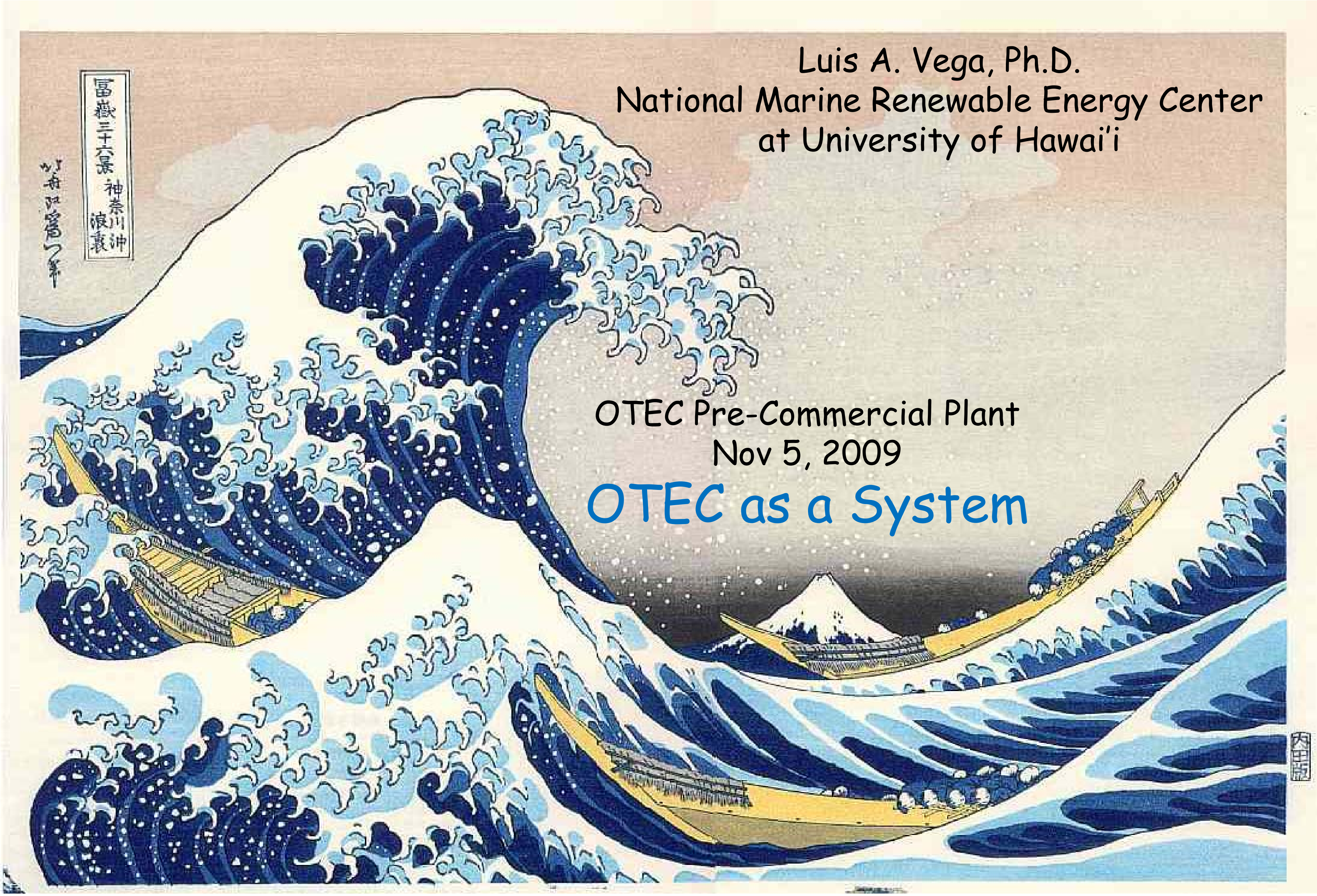


Luis A. Vega, Ph.D.
National Marine Renewable Energy Center
at University of Hawai'i

OTEC Pre-Commercial Plant
Nov 5, 2009

OTEC as a System

Workshop Objectives

- Are commercialization challenges:

    (i) ~~*Technical,*~~

    ~~*(ii) Engineering,*~~

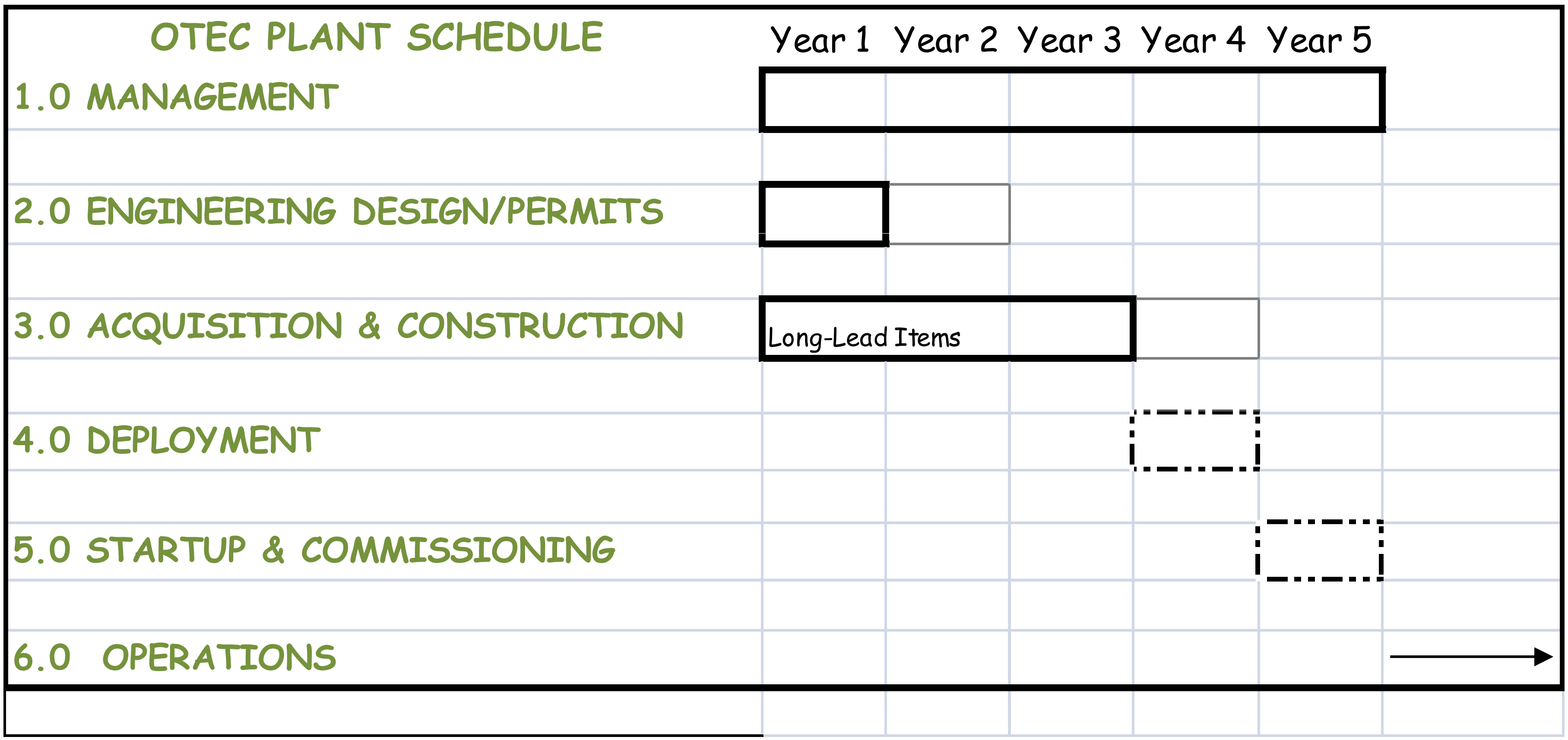
    (iii) **Development costs**

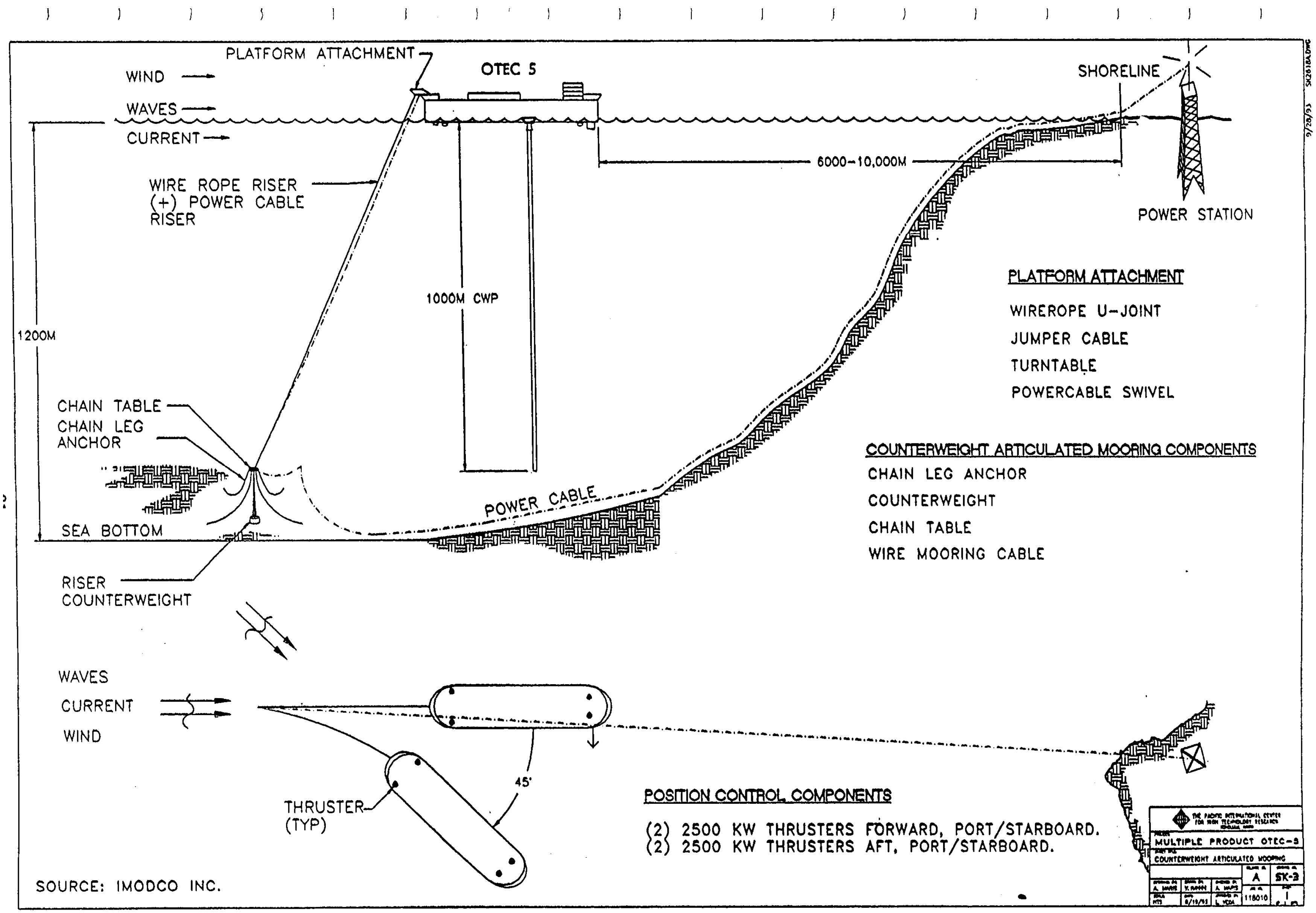
- OTEC Development Roadmap →

What is the development time frame (e.g., today, 1-2 yr, 5-10 yr) for a commercial OTEC system?

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	→	→
NH_3/H_2 Plantships Supplying all States				Prelim Design		Ops →

OTEC Pre-Commercial Plant Schedule




PLATFORM ATTACHMENT
OTEC 5
WIND
WAVES
CURRENT
SHORELINE
6000–10,000M
POWER STATION
WIRE ROPE RISER (+) POWER CABLE RISER
1000M CWP
1200M
PLATFORM ATTACHMENT
WIREROPE U–JOINT
JUMPER CABLE
TURNTABLE
POWERCABLE SWIVEL
CHAIN TABLE
CHAIN LEG ANCHOR
POWER CABLE
SEA BOTTOM
COUNTERWEIGHT ARTICULATED MOORING COMPONENTS
CHAIN LEG ANCHOR
COUNTERWEIGHT
CHAIN TABLE
WIRE MOORING CABLE
RISER COUNTERWEIGHT
WAVES
CURRENT
WIND
45'
THRUSTER (TYP)
POSITION CONTROL COMPONENTS
(2) 2500 KW THRUSTERS FORWARD, PORT/STARBOARD.
(2) 2500 KW THRUSTERS AFT, PORT/STARBOARD.
SOURCE: IMODCO INC.
MULTIPLE PRODUCT OTEC–3
COUNTERWEIGHT ARTICULATED MOORING
A
SK-3
118010

Baseline Pre-Commercial Plant

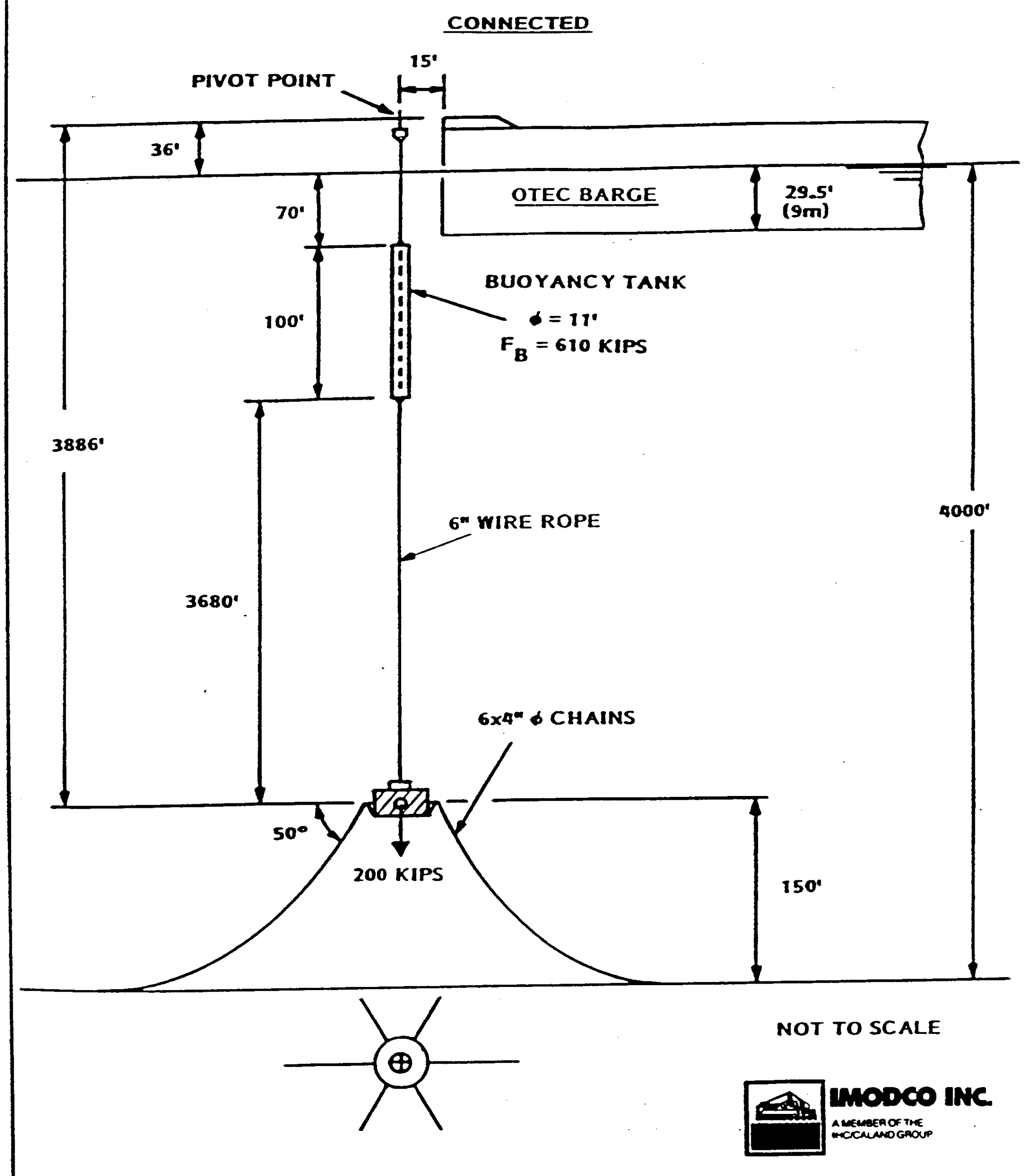
<u>Platform</u>: Ship-Shaped (SOA Tanker construction);

<u>Mooring</u>: Single Point Mooring with Power Swivel (SBM/IMODCO) and Dynamic Thrusters

<u>Challenges</u>:

- None

CAM MOORING SYSTEM



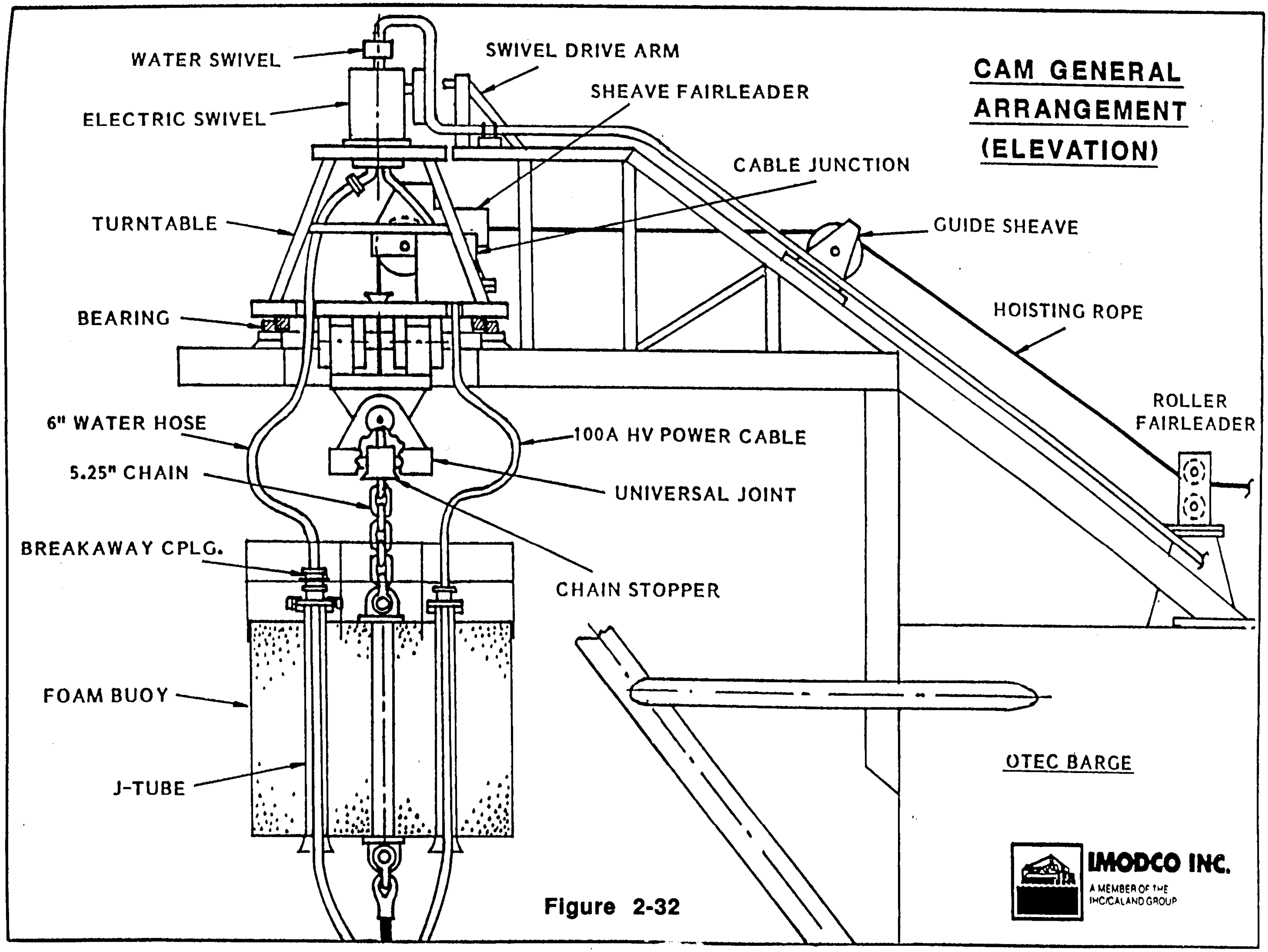
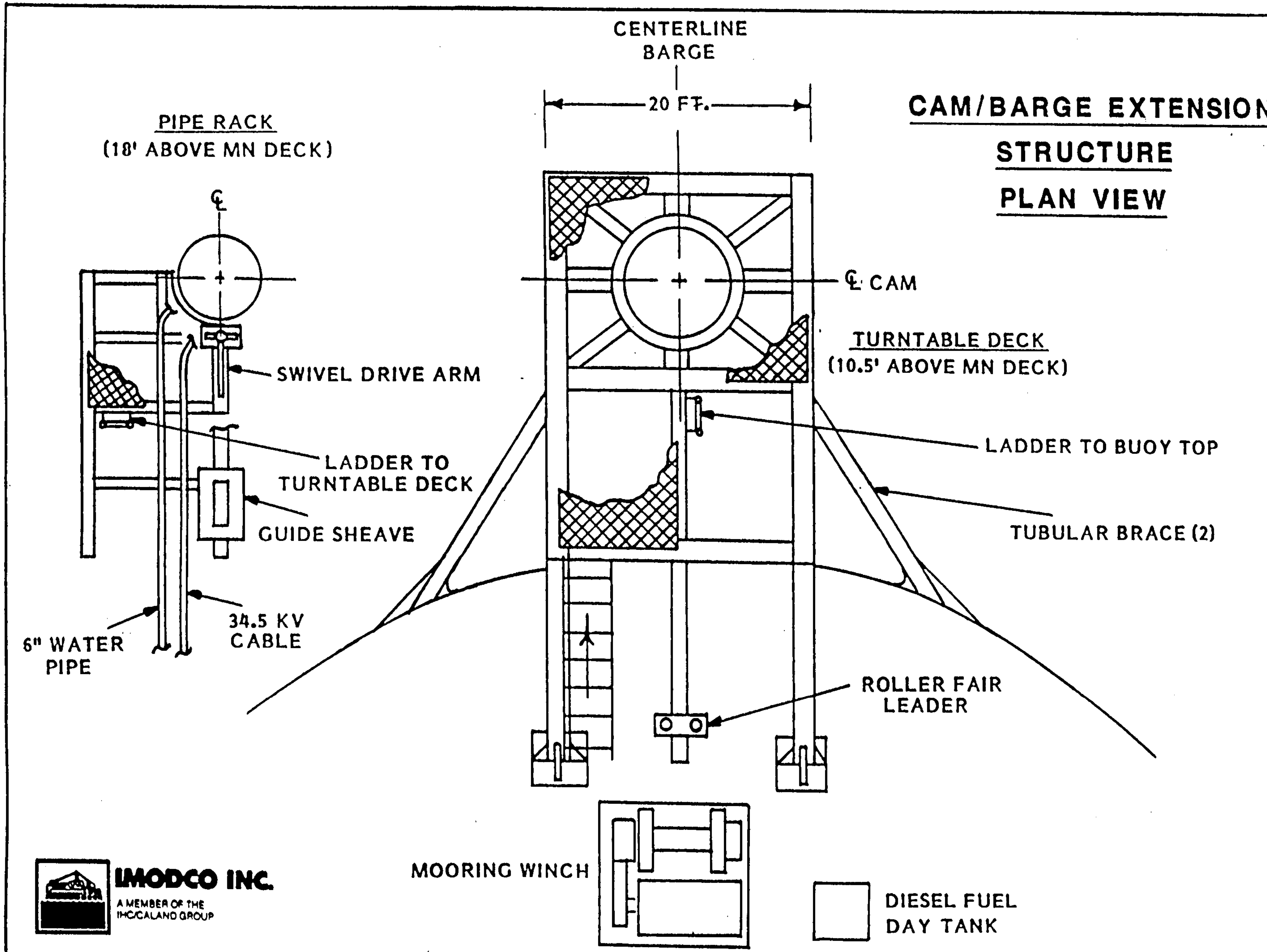

CAM GENERAL ARRANGEMENT (ELEVATION)
WATER SWIVEL
SWIVEL DRIVE ARM
SHEAVE FAIRLEADER
ELECTRIC SWIVEL
CABLE JUNCTION
TURNTABLE
GUIDE SHEAVE
BEARING
HOISTING ROPE
ROLLER FAIRLEADER
6" WATER HOSE
100A HV POWER CABLE
5.25" CHAIN
UNIVERSAL JOINT
BREAKAWAY CPLG.
CHAIN STOPPER
FOAM BUOY
J-TUBE
OTEC BARGE
IMODCO INC.
A MEMBER OF THE IHC/CALAND GROUP

Figure 2-32

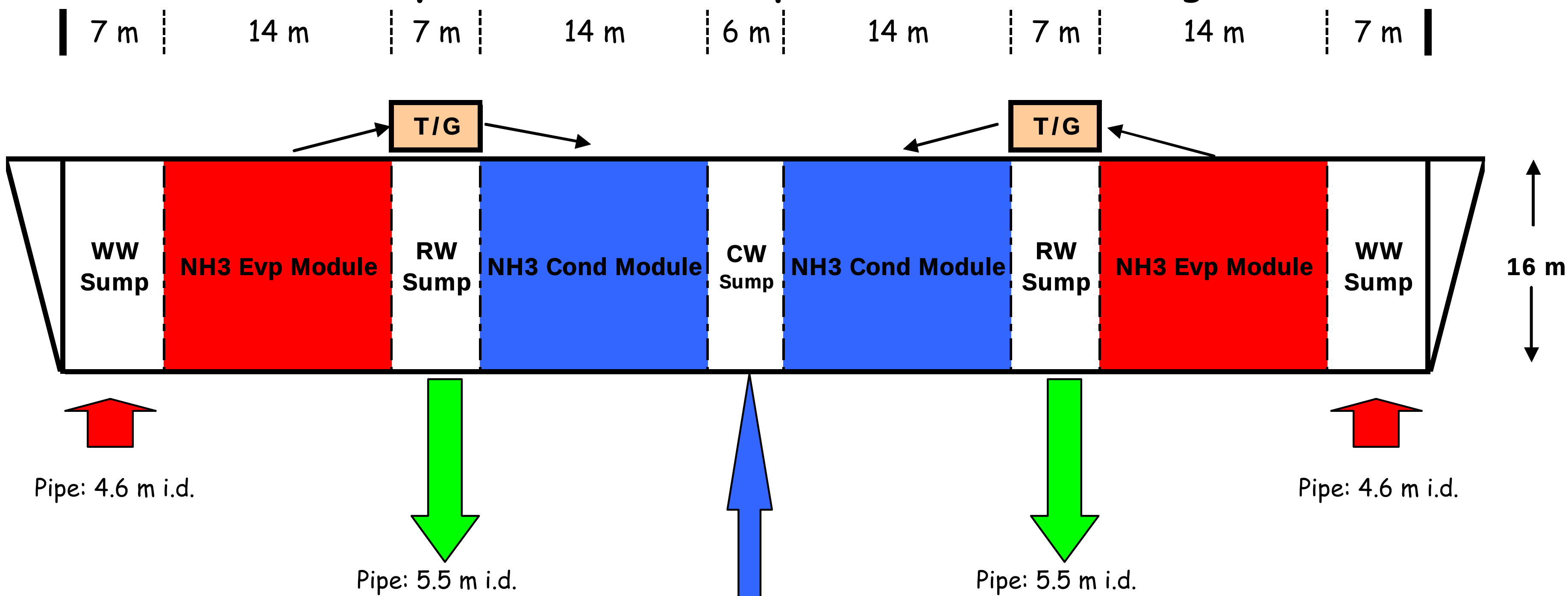
CAM/BARGE EXTENSION STRUCTURE PLAN VIEW



IMODCO INC.
A MEMBER OF THE IHC/CALAND GROUP

Mode	LBP (m)	Beam (m)	Ops Draught (m)	Height/Depth, (m)	Displacement (tonnes)
CC- 10 MW Pre-Commercial Plant	**90**	**32**	**9**	**16**	**26,000**
100 MW H_2 Plantship	250	60	20	28	285,000
"Typical" Double Tanker	180	32.2	11.2	19.2	≈ 63,000
"Typical" Double Container	205 LOA: 217	32.2	10.5	20.3	≈ 68,000
Panamax Limits	≤ 294.1 (LOA)	≤ 32.3	≤ 12		

Side View Closed-Cycle-OTEC Plantship: Two of four 4 MWgross Modules



<u>Global Volume (L x W x H)</u>

NH3 HX-module: 14 m x 10 m x 14 m

NH3 TG-module: 17 m x 4 m x 4 m

Warm Water-Sumps: 2 x 7 m diameter

Cold Water-Sump: 1 x 6 m diameter

Return Water-Sumps: 2 x 7 m diameter

LBP: 90 m

Draught: 9 m

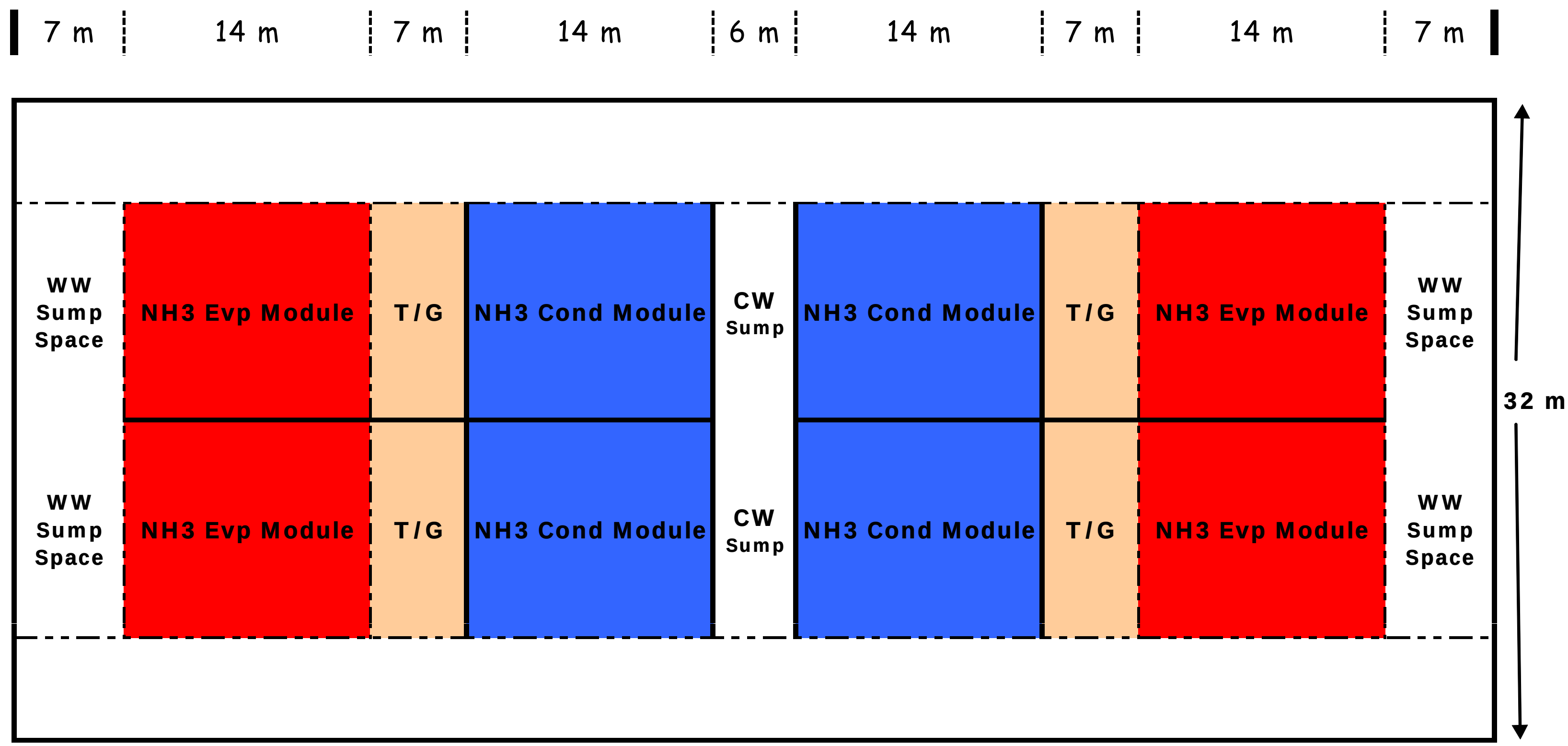
Heigth: 16 m

Beam: 32 m

Displacement: 26,000 tonnes

Not to Scale

Top View Closed-Cycle-OTEC Plantship: Four of four 4 MWgross Modules



Global Volume (L x W x H)

NH3 HX-module: 14 m x 10 m x 14 m

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LBP: 90 m

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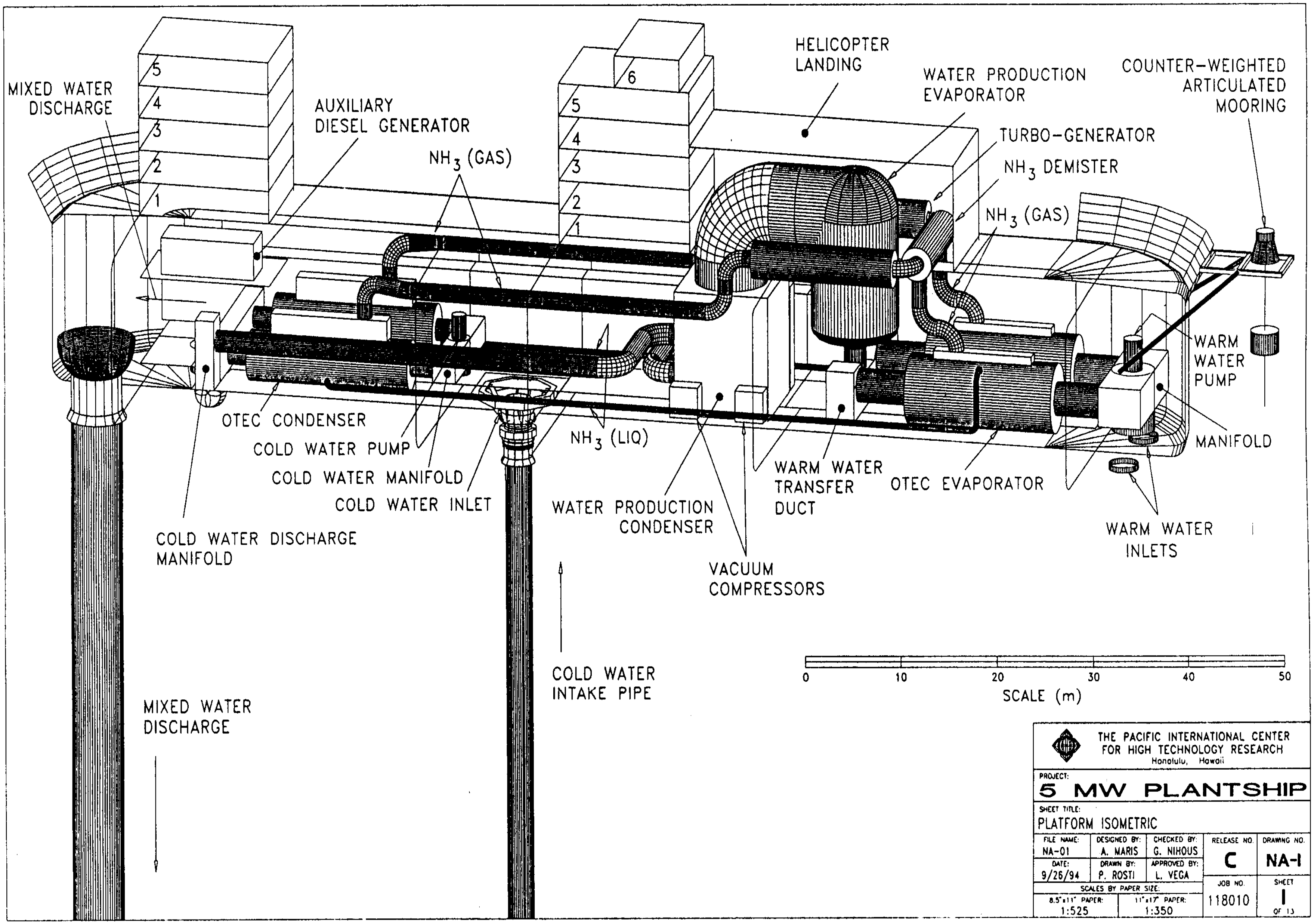
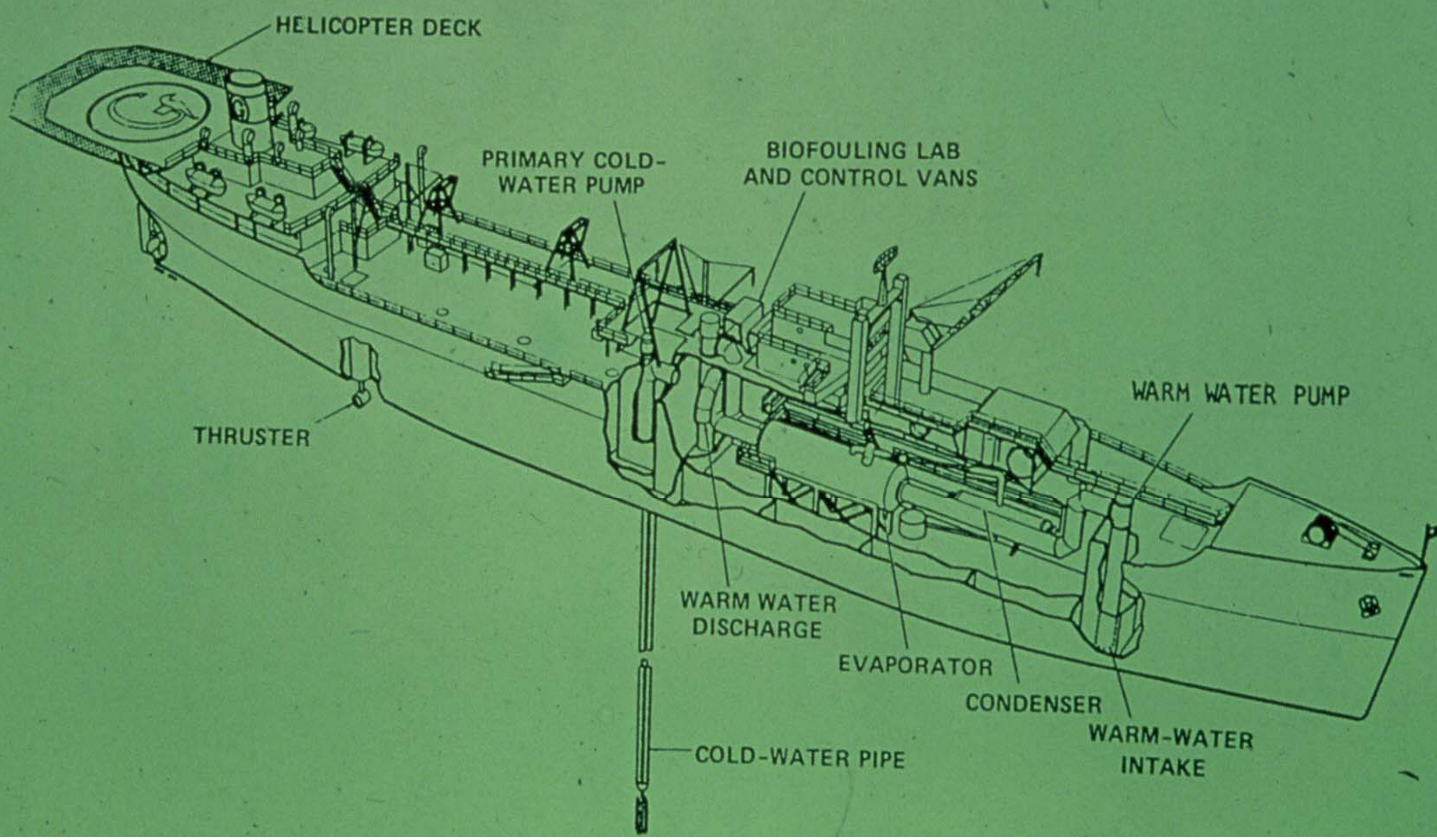
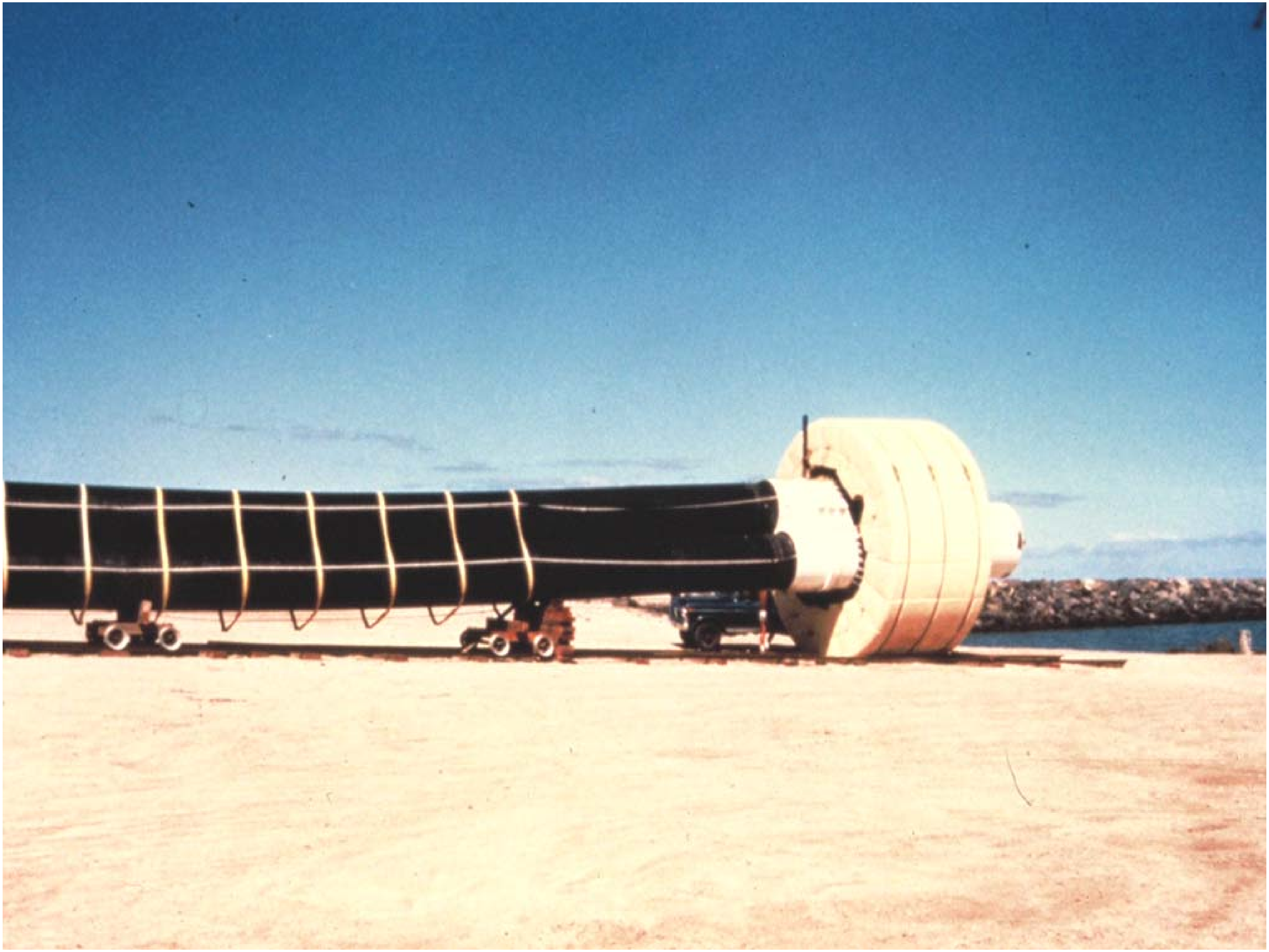

MIXED WATER DISCHARGE
AUXILIARY DIESEL GENERATOR
NH_3 (GAS)
HELICOPTER LANDING
WATER PRODUCTION EVAPORATOR
COUNTER-WEIGHTED ARTICULATED MOORING
TURBO-GENERATOR
NH_3 DEMISTER
NH_3 (GAS)
5 4 3 2 1
6 5 4 3 2 1
WARM WATER PUMP
MANIFOLD
OTEC CONDENSER
COLD WATER PUMP
COLD WATER MANIFOLD
COLD WATER INLET
NH_3 (LIQ)
WATER PRODUCTION CONDENSER
WARM WATER TRANSFER DUCT
OTEC EVAPORATOR
WARM WATER INLETS
COLD WATER DISCHARGE MANIFOLD
VACUUM COMPRESSORS
COLD WATER INTAKE PIPE
MIXED WATER DISCHARGE
0 10 20 30 40 50
SCALE (m)
THE PACIFIC INTERNATIONAL CENTER FOR HIGH TECHNOLOGY RESEARCH
Honolulu, Hawaii
PROJECT:
5 MW PLANTSHIP
SHEET TITLE:
PLATFORM ISOMETRIC
FILE NAME: NA-01
DESIGNED BY: A. MARIS
CHECKED BY: G. NIHOUS
RELEASE NO. C
DRAWING NO. NA-1
DATE: 9/26/94
DRAWN BY: P. ROSTI
APPROVED BY: L. VEGA
JOB NO. 118010
SHEET 1 OF 13
SCALES BY PAPER SIZE:
8.5"x11" PAPER: 1:525
11"x17" PAPER: 1:350

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





CWP - Platform Attachment (OTEC-1)

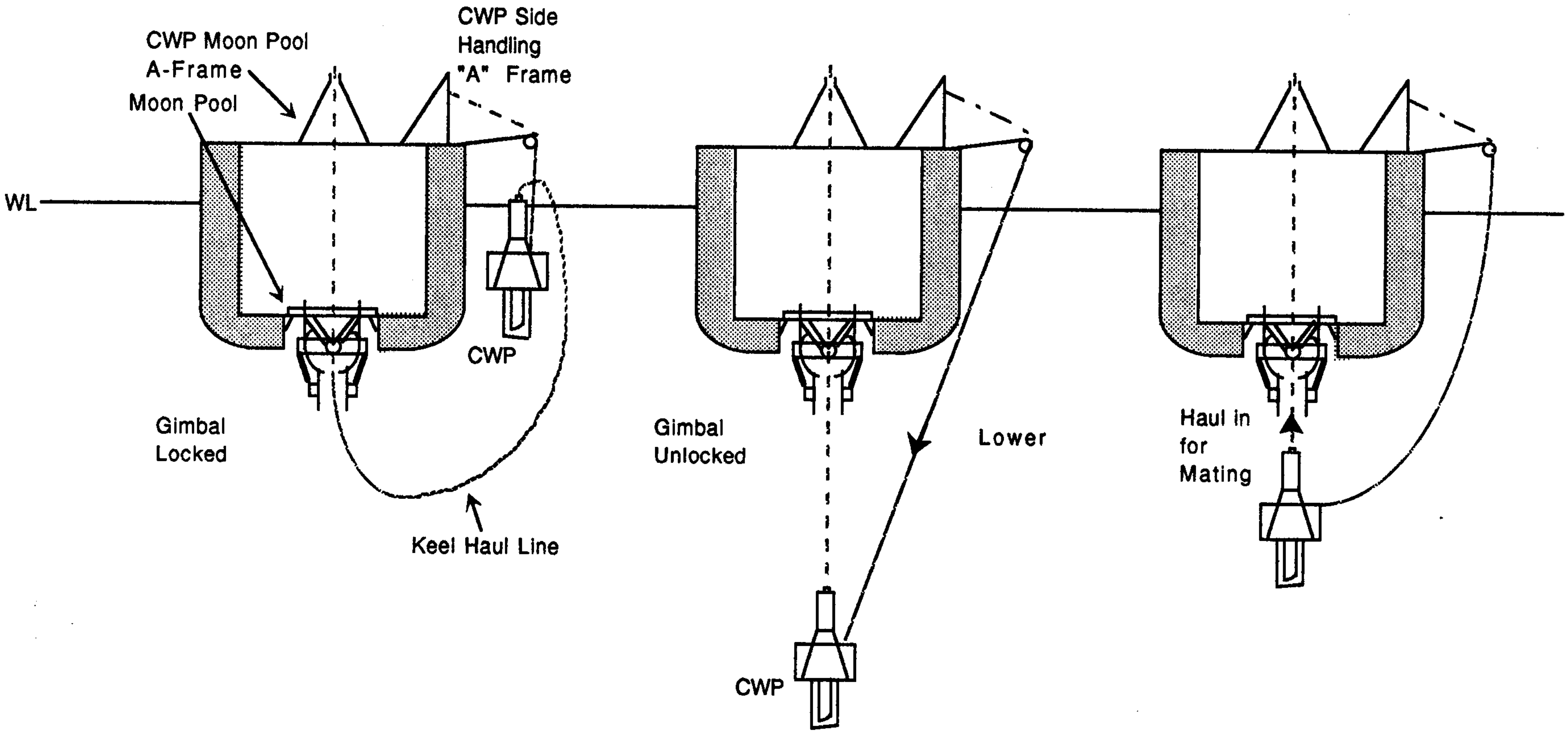


Figure (a) Figure (b) Figure (c)

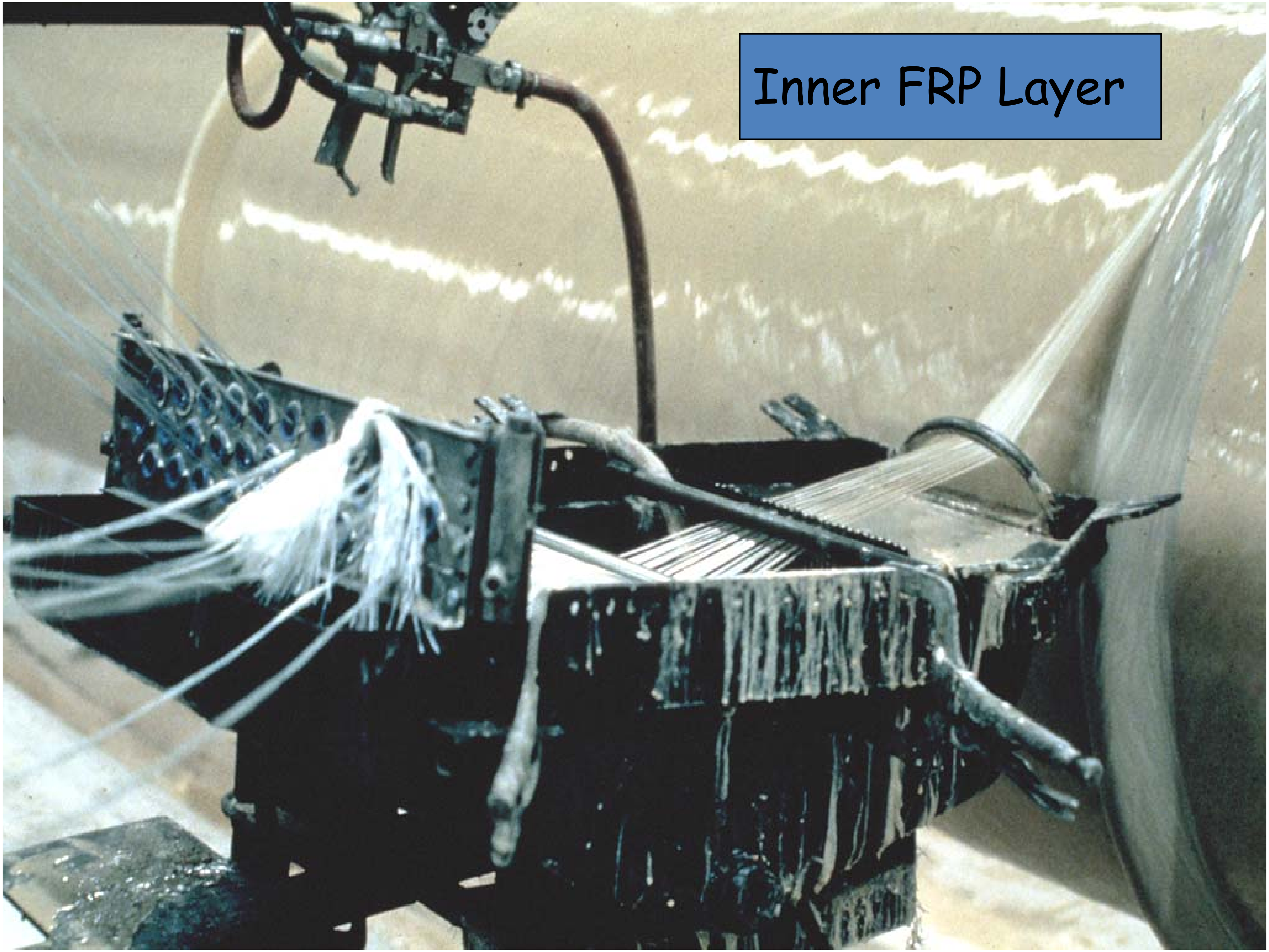
Baseline Pre-Commercial Plant

CWP: FRP-Sandwich per NOAA/DOE 1980s Design and At-Sea Testing, with horizontal towing and upending in-situ; Gimbal connected

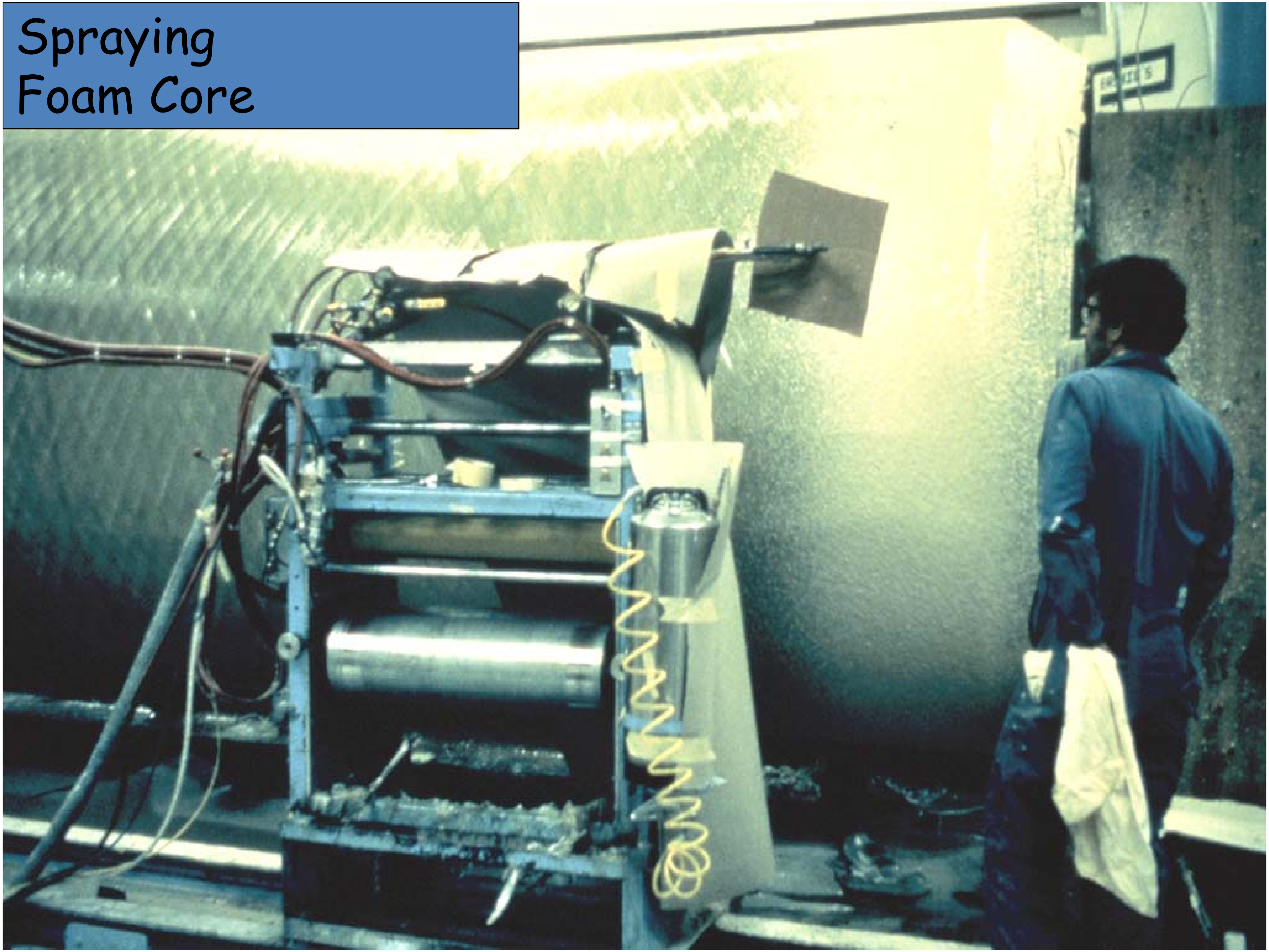
Challenges:

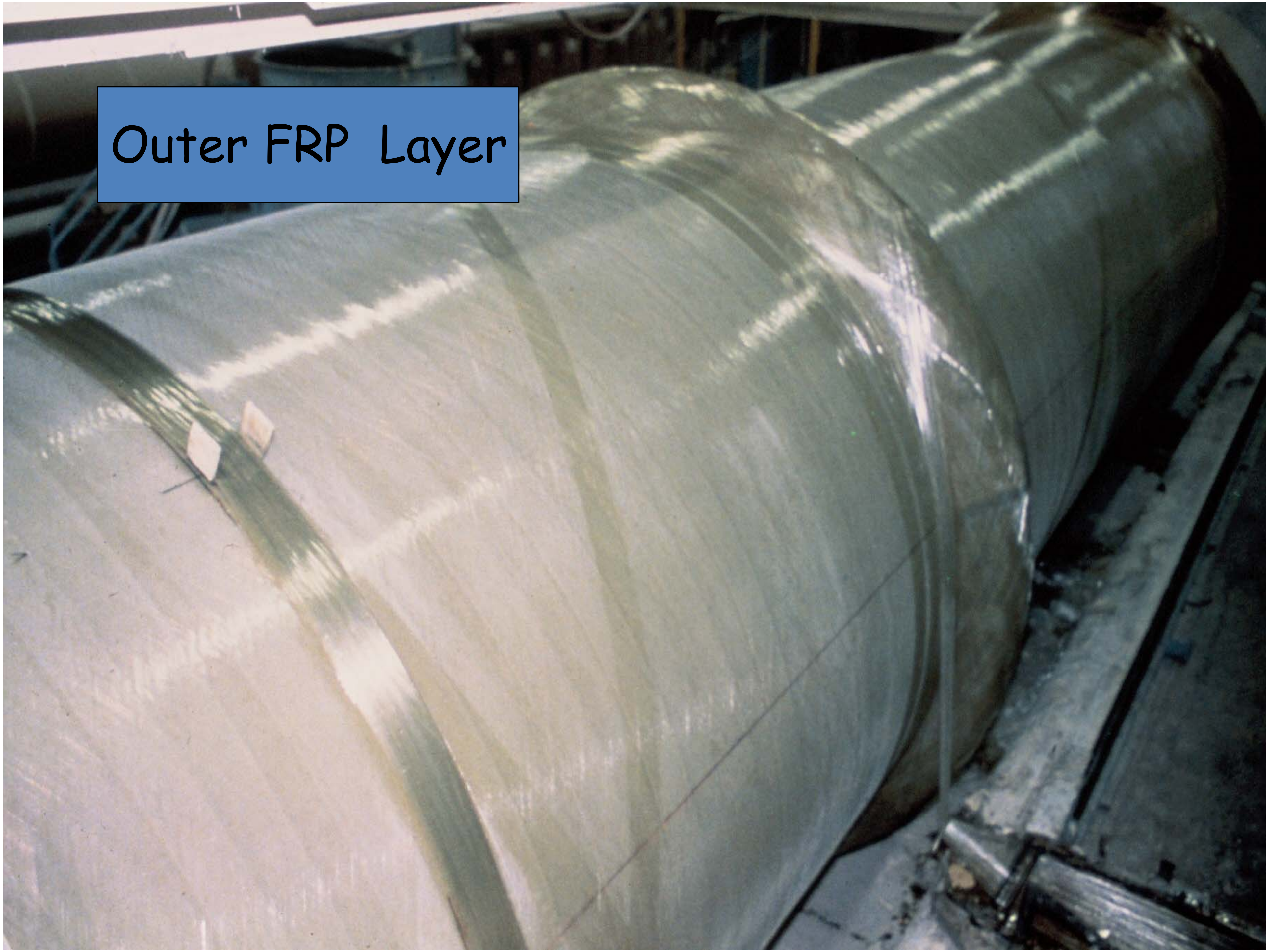
- **Syntactic Foam spraying**
- **Weather window**

Inner FRP Layer



Spraying Foam Core




Outer FRP Layer

CWP:
FRP Sandwich
0.38" Laminates
1.3" core

Parameter	Value
Inside Diameter	3.9 m
Laminate (facesheet) thickness	14 mm
Core (syntactic foam) thickness	50 mm
Laminate Density	1714 kg/m^3
Outside Diameter	4.056 m
Core Density	670 kg/m^3
Dry (air) Weight	1,010 kg/m
Wet (submerged) Weight	33 kg/m
Flexural Rigidity, EI	1.7×10^{10} N-m^2 (4.2×10^{10} lb-f^2
Laminate Modulus of Elasticity	20,600 MPa (3×10^6 psi)
Core Modulus of Elasticity	2,360 MPa (0.34×10^6 psi)

Baseline Pre-Commercial Plant

<u>HXs</u>: Aluminum Plate-Fin Evaporator and Condenser manufactured by CHART

<u>Challenges</u>:

- **Must get CHART involved in design**
- **Replace every 15-years**

Surface Condenser: Steam Fins

Surface Condenser:
Extruded Water Channels

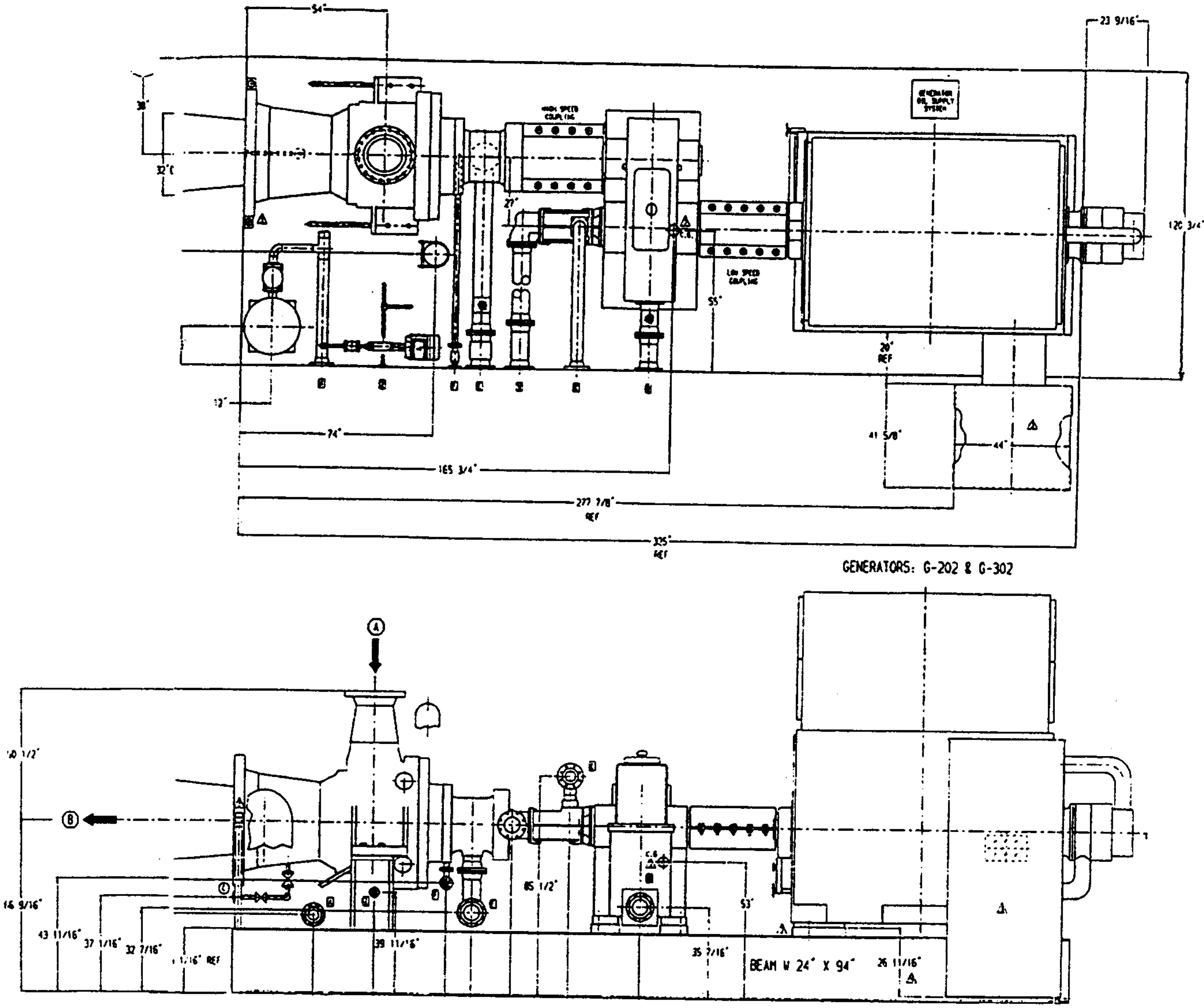
Baseline Pre-Commercial Plant

NH_3 T-G: SOA to about 16 MW-gross from GE/ROTOFLOW or Mitsubishi;

Pumps: SOA but multiple units (low head-high flow)

Challenges:

- None



ROTOFLOW EXPANDER DRAWING (2 UNITS; 4,000 kWe OUTPUT EACH)

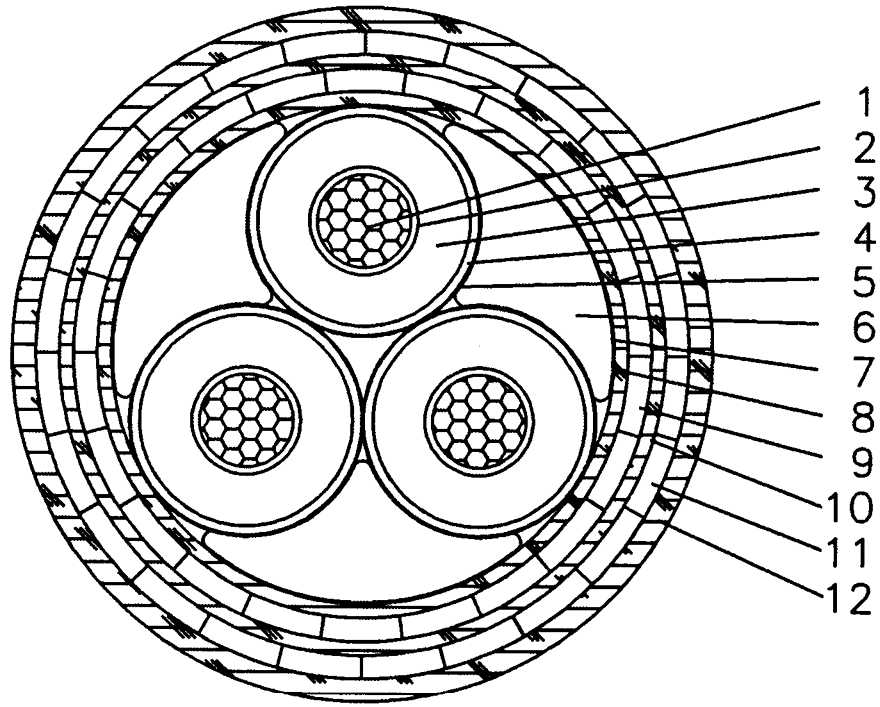
Baseline Pre-Commercial Plant

Submarine power cable: AC with ethylene-propylene-rubber (EPR) insulation $V \leq 35$ kV; $P \leq 25$ MW and $L \leq 100$ km;

Challenges:

- Not scalable from pre-commercial to commercial. For 100 MW: AC or DC with self-contained-fluid-filled (SCFF) insulation etc.

5.2 Typical Drawing of a 3-core EPR DWA Submarine Cable (AC only)



1	Conductor	7	Tape binder
2	Conductor shield	8	PPL bedding
3	Insulation	9	Galvanized steel flat wire armour
4	Insulation shield	10	PPL bedding
5	Metallic tape	11	Galvanized steel flat wire armour
6	Fillers & penetrating sheath	12	PPL serving

What are the performance metrics that must be demonstrated prior to commercial development?

Need a minimum of one year operational record with plant that is big enough (> 5 MW) to be scaled to commercial size plants (> 50 MW)

What are the potential failures that could lead to the shutdown of an OTEC system?

Power block is of modular design, therefore, the only failure leading to 100% shutdown would be: catastrophic CWP failure; or, submarine power cable failure (2x?).

What processes/diagnostics are needed to detect, monitor and reduce these risks?

State-of-the-art monitoring is routine for similar submarine power cables but in the case of the CWP we will have to rely on technology developed for marine risers. This is part of the final engineering design

What are the flexibilities in the OTEC system's components that could minimize environmental impacts?

Design must mitigate potential environmental impact.

N.B. The pre-commercial plant will also provide environmental monitoring and subsequent analyses to mitigate impact from the commercial size plants.