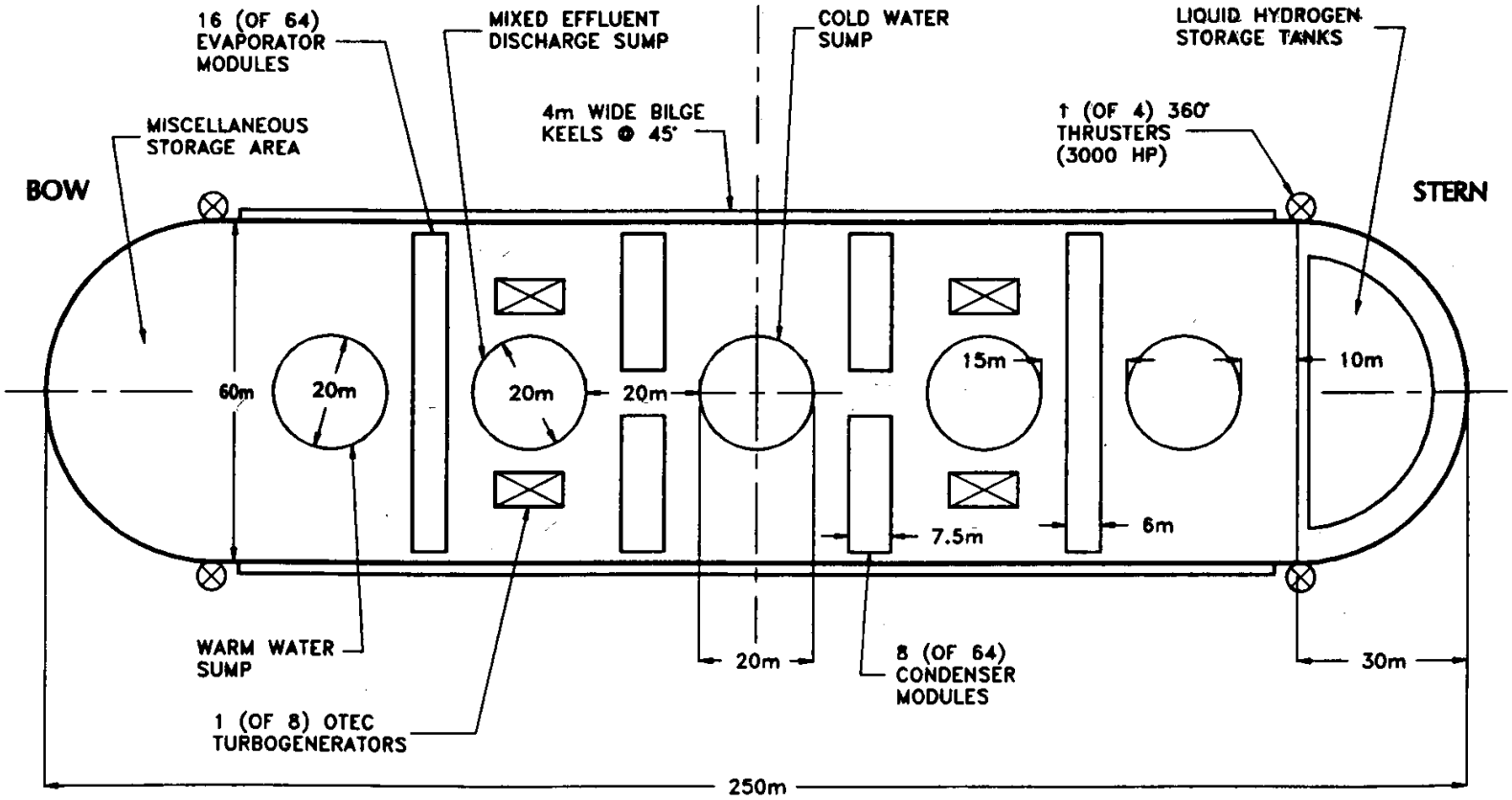


Fig. 4. Baseline conceptual design for the 100 MW OTEC–hydrogen plantships (lower deck).

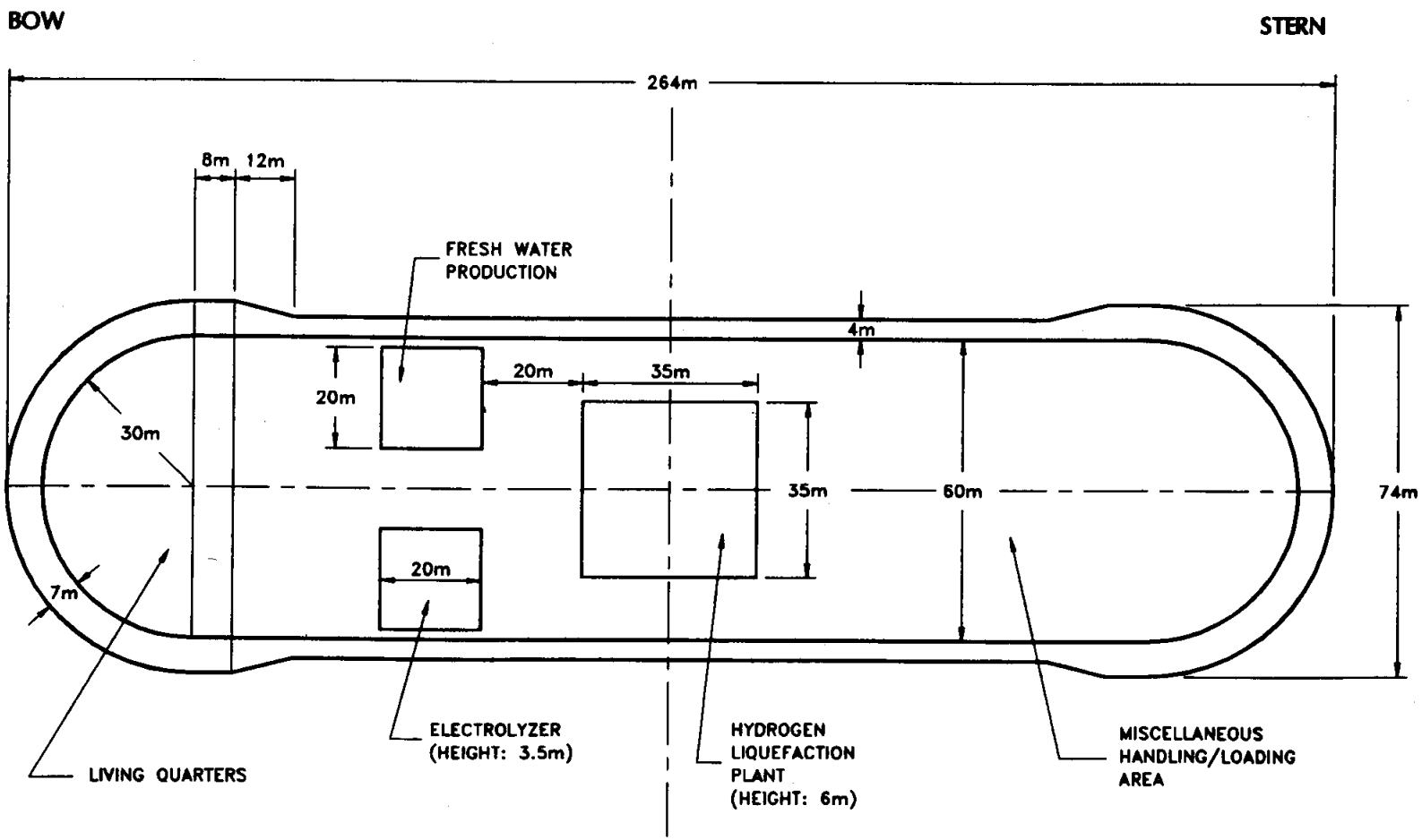


Fig. 5. Baseline conceptual design for the 100 MW OTEC–hydrogen plantships (main deck, living quarters, storage tanks).

Momentum Flux Plantship

- A more compact plantship, jet-propelled by the momentum flux of the OTEC discharge seawater is conceptualized;

- The length is reduced to 200 m for a displacement of 225,000 tonnes. Only one sump is required and warm seawater is fed through lateral openings.

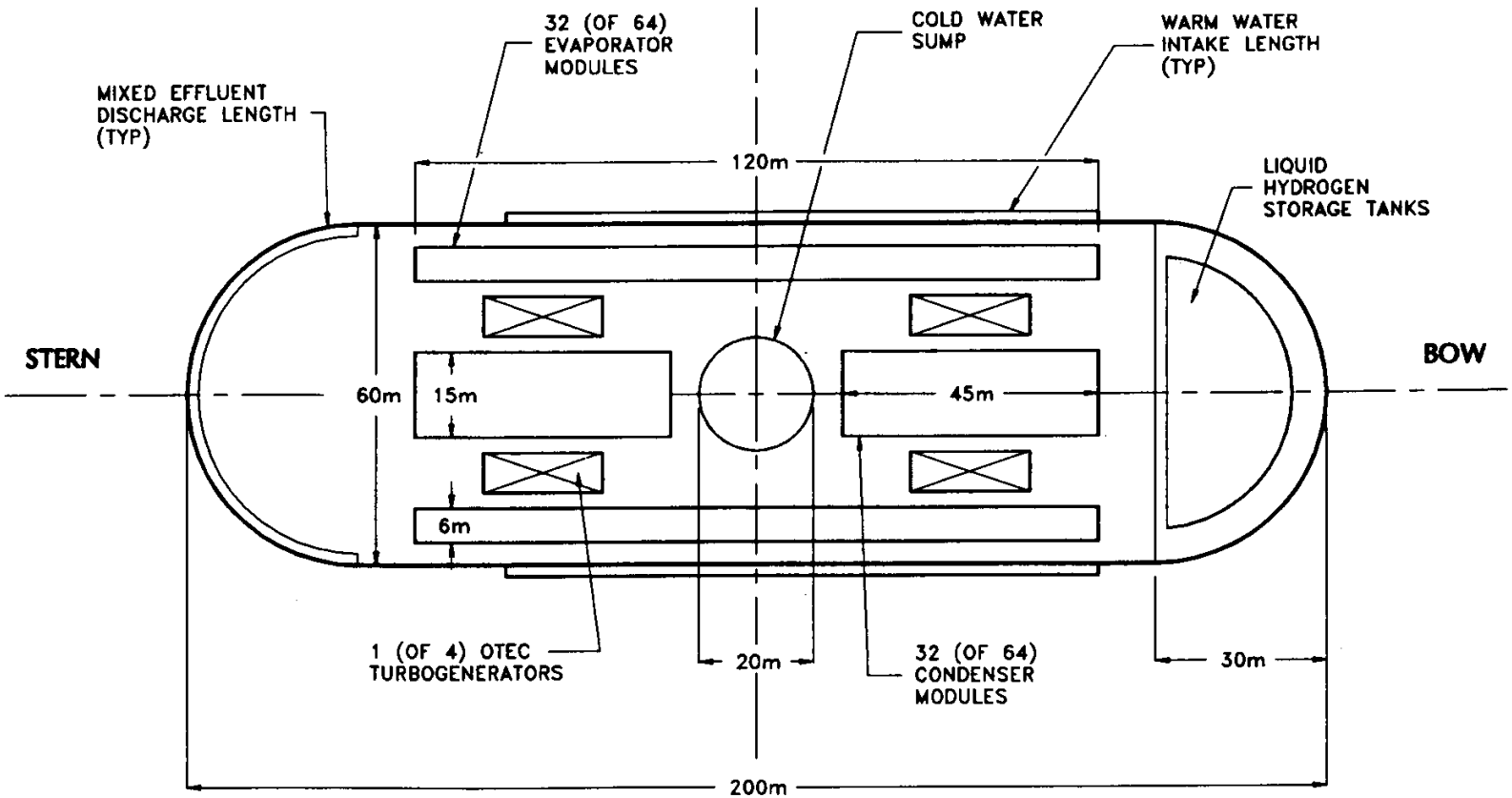


Fig. 6. Alternate design (compact) for the 100 MW OTEC–hydrogen plantships (lower deck).

OTEC: The Challenge

- **Major Challenge** is not technical but rather **financing of a capital intensive technology without an operational record;**
- If plant > **50 MW, cost of electricity ($/kWh)** would be **cost competitive;**

  → *How do you get more than ¾ Billion Dollars for a 100 MW plant without a "track record" and without invoking national security, global warming, environmental credits, etc.?*

- **Without operational records** from a pre-commercial plant (~ 5 MW) **financing** of commercial sized plants (> 50 MW) is **highly doubtful;**

Development Schedule

(Assumption/Hope/Please)

USA OTEC DEVELOPMENT	← YEARS →					
	1 to 5	6 to 10	11 to 15	16 to 20	21 to 25	26 to ∞
Pre-Commercial Plant (> 5 MW)		Ops				
Electricity (Desal Water) Plants in Hawaii and USA Territories: ~ 20 x 100 MW Plants	Prelim Design		Ops	Ops	→	→
NH3/H2 Plantships Supplying all States				Prelim Design		Ops →

Global Oil Resources

- Consensus:

  < 50 years until oil gone

  Diminishing resources → Price Increases

- Presently, H_2 produced with OTEC electricity is equivalent to ~ 6 x price of oil

→ Would it be wise to begin to consider H_2 production onboard OTEC plantships deployed along Equator?