United States Patent [19]

Husseiny

[11] **Patent Number: 5,055,237**

[45] **Date of Patent: Oct. 8, 1991**

[54] **METHOD OF COMPACTING LOW-LEVEL RADIOACTIVE WASTE UTILIZING FREEZING AND ELECTRODIALYZING CONCENTRATION PROCESSES**

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[73] Assignee: **Technology International Incorporated**, LaPlace, La.

[21] Appl. No.: **566,880**

[22] Filed: **Aug. 14, 1990**

[51] **Int. Cl.**^{5} **G21F 9/08**

[52] **U.S. Cl.** .... **252/631**; 252/626; 252/633; 204/1.5; 204/182.5; 210/682; 210/640; 210/642; 210/651; 23/295 R

[58] **Field of Search** .... 252/627, 628, 629, 631, 252/633; 204/1.5, 182.5; 210/640, 642, 651, 682; 260/707; 23/295 R

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Primary Examiner—Brooks H. Hunt
Assistant Examiner—Ngoclan Mai
Attorney, Agent, or Firm—Sixbey, Friedman, Leedom & Ferguson

[57] **ABSTRACT**

A volume reduction process comprises combinations of a freezing eutectic, bulk, indirect crystallization process and a radwaste electrodialysis process. When employed as a liquid radioactive waste management system (LWMS) for light water reactors (LWR's), this process is designed to process liquid low-level radioactive waste (LLW) and to handle the radioactive influent in nuclear power plants (NPPs) prior to release to the environment and disposal of the radioactive material present in the waste streams.

19 Claims, 8 Drawing Sheets

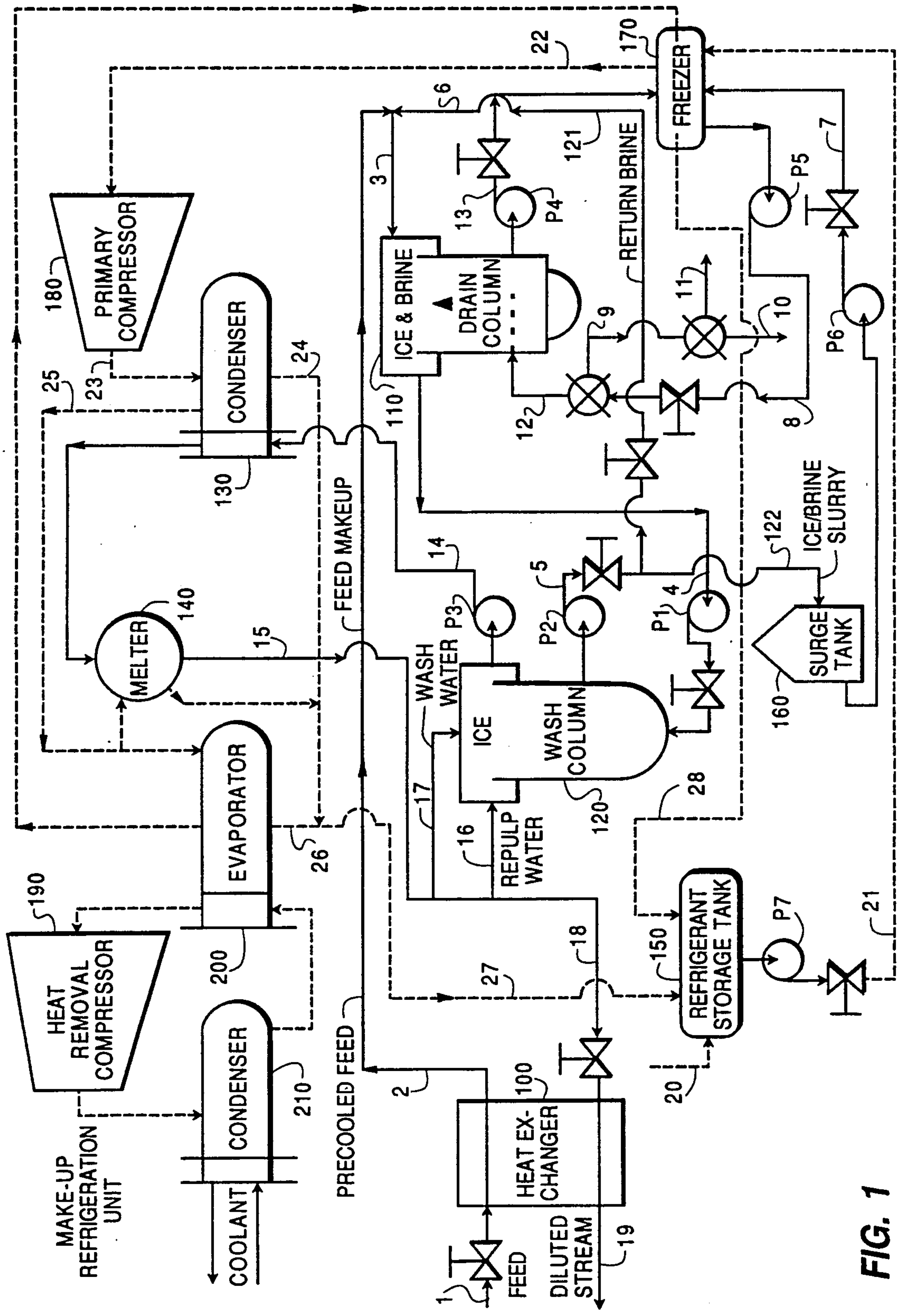

PRIMARY COMPRESSOR
180
CONDENSER
130
MELTER
140
EVAPORATOR
200
HEAT REMOVAL COMPRESSOR
190
CONDENSER
210
MAKE-UP REFRIGERATION UNIT
COOLANT
PRECOOLED FEED
FEED MAKEUP
FEED
1
2
HEAT EX-CHANGER
100
DILUTED STREAM
19
18
REFRIGERANT STORAGE TANK
150
P7
20
21
27
28
26
25
24
23
22
170
FREEZER
ICE & BRINE
DRAIN COLUMN
110
RETURN BRINE
121
3
6
13
P4
12
9
11
10
8
P5
7
P6
ICE/BRINE SLURRY
122
SURGE TANK
160
P1
4
P2
5
P3
14
15
WASH WATER
ICE
WASH COLUMN
120
17
16
REPULP WATER

FIG. 1

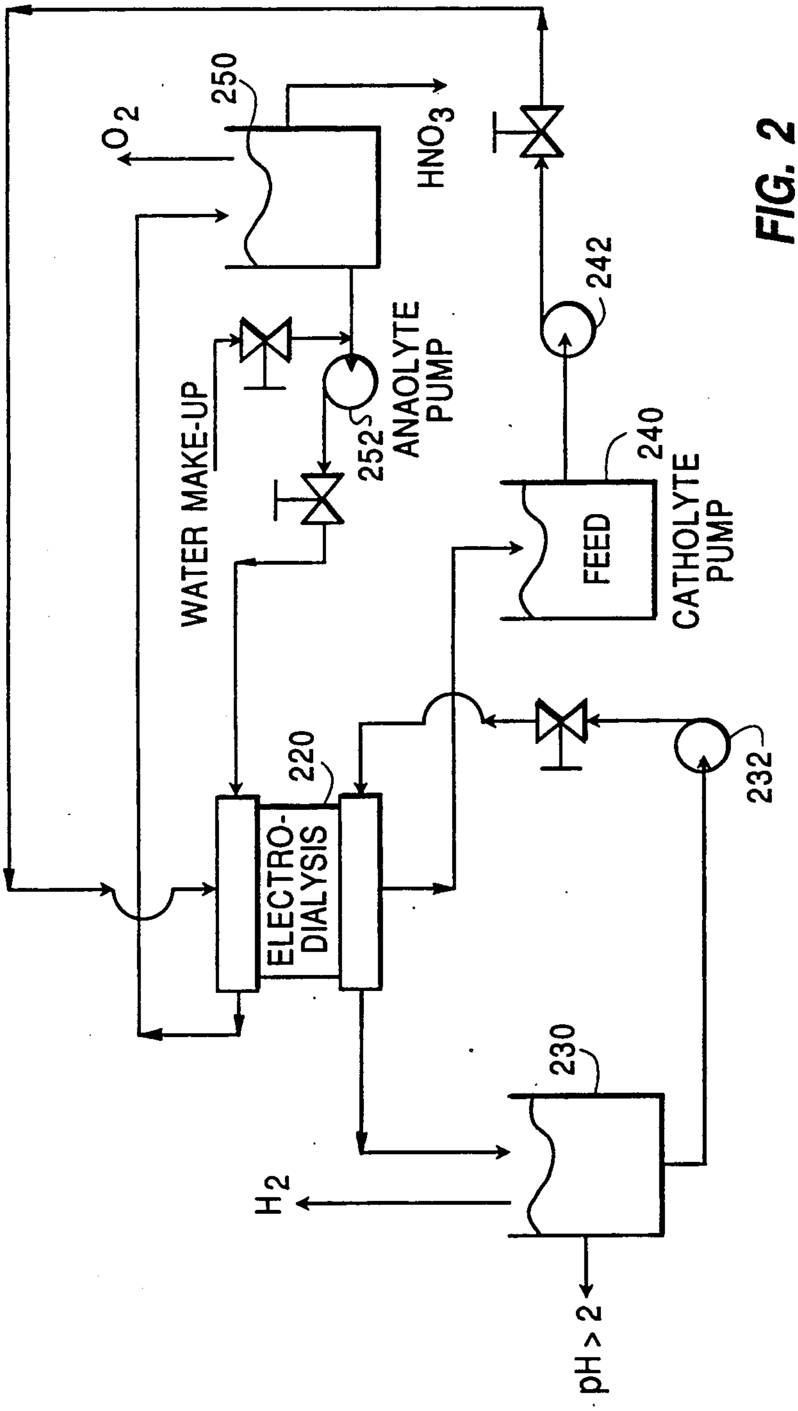

250
O_2
HNO_3
WATER MAKE-UP
252
ANAOLYTE PUMP
242
240
FEED
CATHOLYTE PUMP
220
ELECTRO-DIALYSIS
232
230
H_2
pH > 2

FIG. 2

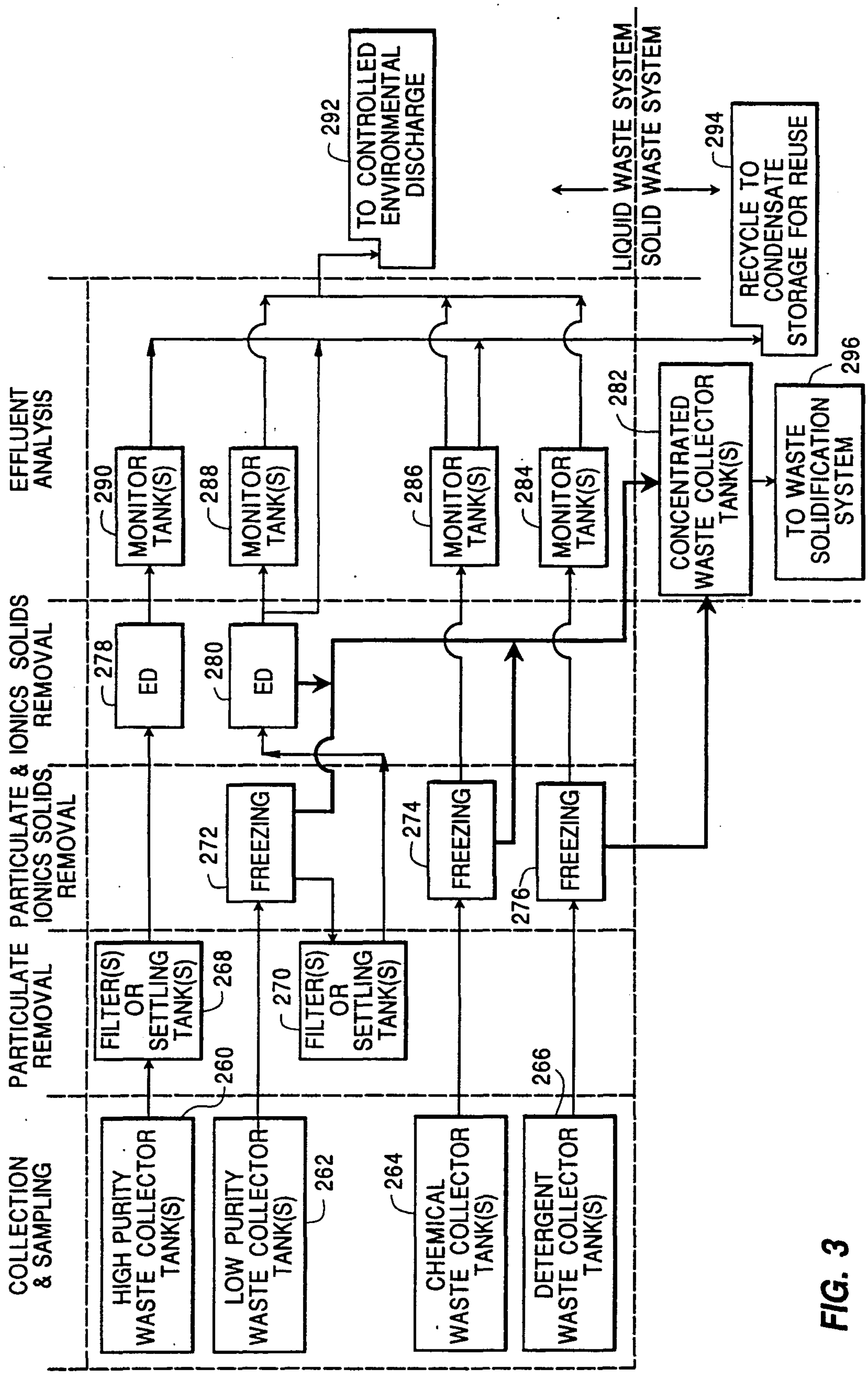

COLLECTION & SAMPLING
PARTICULATE REMOVAL
PARTICULATE & IONICS SOLIDS REMOVAL
IONICS SOLIDS REMOVAL
EFFLUENT ANALYSIS
HIGH PURITY WASTE COLLECTOR TANK(S)
260
LOW PURITY WASTE COLLECTOR TANK(S)
262
CHEMICAL WASTE COLLECTOR TANK(S)
264
DETERGENT WASTE COLLECTOR TANK(S)
266
FILTER(S) OR SETTLING TANK(S)
268
FILTER(S) OR SETTLING TANK(S)
270
FREEZING
272
FREEZING
274
FREEZING
276
ED
278
ED
280
MONITOR TANK(S)
290
MONITOR TANK(S)
288
MONITOR TANK(S)
286
MONITOR TANK(S)
284
CONCENTRATED WASTE COLLECTOR TANK(S)
282
TO WASTE SOLIDIFICATION SYSTEM
296
TO CONTROLLED ENVIRONMENTAL DISCHARGE
292
LIQUID WASTE SYSTEM
SOLID WASTE SYSTEM
RECYCLE TO CONDENSATE STORAGE FOR REUSE
294

FIG. 3

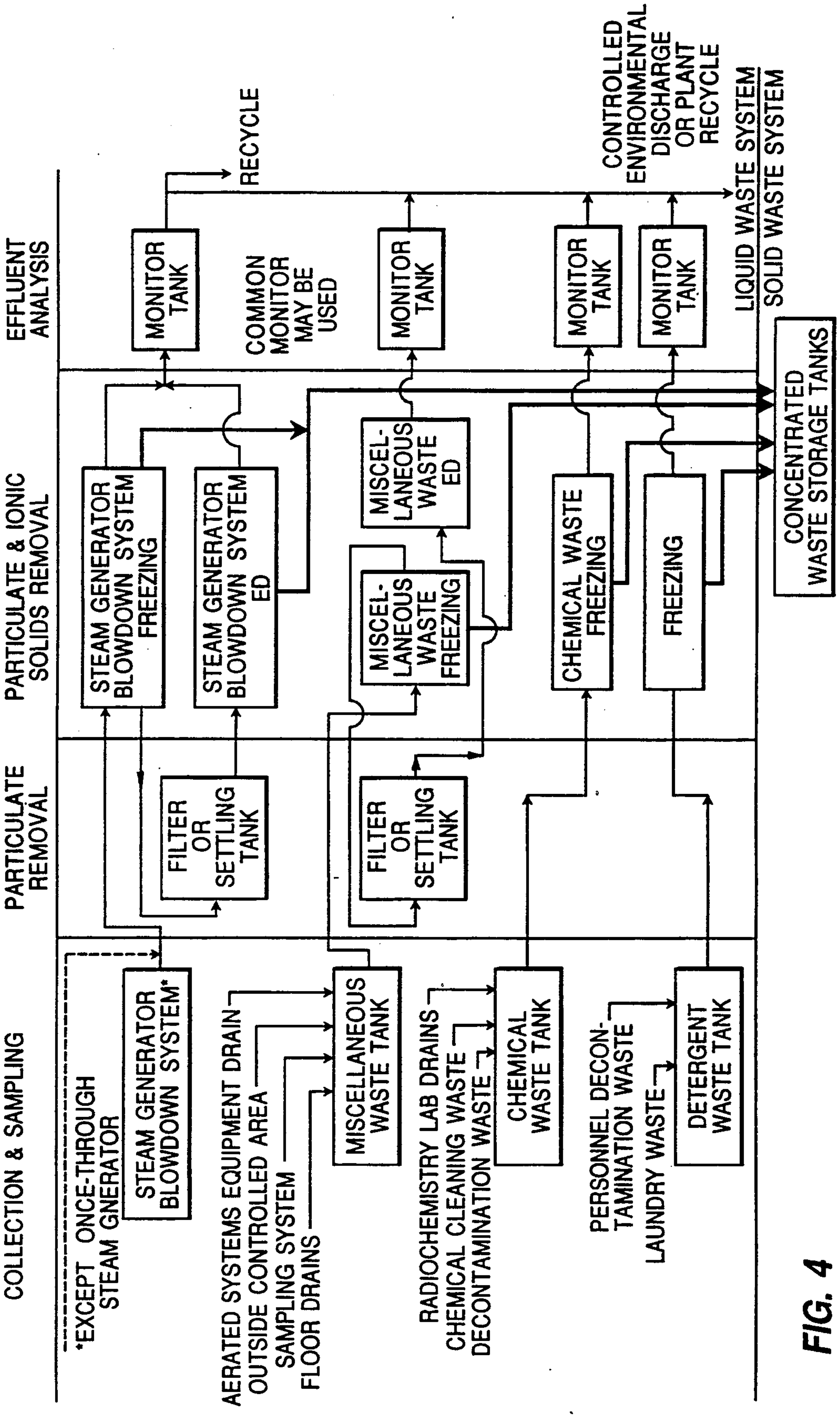

COLLECTION & SAMPLING
PARTICULATE REMOVAL
PARTICULATE & IONIC SOLIDS REMOVAL
EFFLUENT ANALYSIS
*EXCEPT ONCE-THROUGH STEAM GNERATOR
STEAM GENERATOR BLOWDOWN SYSTEM*
AERATED SYSTEMS EQUIPMENT DRAIN
OUTSIDE CONTROLLED AREA
SAMPLING SYSTEM
FLOOR DRAINS
MISCELLANEOUS WASTE TANK
RADIOCHEMISTRY LAB DRAINS
CHEMICAL CLEANING WASTE
DECONTAMINATION WASTE
CHEMICAL WASTE TANK
PERSONNEL DECON-TAMINATION WASTE
LAUNDRY WASTE
DETERGENT WASTE TANK
FILTER OR SETTLING TANK
FILTER OR SETTLING TANK
STEAM GENERATOR BLOWDOWN SYSTEM FREEZING
STEAM GENERATOR BLOWDOWN SYSTEM ED
MISCEL-LANEOUS WASTE FREEZING
MISCEL-LANEOUS WASTE ED
CHEMICAL WASTE FREEZING
FREEZING
CONCENTRATED WASTE STORAGE TANKS
MONITOR TANK
COMMON MONITOR MAY BE USED
MONITOR TANK
MONITOR TANK
MONITOR TANK
RECYCLE
CONTROLLED ENVIRONMENTAL DISCHARGE OR PLANT RECYCLE
LIQUID WASTE SYSTEM
SOLID WASTE SYSTEM

FIG. 4

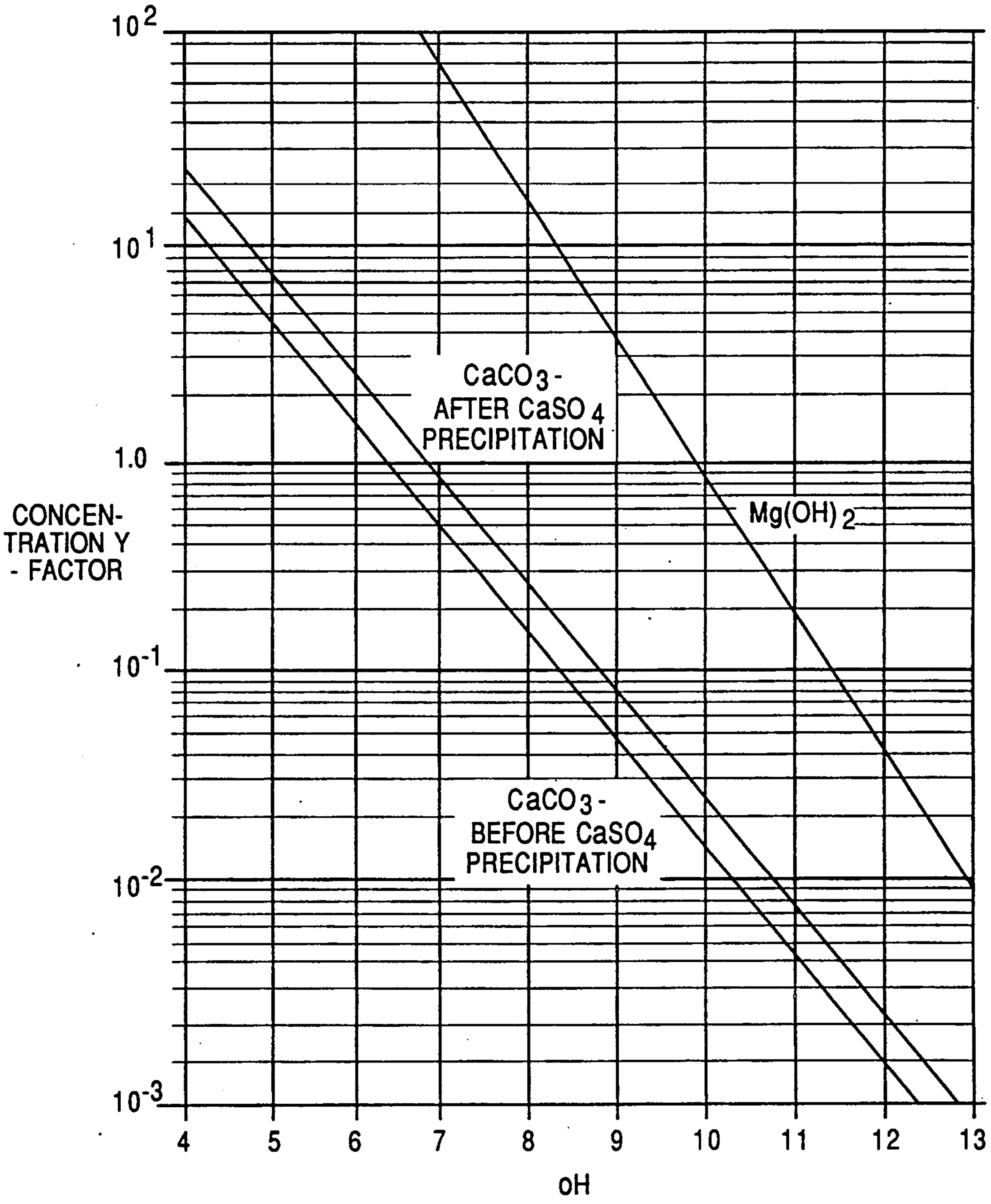

10^2
10^1
1.0
10^{-1}
10^{-2}
10^{-3}
CONCEN-
TRATION Y
- FACTOR
4
5
6
7
8
9
10
11
12
13
oH
$CaCO_3$ -
AFTER $CaSO_4$
PRECIPITATION
$Mg(OH)_2$
$CaCO_3$ -
BEFORE $CaSO_4$
PRECIPITATION

FIG. 5

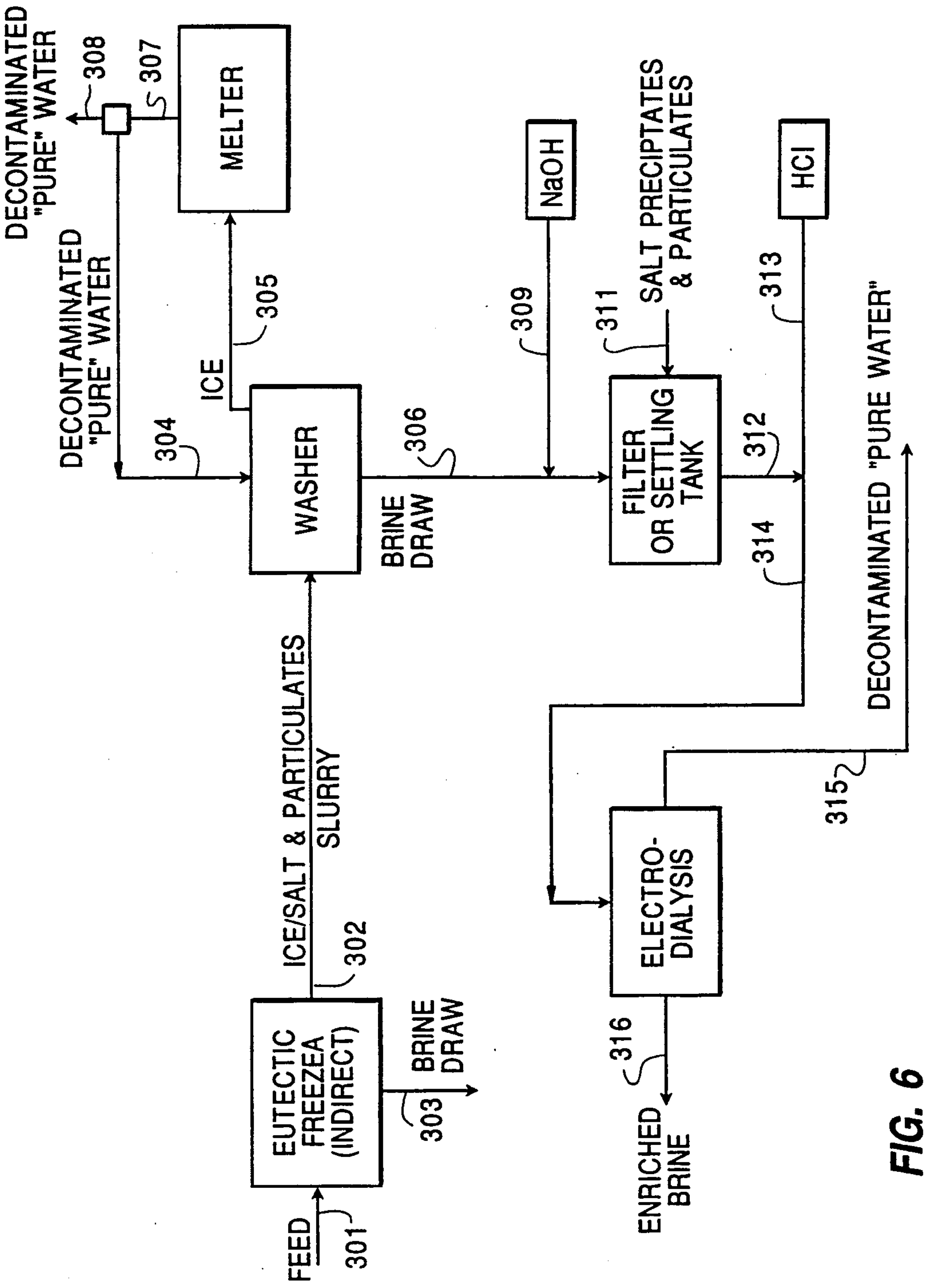

FEED
301
EUTECTIC FREEZEA (INDIRECT)
303
BRINE DRAW
302
ICE/SALT & PARTICULATES SLURRY
WASHER
304
DECONTAMINATED "PURE" WATER
ICE
305
MELTER
307
308
DECONTAMINATED "PURE" WATER
306
BRINE DRAW
NaOH
309
311
SALT PRECIPTATES & PARTICULATES
FILTER OR SETTLING TANK
312
HCl
313
314
ELECTRO-DIALYSIS
316
ENRICHED BRINE
315
DECONTAMINATED "PURE WATER"

FIG. 6

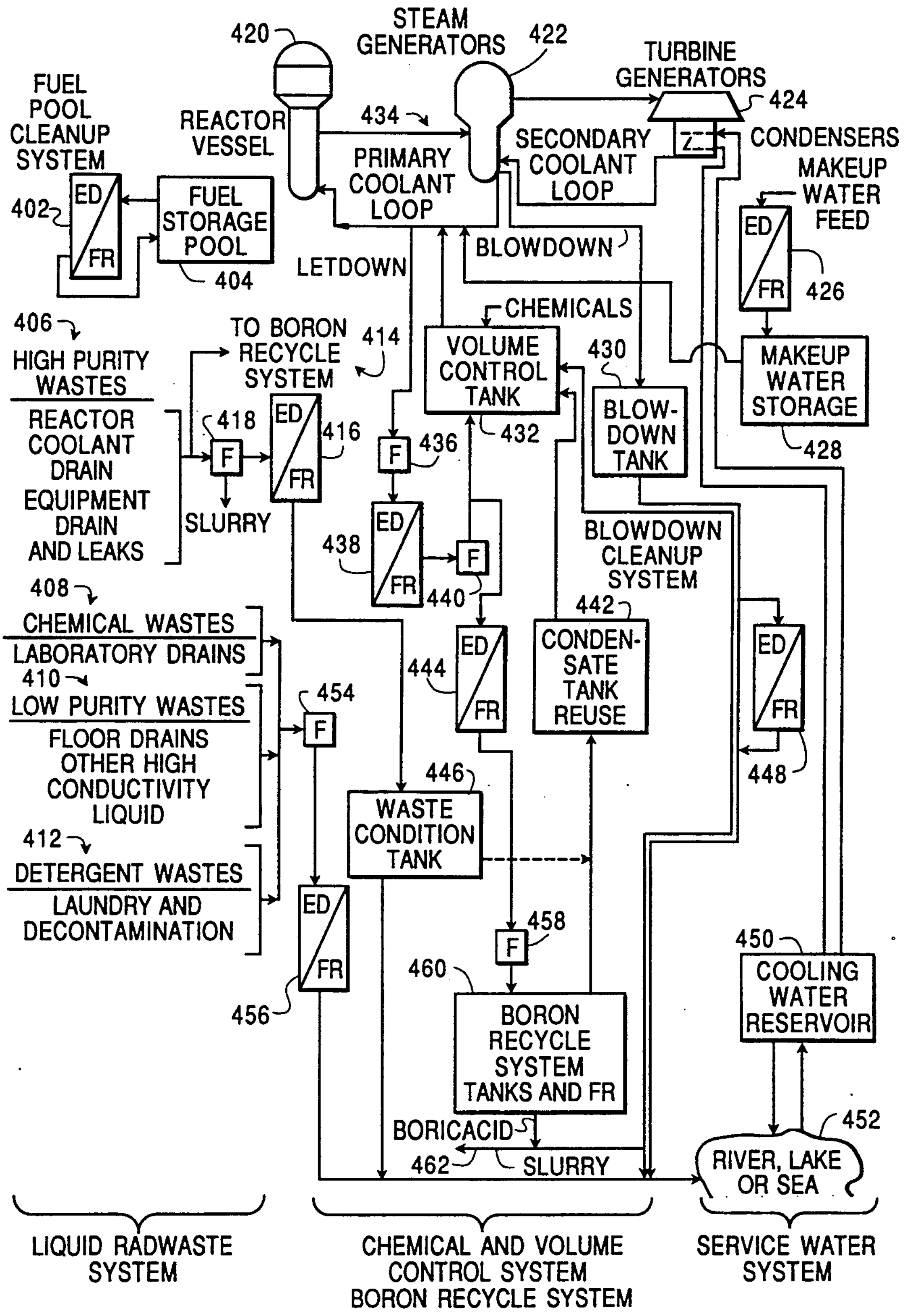
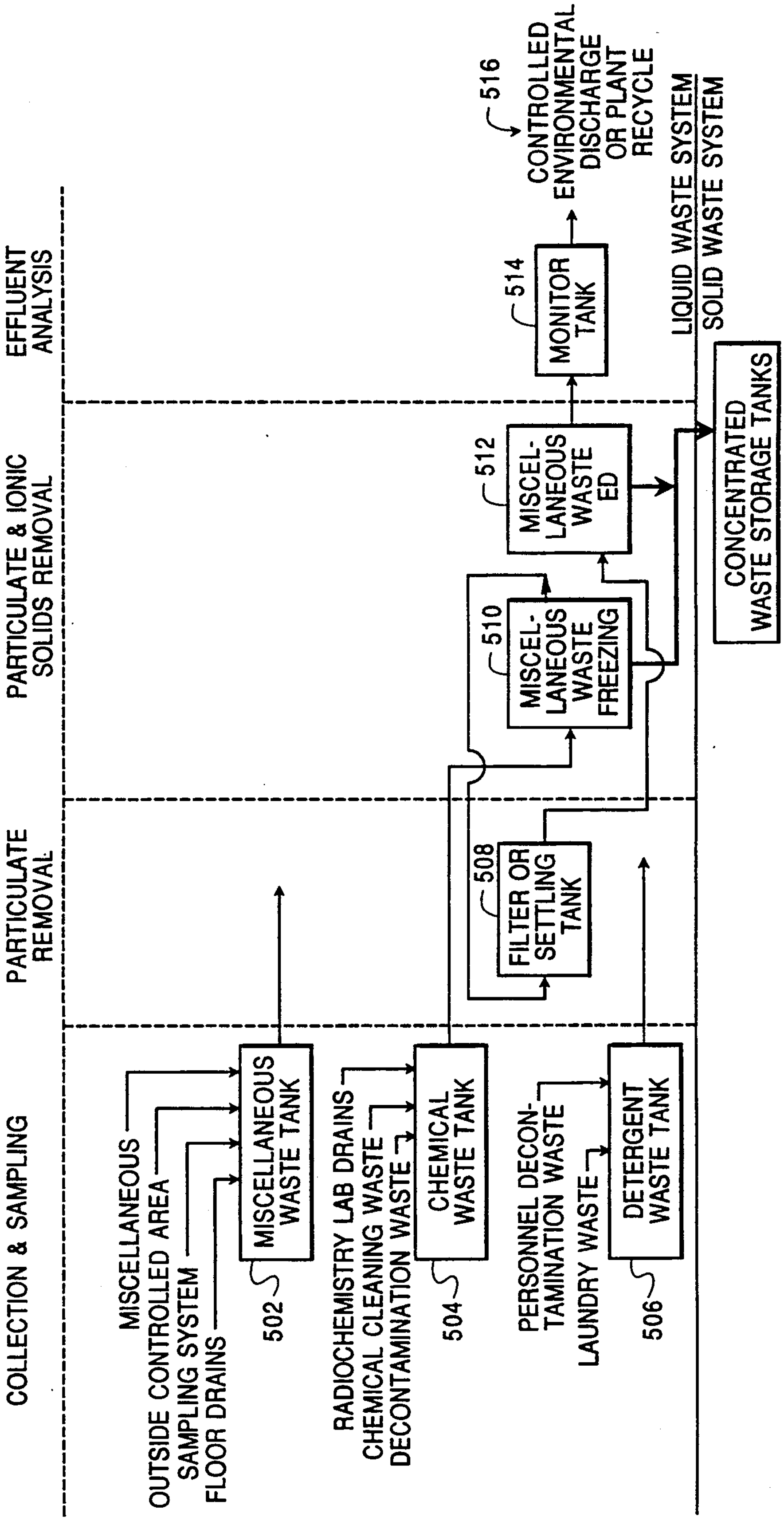

STEAM GENERATORS
420
422
TURBINE GENERATORS
424
FUEL POOL CLEANUP SYSTEM
REACTOR VESSEL
434
CONDENSERS
SECONDARY COOLANT LOOP
PRIMARY COOLANT LOOP
MAKEUP WATER FEED
402
ED
FR
FUEL STORAGE POOL
404
LETDOWN
BLOWDOWN
426
406
HIGH PURITY WASTES
REACTOR COOLANT DRAIN
EQUIPMENT DRAIN AND LEAKS
TO BORON RECYCLE SYSTEM
414
418
F
416
SLURRY
CHEMICALS
VOLUME CONTROL TANK
432
430
BLOW-DOWN TANK
MAKEUP WATER STORAGE
428
436
438
440
BLOWDOWN CLEANUP SYSTEM
442
CONDEN-SATE TANK REUSE
408
CHEMICAL WASTES
LABORATORY DRAINS
410
LOW PURITY WASTES
FLOOR DRAINS
OTHER HIGH CONDUCTIVITY LIQUID
412
DETERGENT WASTES
LAUNDRY AND DECONTAMINATION
454
444
446
WASTE CONDITION TANK
448
458
460
BORON RECYCLE SYSTEM TANKS AND FR
450
COOLING WATER RESERVOIR
456
BORICACID
462
SLURRY
452
RIVER, LAKE OR SEA
LIQUID RADWASTE SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM BORON RECYCLE SYSTEM
SERVICE WATER SYSTEM

FIG. 7



COLLECTION & SAMPLING
PARTICULATE REMOVAL
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502
RADIOCHEMISTRY LAB DRAINS
CHEMICAL CLEANING WASTE
DECONTAMINATION WASTE
CHEMICAL WASTE TANK
504
PERSONNEL DECON-TAMINATION WASTE
LAUNDRY WASTE
DETERGENT WASTE TANK
506
508
FILTER OR SETTLING TANK
510
MISCEL-LANEOUS WASTE FREEZING
512
MISCEL-LANEOUS WASTE ED
514
MONITOR TANK
516
CONTROLLED ENVIRONMENTAL DISCHARGE OR PLANT RECYCLE
LIQUID WASTE SYSTEM
SOLID WASTE SYSTEM
CONCENTRATED WASTE STORAGE TANKS

FIG. 8

METHOD OF COMPACTING LOW-LEVEL RADIOACTIVE WASTE UTILIZING FREEZING AND ELECTRODIALYZING CONCENTRATION PROCESSES

This application is a Continuation of Ser. No. 07/411,217, filed Sept. 22, 1989 now abandoned which is a continuation of Ser. No. 07/116,759 filed Nov. 4, 1987 now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to radioactive waste management systems, and in particular to a process employing freezing an electrodialysis for concentration of liquid waste streams.

2. The Prior Art

The U.S. Pat. No. 3,271,163 to Malick discloses a combination process for the removal of radioactive material (strontium 90) from milk employing fractional crystallization and ion exchange media but does not disclose the use of ion exchange membranes or electrodialysis.

The U.S. Pat. No. 3,305,320 to Weech discloses a method of purifying aluminum nitrate employing an alternate melting and crystallization process. It also mentions the invention's applicability to eutectic systems, solid-solution systems and the separation of fission products such as impurities from atomic reactor wastes. The Van de Voorde patent discloses as prior art a chemical coprecipitation method of treating radioactive materials additionally employing filtration of the precipitate dehydrated by "the freeze-thaw method".

The U.S. Pat. No. 3,405,050 to Bovard, et al. discloses the use of electrodialysis and precipitation as prior art in the decontamination of radioactive wastes. The Bovard, et al. invention itself is directed toward radioactive decontamination of wastes by way of a filter employing ion exchange materials and electrolysis. A further reference may be found in the McGraw-Hill Encyclopedia of Science and Technology (5th ed. 1982) which briefly discusses the role of ion exchange resin membranes in dialysis and the utilization of micro- and semimicroelectrodialyzers in radioisotope tracer studies. The Shiroki patent, U.S. Pat. No. 4,483,754 discloses and claims a process of electrolysis of NaCl employing ion exchange membranes but does not, however, mention its use in radioactive waste treatment.

The Carlin, et al. and Van de Voorde patents, U.S. Pat. Nos. 3,922,231 and 3,716,490, respectively, disclose methods for decontaminating radioactive liquids by adsorption of the radioactive materials onto ion exchange material but make no specific mention of ion exchange membranes or dialysis. The L. F. Ryan patent, U.S. Pat. No. 3,520,805, achieves a reduction in volume of liquid radioactive waste by filtration through a finely divided ion exchange resin.

SUMMARY OF THE INVENTION

FREDCON is a process employing freezing (FR) and electrodialysis (ED) for concentration (CON) of liquid waste streams. FREDCON is designed to surpass present processes in overcoming limitations on volume reduction (VR) of contaminants and/or dissolved solids in the waste influent. A high VR would alleviate costs incured in disposal of concentrated contaminants and result into high recovery of pure water for reuse or for safe release to the environment.

The FREDCON process comprises combinations of a freezing eutectic, bulk, indirect crystallization (FEUBIC) process and a radwaste electrodialysis (RADWED) process. When employed as a liquid radioactive waste management system (LWMS) for light water reactors (LWR's) FREDCON is designed to process liquid low-level radioactive waste (LLW) and to handle the radioactive influent in nuclear power plants (LLW)(NPPs) prior to release to the environment and disposal of the radioactive material present in the waste streams.

The principal design objectives of the overall FREDCON process in its applications to commercial LWRS used in NPPs are:

1. To protect NPP personnel, the general public, and the environment by ensuring that all releases of radioactive materials, both in the NPP and to the environment, are "As Low As Achievable" (ALARA) and within the limits of the Code of Federal Regulations (CFR), namely 10 C.F.R. 20 and Appendix I to 10 C.F.R. 50.
2. Reduction of the volume of concentrated streams to an extent that allows for economical ultimate disposal.

FREDCON is intended to replace current LWMSs which utilize ion exchangers, filters, and evaporators.

FREDCON processes radwaste streams from NPP's to precipitate dissolved radioactive materials and to provide a concentrated stream of organic as well as inorganic contaminants. The parametric design of the FREDCON process is dependent on the radioactive content of the radwaste water. In certain situations, RADWED may be used as a pre-processing stage. In other radwaste streams, RADWED is more suitable for further concentration of brines produced by FEUBIC. In case of high purity wastes, RADWED may become satisfactory by itself if combined with filters or settling tanks.

FEUBIC comprises an indirect bulk freezing process driven to the eutectic freezing range. In "indirect freezing processes" crystallization is achieved by removal of heat from an LLW feed stream through heat transfer surfaces as opposed to direct contact with a refrigerant which could be water or secondary refrigerant.

In bulk freezing, an LLW feed stream is introduced into the system through a plate precooler where it is chilled to near the freezing point by the exiting brine. The feed is then introduced into the tube side of a shell and tube evaporator. On the shell side ammonia is evaporated, thus removing heat through the tube wall, freezing a portion of the feed. A recirculation loop is employed around the crystallizer to maintain proper velocity and uniformity of ice fraction in the tubes. The ice fraction is also controlled by introducing brine from a wash column into this loop to ensure proper heat transfer, minimum wall subcooling, and sufficient seed crystals.

A flow equal to the feed and recirculation flow is extracted from the crystallizer loop and directed to a gravity wash column which is a cylinder with brine tubes and a rotating cutter. The column is exposed to atmospheric pressure at the top. Ice is consolidated and propelled to the top by hydraulic piston action. Regulated flow of pure water enters over the top surface of the ice to wash away adhering brine.

A controlled portion of the unprocessed feed or brine is extracted from the drainage tubes and pumped out of the wash column through a feed precooler and then partially circulated to the crystallizer. Ice is harvested from the top of the wash column and slurried in a repulp tank with melted ice. The slurried ice is circulated through the melter, which is a shell and tube condenser. The ice slurry flows through the tubes and the refrigerant condenses on the shell side to indirectly melt the ice.

Purified water is extracted from the repulp tank. The refrigerant from the evaporator is compressed and delivered to the melter at a saturation temperature sufficient to allow condensation on the shell side of the melter tubes.

A portion of the compressed vapor, equal to the internal heat load, is compressed slightly above ambient feed saturation temperature and condensed in a shell and tube condenser by water from the feed source.

To dislodge incipient ice buildup on the walls of the crystallizer tubes, a valving arrangement is provided in order to allow hot gas from the compressor discharge to be sequentially introduced to the tube side of th various sections of the crystallizer. The hot gas condenses on and warms the surface of the tubes thus loosening and allowing incipient ice buildup to be scrubbed away by the high velocity brine/ice slurry.

Eutectic freezing refers to th conditions wherein ice and solute crystals are simultaneously formed. The eutectic process involves driving the freezing process at a very high water (aqueous solution) purification rate. The rate of ice formation is increased until the concentration of the residual salts becomes high enough to precipitate some of the salts. The wet salts can be processed for disposal.

Generally, in electrodialysis (ED) processes, positive and negative ions in a solution containing dissolved solids, move towards oppositely charged electrodes immersed in the solution. By alternately placing cationic and anionic membranes between the electrodes, the salts in the solution are concentrated in one stream and depleted in the other. The two streams move counter-currently to each other.

In processing of radioactive waste by RADWED, the fairly high concentration of inactive ions in addition to the traces of radioactive ions, supports a high conductivity in the liquid. Such conductivity is necessary for ED.

Detailed design variables of the FREDCON process are dependent on specific plant designs and on whether the nuclear steam supply system (NSSS) is for a boiling water reactor (BWR) or a pressurized water reactor (PRW). However, the basic elements of FREDCON mostly remain the same in each situation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** schematically depicts freezing by the FEUBIC process;

FIG. **2** schematically depicts a process for liquid lowlevel radioactive waste concentration;

FIG. **3** is a schematic diagram representing the FREDCON liquid radioactive waste system for a boiling water reactor;

FIG. **4** depicts a system as shown in FIG. **3**, as used for a pressurized water reactor;

FIG. **5** is a graph showing concentration of a gamma factor versus pH;

FIG. **6** schematically illustrates a process sheet for an example according to the present invention;

FIG. **7** represents a schematic diagram of liquid stream treatment by the present invention for a pressurized water reactor; and

FIG. **8** is a schematic diagram similar to FIG. **4**, for the system shown in FIG. **7**.

DETAILED DESCRIPTION OF THE INVENTION

As an example of the FREDCON process design, the inorganic chemical waste (ICW) stream from a PWR is considered. Table 1 presents data on a water balance of the ICW stream. The water balance reflects a dissociation of Na_zSO_4 which in turn would cause C_aSO_4 to precipitate. The Ca^{2+} concentration would then be 2.04×10^{-3} Moles/liter and the final SO_4^{2-} concentration would be 9.56×10^{-2} Moles/liter.

TABLE 1

Inorganics	Formula Weight	Valence	Equivalent Weight	ppm	epm (+)	epm (−)	Moles/liter
HCO_3	61	−1	61	1,200		19.7	0.0197
Cl	35.5	−1	35.5	200		5.6	0.0056
NO_3	62	−1	62	100		1.6	0.0016
Ca	40	+2	20	200	10		0.005
Mg	24.3	+2	12.2	100	8.2		0.0041
NH_4	18	+1	18	100	5.6		0.0056
Na_2SO_4	142			14,000			
Na	23	+1	23	4,536	197.2		0.197
SO_4	96	−2	48	9,465		197.2	0.09859

FIG. **1** illustrates freezing by the FEUBIC process. In this process, feed make-up is supplied via a valve (unnumbered) to a heat exchanger **100** where it exits as a precooled feed **2**. The precooled feed **2** mixes with return brine **6** to form a repulp brine **3**, which is supplied to an ice and brine drain column **110**.

An ice/brine slurry **4** leaves the column **110** and is input via a pump cap **P1** to an ice wash column **120**. The column **110** receives an ice/brine slurry **12**. The column **110** outputs, via a pump **P4**, a recycle brine **13** which joins with a return brine **121** from the column **120**, to form the return brine **6**. Excess mixture is supplied to a freezer **170**.

The ice wash column **120** outputs a return brine **5** via a pump P2. The return brine **5** splits into the return brine **121** and an ice/brine slurry **122**. The slurry **122** is supplied to a surge tank **160** which in turn outputs a freezer feed **7** via a pump **P6**. The freezer feed **7** is supplied to the freezer **170**. The freezer **170** outputs an ice/hydrate/brine slurry **8** via a pump **P5**, which is then supplied as an ice/brine slurry **12** to the column **110**, as well as a hydrate/brine slurry **9** which is separated at a separator (unnumbered) into salt solids **10** and brine filterate **11**.

The freezer **170** supplies ammonia vapors **22** to a primary compressor **180**, which then outputs compressed ammonia vapors **23**. The compressed ammonia vapors **23** are supplied to a condenser **130** which outputs ammonia condensate **24** and ammonia vapors **25**. Passing in heat exchange relationship in the condenser is a wash column discharge **14** from a pump P3, which on the discharge side of the condenser **130** a wash column discharge **14**.

The melter **140** also receives ammonia vapors **25**, and outputs a diluted stream/repulp water **15**. The ammonia vapors **25** join the ammonia condensate **24** and ammonia condensate **26** from an evaporator **200**.

The diluted stream/repulp water **15** is supplied as wash water **17** and as repulp water **16** to the ice wash column **120**. The remainder of the water **15** is supplied as diluted stream water **18** to the heat exchanger **100**, where it exits as the diluted stream water effluent **19**.

As seen in FIG. **1**, the ammonia flow path is indicated as dotted lines, while the liquid and ice flow paths are indicated in solid lines.

The freezer **170** supplies an ammonia condensate return to a refrigerant storage tank **150**. The tank **150** receives an ammonia make-up **20** and also receives an ammonia condensate return **27** from the evaporator **200**. The tank **150** outputs, via a pump P7, an ammonia feed **21** to the freezer **170**.

A heat removal compressor **190** receives evaporated ammonia from the evaporator **200**, and, in a heat removal stage, supplies the compressed ammonia to a condenser **210** where the ammonia is cooled by a coolant (unnumbered), thereby forming a make-up refrigeration unit. The output of condensed refrigerant **215** is then supplied to the evaporator **200** as coolant.

The pumps described are named as follows. Pump P1 is a drain column repulp slurry pump. Pump P2 is a wash column brine discharge pump. Pump P3 is a wash column repulp slurry pump. Pump P4 is a drain column brine discharge pump. Pump P5 is a freezer product pump. Pump P6 is a freezer feed pump. Pump P7 is an ammonia refrigerant pump.

FIG. **2** schematically shows a process for liquid low-level radioactive waste concentration using electrodialysis. An electrodialysis unit **220** has an output supplied to a feed **240**. The feed **240** is returned to the electrodialysis unit **220** via a pump **242** controlled by a valve (unnumbered). An anaolyte pump **252** receives liquid from a tank **250** as well as water makeup from a valve (unnumbered) and supplies it via a valve (unnumbered) to a top portion of the electrodialysis unit **220**, whereafter it returns to the tank **250**. In this process, in the tank, oxygen molecules escape from the top of the tank, and HNO^3 is removed from the tank. In another fluid flow loop, a tank **230** supplies catholyte liquid via a catholyte pump **232** via a valve (unnumbered) to a lower portion of the electrodialysis unit **220**. This liquid is then returned to the tank **230**. Hydrogen molecules escape from the tank **230**, and liquid is drained off having a pH which is greater than 2. FIG. **2** illustrates the processing of radioactive waste by a RADWED.

FIG. **3** illustrates a preferred embodiment of the FREDCON process in processing various streams of a boiling water reactor in a nuclear power plant. A collection and sampling zone in the figure includes elements **260**, **262**, **264**, and **266** which represent liquids of differing types to be processed. High purity waste **260** is supplied to filters **268** and then to an electrodialysis process **278**. From there, liquid is supplied to monitor tanks **290** and from there to a storage **294** to recycle condensate for reuse.

Low purity waste **262** is supplied to a freezing process **272** which supplies concentrated waste to a storage tank **282** which in turn supplies material to a waste solidification system **296**. Chemical waste **264** is supplied to a freezing unit **274** which supplies effluent to monitor tanks **286** and supplies concentrated waste to storage tank **282**. Detergent waste **266** is supplied to a freezing process **276**, whereafter liquid effluent is supplied to monitor tanks **284**, and concentrated effluent is supplied to tanks **282**. Liquid from the monitor tanks is supplied to a controlled environmental discharge **292**.

The freezing processing shown in FIG. **3** include particulate an ionics solids removal. The filters shown in FIG. **3** are for particulate removal. The electrodialysis units are for ionics solids removal. The monitor tanks, concentrated waste storage tank **282**, waste solidification system **296**, form part of the effluent analysis portion of the system. Affluent from the monitor tanks **288**, **286**, and **284** is supplied to the controlled discharge **292**. The affluent of the monitor tank **290** is stored at **294** for reuse.

FIG. **4** shows the FREDCON process for a pressurized water reactor. The contents schematically depicted in FIG. **4** are similar to that shown in FIG. **3** previously described.

FIG. **5** presents plots of concentration "y-factor" for $CaCO_3$ and $Mg(OH)_2$ at selected values of pH. The ion products are based on the ICW stream data. The $CaCO_3$ plots present cases for both before and after $CaCO^3$ precipitation.

FIG. **6** shows the process sheet, and Table 2 lists the material flow rates at each numbered position thereof. The ICW feed enters the FEUBIC process **301** where ice is formed in the freezer. A slurry of ice/salts and particulates is directed to the washer **302**. Five percent (5%) of H_2O is assumed to be brine covering the ice. Brine is drawn from the freezer **303**, or it may be recycled to increase the concentration rate. In the washer, a portion of the decontaminated "pure" water **304** is recycled to wash away the brine adhering to the ice crystals. The washed ice **305** is directed to a melter and the brine which contains salt precipitates and particulates **306** is prepared for further processing by the RADWED. The decontaminated "pure" water stream from the melter **307** is partitioned into a small portion to provide wash water for the washer and the rest is then released to the environment **308**.

In the RADWED process, NaOH **309** is added to the brine from the FEUBIC process. The solution **310** then passes through a filter or a settling tank wherein salt precipitates and particulates **311** are separated from the brine **312**. HCl **313** is added to adjust for pH of the brine stream. The adjusted stream **314** enters the ED stacks, where decontaminated "pure" water **315** is extracted leaving a concentrated enriched brine stream **316** for further processing. The overall recovery rate of

TABLE 2

POSITION	301	302*	303	304
DISSOLVED INORGANICS				

TABLE 2-continued

$[SO_4^{-2}]$	0.0986 M	0.0468	0.9360	4.68×10^{-3}
$[HCO_3^{-}]$	0.0197 M	9.85×10^{-3}	0.1970	9.85×10^{-4}
$[CO_3^{-2}]$	9.22×10^{-6} M	4.61×10^{-6}	9.22×10^{-5}	4.61×10^{-7}
$[H^{+}]$	1.00×10^{-7} M	1.00×10^{-7}	1.00×10^{-7}	1.00×10^{-7}
$[Cs^{+}]$	1.00×10^{-11} M	5.00×10^{-12}	1.00×10^{-10}	5.00×10^{-13}
$[CA^{+2}]$	0.0050 M	1.2425×10^{-6}	2.485×10^{-5}	1.2425×10^{-7}
$[Mg^{+2}]$	0.0041 M	2.05×10^{-3}	0.0410	2.05×10^{-4}
$[Sr^{+2}]$	1.00×10^{-12} M	5.00×10^{-13}	1.00×10^{-11}	5.00×10^{-14}
OTHER ANIONS				
$(CL^{-}$, $NO_3^{-})$	0.006082 M	3.041×10^{-3}	0.06082	3.041×10^{-4}
POSITION	305	306	307	308
DISSOLVED INORGANICS				
$[SO_4^{-2}]$	4.68×10^{-3}	0.18240	4.68×10^{-3}	4.68×10^{-3}
$[HCO_3^{-}]$	9.85×10^{-4}	0.03837	9.85×10^{-4}	9.85×10^{-4}
$[CO_3^{-2}]$	4.61×10^{-7}	1.796×10^{-5}	4.61×10^{-7}	4.61×10^{-7}
$[H^{+}]$	1.00×10^{-7}	1.00×10^{-7}	1.00×10^{-7}	1.00×10^{-7}
$[Cs^{+}]$	5.00×10^{-13}	1.95×10^{11}	5.00×10^{-13}	5.00×10^{-13}
$[CA^{+2}]$	1.2425×10^{-7}	1.392×10^{-4}	1.2425×10^{-7}	1.2425×10^{-7}
$[Mg^{+2}]$	2.05×10^{-4}	7.99×10^{-4}	2.05×10^{-4}	2.05×10^{-4}
$[Sr^{+2}]$	5.00×10^{-14}	1.95×10^{-11}	5.00×10^{-14}	5.00×10^{-14}
OTHER ANIONS				
$(CL^{-}$, $NO_3^{-})$	3.041×10^{-4}	1.185×10^{-2}	3.041×10^{-4}	3.041×10^{-4}

decontaminated "pure" water is about 90%. Further reduction in the radwaste volume effluent can be achieved by recycling the drawn brine **330** in the FEUBIC process.

Combination of both FEUBIC and RADWED processes in the FREDCON process leads to a small volume of concentrated radioactive matter that is ready for appropriate disposal and a diluted pure water stream that can be recycled in the plant or safely released to the environment. The released water can meet the regulatory limits. No pre- or post- treatment of the waste stream is required. Also, the process will only generate minimal secondary solid or liquid waste streams. Current WMSs vis-a-vis FREDCON produces extensive secondary waste streams that increase the volume of the concentrated stream or add to the solid waste volume to be disposed of.

In the design of the FEUBIC component of FREDCON, several features prevail. The FEUBIC process does not require pretreatment or sorting of waste. The indirect freezing utilized in the FEUBIC process has the merits of being simple conceptually and mechanically while no stringent constraints are imposed on the construction since the process takes place at atmospheric pressure. Since there is no contact between the radwaste stream and the refrigerant in FEUBIC, no further contamination will take place in the LWMS.

In the RADWED component of FREDCON, the radwaste treatment is simple, no regeneration processes are necessary, and the interference due to the coexistent of inactive and radioactive ions is minor.

FREDCON is suitable for processing of aqueous solution wastes in general where the product is a minimum waste volume. In particular, FREDCON is appropriate for volume reduction of radwaste from NPPs, fuel processing plants, uranium enrichment plants, plutonium production plants, and non-fuel cycle applications of nuclear energy.

The feed to the low level liquid radwaste management system comes from many sources in a PWR nuclear power plant. The treatment system can be centralized or designed specifically for each source. Typical streams and the associated treatment equipment for each sources are shown in FIG. 7.

Electrodialysis (ED) and freezing (FR) processes are shown for each source. Filtration (F) is shown as an illustrative means of solids removal although other means such as a cyclone separator are equally appropriate if not preferred when the solid materials are radioactive.

Treatment of all streams by the ED/FR process is not necessarily beneficial compared with the current treatment processes. In particular, preliminary examination of the stream designated high purity wastes in FIG. 7 suggested that the ED/FR process would be of marginal benefit and that certainly this stream was not a principal stream for the hybrid process. The streams of major importance for the ED/FR process primarily include the streams feeding the chemical waste tank.

In FIG. 7, items **406**, **408**, **410**, and **412** relate to various wastes which are processed by the system. These materials are supplied as seen in FIG. 7 to filtering units and electrodialysis units combines with freezing units as indicated in the drawings. The various elements are labelled in the drawings, each unit having an element designation number as shown. A reactor vessel 420 is shown supplying steam **434** to steam generators 422, the steam driving turban generators 424. Electrodialysis/freezer process units **416**, **456**, **438**, **444**, and **448** are shown at appropriate locations in the system as indicated.

FIG. **8** is a schematic diagram showing the flow of material from collection and sampling units labelled in FIG. **8**, to particulate removal steps **508**, and particulate in ionic solids removal steps **510** and **512**, and finally to an effluent analysis step at monitor tank **514**. After this, there is controlled environmental discharge or plant recycling of liquid **516**. Solid waste is supplied to concentrated waste storage tanks (unnumbered in FIG. 8).

In addition, the low purity wastes (miscellaneous wastes) and detergent wastes could be effectively treated by the ED/FR process. Depending on the specific contaminants, these three streams could be treated most effectively in a centralized system as suggested in FIG. 7 or the secondary streams could be treated by some other means as indicated in FIG. 8. The water analysis for the primary stream in the waste stream is given in Table 3.

Besides the option of centralized versus decentralized system, the sequence of the ED and FR processes and the choice of operating conditions are process options which need to be considered.

TABLE 3

SUMMARY OF PERFORMANCE OF THE HYBRID PROCESS AS A FUNCTION OF THE PROCESS SEQUENCE AND CONDITIONS

		BLOWDOWN FROM CHEMICAL TREATMENT			
Process Sequence	Scenario #	TDS	PARTICULATES/ H_2O FOW	TOTAL SOLIDS CONCENTRATION (%)	TOTAL VOLUME FRACTION
Primary freezing process with chemical precipitation of wash water and subsequent treatment by ED	1	5,279	1.68/7,633	22.54	0.00242
	2	8,490	1.89/4,677	41.26	0.00148
	3	3,977	1.58/12,639	12.90	0.00400
	4	4,849	1.58/10,308	15.81	0.00326
	5	2,772	1.58/18,896	8.64	0.00598
	6	3,006	1.58/17,347	9.41	0.00549
Pretreatment by chemical precipitation and primary ED process with brine concentration by subsequent freezing treatment	7	1.961	2.114/31,600	6.89	0.01000
	8	1,961	2.114/31,600	6.89	0.01000
	9	1,961	2.114/31,600	6.89	0.01000
	10	1,961	2.114/31,600	6.89	0.01000
	11	1,961	2.114/31,600	6.89	0.01000
	12	1,961	2.114/31,600	6.89	0.01000

	Design Parameters for Processing PWR Inorganic Streams§							
POSITION	1	2*	3	4	5	6	7	8
DISSOLVED INORGANICS								
OTHER CATIONS								
(Na^+, NH_4^+)	0.2048 M	0.1024	2.048	0.01024	0.01024	0.3989	0.01024	0.01024
Total Dissolved Inorganics (Normality)	0.2230 M	0.1115	2.230	0.01115	0.01115	0.4343	0.01115	0.01115
TDS [Inorganics] (mg/l)	≈16,000	≈8,000	≈160,000	≈800	≈800	≈31,000	≈800	≈800
H_2O (kg/hr.)	3,160	2,844	316	543	2,716	671	2,716	2,173
$CaSO_4$ (kg/hr.)	—	21.5	—	—	—	4.55	—	—
$CaCO_3$ (kg/hr.)	—	—	—	—	—	—	—	—
$Mg(Ou)_2$ (kg/hr.)	—	—	—	—	—	—	—	—
$Mg\ CO_3$ (kg/hr.)	—	—	—	—	—	—	—	—
$^{90}Sr\ SO_4$ (kg/hr.)	—	—	—	—	—	—	—	—
Particulates [@ 1,000 ppm] (kg/hr.)	3.16	3.16	—	—	—	3.16	—	—

POSITION	9	10	11**	12	13	14	15	16
DISSOLVED INORGANICS								
$[SO_4^{-2}]$	—	0.1824	0.18240	0.18240	—	0.18240	4.68×10^{-3}	1.26
$[HCO_3^-]$	—	0.02041	0.02041	0.02041	—	0.02041	5.23×10^{-4}	0.141
$[CO_3^{-2}]$	—	1.782×10^{-2}	1.782×10^{-2}	1.782×10^{-2}	—	1.782×10^{-2}	4.57×10^{-4}	0.123
$[H^+]$	4.00×10^{-16}	1.00×10^{-10}	1.00×10^{-10}	1.00×10^{-10}	10	1.00×10^{-7}	1.00×10^{-7}	1.00×10^{-7}
$[Cs^+]$	—	1.95×10^{-11}	1.95×10^{-11}	1.95×10^{-11}	—	1.95×10^{-11}	5.00×10^{-13}	1.35×10^{-10}
$[Ca^{+2}]$	—	2.54×10^{-7}	2.54×10^{-7}	2.54×10^{-7}	—	2.54×10^{-7}	6.51×10^{-9}	1.75×10^{-6}
$[Mg^{+2}]$	—	1.20×10^{-3}	1.20×10^{-3}	1.20×10^{-3}	—	1.20×10^{-3}	3.08×10^{-5}	8.38×10^{-3}
$[Sr^{+2}]$	—	1.95×10^{-12}	1.95×10^{-12}	1.95×10^{-12}	—	1.95×10^{-12}	5.00×10^{-14}	1.35×10^{-11}
OTHER ANIONS								
(CL^-, NO_3^-)	25	1.195×10^{-2}	1.195×10^{-2}	1.195×10^{-2}	—	1.195×10^{-2}	3.064×10^{-4}	8.25×10^{-2}
OTHER CATIONS								
(Na^+, NH_4^+)	25	0.3990	0.3990	0.3990	—	0.3990	0.01023	2.75
Total	25	0.4343	0.4343	0.4343	—	0.4343	0.11136	3.00

TABLE 3-continued

Dissolved Inorganics (Normality)								
TDS [Inorganics] (mg/l)	1.00 × 10−	≈31,000	≈31,000	≈31,000	≈365,000	≈31,000	≈800	214,000
H_2O (kg/hr.)	2.68×10^{-3}	637	34	603	6.0×10^{-6}	603	513	90
$CaSO_4$ (kg/hr.)	—	4.55	4.55	—	—	—	—	—
$CaCO_3$ (kg/hr.)	—	0.009	0.009	—	—	—	—	—
$Mg(Ou)_2$ (kg/hr.)	—	0.252	0.252	—	—	—	—	—
Mg CO_3 (kg/hr.)	—	—	—	—	—	—	—	—
^{90}Sr SO_4 (kg/hr.)	—	—	—	—	—	—	—	—
Particulates [@ 1,000 ppm] (kg/hr.)	—	3.16	3.16	—	—	—	—	—

§Positions are indicated on EXHIBIT 7 and the water balance of the ICW stream data is provided in EXHIBIT 5.

*Assumes 5% of H_2O is brine covering the ice and 90% H_2O is in the form of ice.

**Assumes 5% blowdown.

Assumes 20% of H_2O from melter is used to wash ice to a point where only 0.5% of H_2O is brine covering the ice and 0.45% of ice is melted and lost with brine.

The major parameters considered for the operating conditions involve the freezing process; that is,

(1) the percentage of the water from the melter that is used to wash the ice slurry in the washer, and

(2) the percentage of water in the ice slurry that occurs as brine.

The other operating conditions, include,

(1) the percentage blowdown in the chemical precipitation step (for solids separation),

(2) the pH of the chemical precipitation,

(3) the percentage of the feed water that becomes the ice slurry,

(4) the percentage of the washed ice water that remains as brine, and

(5) the percentage of the ice that is melted in the wash step and lost to the wash water, are held at nominal values.

The process sheet for the hybrid process with the freezing process first is shown schematically in FIG. **6**. A summary of the cases evaluated in terms of the two variable parameters selected for the operating conditions is given in Table 4.

CRITERIA FOR PROCESS SELECTION

The criteria for process selection include,

(1) the decontamination factor for the diluted stream, achieved by the process,

TABLE 4

% Slurry H_2O as Brine % Melter H_2O Used as Wash	5%	25%	50%
10%	2/8	4/10	6/12
20%	1/7	3/9	5/11

(2) the concentration factor of soluble salts (including the radioactive elements),

(3) the solids (suspended and dissolved) content in the flow-down from the solids separator, and

(4) the overall volume reduction in the radioactive liquid stream.

For each criterion, the maximum value is sought for the overall process.

COMPUTER SIMULATION OF SYSTEM PERFORMANCE

Because of the complexity of the concentrator, a computer model of the hybrid process was developed. This model simulates the performance of a combined ED-freezing process with a classical chemical treatment and clarification step to remove suspended particulates and any precipitated material. In order to select the optimal sequence of treatment stages for a given radioactive waste stream, several scenarios have been evaluated. Those scenarios involve two arrangements; namely;

* FRED: a freezing unit followed by ED, and

* EDFRA: an ED unit followed by a freezing unit.

In both cases; the feed to the ED section is pretreated by chemical means, that is pH adjusted to pH 10 and all solid materials separated by settling an clarification equipment. The feed stream to the system is the organic chemical waste stream from PWR nuclear power plant. The sources of this stream are listed in FIG. **8** and primarily include the sources feeding the chemical waste tank.

For a centralized treatment system, the sources could also include those feeding the miscellaneous waste tank and the detergent waste tank.

The water analysis for the waste stream under consideration is given in Table 1. The process sheet for the combined system is given in FIG. **6**. There are two locations for decontaminated water to be released from the system; namely points **308** and **315**. These are respectively the product water outlets of the freezing process and the ED process.

There are three sources of radioactive brine, namely;

* the brine drawn from the freezer at point **303**.

* the enriched brine from the ED section at point **316**, and

* the blowdown from the chemical treatment section at point **311**.

The freezer and ED sections are linked via the wash water from the freezing process at point **306**.

In the cases of the freezer and the chemical treatment section where the formation of solids is not necessarily a problem, each of the brine and blowdown requires about one percent of the feed water. The enriched brine in the ED section is limited by the solubility limits of the remaining salts in the treated wash water and by electro-osmotic transfer of water with the salt. In the later case, the final brine concentration is about 3 equivalents per kg of water. If the solubility of one of the salts is exceeded before the electro-osmotic limit, the brine concentration will be less since the ED system will

TABLE 5

FRED SEQUENCE FOR CASE 1 CONDITIONS
RESULTS FOR THE FREEZING PROCESS

FRED.FREEZE.VC1
Design Parameters for Processing PWR Inorganic Streams (Part 1; Freeze/Wash/Melt)

Percent Feed Water to Slurry: 99
Percent Slurry H2O as Brine: 5
Percent Washed Ice H2O as Brine: .5
Percent Melter H2O used as Wash: 20
Percent Ice melted and lost: 1

Percent Water Recovery: 74.84
Percent Water Delivered to ED System: 24.16

POSITION	1	2	3	4	5	6	7	8
DISSOLVED INORGANIC CONCENTRATIONS								
[SO4=] Init.		0				0		
[SO4=] Final	0	0	0	0	0	0	0	0
[HCO3−] INITIAL	.0197	.2469896				.0472245		
[HCO3−] FINAL	.0196908	.2468740	.2468740	.0012344	.0012344	.0472024	.0012344	.0012344
[CO3=] INITIAL		1.549E−4				3.158E−5		
[CO3=] FINAL	9.215E−6	1.155E−4	1.55E−4	5.777E−7	5.777E−7	2.209E−5	5.777E−7	5.777E−7
[H+]	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001
[Cs+]	1.E−11	1.68E−10	1.68E−10	8.40E−13	8.40E−13	3.18E−11	8.40E−13	8.40E−13
[Ca+2] Init.		8.563E−5		0	0	4.479E−4	0	0
[Ca+2] Final	.005	8.563E−5	8.563E−5	4.282E−7	4.282E−7	4.479E−4	4.282E−7	4.282E−7
[Mg+2]	.0041	.0689076	.0689076	3.445E−4	3.445E−4	.0014263	3.445E−4	3.445E−4
[Sr+2]	1.68E−11	2.82E−10	2.82E−10	1.41E−12	1.41E−12	5.35E−11	1.41E−12	1.41E−12
Other Anions (Cl−, NO3−)	.0072	.1210084	.1210084	6.050E−4	6.050E−4	.0229222	6.050E−4	6.050E−4
Other Cations		0				0		
(Na+, NH4+)	.0087092	.2301271	.2301271	.0011506	.0011506	.0664203	.0011506	.0011506
Total Dissolved Inorganics (Normality)	.0269092	.3681135	.3681135	.0018406	.0018406	.0701687	.0018406	.0018406
CHECK ANIONS	.0269092	.3681135	.3681135			.0701688		
TDS [Inorganics] (milligram/liter)	1957	26333	26333	131.6642	132	5275	131.6642	131.6642
H2O (kg/hr)	3160	3128.4	31.4	591.2676	2956.338	763.3296	2956.338	2365.070
CaSO4 (x, molality)								
CaSO4 (kg/hr)		0				0		
CaCO3 (kg/hr)		1.580562				1.545442		
Mg(OH)2 (kg/hr)								
MgCO3 (kg/hr)		0				0		
SrSO4 (kg/hr)								
Particulates (@ 1000 ppm) (kg/hr)	3.16	3.16				3.16		

FRED SEQUENCE FOR CASE 1 CONDITIONS
RESULTS FOR THE ELECTRODIALYSIS PROCESS

FRED.ED.VC1

TABLE 5-continued

Design Parameters for Processing PWR Inorganic Streams (Part 2; Filter/ED)

Settling Tank pH:	10	ED PLANT Percent Water Recovery:	97.69
ED Unit Feed pH:	7	CHEMICAL PLANT RECOVERY:	99
DECONTAMINATION FACTOR:	100	OVERALL WATER RECOVERY:	.9671138
Percent Settler Blowdown:	1		

POSITION	6	9	10	11	12	13	14	15	16
DISSOLVED INORGANIC CONCENTRATIONS									
[SO4=], Init.	0								
[SO4=], Final	0	1.E−10	4.00E−16	4.00E−16	4.00E−16		4.00E−16	4.00E−18	1.71E−14
	.0472245		.0252523						
[HCO3−]	.0472024	1.E−10	.0172018	.0172018	.0172018		.0172018	1.720E−4	.7367139
[CO3=], Init.	3.158E−5	1.E−10	.0150552						
[CO3=], Final	2.209E−5	1.E−10	.0080504	.0080504	.0080504		1.181E−5	1.181−7	5.059E−4
[H+]	.0000001	4.E−16	1.E−10	1.E−10	1.E−10	10	.0000001	.0000001	.0000001
[Cs+]	3.18E−11		3.18E−11	3.18E−11	3.18E−11		3.18E−11	3.18E−13	1.363E−9
[Ca+2], Init.	4.479E−4	1.E−10	4.479E−4						
[Ca+2], Final	4.479E−4	1.E−10	4.523E−7	4.523E−7	4.523E−7		4.523E−7	4.523E−9	1.937E−5
[Mg+2], Init.		1.E−10	.0014263						
[Mg+2], Final	.0014263	1.E−10	.0012000	.0012000	.0012000		.0012000	1.200E−5	.0513932
[Sr+2]	5.35E−11		5.35E−11	5.35E−11	5.35E−11		5.35E−11	5.35E−13	2.291E−9
Other Anions (Cl−, NO3−)	.0229222	25	.0230220	.0230220	.0230220	10	.0230221	2.302E−4	.9859820
Other Cations	0								
(Na+, NH4+)	.0664203	25	.0539238	.0539238	.0539238		.0378465	3.785E−4	1.620883
Total Dissolved Inorganics (Normality)	.0701687	25.00000	.0563247	.0563247	.0563247	10	.0402475	4.026E−4	1.723708
CHECK ANIONS	.0701688	25.00000	.0563247	.0563247	.0563247	10	.0402475	4.025E−4	1.723708
TDS [Inorganics] (milligram/liter)	5275	1000000	5279	5279	5279	365000	5278.630	52.78630	226071.5
H2O (kg/hr)	763.3296	.0030503	763.3327	7.633327	755.6993	7.549E−6	755.6993	738.2266	17.47274
CaSO4 (kg/hr)	0		0	0					
CaCO3 (kg/hr)	1.545442		1.579594	1.579594					
Mg(OH)2 (kg/hr)			.0100708	.0100708					
MgCO3 (kg/hr)	0		0	0					
SrSO4 (kg/hr)									
Particulates (@ 1000 ppm) (kg/hr)	3.16		3.16	3.16					

FRED SEQUENCE FOR CASE 2 CONDITIONS RESULTS FOR THE FREEZING PROCESS

FRED.FREEZE.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 1; Freeze/Wash/Melt)

Percent Feed Water to Slurry:	99	Percent Water Recovery:	84.20
Percent Slurry H2O as Brine:	5	Percent Water Delivered to ED System:	14.80
Percent Washed Ice H2O as Brine:	.5		

TABLE 5-continued

Percent Melter H2O used as Wash: 10
Percent Ice melted and lost: 1

POSITION	1	2	3	4	5	6	7	8
DISSOLVED INORGANIC CONCENTRATIONS								
[SO4=] Init.		0				0		
[SO4=] Final	0	0	0	0	0	0	0	0
[HCO3−] INITIAL	.0197	.2469896				.0758434		
[HCO3−] FINAL	.0196908	.2468740	.2468740	.0012344	.0012344	.0758079	.0012344	.0012344
[CO3=] INITIAL		1.549E−4				5.117E−5		
[CO3=] FINAL	9.215E−6	1.155E−4	1.155E−4	5.777E−7	5.777E−7	2.548E−5	5.777E−7	5.777E−7
[H+]	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001
[Cs+]	1.E−11	1.68E−10	1.68E−10	8.40E−13	8.40E−13	5.14E−11	8.40E−13	8.40E−13
[Ca+2] Init.		8.563E−5		0	0	2.789E−4	0	0
[Ca+2] Final	.005	8.563E−5	8.563E−5	4.282E−7	4.282E−7	2.789E−4	4.282E−7	4.282E−7
[Mg+2]	.0041	.0689076	.0689076	3.445E−4	3.445E−4	.0023279	3.445E−4	3.445E−4
[Sr+2]	1.68E−11	2.82E−10	2.82E−10	1.41E−12	1.41E−12	8.64E−11	1.41E−12	1.41E−12
Other Anions	.0072	.1210084	.1210084	6.050E−4	6.050E−4	.0370290	6.050E−4	6.050E−4
(Cl−, NO3−)								
Other Cations		0				0		
(Na+, NH4+)	.0087092	.2301271	.2301271	.0011506	.0011506	.1076943	.0011506	.0011506
Total Dissolved Inorganics (Normality)	.0269092	.3681135	.3681135	.0018406	.0018406	.1129077	.0018406	.0018406
CHECK ANIONS	.0269092	.3681135	.3681135			.1129078		
TDS [Inorganics] (milligram/liter)	1957	26333	26333	131.6642	132	8486	131.6642	131.6642
H2O (kg/hr)	3160	3128.4	31.6	295.6338	2956.338	467.6958	2956.338	2660.704
CaSO4 (x, molality)								
CaSO4 (kg/hr)		0				0		
CaCO3 (kg/hr)		1.580562				1.566573		
Mg(OH)2 (kg/hr)								
MgCO3 (kg/hr)		0				0		
SrSO4 (kg/hr)								
Particulates (@ 1000 ppm) (kg/hr)	3.16	3.16				3.16		

FRED SEQUENCE FOR CASE 2 CONDITIONS RESULTS FOR THE ELECTRODIALYSIS PROCESS

FRED.ED.VC1
Design Parameters for Processing PWR Inorganic Streams (Part 2; Filter/ED)

Settling Tank pH: 10
ED Unit Feed pH: 7
DECONTAMINATION FACTOR: 100
Percent Settler Blowdown: 1
ED PLANT Percent Water Recovery: 97.07
CHEMICAL PLANT RECOVERY: 99
OVERALL WATER RECOVERY: .9609481

POSITION	6	9	10	11	12	13	14	15	16
DISSOLVED									

TABLE 5-continued

INORGANIC CONCENTRATIONS									
[SO4=], Init.	0								
[SO4=], Final	0	1.E-10	4.00E-16	4.00E-16	4.00E-16		4.00E-16	4.00E-18	1.35E-14
	.0758434		.0406831						
[HCO3-]	.0758079	1.E-10	.0277133	.0277133	.0277133		.0277133	2.771E-4	.9350949
[CO3=], Init.	5.117E-5	1.E-10	.0241790						
[CO3=], Final	3.548E-5	1.E-10	.0129698	.0129698	.0129698		1.903E-5	1.903-7	6.421E-4
[H+]	.0000001	4.E-16	1.E-10	1.E-10	1.E-10	10	.0000001	.0000001	.0000001
[Cs+]	5.14E-11		5.14E-11	5.14E-11	5.14E-11		5.14E-11	5.14E-13	1.735E-9
[Ca+2], Init.	2.789E-4	1.E-10	2.789E-4						
[Ca+2], Final	2.789E-4	1.E-10	2.800E-7	2.800E-7	2.800E-7		2.800E-7	2.800E-9	9.446E-6
[Mg+2], Init.		1.E-10	.0023279						
[Mg+2], Final	.0023279	1.E-10	.0012000	.0012000	.0012000		.0012000	1.200E-5	.0404901
[Sr+2]	8.64E-11		8.64E-11	8.64E-11	8.64E-11		8.64E-11	8.64E-13	2.915E-9
Other Anions (Cl-, NO3-)	.0370290	25	.0371287	.0371287	.0371287	10	.0371288	3.713E-4	1.252792
Other Cations	0								
(Na+, NH4+)	.1076943	25	.088381	.088381	.088381		.0624795	6.248E-4	2.108179
Total Dissolved Inorganics (Normality)	.1129077	25.00000	.0907816	.0907816	.0907816	10	.0648802	6.489E-4	2.189178
CHECK ANIONS	.1129078	25.00000	.0907816	.0907816	.0907816	10	.0648802	6.488E-4	2.189171
TDS [Inorganics] (milligram/liter)	8486	1000000	8490	8490	8490	365000	8489.596	84.89596	286453.9
H2O (kg/hr)	467.6958	.0018689	467.6977	4.676977	463.0207	4.626E-6	463.0207	449.4314	13.58929
CaSO4 (kg/hr)	0		0	0					
CaCO3 (kg/hr)	1.566573		1.579602	1.579602					
Mg(OH)2 (kg/hr)			.0307534	.0307534					
MgCO3 (kg/hr)	0		0	0					
SrSO4 (kg/hr)									
Particulates (@ 1000 ppm) (kg/hr)	3.16		3.16	3.16					

FRED SEQUENCE FOR CASE 3 CONDITIONS
RESULTS FOR THE FREEZING PROCESS

FRED.FREEZE.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 1; Freeze/Wash/Melt)

Percent Feed Water to Slurry:	99	Percent Water Recovery:	59.00
Percent Slurry H2O as Brine:	25	Percent Water Delivered to ED System:	40.00
Percent Washed Ice H2O as Brine:	.5		
Percent Melter H2O used as Wash:	20		
Percent Ice melted and lost:	1		

POSITION	1	2	3	4	5	6	7	8
DISSOLVED INORGANIC CONCENTRATIONS								
[SO4=] Init.		0				0		
[SO4=] Final	0	0	0	0	0	0	0	0

TABLE 5-continued

[HCO3−] INITIAL	.0197	.0574199				.0354804		
[HCO3−] FINAL	.0196908	.0573931	.0573931	2.870E−4	2.870E−4	.0354638	2.870E−4	2.870E−4
[CO3=] INITIAL		3.579E−5				2.217E−5		
[CO3=] FINAL	9.215E−6	2.686E−5	2.686E−5	1.343E−7	1.343E−7	1.660E−5	1.343E−7	1.343E−7
[H+]	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001
[Cs+]	1.E−11	3.88E−11	3.88E−11	1.94E−13	1.94E−13	2.37E−11	1.94E−13	1.94E−13
[Ca+2] Init.		3.683E−4		0	0	5.961E−4	0	0
[Ca+2] Final	.005	3.683E−4	3.683E−4	1.842E−6	1.842E−6	5.961E−4	1.842E−6	1.842E−6
[Mg+2]	.0041	.0159223	.0159223	7.961E−5	7.961E−5	1.990E−4	7.961E−5	7.961E−5
[Sr+2]	1.68E−11	6.52E−11	6.52E−11	3.26E−13	3.26E−13	3.99E−11	3.26E−13	3.26E−13
Other Anions (Cl−, NO3−)	.0072	.0279612	.0279612	1.398E−4	1.398E−4	.0170965	1.398E−4	1.398E−4
Other Cations (Na+, NH4+)	.0087092	.0528267	.0528267	2.641E−4	2.641E−4	0 .0510030	2.641E−4	2.641E−4
Total Dissolved Inorganics (Normality)	.0269092	.0854080	.0854080	4.270E−4	4.270E−4	.0525933	4.270E−4	4.270E−4
CHECK ANIONS	.0269092	.0854080	.0854080	4.270E−4	4.270E−4	.0525934	4.270E−4	4.270E−4
TDS [Inorganics] (milligram/liter)	1957	6112	6112	30.55933	31	3973	30.55935	30.55935
H2O (kg/hr)	3160	3128.4	31.6	466.1316	2330.658	1263.874	2330.658	1864.526
CaSO4 (x, molality)								
CaSO4 (kg/hr)		0				0		
CaCO3 (kg/hr)		1.552214				1.503153		
Mg(OH)2 (kg/hr)								
MgCO3 (kg/hr)		0				0		
SrSO4 (kg/hr)								
Particulates (@ 1000 ppm) (kg/hr)	3.16	3.16				3.16		

FRED SEQUENCE FOR CASE 3 CONDITIONS RESULTS FOR THE ELECTRODIALYSIS PROCESS

FRED.ED.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 2; Filter/ED)

Settling Tank pH:	10	ED PLANT Percent Water Recovery:	97.64
ED Unit Feed pH:	7	CHEMICAL PLANT RECOVERY:	99
DECONTAMINATION FACTOR:	100	OVERALL WATER RECOVERY:	.9666675
Percent Settler Blowdown:	1		

POSITION	6	9	10	11	12	13	14	15	16
DISSOLVED INORGANIC CONCENTRATIONS									
[SO4=], Init.	0								
[SO4=], Final	0	1.E−10	4.00E−16	4.00E−16	4.00E−16		4.00E−16	4.00E−18	1.68E−14
	.0354804		.0197707						
[HCO3−]	.0354638	1.E−10	.0134678	.0134678	.0134678		.0134678	1.347E−4	.5657672
[CO3=], Init.	2.217E−5	1.E−10	.0113112						
[CO3=], Final	1.660E−5	1.E−10	.0063029	.0063029	.0063029		9.248E−6	9.248E−8	3.885E−4
[H+]	.0000001	4.E−16	1.E−10	1.E−10	1.E−10	10	.0000001	.0000001	.0000001

TABLE 5-continued

[Cs+]	2.37E−11		2.37E−11	2.37E−11	2.37E−11		2.37E−11	2.37E−13	9.98E−10
[Ca+2], Init.	5.961E−4	1.E−10	5.961E−4						
[Ca+2], Final	5.961E−4	1.E−10	6.066E−7	6.066E−7	6.066E−7		6.066E−7	6.066E−9	2.548E−5
[Mg+2], Init.		1.E−10	1.990E−4						
[Mg+2], Final	1.990E−4	1.E−10	1.990E−4	1.990E−4	1.990E−4		1.990E−4	1.990E−6	.0083618
[Sr+2]	3.99E−11		3.99E−11	3.99E−11	3.99E−11		3.99E−11	3.99E−13	1.676E−9
Other Anions (Cl−, NO3−)	.0170965	25	.0171963	.0171963	.0171963	10	.0171964	1.720E−4	.7224012
Other Cations	0								
(Na+, NH4+)	.0510030	25	.0428706	.0428706	.0428706		.0302833	3.028E−4	1.272170
Total Dissolved Inorganics (Normality)	.0525933	25.00000	.0432699	.0432699	.0432699	10	.0306827	3.069E−4	1.288945
CHECK ANIONS	.0525934	25.00000	.0432699	.0432699	.0432699	10	.0306827	3.068E−4	1.288945
TDS [Inorganics] (milligram/liter)	3973	1000000	3977	3977	3977	365000	3976.943	39.76943	167067.0
H2O (kg/hr)	1263.874	.0050505	1263.879	12.63879	1251.240	1.250E−5	1251.240	1221.746	29.49428
CaSO4 (kg/hr)	0		0	0					
CaCO3 (kg/hr)	1.503153		1.578416	1.578416					
Mg(OH)2 (kg/hr)			0	0					
MgCO3 (kg/hr)	0		0	0					
SrSO4 (kg/hr)									
Particulates (@ 1000 ppm) (kg/hr)	3.16		3.16	3.16					

FRED SEQUENCE FOR CASE 4 CONDITIONS
RESULTS FOR THE FREEZING PROCESS

FRED.FREEZE.VC1
Design Parameters for Processing PWR Inorganic Streams (Part 1; Freeze/Wash/Melt)

Percent Feed Water to Slurry:	99	Percent Water Recovery:	66.38
Percent Slurry H2O as Brine:	25	Percent Water Delivered to ED System:	32.62
Percent Washed Ice H2O as Brine:	.5		
Percent Melter H2O used as Wash:	10		
Percent Ice melted and lost:	1		

POSITION	1	2	3	4	5	6	7	8
DISSOLVED INORGANIC CONCENTRATIONS								
[SO4=] Init.		0				0		
[SO4=] Final	0	0	0	0	0	0	0	0
[HCO3−] INITIAL	.0197	.0574199				.0431967		
[HCO3−] FINAL	.0196908	.0573931	.0573931	2.870E−4	2.870E−4	.0431765	2.870E−4	2.870E−4
[CO3=] INITIAL		3.579E−5				2.215E−5		
[CO3=] FINAL	9.215E−6	2.686E−5	2.686E−5	1.343E−7	1.343E−7	2.021E−5	1.343E−7	1.343E−7
[H+]	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001
[Cs+]	1.E−11	3.88E−11	3.88E−11	1.94E−13	1.94E−13	2.91E−11	1.94E−13	1.94E−13
[Ca+2] Init.		3.683E−4		0	0	4.896E−4	0	0
[Ca+2] Final	.005	3.683E−4	3.683E−4	1.842E−6	1.842E−6	4.896E−4	1.842E−6	1.842E−6
[Mg+2]	.0041	.0159223	.0159223	7.961E−5	7.961E−5	2.441E−4	7.961E−5	7.961E−5

TABLE 5-continued

[Sr+2]	1.68E−11	6.52E−11	6.52E−11	3.26E−13	3.26E−13	4.88E−11	3.26E−13	3.26E−13
Other Anions (Cl−, NO3−)	.0072	.0279612	.0279612	1.398E−4	1.398E−4	.0209304	1.398E−4	1.398E−4
Other Cations						0		
(Na+, NH4+)	.0087092	.0528267	.0528267	2.641E−4	2.641E−4	.0626798	2.641E−4	2.641E−4
Total Dissolved Inorganics (Normality)	.0269092	.0854080	.0854080	4.270E−4	4.270E−4	.0641472	4.270E−4	4.270E−4
CHECK ANIONS	.0269092	.0854080	.0854080	4.270E−4	4.270E−4	.0641473	4.270E−4	4.270E−4
TDS [Inorganics] (milligram/liter)	1957	6112	6112	30.55935	31	4845	30.55935	30.55935
H2O (kg/hr)	3160	3128.4	31.6	233.0658	2330.658	1030.808	2330.658	2097.592
CaSO4 (x, molality)								
CaSO4 (kg/hr)		0				0		
CaCO3 (kg/hr)		1.552214				1.527979		
Mg(OH)2 (kg/hr)								
MgCO3 (kg/hr)		0				0		
SrSO4 (kg/hr)								
Particulates (@ 1000 ppm) (kg/hr)	3.16	3.16				3.16		

FRED SEQUENCE FOR CASE 4 CONDITIONS
RESULTS FOR THE ELECTRODIALYSIS PROCESS

FRED.ED.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 2; Filter/ED)

Settling Tank pH:	10	ED PLANT Percent Water Recovery:	97.64
ED Unit Feed pH:	7	CHEMICAL PLANT RECOVERY:	99
DECONTAMINATION FACTOR:	100	OVERALL WATER RECOVERY:	.9666714
Percent Settler Blowdown:	1		

POSITION	6	9	10	11	12	13	14	15	16
DISSOLVED INORGANIC CONCENTRATIONS									
[SO4=], Init.	0								
[SO4=], Final	0	1.E−10	4.00E−16	4.00E−16	4.00E−16		4.00E−16	4.00E−18	1.68E−14
	.0431967		.0241970						
[HCO3−]	.0431765	1.E−10	.0164829	.0164829	.0164829		.0164829	1.648E−4	.6925450
[CO3=], Init.	2.715E−5	1.E−10	.0137712						
[CO3=], Final	2.021E−5	1.E−10	.0077140	.0077140	.0077140		1.132E−5	1.132E−7	4.756E−4
[H+]	.0000001	4.E−16	1.E−10	1.E−10	1.E−10	10	.0000001	.0000001	.0000001
[Cs+]	2.91E−11		2.91E−11	2.91E−11	2.91E−11		2.91E−11	2.91E−13	1.221E−9
[Ca+2], Init.	4.896E−4	1.E−10	4.896E−4						
[Ca+2], Final	4.896E−4	1.E−10	4.955E−7	4.955E−7	4.955E−7		4.955E−7	4.955E−9	2.082E−5
[Mg+2], Init.		1.E−10	2.441E−4						
[Mg+2], Final	2.441E−4	1.E−10	2.441E−4	2.441E−4	2.441E−4		2.441E−4	2.441E−6	.0102541
[Sr+2]	4.88E−11		4.88E−11	4.88E−11	4.88E−11		4.88E−11	4.88E−13	2.052E−9
Other Anions (Cl−, NO3−)	.0209304	25	.0210302	.0210302	.0210302	10	.0210303	2.103E−4	.8836051
Other Cations	0								

TABLE 5-continued

(Na+, NH4+)	.06268	25	.052452	.052452	.052452		.0370466	3.705E−4	1.556551
Total Dissolved Inorganics (Normality)	.0641473	25.00000	.0529411	.0529411	.0529411	10	.0375358	3.755E−4	1.577101
CHECK ANIONS	.0641473	25.00000	.0529411	.0529411	.0529411	10	.0375358	3.754E−4	1.577101
TDS [Inorganics] (milligram/liter)	4845	1000000	4849	4849	4849	365000	4849.144	48.49144	203741.0
H2O (kg/hr)	1030.808	.0041191	1030.812	10.30812	1020.504	1.019E−5	1020.504	996.4524	24.05137
CaSO4 (kg/hr)	0		0	0					
CaCO3 (kg/hr)	1.527979		1.578399	1.578399					
Mg(OH)2 (kg/hr)			0	0					
MgCO3 (kg/hr)	0		0	0					
SrSO4 (kg/hr)									
Particulates (@ 1000 ppm) (kg/hr)	3.16		3.16	3.16					

FRED SEQUENCE FOR CASE 5 CONDITIONS
RESULTS FOR THE FREEZING PROCESS

FRED.FREEZE.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 1; Freeze/Wash/Melt)

Percent Feed Water to Slurry:	99	Percent Water Recovery:	39.20
Percent Slurry H2O as Brine:	50	Percent Water Delivered to ED System:	59.80
Percent Washed Ice H2O as Brine:	.5		
Percent Melter H2O used as Wash:	20		
Percent Ice melted and lost:	1		

POSITION	1	2	3	4	5	6	7	8
DISSOLVED INORGANIC CONCENTRATIONS								
[SO4=] Init.		0				0		
[SO4=] Final	0	0	0	0	0	0	0	0
[HCO3−] INITIAL	.0197	.0298004				.0248381		
[HCO3−] FINAL	.0196908	.0297864	.0297864	1.489E−4	1.489E−4	.0248265	1.489E−4	1.489E−4
[CO3=] INITIAL		1.825E−5				1.513E−5		
[CO3=] FINAL	9.215E−6	1.394E−5	1.394E−5	6.970E−8	6.970E−8	1.162E−5	6.970E−8	6.970E−8
[H+]	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001	.0000001
[Cs+]	1.E−11	1.98E−11	1.98E−11	9.90E−14	9.90E−14	1.63E−11	9.90E−14	9.90E−14
[Ca+2] Init.		7.097E−4		0	0	8.515E−4	0	0
[Ca+2] Final	.005	7.097E−4	7.097E−4	3.549E−6	3.549E−6	8.515E−4	3.549E−6	3.549E−6
[Mg+2]	.0041	.0081188	.0081188	4.059E−5	4.059E−5	4.789E−5	4.059E−5	4.059E−5
[Sr+2]	1.68E−11	3.33E−11	3.33E−11	1.66E−13	1.66E−13	2.74E−11	1.66E−13	1.66E−13
Other Anions (Cl−, NO3−)	.0072	.0142574	.0142574	7.129E−5	7.129E−5	.0117558	7.129E−5	7.129E−5
Other Cations (Na+, NH4+)	.0087092	.0264147	.0264147	1.321E−4	1.321E−4	0 .0347666	1.321E−4	1.321E−4
Total Dissolved Inorganics (Normality)	.0269092	.0440718	.0440718	2.204E−4	2.204E−4	.0366054	2.204E−4	2.204E−4

TABLE 5-continued

CHECK ANIONS	.0269092	.0440718	.0440718	2.204E−4	2.204E−4	.0366055	2.204E−4	2.204E−4
TDS [Inorganics] (milligram/liter)	1957	3157	3157	15.78581	16	2768	15.78581	15.78581
H2O (kg/hr)	3160	3128.4	31.6	309.7116	1548.558	1889.554	1548.558	1238.846
CaSO4 (x, molality)								
CaSO4 (kg/hr)		0				0		
CaCO3 (kg/hr)		1.468967				1.416419		
Mg(OH)2 (kg/hr)								
MgCO3 (kg/hr)		0				0		
SrSO4 (kg/hr)								
Particulates (@ 1000 ppm) (kg/hr)	3.16	3.16				3.16		

FRED SEQUENCE FOR CASE 5 CONDITIONS RESULTS FOR THE ELECTRODIALYSIS PROCESS

FRED.ED.VC1

Design Parameters for Processing PWR Inorganic Streams (Part 2; Filter/ED)

Settling Tank pH:	10	ED PLANT Percent Water Recovery:	97.64
ED Unit Feed pH:	7	CHEMICAL PLANT RECOVERY:	99
DECONTAMINATION FACTOR:	100	OVERALL WATER RECOVERY:	.9666020
Percent Settler Blowdown:	1		

POSITION	6	9	10	11	12	13	14	15	16
DISSOLVED INORGANIC CONCENTRATIONS									
[SO4=], Init.	0								
[SO4=], Final	0	1.E−10	4.00E−16	4.00E−16	4.00E−16		4.00E−16	4.00E−18	1.67E−14
	.0248381		.0136713						
[HCO3−]	.0248265	1.E−10	.0093129	.0093129	.0093129		.0093129	9.313E−5	.3901288
[CO3=], Init.	1.513E−5	1.E−10	.0079184						
[CO3=], Final	1.162E−5	1.E−10	.0043584	.0043584	.0043584		6.395E−6	6.395E−8	2.679E−4
[H+]	.0000001	4.E−16	1.E−10	1.E−10	1.E−10	10	.0000001	.0000001	.0000001
[Cs+]	1.63E−11		1.63E−11	1.63E−11	1.63E−11		1.63E−11	1.63E−13	6.84E−10
[Ca+2], Init.	8.515E−4	1.E−10	8.515E−4						
[Ca+2], Final	8.515E−4	1.E−10	8.821E−7	8.821E−7	8.821E−7		8.821E−7	8.821E−9	3.695E−5
[Mg+2], Init.		1.E−10	6.789E−5						
[Mg+2], Final	6.789E−5	1.E−10	6.789E−5	6.789E−5	6.789E−5		6.789E−5	6.789E−7	.0028439
[Sr+2]	2.74E−11		2.74E−11	2.74E−11	2.74E−11		2.74E−11	2.74E−13	1.149E−9
Other Anions (Cl−, NO3−)	.0117558	25	.0118556	.0118556	.0118556	10	.0118557	1.186E−4	.4966506
Other Cations	0								
(Na+, NH4+)	.0347666	25	.0297479	.0297479	.0297479		.0210438	2.104E−4	.8815533
Total Dissolved Inorganics (Normality)	.0366054	25.00000	.0298854	.0298854	.0298854	10	.0211814	2.119E−4	.8873151
CHECK ANIONS	.0366055	25.00000	.0298854	.0298854	.0298854	10	.0211814	2.118E−4	.8873151
TDS [Inorganics] (milligram/liter)	2768	1000000	2772	2772	2772	365000	2771.773	27.71773	116112.9

TABLE 5-continued

H2O (kg/hr)	1889.554	.0075507	1889.561	18.89561	1870.666	1.869E−5	1870.666	1826.446	44.21932
CaSO4 (kg/hr)	0		0	0					
CaCO3 (kg/hr)	1.416419		1.577151	1.577151					
Mg(OH)2 (kg/hr)			0	0					
MgCO3 (kg/hr)	0		0	0					
SrSO4 (kg/hr)									
Particulates (@ 1000 ppm) (kg/hr)	3.16		3.16	3.16					

TABLE 6

Scenario #	Sequences	Slurry Brine %	Wash Water %
1	FRED	5	20
2	FRED	5	10
3	FRED	25	20
4	FRED	25	10
5	FRED	50	20
6	FRED	50	10
7	EDFRA	5	20
8	EDFRA	5	10
9	EDFRA	25	20
10	EDFRA	25	10
11	EDFRA	50	20
12	EDFRA	50	10

*FRED: Freezing followed by ED
EDFRA: ED followed by freezing
brine cover: slurry water used as brine
wash water: water from melter used to wash the ice

not operate with significant solids present in the stream. The pH of the streams outside the chemical treatment section is held constant at 7 (by the limited addition of HCL or NaOH).

In washing the ice, the brine solution containing the ice crystals will not be completely removed. The simulation assumes that at a half of a percent (0.5%) of the water leaving the washer is brine. This residual brine determines the salt content of the decontaminated product water leaving the freezing process.

It is also assumed in the washing step that one percent (1%) of the ice is melted. This water is lost to the wash water.

The ED process is designed for a 100-fold reduction of the feed stream salinity in the simulation. Higher reductions are possible with ED. ED plants have been designed for reductions as high as 20,000 fold.

RESULTS OF THE COMPUTER MODEL

In total, twelve cases have been analyzed with the simulator model. Six of the freezing process first (FRED) as shown in Table 5 and 6 for the chemical treatment and the ED first (EDFRA). The scenarios are listed in Table 5 and the case numbers for each set of six are summarized in Table 6 relative to the values of:

- * the percent melter water used as wash water, and
- * the percent slurry water used as brine.

TABLE 7

Process Sequence	Scenario #	DECONTAMINATION DF	DECONTAMINATION VOLUME FRACTION	CONCENTRATION OF RADIOACTIVITY CF	CONCENTRATION OF RADIOACTIVITY VOLUME FRACTION
Primary freezing process with chemical precipitation of wash water and subsequent treatment by ED	1	17.3	0.9821	58.6	0.0179
	2	15.7	0.9842	68.1	0.0158
	3	57.2	0.9767	46.7	0.0233
	4	53.8	0.9791	52.0	0.0209
	5	85.5	0.9700	37.0	0.0300
	6	82.9	0.9717	39.0	0.0283
Pretreatment by chemical precipitation and primary ED process with brine concentration by subsequent freezing treatment	7	25.6	0.9843	51.0	0.0157
	8	23.4	0.9866	58.1	0.0134
	9	66.3	0.9806	44.7	0.0194
	10	63.7	0.9823	48.8	0.0177
	11	85.5	0.9759	36.5	0.0241
	12	84.0	0.9771	38.4	0.0229

The results of the analysis are given in Table 5. The results are divided into two parts corresponding to the two sequences for the processes. The performance of the combined process is given both in terms of the level of decontamination achieved and in terms of the concentration of radioactivity. The volume fractions of water indicate how the feed stream is divided between the decontaminated stream and the concentrated The basic assumptions are:

- * The inorganic chemical waste stream was used as basis for the evaluation (Table 6).
- * the 1.4% sodium sulfate produced by the IX processes has been dropped out from the stream analysis, assuming that FREDCON shall replace all the existing LWMS in the plant under consideration.
- * pH 10 of chemical precipitates is used.
- * 0.5% washed ice water is assumed as brine. The freezing unit suppliers claim that this fraction can be maintained at nearly 0.0%.
- * 1% ice melted and lost to wash.
- * 99% feed water converted to ice slurry.
- * 1.0% blowdown of chemical precipitation is used.

From the results shown in Table 7:

- * A high concentration factor (CF) of radioactive material (or large VR) is achieved in both system at the expense of achieving a high decontamination factor (DF). Namely the DF increased monotonically as the percent of the slurry water as brine increases while the concentration factor decreases monotonically.
- * The magnitude of the DF is dependent upon the amount of residual brine on the ice after washing.
- * At lower levels; less than 0.5%, a higher DF will be achieved.
- * If a lower level of brine can be obtained from the washing step, a second ED can be added to further decontaminate the product water from the freezer system. This ED step can be added into either FRED or EDFRA arrangement.
- * The difference between both arrangements does not clearly favor one over the other in terms of the CF or DF analyses. This is especially because of the conservative assumptions related to freezing. Using suppliers' number can entirely reverse the situation.

FRED may be favored over EDFRA due to the ability of the first arrangement to consolidate solids up to 41% in the blowdown from the chemical treatment section. This is while the second sequence is limited to @7% precipitation. This observation came out from a detailed analysis with the results shown in Table 3.

- * The higher solid content in the blowdown is of significant potential, since these solids while in themselves are not necessarily radioactive, will carry with them some radioactive materials. The blowdown will therefore require special handling and disposal.

These results of Phase I suggest that the preferred sequence is to place the freezing process first (FRED) and then to treat the wash water (and possibly the product water) with ED. At least in the case of the wash water, the water should be pretreated by chemical means before it is processed by the ED section. This sequence is the sequence proposed for the pilot plant to be tested in Phase II.

According to these observations, it is necessary to include in the test plan for Phase II the following items:

* Verification of the fraction of contaminated water that remains covering the ice after wash.
* Optimization of the design for maximum VR within the constraints of a fixed high DF (regulatory limits).

The computer printouts for the process sequence where the freezing process is first are given in Table 5a through Table 5f for cases one through six, respectively. In this sense, the "a" labels are for the freezing process and the "b" labels are for the electrodialysis process.

The computer printouts for the process sequence where the electrodialysis (and filtration) process is first are given in Table 5g through Table **51** for the cases one through six, respectively. In this series, the electrodialysis results are given in Table 5g and, since they are the same for the other five cases, they are omitted. The freezing results are however, different so the full "b" series of figures are given.

ANALYSIS OF THE RESULTS

A summary of the decontaminated (DF) and concentration (CF) factors for the twelve cases is given in Table 7. The six cases in the upper half of Table 7 are for the process sequence where the freezing process is first. The six cases in the lower half are for the process sequence where the electrodialysis process is first. In each half, the cases are in order, i.e. starting with case one and ending with case six.

Inspection of the results in Table 7 indicates an inverse correlation between the DF and CF for both sequences where the DF comes approximately as the inverse cube of the CF. That is, if one designs the process to achieve a high CF (volume reduction) then the degree of decontamination of the decontaminated product water is reduced. To a large extent, this correlation is due to the assumed inefficiency of the washing step in the freezing process. In particular, it is "assumed that" the ice slurry leaves the washing step with 5 percent of the water as brine coating the ice. If the washing step is actually more efficient than this, then correlation can be broken or at least minimized and both high values of CF and DV can be achieved simultaneously.

If the efficiency of the washing step can not be improved from the assumed level, then it may be necessary to treat the product water from the freezer process by electrodialysis and thereby increase the DF for a given CF. In this case, separate ED steps would probably be used for the product and wash waters since the wash water is first treated by the chemical precipitation and clarification step.

In general, the results for DF and CF in Table 7, do not favor either process sequence. If the efficiency of the washing step is as assumed, then the process sheet with a second ED step is probably more straight forward with the freezing process as the first process.

An additional criterion for selecting the preferred sequence is the solids content which can be achieved in the blowdown from th chemical precipitation step. These results are summarized in Table 3 for the twelve cases. The organization of the results in Table 3 is identical with the organization in Table 7 in that the results for the freezing first process are in the upper half and cases are sequential starting with case one at the top of each half.

Note in particular, that with the ED process first, the solids content is limited to about 7 percent, assuming a one percent blowdown for the clarification (filtration or other process) step, for all six cases. This occurs because with the ED process first, the process, always sees the same feed and the results are not influenced by alterations in the freezing process.

In all six cases where the freezing process is first, the total solids content in the flowdown exceeds 7 percent. The solids content also increases as expected with increasing values of CF (see Table 7 for CF's). While in practice, it may not be possible to achieve the highest concentrations of solids irradiated in Table 3, the potential for high solids content in the blowdown suggests that the process sequence should be the sequence with the freezing process first.

SUMMARY AND CONCLUSION

The major conclusions of the study of alternative process sequences and preferred operating conditions are:

(1) the freezing process should be the first process in the sequence, and

(2) the efficiency of the washing step in the freezing process, in general, determines the level of decontamination of the product water.

Both conclusions are subject to experimental test since they ultimately are only as good as the assumptions used in developing the simulated results with the computer model.

With regard to the first conclusion, the selection of the freezing process as the first process is based on the higher solids content attainable in the blowdown from the chemical precipitation and clarification step. The critical assumption is that the blowdown in either process sequence requires one percent of the water in the feed to this step. If, for example, lower percentage can be used with the electrodialysis process as the first process, then this conclusion could be reversed.

With regard to the second conclusion, the efficiency of the washing step is less significant in determining the level of decontamination if the process is modified such that the product water from the freezing process is further treated by a second electrodialysis step. In the latter case or in the case that the efficiency of the washing step is better than assumed (washed ice slurry leaves the washer with 0.5 percent of the water as brine coating the ice), both high values of decontamination and concentration can be achieved simultaneously.

While preferred embodiments have been shown and described, it will be understood that the present invention is not limited thereto, but may be otherwise embodied within the scope of the present invention.

What is claimed is:

1. A nuclear plant low level liquid radioactive waste treatment and volume reduction process comprising the steps of:

collecting the low-level liquid radioactive wastes influent within the plant into a holding tank for processing;

directing a first waste-containing stream containing the low-level liquid radioactive wastes at a regulated flow rate from the holding tank to a plate precooler wherein the first waste-containing stream is chilled to near its freezing point;

introducing the chilled waste-containing stream into a freezing crystallizer to form ice crystals from the water in the stream and to obtain a waste stream containing residual salts and having a reduced volume relative to the first waste-containing stream;

recirculating the reduced volume stream into a recirculation loop around the crystallizer to maintain proper velocity and uniformity of ice fraction in the crystallizer;

increasing the formation rate of ice until the concentration of the residual salts in the recirculating waste-containing stream becomes high enough to precipitate some of the salts as wet salts;

directing the wet salts and any other solid contaminants to a disposal tank for eventual packaging in standard radioactive waste forms for shipment to disposal sites;

separating the ice crystals and washing the ice to remove adhering waste liquid, melting the ice, and then recycling or disposing the melted ice as a purified liquid;

collecting the reduced volume stream after separating the wet salts of ice to form a second waste-containing stream which includes the waste liquid removed from the ice;

electrodialyzing the second waste containing stream to further reduce the volume of the second waste-containing stream and thereby produce a third stream concentrated with inactive ions and other waste ions; and then recycling the third waste stream through the precooling and crystallizing freezing steps.

2. A process as claimed in claim **1**, further comprising:

adding of sodium hydroxide to the second waste-containing stream produced by the freezing steps prior to the electrodialysis step to form precipitates;

filtering the second waste stream to separate precipitates;

directing the precipitates to a disposal tank for eventual packaging in standard radioactive waste forms for shipment to disposal sites; and then

adding hydrochloric acid to the filtrate of the second waste stream to adjust the pH of the second waste stream.

3. A process as claimed in claim **1**, wherein said freezing is a eutectic, bulk, indirect crystallization process comprising introducing the precooled first waste-containing stream into the tube side of a shell and tube evaporator with a recirculation loop; and evaporating ammonia on the shell side to remove heat through the tube wall, thus freezing a portion of the stream.

4. A process as claimed in claim **1**, comprising the step of separating the water ice crystals from the reduced volume waste stream by consolidating and propelling the ice on the top of a wash column by hydraulic piston action while allowing water to enter over the top surfaces of the wash column at atmospheric pressure and fall down by gravity to wash away the liquid waste adhering to the water ice crystals.

5. A process as claimed in claim **1**, wherein the waste-containing stream contains low-level liquid radioactive wastes of variable composition comprising high/low conductivity waste; chemical waste; laundry/detergent wastes; or stream generator blowdown.

6. A waste treatment process comprising the steps of freezing an aqueous, radioactive waste-containing stream to form (a) a brine containing at least a portion of the waste, and (b) a slurry containing ice and the remainder of the waste;

removing a portion of the slurry containing at least some of the remainder of the waste;

washing the ice to remove therefrom a further portion of the waste as an aqueous solution thereof; and

electrodialyzing the aqueous solution and the brine to remove at least said further portion of the waste as a further concentrated brine.

7. A process as in claim **6** wherein said radioactive waste-containing stream is produced within a nuclear plant and where the process occurs in the plant; said plant is a boiling water reactor, a pressurized water reactor or a nuclear facility.

8. A process as in claim **6** including melting the washed ice to provide a first stream of decontaminated water for disposal to the environment.

9. A process as in claim **8** including reusing a portion of the first stream of the decontaminated water as the water used in said washing step to reduce adding fresh water.

10. A process as in claim **6** where said electrodialyzing step forms a second stream of decontaminated water for disposal to the environment.

11. A process as in claim **6** including filtering any particulate matter from said brine and adding NaOH to said brine to precipitate salts from said brine and adjusting the pH of acid brine prior to electrodialyzing.

12. A process as claimed in claim **10** wherein decontaminated water is recycled in the plant.

13. A process as claimed in claim **8** wherein decontaminated water is recycled in the plant.

14. A process as claimed in claim **6** wherein said brine from electrodialyzing is further processed by the freezing stage to produce wet salts.

15. A process as claimed in claim **8** wherein said decontaminated water is not potable water.

16. A process as claimed in claim **10** wherein said decontaminated water is not potable water.

17. A process as claimed in claim **6** wherein said waste is radioactive inorganic chemical waste and detergent.

18. A process for continuous concentration of aqueous waste stream containing wastes of unknown composition that may vary in concentration over short periods of time comprising the steps of:

freezing the aqueous waste stream to extract water as ice crystals leaving a secondary aqueous waste stream and a slurry of wet solid particulates;

settling and filtering the secondary aqueous waste stream to remove particulates in a tank;

adding sodium hydroxide to

collecting the aqueous waste stream in said tank to form a third waste stream;

adjusting the pH of the third stream;

electrodialyzing the third stream to produce a fourth waste stream with high concentration of salts;

recycling the fourth stream by the freezing step until all wastes are transformed into a slurry of wet solid particulates; and

disposing of the slurry of wastes.

19. A process as claimed in claim **18** wherein the ice crystals are melted and discharged to the environment as water.

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