STUDY OF PROCESSES FOR THE PRODUCTION OF POTABLE WATER FROM AQUEOUS WASTES DEVELOPED IN A SHELTER

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by

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FOREWORD

The results presented in this report are based upon a "paper study". No laboratory or experimental work was performed under this contract. An extensive search of the literature, along with data from manufacturers provided the basis for the development of the information contained in this report.

Preliminary, but not final, specifications for equipment that may be used have been prepared. Costs, where cited, should be considered only as order of magnitude since further data, which can be obtained only through a program of research and development, will be necessary for detailed cost information.

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I. ABSTRACT

An adequate supply of potable water is an essential requirement in a fallout shelter. This study has evaluated many known means of converting aqueous shelter wastes into potable water. A comparison of various processes led to the selection of the three most feasible systems with a system of pre- and post-treatment and testing common to all.

The processes selected as most likely to produce acceptable potable water are:

      (1) Vapor compression distillation;
      (2) Ion exchange and charcoal adsorption and,
      (3) Electrodialysis.

Preliminary specifications of equipment, utilities consumed and estimated costs are given for each process.

Water from the air, extracted by an air conditioning system, is discussed and recommendations made.

Recovery systems are contrasted to the normal means of water supply and it is recommended that the conventional means of supply should ordinarily used.

Recommendations are made for future research and development work. A bibliography covering the literature studied, charts and process flow diagrams are included.

II. CONCLUSIONS

Conventional schemes for providing water to a shelter will usually cost less and be more desirable than depending upon the conversion of aqueous wastes generated within a shelter into a potable water supply.

However, detailed consideration has been given to the production of potable water from aqueous wastes generated within a shelter. Of the basic processes evaluated only three are sufficiently attractive for further study. These are: 1) Vapor compression distillation, 2) A combination of ion exchange and activated carbon adsorption, and 3) Electrodialysis. A system of pre- and post-treatment common to all processes is required.

Criteria have been established for the evaluation of all processes. These are established in detail in Section VI-B. A tabulation comparing these three processes based upon the enumerated criteria is given below:

	Vapor Compression Distillation	Ion Exchange – Activated Carbon	Electrodialysis
1. Purity of Product	Satisfactory in lab	Must be demonstrated in lab that purity is satisfactory	Must be demonstrated in lab that purity is satisfactory
Sterilization	Heated above B.P.	None	None
Disinfection	Desirable	Required	Required
2. Utility Requirements			
Electricity	3KW	<0.2KW	0.4KW
Cooling Water	None	None	None
Operate Manually	No	Yes	No
3. Reliability	Good	Excellent	Good
4. Safety	Good	Excellent	Good
5. Simplicity	May be operated with little training	Very simple	May be operated with little training
6. Size, Weight & Volume			
a. Basic process	4' x 4' x 8' high 2200 lb. 128 ft^3	7' x 7' x 8' high 10,800 lb. 392 ft^3	7' x 7½' x 5½' high 3000 lb. 289 ft^3
b. Pre- & Post-Treatment	1500 lb. 250 ft^3	1500 lb. 250 ft^3	1500 lb. 250 ft^3
7. Availability	Easy to fabricate	Easy to fabricate	Specialized equipment
8. Stability during standby	High	High	Medium
9. Ease of maintenance	Moderate	Very easy	Moderate
10. Materials of construction	Mostly carbon steel	All carbon steel	All carbon steel except membranes
11. Flexibility	High	Low - would have a fixed capacity	High
12. Estimated Cost			
a. Basic process	$6250.	$8450.	$8400.
b. Pre- & Post-Treatment	$3500.	$3500.	$3500.

It has been demonstrated that distillation will produce a product that will meet purity requirements. In addition, the high temperature at which it operates will sterilize the water. Its main drawbacks are: 1) it cannot be operated manually, 2) it is more complicated than the ion-exchange-adsorption process, and 3) it uses more power than the other processes; however, the power consumption does not appear to be excessive.

It has not been demonstrated that the ion-exchange-adsorption process will effectively produce a water of suitable purity. If it is assumed that satisfactory purity can be achieved, then the only disadvantages of this process are: 1) it would be capable of treating only a fixed volume of water, and 2) it is larger and heavier than the other two processes.

Electrodialysis has not been demonstrated as a process that will produce a water of suitable quality. If it is assumed that satisfactory purity can be achieved then the only disadvantages are: 1) it cannot be operated manually and 2) it is more complex than the ion-exchange-adsorption process. However, the consumption of power is low and the volume of water that it will treat is not fixed.

None of these basic processes will operate with raw sewage and other wastes. It will be necessary to separate the solids from the wastes. Thus, the feed to these processes will be liquid essentially free of suspended solids. Chlorination and purity testing of the product water will be required.

A theoretical water balance, based upon shelter atmospheric conditions, was made for a shelter taking into consideration all of the parameters that would affect it. This shows that under certain adverse conditions, without operating specialized equipment, there could be a severe loss of water from a shelter. Conversely, under more favorable conditions an accumulation of water within the shelter may result.

No single process can be singled out at this time as being superior to any other. If detailed specifications for a particular shelter were available, this could be done. It is conceiveable that under one particular set of conditions one process would be the most suitable whereas under another set of conditions a different process would be favored.

III. RECOMMENDATIONS

It is recommended that a development program be initiated to obtain basic information on these three processes.

1. Distillation. A prototype model of a vapor compression distillation unit should be built. From the operation of it, such criteria could be established as: operability, capacity, dependability, power requirements, physical characteristics of materials handled, product quality and cost.

2. Ion-Exchange-Adsorption. It would be necessary to validate the adsorption capacity of ion-exchange resins and activated charcoal for the many materials that must be removed by such a system.

3. Electrodialysis. A prototype model of an electrodialysis unit should be built. From the operation of it, such criteria could be established as: rate of water transfer, amount of organic and inorganic fouling of the membrane surfaces, the degree of demineralization effected, power requirements, the effect of urea and other amino acids on electrodialysis, the effect of long term storage on membrane permeability, and cost.

4. Pre- and Post-Treatment. A test program should also be conducted to develop firm techniques to be used for the separation of waste solids from liquids, the treatment of product water and the development of water testing procedures and standards.

IV. INTRODUCTION

Living conditions inside a fallout shelter will be austere, because the area must be self-sufficient in the matter of supplies and services necessary for life. A nuclear attack may destroy or make unfit for use our normal sources of electric power, food, and water.

An adequate supply of potable water is an essential requirement in a shelter. The occupants must have water for drinking, for preparing food, for washing and for other sanitary purposes.

Various conventional methods may be used to supply water to a shelter:

(1) the storage of water in the shelter;
(2) the drilling of wells in or around the shelter;
(3) the continued operation of a municipal system.

The advantages of such conventional methods are obvious, but certain difficulties may occur in their use. This is discussed more fully in Section VII of this paper. A conventional scheme will usually cost less than the proposals set forth in this study.

Aqueous wastes will be accumulated within a shelter during occupancy. These will consist of water vapor introduced into the atmosphere from the occupants, sewage wastes, and wastes from washing and food preparation. Obviously, such wastes must be removed from the shelter or disposed of inside the area. It has been proposed that the collected wastes be used to provide a source of water for the occupants. This study is concerned with possible methods for the reconstitution of aqueous wastes into a potable water supply.

Two types of waste will be available from the shelter usage - water removed from the air by any air tempering system, and all other waste water. A much simpler recovery method may be used for the waste from an air tempering system, because it is of a very different nature.

An evaluation of the various methods which may be used to recover a potable water is an integral part of this study. A search of the literature in the field showed that very little work

has been done in this specific area, though some work has been done on the problem of furnishing a suitable water supply for space travel. The Office of Saline Water of the United States Department of the Interior has done research on the production of fresh water from saline water. Some of the information developed by the saline water program has been of value to the study.

A number of processes for recovering potable water from shelter wastes have been evaluated to determine which of them would produce water of good quality. Subsequently, these processes were measured against other established criteria, such as product quality, initial cost and utility requirements.

This study is one facet of the research and development program of the Office of Civil Defense. Any proposed system of water recovery must depend upon, and its design must be ultimately correlated with, all other systems which comprise the complicated development of a shelter with all of its auxiliary components.

The design of the water recovery system presupposes the existence of:

(1) an air tempering system to control the temperature within the shelter; water removed from the air by such a unit will be collected and purified;

(2) a method of collecting waste from toilets and other disposal units;

(3) a system for distributing the potable water throughout the shelter.

Criteria to evaluate a water recovery process for shelters have been established. The essential requirement for any process under consideration is the ability to produce water which meets recognized standards. All recovery processes which can furnish water of good quality have been measured against the remaining criteria.

Only those materials generated within the shelter have been considered. No plan is submitted for the removal of radioactive materials and bacteriological and chemical (CBR) warfare agents. However, if certain of these agents were present in the raw feed they may be removed to some undetermined extent.

V. PREVIOUS WORK

Little work has been done on the problem of recovering potable water from human wastes. For the past several years research has proceeded primarily under the sponsorship of the National Aeronautics and Space Administration on the design of closed ecological systems. One facet of such research has been concerned with the recovery of potable water from aqueous wastes. Long space flights will require a method for the recovery of water because weight limitations will prohibit the storage of fresh water.

Several systems have been proposed and evaluated in paper studies but a firm design has not yet been developed. The basic processes which have been suggested are:

1. Freeze sublimation
2. Distillation -a) vacuum; b) atmospheric
3. Ion exchange and adsorption

None of these processes previously studies, if used alone will produce a satisfactory product. The product will have to be treated further to make it potable.

Potable water extracted from aqueous wastes has been tested on humans and white rats. To date no harmful physiological effects have appeared in any of the test subjects.

Although most of the work to date has been confined to paper studies and laboratory tests, the General Electric Company has designed, built and tested units at the Missile and Space Vehicle Department, Valley Forge Space Technology Center, Philadelphia, Pennsylvania. General Electric used a vacuum distillation process to accomplish the basic separation with catalytic oxidation of volatile materials. The units recover a potable water from urine and wash water.

This study has not revealed any other processes which have been developed to the stage of the General Electric unit. However, a freeze sublimation (lyophilization) unit has been operated on a laboratory scale to obtain potable water.

None of the work performed in this area has considered seriously the possibility of recovering water from fecal matter. The water content of such waste is small. The loss from it is less than the water produced by metabolic processes. This study has not

considered fecal matter as a usable waste.

The Public Health Service of the Department of Health, Education and Welfare is studying methods of treating sewage to produce potable water in conjunction with its continuing efforts to minimize stream pollution. Some of the problems are different from those encountered in this study, both from a technical and an economic standpoint. We have, however, drawn upon some of the information developed in the course of their program.

The Office of Saline Water of the Department of the Interior has worked extensively on methods of obtaining fresh water from saline water. This study has used several of the OSW reports as references.

VI. DESIGN BASIS

Only general basic specifications or guides were established which would be applicable to any shelter. No detailed specifications were considered. These general specifications are discussed in the following paragraph A. Criteria upon which to judge the value of a particular process have been established and are discussed in the following paragraph B.

A. STUDY CONSIDERATIONS

1. Type of Construction:
Shelters will be underground and will be constructed of steel, concrete, masonry or wood. It has been recognized that the Office of Civil Defense may establish shelters in existing buildings and structures. No consideration was given to the use of such structures as mines, subways, sewers etc.

2. Size of Shelter:
Consideration has been given only to community type shelters. An allowance of 10 sq.ft. of floor area per occupant is planned. No value was set for the head room available. The processes developed have been designed to hold the size of the equipment to a minimum. If the equipment is to be considered for a new structure, the problem of size is easily adjusted. The design of equipment may have to be modified somewhat when it is to be installed in shelters placed in existing structures.

3. Number of Shelter Occupants:
The number of people to be served will vary considerably, depending upon the population density of the area where the shelter is located. Consideration has been given to community sized shelters.

For this study, consideration has been given only to groups in multiples of 250 people, with the maximum number of occupants to be 1000 in any one shelter.

4. Purpose of Shelter:
The purpose of the shelter is only for the physical protection of civilians. No consideration has been given to special types of shelters that may be required for such uses as hospitals, temporary governmental units, troop units.

However, most of the processes proposed would be applicable to any special activity shelter.

It shall be considered that the activity of the occupants will be at an absolute minimum - simply enough manual work done to maintain living conditions within the shelter.

5. Facilities to be Included in Shelter:
It has been assumed that certain facilities for shelter operation will be required. These units will be auxiliaries for the operation of any process presented in this report. It has been assumed that these facilities will be available but no design details have been developed for such units. The auxiliaries which must be provided are:

a. Electric Power. The amount required has been assumed to be available. The electrical character-istics are not critical.

b. Air Tempering System. The unit will maintain the following conditions: 1) a minimum of 3 cfm of fresh air per occupant, 2) an effective temperature below 85°F.

c. Sewage Collection System. It has been assumed that an adequate sewage collection system will be installed. This will have to be a system unlike the conventional systems in that the water required for such systems is not available. However, separation of solids from the liquid waste is considered.

d. Water Distribution System. A potable water distri-bution system will be required. This report is con-cerned only with delivering potable water to a suit-able storage tank and distribution system.

e. Ventilation System. Filtered fresh air will be furnished the shelter at a minimum rate of 3 cfm per occupant.

f. Process Cooling System. Heat generated within a shelter will be difficult to dissipate. In chemical processes, a common method for removal of heat from the process is to use cooling water. As there will be no assured supply of cooling water, consideration has

been given to processes that will operate with either
no external cooling requirements or an absolute minimum.

6. Duration of Occupancy:

   All planning has been based upon a maximum occupancy
of 14 days.

7. Geographical Location of Shelter:

   In this study, the main consideration given to the
geographical location of the shelter would be the effect of the
temperature and humidity conditions of the incoming air on the
water balance. This is discussed in detail in Section VIII.

   Of course, the geographical location will affect many
aspects of shelter operation but all other considerations must
be compensated for by other systems.

8. Contaminants to be Removed:

   The contaminants to be removed from the aqueous wastes
will only be those that would be generated within the shelter
including, but not limited to, such items as dirt, metabolic
wastes, garbage, pathogenic bacteria, soap, miscellaneous tastes
and odors, dissolved salts, and suspended matter.

   No consideration was given to the removal of contamin-
ants that would result from CBR warfare. However, if the conta-
minants were present in the raw feed, they would be removed to
some undetermined extent.

9. Water Standards:

   All water that is reconstituted shall meet standards
established by the United States Public Health Service. An
abstract of these standards is given in Table 1.

10. Water Requirements:

    All shelters will be stocked with 14 quarts of water
for each occupant. This supply will be supplemented with what-
ever water may be available in the shelter from sources such
as pipe lines, hot water heaters and toilets.

    The water usage considered in this study is 1 gallon
per day per person. Shelters, as stated above, will be initially
supplied with water. To supply 1 gallon per day per person will
require 14 gallons per person maximum. Thus, 25 percent of the
water requirements will be on hand. In other words, the overall
recovery of water from the collected wastes needs only to be 75%.

11. Social and Psychological Consideration:

It is not within the scope of this project to dwell upon social and psychological considerations. One must be mindful of these considerations if installing a system such as considered in this report.

12. Water Balance in Shelter:

A diagramatic shelter water balance is given in Fig. 1. This balance is based upon what might be expected if the shelter environment was maintained at 70-75°F and all of the occupants were inactive. A number of authorities give different figures for the amount of water lost by respiration and perspiration to the atmosphere. This figure does vary considerably with temperature, humidity and activity. The value used in Figure 1 is possibly low. Thus a high, conservative value is obtained for the liquid wastes to be considered for processing.

Section VIII discusses the variation of the water balance within a shelter, resulting from changes in atmospheric temperature and weather conditions.

B. PROCESS CRITERIA

Criteria must be established before a process can be evaluated for a specific application. The criteria upon which the processes discussed are evaluated is given below. No attempt was made to assign weighted values to these criteria to develop absolute values upon which different processes could be compared.

1. Purity of Product Water:

A process that will not give a product that will meet acceptable purity standards need not be considered.

Any system, in which human wastes are processed must be given scrutiny in relation to possible health hazards involved.

Bacteria are present in drinking water and are tolerated within defined limits. No more than 10% of the standard portions examined may contain organisms of the coliform group. (See Table No. 1)

SHELTER
WATER
BALANCE
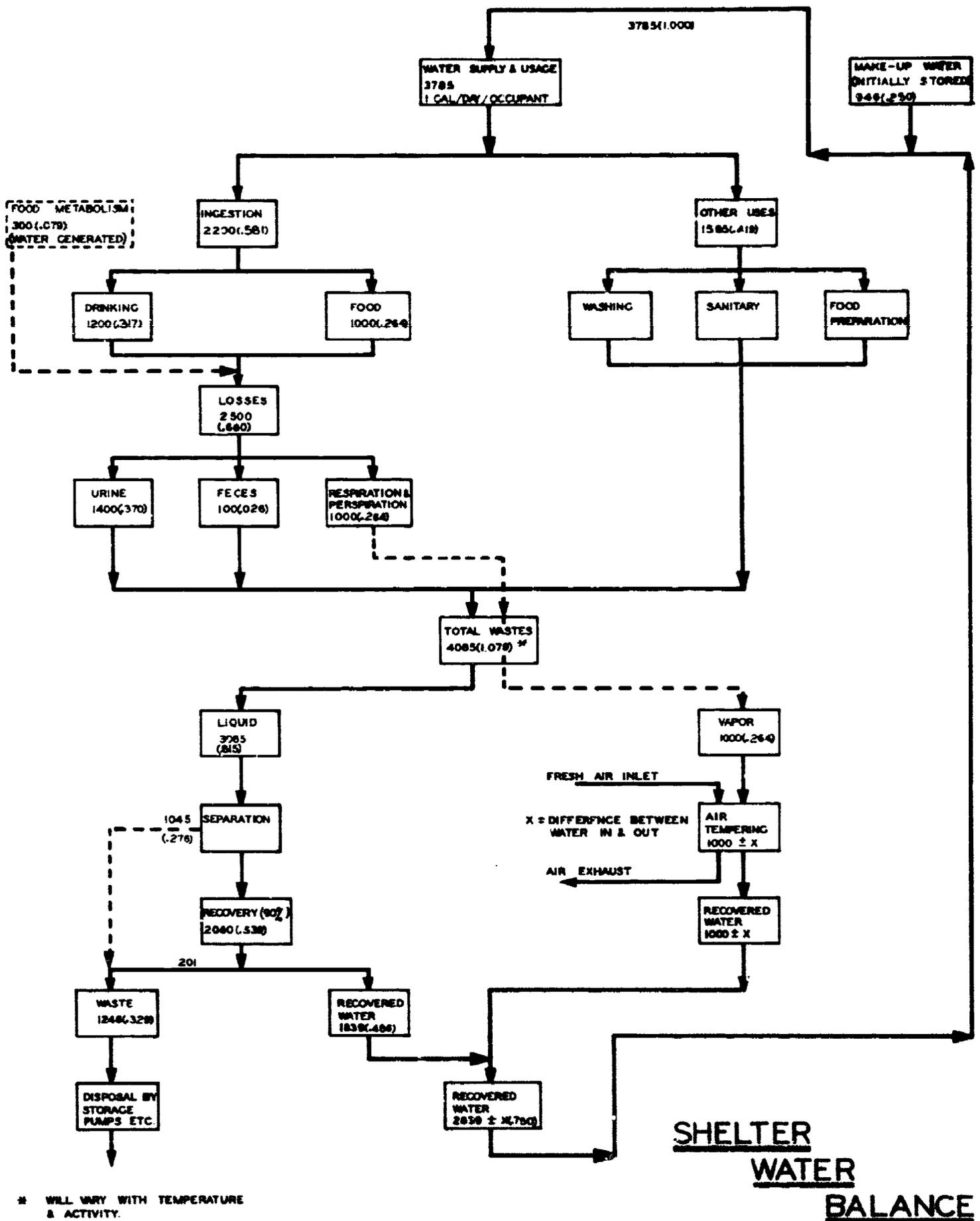
FIGURE 1

* WILL VARY WITH TEMPERATURE & ACTIVITY.

NOTE: ALL FIGURES EXPRESSED IN ml / OCCUPANT / DAY
FIGURES IN ( ) EXPRESSED IN GAL./OCC./DAY

Intestinal bacteria, mainly escherichia coli, make up about one third the solid weight of feces. (R-79).

Other parasitic bacteria produce pathological disease in their hosts and are easily waterborne. Among the waterborne diseases are typhoid fever, bacillary dysentery, amoebic dysentery, gastroenteritis, cholera and infectious jaundice.

Many of the pathological bacteria respond to chlorination which kills coliform bacteria. Typhoid fever and bacillary dysentery are in this group.

The exact causes of gastroenteritis, a disturbance of the gastro-intestinal tract, are not known but usually follow the consumption of infected food or water and result in diarrea. If it is caused by a virus, as is suspected, it could spread in the confines of a shelter.

Amoebic dysentery is caused by a protozoan known as endamoeba histolytic, and is not destroyed by normal chlorination. Super chlorination, producing residuals of 1.0 to 2.0 ppm will lead to the destruction of the cyst or inactive and more resistant stage of this organism. (R-13).

The general health of any large group of people that may be in a shelter is necessarily indeterminate. It must be assumed that there will be several people in the group who are suffering from some form of disease of an infectious nature, the effects of which must be guarded against. An isolation area should be considered.

2. Utility Requirements:
No standard has been set for the utilities that may be available for a water system. Of course, the utility requirements should be at the lowest possible level. The processes discussed in this report will require only electric power. Certain of the processes could be operated manually in the event of power failure. A dependable source of cooling water cannot be assured. Therefore, none of the processes suggested rely upon cooling water.

3. Reliability:
Any process that is selected must be reliable. The well being of many people is dependent upon the equipment and a failure of the equipment may well result in extreme

hardship or even death of the occupants.

4. Safety:
    The process that is to be used must be safe to operate.

    There are many operations that are associated with the chemical industry that may be operated safely. However, many of these operations cannot be considered safe under shelter occupancy. Some broad rules are:

        a. Toxic, inflamable, and corrosive chemicals should not be used. If absolutely necessary, only laboratory quantities of such materials should be permitted.

        b. Processes that evolve gases should be avoided.

        c. High temperatures and pressures should be avoided.

        d. Moving machinery should be held to a minimum.

    These guides have been considered in the various processes.

5. Simplicity of Operation and Control:
    The operation of the system must be simple. It must be realized that the units will not be operated by technically trained personnel. It must be simple enough so that the operation can be learned as a part of shelter management training. Even if a trained operator is not available, the unit should be operable by someone mechanically inclined, following detailed instructions.

    The control instruments should be of the simplest type consistent with reliable operation.

6. Size and Weight of Equipment:
    No specifications have been set for the maximum size and weight of equipment. Of course, the equipment should be as small and as light as possible. This will be an advantage in placing equipment in existing structures. Skid mounted units are desirable.

No arbitrary limit has been made for floor area required for the equipment. A 9' vertical clearance is sufficient for the installation of all proposed equipment.

7. Availability of Equipment:
It is desirable to use standard equipment. If equipment is to be specially fabricated, it should be designed so that it can be fabricated by many shops throughout the country.

Many such systems may be built for installations throughout the country. Thus, equipment that would lend itself to multiple fabrication would be desirable.

8. Stability During Standby:
The equipment must not deteriorate during standby. Certain measures will have to be taken to "mothball" the equipment during standby periods. However, this "mothballing" procedure must be simple enough so that the equipment can be placed into operating condition in less than two hours.

The equipment should be inspected and serviced about once a year. Equipment that requires frequent inspection and servicing is undesirable.

9. Ease of Maintenance:
As pointed out above, the equipment must of necessity be operated by non-technical personnel. This will also be true for maintenance; therefore, the equipment must be easy to maintain. It must be realized that a shelter must be self sufficient; thus, if there is an equipment failure it must be repaired within the shelter under adverse conditions with a minimum of tools and facilities. Spare parts, of course, must be on hand but these shall be held to a minimum.

To the advantage of the equipment, it is only necessary to operate for a maximum of two weeks at any one time. After this period of operation, it may be serviced and placed into standby status again.

10. Materials of Construction:
Materials of construction should be carbon steel, to the greatest extent, because of its availability, low cost and ease of fabrication. Plastic materials may also be

employed when process conditions and cost considerations warrent. However, alloy materials may be required when necessary for considerations such as corrosion resistance, heat transfer, or product purity.

11. Flexibility:

The process should be flexible enough to handle reasonable peaks and valleys in the generation of waste materials.

12. Recovery Efficiency:

The waste water within the shelter that has been considered as available for processing will amount to 0.79 gal. per person per day. Feces will not be processed. Water from perspiration and respiration will be recovered by other means.

Any process selected should have a 90 to 95% effective recovery rate to merit consideration.

12. Cost:

The cost of the process equipment must be carefully considered. Cost is of secondary importance to the criteria enumerated above. It is desirable to lower the cost of the unit only when there is no sacrifice in the other established criteria.

VII. CONVENTIONAL SCHEMES FOR WATER SUPPLY

Generally speaking, conventional schemes of supplying water to shelters should be considered. This would include storing water in vessels, drilling a well as an independent source of water and depending upon the continued satisfactory operation of a municipal water system.

Such schemes should ordinarily be selected for a shelter as they are simple, low in cost and do not require trained personnel for their operation. However, there are certain disadvantages which are difficult to evaluate in the use of such systems.

A. STORAGE OF WATER:

The storage of water within a shelter is being studied extensively by the Quartermaster Food and Container Institute. As a result, only brief consideration has been given to it in this study.

The storage of water may be accomplished by using large underground tanks or small storage vessels using either plastic, glass or metal containers. The storage of water is subject to certain hazards which might result in either the loss of suitable water or in curtailment of its use. Among these hazards are:

1) Mechanical damage to the storage tanks, and consequent loss of the contents; 2) Necessity for accomodating more people than planned; 3) Necessity for extending the planned stay in the shelter; 4) Possibility of contaminating the entire supply of water; 5) Possibility of wasting water during the early part of occupancy.

A system which will produce water from aqueous wastes will overcome certain of these hazards as well as being subject to some of them. In any event, water must be stored in the shelter at the beginning of occupancy. The established standard is 14 quarts per occupant.

The stability of normal tap water may vary considerably depending upon the source of the water and the treatment provided. In some areas ordinary tap water may be stored indefinitely without affecting the quality of the water. On the other hand, some tap water may develop an undesirable odor and

taste during storage that may make it unsuitable for use. Thus, consideration must be given to the source and treatment of water before storing for an indefinite period of time.

As shelters would probably be placed in structures normally using reasonable quantities of water, storage tanks may be placed between the water main and the point of use so that the water will not remain in the system long enough to develop an undesirable odor and taste. Valving would be provided so that upon entering the shelter the tank could be isolated and the water made available for the shelter. A diagram of such a system is shown in Figure 2.

The pretreatment of water may be necessary prior to storage for indefinite periods. This treatment may consist of distillation, deaeration, demineralization, sterilization and chemical treatment. No study has been made of the stability of water during storage.

For a shelter to handle 250 occupants, a storage capacity of 3500 gallons would be required for their total requirements for 14 days. It is estimated that such a tank would cost $2500. On the other hand, for a shelter housing 1000 people, about 15,000 gallons would be required. The estimated cost of a system as shown in Figure 2 is $6700. These estimated costs are minimum as the installed cost will vary considerably with local conditions.

B. WELLS:

Underground water wells would provide an excellent source of water for a shelter. Unfortunately, the geological formations in many parts of the United States are such that water is not available or else the water would be brackish and thus unsuitable. If underground wells were used, that were not fed directly by surface waters, the possibility of radiological contamination would be remote. However, mechanical damage to a well sufficient to make it inoperative is a distinct possibility within the radius of the shock wave resulting from a nuclear blast.

Normally, the cost of drilling wells that may have a capacity of 1-2 gal. per minute is quite nominal - approximately $2.00 per foot of depth. A pump could be installed for approximately $750.

-18-

GROUND LINE

SHELTER

LIQUID
LEVEL
GAGE

WATER STORAGE
15 000 GAL. CAP.
3 - 5000 GAL. TANKS

AIR
COMPRESSOR

TO NORMAL
BUILDING
SERVICES

CHECK
VALVE

CITY WATER MAIN
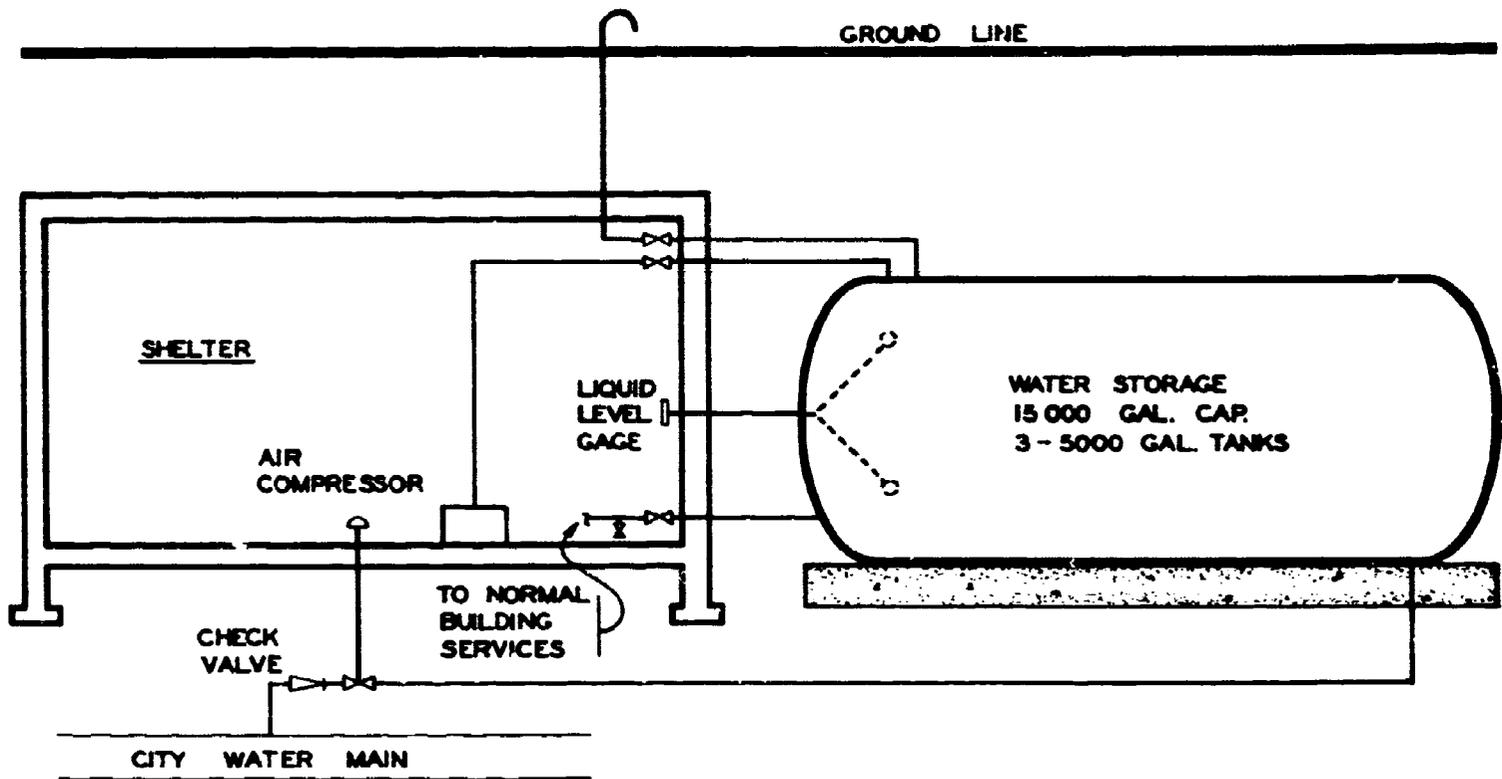
WATER
STORAGE
SYSTEM

FIGURE 2

An added advantage to the use of a well is the fact that undoubtedly more water could be made available to the occupants than the amount of 1 gallon/occupant/day. A small amount of power will be desirable for the operation of the pump though manual operation could probably be achieved.

C. MUNICIPAL WATER SUPPLY:

Of course, the ideal situation would be to depend upon the continued operation of the municipal water supply. The possibility of mechanical damage to both the purification plant and/or the distribution system is too great to depend upon its continued operation. Even if the water system was not damaged mechanically, the water may become contaminated.

Therefore, of the three conventional schemes suggested for supplying water to a shelter, the storage of water or the use of underground wells would probably be the most attractive system.

VIII. ATMOSPHERIC WATER BALANCE

It will be necessary to introduce fresh air into a shelter. The fresh air will have a certain water content when it is brought into the shelter. It will usually be discharged with a different water content. This may result either in an accumulation or a deficit of water. The parameters that will affect the water balance are:

Inlet air conditions (temperature & humidity)
Effective temperature maintained within
    the shelter
Quantity of inlet air
Activity of occupants
Shelter size, construction, & location

Calculations have been made which show the variation of the water balance in the shelter atmosphere resulting from the effects of these parameters.

A. SHELTER SIZE, CONSTRUCTION AND LOCATION

The shelter size, construction and location will affect the water balance through the rate of heat loss through the walls of the shelter. If we assume that the shelter volume is equivalent to 90 ft.^{3} per person, assume a 25' x 100' rectangular shape, assume the shelter is completely buried, then the external surface of the shelter is about 29 ft.^{2} per person. The estimated average heat loss through the shelter walls is 5.0 Btu/hr/ft.^{2}. Thus, the total heat loss is 145 Btu/man-hour or 36,250 Btu/hr. for a shelter with 250 occupants. The figure of 5.0 Btu/hr./ft.^{2} for the heat flux through a shelter wall is averaged from results of shelter tests. (R-25,86)

For a community shelter that is not totally underground, the dissipation of heat may be somewhat less than indicated above. In this case, assuming no heat loss through the ceiling, the total heat loss to the soil would be 23,750 Btu/hr. An average of these two figures is 30,000 Btu/hr which is equivalent to 120 Btu/man-hour. This figure will be used in subsequent calculations.

The heat flux through shelter surfaces will, of course, vary considerably with geographical location and season, soil composition, moisture content, proximity of a water table, wall thickness, and construction and internal temperature. All of these variations cannot be taken into account in a general study such as this.

B. INLET AIR CONDITIONS

The two main sources of water vapor in shelter air are the humidity of the fresh air and that respired and perspired by the shelter occupants. The moisture entering the shelter with the ventilating air is determined by the ventilation rate and the specific humidity (lb. water/lb. dry air) of the air. A table relating specific humidity to dry bulb temperature and relative humidity is given in Table 4. For more detailed information refer to a psychometric chart.

A table showing the lb./man-hour of water that would be introduced into a shelter with air is given below:

	Water Content of Air - lb/man-hour		
Specific Humidity	Ventilation Rate - cfm/man		
(lb.H$_2$O/lb. air)	3	6	15
0	0	0	0
0.004	0.0528	0.1056	0.264
0.008	0.1056	0.2112	0.528
0.012	0.1584	0.3168	0.792
0.016	0.2112	0.4224	1.056
0.020	0.264	0.528	1.320

Expressed as gallons per day per person, this table may be rewritten as follows:

	Water Content of Air - gal/man-day		
Specific Humidity	Ventilation Rate - cfm/man		
(lb.H$_2$O/lb. air)	3	6	15
0	0	0	0
0.004	0.152	0.304	0.760
0.008	0.304	0.608	1.520
0.012	0.456	0.912	2.280
0.016	0.608	1.216	3.04
0.020	0.760	1.520	3.80

The moisture released to the air by the shelter occupants by perspiration and respiration depends mainly on the activity level (metabolism rate) of the occupants and the temperature of the shelter air.

At a low activity level, the body metabolism rate is approximately 100 calories per hour or 400 Btu/hr. Thus, the body must dissipate 400 Btu/hr. in order to prevent a rise in the body temperature. This energy is dissipated partially by radiation and convection (sensible heat) and partially by evaporation of perspiration (latent heat). The division of the total energy into these two forms is highly dependent upon the air temperature. It is given below expressed as Btu/man-hour.

D.B. Air Temp., °F	Sensible Heat	Latent Heat	Total Metabolism
70	300	100	400
75	265	135	400
80	220	180	400
85	170	230	400
90	110	290	400
95	50	350	400

An effective temperature of 85°F corresponds to the following combinations:

D.B. Temp., °F	Relative Humidity, %
85	100
90	72
95	50
100	34

The amount of water vapor released by the body to its environment and corresponding to these energy requirements is as follows:

D.B. Temp., °F	Latent Heat Btu/man-hour	Water Released lb/man-hr.	Water Released gal/man-day
70	100	0.096	0.276
75	135	0.129	0.372
80	180	0.172	0.496
85	230	0.220	0.634
90	290	0.278	0.800
95	350	0.335	0.965

An increase in the activity of an occupant will result in a higher rate of body energy release; the greater portion of the additional energy would be released in a latent form, with very little increase in body radiation and convection. For a person doing light work at 80°F, very nearly 2/3 of this energy would be

released in latent form. The general level of activity in the shelter should be very close to the minimum though a few people will perform light tasks. For the purposes of this study, the above minimum of 400 Btu/man-hour will be augmented by the following:

Low level lighting — 20 Btu/man-hour
Allowance for appliances, — 20 Btu/man-hour sensible
cooking and light work — 20 Btu/man-hour latent

This results in the following schedule for the release of energy (and moisture) to the shelter air expressed as Btu/man-hr:

D.B. Temp., °F	Sensible	Latent	Total
70	340	120	460
75	305	155	460
80	260	200	460
85	210	250	460
90	150	310	460
95	90	370	460

This schedule for latent heat corresponds to the following water release to the air:

D.B. Temp., °F	Latent Heat Btu/man-hour	Water Release lb/man-hr.	gal/man day
70	120	0.115	0.332
75	155	0.149	0.428
80	200	0.192	0.553
85	250	0.240	0.691
90	310	0.298	0.857
95	370	0.355	1.02

As the shelter rises above 80°F, the amount of water released by the body not only rises rapidly but becomes increasingly dependent upon the shelter temperature.

The schedule for the release of the body energy given above is comparable to the results reported by Heiskell (R-24) and Brand-Persson (R-57).

C. NET WATER BALANCE

Based upon the figures presented, a net water balance is given below. It has been assumed that the air will be tempered in some manner to remove heat and consequently moisture.

The net water balance for such a system is given below assuming that a 60°F dewpoint and a 55°F dewpoint are reached. The minus (-) signs indicate the loss of water from the shelter and the plus (+) signs indicate an accumulation of water in the shelter.

60°F Dewpoint

Inlet Air Humidity (lb.H₂O/lb. air)	Water Balance - lb/man-hour Ventilation Rate - cfm/man		
	3	6	15
0	-0.147	-0.293	-0.733
0.004	-0.094	-0.187	-0.469
0.008	-0.041	-0.082	-0.205
0.012	+0.012	+0.024	+0.059
0.016	+0.065	+0.129	+0.323
0.020	+0.188	+0.235	+0.587

Expressed as gallons per day per person. this table may be rewritten as follows:

Inlet Air Humidity (lb.H₂O/lb. air)	Water Balance - gal/man-day Ventilation Rate - cfm/man		
	3	6	15
0	-0.422	-0.844	-2.11
0.004	-0.270	-0.540	-1.35
0.008	-0.118	-0.236	-0.59
0.012	+0.034	+0.068	+0.17
0.016	+0.186	+0.372	+0.93
0.020	+0.338	+0.676	+1.69

<u>55°F Dewpoint</u>

<u>Water Balance - lb/man-hour</u>

Inlet Air Humidity (lb.H$_2$O/lb. air)	Ventilation Rate - cfm/man		
	3	6	15
0	-0.121	-0.243	-0.607
0.004	-0.069	-0.137	-0.343
0.008	-0.016	-0.032	-0.079
0.012	+0.037	+0.074	+0.185
0.016	+0.090	+0.180	+0.449
0.020	+0.143	+0.285	+0.713

Expressed as gallons per day per person, this table may be rewritten as follows:

<u>Water Balance - gal/man-day</u>

Inlet Air Humidity (lb.H$_2$O/lb. air)	Ventilation Rate - cfm/man		
	3	6	15
0	-0.350	-0.700	-1.749
0.004	-0.198	-0.396	-0.989
0.008	-0.046	-0.092	-0.229
0.012	+0.106	+0.212	+0.531
0.016	+0.258	+0.516	+1.291
0.020	+0.410	+0.820	+2.051

D. <u>CONCLUSIONS</u>

The air of the shelter will pick-up moisture from the respiration and perspiration of the shelter occupants which may be reclaimed if inlet air conditions are favorable, or lost to the air if outside air humidity is low. For a shelter with 250 occupants, it is reasonable to assume that under favorable conditions of humidity that 25 lbs. of water per hour could be recovered. A system to recover this water is outlined and discussed in Section IX.

The use of the air conditioning system of the shelter to recover water will be entirely dependent on geographical location of the shelter, construction, and other local conditions, therefore final judgment on the feasibility of using the system must be based on these local considerations.

IX. RECOVERY OF WATER FROM WASTES

A number of processes have been developed which may be used for the purification of water. The development of these many processes range from laboratory techniques to commercial operations. These processes are evaluated for their possible application to the recovery of water from shelter sewage wastes. The basic processes which have been considered in this study are:

1. Membrane and Adsorption Processes
2. Evaporation Processes
3. Chemical Oxidation
4. Wet Oxidation
5. Digestion and Conventional Sewage Treatment
6. Solvent Extraction
7. Freezing Processes
8. Air Evaporation
9. Air Conditioning and Dehumidification

All of these processes are discussed under paragraph A of this Section. The three processes deemed to be of particular interest are discussed in detail under paragraph B. In all cases it has been assumed that solid matter has been effectively separated from the liquid wastes.

A. BASIC PROCESSES

1. Membrane and Adsorption Processes

All the processes considered in this section depend on the ionic nature of the solute and/or its ability to pass through or be retarded selectively by a membrane barrier. The aqueous waste to be processed is· a mixture of urine and wash water derived from human excretion, food preparation, and general sanitary needs. The composition of urine utilized in this study is based on that published by Wallman and Barnett (R-79) while the wash water mixture is based on the data of Zeff and Bembenek (R-87). This information is given in Tables 2 and 3. The human water cycle including urine, wash water, respiration, and perspiration as given in (R-79) was adjusted to provide 1 gallon per day of water for each shelter occupant. The water contained in the feces combined with the losses in the recovery process are assumed to balance the metabolic water production of the human system and thus no attempt is made to reclaim the former. Some of the following operations will not by themselves be suitable but when used in conjunction with other processes may produce potable water.

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The primary membrane processes to be considered are osmosis, reverse osmosis, electro-osmosis, thermo-osmosis, osmionosis, ultrafiltration and electrodialysis. The adsorption processes consist of charcoal adsorption and ion exchange. Consideration will also be given to other electrolytic and chemical methods.

a. Osmosis:

The various osmosis processes depend on the migration of certain species through a semi-permeable membrane under an osmotic pressure gradient. The use of the osmotic gradient alone is a very slow process which is not particularly suited to yield a potable product in a finite amount of time. Although the process of osmosis is the basis for most of the subsequent processes to be described it is inadequate as a means of recovering water from wastes by itself. Each of the following methods uses other driving forces in addition to the osmotic gradient to promote transfer through the membrane.

b. Reverse Osmosis:

The reverse osmosis process separates the water from the waste by withdrawing the water through a membrane impermeable to the other constituents of the waste. The membrane material used for desalting sea water and synthetic urine was a T.N.O. Type C-60 membrane made by the Dutch National Council for Applied Scientific Research. The sea water or synthetic urine was placed on one side of the membrane and the water passed through into a fructose solution which created the osmotic gradient. The synthetic urine solution, composed of 0.78% sodium chloride and 2.3% acetic acid, permeated the membrane at the rate of 6 liters/sq. meter/day while allowing 3% of the sodium chloride and 20% of the acetic acid to also permeate the membrane (R-79). While the results are promising with respect to the feasibility of the process, due to the membrane area needed, i.e., 134 sq. meter or 1,450 ft² for 250 people, and the high leakage rate of acetic acid which has a permeability similar to urea, it may be concluded that such a process is unsuitable for other than small scale operations.

c. Electro-Osmosis:

To aid in the passage of solute through a membrane, an electric field can also be impressed across the membrane. This process is known as electro-osmosis. Inherent with the transport of solute through the membrane, however, is the transport of water. In order to achieve a reasonable amount of solute

removal, the porosity of the film must be increased and consequently more water is transported with the solute. Eventually the situation degrades to the point that essentially all components of the solution migrate through the membrane and the resultant composition is the same on both sides of the membrane. As a product water of suitable purity cannot be produced, this process will not be considered further.

d. Thermo-Osmosis:

A thermal gradient may be established across the membrane in addition to the osmotic pressure. The temperature difference will induce a larger flow of solute through the membrane than can be attributed to purely osmotic effects. This increased rate of water transport is a function of the temperature gradient and the heat adsorbed or evolved as the water enters the membrane from one solution and then leaves the membrane to enter the other. At present there is no pertinent experimental data on thermo-osmosis available but from previous experience with a thermal gradient applied for mass transfer, the process should be relatively slow and require a large number of stages to effect a satisfactory separation. At any rate, due to the lack of data an extensive program would need to be undertaken to establish preliminary data and operating parameters.

e. Osmionosis:

The osmionic process, recently developed, takes its name from the combined driving forces of osmotic pressure and ionic concentration gradients. The basic osmosotic cell is multiplied by separating the solution by alternating anion and cation permeable membranes. A concentrated brine is circulated around the exterior compartment of the membrane stack. Due to the concentration gradient between the brine and the adjacent solution the cations flow through the cation permeable membrane and the anions pass across the anion permeable membrane. At this point an electrical unbalance exists in the individual compartments and anions and cations must pass into the respective compartments from the central compartment to preserve electroneutrality. This action creates a central compartment depleted of salts which can, by suitable removal of non-electrolytes, be made potable.

The principal advantage of this process is the fact that no exterior power source is needed to produce the higher purity water. Again, however, as in the process of osmosis the system is eventually limited by natural equilibrium. Nevertheless the degree of separation and resultant purity of the effluent is much greater than by osmosis itself, due to the ionic

gradient.   The primary drawback to the osmionic process is
the large volumes of solution needed to produce the required
quantity of potable water. It has been estimated that one
volume of concentrated brine and ten volumes of dilute solution
could be converted to six volumes of moderately concentrated
solution and five volumes of deionized water (R-79). Thus, for
a two week supply the storage facilities required would be twice
that of the volume of water needed for the occupants.

f. Ultrafiltration:
          In the ordinary osmotic process the naturally existing
osmotic pressure is used as the driving force for mass transfer.
To increase the rate of material transfer an external pressure
may be impressed on one side of the membrane resulting in an
ultrafiltration of the water through the membrane. From theor-
etical considerations it can be deduced that a pressure of 700
psig is required to obtain 100% filtration of a 1.0 N NaCl sol-
ution.   In actual practice this figure must be tempered to ac-
count for inefficiencies and irreversibilities. Using a Nalfilm
-2 membrane, McKelvey et al obtained only 46% filtration of a
1.0 N NaCl solution with 1000 psig. The rate of permeation
under these conditions was 0.5 liters/sq. meter/day (R-9). In
contrast to these figures, 73% of a 1.0 N NaCl solution was
filtered through an AMF membrane using 1000 psig. The rate of
permeation in this case was 1.0 liter/sq. meter/day.

          Reid has also studied the ultrafiltration technique
(R-60). He investigated the permeability of cellulose acetate
membranes. Under the best conditions, a 0.1 N NaCl solution
was filtered removing 99% of the solute using a pressure of
600 psig. The permeation rate was 26,400 liters/sq. meter/day.
While this value is extremely favorable, it must be qualified
by noting that under these conditions the membrane failed after
40 minutes of operation. Another drawback of cellulose acetate
membranes is their low durability. The membranes loose their
salt-rejecting property in 1-3 weeks, due to the hydrolysis of
the ester groups. From the work on cellulose acetate it can be
determined that a suitable membrane should have a high concent-
ration of groups which form hydrogen bonds with water, cross
linking to a controllable extent, ease of formation into a thin
uniform film, and chemical stability in salt solutions.

          Utilizing the more realistic permeation rate of 1.0
liter/sq. meter/day for AMF membranes, 800 sq. meters or 8,700
ft² of membrane area are required. In addition to the high area
required, operation at 1000 psig will tend to create a system
which is very prone to leak. Maintenance of such a system in

adequate stand-by condition would require frequent pressure testing and leak detection. Although the process does not appear to be practical at this time, further research and membrane development may yield a suitable membrane material which could operate at lower pressures and higher permeation rates.

g. Electrodialysis:

Membrane electrodialysis requires a direct current source operating on metallic electrodes with a number of cation--permeable and anion-permeable membrane pairs interposed. The electrodes are placed in the end compartments and when a D.C. power source is turned on the cations migrate through the cation-permeable membrane toward the cathode. No cations can replace those which have migrated out of the compartment because the opposite wall of the compartment is an anionic membrane which is impermeable to cations. A similar action takes place with respect to anion movement but in the opposite direction toward the anode. The result of this operation is the depletion of salts in alternate compartments and the enrichment of salts in the compartments adjacent to the depleted ones. Some salt will always remain in the depleted compartments as the membranes are never ideal ion barriers. Some water will tend to migrate across the membranes, the amount being proportional to the applied current. The rate of leakage of oppositely charged ions across the membranes has been greatly reduced so that a negligible amount of leakage now occurs even in two molar solutions. (R-79).

The size of the electrodialyzer is a function of the ion concentration, the solution flow rate, and the current density, as related by Faraday's law. The total power requirements can then be determined from the current density, the membrane area and the electrical resistance of the membrane stack. New developments in membrane material and support material are such that low electrical resistances result and the required power is greatly decreased. The electrodialyzer will only separate the salts which are ionized and therefore some of the amphoteric constituents and the urea will pass through the process unaffected and will need to be removed in subsequent operations. The present results available indicate that at low flow rates 75% demineralization can be obtained in a single pass through the dialyzer. Thus using two passes or a two stage unit 94% of the contaminating ions can be removed from the solution. (R-30).

While the previously described membrane processes have been limited to relatively small batch type operation due to slow transfer rates or large membrane areas, electrodialysis is

a process which proceeds at a finite rate with reasonably sized equipment. The process operates at room temperature and atmospheric pressure. The unit requires some electrical power but the requirement is less than 0.5 watts per man. The process is such that it can be maintained in stand-by condition and activated in a few hours by inexperienced personnel. The draw back common to all the selective membrane processes is that some organic compounds, primarily urea in this case, are unaffected by the operation. This will necessitate using a combined operation to remove the non-electrolytes following the membrane process. Of all the above mentioned processes the only one which has been adequately verified as to operability beyond the laboratory stage is electrodialysis. Electrodialyzers have operated successfully on saline waters and have been thoroughly tested. Therefore, due to the advanced state of technology, the only membrane process to receive further consideration will be electrodialysis.

h. Ion Exchange:

The process of ion exchange is actually an exchange reaction in which a molecule of treated resin undergoes a transfer reaction with an undesired ion in the solution. This may be accomplished using synthetic or natural zeolites or synthetic organic resins. While the use of zeolites provide a high weight ratio of processed water to adsorbent, their affinity for the organic constituents present in urine is quite low. The zeolites are natural alumino-silicates which react with the ions in solution as follows:

$$Ag_2Z + 2NaCl \longrightarrow Na_2Z + 2AgCl$$
$$Ag_2Z + CaCl_2 \longrightarrow CaZ + 2AgCl$$
$$BaZ + MgSO_4 \longrightarrow MgZ + BaSO_4$$

In order to reduce the weight of zeolite required, silver oxide is sometimes substituted:

$$Ag_2O + H_2O + 2NaCl \longrightarrow 2NaOH + 2AgCl$$
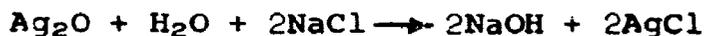
The resulting sodium hydroxide then reacts with uric acid to precipitate sodium hydrogen urate:

$$NaOH + H_4 (C_5N_4) O_3 \longrightarrow H_2O + NaH_3 (C_5N_4)O_3$$

Also due to weight considerations $Ba(OH)_2 \cdot 8H_2O$ is used in preference to BaZ.

The weight of zeolites needed is quite small but the capacity of the zeolites per unit volume is also very low. Therefore, the volume of zeolite needed is rather large. The large volume of resin needed combined with the poor affinity for ion-ionic constituents renders this process inferior to that utilizing synthetic organic resins. As the removal of organic compounds presents a large problem it is advantageous to remove as much as possible in the same process in which the electrolytes are removed.

Synthetic organic ion exchange resins are of two types - cationic and anionic. The basic organic resin is a copolymer of styrene and divinyl benzene. The degree of cross linking of the polymers is the chief property which determines the limiting size of the molecule to be exchanged. To prepare the cationic resin, the copolymer is sulfonated with sulfuric acid under controlled conditions. The resulting resin may be prepared in a number of forms, the most suitable for the present purpose being the hydrogen form. The exchange reaction thus effected is:

$$RSO_3H + Na^+ \longrightarrow RSO_3Na + H^+$$

where the R represents the copolymer group. As can be seen from the reaction mechanism it is an equivalence reaction and thus resin capacities are commonly expressed in equivalents per unit of resin.

The anionic form uses the same basic styrene - divinyl benzene copolymer. The copolymer is first subjected to chloromethylation and then subsequent amination. The degree of basicity is determined by the choice of amine. The resulting resin is transformed to its hydroxide form to yield the following reaction:

$$RNH_3OH + Cl^- \longrightarrow RNH_3Cl + OH^-$$

When the cation and anion exchange reactions are conducted in a common vessel the hydrogen and hydroxide ions form water thus providing an automatic acidity control of the process effluent.

Recent work with weak organic electrolytes or ampholytes indicate that the synthetic organic resins are capable of absorbing them. The exact mechanism is not known but it has been determined that the retention or the organic molecules cannot be completely accounted for by adsorption phenomena (R-9).

Irrespective of the manner of retention, the removal of amino acids, cations and large amounts of urea on cation resins has been experimentally verified (R-10). Based on these favorable laboratory results, further consideration will be given to a combined cation - anion exchange bed for removing all electrolytes and ampholytes. Certain nonionic organic matter will not be removed but this problem is common to all membrane or ionic processes and will be discussed in a later section. Using these improved synthetic organic resins it is possible to obtain nearly 3 volumes of potable water for each volume of resin.

i. Charcoal Adsorption:

A standard method utilized in water treatment plants for removing organic residues, miscellaneous tastes and odors, and other intangibles is adsorption on activated charcoal. Standard dosages have varied from 2-5 ppm depending on the amount of pretreatment the water has received (· 3). This generally amounts to 25-75 lbs. of charcoal p _ million gallons of processed water. The affinity of activated charcoal for inorganic or ionic material in general seems quite low. Therefore, as a method for totally purifying urine in itself, the volume of charcoal needed would be prohibitive. Because of this large volume requirement, the use of activated charcoal will be restricted to removing organic matter which is not extracted from the main process during prior treatment.

Previous work on urine has indicated that 28 gms of charcoal per man-day would be required to remove the color and odor from the product (R-87). This is not a representative figure, however, because under the experimental conditions at which the above value was determined the charcoal was adsorbing much more organic material than that causing taste and odor alone. As the exact composition and quantity of color and odor contaminants are unknown, the amount of charcoal needed will have to be determined experimentally on treated solutions from which urea, amino acids and other organic acids have been removed. Recent experimental data indicate that for removal of biologically-resistant organic material the average charcoal capacity is 0.1 gm of material per gram of activated charcoal (R-47). Using this value and knowing which organic compounds are not removed by prior processing, the required amount of charcoal can be determined. To this quantity a sufficient amount will be added to insure removal of tastes and odors thus producing an adequately palatable water.

j. Miscellaneous Processes:

A few other processes which do not necessarily involve membrane or adsorption techniques will now be considered. Most of these methods are either new unproven innovations or laboratory techniques. Although far from the commercial process stage they may merit future consideration and are therefore briefly described below.

(1). Fallout Shelter Water Purifier - The Permutit Company of Paramus, New Jersey, manufactures a water purifier - Model 3000 which processes 50 gallon batches in 30 minutes. The unit first chlorinates and precipitates solid matter. The effluent from this operation is then filtered, passed through a mixed bed ion exchanger, and then purified with activated charcoal. From the data listed pertaining to the size of the various units and the quantities of the material provided it is assumed that this purifier was designed to treat radiologically - contaminated rain or ground water and not urine or waste wash water. This unit might prove useful in locations where previously stored water exterior to the shelter proper was available in reasonable quantities.

(2). Urea Hydrolysis - The primary constituent of the dissolved solids present in urine is urea. It constitutes 45% of the dissolved solids and is generally non-ionic in nature. The removal of urea by hydrolysis to form ammonia and carbon dioxide is a naturally occurring but slow process. The rate of hydrolysis can be greatly accelerated by utilizing the catalytic action of the enzyme urease. Unfortunately the enzyme reactions are ultra-specific and urease will only affect the urea. Also, although the urease is only used as a catalyst, due to its solubility in water it cannot be reclaimed without extensive crystallization techniques. The proposed reaction mechanism is:

$$H_2O + H_2N - \underset{\displaystyle \overset{\displaystyle O}{\|}}{C} - NH_2 \xrightarrow{\text{urease}} CO_2 + 2NH_3$$
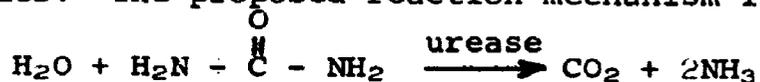
The NH_3 is absorbed as NH_4^+ ion and can be removed by certain of the above mentioned processes while the CO_2 is only slightly soluble and can be stripped from the solution. The ion load on any particular process is greatly increased, however, as two equivalents of NH_3 are formed from one equivalent of urea. The hydrolysis may also be catalyzed by strong acids

yielding the ammonium salt but the hazards involved in handling concentrated acids in a shelter environment are very large. Therefore, subsequent calculations for urea hydrolysis will be based on using the enzyme urease as the catalyst.

(3). Electrolysis - A novel method for purifying water has been formulated by Kallman and Pope. These workers electrolyze the water into hydrogen and oxygen by the photochemical action of ultra-violet light (R-12). The resulting gases can then be recombined in a fuel cell to form potable water. An anthracene disc is mounted in an electrical cell and a salt solution is circulated around the surface of the disc. Ultra-violet light is shown on the disc creating a battery, the developed voltage of which is used to electrolyze the hydrogen and oxygen. If reasonable pH control is not maintained chlorine will form at the anode in preference to oxygen. The hydrogen and oxygen are then recombined in a fuel cell, generating electrical power to operate the ultraviolet light. As the process operates near reversible conditions it is inherently slow but as new fuel cells are developed its potential will increase. No results are available on the effects of other neutral molecules on the electrolysis of the water. Some volatile organics may also be transferred with the hydrogen and oxygen but these may be removed by adsorption on charcoal following the recombination in the fuel cell.

2. EVAPORATION (DISTILLATION) PROCESSES

a. Introduction:

Evaporation or distillation is essentially a process of vaporizing a liquid and collecting the vapor which is condensed to a liquid. In vaporization the water is evaporated from the mixture and the residue is drawn off. This may be accomplished in a number of ways, heating the liquid or lowering the pressure with subsequent lowering of the boiling point. The various ways in which evaporation may be carried out are discussed here to arrive at the best application of this process to recover water from shelter wastes.

b. Previous Work:

Samples of human urine have been evaporated in simple glass laboratory equipment with varying degrees of success (R-79,58,64,87 61). It is evident from these results, that

evaporation alone will not produce a potable water; however, an evaporation process combined with various purification processes can produce a desirable product. In fact, such product water has been injested by a human subject for a number of days with no ill effects (R-76). It is difficult to compare the results of the several experiments because of the different manners in which they were performed, the lack of complete description of the experiment, and the various purification processes used.

Wallman and Barnett (R-79) evaporated urine to dryness at 70-86°C. The product contained 28 ppm of ammonia, 170 ppm of urea, and was highly odiforous and colored. The product was treated with ion exchange resins to remove the ammonia. Activated carbon reduced the urea content to 9 ppm and the color and odor to acceptable levels.

Sendroy and Collison (R-65,64) recovered water amounting to 85% of the total volume of an evaporated urine. The color and odor of the product were removed by treatment with activated carbon.

Zeff and Bambenek (R-87,88,89) recovered 88.9% of a urine sample by evaporation at atmospheric pressure. The product was free of color and bacteria. It did have an ammonia odor and contained 24 ppm of solids.

Based upon these results, it is concluded that the product from the atmospheric evaporation of urine may be relatively free of color and solids but will contain ammonia, which results from the thermal decomposition of urea and other amines in urine.

A very effective method of removing the final traces of color and odor from evaporated urine is vapor phase catalytic oxidation (R-61). This method uses a platinum catalyst at a reaction temperature of 2300°F. Another effective method uses the combined ion exchange and activated carbon treatment mentioned above. In any case, it is concluded that evaporation is an effective method of recovering water from human wastes and that methods do exist for rendering potable the water so recovered.

c. Types of Systems:

(1) Single Effect Evaporation: The most simple but least economical method of evaporation may utilize steam under pressure (high temperature) to evaporate water from a

vessel. The vapor is condensed by cooling.
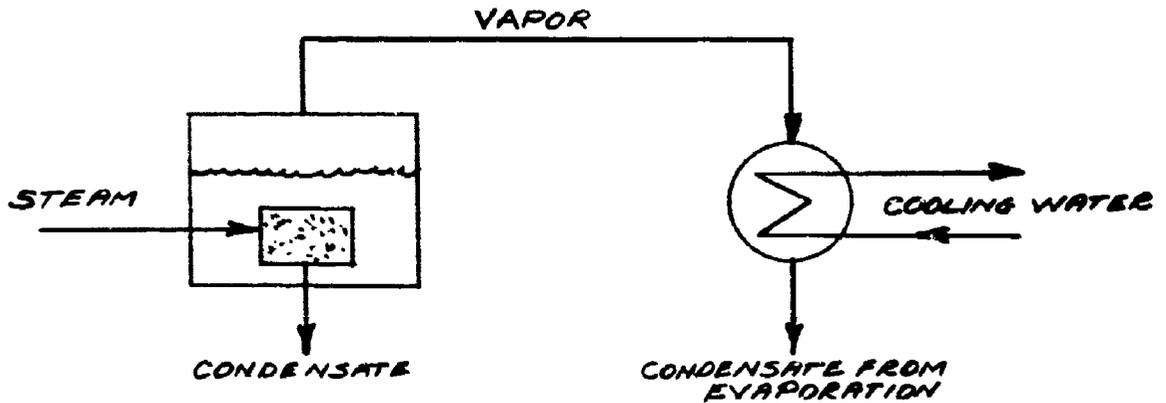
This method will produce approximately one pound of vapor per pound of steam.

(2) Multiple Effect Evaporation: Simple evaporation has been adapted commercially by using the steam from the first effect to vaporize water from the second, and so on; the whole system being called a multiple effect evaporator.
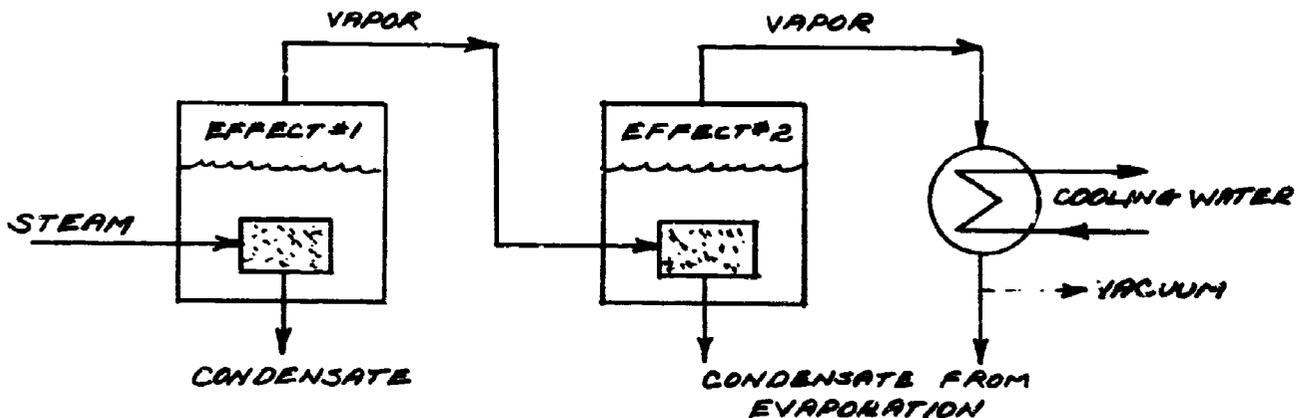
Multiple effect evaporation will produce approximately as many pounds of evaporated water for one pound of steam as the number of effects used. The condensing duty is decreased by the same factor. The temperature difference necessary for heat transfer is obtained by maintaining each effect at a pressure lower than that in the effect immediately proceeding. Thus, when using low pressure steam, there must be a source of vacuum; when using high temperature steam, vacuum may or may not be used depending

on what is being evaporated and the temperature of the initial steam and the cooling water.

A fallout shelter should not be dependent upon either steam or large requirements of cooling water. Therefore, for evaporative processes for water recovery, the elimination of requirements for cooling water and external sources of steam is desirable.

(3) Vapor Compression: A common method of providing the temperature difference without an external source of steam or cooling water is "vapor compression" (R-14,28,36,37). This is commonly used on both land and sea installations for obtaining pure water from an impure source. Its main feature is the compression of the vapor to raise its condensing temperature to the point where it may be used as the heat source.

VAPOR

T_1, P_1

T_2, P_2 ENERGY

COMPRESSOR

T - TEMPERATURE
P - PRESSURE
SUB 1 - LOWER LEVEL
SUB 2 - HIGHER LEVEL

CONDENSATE FROM
EVAPORATION
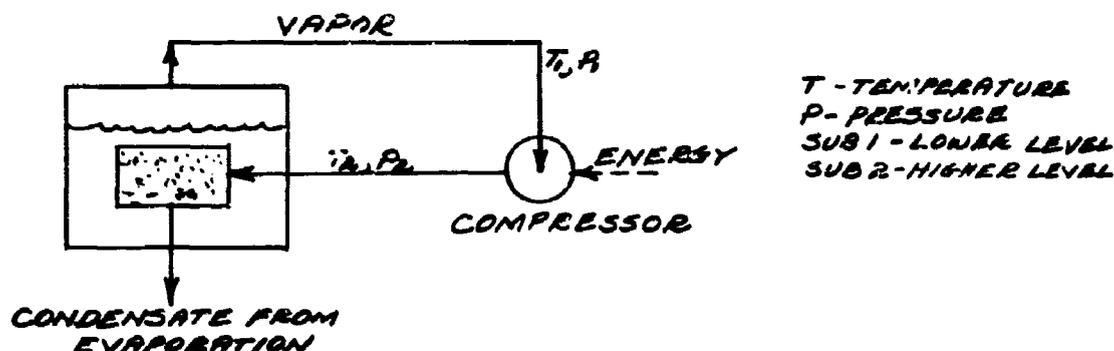
Using a compressor to lower the pressure over the liquid being evaporated and using the heat of the compressed vapor to induce vaporization through boiling, the cycle is able to produce water using only mechanical energy.

The energy of compression may be supplied in any convenient form. For use in fallout shelters electrical energy would be convenient. The amount of energy varies with the magnitude of the temperature difference required for operability and operating economy. In theory, with reversible heat transfer, the work of compression is zero. In practice the work of compression is 5% or less of the energy necessary for simple evaporation.

Due to its proven operability, its relative independence from external utilities, and its simplicity and economy of operation, vapor compression has been selected over single and multiple effect evaporation as the most practical method for recovering water from wastes.

d. Vacuum vs. Atmospheric Evaporation:

Most dissolved salts are more soluble at higher than that at low temperatures. However, there are some salts in urine which behave in an opposite manner and are said to have an inverted solubility. The most critical of these is calcium sulfate, whose concentration in the feed to the evaporator will average 0.0268 grams per 100 grams feed. (R-79,87).

The limiting solubility of calcium sulfate as the hemi-hydrate (the prevalent form) is 0.2 percent at 212°F and 0.4 percent at 140°F. If the material in the boiler tends to exceed these concentrations, the calcium sulfate will deposit on the heating surface as an insoluble scale, increasing the resistance of the surface to heat transfer and decreasing the capacity of the evaporator. Thus, if the boiling point of the concentrate were lower, a greater concentration could safely be achieved. A way to accomplish this is to operate at a reduced pressure.

Vacuum equipment is, however, notorious for developing leaks during operation. Such leaks, even though small, would tend to render an evaporator inoperative. Moreover, due to chemical and physical changes which occur in vacuum sealing materials during storage, it is quite probably that the equipment will leak on startup. A small leak in equipment operating at atmospheric or moderate pressures is not serious. Although some material will be lost, operability will not be affected.

Vapors under vacuum occupy much more space than vapors under atmospheric pressure. For example, one pound of water vapor at 1.7 psia (120°F) occupies 203.3 cubic feet, whereas the same pound of vapor at one atmosphere (212°F) occupies only 26.8 cubic feet. Thus, equipment utilizing vacuum must be correspondingly larger than equipment operating at atmospheric pressure.

The use of vacuum requires a vacuum pump in the system. This of course, in itself reduces the overall reliability of the system since there is one more piece of mechanical equipment which could fail. In view of these considerations, it is felt preferable to operate an evaporator under atmospheric pressure.

The scaling may or may not occur in a complex mixture such as is present in urine, but this can be determined only

in prototype equipment. Modification of such equipment for vacuum operation would not be difficult.

The above discussion has been centered upon selecting the best type of evaporator considering only well developed and commercially proven processes.

e. Types of Evaporators:
Three types of conventional evaporators can be considered, the vertical tube evaporator, the natural convection evaporator, and the forced circulation evaporator. Calculations of heat transfer area and compression energy requirements have been made for each of these as a basis of choosing the most logical one of them.

(1) Vertical Tube Evaporator:
Relatively high heat transfer coefficients may be attained in this type evaporator by forcing the feed to flow in a thin layer down the tube.
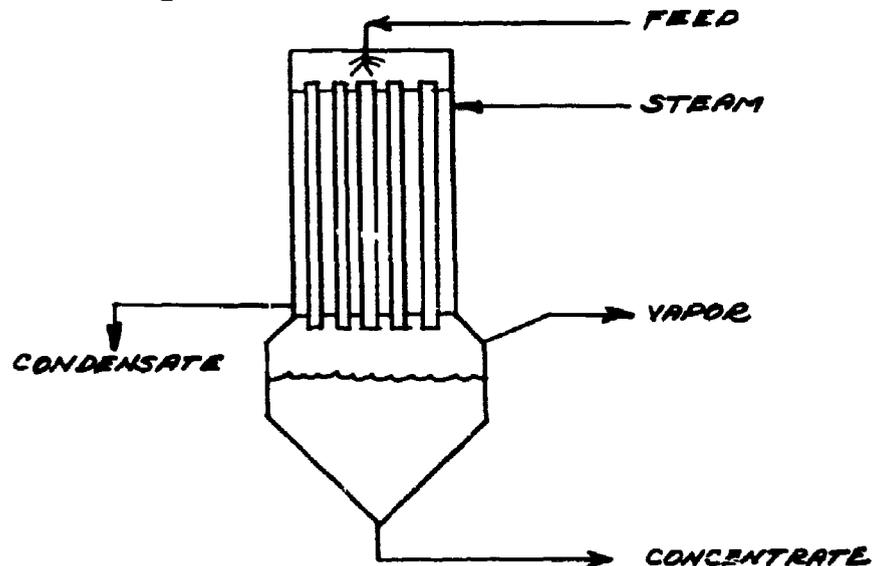
This type of evaporator has the advantage over other types in that the water is at all times being evaporated from liquids less concentrated than the blowdown. Therefore, a low average boiling point rise is attained requiring in turn a low degree of superheat in the compressed steam. Thus, less work of compression is required than with other types of evaporators.

Two difficulties arise though, due to the high degree of concentration required. First, the liquid flow to each tube would be very low. Thus even liquid distribution over the whole area of a tube may be difficult, and even

impossible. It is quite possible, therefore, that the evaporator would be inoperative. If recirculation were employed to overcome this difficulty, the low power advantage would be lost.

Second, increasing concentration factors result in higher boiling point rises along the length of the tube. Therefore, the heat flux at the top of the tube would be higher than that at the lower end of the tube. The high heat fluxes at the top of the tube may result in vigorous boiling there, repelling the liquid film from the wall, and thus making it inoperative (R-66).

(2) <u>Natural Convection Evaporation</u>:
Natural convection evaporators operate with low heat fluxes, and are, therefore, fully capable of foamless operation. A larger heating surface is required than for other types of evaporators discussed here. The vapor compression power requirements are higher than for a vertical tube evaporator with the same heating surface.
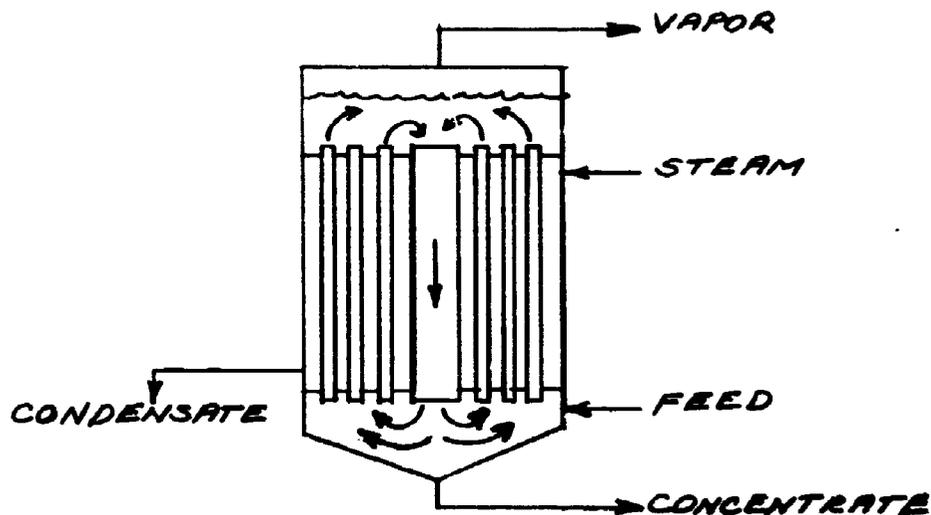
(3) <u>Forced Circulation Evaporation</u>:
Forcing the evaporating liquid through the heating tubes greatly increases the heat transfer coefficient with a small increase in power consumption due to pumping. A compact installation results.

The use of forced circulation results in a more flexible evaporator as well. If, due to scaling or vapor binding, the output falls off, increasing the circulation rate will increase the heat transfer coefficient thus tending to restore output. If necessary, a higher capacity may be achieved in the same manner.

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In addition, boiling action in the tubes can be suppressed by operating the heat exchanger under a hydrostatic head.
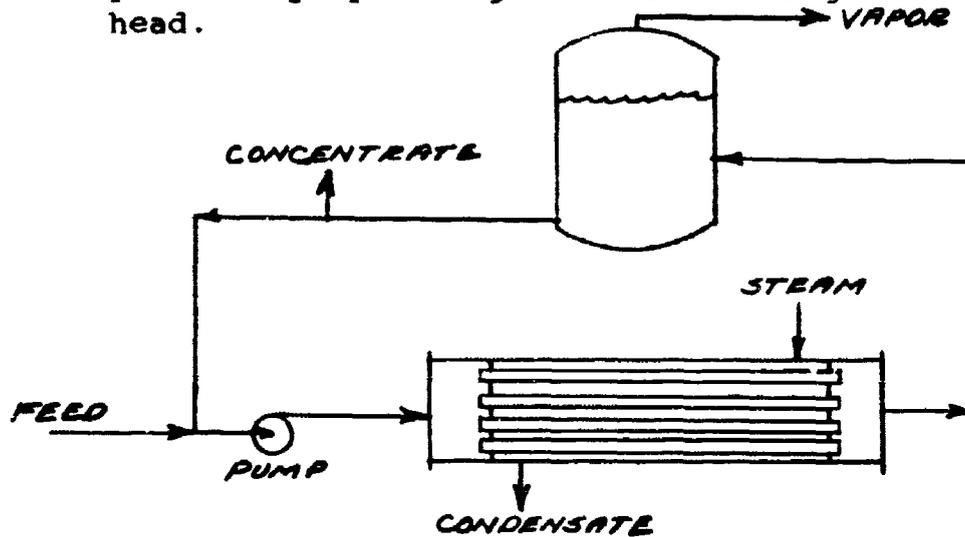
f. Summary of Evaporator Types:

The main features of the conventional evaporators are compared in the table below. The specific figures are given for an evaporator large enough to handle the waste from a shelter occupied by 250 people.

	Vertical Tube	Natural Convection	Forced Circulation
Heat Trans. Area - ft^2	10.8	47.0	4.8
Theoretical Consumption Power - KW	0.248	0.600	1.042*
Boiling Suppressed	Maybe	No	Yes
Simple Maintenance	Yes	No	Yes
Flexibility	Moderate	Low	High
Operability	Questionable	Should Work	Should Work
Extra Equipment	Small circulation pump may be required	None	80 GPM Pump

*Includes power to drive circulating pump.

On the basis of the types of systems examined and the types of evaporators available, it was concluded that a vapor compression system using forced circulation evaporation would be the system best suited for shelter use. A detailed discussion of such a system is presented under Section IX-B-3, "Evaporation Process".

g. Special Applications:

A number of evaporators have been developed for special services. Some of these have been developed primarily for use in the conversion of saline water to fresh water. The applicability of some of these special evaporators to the reclamation of shelter wastes is discussed below.

(1) Wiped Film Evaporator: The General Electric Company has developed what is known as the wiped film evaporator (R-5, 75, 48). Extremely high heat transfer coefficients have been obtained from a thin film of liquid, using this apparatus. The film is generated by continuously wiping the inner (evaporating) surface of a tube with a set of rotating blades.

Although this type of evaporator has been proven feasible for sea water conversion, the recovery of water from the process is on the order of 50% which would not be acceptable for shelter use. Higher rates of recovery would entail concentrating the solution which would build up scale on evaporative surfaces. For these reasons no further consideration has been given to this equipment.

(2) Centrifugal Evaporator: The Hickman rotary still (R-5,75,48) achieves coefficients of 3000-4500 $Btu/hr/ft^2/°F$ by spraying the feed liquor onto a disk revolving rapidly (1400 RPM) about its axis. In the 500 gallon per day unit known as the Aquastill (Aquastills, Inc., Rochester,N.Y.) several annular disks are joined at successive inner and outer surfaces to form a basket centrifuge. The vapors form on the inner surface of the basket, are compressed, and condense on the outside surface. This equipment operates on the principal of vapor compression and operates under 25" to 27" of vacuum. It requires about 2.0 KW of power to operate. This unit was designed for saline water conversion for beach homes, small boats and similar applications. Based upon existing information the mechanical reliability of the unit is questionable - 500 hours being the longest continuous run reported in the literature.

The unit was not designed to handle highly concentrated fluids that are necessary to be handled in a shelter due to the high water recovery ratio necessary. With the high solids concentration, the boiling point rise of the liquid is too high for the thermo-compression unit. Any solids that would have a tendency to form on the rotating heating surfaces would result in an unbalanced condition. Based

upon these factors, no further consideration is given to this unit for this application.

(3) <u>General Electric Company Experimental Unit</u>:   Under a contract sponsored by NASA, the General Electric Co. has developed a vacuum distillation unit for the purification of metabolic wastes. (R-61).

The process consists of an electrically heated evaporator evolving water vapor with traces of ammonia and volatile organic compounds, which are oxidized when passing through a heated platinum or platinum -10% rhodium catalyst.   The water vapor is condensed in water cooled coils and is collected as product water.   The evaporator operates at sub-atmospheric pressure.

A small quantity of air is fed to the system ahead of the reactor to assist in the oxidation of the ammonia and the volatiles.   The best quality product was obtained when the reactor operated at 2300°F. (R-61,55).   The product from this unit was consumed by a human subject with no adverse effects. (R-75).   A diagramatic sketch of this unit is given in Figure 3.

The laboratory unit that was tested operates on a batch basis (R-54).   The still has a 50 quart capacity.   The capacity of the unit is 3/4 to 1 gallon per hour.   The unit requires 4 GPM of cooling water.

This is the largest test unit known.   Such a unit, scaled up in size to have a capacity sufficient for a fallout shelter has some inherent disadvantages which would preclude its use in a shelter.   Based upon the power requirement for the unit of 0.644 watts/ml of recovered product/hr (R-55) it is estimated that a unit for a 250 man shelter would require 24KW of electrical energy.   A source of cooling would be required.   This would have to depend upon a source of cooling water which cannot be relied upon or mechanical cooling which would expend additional electrical energy.   The temperatures required for the catalytic oxidation are extremely high and are considered to be undesirable in a shelter.   Of course, the capital cost would be quite high due partially to the high cost of the platinum catalyst.

URINE RESERVOIR

MANOMETER

AIR BLEED

STILL POT

IMMERSION HEATER

COOLANT OUT

REACTOR W CATALYST

CONDENSER

COOLING WATER IN

VACUUM PUMP

HEATER LEADS

POTABLE WATER RESERVOIR

POTABLE WATER RESERVOIR

TO WATER SUPPLY

GENERAL ELECTRIC WATER RECOVERY PROCESS
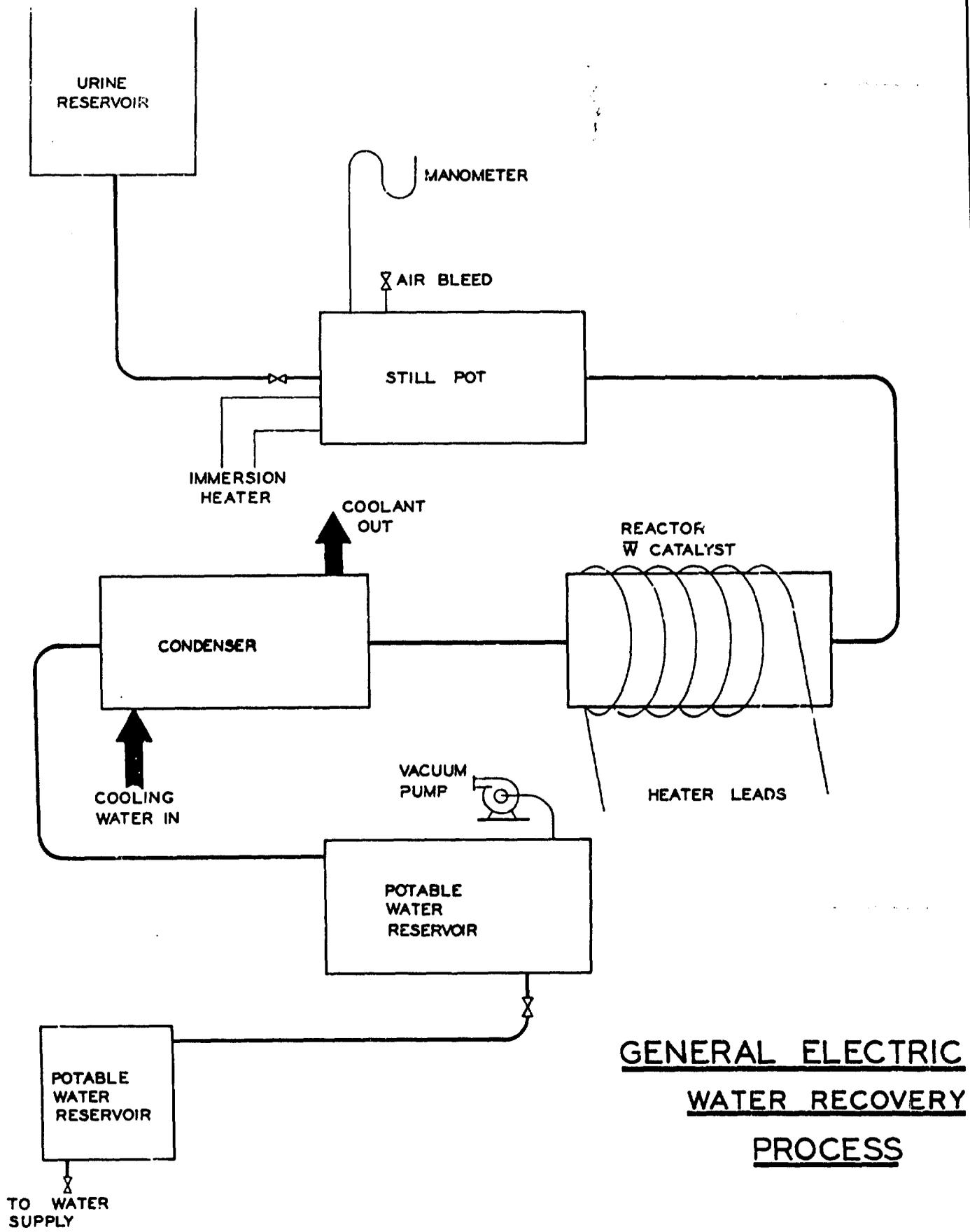
FIGURE 3

3. CHEMICAL OXIDATION

Chemical oxidation, by itself, cannot be used to re-
cover the water from human wastes. Even if there were
available an oxidant sufficiently strong to decompose the
organic constituents, and not form a residue itself, the
inorganic constituents would remain. However, these oxid-
ants which are sufficiently strong - potassium permanganate,
chromic acid, and potassium persulfate - all leave a residue
to be removed. Chemical oxidation can be used as a pre-
treatment in evaporation purification; however, Sendroy and
Collison (R-64,65) have found that in the evaporation of
urine, the product water contains urea, phenol, ammonia,
and volatile organic acids. In attempting to keep the
volatile organics from collecting in the product water, they
added chromic acid (sulfuric acid plus potassium dichromate)
and potassium persulfate to the urine in separate experiments.
Although the ammonia was partially retained, hydrochloric
acid was formed and collected in the product water along
with an odiferous decomposition product, urinod. Treatment
with activated carbon was necessary to yield a product suit-
able for human consumption.

In the proportions used by Sendroy and Collison, a
two week shelter occupancy by 250 people would require the
prestorage of 1200 lbs. of potassium persulfate or 53 gall-
ons of concentrated sulfuric acid and 1000 lbs. of potassi-
um dichromate.

As the use of these chemicals would only serve as a
pre-treatment process for a subsequent process, the chem-
icals would be difficult to handle, the reaction would be
difficult to control, and there appears to be no major
process advantage. No further consideration has been given
to chemical oxidation.

4. WET OXIDATION (ZIMMERMAN PROCESS)

This process, designed primarily to dispose of waste
sludges, uses the heat value of the oxidation of the waste
material to maintain a self sustaining reaction (R-90,91).

The waste liquor to be treated is pre-heated to
300°F and fed at 1500 psi to a pre-heated high pressure re-
actor where it is mixed with 1500 psi compressed air at
500 to 600°F reactor temperature. Oxidation of the waste
takes place and the resultant liquid is flashed in a flash

chamber producing high pressure steam and liquid which is used in the humidifier to pre-heat the compressed air entering the reactor. Effluent leaving the humidifier is odorless and can be further treated for potable water.

The steam produced, at 1500 psi, is used to drive a turbine type air compressor and pre-heat the waste liquor feed. It is then condensed for use as product water. The steam could also be used to run an electric generator, but the use of a steam turbine for such a short period would not justify an installation in a shelter.

The reaction rate in the process is a function of temperature and pressure. Thus, while at 572°F the reaction is almost instantaneous, it would require several hours at lower temperatures and pressures.

This process was designed primarily for waste disposal, the production of water being of secondary consideration. The high pressure and high temperature requirements of the process make it hazardous and too difficult to operate in the hands of inexperienced personnel. This process will remove only the organic material and will leave an ash in the effluent as well as inorganic chemicals unaffected by vaporization and oxidation, thus the effluent would need to be treated further. A source of cooling which may not be readily available in a shelter, would be required. The equipment cost for such equipment would undoubtedly be very high. For these reasons, no further consideration has been given to this process.

5. DIGESTION AND CONVENTIONAL SEWAGE TREATMENT METHODS

Consideration has been given to conventional sewage operations for the treatment of water. Three basic methods are used for the removal of solids from sewage - biological digestion, filtration, chemical precipitation and flocculation.

Aerobic bacteria have the ability of destroying organic matter. However, it will take about 12 days for this digestion reaction to start after innoculation. Since the maximum occupancy period is 14 days, this is not a feasible process. In addition, the control of digestion is difficult even under ideal conditions. Gases are evolved in this process which are undesirable. In view of the above, no further consideration was given to digestion.

Filtration is commonly carried out in water plants using sand filters. A sand filter that would handle the effluent from a 1000 man shelter would require a surface area of approximately 2000 ft^2. It is felt that such a unit is too large for further consideration.

Consideration was given to using chemical precipitation and flocculation. Such processes remove only 80% of the solids. In addition, the control of such a process would be difficult as a number of chemicals such as lime, aluminum sulfate, sodium silicate, or ferrous and ferric salts would have to be added in controlled quantities. Accordingly, no further consideration is given to this process.

A filter which it is felt would remove suspended solids satisfactorily is discussed in Section IX-B-4 of this report.

6. SOLVENT EXTRACTION

Solvent extraction has been suggested as a process for the conversion of saline water to fresh water (R-6,79). Consideration has been given to the use of this process for the recovery of fresh water from shelter wastes.

In this process, a primary organic solvent is used to extract water from the raw feed which will dissolve more water at a lower temperature than at a higher temperature. The extract is heated and water is separated from it. The primary solvent is then extracted from the water with a secondary solvent. The primary solvent may be one such as tertiary octylamine and the secondary solvent one such as Skellysolve-C.

It has been found that the product water may have a solvent content as high as 1%. This process is complicated and would conceivably be difficult to operate in a shelter with untrained personnel. The handling of inflamable solvents is undesirable in a shelter. No specific information is known on the solubility of the various organic materials in urine in the extraction solvent. It is felt that the solubility of the organic contaminants may be high enough in the solvents to be carried over into the product water in excessive amounts. Therefore, no further consideration has been given to this process.

A great deal of work has been done in the field of saline water conversion using freezing processes (R-72,73,74). The processes that have been developed in this area are based upon freeze crystallization. In other process areas, freeze sublimati n is a processing technique that has been used effectively in the food and drug industry. The possible application of these two basic freezing processes is given below.

a. Freeze Crystallization:
    A number of variations of the same basic idea has been developed in which the impure solution is partially frozen, the ice formed is separated from the concentrated solution and melted as the product water. The freezing may be accomplished in any suitable manner. A number of different methods have been developed.

    It has been found that water in a brine solution upon freezing forms small ice crystals and may trap up to 20 to 40% of its weight of mother liquor between the interstices of its crystals. The separation of the mother liquor from the ice crystals has been one of the most difficult problems to solve. Many methods have been tried but washing the ice crystals with fresh water appears to give the best but not necessarily ideal results.

    Hendrickson (R-73) studied a process in which three stages of freezing was used. He was able to obtain a product water with less than 500 ppm of dissolved solids.

    Based upon the power required for the process, as reported by Hendrickson, 60 tons of refrigeration would be required to produce 1000 gal/day of fresh water from sea water. Relating this figure to a 250 person shelter would require approximately 53KW for its operation.

    A direct freeze process operating at a low absolute pressure and using a lithium bromide absorption system has been developed (R-74). A pilot plant has been built by the Carrier Corporation using this process.

    A preliminary experiment reported by Wallman and Barnett (R-79) indicates that freeze crystallization is unsatisfactory as a process for the conversion of urine to potable water. A sample of urine was placed in a freezer at

30°F at which temperature a flocculent precipitate formed. Ice did not form until the temperature was lowered to 20--25°F. The premature precipitation of solids would collect with ice crystals thus making the process unsatisfactory.

Considering freeze crystallization processes in general, one of the most difficult problems encountered is the separation of pure ice crystals from the mother liquor. It is not considered that the purity of the product water would be satisfactory from a freeze crystallization process. Such processes are complicated and would be difficult to operate by inexperienced personnel. The power requirements are higher than for other processes. As the equipment is somewhat complex, the initial cost would be considerably higher than for other processes. None of the freeze crystallization processes developed approach the 90% water recovery desired. For these reasons, no further consideration is given to freeze crystallization.

b. Freeze Sublimation:
Freeze sublimation (lyophilization) has been investigated as a process for the conversion of urine to potable water (R-79,64,65). A satisfactory product has been produced by this process.

Freeze sublimation is a process where the impure water is frozen at a low temperature and pressure, the ice is sublimed and the vapor condensed as product water.

This process is used commercially (known as freeze drying) in the food and drug industry where recovery of a dry or semi-dry product is the goal. The use of low temperature permits the processing of food, blood plasma, and other heat sensitive materials. It is used primarily in industries where the high cost of operation and equipment is justified by the high value of the product (R-16).

Commercially, freeze sublimation is carried out on a batch basis. An attempt to design a continuous process for a shelter was not successful.

It was not felt that a batch process was suitable for a shelter so a semi-continuous process has been conceived. A schematic diagram of this process is shown in Figure 4.

The feed stock would first be frozen at 14-16°F by spraying into a mechanically refrigerated vessel. Upon

freezing, vacuum would be applied (3mm Hg abs.) to the vessel, the refrigeration cycle reversed, thus subliming the ice crystals formed. The vapor would be introduced into a second vessel where it would be condensed and frozen. Upon freezing, the refrigeration cycle would be reversed and the ice melted. This would be the product water. A parallel set of equipment performing the same operations but in a different phase would be required. The subliming and melting vessels serve as a heat sink for the refrigeration system which would operate at a constant load.

Referring to Figure 4, the basic equipment will consist of a refrigeration system and 4 refrigerated vessels each of which will serve a dual purpose. Vessels No. 2 and No. 3 will freeze or sublime alternately while vessels No. 1 and No. 4 will condense or melt alternately. The refrigeration system will be equipped with a number of 3-way solenoid valves to allow the cycles to be automatically reversed on a predetermined schedule.

1st Cycle - Vessel No. 2 received a charge of raw stock and freezes while vessel No. 1 melts the final product. Vessel No. 3 sublimes a previously frozen charge which is condensed and frozen in vessel No. 4.

2nd Cycle - Vessel No. 2 sublimes the frozen charge which is condensed and frozen in vessel No. 1. Vessel No. 3 received a fresh charge and freezes while vessel No. 4 melts.

A 3-way solenoid valve on the suction side of the vacuum pump will allow vacuum to be applied on the sublimation-condensation side of the cycle alternately.

As this process has been considered from only a theoretical standpoint, no attempt has been made to prepare a detailed design of the equipment. It has been estimated that the process could handle the waste from a 250 occupant shelter using 4 H.P. in the refrigeration compressor. The effluent from such a process would have to be chlorinated and treated with activated charcoal.

Based upon laboratory information, this process would appear to produce a high quality product. It would also operate at a low enough power input to be attractive for shelter use. However, there are a number of mechanical aspects that must be considered:

2 & 3   FREEZE & SUBLIME
1 & 4   CONDENSE & MELT

65 LB/HR
FEED

3700 CU FT./ MIN.
VAPOR

1

2

PRODUCT WATER
30 LBS/HR

DRAIN

COLD
TRAP

VACUUM
PUMP

3

4

DRAIN

PRODUCT WATER
30 LBS/HR

32° F

50° F   10° F

0° F

RECEIVER

M

COMPRESSOR
4 HP
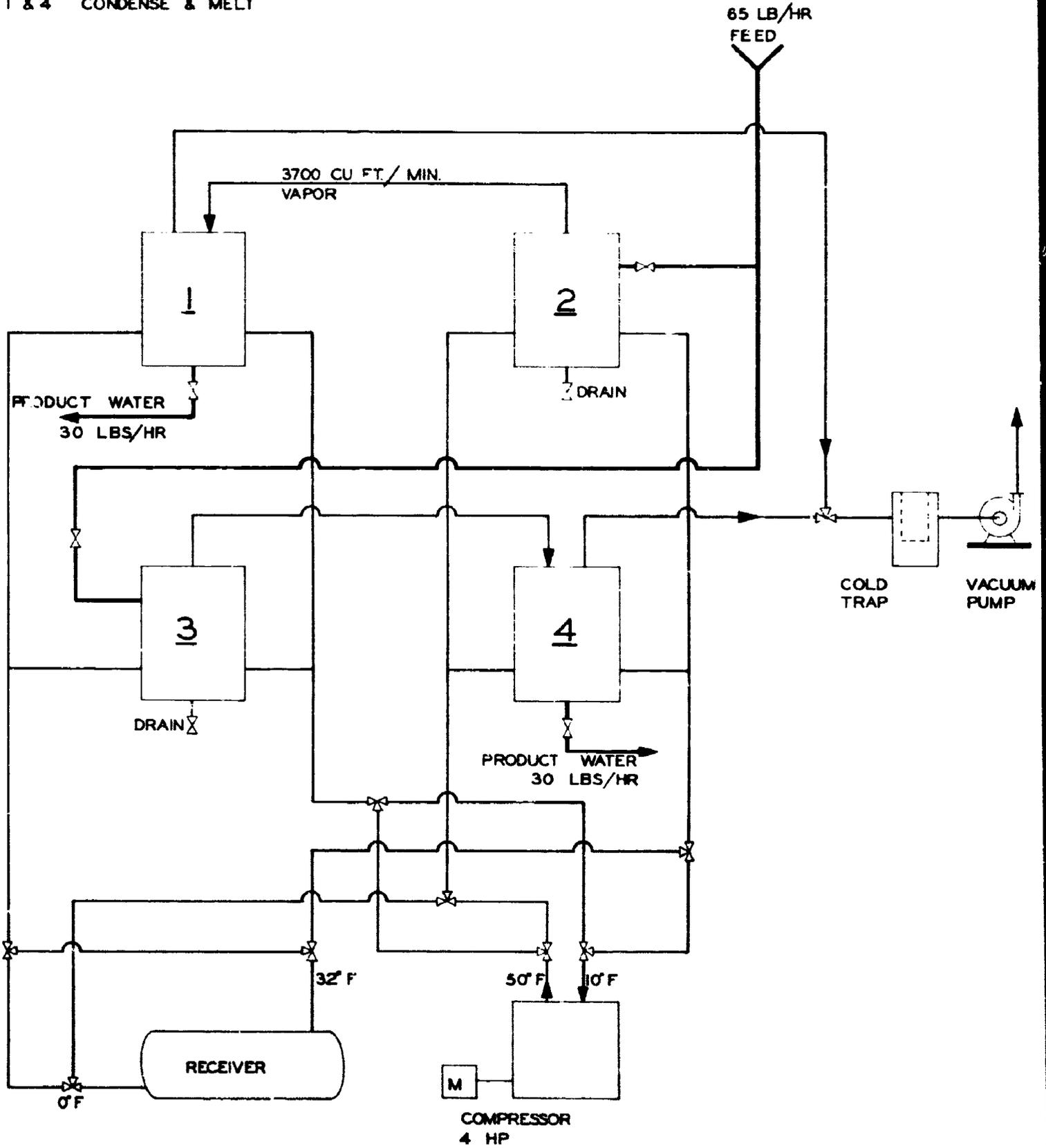
FREEZE
SUBLIMATION

FIGURE 4

1) A relatively high vacuum will be required. After standing for a period of time, it might be difficult to maintain the necessary tightness.

2) The sublimer would accumulate a residue of unvaporized material amounting to about 5% of the feed. This would remain in the solid state and would have to be removed periodically.

3) The heat exchange surfaces would be large. The vessels themselves would be relatively large due to the necessity of handling large volumes of vapor at a low absolute pressure.

4) The instrumentation would be somewhat complicated due to the necessary number of automatic valves.

5) The cost of the equipment would undoubtedly be higher than for other suitable processes.

6) Extensive development costs would be required as there is no comparable process known upon which to rely for process information.

Based upon the above, freeze, sublimation has been given no further consideration.

8. AIR EVAPORATION METHOD

It was considered that a system could be devised to serve a dual function. Stage 1 would dehumidify room air, Stage 2 would recover water from wastes. It would consist of a wick evaporator, a condensing coil and a heat sink coil. A mechanical refrigeration system would be required.

A flow diagram, heat and material balance for such a theoretical system is shown in Figure 5. An examination of this system shows that 3000 cfm of shelter air will yield 1000 lbs/hr of water. (Stage 1) This requires a minimum theoretical work load of 14 H.P.

The air from Stage 1 at 170°F and 5% humidity is used in conjunction with an additional 500 cfm of air recirculated from cooling the refrigerant of Stage 2 to evaporate

approximately 250 lb/hr of waste water through a system of evaporative wicks. 3500 cfm of moist air at 85°F and 100% humidity is cooled to 60°F and 100% humidity, yielding approximately 250 lbs. of water per hour. The resultant air is used to cool the refrigerant and bring the air stream to 170°F and 5% humidity. 3000 cfm is discharged from the shelter and 500 cfm is recirculated through the evaporator.

For the combined dehumidification cooling loads of Stage 1 and Stage 2, the theoretical H.P. requirements is 62.5 (77 H.P. based on 81% efficiency).

As the power requirements for such a scheme are so high no further consideration has been given to this process. However, as it is necessary to cool the shelter air and thus remove water from it, further consideration is given below to the first stage of this process.

9. AIR CONDITIONING SYSTEM AND AIR DEHUMIDIFIER

Water obtained from the dehumidification sections of air conditioning systems aboard U. S. submarines has been found to be acceptable as potable water; however, it was found to have a strong metallic taste. (R-79).

According to Hawk (R-22), 1000 grams per day per person is lost in the form of respiration and perspiration. For a shelter with 1000 occupants, this would amount to about 100 lb/hour. The "ASHRE Guide and Data Book" indicates that twice this figure may be expected.

It is proposed to place a coil in the ventilating exhaust system to condense 100 lbs. of water per hour out of the exhaust air.

A refrigeration system (evaporative condenser) which would cool the air for dehumidification and use the cool air as a heat sink before exhausting the air from the shelter, could be employed.

a) Air Dehumidification by Mechanical Means:
If it is assumed that 3000 cfm of air is exhausted from the shelter at 78°F (73°F wet bulb) and 80% relative humidity, then the system would operate as follows (refer to Figure 6):

STAGE ONE

CONDENSER
COIL   COIL

78°F 80% RH   80°F 100% RH   170°F 5% RH
H=38.4   H=28.4   H=53.4
h=.018   h=.011   h=.011
13 000 LB HR   →

100 LB/HR
WATER

169,000 BTU/HR

350,000/BTU HR

13,000 LB/HR

H = ENTHALPY BTU/LB
h = LBS WATER / LB DRY AIR

STAGE TWO

250 LB/HR
WASTE WATER   COIL

85°F 100% RH   80°F 100% RH
H=49.4   H=28.4
h=.026   h=.011

16,000 LB/HR

WICK
EVAPORATOR

250 LB/HR
WATER

3000 LB/HR

369,000 BTU/HR

170°F 5% RH
H=53.4
h=.011
12,800 LB/HR AIR

9500 LB AIR
2200 CFM
OUT OF SHELTER

324,000 BTU/HR

3500 LB AIR
800 CFM
OUT OF SHELTER

BLOWER
3500 CFM
3 HP MOTOR

RECEIVER

COMPRESSOR
77 HP

MOTOR

ROOM DEHUMIDIFICATION & WICK EVAPORATION SYSTEM

FIGURE 5

13,000 lbs. air/hr. is cooled to 57°F and 100% relative humdiity removing 170,000 Btu through the evaporative condenser and yielding 100 lbs. water/hr. The 57°F air is used to remove the heat of the refrigerant resulting in 122°F air being discharged from the shelter. Such a system would require 13 H.P. to operate.

It is estimated that such a system would cost $5,200 installed.

The water obtained from this system might have a metallic taste, (from contact with the coils and collection system) may pick up dust, odors, bacteria, etc. It would therefore be necessary to treat it before use. Chlorination would be required. However, this could be handled in equipment described later.

The removal of dirt and miscellaneous tastes and odors can be readily removed by filtration and activated charcoal. A small commercial unit that may be satisfactory for such treatment is available. The trade name for this unit is "Dynion" and it is manufactured by J. H. Scharf Manufacturing Company, Omaha, Nebraska.

The filter consists of a hollow fine porous ceramic tube (candle) impregnated with silver. The hollow core is filled with activated charcoal. One or more of these candles may be placed in a housing. Impure water flows from the outside of the candle to the activated charcoal filled hollow core. The suspended solids collect on the outside of the candle. The candle may be cleaned by brushing and re-used.

A 3 candle unit will handle a flow of 2 to 3 GPM, and can process a total of 90,000 gallons. The cost of such a unit is less than $200.

Tests at Western Reserve University (Private Communication with Mr. Ivan Crawl of Telco, Inc., Cleveland, Ohio) using a mixture of feces and water as feed stock produced water which, when introduced into a culture, showed no bacteria present.

An alternate system for final clean-up of the water would be a charcoal adsorption column described in Section IX-B.

Small standard dehumidifier units are available which might be useful in small shelters. They operate on the same basic principle as the system previously described. It is not considered to be practical to employ these small units in a large shelter.

b) Air Dehumidification by Solid Adsorbents:

As a minimum of 1000 grams per day are lost by each individual through respiration and perspiration it is necessary to recover this moisture from the air to complete the human water cycle. Although the air conditions in the shelter are quite variable, an assumed hypothetical value of 78°F and 80% relative humidity will be used. This condition while not representing the worst possible condition, is a reasonable value to be anticipated over the entire year for varying geographical conditions.

The minimum air circulation rate will be 3 cfm per occupant. Due to the nature of the circulating system, it is preferable to process the air requirements of a maximum shelter population in a single unit. Therefore, for a 1000 man shelter, 3000 cfm or 13,000 lb. per hour will require processing.

The proposed system would only reclaim the moisture lost by the occupants and thus would not serve as an air conditioning device. The moisture may be removed by adsorption using a solid dessicant. This moisture will be reclaimed from the dessicant by thermal regeneration. The process may be accomplished in a three step operation consisting of adsorption by the solid dessicant, thermal regeneration of the saturated dessicant, and cooling of the dessicant back to the temperature of the adsorption operation.

While many solid adsorbents were considered, based on the high capacity to cost ratio, activated florite appears to be the preferred dessicant. In order to keep the amount of dessicant needed within a reasonable limit a one hour drying cycle is specified. The inlet air conditions are 78°F, 80% relative humidity, 73°F wet bulb temperature and 0.017 lb. moisture per pound of dry air. At 1000 grams per man per day, 92 lb. per hour of moisture must be reclaimed. This yields an outlet air condition of 110°F, 20% relative humidity, 73°F wet bulb temperature and 0.010 lb. moisture per pound of dry air. The above values assume adiabatic operation of the adsorption process.

COOLING
COIL

PERFORATED
BAFFLE

HEAT
SINK

13 000 LBS/HR
3000 CFM
78°F 80% RH
H=38.0
h=.018

57°F 100% RH
H=25.0
h=.010

120°F
H=40.0
h=.010

OUT OF
SHELTER

104 LBS/HR
WATER

MOTOR

COMPRESSOR

RECEIVER
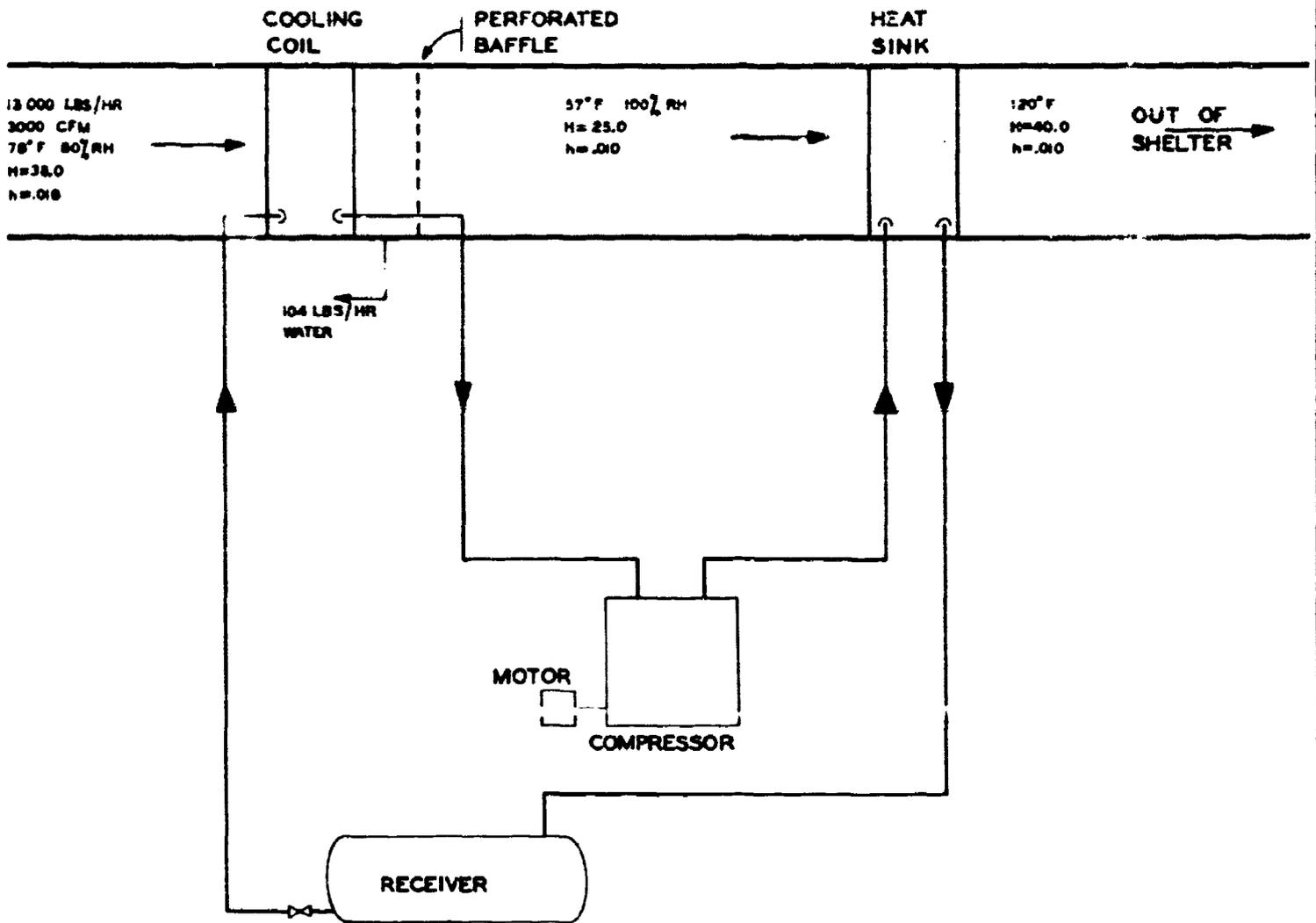
H - ENTHALPY OF AIR
h - MOISTURE CONTENT LBS/FT³

WATER RECOVERED
FROM AIR
CONDITIONING

FIGURE 6

For activated florite with regeneration at 250°F the adsorptive capacity by weight is 6% (R-20). Using this capacity and a one hour cycle, 1535 lbs. (31 ft³) of florite are required. In order to achieve a residence time in the adsorber of 5 to 10 seconds, the bed height is set at three times the column diameter. The dessicant is packed on closely spaced screen trays to reduce the pressure drop and prevent channeling of the moist air.

To regenerate the bed and reclaim the water the inlet air stream is preheated partially by heat exchange with the effluent gas from the regeneration cycle and partially by an electrical resistance heater. The entering gas is at 300°F while the effluent gas is at 250°F. The effluent gas is passed through a perforated plate compact heat exchanger which preheats the incoming gas. The moisture removed from the solid adsorbent is condensed in the heat exchanger and recycled to the water storage. As mentioned previously, tests have/shown this water to be potable following light chlorination and treatment with activated charcoal.

After regeneration, the hot bed at 250°F must be cooled by circulating room temperature air through the column. The bed is cooled down to essentially ambient temperature. Due to the batch nature of this process, three identical adsorption columns are provided. Thus while one is adsorbing, the second is being regenerated, and the third is being cooled. During any stand-by conditions the solid adsorbents should be closed off from the remainder of the system to prevent reduction in adsorptive capacity.

In the following table is summarized the major pieces of process equipment necessary for the air dehumidification system. These specifications are only of a preliminary nature as they are based on literature data.

PROCESS EQUIPMENT SPECIFICATIONS

1. Air Dehumidification Column
   No. required: Three
   Type: Carbon steel, vertical vessel
   Diameter: 2.5 ft.
   Height: 8 ft; 6.5 ft. bed height
   Wall thickness: 3/16"
   Charge: 31 ft.³ Activated Florite

2. Regenerating Gas Heat Exchanger
   Type: Aluminum, perforated plate
   Area: 950 ft.^{2}
   Volume: 2.5 ft.^{3}

3. Electrical Resistance Heater
   Type: Forced air duct
   Power: 50 kilowatts
   Voltage: 220 volts

4. Condensate Pump
   Type: Cast iron, centrifugal
   Horsepower: ¼ H.P.
   Flow rate: 0.18 GPM

The entire dehumidification unit will weight approximately 7,500 lbs. and occupy a space 6 ft. wide by 6 ft long by 8 ft. high. The estimated erected cost of the unit is $5,800. The unit will require 50KW of power to heat the air used for regeneration of the solid adsorbent. While the unit is comparable in weight, size and cost to the proposed refrigeration system, the power required is 5 times that of the refrigeration unit. Considering the relatively small degree of moisture removal, the process of solid adsorption is uneconomical with respect to utilities. Only in a unit which requires exceptionally dry air is the solid adsorption process economically superior to the refrigeration process.

CONCLUSION

Of the two methods for obtaining water from the air, the system employing mechanical refrigeration is preferred. It is easy to install and operate, has a lower power requirement, and lower initial cost. However, the advisability of depending completely upon water from this system can be determined only by evaluating local climatological conditions (see Section VIII).

B. SELECTED PROCESSES

Of the various processes evaluated, only 3 basic systems are considered to be of sufficient merit to warrant further consideration. These processes - electrodialysis, ion-exchange-adsorption, and vapor compression evaporation - are discussed below. These processes, using filtration as pre-treatment and chlorination as post-treatment in common for all, show the most promise of producing an acceptable product water.

1. Electrodialysis

As previously stated, electrodialysis is not capable of removing non-ionic material. Therefore, the neutral organic compounds, urea, and other tastes and odors will have to be removed by adsorption on activated charcoal and possibly urea hydrolysis. According to Wood, however, a number of the organic constituents are weakly ionized and dialyzable (R-82). Gregor has also investigated the removal of organic material and determined that organic ions up to molecular weights as high as 500 can be removed easily. The weak electrolytes or ampholytes such as phenol are removed very slowly (R-19). Wood has also shown that the resistance of the dialyzer and thus the power required increases greatly as the inorganic ampholytes become the primary current carriers (R-83).

By combining the above experimental results it can be determined that of the primary constituents in urine as listed in Table 2 in the appendix, creatinine, creatine, glycine, cystine, lysine, imidazole, and urea are undialyzable. Hippuric acid, uric acid, the organic acids and the amino acids not listed above as well as the inorganic constituents will all be removed from the solution. From Wood's data, all the organic materials behave as anions and migrate toward the anode (R-82).

Using the above qualitative conclusions the design of the dialyzer may now be undertaken. As the exact effect of electrodialysis on urea is undetermined, it is assumed that urea will behave as a cation in the hope of reducing the subsequent adsorption load. From the average urine composition as given in (R-79) the cation load on the electrodialyzer is calculated to be 0.226 equivalents per liter. Although a gallon per day of water is supplied to each person, 25% of this is lost to the air as perspiration and respiration. Therefore, designing on a shelter population for each water recovery system of 250 occupants a total of 180 equivalents per day must be removed from the

waste stream. The membrane area required to achieve this trans-
fer rate may be determined from Faraday's law

$$\frac{eita}{F} = fT$$

where

e = current efficiency
i = current density
t = time of transfer
a = useful membrane area
F = Faraday's equivalency constant
f = fractional demineralization
T = equivalents transferred

As most of the data available on electrodialysis and its assoc-
iated equipment has been published by Ionics, Inc., the performance
indices and equipment characteristics used in the following de-
sign will be taken from their data (R-30,41,42). For a low pro-
cess flow rate, using Mark II tortuous path spacers, .040" thick
a 75% demineralization can be obtained in a single pass. At
optimum conditions and moderately concentrated solutions the
current efficiency is 95%. The time of transfer is based on a
24 hour period. To avoid local polarization and also to keep
power requirements reasonably small, a current density of 15 mil-
liamperes per square centimeter was chosen. Using the values
given in the above relationship the effective membrane pair
transfer area was determined to be 11.5 ft^2. For a Mark II
spacer the maximum membrane area utilization is 65%. With this
basis the first stage unit was set at 8 membrane pairs, 18" x
20" using the 4 ounce dynel backed CR 61 and AR 111A membranes.
These new thinner membranes have adequate burst strength and
structural rigidity. The CR 61 and AR 111A membranes are both
23 mils thick. The total membrane area in the first stage is
40 ft^2.

Due to the new lighter membranes and the dynel backing
material, the membrane electrical resistance has been lowered
significantly. In the first stage as the ion concentration is
quite high the membrane pair area resistance is 11 ohm-cm^2 (R-30).
The stack resistance is determined from

$$r_s = n \frac{Rp}{Ap}$$

where

r_s = membrane stack resistance
n = number of membrane pairs
Ap = effective membrane area
Rp = membrane pair area resistance

For eight membrane pairs the stack resistance was 0.06 ohms. Knowing the effective membrane area, the current density and the stack resistance the power required, and the input voltage may be determined. Again, for the first stage, 31 watts at 1.4 volts are needed. This will require a 23 ampere D.C. constant current source which, assuming standard 60 cycle power to be available, can be obtained through a transformer and rectification network.

The first stage of the electrodialyzer removes 75% of the electrolytes present. Therefore, the equivalents transferred to the second stage are 45 equivalents per day. The same membranes and spacers are used in the second stage as in the first stage. The current density throughout is maintained at 15 milliamperes per square centimeter. Using this data and Faraday's relationship the effective membrane pair transfer area was 3.0 ft^2. Again using 65% effective area the second stage unit was set at 2 membrane pairs, 18" x 20" using the 4 ounce dynel backed CR 61 and AR 111A membranes. The total membrane area in the second stage is 10 ft^2. As the ion concentration in the second stage is considerably reduced the membrane pair area resistance is 14 ohm-cm^2 (R-30). This yields a stack resistance of 0.02 ohms requiring 10 watts at 0.5 volts. The same 23 ampere D.C. current source is used to supply both stages.

The total power required for the entire unit to produce sufficient water to supply 250 people for a two week period is 41 watts or 0.17 watts per occupant. For the required flow through the dialyzer this is equivalent to 16.5 KWH. This unit will provide for 94% demineralization of the feed stock, the nontransferred components being primarily the weak organic ampholytes.

As stated in the basic assumptions no attempt is made to recover the water from the feces. Metabolic water production and the water on hand is sufficient to provide for this loss and also to make up losses in the electrodialyzer. During the process of electrodialysis a certain amount of water is

inadvertently transferred through the membranes with the elect-
rolytes. The design efficiency of the unit is therefore, set
at 94% recovery. This value will have to be checked experiment-
ally utilizing the current density and waste stream composition
as specified for urine and wash water.

In the actual electrodialyzer the stream to be dilut-
ed and the waste stream to which the electrolytes are transfer-
red are circulated in alternating passages between the membranes.
The waste stream can be recirculated to the point of incipient
saturation with the least soluble electrolyte. In the present
case the first salt to precipitate is $CaSO_4 \cdot 2H_2O$. The con-
centration of Ca^{++} in the entering stream is 0.002 moles per
liter while the solubility limit is 0.015 moles per liter.
Setting the waste stream flowrate the same as the stream to be
purified, the waste stream may be recirculated for 7 hours be-
fore necessitating disposal. At the system flow rate this would
require a 500 gallon storage tank for the waste stream and its
associated circulating equipment. As all the other salt present
have higher solubilities the only inorganic salt which might
deposit is $CaSO_4 \cdot 2H_2O$. The effect of organics on fouling the
membranes has not been determined and experimental data in this
area will have to be obtained.

Following the electrodialyzer the effluent stream
will still contain urea, creatinine, creatine, glycine, cystine,
lysine and imadazole. Initially the hydrolysis of urea with
the enzyme urease was studied prior to the electrodialysis unit.
Preliminary results indicated that an essentially zero order re-
action rate was obtained. At 30°C with a urease concentration
of 1.86 gm per liter the rate of hydrolysis was 0.71% of the
urea per minute (R-17). The CO_2 was vented or removed by aera-
tion, while the NH_3 was absorbed by the solution and subsequent-
ly dialyzed. A more careful study of the hydrolysis reaction
revealed that the reaction was first order initially but then
changed to zero order with time. The governing rate equation
postulated on the basis of Langmuir adsorption of the urea and
water on the urease was given by Laidler and Hoare (R-35) as

$$V = \frac{K_o K_1 Ce Cu}{(1 + K_1 C_u)(1 + K_2 C_u)}$$

where

$$V = \text{reaction rate (moles/l} \cdot \text{sec)}$$
$$K_1 = \text{urea adsorption constant (1/mole)}$$
$$K_2 = \text{water adsorption constant (1/mole)}$$
$$K_0 = \text{reaction rate constant (sec}^{-1})$$
$$Ce = \text{urease concentration (moles/l)}$$
$$Cu = \text{urea concentration (moles/l)}$$

The values of K_1 and K_2 were taken as 7.56 1/mole while K_0 was 1.94×10^3 sec.$^{-1}$ at the initial rate. For an initial urea concentration of 1.18×10^{-3} moles/sec. and assuming that the urea must be hydrolyzed as fast as it is produced the rate expression reduces to

$$\text{Urease Needed (lbs.)} = 29/Q$$

where Q is the volume of the reactor in liters. Allowing a 25 liter reaction vessel, 1.2 lbs. of urease are required.

The above results postulate the ability to maintain the high initial reaction rate. In actuality the rate decreases and drops to a zero order rate and therefore, the above value represents an overly optimistic viewpoint. At any rate if the above reaction takes place, 1 equivalent of CO_2 will have to be vented and the NH_3 will greatly increase the load on the electrodialyzer. Considering the increased capacity and cost of the electrodialyzer, the cost of urease at $104. per pound and the probability of actually needing more urease than indicated above it was deemed unadvisable to consider the hydrolysis of urea in any further detail. Also the effect of dissolved urease on the human system could not be ascertained. It would be extremely difficult to remove the urease from the solution. As will be shown below, removal of the urea by charcoal adsorption is a much simpler and more economical process.

Regardless of the urea hydrolysis the other organic constituents must be removed following electrodialysis. As the hydrolysis does not look favorable the urea will also be adsorbed on activated charcoal. Cheldelin and Williams have studied the adsorption of urea, creatine, creatinine, glycine, lysine and aspartic acid on Darco G-60, an activated charcoal (R-11). The results given were at 25°C and represent equilibrium values for 30 minutes contact.

Adsorption on Darco G-60

Substance	Equilibrium Conc. (moles/l) Maximum	Minimum	mg. of charcoal per cc of solution
Glycine	.659	.082	20
Lysine	.0446	.0052	10
Aspartic acid	.0414	.0032	20
Urea	.762	.042	40
Creatine	.0367	.0017	1
Creatinine	.0862	.0045	1

Using the average of the above values were applicable and the figure of 0.1 gms of organics per gram of charcoal (R-47) for the other substances which are not dialyzable the amount of charcoal needed is 382 lbs. Allowing an additional 18 lbs. for miscellaneous tastes and odors, a total of 400 lbs. or 16 ft^3 of activated charcoal is specified. To allow sufficient contact time to achieve equilibrium adsorption the charcoal adsorber was sized 2 ft in diameter and 5 ft high. The exact adsorption life of the charcoal will have to be validated by experimental results. Following the charcoal absorber the purified effluent goes to final treatment and storage.

The electrodialyzer and charcoal adsorber should be unaffected by long periods of stand-by condition. It is recommended that the membranes be stored in an essentially dry environment by closing off all the valves to the process and providing for a dessicant storage area to remove any moisture developing in the electrodialyzer. The requirements of the charcoal adsorber are less severe and merely closing off the valves to the unit should be sufficient for stand-by conditions. It is recommended that samples be taken annually to certify the adsorptive power of the charcoal and that the membranes be inspected for deterioration and failure on the same time interval.

Due to the slow flow rates throughout the process it is tenatively estimated that although only one hour will be needed to put the process in operation, approximately 1/4 to 1/2 of a day will be needed before product water can be obtained from the process.

In the following table is summarized all the major pieces of process equipment necessary for operation of the electrodialysis - adsorption waste water purification process.

It is to be recalled that these specifications are only of a preliminary nature based on data extracted from the literature and may require modification upon obtaining actual experimental data.

PROCESS EQUIPMENT SPECIFICATIONS

1. Electrodialyzer

Demineralization per stage	= 75%
Current efficiency	= 95%
Flow rate	= 210 gallons/day
Effective membrane area	= 65%
Current density	= 15 m.amps./cm^2
Membrane size	= 18" x 20" x .023"
4 oz. dynel backing	
Spacer size	= 18" x 20" x 0.040"
D. C. current	= 23 amps.

    Stage I

Membrane area	= 40 ft^2
Membrane pairs	= 8
Stack resistance	= .06 ohms.
Input voltage	= 1.4 volts
Power required	= 31.0 watts

    Stage II

Membrane area	= 10 ft^2
Membrane pairs	= 2
Stack resistance	= .02 ohms.
Input voltage	= 0.5 volts
Power required	= 10 watts

2. Transformer and Rectifier

    Type: 60 cycle, 220 volt AC to
             23 amps. D.C.

3. Concentrated Waste Recycle Tank

    Type : Carbon steel, horizontal vessel
    Diameter: 4 ft.
    Length: 6 ft.
    Wall thickness: 3/16"

4. Concentrated Waste Recycle Pump

    Type: Cast iron, centrifugal
    Horsepower: 1/4 H.P.
    Flow rate: 0.15GPM

5. Electrodialyzer Influent Pump
        Type: Cast iron, centrifugal
        Horsepower: 1/4 H.P.
        Flow rate: 0.15 GPM

6. Activated Charcaol Adsorber
        Type: Carbon steel, vertical vessel
        Diameter: 2 ft.
        Height: 5 ft.
        Wall thickness: 3/16"
        Charge: 400 lb. activated charcoal

        A process flow diagram for the electrodialysis – adsorption process may be seen in Figure 7. The power requirement for the electrodialysis is 0.4 KW. The approximate overall dimensions of a skid mounted assembled unit will be 7 ft. wide by 7½ ft. long by 5½ ft. high with a total weight of approximately 3000 lbs. The estimated assembled cost of the unit is $8,400.

ELECTRODIALYZER

FROM
FILTRATION

PUMP

TRANSFORMER – RECTIFIER

ACTIVATED
CHARCOAL
ADSORBER

CONCENTRATING
STREAM STORAGE

TO FINAL
TREATMENT

RECYCLE
PUMP
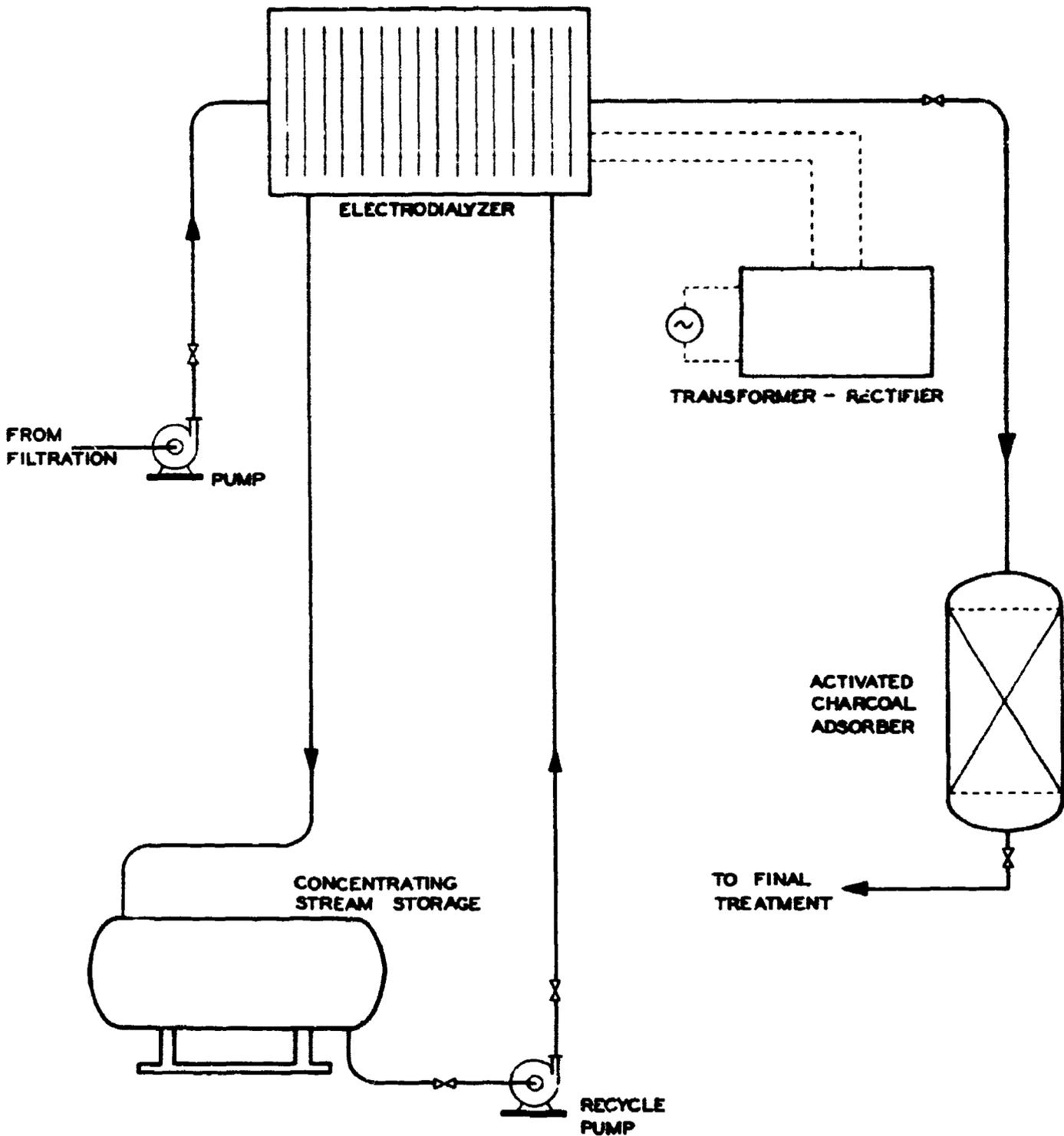
ELECTRODIALYSIS–
ADSORPTION
PROCESS

FIGURE 7

2. Ion Exchange

The separation of dissolved solids from urine by ion exchange transfer has been partially accomplished by a number of workers (R-9, 10). The main objective of these workers was not the removal of the components but the fractionation of them by ion exchange chromatography for analysis purposes. Their results, however, can act as a qualitative guide for the ionic behavior of some of the organic ampholytes in the solution.

The basic scheme common to all work has been the use of a strong acid cation exchange resin, first followed by a weak base anion exchange resin. Amberlite IRA 120 was used to remove the majority of the basic and neutral amino acids while Amberlite IR 4B retained the acidic amino acids. Nevertheless with the above scheme many of the neutral organics still passed through the bed unadsorbed. By using Zeo-Karb 215 in addition to removing inorganic cations the basic amino acids and creatinine were removed. The acidic components were then exchanged with Dowex 2. However, aspartic acid, glutamic acid, and glycine were readily eluted from the Zeo-Karb 215. Again, urea and other neutral components were not affected by the ion exchange bed. Dowex 50 was also used to remove the majority of the amino acid fraction in combination with Dowex 2 but weak ampholytes were still present in the effluent. Carsten, (R-10) using the H^+ form of Amberite IR 100 or Duolite C3 combined with OH^- form of Amberlite 400, removed all the inorganic and organic cations, creatinine, creatine, amino acids, and the majority of the urea.

From the above experimental results it can be determined that of the primary constituents in urine as listed in Table 2 in the appendix, inorganic cations, amino acids, creatinine and urea will be adsorbed on cation resins while hippuric acid, uric acid, inorganic anions and other organic acids will be retained on anion resins. With this qualitative basis, the cation load is 0.240 equivalents per liter and the anion resin load is 0.179 equivalents per liter. The following design is based on a shelter occupancy of 250 people.

The ion exchange process may be conducted in one of two manners. Either a sufficient quantity of resin may be supplied to handle the entire electrolyte load for the two week period or a lesser amount of resin is supplied and means of regenerating the resin must be provided. Initially it will be assumed that no regeneration is available and that enough resin is provided, for the entire period of occupancy. The latter alternative will be considered following the present discussion and then a comparative evaluation will be made.

From the experimental work described above consideration was given to the following resins. Amberlite IR 120, Dowex 50, Zeo-Karb 215, Amberlite XE 100, Duolite C3, Dowex 2, Amberlite IRA 402, and Amberlite IR 4B. The ion exchange capacities of these resins are tabulated below (R-33,15).

Ion Exchange Resin Capacities

Name	Manufacturer	Capacity meq/gm	meq/ml
Cation Resins			
Amberlite IR 120	Rohm & Haas Co.	4.6	1.7
Dowex 50	Dow Chemical Co.	4.6	1.7
Zeo-Karb 215	Permutit Ltd.	2.6	1.0
Amberlite XE 100	Rohm & Haas Co.	4.0	1.2
Duolite C3	Diamond Alkali Co.	3.2	1.0
Anion Resins			
Dowex 2	Dow Chemical Co.	3.6	1.3
Amberlite IRA 402	Rohm & Haas Co.	4.3	1.3
Amberlite IR 4B	Rohm & Haas Co.	10.0	2.5

The anticipated volume of waste water to be processed, predicated on a gallon of water being supplied to each shelter occupant per day, is 2950 gallons. As the capacity of Amberlite IR 120 and Dowex 50 is equivalent, consideration will only be given to Dowex 50. Also, as no cost data was available for Zeo-Karb 215, it will not be considered further. With the above flow and cation load, 2,700 equivalents of cations must be exchanged. Using this value and the capacities as given, 56 ft^3 of Dowex 50, 80 ft^3 of Amberlite XE 100 or 96 ft^3 of Duolite C3 is needed. Correspondingly, 2,000 equivalents of anions needed to be retained. As it was preferable to use a strong base anion exchanger, the Amberlite IR 4B was no longer considered. Using the anion equivalents and the tabulated capacities, 53 ft^3 of Dowex 2 or 53 ft^3 of Amberlite IRA 402 is the amount of anion resin necessary.

While the mechanism of ion exchange is merely an exchange reaction between the undesired ion and the active molecule of the resin, the neutral organic molecules or ampholytes do not appear to be retained by this mechanism. Calculations indicate that the large organic molecules are absorbed through

the porous structure of the resin copolymer base. This absorption is governed by a complex relationship caused by van der Waals and polar interactions. Therefore, the degree of cross linking of the copolymer structure becomes an important variable. For normal inorganic cations, 7-12% cross linking is the desirable range but for large organic cations such as amino acids the cross linking should only be 3-5% to allow space for accomodating the larger sized molecules. With these factors in mind it was decided to utilize the same resins as used in the experimental investigations as these resins have been tested and proven in actual operation.

Evaluating the available data, it can be seen that usage of Amberlite IR 100 or Duolite C3 gives the best removal of ampholytes and even removes 40-60% of the urea (R-10). The Amberlite IR 100 is no longer made, however, and the new Amberlite XE 100 is only in the experimental stages. It has a low degree of cross linking and thus should retain the large organic molecules but has not been proven in urine applications. Although a greater amount of Duolite C3 is needed than Dowex 50, the unit cost is considerably less and therefore the overall cost is only slightly higher. At any rate the proven capability of the Duolite C3 far offsets the cost differential. With respect to the anion resin, the Amberlite IRA 400 was substituted with IRA 402 because the exchange capacities are equivalent while the latter has a lower degree of cross linking and thus can accomodate the organic acids more readily. Rather than operating the cation and anion exchange resins as two separate beds, it was found that by mixing the two resins together in a single bed the OH^- and H^+ liberated in the respective exchange reactions combined to form water which provided an automatic control of the pH of the solution. Therefore, the final choice of ion exchange resins consisted of a mixed bed containing Duolite C3 as the cation resin and Amberlite IRA 402 as the anion resin.

As previously mentioned, the ion exchange process may be conducted with intermediate regeneration of the resin. The resin bed is then run to exhaustion, regenerated by a reverse exchange reaction and then washed clean of the regenerating solution. As the acid and base forms of the resin are utilized to prevent any ion contamination of the product, strong acids and bases must be used to regenerate the resin. A twelve hour regeneration cycle will be used as the design basis. According to Kunin, in order to achieve high exchange capacities at least three times the theoretical amount of regenerating solution must be used. In general, 10% regeneration solutions are used (R-33).

For a twel·e hour cycle 3.5 ft³ of Duolite C3 and 2.0 ft³ of Amberlite IRA 402 are needed. Two identical beds are required as one is being regenerated while the other is processing the waste water stream.

Storage of the regenerating solution must be provided for the entire two week period. To provide three times the minimum quantity of regenerant, 650 gallons of 10% sodium hydroxide solution and 1,050 gallons Ϲ 10% sulfuric acid solution are required. Providing wash so‗ʉ‗‗‗‗ on a 1:1 basis with the regenerant, 1,700 gallons of wash water will need to be stored. In all, including the volume of resin, sodium hydroxide, sulfuric acid and wash water, storage facilities are needed for 3,480 gallons.

To select the preferred method of operation for the ion exchange process several factors must be considered. The most critical are: 1) safety, 2) cost, and 3) volume ratio of process equipment to water storage.

3,500 gallons of water would need to be stored for 250 people for a two week period. A regenerative ion exchange process requires that 3,480 gallons of resin, chemicals and wash water be stored. Thus it would not be practical to devote the same equipment volume to a chemical process that would be required simply for the storage of water. In addition, the storage and handling of strong acids and bases in a shelter is undesirable from a safety standpoint. It is estimated that the initial cost of the regenerative ion exchange process would be $2000 less than for a non-regenerative process. However, any economic advantage is offset by the disadvantages discussed above.

To provide sufficient contact time to allow all the electrolyte species to undergo exchange reactions the ion exchange beds are designed with a 2:1 height to diameter ratio. Even with this measure, the organic acids tend to elute from the Amberlite IRA 402. Therefore, means are necessary to remove these components as well as the neutral organic compounds from the solution. The substances which are either unaffected or weakly affected by ion exchange are urea, uric acid, hippuric acid, glutamic acid and aspartic acid. Again, as in electrodialysis, the possibility of urea hydrolysis exists. However, in addition to the CO_2 deaeration, as two NH_3 equivalents are formed from every urea equivalent, an additional 52 ft³ of resin would be required. To avoid this additional resin load the eluted organics as well as the undesirable tastes and odors will be adsorbed on activated charcoal.

The adsorption of urea will be based on the data of Cheldelin and Williams (R-11), while the remaining non-electrolytes will be adsorbed at the rate of 0.1 gms per gram of charcoal. On this basis the amount of charcoal needed is 477 lbs. An additional 23 lbs. of charcoal are provided to remove objectional tastes and odors. Thus a total of 500 lbs. or 20 ft³ of activated charcoal is required to remove all organic contaminants in the ion exchanger effluent. To allow sufficient contact time to achieve equilibrium adsorption of the organics, the charcoal adsorber was sized 2 ft. in diameter and 6.5 ft. high. The exact adsorption capacity of the charcoal, however, will need to be established by experimental data. Following the charcoal adsorber the purified effluent goes to final treatment and storage.

The ion exchanger and charcoal adsorber should be unaffected by long periods of stand-by condition. The individual pieces of equipment should be closed off by suitable valving. With this precaution the bound moisture of the resin should be kept intact and the exchange capacity retained. Similarly the charcoal adsorber should be isolated from the system by closed valves. It is recommended that samples be taken annually to check the adsorbing power of the activated charcoal and the exchange capacity of the resin.

Due to the slow flow rates throughout the process it is tentatively estimated that although less than an hour will be needed to put the process in operation, approximately 3/4 to 1 day will be needed before product water can be obtained from the process. As both the ion exchange and the charcoal adsorption depend on equilibrium contact the hold up time is quite long. The ion exchange resin will be supplied in three columns only one of which will be handling the waste stream. When one column becomes exhausted, another column will be switched into its place to handle the process stream.

In the following table is summarized all the major pieces of process equipment necessary for operation of the ion exchange - adsorption waste water purification process. It is to be recalled that these specifications are only of a preliminary nature based on data extracted from the literature and may require modification upon obtaining actual experimental data.

PROCESS EQUIPMENT SPECIFICATIONS

1. Ion Exchange Column
   No. required: Three
   Type: Carbon steel, vertical vessel
   Diameter: 3 ft.
   Height: 8 ft., 7 ft. bed height
   Wall thickness: 3/16"
   Charge: 32 ft.^{3} Duolite C3
            17.5 ft.^{3} Amberlite IRA 402

2. Ion Exchanger Influent Pump
   Type: Cast iron, centrifugal
   Horsepower: ¼ H.P.
   Flow rate: 0.15 GPM

3. Activated Charcoal Adsorber
   Type: Carbon steel, vertical vessel
   Diameter: 2 ft.
   Height: 6.5 ft.
   Wall thickness: 3/16"
   Charge: 500 lb. activated charcoal

A process flow diagram for the ion exchange-adsorption process is given in Figure 8. Due to the relatively large dimensions of the ion exchange columns a skid mounted unit may not be practical. However, the individual pieces may be grouped together such that the approximate overall dimensions of the unit will be 7 ft. wide by 7 ft. long by 8 ft. high. The unit will require less than 0.2KW for pumping. It could be operated with a hand pump in the event of electrical failure. The entire unit including resin would weight approximately 10,800 lbs. and is estimated to cost $8,450 including erection.

FROM
FILTRATION

PUMP

MIXED BED
ION EXCHANGE
COLUMNS

ACTIVATED
CHARCOAL
ADSORBER

TO FINAL
TREATMENT

ION EXCHANGE-
ADSORPTION
PROCESS
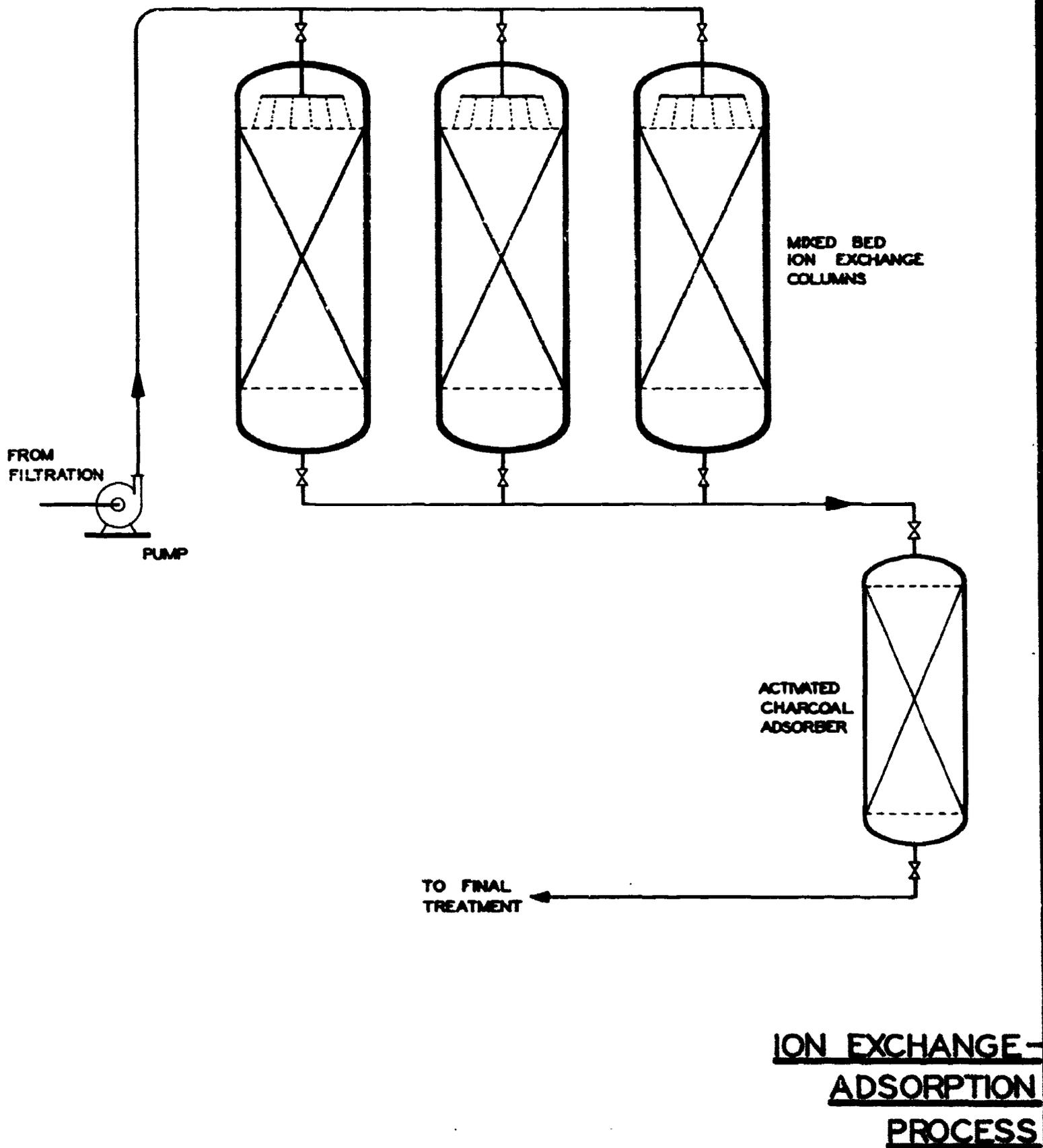
FIGURE 8

3. Evaporation Process

Based upon the discussion above, it was concluded that evaporation with final product cleanup is a suitable process for producing potable water from shelter wastes.

The specific scheme considered to be the most suitable is a forced circulation evaporator using vapor compression operating at atmospheric pressure.

A process flow diagram of this equipment is given in Figure 9. The filtered wastes to be treated are pumped through the preheater, H-1, at a rate set on rotameter R-1 to match the water production rate indicated on R-2. Wastes combine with the circulating stream and are heated in H-2 to 220°F. Flashing of the liquid occurs in vessel C-1 which is 5 ft. above H-2. Blowdown is removed manually through V-2 at 1 or 2 hour intervals. P-3, which runs off the same motor as P-1 and P-2, compresses the flashed vapors to 28.8 psia sending them to the steam side of H-2. Saturated condensate at 248°F is released from H-2 at a constant rate by the steam trap. The condensate heats incoming waste in H-1 and is collected in tank C-2 while C-3 is emptying into the cleanup system. If, when C-2 is full, its content is within acceptable color limits, it is sent through the cleanup system. If the color is too deep, it is allowed to drain back into the waste storage system for reprocessing.

In preparing the process design for this equipment, it was necessary to estimate certain physical properties of the solution as detailed information could not be found in the literature. The basis used is discussed in the appendix(A-8).

The product from the distillation unit will not by itself produce a suitable product. It has been shown that water recovered from human wastes by evaporation will contain traces of the materials in the waste plus some formed by thermal decomposition of those original materials (R-88,89,61,79,48,64). Since, however, vapor compression evaporation will heat all of the product water to 340°F when in the vapor state it is assumed that the water issuing from the recovery unit will be free from living bacteria.

The contamination which occurs is expected to consist chiefly of: chlorides and sulfates; sodium, potassium, magnesium and calcium; urea and amino acids; phenol; ammonia; and color bodies.

Although conclusive experimental evidence is not available, the information that is available plus industrial evaporation experienced indicates that the amount of contamination will vary with the vigor of the boiling. If the bubbling is excessive, and/or if foaming occurs, then equipment not designed for entrainment removal will most definitely produce water high in contamination.

If, however, the boiling is gentle and the flash chamber is large enough to allow entrained materials to settle out, then it may be assumed that the product contamination will be low. This is the present circumstance. In any case it is not safe to assume that the contamination will be lower than that in the best experimental work done at atmospheric pressure. This was the work of Zeff and Bambenek (R-87) whose results are listed below:

Odor	NH_3
Color	None
pH	9.6*
Total Solids	24 ppm
Cl^-	None
SO_4	None

* This corresponds to 0.7 ppm NH_3.

It is felt that in order to handly any unusual or emergency conditions the final cleanup system should be able to remove 50 ppm ammonia, 50 ppm solids, and any nitrates formed along the way.

Nitric acid is produced from ammonia commercially by oxidation in air at one atmosphere and 1600°F over a platinum -
- 10% rhodium catalyst. Okomoto, Miller, Reynolds and Konikoff (R-61, 54) have adapted this process for the purification of the vapor resulting from the vacuum distillation of urine and wash water. The results were very good. However, the catalyst had to be maintained at 2300°F in order to achieve the desired purification: 0.1 ppm NH_3, 6.8 pH, and no odor. Why the oxidized ammonia did not show up as nitrate or nitrate was not discussed.

In purifying 1 gallon per hour, 2.3 KW was required to maintain the catalyst at 2300°F. This is more energy than the whole vapor compression system, pumps and all, will require for purifying 8.5 gallons per hour. It is felt that catalyst heat requirements could be reduced considerably if efficient
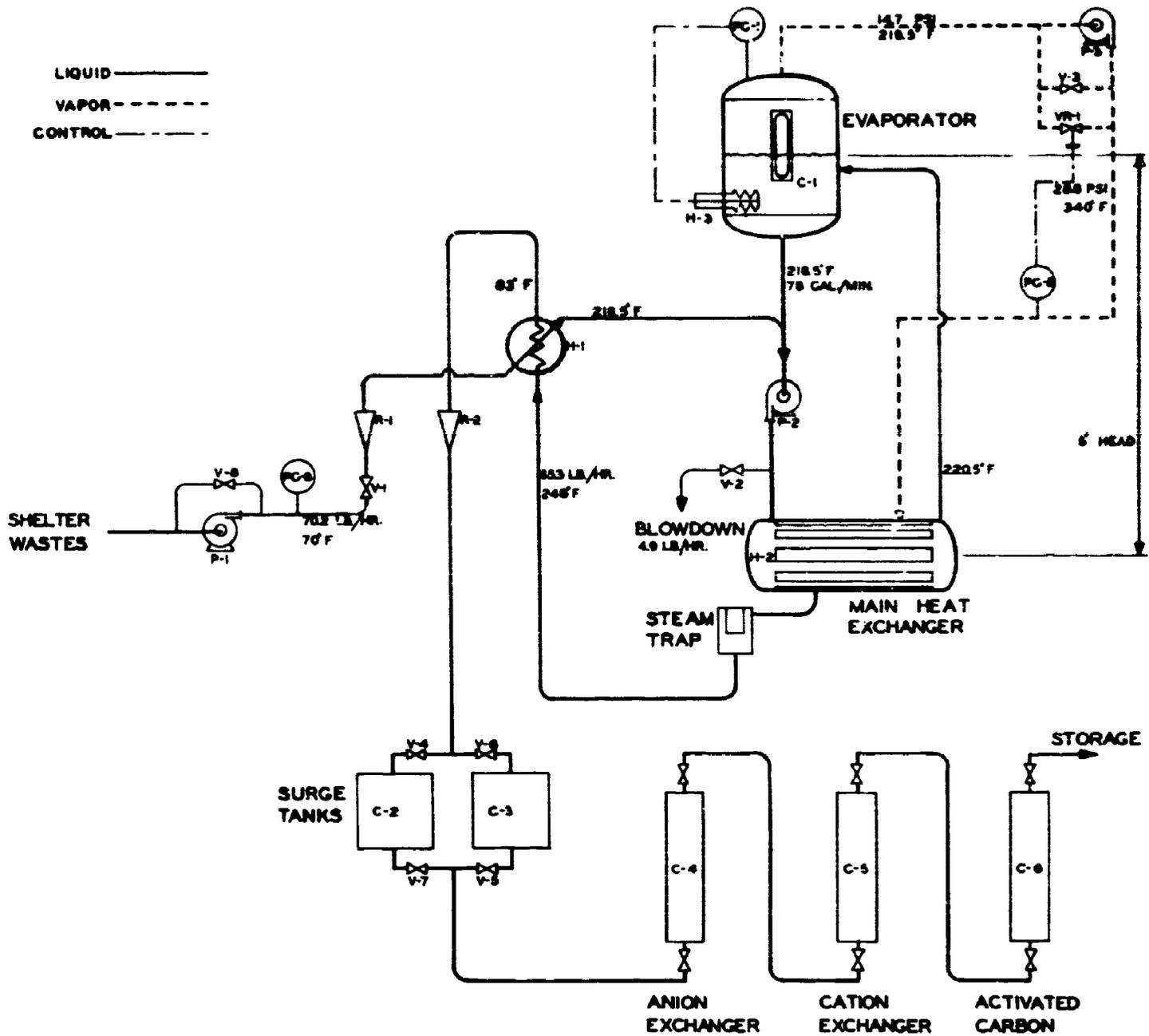
VAPOR COMPRESSION
EVAPORATION PROCESS

FIGURE 9

heat exchange were provided between the gases coming into the oxidizer and the gases leaving the oxidizer. In view of the great amount of energy to be transferred, however, and the temperatures to which the gas must be raised, a large, expensive (possibly constructed of titanium) heat exchanger would be necessary.

Based upon the catalyst requirements for the experimental unit, it was estimated that 1.9 Kgm of catalyst would be required for a unit large enough to handle the wastes from 250 people. The estimated cost of the catalyst alone is $7200.

Due to the high temperature required, selection of suitable materials of construction will be a problem. This, along with relatively high power consumption and high cost suggested that a different final purification process would be in order.

The removal of the last traces of ammonia, nitrates, and other dissolved solids from water is quite feasible using a combined, cation exchange resin, for the ammonia, anion exchange resin for the nitrates, and activated carbon treatment for whatever is left.

This method has, therefore, been chosen for the clean-up step associated with evaporative water recovery.

The material requirements are:

50 ppm NH_3 - 0.8 ft.^{3} Amberlite IRC-50 resin
(2-0.4 ft.^{3} units, - one active, one spare)

Traces of Nitrate - 0.8 ft.^{3}
(2-0.4 ft.^{3} units, - one active, one spare)

50 ppm dissolved solids - 2 ft.^{3} Darco - 60 activated carbon
(5-0.4 ft.^{3} units, - two active, 3 spare)

General specifications for the equipment for this unit are listed below:

C-1 Flash Chamber
  Body: Sch 20, 12" Seamless steel pipe, 18" long
  Heads: Top - 125 lbs., 12" forged steel blind
              flanges
           Bottom - 12" lightweight weldcap
  12 $\frac{1}{4}$" Pad type reflex gage on body

H-1 Preheater
  46 feet of 20 gage $\frac{1}{4}$" OD steel tubing wound with
  a $\frac{1}{2}$" pitch. 4" pipe
  1-$\frac{1}{2}$ ft. long

  Body: 6" Sch 10 steel pipe,
           1$\frac{1}{2}$" ft. long closed at one end by a welded
              plate
           125 lb. flanges on other end

H-2 Main Heat Exchanger
  Tubes: 13 1" OD x 16 ga. steel, 1$\frac{1}{2}$" ft. long
  Tubesheets: Steel
  Body: 8" Sch 40 steel pipe 1$\frac{1}{2}$" ft. long
           125 lb. forged steel flanges on both ends

P-3 Compressor
  30 ACFM capacity, Reciprocating
    non-lubricated (carbon rings)

P-1 Feed Pump
  Type: Cast iron centrifugal
  Capacity: 8.5 GPM vs 15 psi

P-2 Circulating Pump
  Type: Cast iron, centrifugal
  Capacity: 78 GPM vs 4 psi

H-3 Start-up Heater
  Electrical immersion heater - 3KW capacity

Final Purification
  Cation units - 2 required
        4" Sch 40 steel pipe - 5 ft high each
        packed with 0.4 ft^3 Amberlite IRC-50

Anion units - 2 required
   4" Sch 40 steel pipe - 5 ft high each
   packed with 0.4 ft^3 Amberlite IRC-400
Charcoal units - 5 required
   4" Sch 40 steel pipe - 5 ft high each
   packed with 0.4 ft^3 Darco 60

1 lot of miscellaneous items such as pipe, valve, skid unit, gages, rotameters, motor

It has been estimated that this unit could be skid mounted into a unit 4' x 4' x 8' high. The estimated weight is 2200 lbs. The estimated cost of the unit is $6250.

The advantages of such a unit are:

1. Reasonably low power requirements.
2. Small size.
3. The capacity of the unit can be easily increased without making a proportionate increase in the size or cost.
4. The temperature of the product is raised to the point where sterilization of the water is assured.
5. The estimated cost of the unit does not appear to be excessive.

4.   Pre- and Post-Treatment

All of the basic processes discussed above constitute
only the central element of the complete collection, treatment
and purification system of the shelter. The complete system is
shown in Figure 11. It consists primarily of a method of col-
lecting wastes water, separation of solids from the liquid,
filteration, post-treatment and testing of the product water.
Regardless of the process selected, the above steps are a
necessary auxiliary common to any process.

a.   Filtration and Pre-Treatment:
If recovery of water from human wastes is to be
accomplished, the collection of that water and the separation
of the water from the feces, paper, etc. must be considered.

The conventional type of toilet cannot be used since
its water consumption is too high (5 gal. to flush). A type of
toilet which uses a maximum of 1 quart of water to flush is nec-
essary.

It would be preferable to separate the solids and the
water at the toilet rather than later in the process where the
separation becomes more difficult. A special type of toilet
for this separation is suggested as shown in Figure 10.

The toilet would have a screen device to retain solids
while liquid passes through. A hand operated lever would flip
the solids over into a separate compartment where they would be
chemically treated and stored or rejected to a sewer. A plate,
hinged to the screen would seal the storage chamber to reduce
odor.

This initial step is desirable because once the feces
becomes mixed with water and urine it tends to form a gelatinous
mass which yields its water only with great difficulty.

Waste water from toilets of the type described, wash
water and water from food preparation may be collected in a
sump or collection tank. Units for this purpose are available
which have non-clog duplex pumps and automatic electrical con-
trols.

It is recognized that 100% separation of liquids and
solids will not be achieved at the toilet. It is therefore
desirable to provide additional filtration before the water is
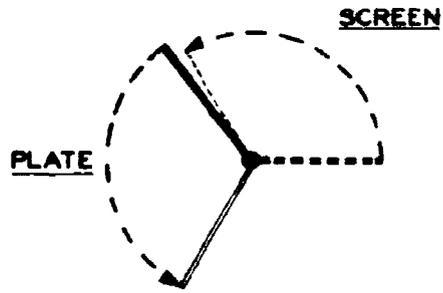
SCREEN

PLATE

PLATE & SCREEN WORK TOGETHER FROM
PIVOT POINT OPERATED BY LEVER.
SCREEN SEPARATES SOLIDS & LIQUIDS,
PLATE PROVIDES SEAL AGAINST ODOR.

SEAT

VENTS

WASH

FLOOR LEVEL

TRAP

PIT, SEWER, OR DISPOSAL UNIT
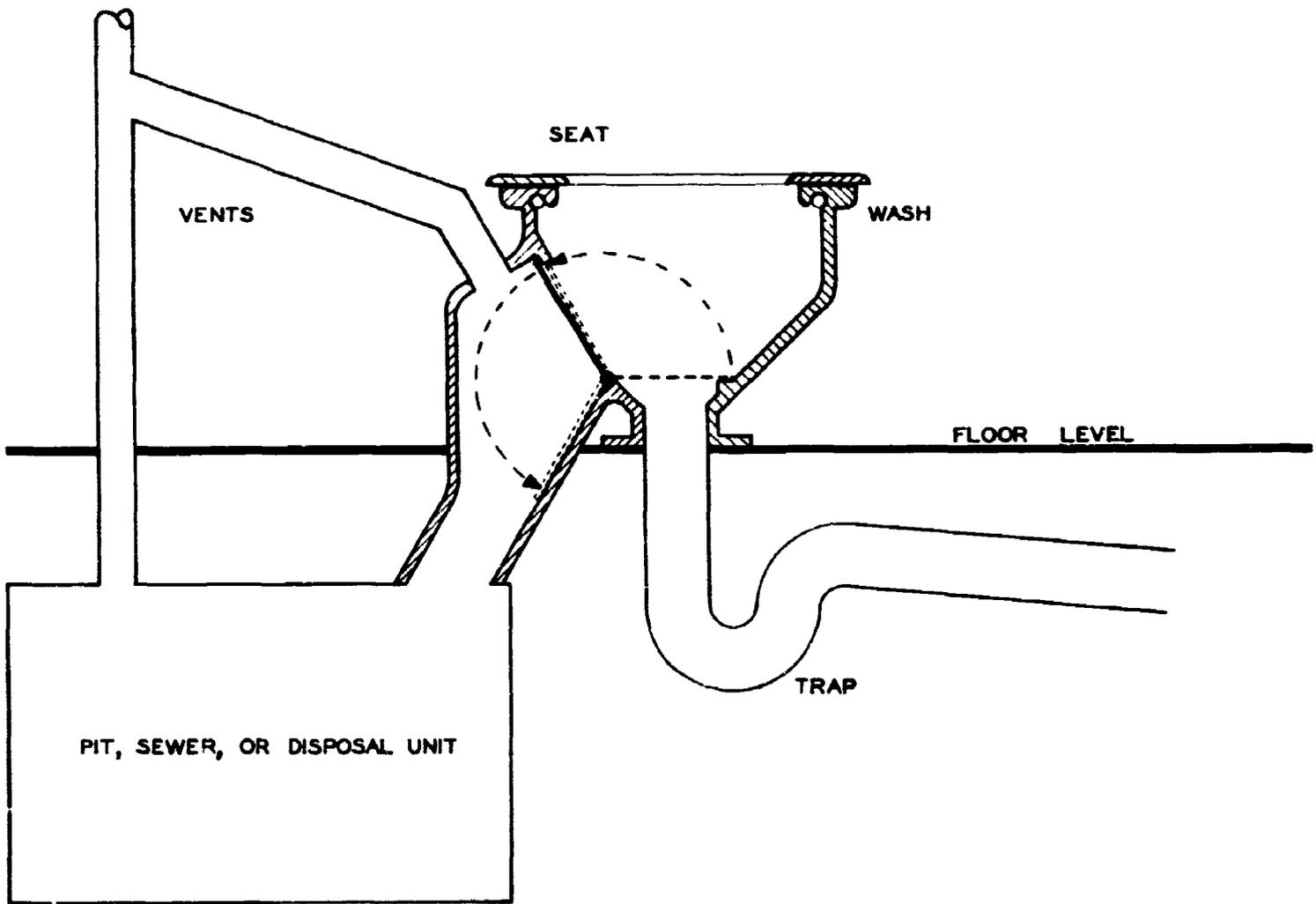
SHELTER TOILET FOR
THE SEPARATION OF
SOLIDS FROM LIQUID

FIGURE 10

WATER
RECOVERY
SYSTEM
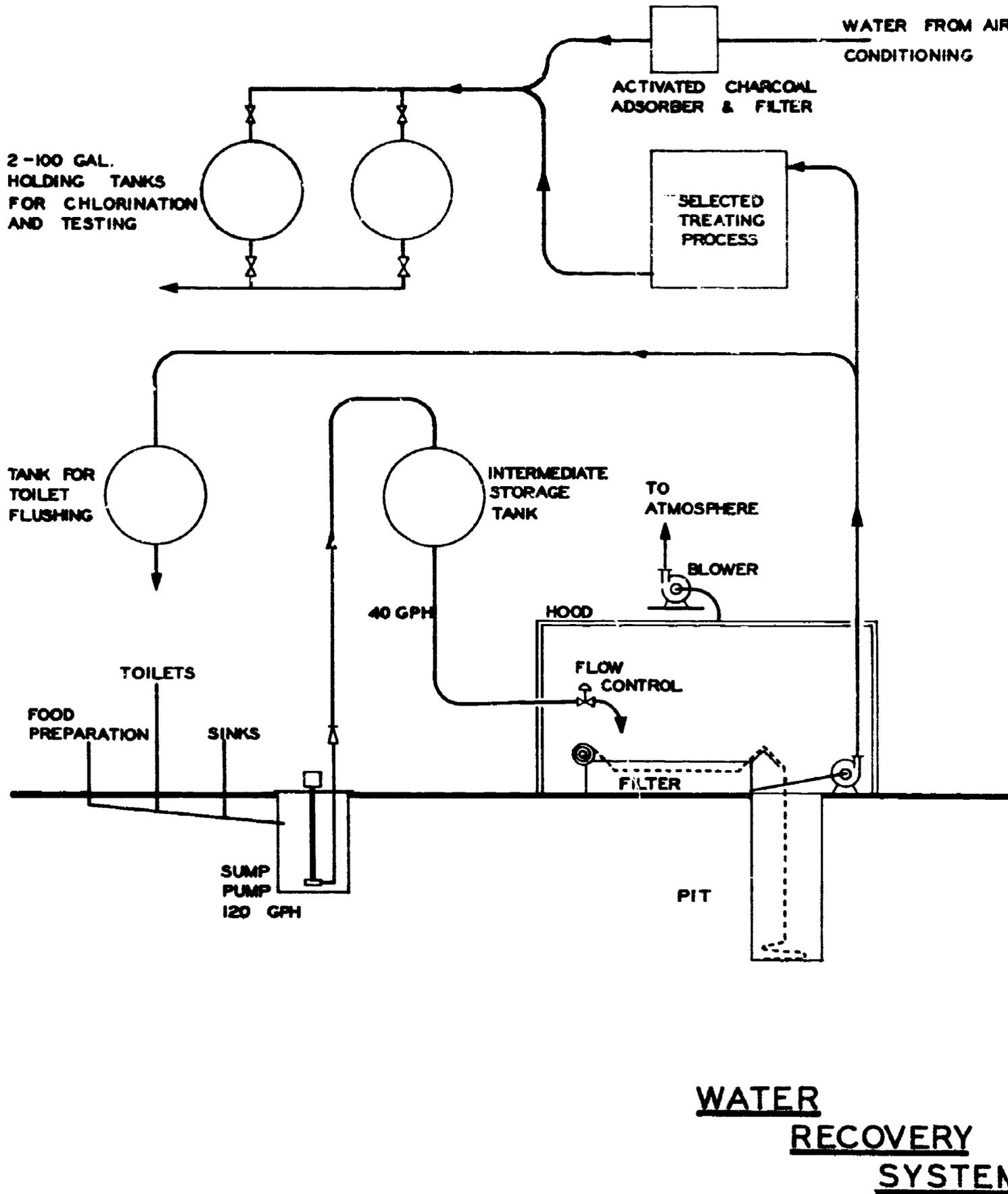
FIGURE 11

introduced into a processing unit.

It is recommended that no detergents be used in the shelter since their presence in the waste water would render it more difficult to process.

To accomplish separation of remaining solids from liquid a commercially available filter is proposed - the Delpark Filter (Commercial Filters Corp., Melrose, Mass). The unit consists of a roll of filter paper which lies on a mesh conveyor belt over a collector pan. The effluent is dumped on the filter paper which holds the solids and permits the water to collect below. As a cake is built up on the filter paper, it actuates a float which starts a motor, moving the mesh conveyor belt and exposing fresh filter paper surface. The used filter paper and sludge drop off the end of the machine.

It is proposed that a pit be constructed to receive the sludge and filter paper. Bags of lime should be available to scatter in the pit daily to hold down odor.

Tote boxes are available for use with this filter, but it is felt that the task of removing them, emptying outside the shelter etc. would be too unpleasant to contemplate. The unit should be provided with a hood and a small exhaust blower.

A study will be necessary to determine the best size unit and the best type of filter paper to use. A number of various sizes of filters and papers are available.

For a flow of 40 GPH the manufacturer recommended model No. 3066 AF with 5 sq.ft. of filter area, using Model WDE filter paper. This will eliminate all solids above the 30 micron range. The filter bed will build up a 3/4" coating of solids before indexing to a new filter surface. Each indexing operation, which is automatic, moves the filter paper 2½ ft forward.

The filter unit would be 40" wide by 90" long and be driven by a ¼ HP motor.

From the filter collection tank the effluent will be pumped into the processing unit. Part of the flow can be recirculated into a storage tank and used for toilet flushing.

b. Post Treatment:

Chlorine disinfection is probably the most commonly used method of killing bacteria. Since the number and type of bacteria present in the water will determine the amount of chlorination required, it is difficult to establish hard and fast rules without laboratory analysis.

Various forms of powders and tablets are available containing calcium hypochlorite such as high test hypochlorite, perchloron, halazone, etc. which contain from 50 to 70% available chlorine by weight. These products, which are readily soluble in water, are quite stable in storage.

As the product water shall have no more than 0.1 to 0.2 ppm of residual chlorine, the introduction of excessive chlorine in the final stage could become troublesome. It, therefore, may be desirable to pre-chlorinate the effluent from the filter stage before treatment begins. A correct balance between pre-chlorination and post-chlorination can be established only through laboratory and pilot plant procedures.

c. Testing:

The extent to which it will be necessary to test water produced from wastes has not been firmly established. It will be necessary to test the product water.

U. S. Department of Public Health standards for drinking water serve as a normal guide but new standards should be established for water recovered from urine which would set safe limits for ammonia and other possible contaminants that would result from processing of sewage wastes.

The necessity of safeguarding the health of the shelter occupants dictates the need for tests to determine the presence of harmful bacteria and chemicals.

Standard methods (R-6) and procedures for making all necessary purity tests are well established. The difficulty lies in the fact that these procedures can be carried out only in a well equipped laboratory by skilled technicians. It would be impractical to provide each shelter with all of the equipment necessary for such testing and with the personnel to make the necessary tests.

A minimum testing program, employing simple color comparison tests, using procedures capable of being learned from

instruction sheets by the average layman, is required. No complete set of simple tests is being marketed today. They could be easily assembled.

Tests for residual chlorine, pH, turbidity, color, sulfides and other chemicals can be made by adding solutions to water samples and comparing the sample color with color standards. The "Hellige Packet Comparator", Jackson Turbidimeter, Nessler Tube Comparator, and other apparatus of this nature could be used.

An electrical conductivity meter similar to the "Barnstead Distilled Water Purity Meter" could be calibrated to established limits (500 ppm total solids maximum) and perhaps eliminate the necessity for certain chemical determinations. This is an instrument that can be used by untrained personnel.

Bacteriological analysis of water samples is a difficult procedure at best. The maintenance of sterile testing conditions, cultivation of bacteriological samples, preparation of fresh culture media, counting and interpretation of test results, time required for culture incubation, and equipment required, all weigh heavily against undertaking such tests in a shelter.

A portable bacteriological water analysis unit has been developed at John Hopkins University by Dr. Charles E. Renn and is available as the "Sabro Bacteriological Water Analysis Unit". It employs a membrane filter technique nutriant solutions, incubation facilities and examination procedures. Although it does provide the best available means of portable bacteriological testing, it needs an experienced operator, whose presence in the shelter cannot be guaranteed.

Other desirable tests for phenol, urea, etc. are possible in a laboratory but not in a shelter.

It appears that under shelter conditions it would be better to rely on heavy chlorination to kill bacteria and to oxidize residual contaminants such as urea and phenols. Chlorination should be followed by active charcoal adsorption.

The absolute minimum tests that should be made on the product water is for pH, total solids, nitrates and residual chlorine. The amount of oxidizable organic materials present in the product water will be indicated only by testing for

residual chlorine at periodic intervals. When the residual chlorine remains constant over a time interval, it will be assumed that all oxidizable organics (including bacteria) have been oxidized.

The product water from the process equipment will be alternately discharged into one of two holding tanks. When one tank is full, the product purity may be tested. If the purity is satisfactory the tank may be discharged into the distribution system. If it is not suitable it may be re-processed.

It is estimated that the filter, storage tanks, pumps, and testing equipment would cost $3500 installed.

APPENDIX

TABLE 1

SPECIFICATIONS FOR RECOVERED WATER
(R-79)

1. **Bacteriological Quality:**

   The recovered water shall conform to the Public Health Service Drinking Water Standards, 1946. Publ. Health Rep. 61:371-384. U. S. Public Health Service.

   The bacteriological tests consist primarily of examining standard portions for organisms of the coliform group. Not more than 10% of the portions examined may show the presence of such organisms.

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2. **Physical and Chemical Characteristics:**

   The following maximum limits apply:

Turbidity	- 10 ppm (silica scale)	Copper	- 3.0 ppm
Color	- 20 ppm (cobalt scale)	Iron & Manganese	- 0.3 ppm
Taste	- not objectionable	Magnesium	-125 ppm
Odor	- not objectionable	Zinc	- 15 ppm
Lead	- 0.1 ppm	Chloride	-250 ppm
Fluoride	- 1.5 ppm	Sulphates	-250 ppm as SO_4
Arsenic	- 0.05 ppm		
Hexavalent chromium	- 0.05 ppm	Phenolic Compounds	- 0.001 ppm as phenol
		TOTAL SOLIDS	- 500 ppm

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3. **Emergency Conditions:**

   Under emergency conditions the following limits apply:

TOTAL SOLIDS	-	2000 ppm	Magnesium	- 500 ppm
Chlorides	-	1000 ppm	Magnesium Sulphate	-1000 ppm
Sulphates	-	750 ppm		

TABLE 2

EXCRETION PRODUCTS: MAN* (R-79)

	Constituent	Excreted in Urine
1.	Water, total	17,000 (7,800-27,500)
2.	Solids, total	860 (780-1000)
3.	Nitrogen, total	160 (112-268)
4.	Protein nitrogen	(0.0046-0.018)
5.	Amino acid nitrogen	2.5 (2.2-4.4)
6.	Ammonia nitrogen	9.2 (4.0-18.2)

Principal N Containing Constituents

7.	Creatinine	15 (12-25)
8.	Hippuric acid	8 (1-12)
9.	Urea	300 (215-500)
10.	Uric acid	9 (5-12)

Amino Acids

11.	Alanine, total	0.55
12.	Arginine, free	0.31 (0.15-0.5)
13.	Arginine, combined	0.1 (0.0-0.2)
14.	Arginine, total	0.4 (0.34-0.5)
15.	Aspartic acid, free	0.02 (0.014-0.26)
16.	Aspartic acid, combined	2.3 (1.2-3.7)
17.	Aspartic acid, total	2.32 (0.37-3.7)
18.	Citrulline, free	0.58 (0.26-0.7)
19.	Citrulline, total	(0.345-0.79)
20.	Cystine, free	1.3 (0.65-2.0)
21.	Cystine, total	(1.5-2.4)
22.	Glutamic acid, free	0.52 (0.0-1.07)
23.	Glutamic acid, combined	4.5 (1.0-10.0)
24.	Glutamic acid, total	5.27 (1.58-11.55)
25.	Glycine, free	10.1 (9.0-12.0)
26.	Glycine, total	(2.3-18.0)
27.	Histidine, free	2.7 (0.94-4.8)
28.	Histidine, combined	0.6 (0.07-1.8)
29.	Histidine, total	3.0 (0.98-6.59)
30.	Hydroxyproline, total	0.02
31.	Isoleucine, free	0.085 (0.03-0.3)

* Values are per kilogram of body weight per day and are expressed as milligrams unless otherwise noted. Values in parentheses are ranges.

TABLE 2 (Cont.)

	Constituent	Amino Acids Excreted in Urine
32.	Isoleucine, combined	0.2 (0.06-0.4)
33.	Isoleucine, total	0.3 (0.11-0.6)
34.	Leucine, free	0.14 (0.05-0.25)
35.	Leucine, combined	0.2 (0.05-0.4)
36.	Leucine, total	0.32 (0.20-0.52)
37.	Lysine, free	0.5 (0.25-1.13)
38.	Lysine, combined	0.6 (0.2-1.1)
39.	Lysine, total	1.04 (0.48-2.0)
40.	Methionine, free	0.11 (0.05-0.18)
41.	Methionine, combined	0.03
42.	Methionine, total	0.14 (0.12-0 17)
43.	Ornithine, free	0.15
44.	Phenylalanine, free	0.23 (0.1 5.-3)
45.	Phenylalanine, combined	0.1 (0.04-0.2)
46.	Phenylalanine, total	0.33 (0.21-0.6)
47.	Proline, free	0.12 (0.05-0.21)
48.	Proline, combined	0.5 (0.3-0.8)
49.	Proline, total	0.61 (0.33-0.9)
50.	Serine, free	0.4 (0.21-0.52)
51.	Serine, combined	0.25 (0.0-0.5)
52.	Serine, total	0.65 (0.35-1.4)
53.	Threonine, free	0.37 (0.17-0.62)
54.	Threonine, combined	0.4 (0.3-0.8)
55.	Threonine, total	0.77 (0.36-1.2)
56.	Tryptophan, free	0.37 (0.12-0.7)
57.	Tryptophan, combined	0.3 (0.009-0.4)
58.	Tryptophan, total	0.7 (0.23-1.3)
59.	Tyrosine, free	0.3 (0.17-0.55)
60.	Tyrosine, combined	0.5 (0.03-0.9)
61.	Tyrosine, total	0.79 (0.35-1.45)
62.	Valine, free	0.065 (0.04-0.125)
63.	Valine, combined	0.2 (0.09-0.4)
64.	Valine, total	0.3 (0.21-0.45)

	Electrolytes and Minor Minerals	
65.	Aluminum µg	(0.7-1.6)
66.	Arsenic µg	0.46 (0.0-1.15)
67.	Bromine µg	(12-110)
68.	Calcium µg	2900 (1100-4910)
69.	Chloride	115 (84-193)
70.	Cobalt µg	0.07 (0.05-0.12)

TABLE 2 (Cont.)

Electrolytes and Minor Minerals

	Constituent	Excreted in Urine
71.	Copper *mg*	2.38 (0.0-7.52)
72.	Fluoride *mg*	(6.7-100)
73.	Iodide *mg*	1.4 (0.2-2.13)
74.	Iron *mg*	0.7 (0.7-1.4)
75.	Lead *mg*	0.5 (0.06-2.1)
76.	Magnesium *mg*	1850 (950-4500)
77.	Manganese *mg*	(0.095-1.4)
78.	Mercury *mg*	(0.007-0.01)
79.	Nickel *mg*	2.1 (2.0-4.0)
80.	Nitrates *mg*	7140
81.	Phosphorus	15 (10-19)
82.	Potassium	34 (14-46)
83.	Selenium *mg*	1.0 (0.0-3.3)
84.	Silicon *mg*	108 (14-200)
85.	Silver *mg*	0.0
86.	Sodium	46 (38-91)
87.	Sulfur, total	16.5 (4-40)
88.	Sulfur, ethereal	1.0 (0.6-4.3)
89.	Sulfur, inorganic	12.5 (3.5-18.25)
90.	Sulfur, neutral	1.9 (1.0-3.0)
91.	Tin *mg*	(0.13-0.31)
92.	Zinc *mg*	18 (11-33)

Organic Acids

93.	Citric acid	(3-17)
94.	Creatine	2.9 (1.1-3.80)
95.	Guanidoacetic acid	(0.23-0.51)
96.	Formic acid	(0.42-2.0)
97.	Indoleacetic acid	(0.03-0.06)
98.	Lactic acid	40
99.	Oxalic acid	0.285 (0.23-0.5)
100.	Phenols	4.0 (0.19-6.6)

Miscellaneous Compounds

101.	Acetone bodies	0.285 (0.03-0.7)
102.	Allantoin	0.27 (0.18-0.36)
103.	Histamine	(0.2-1.0)
104.	Hydroxytyramine *mg*	(1.4-2.8)
105.	Imidazole derivatives	(1.35-9.4)
106.	Indican	0.14 (0.06-0.45)
107.	Methionine sulfoxide	(0.0-0.31)
108.	Purine bases	0.41 (0.18-0.92)

TABLE 2 (Cont.)

Miscellaneous Compounds

	Constituent	Excreted in Urine
109.	Reducing substances	(7-20)
110.	Sugars, as glucose	1.4
111.	Taurine	(0.105-0.2)
112.	Volatile acids, total ml of 0.1 N	0.0

TABLE 3

PROBABLE AMOUNTS OF MATERIALS REMOVED DAILY FROM
THE SKIN OF AN AVERAGE ADULT BY WASHING* (R-88)

Component	Milligrams/day
Free fatty acids	420
Cholesterol	75
Squalene and paraffins	19
Triglycerides	50
Waxes	22
Sodium	800
Potassium	300
Chlorine (Cl)	800
Calcium	10
Magnesium	1
Lactic acid	250
Glucose	50
Total amino acids	34
Uric acid	7
Urea	350
Creatinine	20

* These estimates are based upon average concentrations found in perspiration and on the average water loss through the skin in the absence of excessive perspiration.

TABLE 4

Relation of Specific Humidity to Relative Humidity

Specific Humidity (lb. H_2O/lb. air)	Dry Bulb Temperature °F						
	40	50	60	70	80	90	100
0.004	75	50	37	26	19	13	9
0.008	-	-	72	51	37	27	19
0.012	-	-	-	76	55	39	28
0.016	-	-	-	100	72	52	38
0.020	-	-	-	-	90	65	48

PHYSICAL PROPERTIES OF URINE CONCENTRATES

Human urine is a complex mixture of organic and inorganic chemicals the proportions of which vary from time to time as well as from person to person. In general, however, it contains 5% dissolved solids, the major constituent of which is urea. The next major constituents are the chlorides. See Table 2 for a detailed composition of urine.

In order to design an evaporator to remove the water from this mixture it is necessary to know its physical properties: viscosity, heat capacity, density, thermal conductivity, and vapor pressure, and how these properties vary with concentration and temperature. This information is non-existent; however, it has to be estimated from the properties of the individual constituents of urine. Since more than 50 individual constituents have been identified, an exact estimation is impossible. For the purposes of this work a simplified composition of urine has been assumed:

Urea and urea type materials	4.01 gms
Sodium Chloride	1.0 gms
Calcium Sulfate	0.06 gms
Water	100.00 gms

Based upon the assumed proportions of wash water to urine to be processed, the evaporator feed composition becomes:

Urea and urea type materials	1.83%
Sodium Chloride	0.47
Calcium Sulfate	0.026
Water	97.67
	100.00%

The concentration factor for evaporator operation is defined by:

$$\text{Concentration Factor} = \frac{100}{100 - \% \text{ water recovered}}$$

The evaporator blowdown (removed concentrate) composition therefore becomes:

Concentration Factor	% Water Removed	Urea Type Compounds gms/100 gms water	Sodium Chloride gms/100 gms water	Calcium Sulfate gms/100 gms water
1	0	1.83	0.474	0.0266
5	80.3	9.15	2.37	0.133
8	87.5	14.65	3.78	0.213
9	88.9	16.45	4.25	0.240
10	90.0	18.3	4.74	0.266
20	95.0	36.6	9.48	0.532
50	98.0	91.5	23.7	1.33
100	99.0	183.0	47.4	2.66

The total weight fraction solids is plotted vs concentration factor in Figure 12.

For the calculation of all physical properties except solubility, the concentration of the calcium sulfate may be neglected in comparison to that of urea and sodium chloride.

Data for the vapor pressure lowering of the urea-sodium chloride system are non-existent. The International Critical Tables, however, do give this data for sodium chloride over a wide range of temperatures. The data for urea are given only for 70 and 90°C. For the purposes of this study these data have been extrapolated to 110°C. The solution vapor pressure is then calculated by assuming that the vapor pressure lowerings for urea and sodium chloride are additive to give that for the evaporator concentrates.

The results of this calculation are displayed as vapor pressure vs concentration and temperature in Figure 13.

Physical properties of evaporator concentrate have been estimated. The estimated properties for viscosity, density, thermal conductivity and heat capacity in relation to water are given in Figure 14.

SOLIDS CONTENT OF EVAPORATOR CONCENTRATE

FIGURE 12

WEIGHT FRACTION SOLIDS

CONCENTRATION FACTOR

A-K
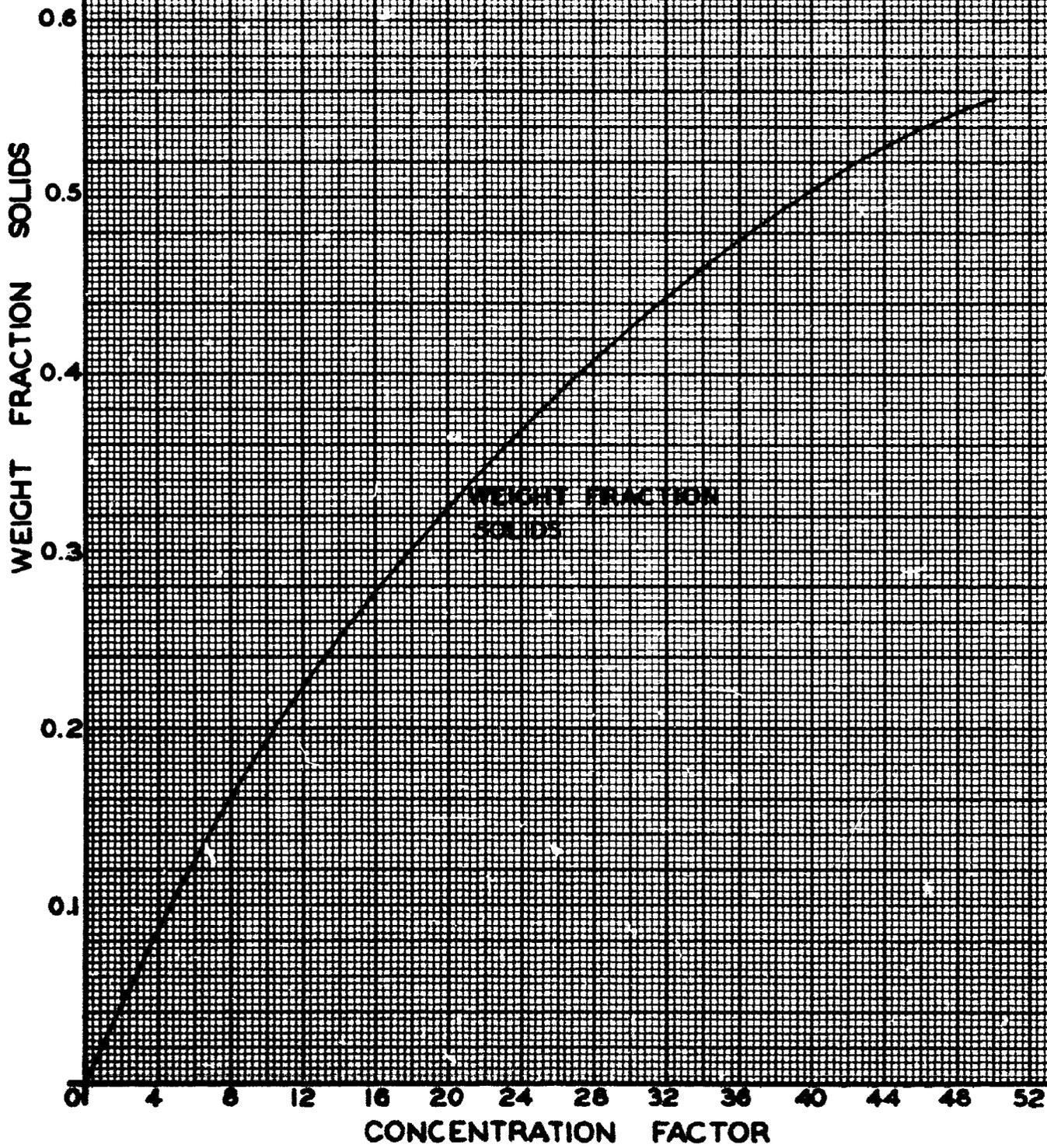
VAPOR PRESSURE OF EVAPORATOR CONCENTRATE
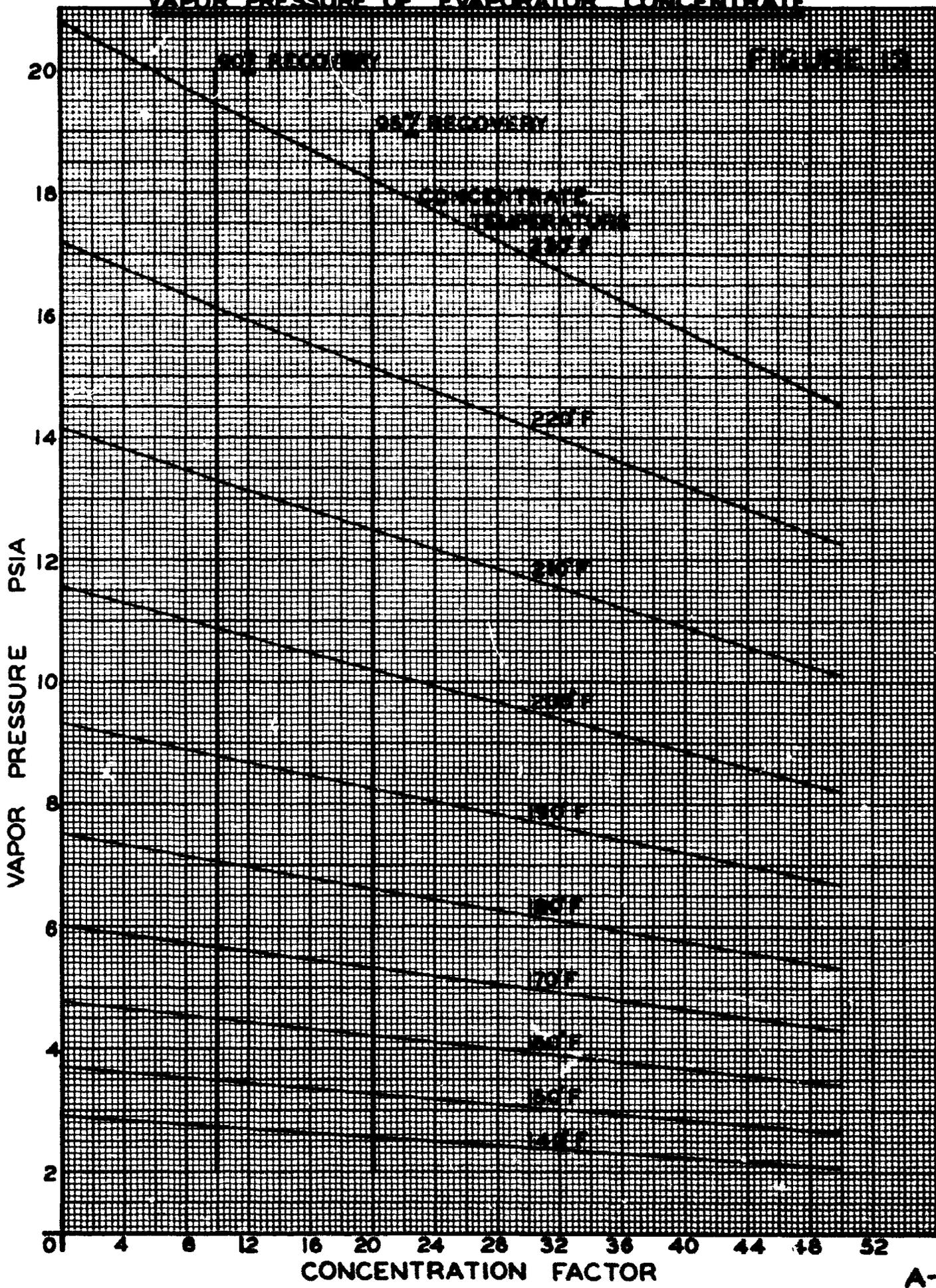
90% RECOVERY

95% RECOVERY

CONCENTRATE
TEMPERATURE
230°F

220°F

210°F

200°F

190°F

180°F

170°F

160°F

150°F

140°F

VAPOR PRESSURE PSIA

CONCENTRATION FACTOR

FIGURE

A-11

PHYSICAL PROPERTIES OF EVAPORATOR CONCENTRATE

FIGURE 14

A-
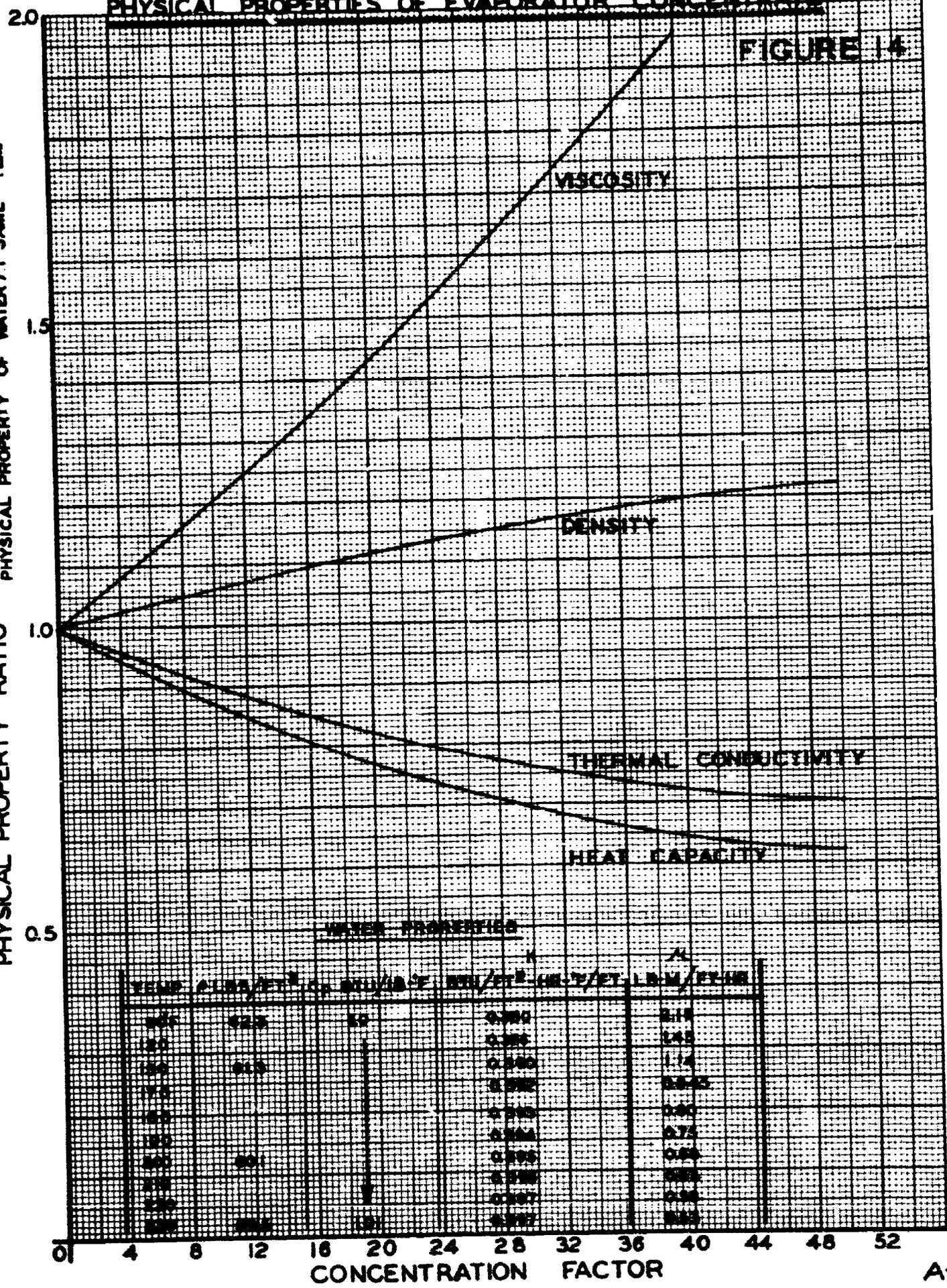
BIBLIOGRAPHY

An extensive literature search was made in the chemical literature to determine what work had been done in the particular field of interest of this report. The areas in which this search was made are:

1. Chemical Abstracts - 1950-1962

2. Engineering Index - 1946-1961

3. Industrial Arts Index - 1954-1962

4. American Water Works Association Journal - 1953-1962

5. Water and Sewage Works Index

6. University of Michigan - General Library Card Catalog

7. University of Michigan - Public Health Library

8. University of Michigan - Engineering Library

9. University of Michigan - Medical Library

10. Catalog of U. S. Government Publications

11. U. S. Superintendent of Documents

12. Armed Services Technical Information Agency

13. Office of Saline Water Reports

14. Miscellaneous handbooks and textbooks

In making this literature survey, more than 250 reports and articles were listed for review. All of these articles were reviewed for information. Many of the references had direct bearing on this study, others were of interest and some were of no interest. No attempt was made to have any foreign references translated.

Only those references which have specific bearing on this study are listed below.

1. Achenbach, P.R., (National Bureau of Standards) "Environ-
    mental Factors in a Family-Size Underground Shelter",
    Environmental Engineering in Protective Shelters, pp 69-
    120 N.R.S. (Feb. 1960).

2. Achenbach, P.R., "Design Requirements for Mechanical
    Systems in Protective Shelters", Heating, Piping & Air
    Conditioning, pp 73-80 (Feb. 1962).

3. Allen. F.C., "Control of Shelter Environment" (Office of
    Civil & Defense Mobilization) Environmental Engineering in
    Protective Shelters, pp 299-313, N.R.C. (Feb. 1960).

4. Altman, J.W., Smith, R.W., et. al. "Psychological and
    Social Adjustment in a Simulated Shelter" (Office of
    Civil & Defense Mobilization) OCDM (July, 1961).

5. American Chemical Society, Saline Water Conversion, Ad-
    vances in Chemistry Series No. 27, Washington,D.C. (1960).

6. American Public Health Assn., "Standard Methods for the
    Examination of Water, Sewage, and Industrial Wastes".

7. Amero, R.C., Moore, J.W. and Capell, R.G., Chemical Engi-
    neering Progress 43, No. 7, pp 349 (1947).

8. Armed Services Technical Information Agency, "Waste Water
    Recovery Systems" A report Bibliography Coverage 1953 to
    May, 1962, ASTIA ARB No. 10548, (May, 1962).

9. Calmon, C. and Kressman, T.R., "Ion Exchangers in Organic
    and Biochemistry", Interscience Publishers, New York,
    (1957).

10. Carsten, M., Journal American Chemical Society 74, pp 5954,
    (1952).

11. Cheldelin, V.H. and Williams, R.J., Journal American
    Chemical Society 64, pp 1513, (1942).

12. Chemical and Engineering News, 37, No. 13, pp. 37. (March 30, 1959).

13. Cox, R. C., "Laboratory Control of Water Purification", Case-Shepperd-Mann Publ. Corp., N.Y.C. (1946).

14. Dodge, B. F., "Fresh Water from Saline Waters", American Scientist, 48, No. 4, pp. 476 (1960).

15. Dowex: "Ion Exchange", Dow Chemical Company, Midland, Michigan (1958).

16. Flosdorf, E. W., "Freeze Drying", Reinhold Publishers, (1949).

17. Fruton, J. S. and Simmonds, S., "General Biochemistry," J. W. Wiley and Sons, New York, p. 258 (1953).

18. Gates, A. S. "Submarine Atmospheric Control Problems and Methods" (Bureau of Ships, U. S. Navy) Environmental Engineering in Protective Shelters, pp. 174-196, N.R.C. (Feb., 1960).

19. Gregor, H. P., Advanced Water Treatment Symposium – U. S. Public Health Dept., – R. A. Taft Center. "Electrodialysis and Synthetic Adsorbents", (May 15, 1962).

20. Gross, W. E., "Preventing Contamination of Shelters by Chemical, Biological, and Radiological Weapons Systems" (Chemical Corps U. S. Army) Environmental Engineering in Protective Shelters pp. 251-274, N.R.C. (Feb., 1960).

21. Gustafson, P. and Smith, S. H., Jr. "Removal of Organic Contaminants from Air by Type BX Molecular Sieve" (Chemical Division, U. S. Naval Research Laboratory) OTS PB 171051 (Dec. 6, 1960).

22. Hawk, P. B., Oser, B. L. and Summerson, W. H., "Practical Physiological Chemistry", McGraw Hill (1954).

23. Hawkins, W. R., J. Aviation Medicine 29 , pp. 525 (1958).

24. Heiskell, R. H. "Environmental Studies of a 100-Man Shelter" (Naval Radiological Laboratory) Environmental Engineering in Protective Shelters, pp. 121-140, N.R.C. (Feb., 1960).

25. Herrington, L. P., "Biophysical Features of Human Thermal Responses". (Pierce Laboratory of Hygiene) Prog. Environmental Engineering in Protective Shelters, N.R.C. pp. 3-30 (Feb., 8-10, 1960).

26. Hickman, K. C. "Distillation as an Agent in Sewage Recycle", Seminar on Advanced Waste Treatment Research, Cincinnati, Ohio, (May 15-16, 1962).

27. Humphrey, A. E. and Deindoerfer, F. H., "Chemical Engineering Problems of Keeping Men Alive in Space Rockets", Chemical Engineering, Vol. 67, No. 8, pp. 183-186, (April 18, 1960).

28. Impagliazzo, A. M., "Distilling Plant Economy", Mechanical Engineering, 69, pp. 387-390 (1947).

29. Ionac Chemical Company, "Ionac CBR Water Purifier", Specificational and Instructional Sheets, (May 8, 1962).

30. Katz, W. E., "Advances in Electric Membrane Demineralization" Saline Water Conversion, Advances in Chemistry Series No. 27, p. 232 (1960).

31. Konikoff, J. J., "Space Flight Ecologies" (Space Science Laboratory, General Electric, Missile and Space Vehicles Dept.) ASTIA AD 268509 (Dec., 1961).

32. Konecci, E. B. and Wood, N. E. "Design of a Operational Ecological System", Douglas Aircraft Company Engineering Paper No. 861, (Nov. 1, 1959).

33. Kunin, R., "Ion Exchange Resins," J. W. Wiley and Sons, New York, (1958).

34. Lacy, W. J. and Lindsten, D. C., "Purification of Water Contaminated with Radioactive Material", ASTIA AD 14230 (Dec. 24, 1952).

35. Laidler, K. J. and Hoare, J. P., "Journal American Chemical Society 71", p. 2699 (1949).

36. Latham, Alan, Jr., "Compression Distillation", Mechanical Engineering, 68, pp. 221-224, (1946).

37. Letters on No. 36 to Mechanical Engineering, 68, pp. 743-745, (1946).

38. Letts, J. C., "Air Conditioning Deep Underground Installations", (Corps of Engineers, U. S. Army) Environmental Engineering in Protective Shelters, pp. 171-178, N.R.C. (Feb., 1960).

39. Leutz, H., "Test Results in Continuously Occupied Shelters" (Federal Housing Ministry, Germany) Ibid. 38, pp. 141-146.

40. Massey, E. E., "Canadian Experiments" (Defense Research Board, Canada) Environmental Engineering in Protective Shelters, pp. 213-218, N.R.C. (Feb., 1960).

41. Mason, E. A. and Kirkham, T. A., "Design of Electrodialysis Equipment", Chemical Engineering Progress Sym. Series 55, No. 24, pp. 173 (1959).

42. Mason, E. A. and Juda, W., "Application of Ion Exchange Membranes in Electrodialysis", Chemical Engineering Progress Sym. Series 55, No. 24, pp. 155 (1959).

43. McKelvey, J. G., Spiegler, K. S., and Wyllie, M. R., "Ultra Filtration Through Ion Exchange Membranes", Chemical Engineering Progress Sym. Series 55, No. 24, pp. 199 (1959).

44. McNeil, W. J., "Urine Evaporator" (Aero Medical Laboratory) ASTIA AD 29012, (Feb., 1954).

45. Metzler, D. F.,Culp, R. L.,et. al. "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas", Journal of the American Water Works Assoc., pp. 1021-1060, Reprint (Aug., 1958).

46. Miller, R. R. and Piatt, V. R., "The Present Status of Chemical Research in Atmosphere Purification and Control on Nuclear-Powered Submarines" (Chemistry Division, U. S. Naval Research Laboratory) OTS PB 161518 (April 21, 1960).

47. Morris, J. C. and Weber, W. J., Advanced Water Treatment Symposium-U. S. Public Health Dept.-R. A. Taft Center, "Adsorption for Removal of Biologically-Resistant Materials from Waste Water" (May 15, 1962).

48. National Research Council, Symposium on Saline Water Conversion, National Academy of Sciences, Washington, D.C. (1958).

49. New York University College of Engineering "The Engineering Biotechology of Handling Waste Resulting from a Closed Ecological System" Research Division, ASTIA AD 162277, (Feb. 1958).

50. Office of Civil Defense "Emergency Sanitation at Home" OCD (Sept. 1961).

51. Office of Civil Defen e "Fallout Shelter Surveys: Guide for Architects and Engineers,"NP 10-2, National Plan Appendix Series"III Space and Ventilation,"OCDM (1958).

52. Office of Civil Defense "IV Water Supply & Sanitation" Ibid 51.

53. Ostron, Thomas, R., "Radiological Decontamination of Food and Waste in Nuclear War", ASTIA AD 264822 (Sept. 1960).

54. Okamoto, A.H., Miller, R.A., Konikoff, J.J., "Instruction Manual for the G.E. Experimental Water Recovery Appartus" General Electric Company, Space Sciences Laboratory, King of Prussia, Pa.

55. Okamoto, A.H., and Konikoff, J.J., "Study of the Purification of Water from Biological Waste", General Electric Company Missile and Space Vehicle Dept., Philadelphia, Pa. ASTIA Report No. 274149, (Feb. 1960).

56. Peavy, B.A., "Available Heat Sinks for Protected Underground Installations" (National Bureau of Standards) Environmental Engineering in Protective Shelters, pp.237-250, N.R.C. (Feb. 1960).

57. Persson, A.B., "Experiments on Air Conditioning in Sealed Rock Shelters" (Defense Research Institute) Ibid pp. 147--170.

58. Pipes, W.O., "Waste Recovery System" (National Academy of Science, National Research Council) ASTIA AD 261193 (April, 1961).

59. Purcell, R.H., "British Experiments", Chie. Scient. Advisor, (British Home Office) Environmental Engineering in Protective Shelters, pp. 219-236, N.R.C. (Feb. 1960).

60. Reid, C.E. Proceeding of Symposium on Saline Water Conversion National Academy of Sciences, National Research Council Publication 568, (1957).

61. Reynolds, L.W. and Konikoff, J.J. "Study of the Purification of Water from Biological Waste" (NASA, Office of Life Sciences) ASTIA AD 248096 (Oct. 1960).

62. Schaffer, K.A. "A Concept of Triple Tolerance Limits Based on Chronic CO_2 Toxicity Studies", (U. S. Naval Medical Research Laboratory) Environmental Engineering in Protective Shelters, pp. 43-60. (Feb. 1960).

63. Seidell, D. "Solubilities of Inorganic and Metal Organic Compounds", Van Nostrand Company, Inc., New York (1960).

64. Sendroy, J. and Collison, H.A., "Potable Water Recycled from Human Urine" ASTIA AD 220837 (May 29, 1959).

65. Sendroy, J. and Collison, H.A., "Potable Water Recycled from Human Urine" Reprint from Aerospace Medicine Vol. 30, pp. 640-649 (Sept. 1959).

66. Sinek, J.R. "Heat Transfer in Falling Film Evaporators", PhD Dissertation, University of Michigan, (Sept. 1961).

67. Solzman, D.M., "Intergrated Systems Provides Mechanical, Electrical Service for Survival Shelters" Heating, Piping and Air Conditioning, pp. 119-124 (June, 1962).

68. Strope, W. E., Porteous, L.G. and Greig, A.L., "Specifications and Cost of a Standarized Series of Fallout Shelters" OTS PB 161973, (Oct. 6, 1959).

69. Teissier, Pierre "Atom Bomb Shelter" AEC-tr 3887, (Feb.1960).

70. Tiger, H.L., Sussman, S., et al "Desalting Sea Water... a Practical Chemical Method" (The Permutit Company, New York) Industrial and Engineering Chemistry Vol. 38, No. 11, pp. 1130-1137 (1946).

71. U.S. Army, Chief of Engineers, "Removal of Radioactive Materials from Contaminated Water by Thermocompression Distillation" (Wahoo II) ASTIA AD 28983, (Aug. 28, 1953).

72. U.S. Department of the Interior, Office of Saline Water, Report No. 7, (Nov. 1955).

73. U.S. Department of the Interior, Office of Saline Water, Report No. 10, (Aug. 1956).

74. U.S. Department of the Interior, Office of Saline Water, Report No. 23 (Jan. 1959).

75. U.S. Department of the Interior, Office of Saline Water, Saline Water Conversion Report, (Jan. 1961).

76. U.S. Naval Air Material Center "Environmental Requirements of Sealed Cabins for Space and Orbital Flights - Space Age Utilization of Recycled Metabolic Waste" Air Crew Equipment Laboratory, ASTIA AD 262556, (Sept. 1, 1961).

77. U.S. Naval Engineering Laboratory "Lithium Hydroxide Canister for Personnel Shelters" OTS AD 258875B, (June 13, 1961).

78. Vernon, J.A. "The Family Shelter" (Princeton University) Environmental Engineering in Protective Shelters, pp. 61-68, N.R.C. (Feb. 1960).

79. Wallman, H. and Barnett, S.M., "Water Recovery System (Multi-Variable)" ASTIA AD 243574 (March, 1960).

80. Wilson, Carl "Forest Fire Research Helps Develop Shelter Criteria" (U.S. Forest Service) Environmental Engineering in Protective Shelters, pp. 275-298, N.R.C. (Feb. 1960).

81. Wollner, H.J., Kahn, P.A. and Kumin, V.M. "Recovery Clarification and Reuse of Laundry Waste Water" (American Conditioning House, Inc.) Reprint.

82. Wood, T., Biochemistry J., 62, 611 (1956).

83. Wood, T., Nature, 186 pp. 634 (May 21, 1960).

84. Worf, Douglas "Environmental Control of Manned Space Capsules" (National Aeronautics and Space Administration) Environmental Engineering in Protective Shelters, pp. 197-212, N.R.C. (Feb. 1960).

85. Wright, F.X., "Self-Contained Water Supply and Cooling Unit" U.S. Patent No. 3,305,418 (May 22, 1962).

86. Yaglow, C.P. "Tolerance Limits of People for Cold, Heat, and Humidity in Underground Shelters", Harvard School of Public Health, Environmental Engineering in Protective Shelters, pp. 31-42, N.R C. (Feb. 1960).

87. Zeff, J.D. and Bambenek, R.A., "Development of a Unit for Recovery of Water and Disposal or Storage of Solids from Human Waste Part I - The Study Phase", ASTIA AD 234007, (Nov. 1959).

88. Zeff, J.D., Bambenek. R.A., and Des Jardins, J., "Waste Collection Unit for a Space Vehicle", (American Machine and Foundry Co.) ASTIA AD 243508 (May, 1960).

89. Zeff, J.D. and Bambenek, R.A. "System for Recovery of Water from Urine. Part II - Design, Fabrication, and Testing of the Prototype System" (American Machine and Foundry Co.) ASTIA 246336, (Aug. 1960).

90. Zimmermann, F.J. "Waste Disposal Method" U. S. Patent No 2,665,249 (Jan. 5, 1954).

91. Zimmermann, F.J. "New Waste Disposal Process" Chemical Engineering (Aug. 25, 1958).