Source: Army Mobility Equipment Research
and Development Command,
Petroleum and Environmental Technology
Division,
Fort Belvoir, VA 22060

MEMORANDUM 15

(1)

3000/2000 GPH ROWPU

Reverse Osmosis Water Purification Unit

by

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ARMY REQUIREMENT

The Army's need for a 3000/2000 GPH ROWPU is stated in a ROC (Required Operational Capability).

"Required Operational Capability for a Family of Water Supply Equipment. CARDS Reference Number 0655. Approved: 4 March 1974".

In response to the above requirement, MERADCOM is developing a 3000/2000 GPH water purification unit for field use, based on the reverse osmosis principle. The unit must be capable of producing drinking water from any of the following raw water sources:

a. Raw fresh water

b. Sea water

c. Brackish water

d. Water contaminated with nuclear agent

e. Water contaminated with biological agent

f. Water contaminated with chemical agent

The unit will be patterned after a 600 GPH unit which has already been standardized. The 3000/2000 GPH ROWPU is scheduled to be type classified 3QFY83, and to reach Initial Operational Capability2QFY85. The unit will supply water to the Division.

The new unit will replace the following pieces of equipment:

a. 420, 600, 1500, 3000 GPH Erdlators

b. 150 GPH distillation unit

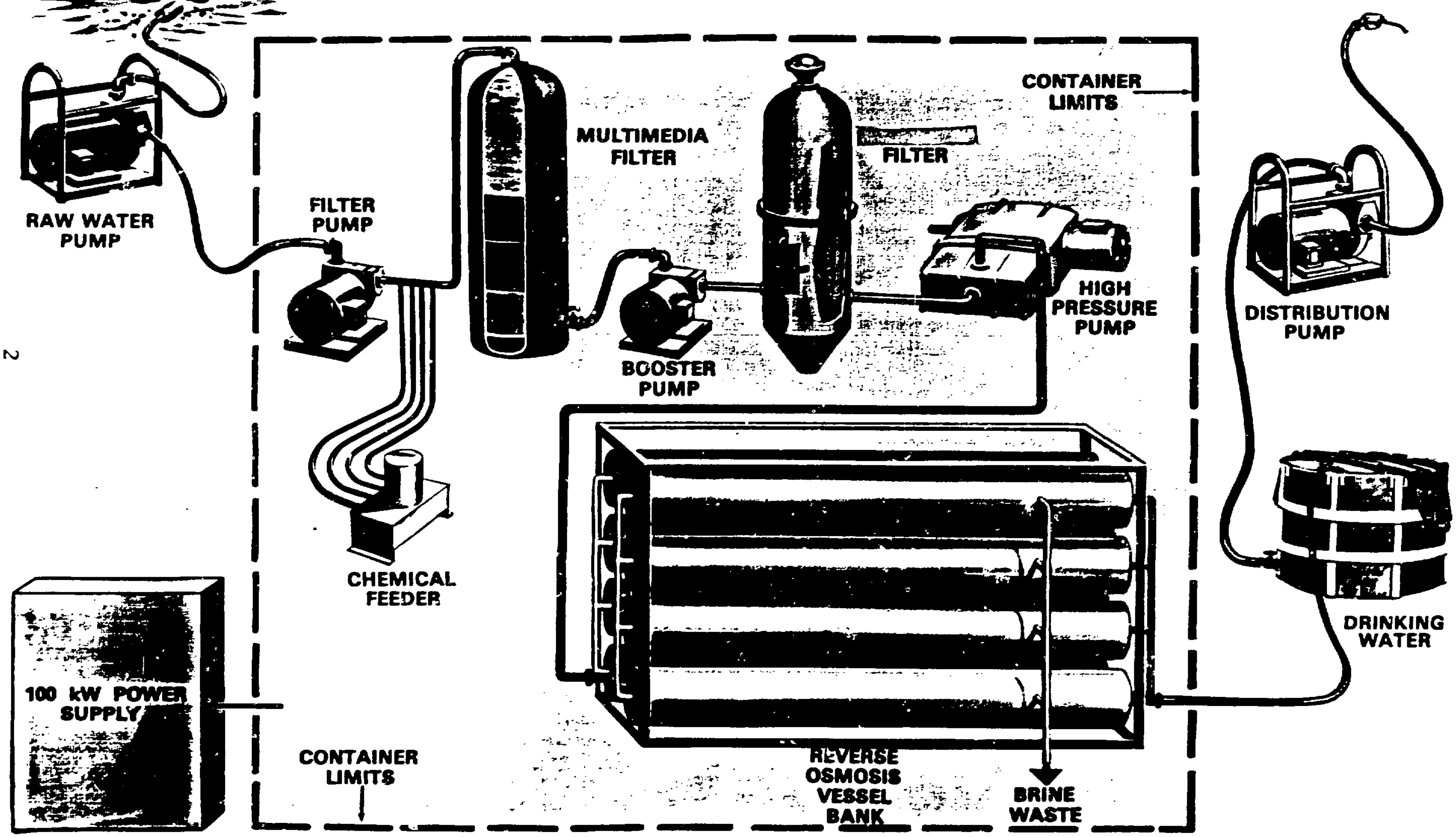
c. 3000 GPH BW-CW pretreatment unit

d. 3000 GPH ion exchange unit

Figure 1 is an artist's concept of the basic flow pattern of the 3000/2000 GPH ROWPU. Figure 2 is an artist's concept of the unit as used in the field. Figure 3 is a line diagram of the flow pattern. Figure 4 is an artist's concept of a reverse osmosis unit being used in the field for decontaminating water containing NBC agents.

Figure 1.

REVERSE OSMOSIS WATER PURIFICATION UNIT (CONTAINERIZED — 3000/2000 GPH ROWPU)



3000/2000 GPH REVERSE OSMOSIS WATER PURIFICATION UNIT (ROWPU)

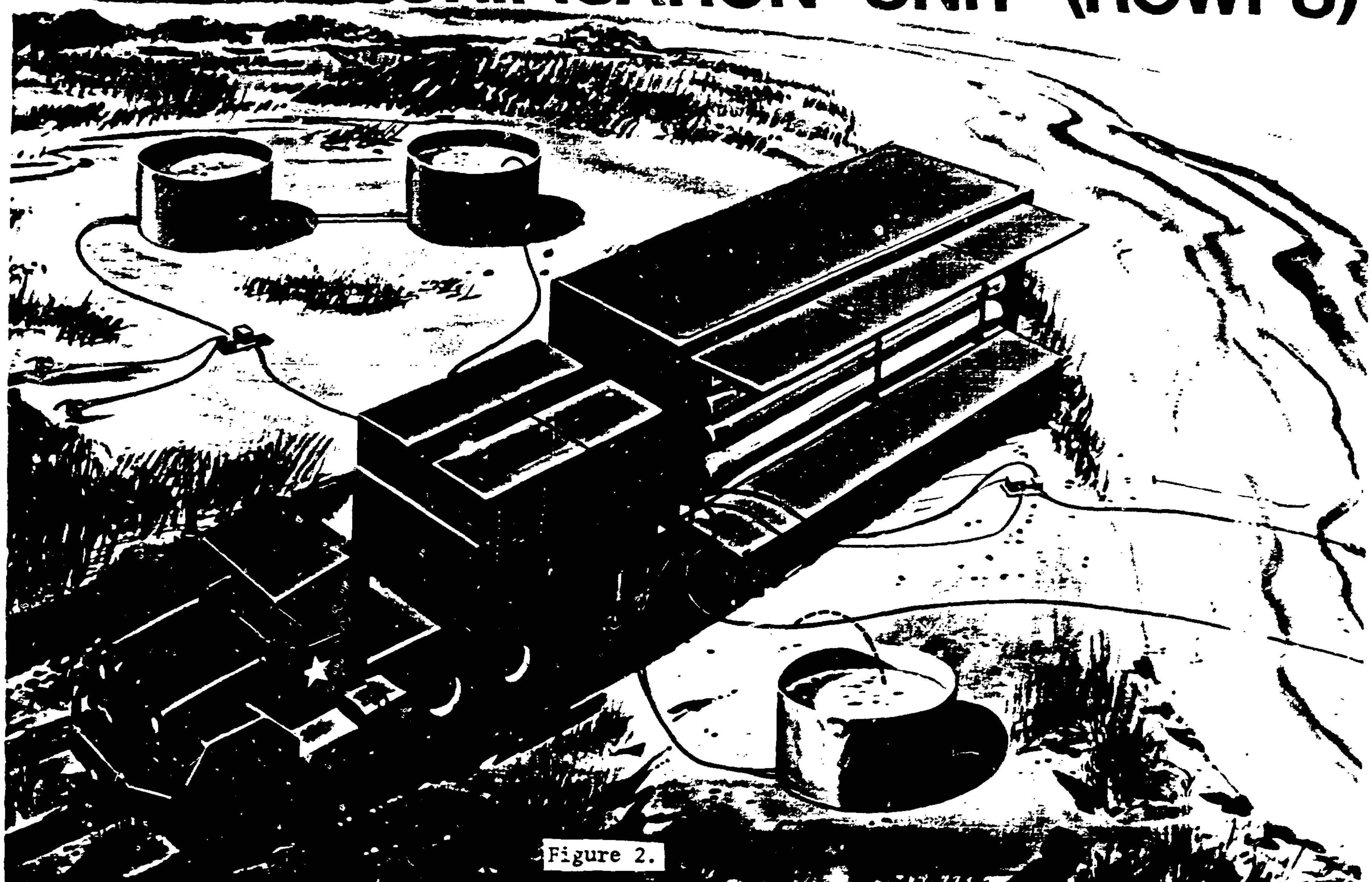
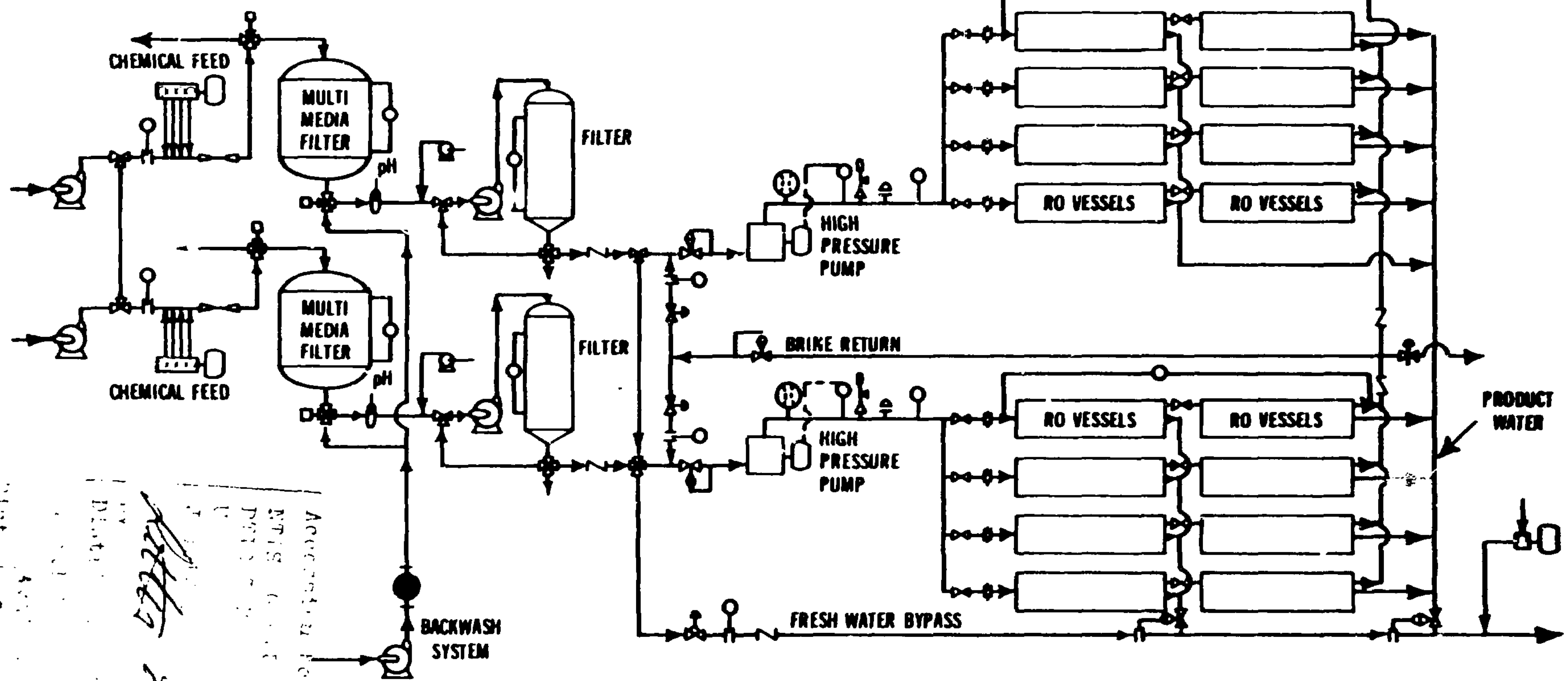


Figure 2.

Figure 3.

3000/2000 GPH REVERSE OSMOSIS WATER PURIFICATION UNIT



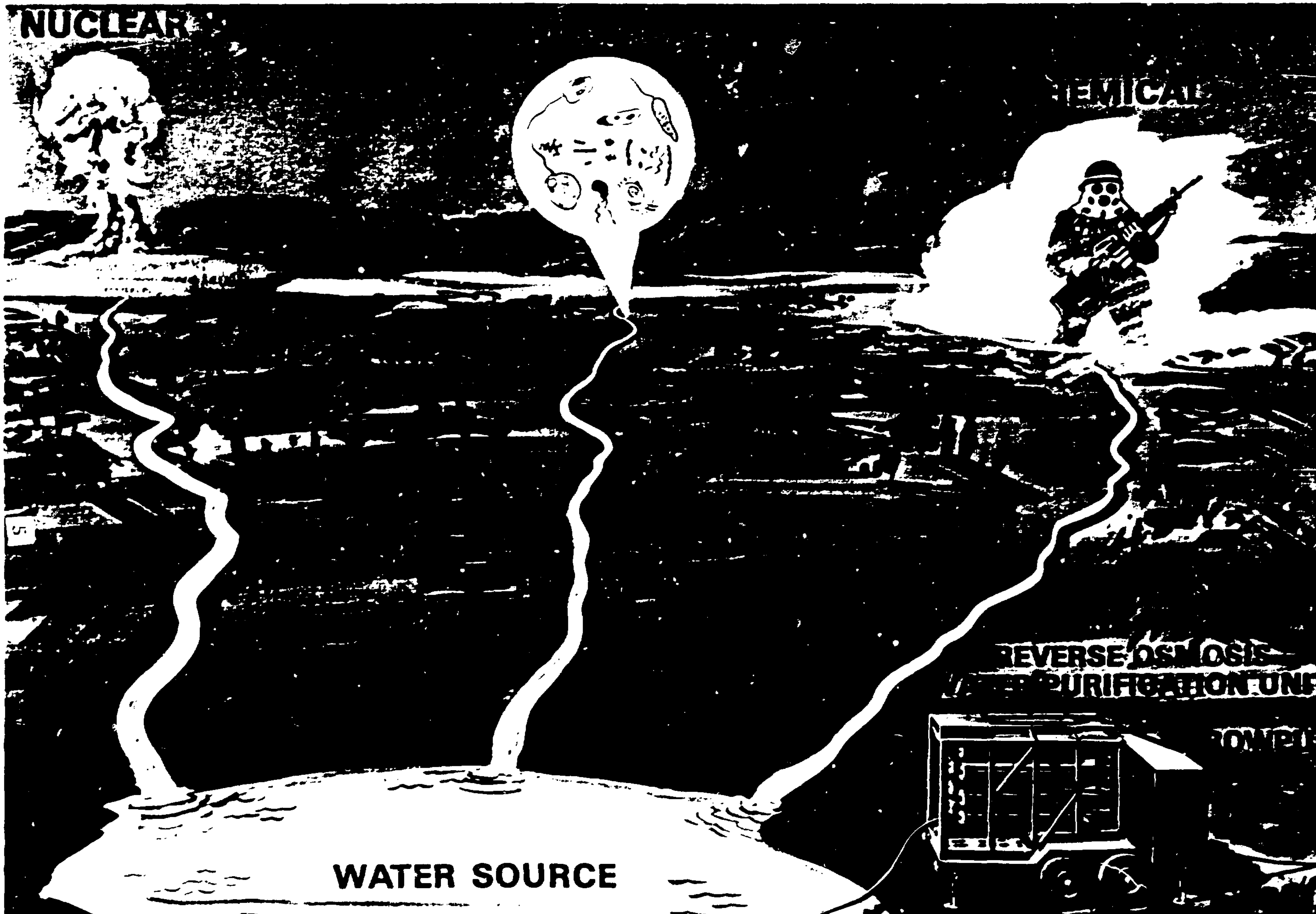


Figure4. Decontamination of Water Containing NBC Agents.

Reverse osmosis is a membrane process in which the input water is pressurized to a value above the osmotic pressure. Pure water passes through the membrane, leaving most of the soluble salts behind. At the same time, essentially all particulate matter, including microorganisms and suspended colloids, is removed.

Passage of water through the membrane is governed by diffusive transport according to the following equation, which relates to permeate quantity.

$$F = K_1(Pa - Po)$$

where:

F = Product (permeate) water flux in gal/sq ft of membrane area/day
Pa = Applied pressure in psi
Po = Osmotic pressure in psi
K_1 = Proportionality constant

An examination of the above equation indicates that no product water is produced when the applied pressure is less than the osmotic pressure. Above the osmotic pressure, the more the pressure, the more the water. Seawater, for example, has an osmotic pressure of 350 psi. The flux obtained at 550 psi would be doubled by going to 750 psi.

Permeate quality is governed by the following:

$$S = K_2 (Cr - Cp)$$

where:

S = Salt flux in grams/sq ft of membrane area/day
Cr = Concentration of salt in raw water
Cp = Concentration of salt in product (permeate) water
K_2 = Proportionality constant

When a tight, high rejection, membrane is used, the Cp term becomes negligible and can be dropped. Under this condition, the amount of salt migrating through the membrane is directly proportional to the salt concentration in the raw water. It is interesting to note that the salt migration is independent of pressure. Hence, the quality of the product water is best at high applied pressure, where a constant salt migration is diluted with a large volume of pure water.

Also, it should be noted that the pressurized water passing thru any RO system is continously being "dewatered". Therefore, the feed becomes more concentrated and the quality of the product continually deteriorates through the system as more salt migrates through the membrane, with less water migrating through the membrane to dilute it. At the end of the system, the concentrated feed is discharged as the waste stream. Alleviation of the concentration problem is achievable by operation at a low "water recovery"; i.e., maintaining a high feed rate so that the product output is a small fraction of the feed. However, when a highly concentrated waste stream is desired, such as when processing wastewater, low "water recovery" is undesirable. Also, low "water recovery" results in a comparatively high energy requirement.

Three basic configurations may be used for employing the RO principle: tubular, hollow-fiber, and spiral-wound.

The tubular configuration has several assets: (a) it utilizes a well-known technology: pumping water through a pipe; (b) the tube itself serves as the pressure vessel and, thus, an outside pressure container is not needed; (c) turbulent flow is easily maintainable, reducing the probability of fouling; and (d) it is more easily cleanable. On the debit side, the tubular configuration has a poor packing density and requires troublesome return bends.

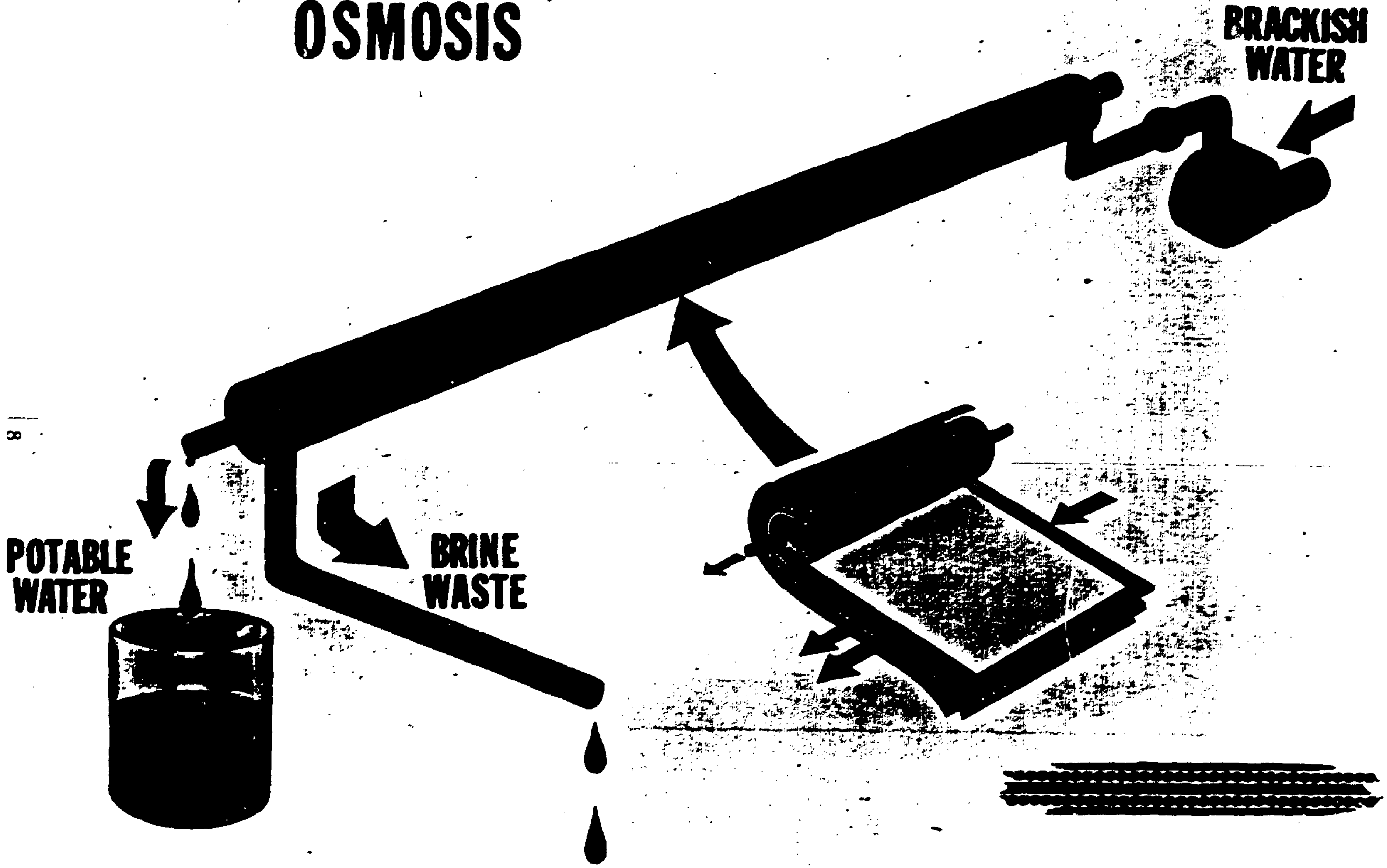
The hollow-fiber configuration is not without its own unique assets and liabilities. A typical hollow-fiber module is a 4-foot-long, 4 ½-inch-diameter aluminum tube containing about 900,000 nylon fibers, each fiber measuring 85 microns outside diameter and 42 microns inside diameter: total area 190 square feet. It is noted that the packing density of a typical hollow-fiber module is sensationally high. Much of the effect of tremendous area per cubic foot of equipment is lost, however, due to low flux. Also, the hollow-fiber configuration is particularly subject to the common problem of membrane fouling.

The spiral-wound configuration is illustrated in Figure 5. This configuration, by tradeoff analysis, is probably the most suitable for use by the modern mobile Army.

With any of the RO configurations, it is noted that a drop in flux as a function of time is a commonly encountered occurrence. It is believed that this phenomenon is a direct result of increased flow resistance due to any or all of the following reasons: (a) compaction of the porous membrane substructure; (b) release of tiny pinpoints of air or dissolved gas on and in the membrane; (c) electrical charge build-up due to streaming potential; (d) deposition of raw water turbidity (including micro-organisms, clay, organic turbidity, suspended iron and manganese, and colloidal color particles); (e) deposition of scale due to the precipitation of sparingly soluble dissolved salts; and (f) accumulation of ions adjacent to the membrane surface, which is responsible for "concentration polarization". Three operational approaches to the fouling problem are as follows: (a) preclarification of the feed, (b) accept the fouling phenomenon, but clean the membrane occasionally,

Figure 5.

SPIRAL WOUND REVERSE OSMOSIS



or (c) accept the fouling phenomenon, but practice modular replacement.

Many polymers have been or are being used for fabrication of the membrane used in the RO process; including the following:

Polyfurane
Piperazine
Cellulose Acetate
Cellulose Acetate Butyrate
Modified Sulfonated Polyphenylene Oxide
Polybenzimidazole
Polysulfone
Polyamide
Poly(ether/amide)
Poly(ether/urea)

At the present time, the poly(ether/urea) is the material of choice by the US Army. A membrane fabricated of poly(ether/urea) is identical in configuration to the poly(ether/amide) membrane shown in cross-section in Figure 6. It is important to note that the effective part of the membrane is the thin skin, shown in red in the diagram. The rest of the membrane is essentially porous support material. The poly(ether/amide) thin film dry composite membrane is produced by the procedure shown in Table 1.

Table 1. Procedure, In-situ Interfacial Polymerization Technique

(1) Deposit a thin layer of an aqueous solution of an epichlorohydrin/ethylene diamine condensate on the finely porous surface of a polysulfone support medium.

(2) Contact the poly(ether/amine) layer with a water immiscible solution of isophthaloyl chloride. A thin semipermeable film of a crosslinked poly(ether/amide) copolymer is formed at the interface.

It is of paramount importance that the RO membrane give both a high flux and a high rejection of dissolved solids. In addition, the following characteristics are highly desirable:

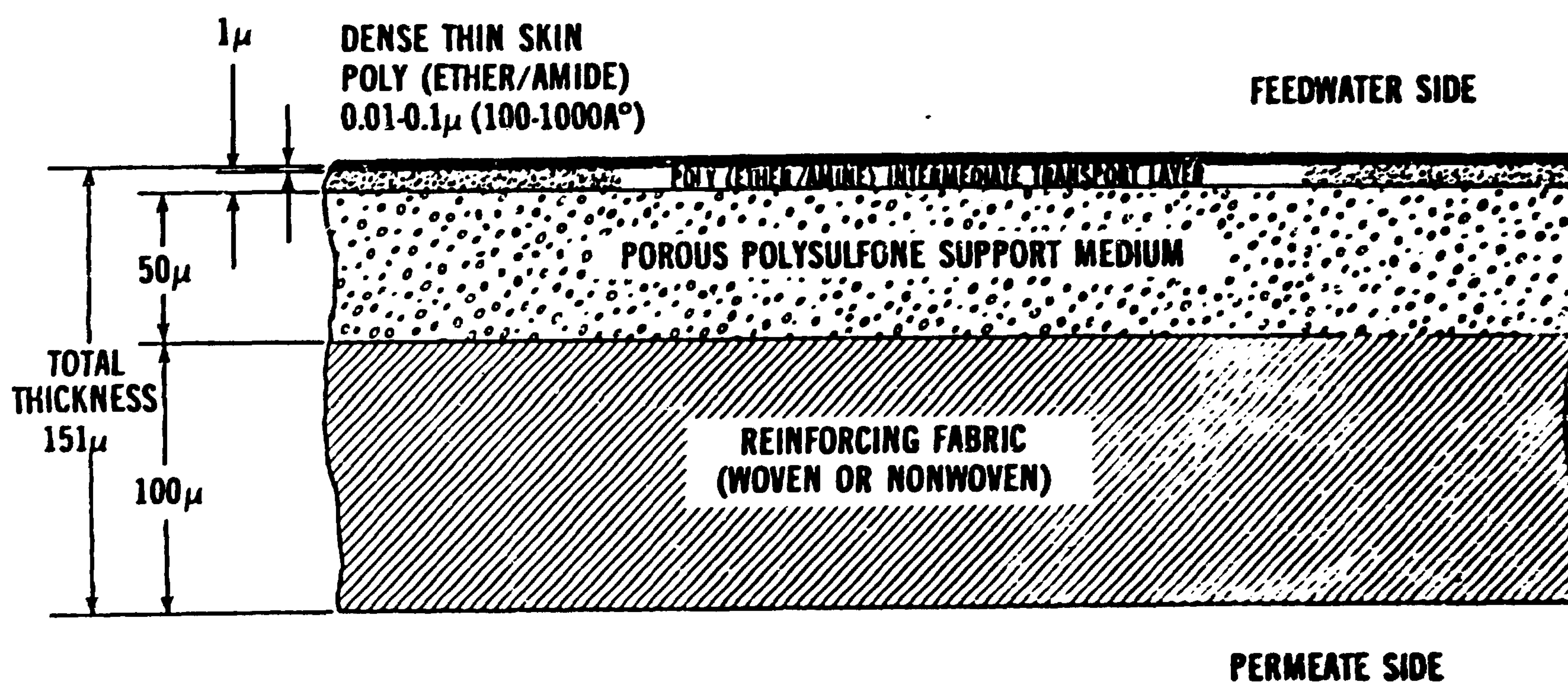
Abrasion resistance
Erosion resistance
pH independence (3-10.5)
Microbiological attack resistance
Freeze damage resistance
Anti-scaling
Anti-fouling
Osmotic shock resistance (relates to problem of permeate tending to float-off the thin skin upon shutdown)

It should be noted that the RO membrane being used by the Army at the present time is not resistant to chlorine. Consequently chlorination (which is required) takes place <u>after</u> the RO step and just prior to distribution. It would be very desirable to have a chlorine-resistant membrane. In this case, chlorination could take place as an initial

Figure 6.

PA-300 POLY (ETHER/AMIDE) THIN FILM DRY COMPOSITE MEMBRANE

(CROSS-SECTION)



processing step. This would (1) prevent undesirable microbiological gowths and slimes in the system, (2) prevent microbiological attack of the membrane itself, (3) destroy biological warfare agents and certain chemical warfare agents, such as VX, and (4) provide extended chlorine contact thus meeting the SG requirement of 30 minutes.

3000/2000 GPH ROWPU Component Information

1. Raw Water Pumps (2)
   Centrifugal
   60 GPM at 110 ft head

2. Feeder
   - Four heads:
   - Cationic polyelectrolyte
   - Calcium hypochlorite
   - Sodium hexametaphosphate
   - Citric acid

3. Mixed Media Filters (2)
   - Anthracite
   - Sand
   - Garnet
   - Gravel

4. Booster Pumps (2)

5. Cartridge Filters
   - Woven polypropylene elements (opening, 5 micrometers)

6. High Pressure Pumps (2)
   - Positive displacement plunger
   - 60 GPM at 1200 psig

7. RO Systems
   - 2 banks

   Each bank
   - 8 pressure vessels
   - 3 RO modules/vessel
   - (Total modules: 48)

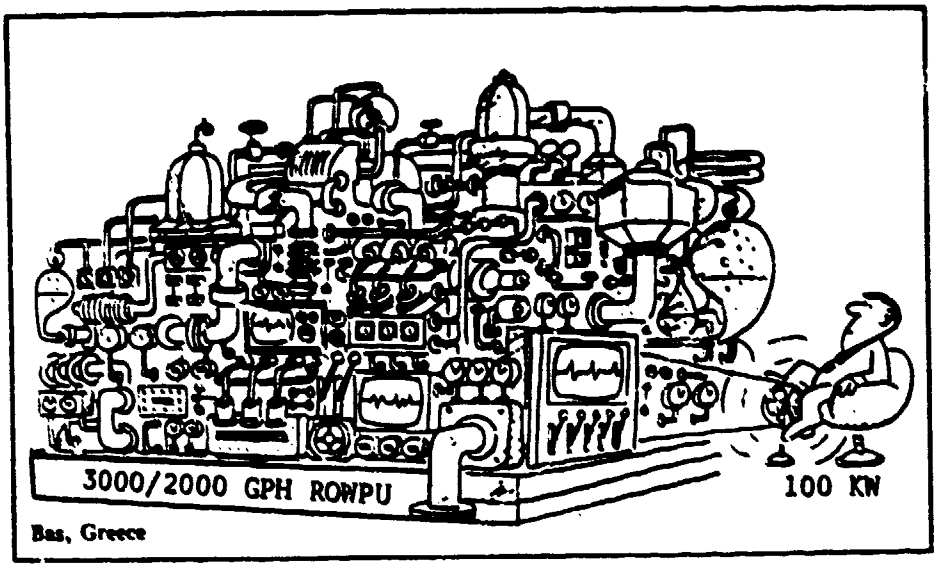
   Module
   - Spiral wound
   - 6" dia, 36" long (40" product tube)
   - Thin-film-composite membrane (wet/dry reversible)
   - Effective membrane area: 165 sq ft/module

8. Distribution Pump

9. Filter Backwash Pump.

The 3000/2000 GPH ROWPU will be housed in a 8' X 8' X 20' ANSI/ISO inclosed frame.

The 3000/2000 GPH ROWPU will operate electrically from a 100 KW, diesel, 4-wire, 3-phase, 120/208 volt generator.



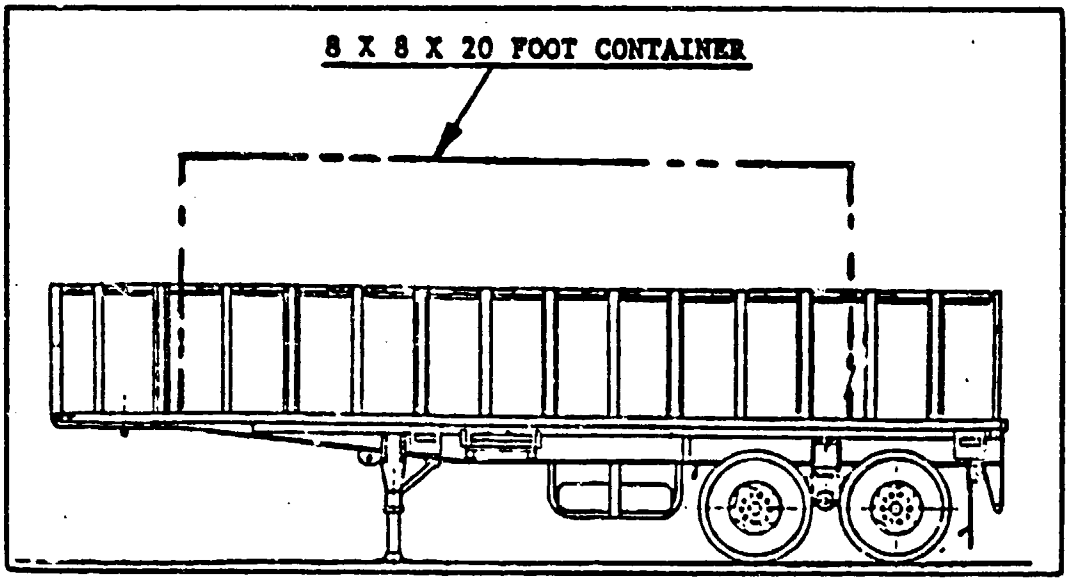
The 3000/2000 GPH ROWPU will be transported on a standard Army M871 semi-trailer pulled by an M818 Tractor. See Figures 7 and 8.

The 3000/2000 GPH ROWPU will be transported by C-130, C-141, C-5A, and CX aircraft.

The 3000/2000 GPH ROWPU will be operated according to the following modes, depending upon the problem water being used:

PROBLEM WATER	OPERATIONAL MODE
(1) Raw fresh water	Pretreatment only Coagulation Filtration Chlorination No RO NOTE: Filter back wash accomplished with filtered water

Figure 7

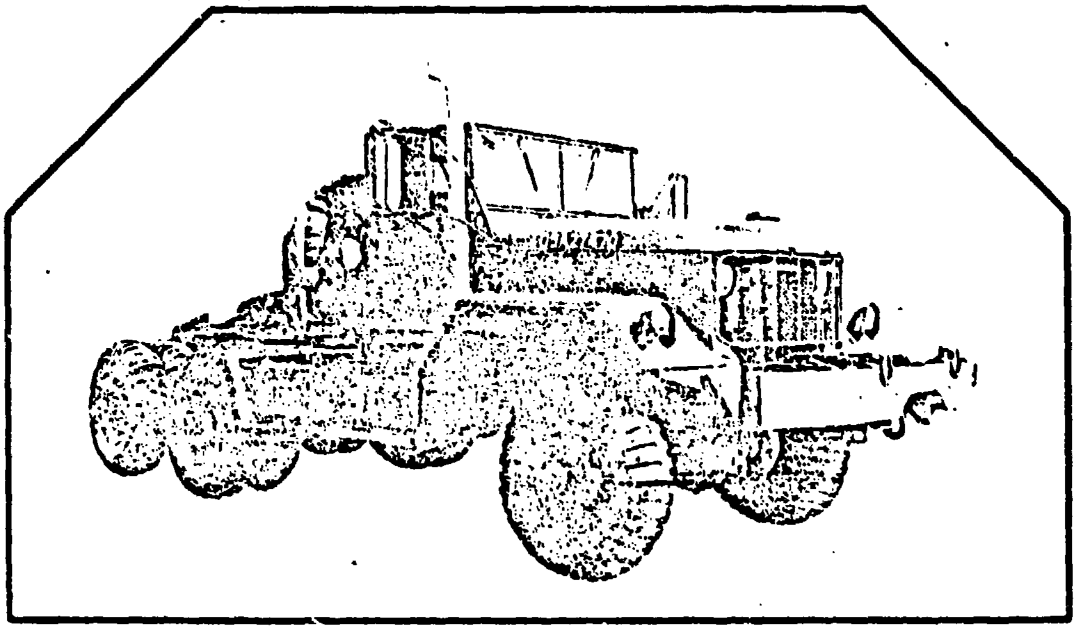


SEMITRAILER
22½ TON
(XM871)

CHARACTERISTICS

Trailer Weight	15,800 lbs
Payload	44,800 lbs
Gross Weight	60,600 lbs
Dimensions	
Length	358 in
Width	96 in
Height	103 in

Figure 8



TRACTOR
5-TON, 6x6
(M818)

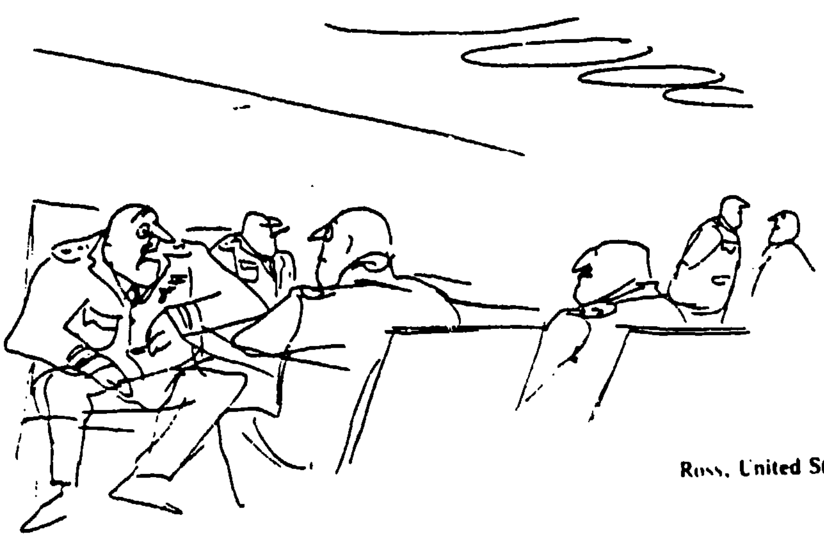
CHARACTERISTICS

	WO/W	W/W
Federal Stock No.	2320-050-8984	2320-050-8978
Gross Combination Weight, Payload and Crew	75,690 lbs	76,355 lbs
Shipping Dimensions		
Length	264 in	280 in
Width	97 in	97 in
Height	116 in	116 in
Maximum Speed	-	52 MPH
Maximum Grade	-	42%
Cruising Range	-	350 miles
Fuel	-	Diesel (3.2MPG)
Air Transport Classification	Phase II Unladen	

(2)	Sea water	Pretreatment Coagulation Filtration RO (33% water recovery) Post Chlorination NOTE: Filter back wash accomplished with RO waste brine
(3)	Brackish water	Pretreatment Coagulation Filtration RO (45& water recovery) Post Chlorination NOTE: Filter back wash accomplished with RO waste brine
(4)	Water contaminated with nuclear warfare agent	Same as for Problem Water 3
(5)	Water contaminated with biological warfare agent	Same as for Problem Water 1
(6)	Water contaminated with chemical warfare agent	Same as for Problem Water 3

Taking into account the above operational modes, plus the effects of temperature, backwash requirements, 20 hour operational day, etc., the projected true output of the machine is shown in Table 2.

The schedule for the development of the 3000/2000 GPH ROWPU is shown in Figure 9.



Ross, United States

"Did I have a nightmare last night! I dreamed that they had a thousand RO units and we had only a hundred."

Table 2.
PRODUCT OUTPUT
- 3000/2000 GPH ROWPU -

OPERATIONAL MODE	PROBLEM WATER TO BE TREATED	PROCESSING STEPS FOR OPERATIONAL MODE	Average GPH Product Output Per 24-hr Period — Water Temperature 32°F	77°F	100°F
A	(1) Raw freshwater (5) Water contaminated with biological warfare agent	Pretreatment only Coagulation Filtration Chlorination No RO	3370	5220	5220
B	(2) Sea water	Pretreatment Coagulation Filtration RO (33% water recovery) Post Chlorination	720 290 (recycle)	1850 660 (recycle)	1850 660 (recycle)
C	(3) Brackish water (4) Water contaminated with nuclear warfare agent (6) Water contaminated with chemical warfare agent	Pretreatment Coagulation Filtration Ro (45% water recovery) Post Chlorination	1660 610 (recycle)	2500 840 (recycle)	2500 840 (recycle)

KEY EVENTS
DEVELOPMENT OF 3000/2000 GPH ROWPU
(Accelerated Schedule)

Figure 9

Event No.	EVENT	Time Frame	CALENDAR YEAR 80	81	82	83	84	85
1	Award Contract	25Sep80-09Oct80						
2	Design Hardware	06Nov80-20Jan81						
3	Fabricate Hardware	31Jan81-01Jul81						
4	Conduct EDT-G Fresh Water Test	10Aug81-15Sep81						
5	Conduct EDT-G Salt Water Test	10Aug81-20Oct81						
6	Conduct FDTE Test; Report	10Aug81-03Nov81						
7	Conduct DTII (TECOM)	12Feb82-17May82						
8	Prepare IER DTII	24May82-18Aug82						
9	Prepare DTII Report	24May82-21Jul82						
10	Conduct OTII	11Aug82-04Nov82						
11	Conduct PCA	03Dec82-01Feb83						
12	Conduct Arctic Test	23Sep82-23Feb83						
13	Prepare OTII Report	11Nov82-13Jan83						
14	Prepare IER OTII	13Jan83-14Mar83						
15	Conduct DEVA IPR	21Mar83-22Apr83						
16	Award Production Contract	12Aug83-19Aug83						
17	Conduct Tropic Testing	06Apr83-06Dec83						
18	Fabricate PPT Hardware	19Aug83-04Jun84						
19	Conduct PPT	04Jun84-02Jul84						
20	Release for Issue	21Nov84-29Nov84						
21	Achieve IOC	20Dec84-05Feb85						
22	Transition	26Feb85-27Feb85						

---"and when you get older, just before you go away to college, your father will tell you all about R.O. What little he knows "----