3. Liquid RW : 0-10% solids, slurry

Basic principles*: volume + cost reduction, minimise generation, reduce volume, optimise treatment + conditioning

Treatment: transfer, concentration, transformation; entire system, options

Forms: decontamination + regenerative solutions, contaminated + scintillation fluids, condensates, drains, laundry, evaporator bottoms..

Sources: mines, reactors, reprocessing,..

Reactors: low + high purity RW, chemical, detergents, miscellaneous, primary + secondary (PWR)

Reprocessing: 5 m^3/t HLW, tanks, 60 m^3/t MLW

Institutions: scintillation, H-3, C-14

Wet waste: 10 - 99% solids, collection, pretreatment, dewatering, solidification

collection: 60 days, decay, surge capacity

pretreatment: remote handling

dewatering: decantation, filtration, centrifugation, 25% cement

WW technologies: disposal <1% free water, absorption (organic and inorganic sorbents), sludge handling: filtration cake 84%, centrifuging, freezing + thawing no RI release

Management of LRW in NPP: regulatory limits NRC

processing systems: filtration (F), ion exchange (IE), evaporation (E), condensate polishing (CP)

High purity: F + IE + recycle, Low purity: <0.01 mho/m: F

+ IE, >0.01 mho/m: E + CP by IE. Chemical: E + ? CP by IE. Detergent: F. Miscellaneous: E + CP. Secondary system: F + IE

Volume reduction: disposal + transportation cost

Drying: injection fluidized bed 300-500 C, 190 l/h, conveyor, hopper, off-gas: gas/solid separator + venturi scrubber + HEPA + C. Drying and incineration: ion exchange resins, off-gas: zeolites-Ag

Crystallization*: 120 l/min, 50% salt

Evaporation: >0.01 mho/m, different compositions

Evaporator = heater + body + deentrainment device + condenser + pumps

Types**: natural/forced circulation, heater: external/internal horizontal/vertical, thin film

Decontamination factors (feed/distillate) used by NRC for evaporators.

Type of waste	All*	Iodine
No Detergent Waste	10000	100
Detergent Waste Included	100	100
Boric Acid	1000	100

* except iodine

Separation factors (bottom/distillate) :100 k - 1 M for nonvolatiles

Ion exchange*: <0.01 mho/m, polymers, styrene divinylbenzene, forms: H+, OH-

Characteristics of ion-exchange resins:

Type	FG	R	RL - %	C-eq/l	pH	MOT-F
SA	S	H_2SO_4	95	1.5-2	1-14	250
SB	QA1	NaOH	80	0.5-1	1-14	140
SB	QA2	NaOH	80	0.5-1	1-14	100
WB	amines	NH4OH	95	1.5-2.5	1-7	200

SA = Strong acid, SB = Strong base, WB = Weak base, FG = Functional Groups (S = Sulfonic, QA = Quaternary ammonium (types 1 or 2)), R = Regenerant, RL = Regeneration level, C = Capacity, MOT = Maximum operating temperature.

Properties: strong exchanger: + efficiency (dissociation of salts), - regeneration; weak exchanger: slow, $, shorter life, pH + T sensitive; nuclear grade leachable impurities, uniform size; selectivity, particle size: 0.4 - 0.7 mm, flow rate 1 - 40 l/s/m^2, pressure drop 0.1 - 2 kg/cm^2, swelling

Mixed vs separate bed: regeneration, separation, mixing

Decontamination factors (<0.1 mCi/l):

System	Cations	Anions	Cs,Rb
Mixed Bed (Li3BO$_3$)	10	10	2
Mixed Bed (H+OH-):			
Powdex (Any System)	10(10)*	10(10)	2(10)
Radwaste	100(10)	100(10)	2(10)
Cation Bed	100(10)	1(1)	10(10)
Anion Bed	1(1)	100(10)	1(1)

Filtration: cake + filtrate, septum (membrane)

Types: PWR: disposable (cartridge*) BWR: precoat*, metallic: sintered metal (5 μm) or wire mesh (8 μm), clogging backflushing cleaning

precoat F: diatomaceous earth, efficiency

flatbed F: belt, screen, e = 95% (> 1 μm), oil

centrifugal F*: horizontal filter discs, P< 4.2 kg/cm^2, spin, e > 95% (> 1 μm), Europe

etched disk F: pressure vessel, 5.3 kg/cm^2, backflushing with compressed air - slurry to evaporator, e = 100% (> 5 μm), no precoat - waste volume

Reverse osmosis: osmotic pressure*, membranes : cellulose acetate, compaction, hydrolysis, fouling;

types*: spiral wound, hollow-fibre (aromatic polyimide, D = 100 μm, walls: 25μm, 42 kg/cm^2 ph 2-14), tubular (external/internal 100/40 kg/cm^2)

Ultrafiltration: colloids. Centrifugation*: basket/helical, plugging. System design: tankage, flexibility, sampling, maintenance, operator exposure

Tanks: bottoms, man way opening 60 cm, shielding, steel, SS, fibreglass; Evaporators: segregated + shielded components; Resin handling, operation: planning, redundancy, cross-connections, training

Solidification of HLW*: aims: monolith, resistance, leaching, $;

Vitrification in France*: 1958, 1963: 15 kg glass blocks 1000 Ci/l, pot technique 1969-73 induction heating 1180 C Marcoule 12 t of glass 3000 Ci/l DF = 1E+6 liquids 1E+11 gas; continuous process: flexible, $, 1972 calciner 300 C glass frit; La Haque 800 m^3/y glass 100 W/l

Vitrification in US: PNL, 1150 C, off-gas C-14 Ru I-129 removed, canisters air-cooled vaults, storage tanks*, in situ vitrification*: PNL, 3.5 MW obsidian

Solidification of MLW: LLW regulations, free liquid detection: process control (boundary conditions), detection (inspection)

Cement: silicates of Ca,Al,Fe oxides, + lime, magnesia, gypsum - swelling + setting; 25% water, boric acid, 5-10% waste solids; mechanical strength: >15% waste, resins, sludge; +: $ well known available self-shielding no vapours shelf life strength leachability mixing: in-container/on-line; -: pH sensitive swelling cracking volume dust premature setting

Urea-formaldehyde*: ~60% solids catalyst (H3PO4,NaHSO4) polymerization 1 -30 min, curing ~ hours, cross-linking evaporator concentrate/UF = 1 - 3, free water release, sludge, resins, Na2SO4, paper pulp/wood flour

Other polymers: thermoplastics, PE, Vinyl ester styrene

Asphalt*: organics, asphaltenes, malthenes, Europe, heating 150 C, mixing: thin film evaporator extruder/evaporator*, +: well known, available, compatible, $, no free-standing water, individual coating, shelf life, leachability, not a chemical process; -: flammable, fires, salts, gas formation, melting, mixing, vapours

Comparison of cement, urea formaldehyde resin and asphalt

Comparison Factor	Cement	Resin	Asphalt
Shelf life of immobilizing agent	Long	Short	Long
Mix fluidity	P	G	F
Mixer cleanability	P	G	F
Chemical tolerances for:			
Boric acid solution	P	G	G
Na_2SO_4 solution	F	RE	G
Alkaline solution	G	RE	G
Detergent waste solution	P	P	F
Organic liquids	P	P	F
Ion exchange resins	F	G	F
Sludge	G	G*	G
Volumetric efficiency$	0.5	0.6-1	>2
Product form	ML	ML	ML
Product density, g/cm^3	1.5-2	1-1.3	1-1.5
Water binding strength	G	F	WE
Residual free water	Seldom	O	Never

Comparison Factor	Cement	Resin	Asphalt
Mechanical strength	G	F	G
Product stability	G	LW	G
Combustibility	No	Yes	Yes
Freeze/thaw resistance	F	P	G
Leach resistance	M	M	High

RE = Reduced efficiency, * = may require pH adjustment, $ = Defined as the ratio of the volume of radwaste treated to the volume of final product. G = Good, P = Poor, F = Fair, M = Moderate, WE = Water evaporation during preparations, LW = loses water, ML = Monolith, O = Occasionally

Management of HLW in the US: reprocessing, nuclear weapons, submarines, underground tanks*: Hanford single-walled 1960 leaks 2000 m^3, Savannah River

Management of LLW: segregation by T and form

Methods: aqueous: T< 90 d decay + drain, T> 90 d burial; organic: incineration 12% burial 88%.

Disposal of LLW: doses to public DEL, operating targets ALARA<<DEL

Ground D: US (Hanford, ORNL, SRP) 1.3E+8 m^3, 2.5E+6 Ci discharged, soil stratigraphy, texture, ion exchange, monitoring wells, Ru-106 370 m in 8 y, nitrates 520 m in 8 y; salt mines, porous sandstones

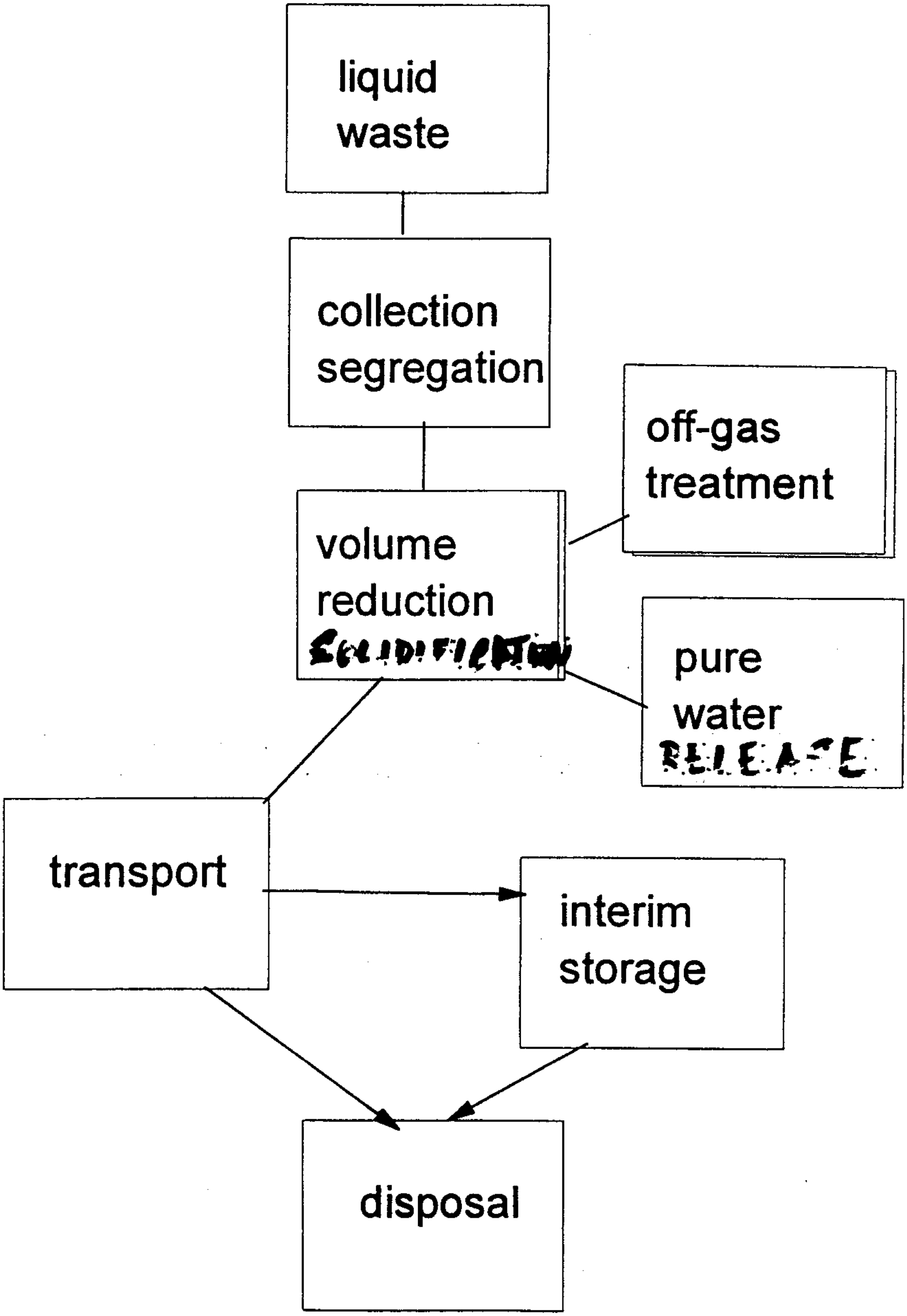
Sea D: volume, not a drinking water, discharge point, horizontal jet, eddy diffusion

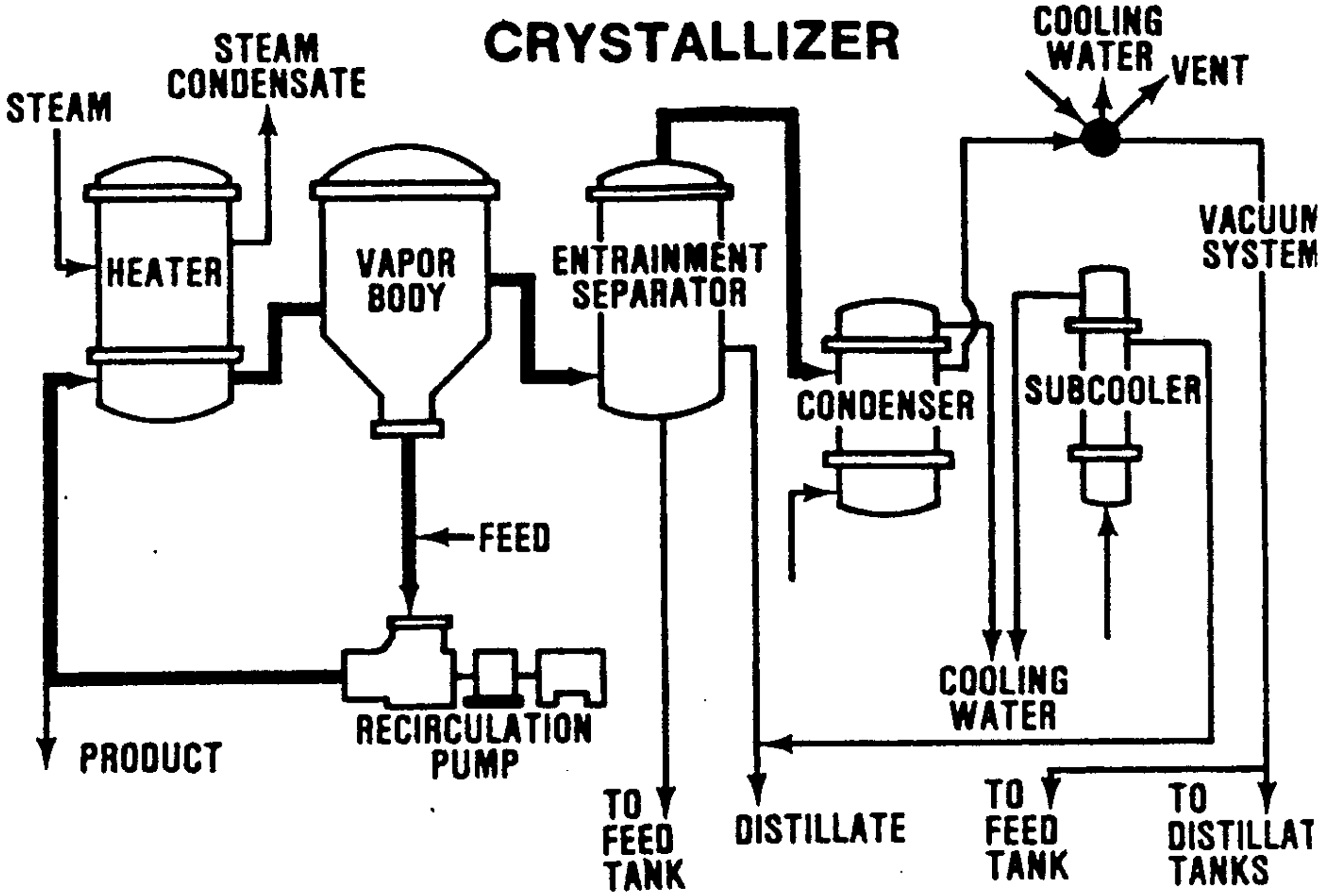
Reconcentration: absorption adsorption, sea bed

Concentration factors , Derived Working Limits (D-nCi/l) for seawater, ICRP Permissible Daily Intakes (PDI-Ci) and safe release rates (R-Ci/y) for fish (F) and white mussel (WM) .

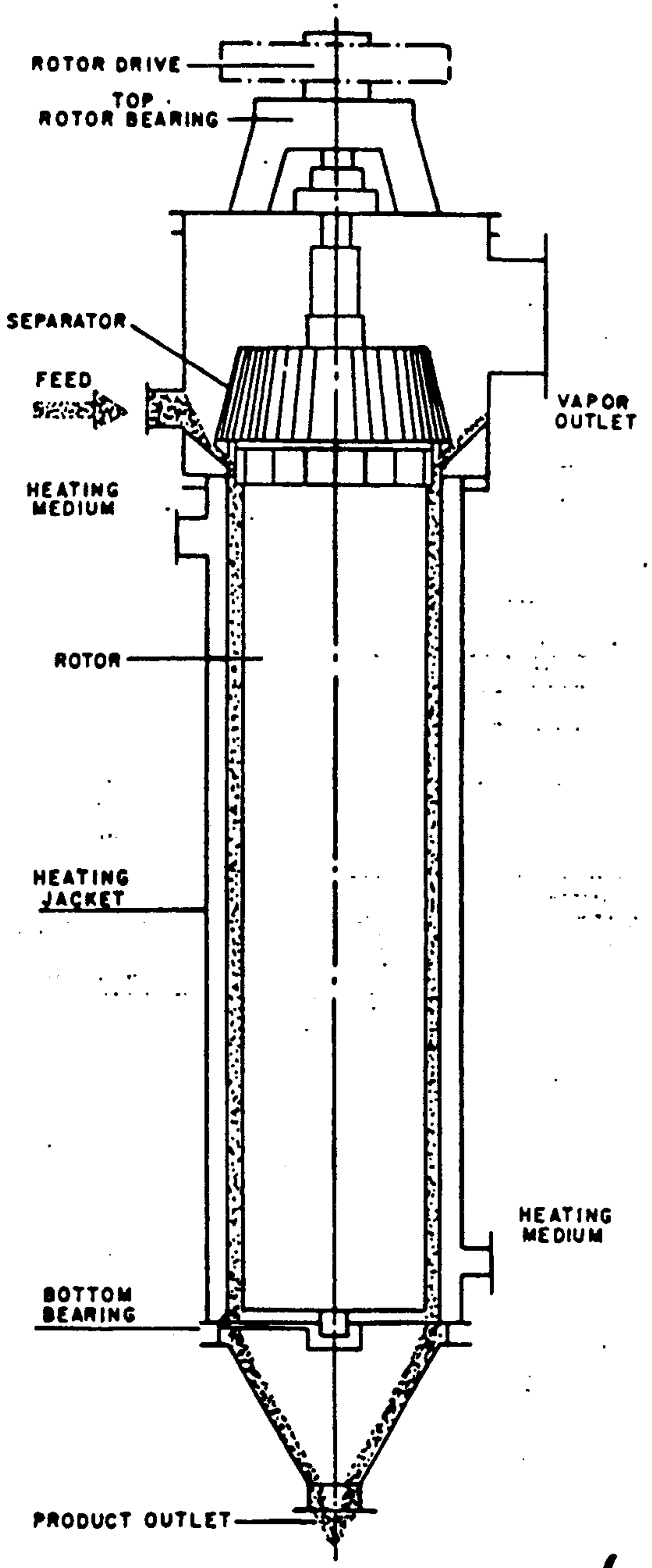
RI	Fe-59	Zn-65	Cs-137	Sr-90	H-3	Pu-239
F	5300	5200	74	1	1	5
WM	27000	13000	14	1	1	290
D	48	140	2400	880	26E+6	380
R	150	450	7500	2800	8E+7	1200
PDI	130	220	44	0.22	6600	11

Environmental surveys: external/internal exposure
Preliminary discharge: sampling, RI concentrations
Disposal in rivers: dry weather flow, drinking water

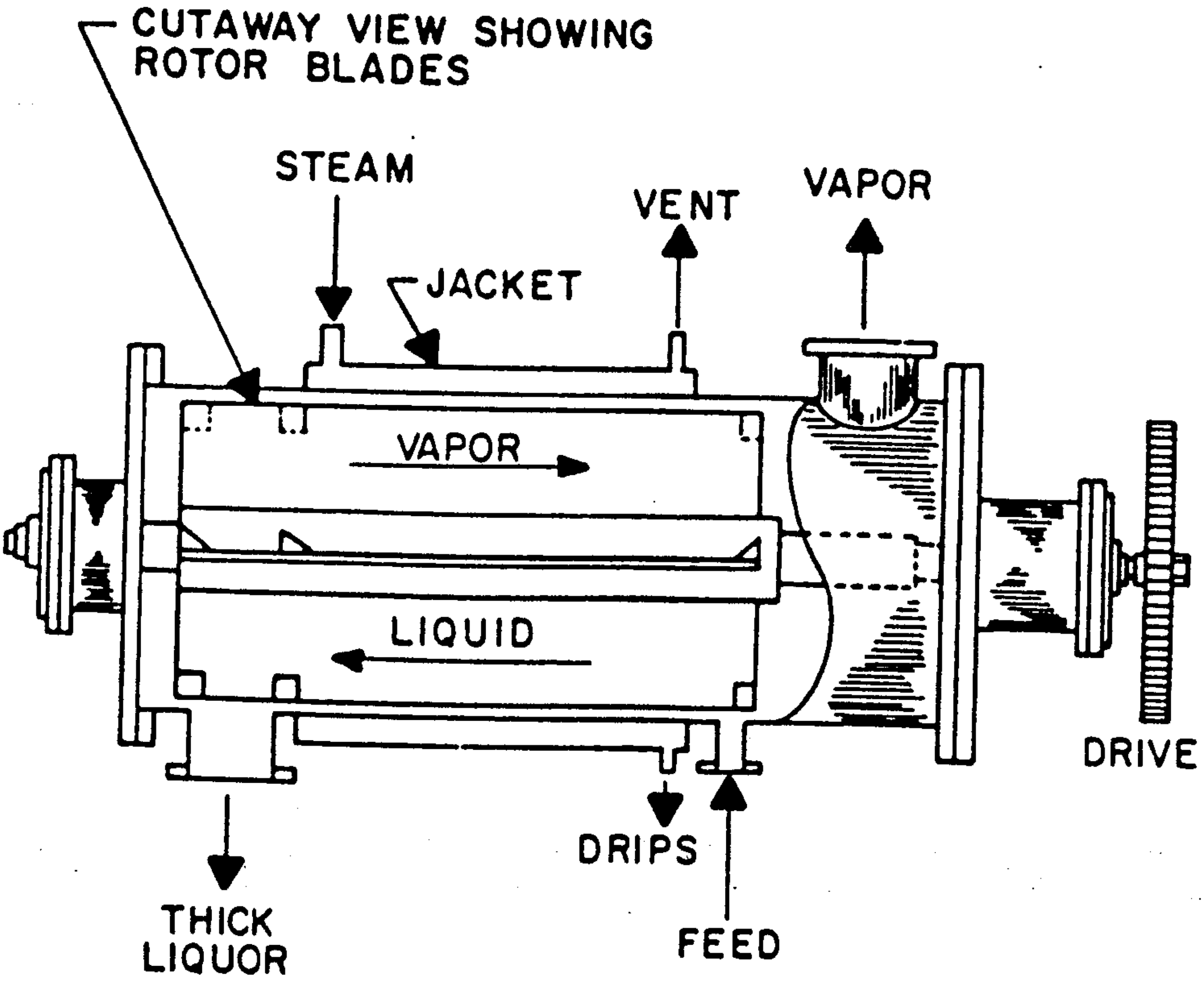

liquid waste
collection segregation
off-gas treatment
volume reduction
SOLIDIFICATION
pure water
RELEASE
transport
interim storage
disposal



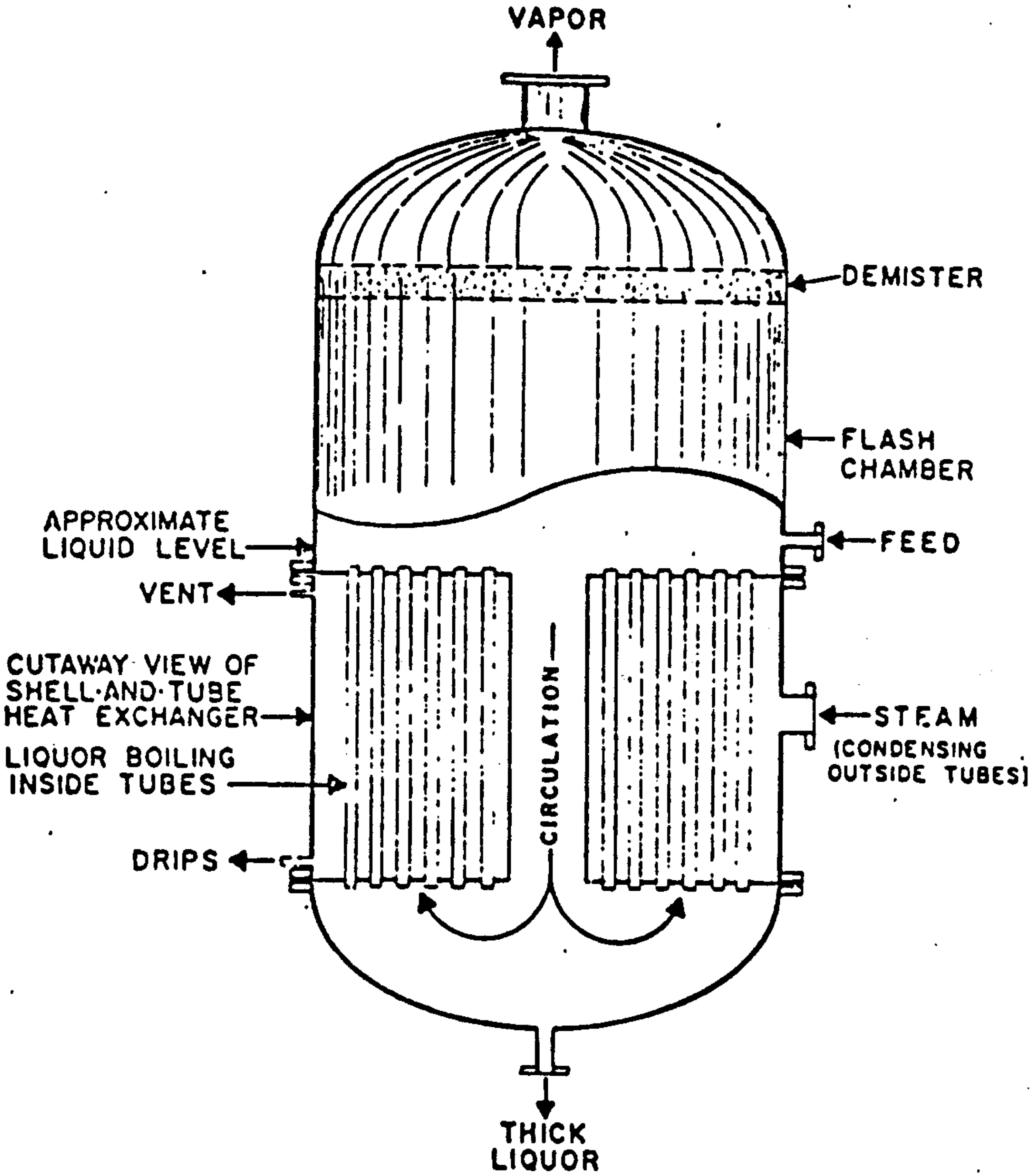
6. LAYOUT OF A CRYSTALLIZER SYSTEM FOR VOLUME REDUCTION OF LIQ
RADWASTE (COURTESY OF GILBERT/COMMONWEALTH COMPANIES' REA
PA., AND HPD CORPORATION, GLEN ELLYN, ILL.)



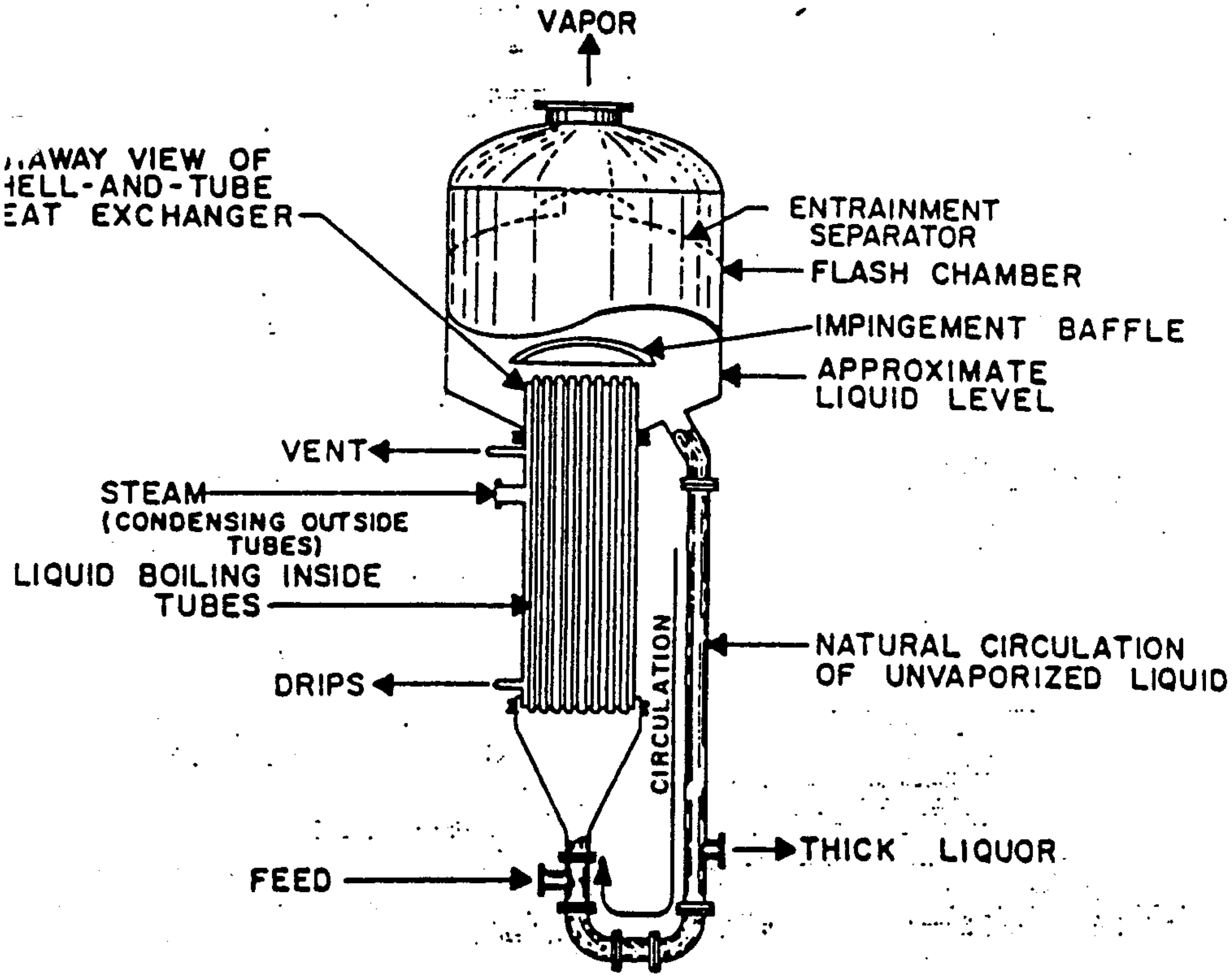
THIN FILM EVAPORATOR (VERTIC



IG. 5. THIN-FILM EVAPORATOR (HORIZONTAL TYPE)



3. SHORT-TUBE VERTICAL (CALANDRIA OR STANDARD) EVAPORA



gure 5-5 Natural-circulation, rising-film, long-tube vertical evaporator with an inter-
l heater. Source: (DOE 1984).

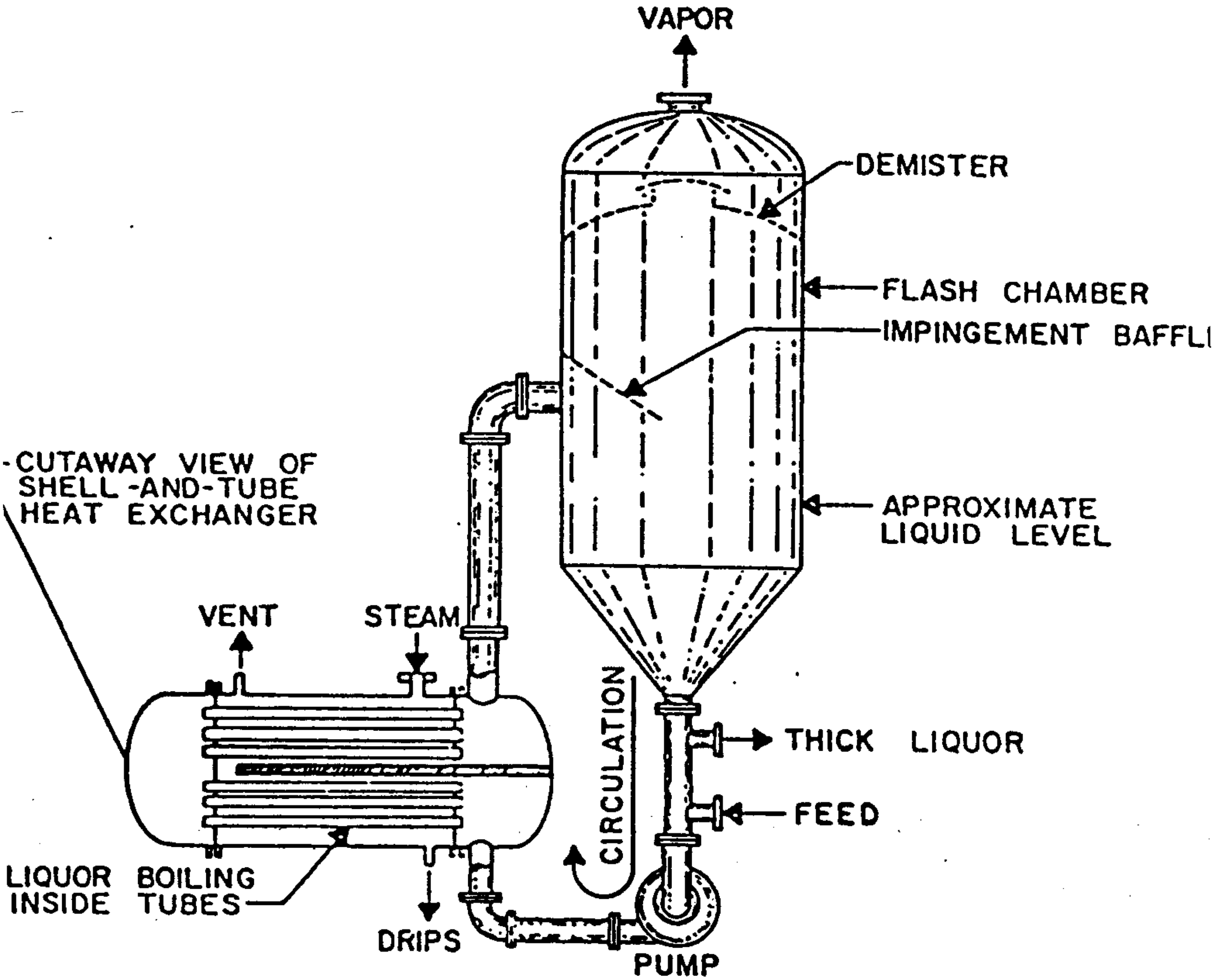
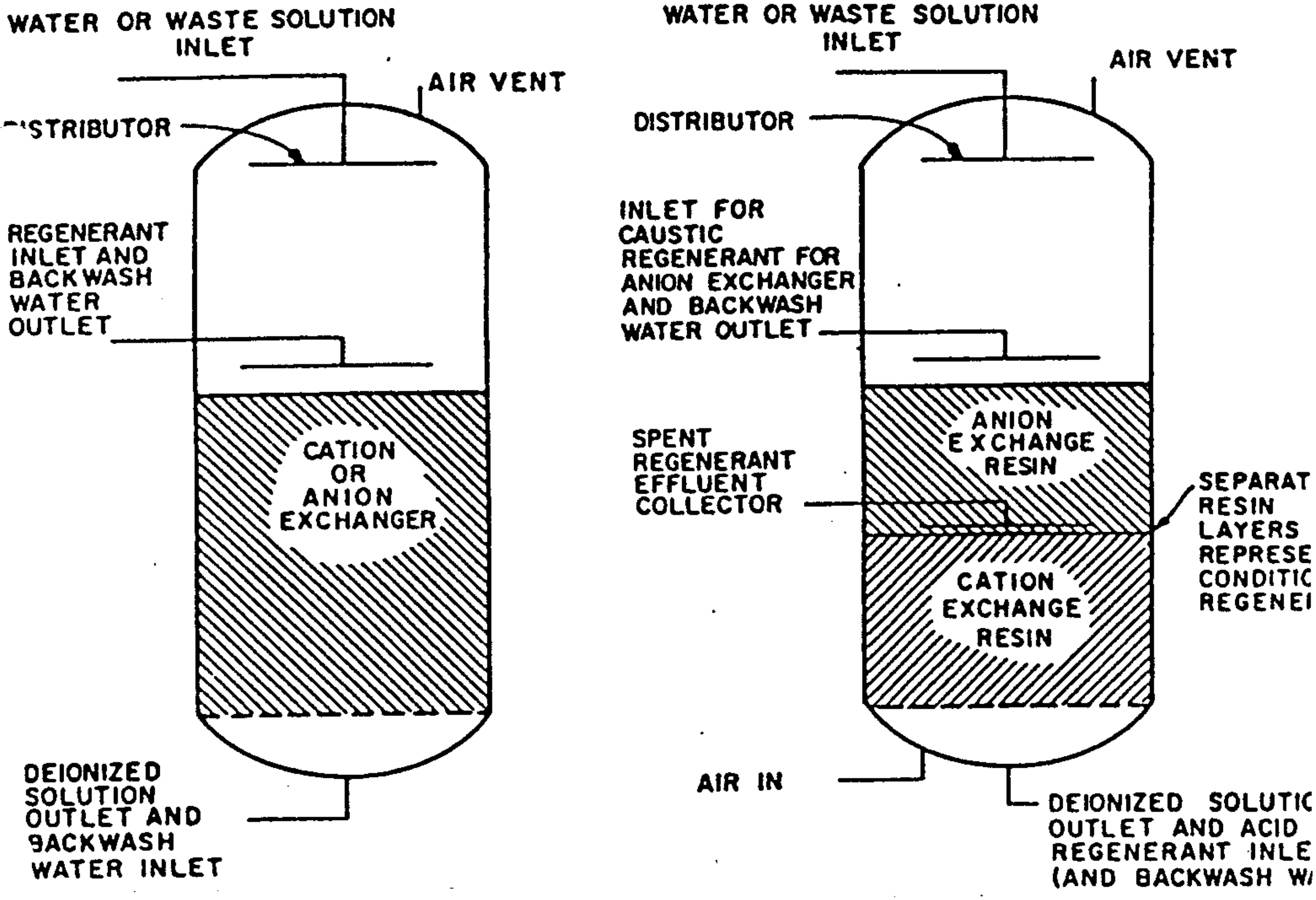


FIG. 7. FORCED-CIRCULATION EVAPORATOR WITH AN EXTERNAL HORIZONTAL HEATER



(a) SEPARATE BED SYSTEM

(b) MIXED-BED SYSTEM

FIG. 9. SCHEMATIC DIAGRAM OF MIXED-BED AND SEPARATE-BED ION EXCHANGE SYSTE

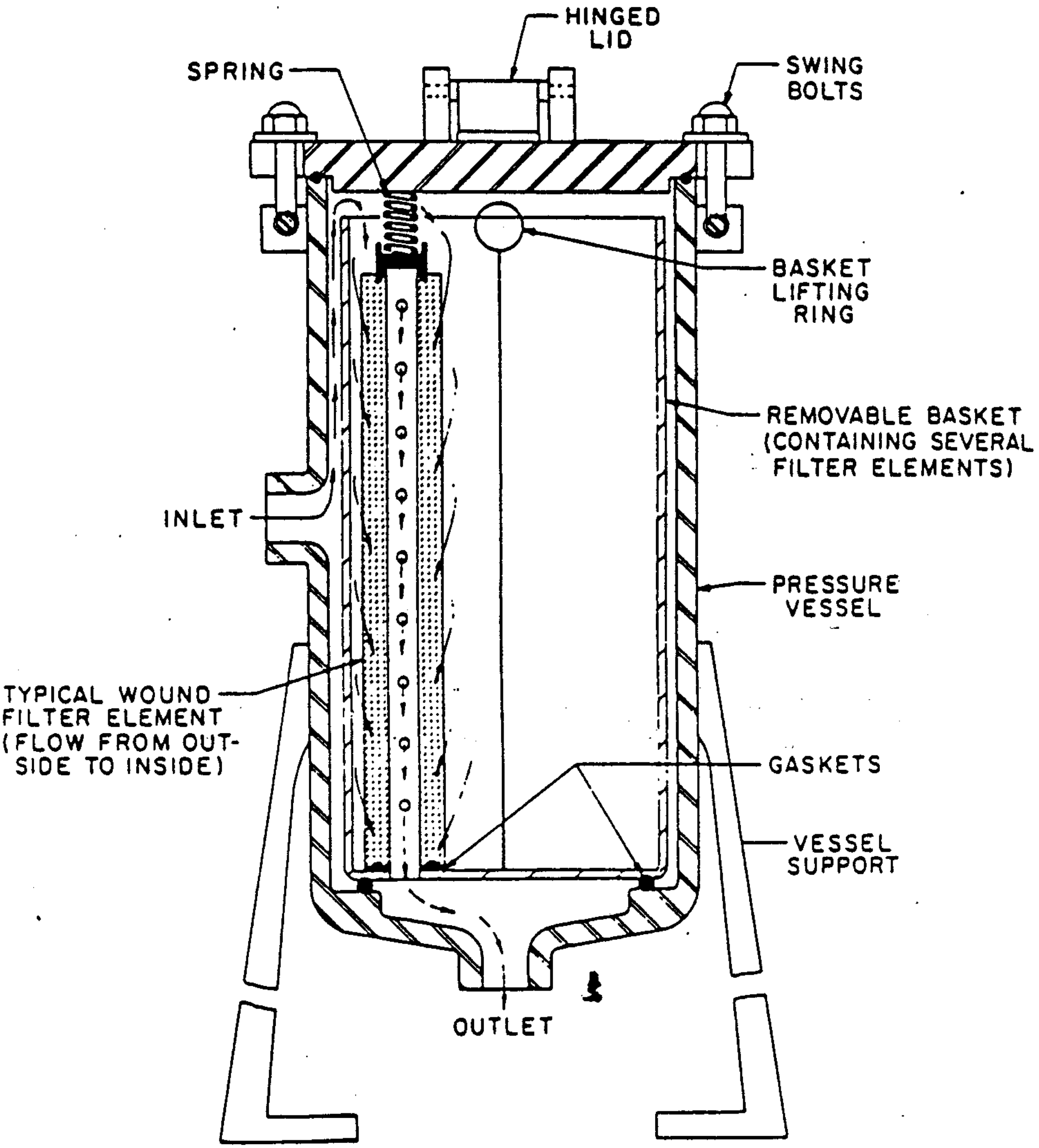
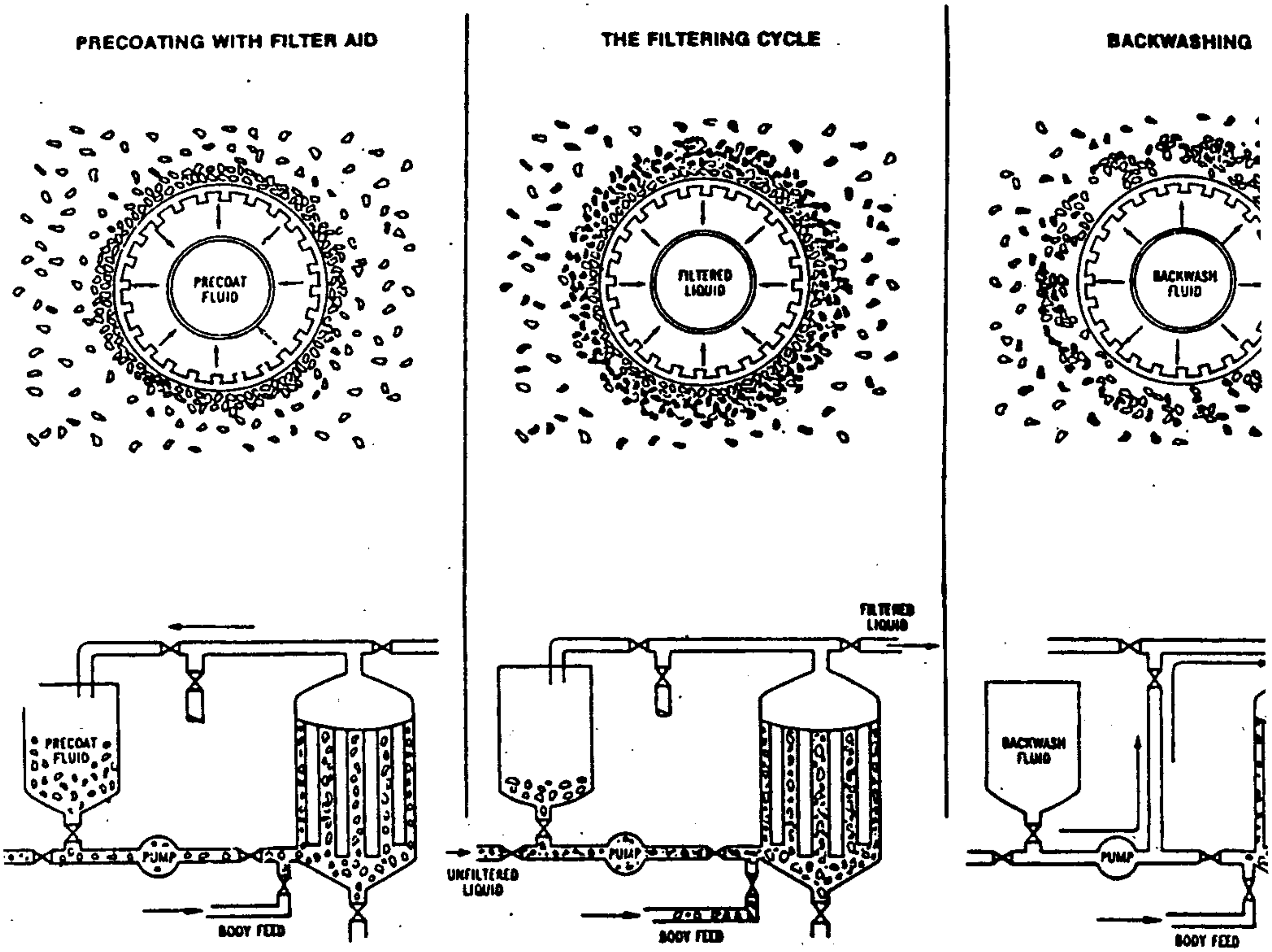


Figure 5-3 Typical disposable cartridge filter illustrating liquid flow from outside inside of element. Source: (DOE 1984).



PRECOATING WITH FILTER AID

THE FILTERING CYCLE

BACKWASHING

FIG. 10. OPERATIONAL CYCLE OF A PRESSURE PRECOAT FILTER HAVING VERTICAL TUBULAR ELEMENTS
(From Croll-Reynolds brochure on ClaRite filters)

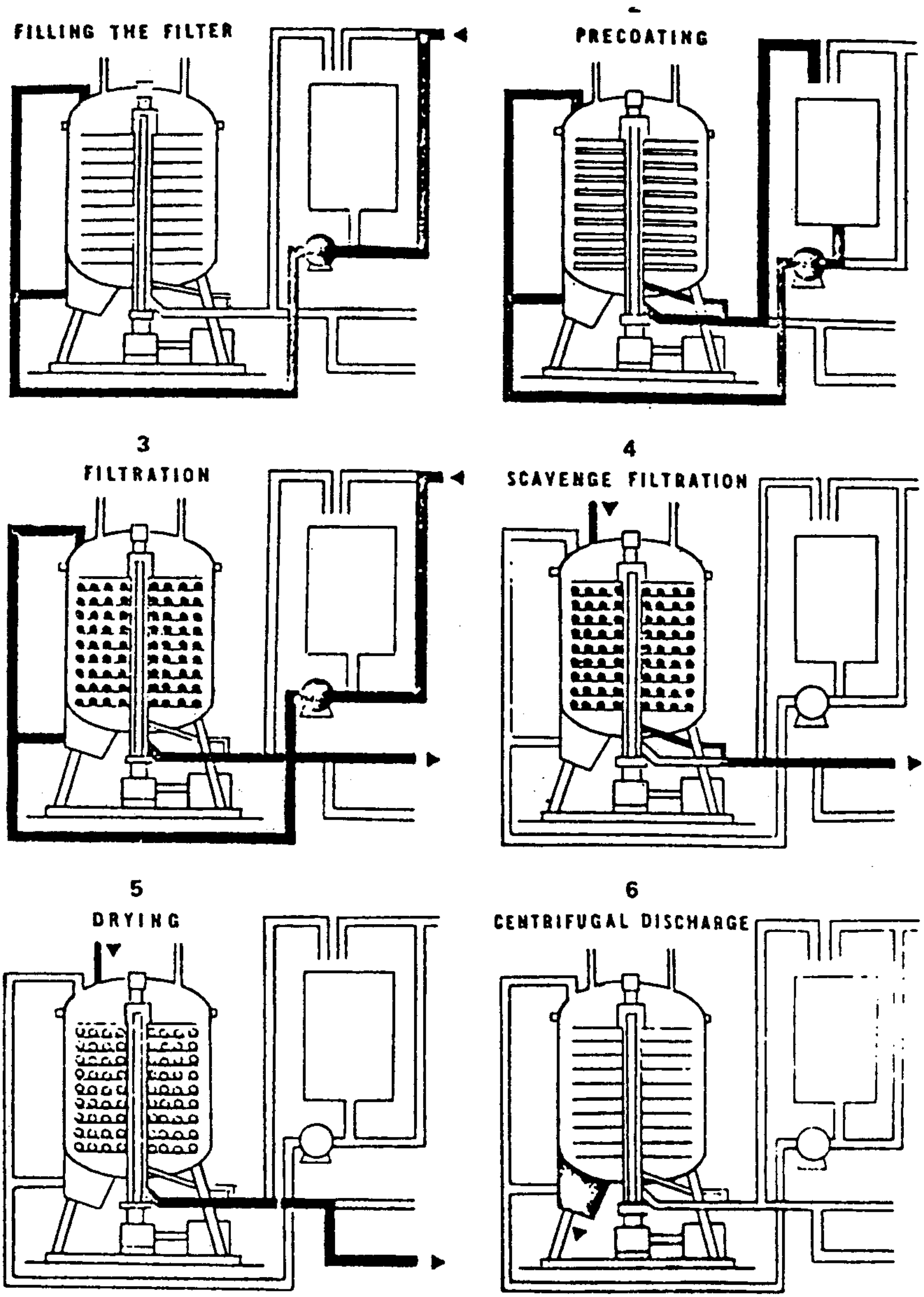


FIG. 11. OPERATIONAL CYCLE OF A CENTRIFUGAL PRECOAT FILTER
(From Nuwco, Inc. brochure on Schenk filters.)

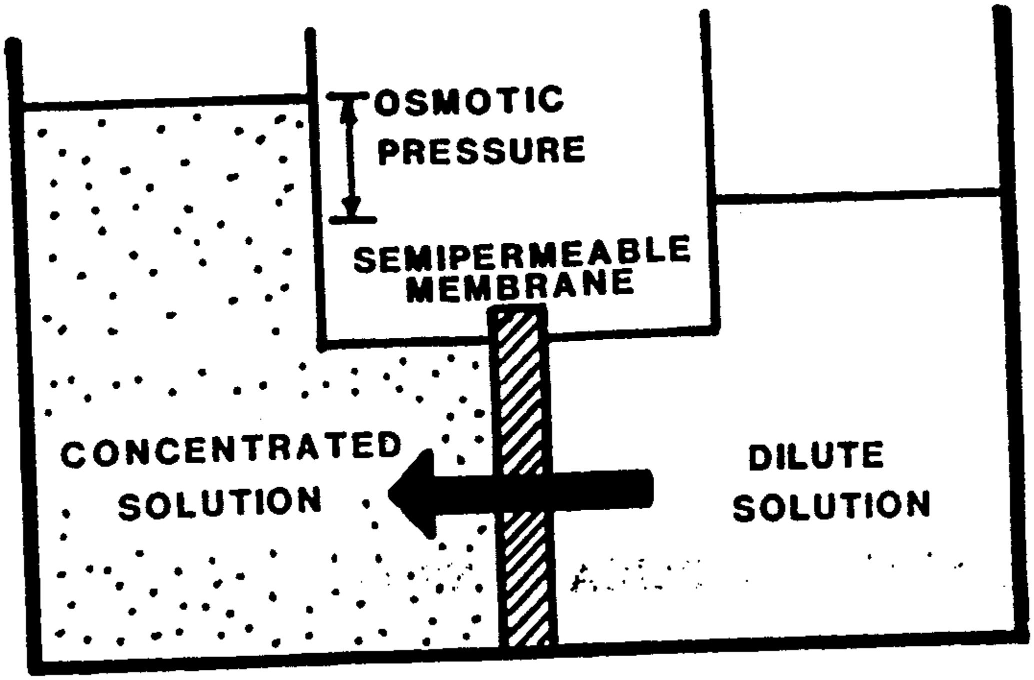
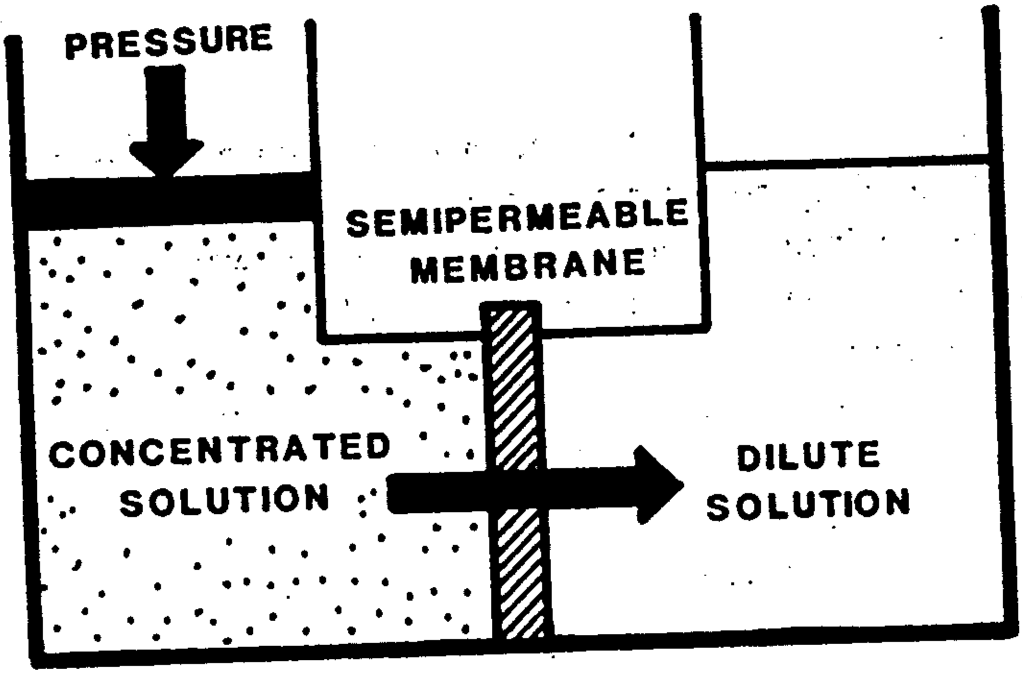


Figure 14.1 Osmosis: normal flow from low to high concentration.



igure 14.2 Reverse osmosis: flow reversed by application of pressure to high-conce
tration solution.

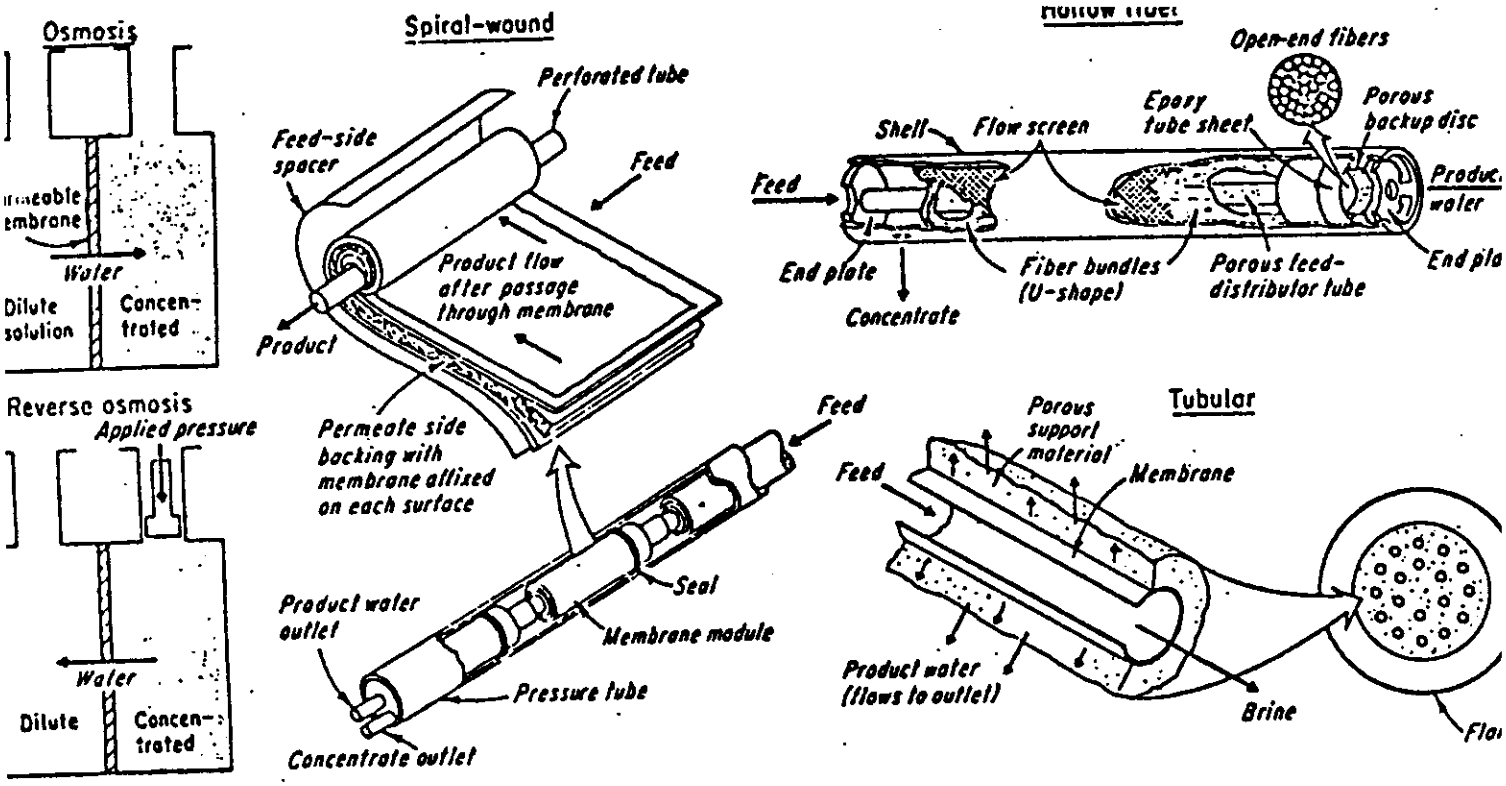


FIG. 12. DRAWINGS OF SEVERAL COMMERCIALLY-AVAILABLE REVERSE OSMOSIS DESIGNS
(Reprinted with permission from POWER, June 1973)

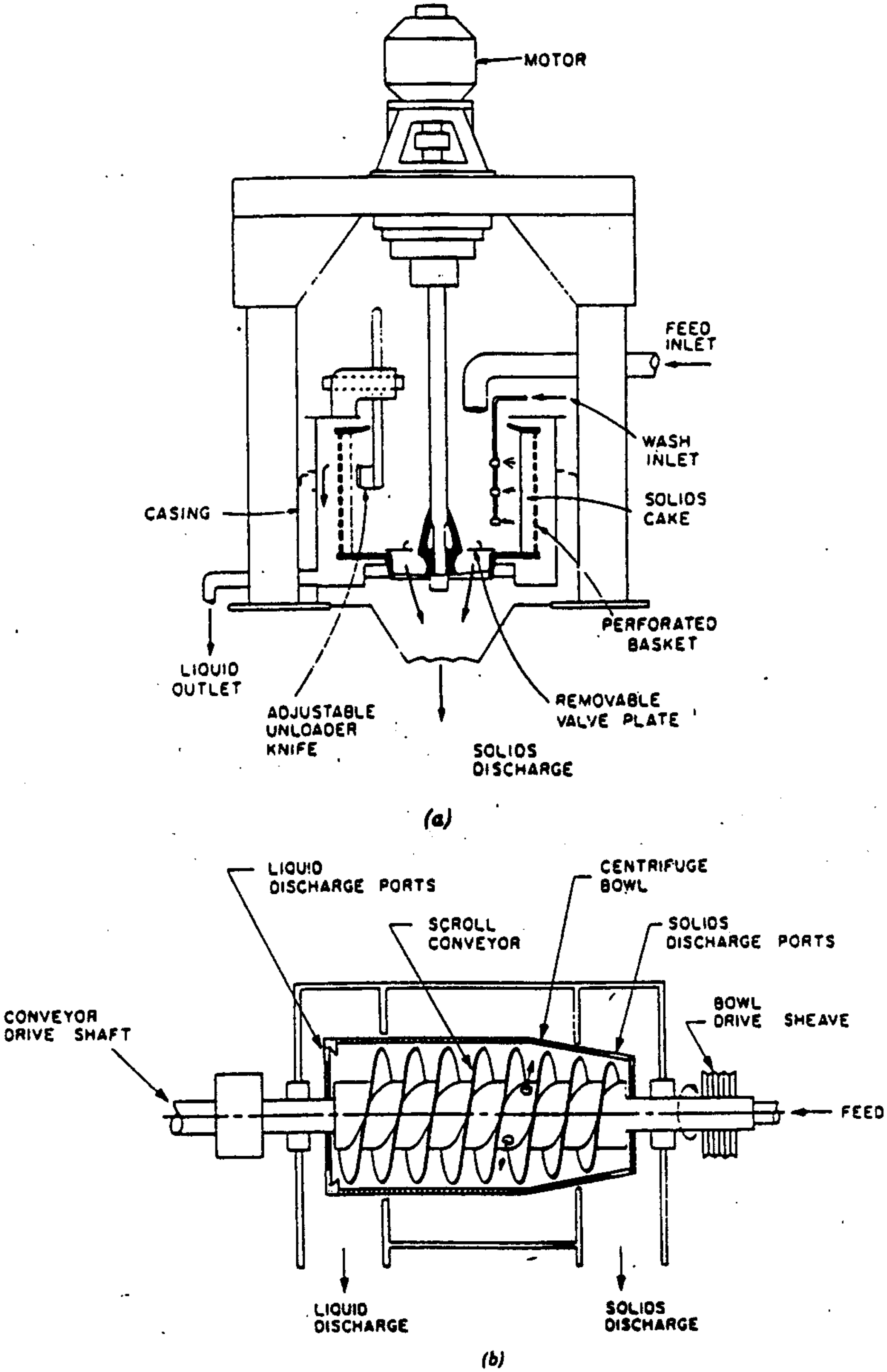


Figure 5-7 Typical centrifuge types (a) top suspended perforated-basket centrifuge and (b) helical conveyor solid-bowl centrifuge. Source: (DOE 1984).

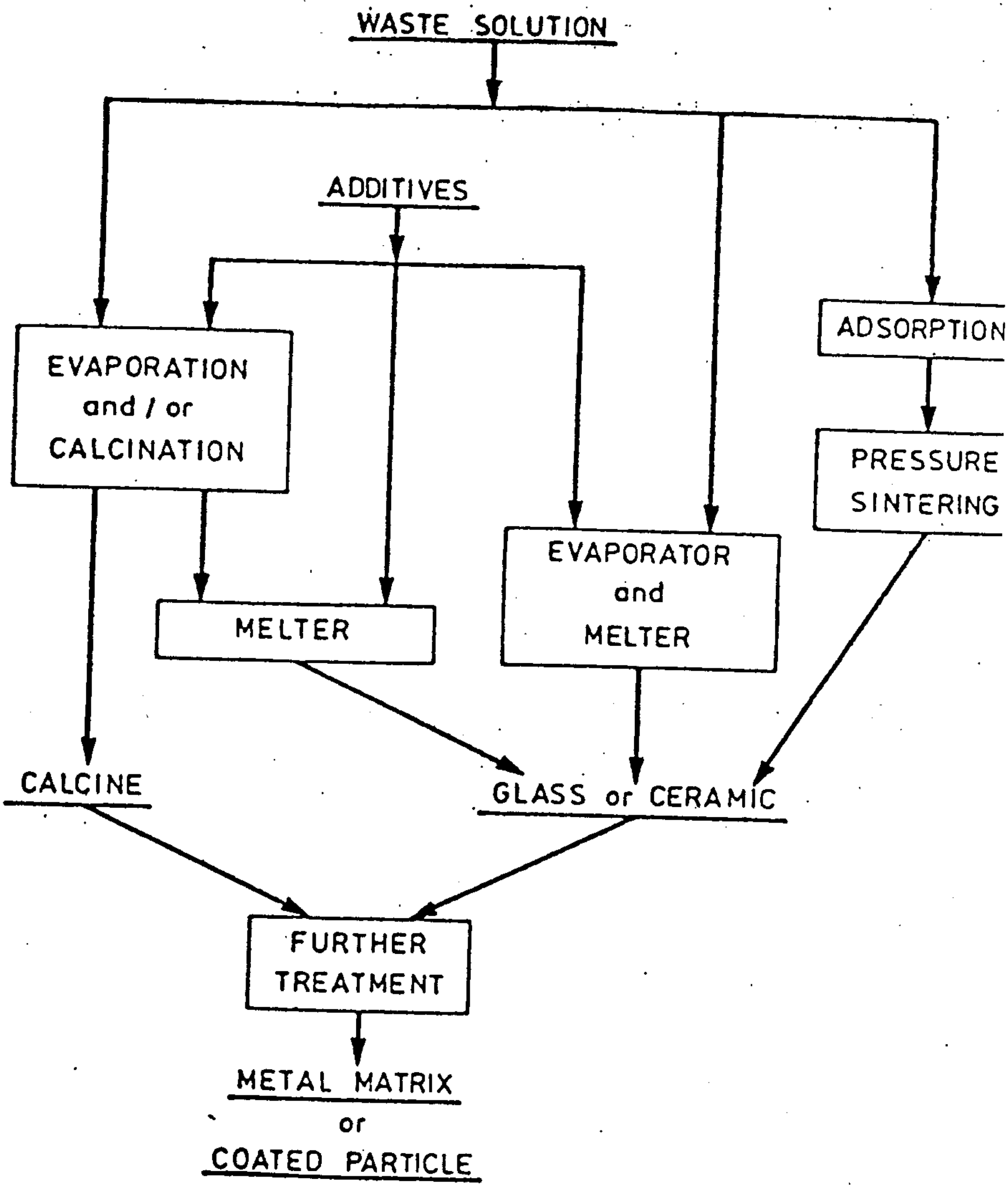


Figure 1: Basic Solidification Processes

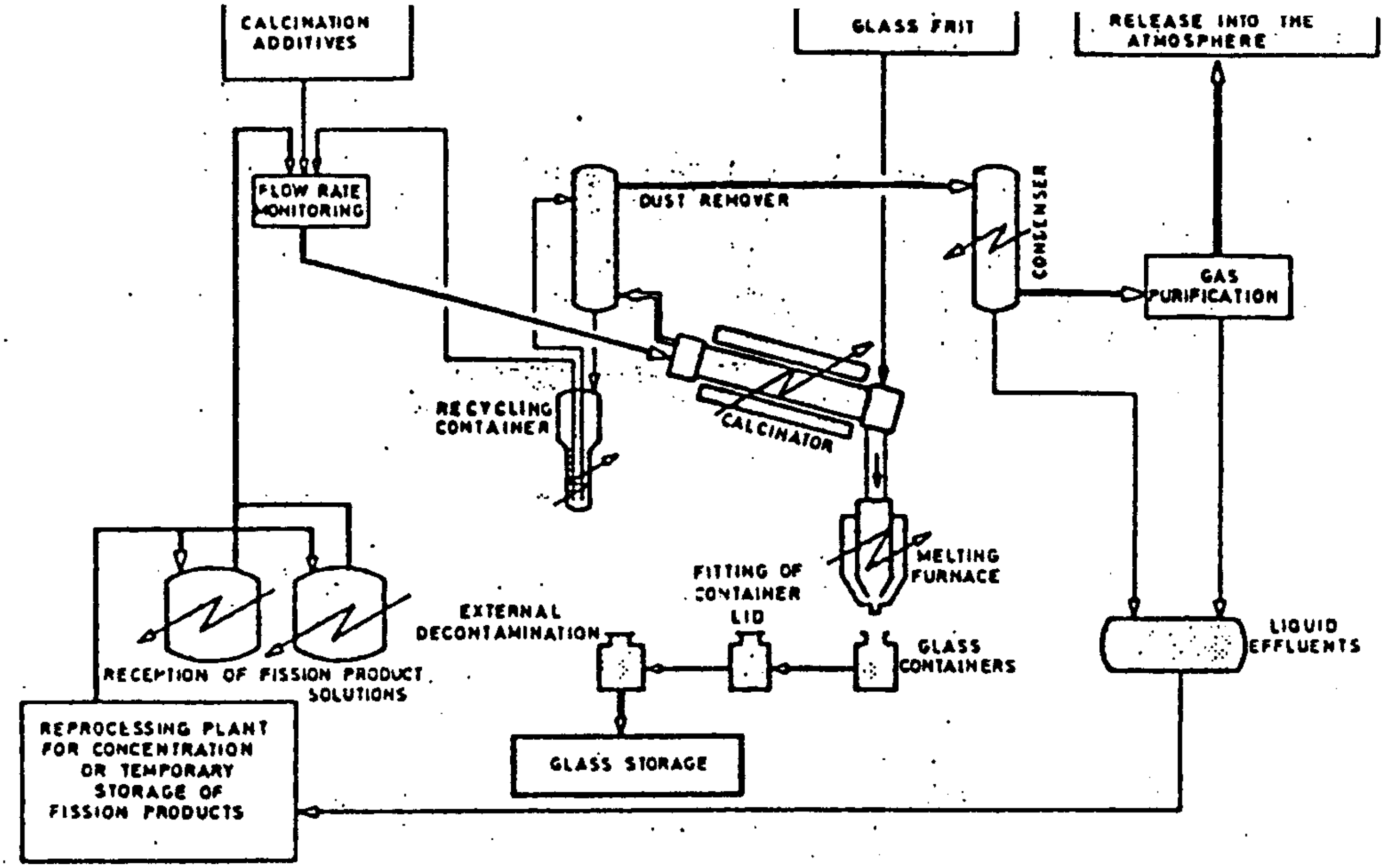
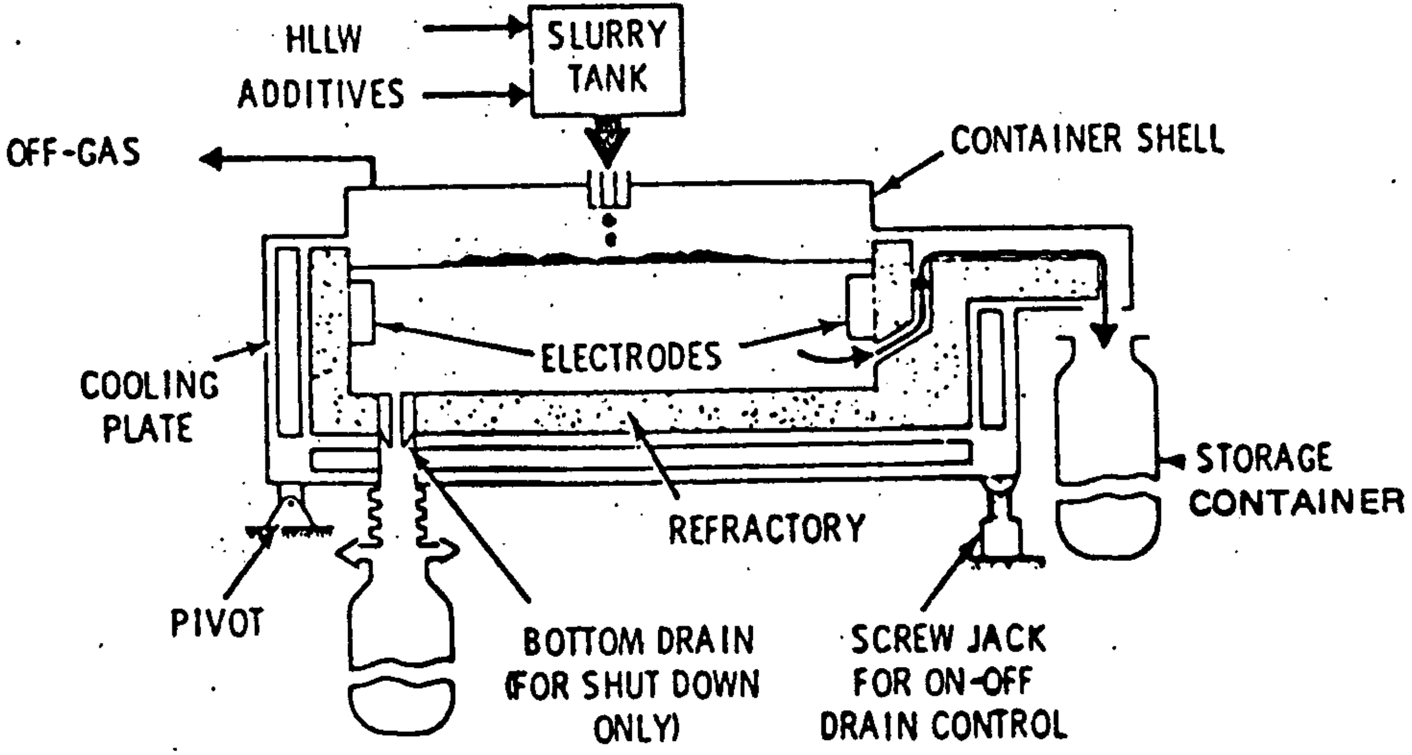
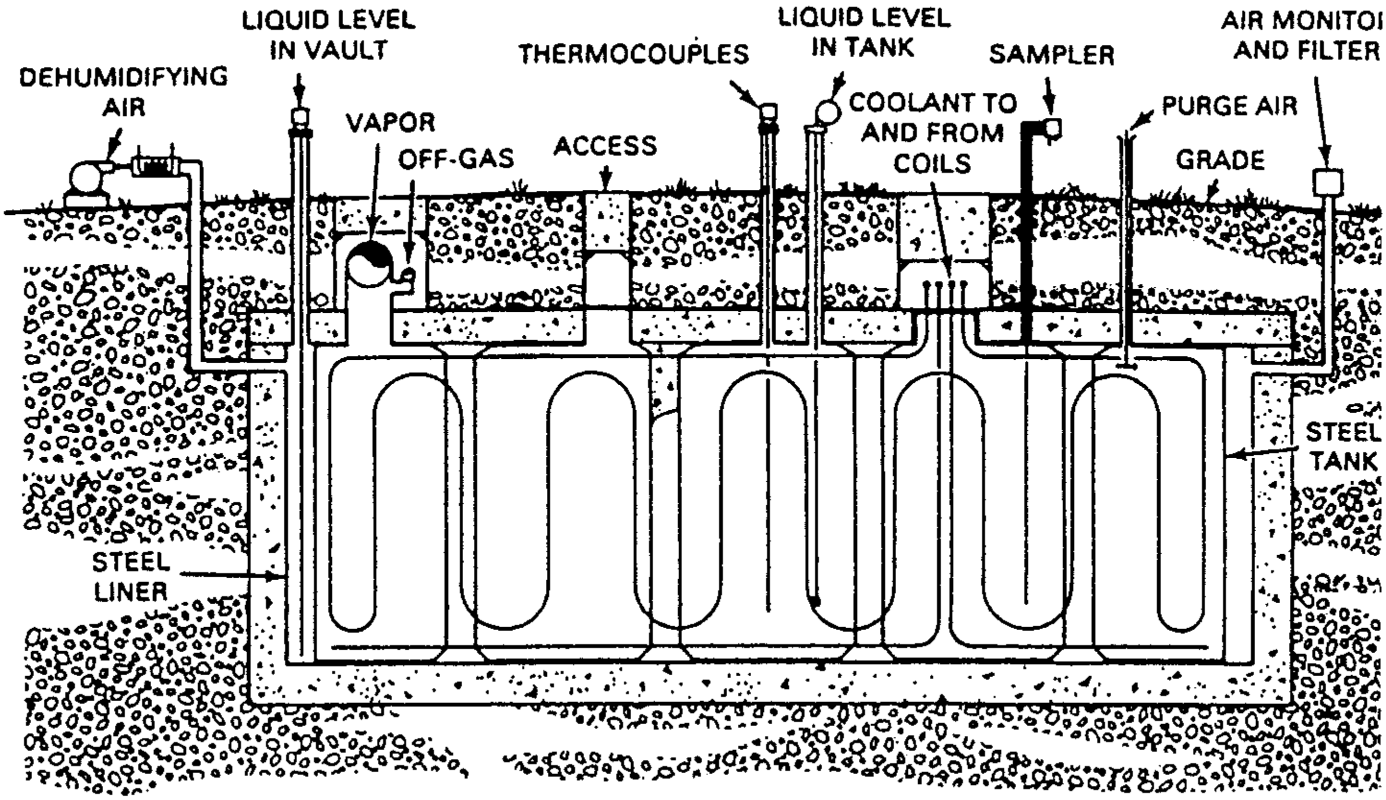
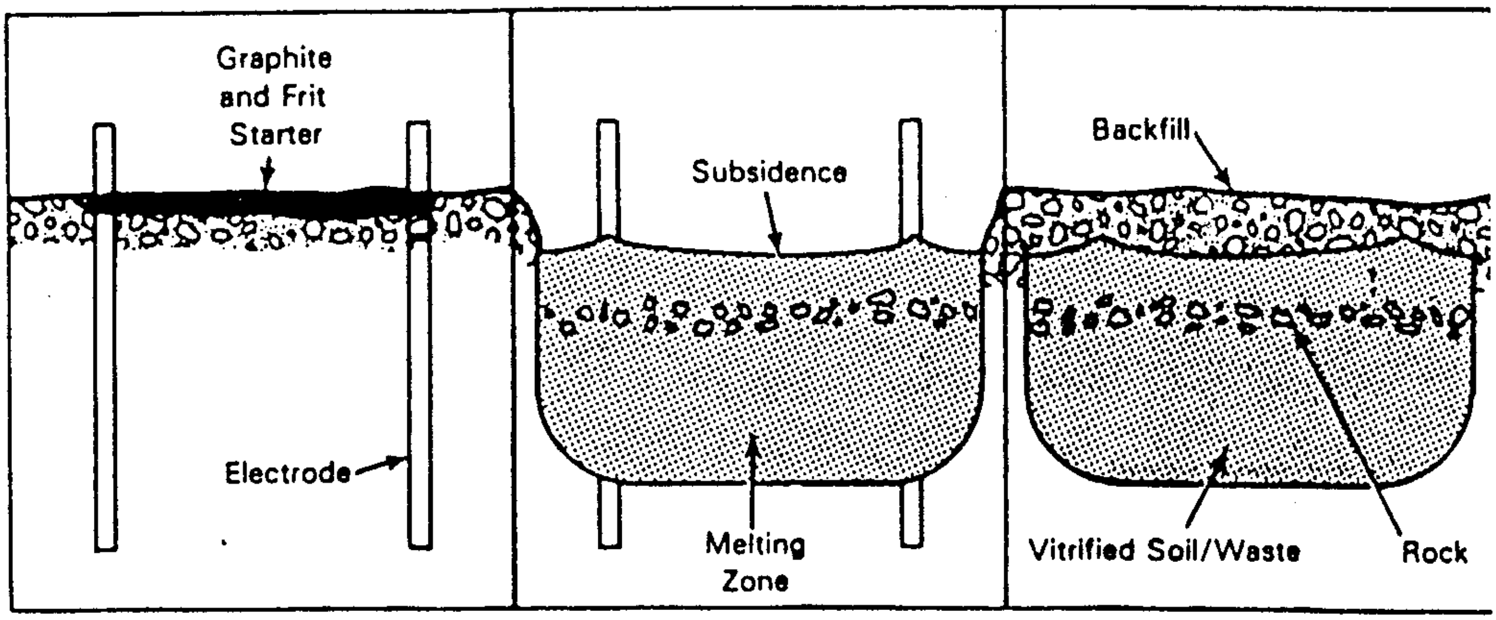


Figure 2: Simplified flowsheet of vitrification plant at Marcoule (AVM)





Defense waste storage tank. (From *The Safety of Nuclear Reactors and Related Fa ties,* WASH-1250, U.S. Atomic Energy Commission, July 1973.)



In situ vitrification. (Courtesy of the Pacific Northwest Laboratory.)

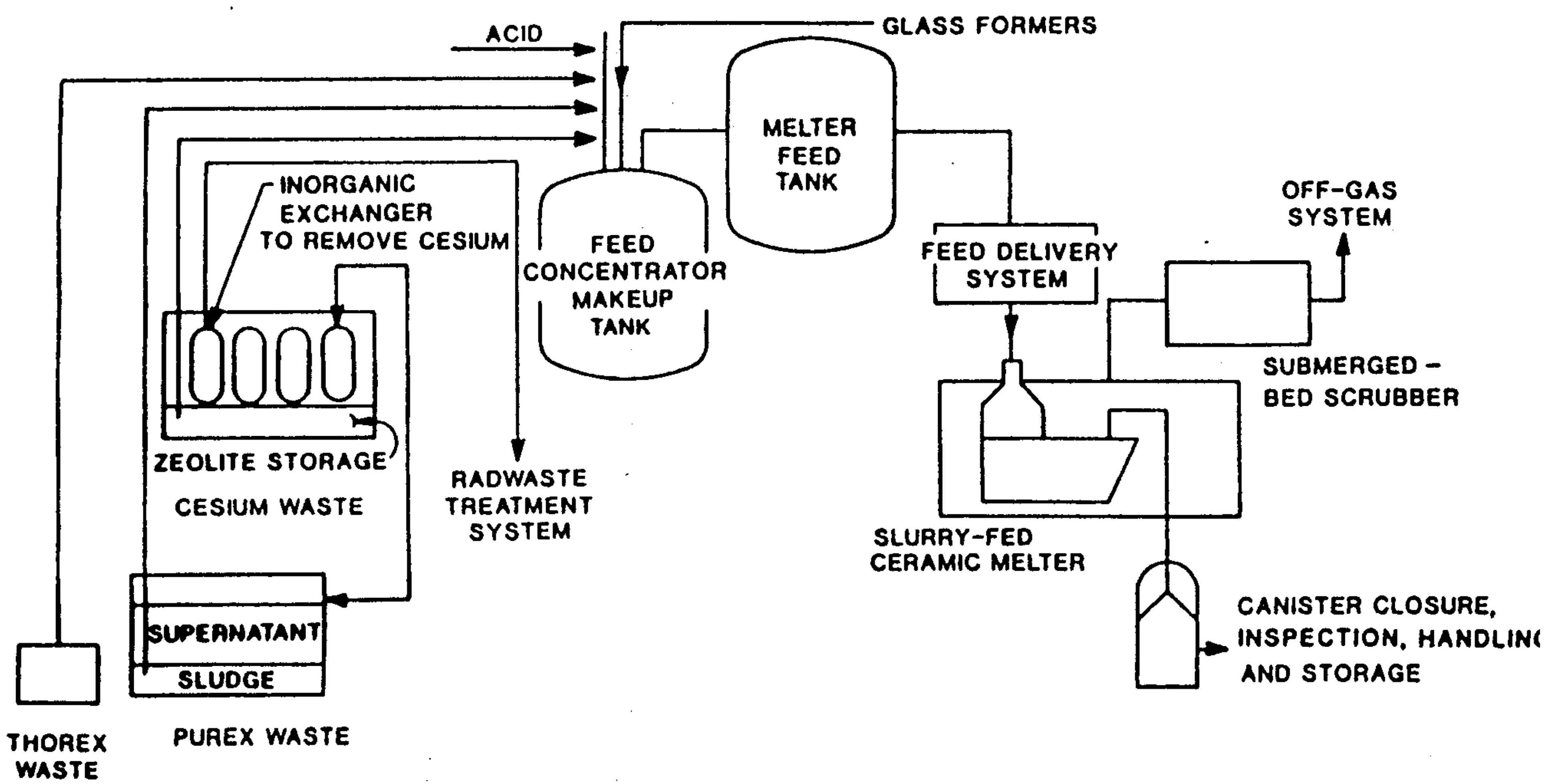
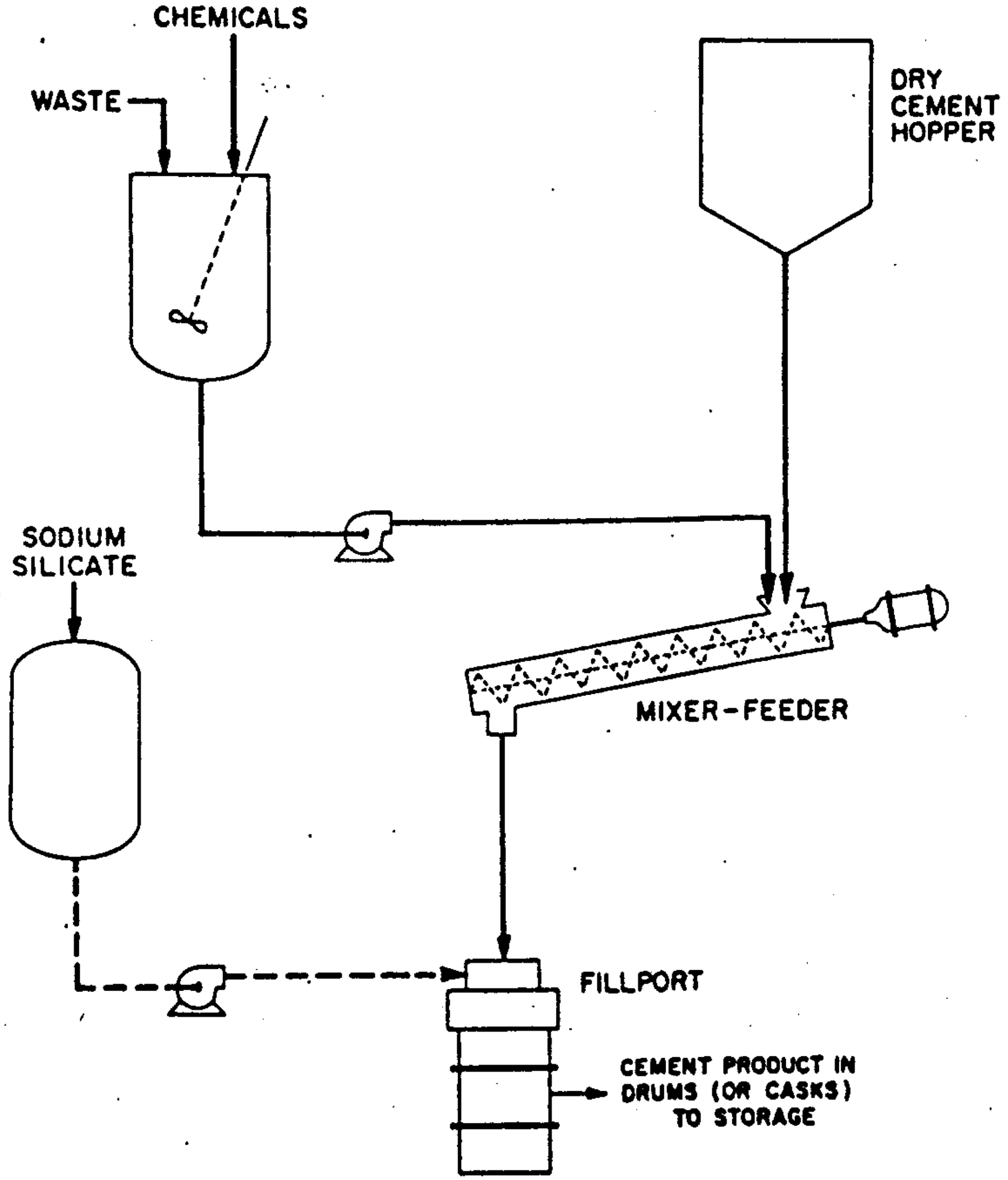
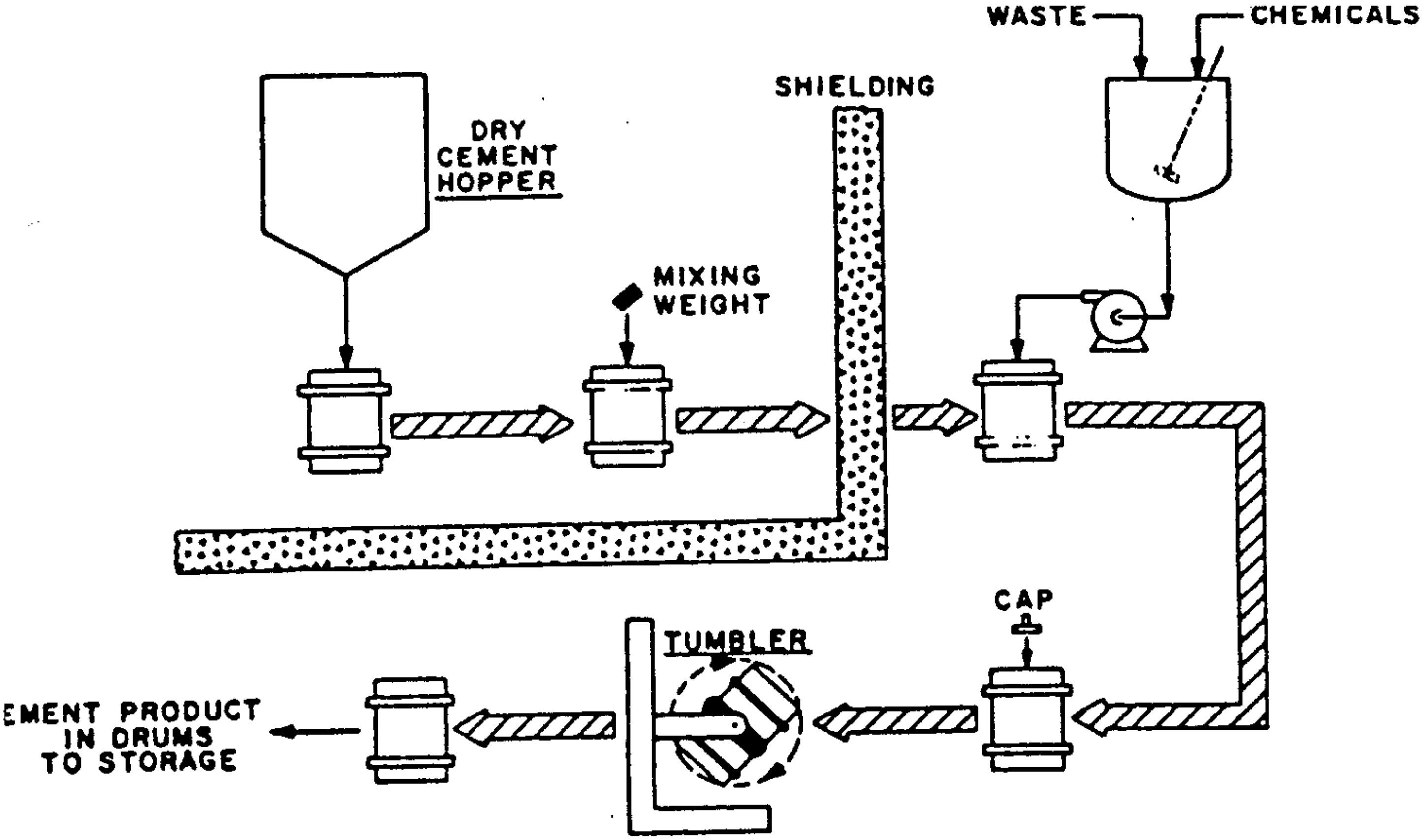


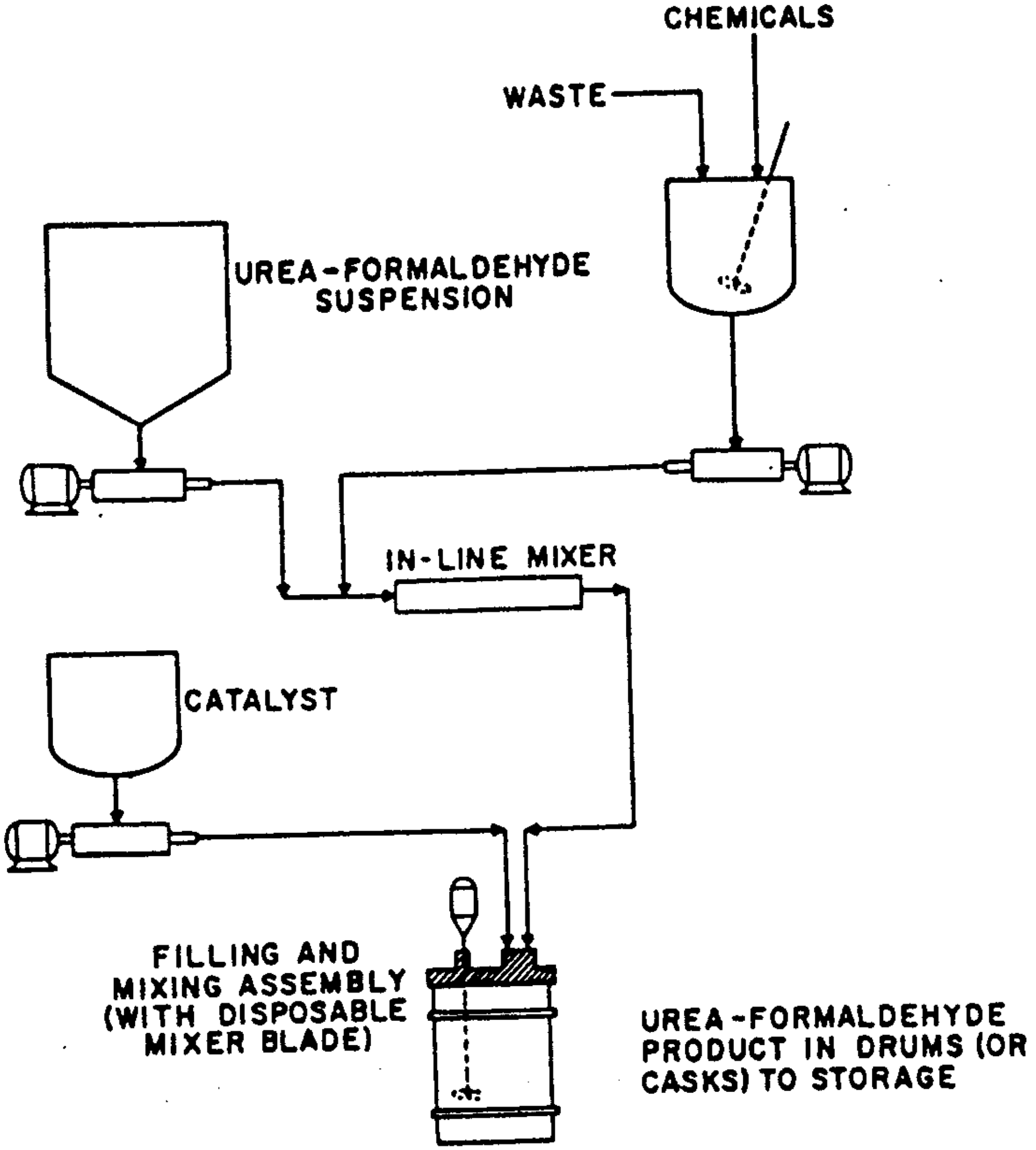
Figure 2-4 Solidification of commercial high-level waste at West Valley. Source: (DOE
1987).



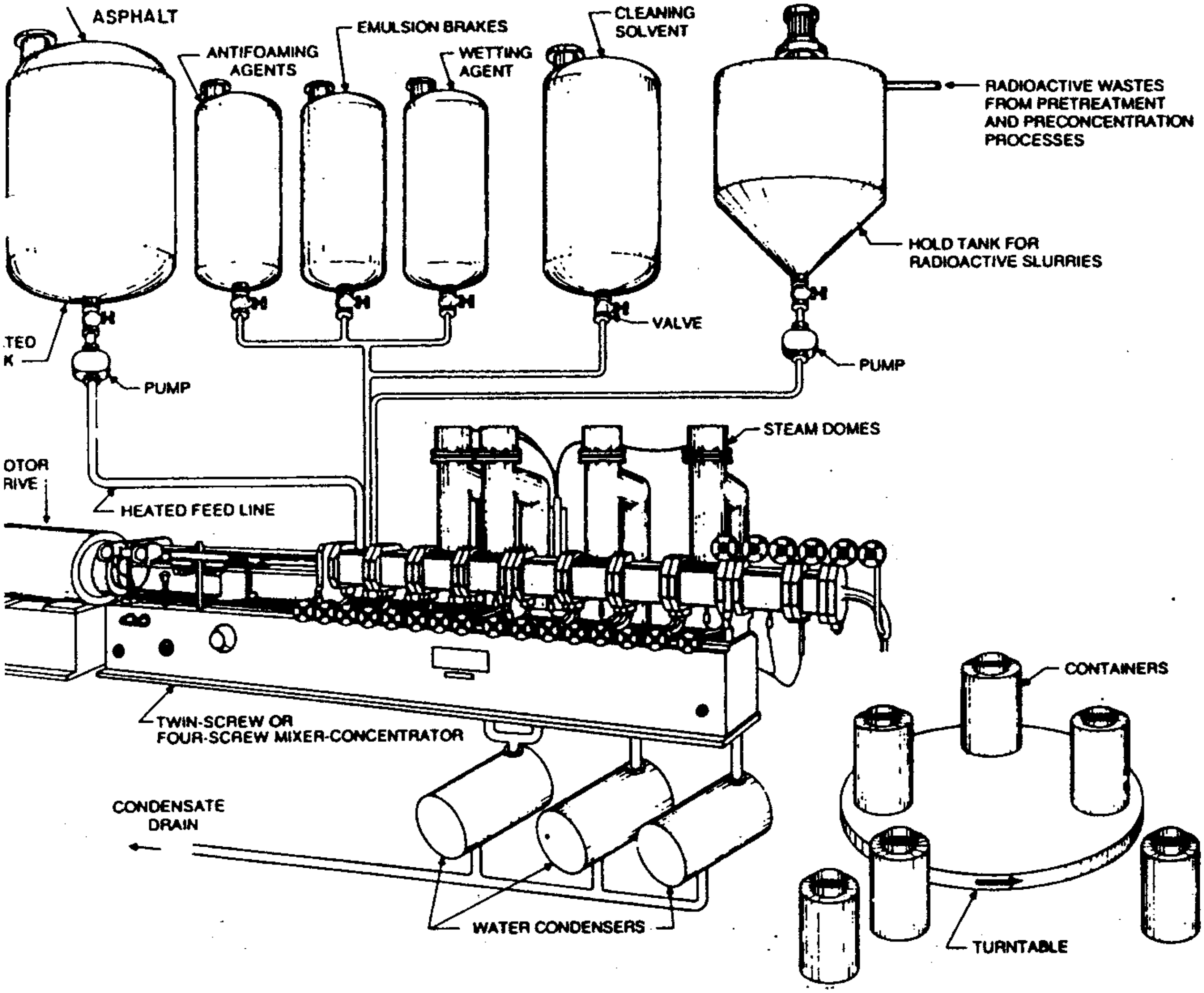
-LINE MIXING PROCESS FOR INCORPORATING RADWASTE IN CEMENT



8. IN-DRUM MIXING PROCESS FOR INCORPORATING RADWASTE IN CEM



STIRRED-VESSEL PROCESS FOR INCORPORATING RADWASTE IN UREA-FORMALDEHYDE RESIN



IG. 7. WERNER AND PFLEIDERER EXTRUDER/VAPORATOR PROCESS FOR VOLUME REDUCTION AND SOLIDIFICATION IN ASPHALT

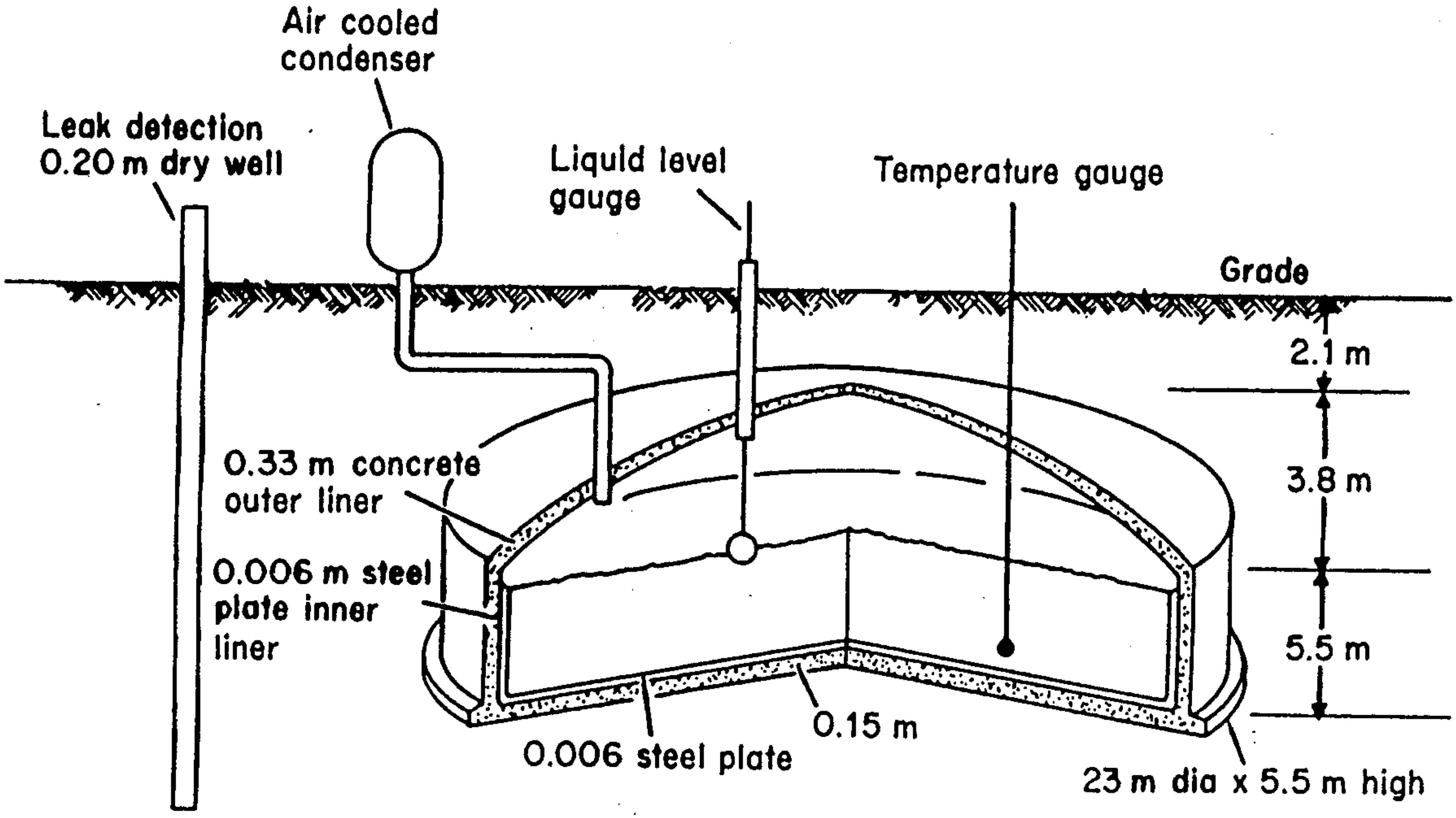


Figure 2.4 Diagram of a tank for holding reprocessing waste. (Based on U.S. Department of Energy)

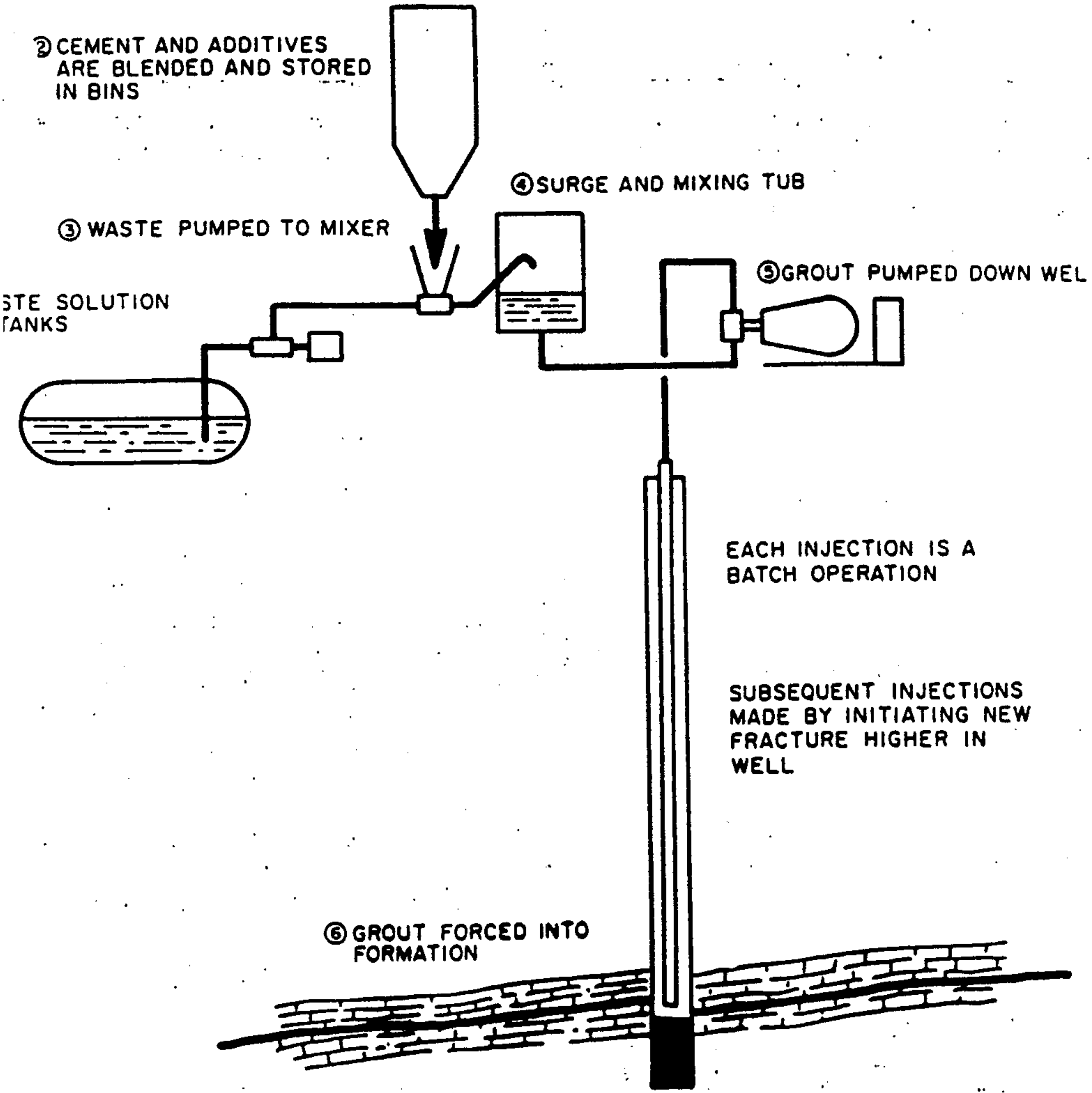


Fig. 6. Hydrofracture flow sheet and operations.