EVALUATION OF HEALTH EFFECTS DATA ON THE REUSE OF SHOWER AND LAUNDRY WATERS BY FIELD ARMY UNITS

FINAL REPORT

APRIL 1979

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Health effects of short-term shower and laundry water reuse have been assessed in a four task program covering: wastewater composition, engineering evaluation of treatability, toxicity, and previous Army-sponsored research. Available data do not indicate that water reuse would result in toxic effects. It is concluded that the next phase of work to consider is human clinical trials. To assess the reasonablenss of such trials, it is recommended that consideration be given to the preparation of five documents, one each on the following topics: the need for and benefits of short-term shower and laundry water reuse, acceptable risks

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associated with short-term shower and laundry water reuse in a combat situation, acceptable risks for human test subjects in clinical trials of water reuse, a protocol for animal studies designed to assess the possibility of human toxic responses to water reuse, and a protocol for human clinical trials of short-term shower and laundry water reuse.

EXECUTIVE SUMMARY

The health effects of short-term shower and laundry water reuse have been assessed by investigating wastewater composition, wastewater treatability, the toxicity of wastewater components, and previous Army-sponsored research. This has led to a consideration of other factors affecting reuse including esthetics and the engineering state-of-the-art for systems compatible with field Army operations. Finally, it has become apparent that health effects evaluations cannot be performed without considering details of the reuse scenario.

Composition of Shower and Laundry Wastewaters

The composition of shower and laundry wastewaters was estimated by determining the constitutents of cleansing and health care products. Information was obtained through telephone contacts, computerized data base searches, and assessment of books and printed reports.

Calculations of wastewater component concentrations were based on USAMBRDL-supplied lists of products present in shower and laundry wastewater and the concentration of each type after a single use of the water. For each of the product types noted, composition data were obtained for several types or brands of products. Constituent concentrations were calculated for each product, corresponding to product concentrations. The highest concentration of each constitutent was selected for each product type, and these were summed by product. Final concentrations of constituents in wastewaters were calculated for shower wastewaters, laundry wastewaters, and a mixture of the two. Ingredient concentrations for laundry, shower, and mixed (55% shower, 45% laundry) wastewater also are given.

Engineering Evaluation

On the basis of a literature survey and relevant experience, five representative wastewater treatment systems were evaluated which appeared to be particularly promising for treating shower and laundry wastewaters generated by field Army units. The relative system performances at 70-90% conversion were estimated from calculations of the concentrations of nine problem contaminants present in treated wastewater which had been recycled an infinite number of times. The problem contaminants consisted of six organic chemicals rank-ordered from the list of total contaminants based on high concentration, low removal efficiency, and toxicity; and three inorganic chemicals selected from the list of total contaminants based on high concentration. Of the five systems evaluated, the system producing the highest purity water was a system which included an ultrafiltration unit followed by a reverse osmosis unit. A system which may be more practical for the given application was dilution, filtration and disinfection.

Five wastewater treatment systems were selected for evaluation:

- ultrafiltration, reverse osmosis
- ultrafiltration
- activated carbon adsorption, ion exchange
- ERDLator
- dilution

Two of the systems were chosen on the premise that a system consisting of processes for removing suspended solids followed by processes for removing dissolved solutes would be required for reliable system performance. The other three systems were selected on the premise that satisfactory performance would be obtained by employing only processes typically used for removing suspended solids. A final step in each of the systems would be some form of disinfection (e.g., hypochlorination, ultraviolet radiation, ozonation, UV-activated ozonation). Certain methods of disinfection (e.g., hypochlorination) have the added advantage of destroying problem chemical contaminants (viz., urea).

An objective of this program is to determine the effectiveness of the representative wastewater treatment systems for removing specific chemical contaminants from wastewaters. Data are available on the specific removal efficiencies for unit processes designed for removing dissolved solids (e.g., IX, ACA, and RO). However, no such chemical-specific data are available for unit processes generally employed for removing suspended solids (e.g., DEF, UF, and DAF), and these data are required for evaluating the wastewater treatment systems. For this reason, an approach was developed for estimating removal efficiencies which was based on comparing removal efficiencies for a suspended solids removal process to those for a dissolved solids removal process. The removal efficiencies which were compared generally were total organic carbon and total dissolved solds. The removal efficiency for a suspended solids removal process was expressed in terms of a percentage of the removal efficiency for a dissolved solids removal process. This percentage was then applied on an individual chemical basis to supply the data required for the evaluation of each system.

Toxicity Evaluation and Previous Army Testing

Toxicity data were sought for each of the compounds predicted to be present in shower or laundry waters. Oral, dermal and ocular toxicity were considered. The factors most strongly influencing the toxicity of particular compounds were assumed to be: inherent chemical reactivity, chemical formulation (e.g., powder, suspension, emulsion, solution), transformation products (e.g., products of chlorination), concentration, and exposure time. References listed in the bibliography were consulted for toxicity data. Data were assembled on a compound-by-compound basis. Notations of test compound concentration, test duration, etc. were made.

No protocol has been established specifically for the assessment of health effects due to shower and laundry water reuse. The present assessment is based on the following assumptions:

(1) toxicity data are required for compounds at concentrations expected in treated, recycled wastewaters.

(2) ocular and dermal exposures of several minutes duration are to be expected,

(3) oral exposures will be minimal, amounting to only a few milliliters of recycled water per shower.

The toxicity data for individual wastewater components did not indicate that human toxic responses would be expected from short-term shower or laundry water reuse by field Army units. However, at least some data were lacking for 36 compounds. Previous Army-sponsored toxicology testing of shower and laundry wastewaters gives further evidence that no toxic responses are expected for the wastewaters.

Summary and Conclusions

In attempting to assess health effects of water reuse, we have learned that at least under certain conditions, limited water reuse is likely to benefit the soldier. Benefits of water reuse can be maximized if, for a carefully defined reuse scenario, we delineate the basis for health effects criteria.

Of all possible kinds of water reuse, consideration has been limited to short-term shower and laundry water reuse by field Army units. These are high-volume uses under field Army conditions which can be readily segregated from other uses. Both the wastewaters and the users of the recycled water are well-defined and subject to a degree of control which will minimize health impacts. One need worry neither about septic wastes nor about unusually sensitive water users (e.g., infants, elderly persons, or medical patients). Concern may be focused on possible acute effects, since exposure would be too short to produce chronic effects.

Results achieved to date indicate that it should be possible to treat and reuse shower and laundry waters without any significant health effects. Literature studies have uncovered no data to indicate adverse health effects. Animal and human (skin patch) tests of wastewater and wastewater concentrates indicate no adverse health effects (oral, dermal or ocular) at concentrations up to several times those expected in treated, recycled water.

Since the present evaluation suggests there will be no adverse effects, what further tests are required to establish the safety, without question, of shower and laundry water reuse by field Army units? If the answer is to be obtained under conditions other than battlefield conditions, human clinical trials must be performed.

U.S. Army Medical Research and Development Command Regulation No. 70-25, "Use of Human Subjects in Research Development, Test, and Evaluation," establishes procedures for conduct of human clinical trials. This regulation specifies three conditions which must be satisfied before and during the conduct of human clinical trials: adequate scientific justification, adoption of appropriate measures to minimize risk, and adoption of administrative review procedures.

It is recommended that consideration be given to:

(1) Preparation of an assessment of the benefits of short-term shower and laundry water reuse by field Army units. This assessment should be phrased in terms meaningful to members of the U. S. Army Medical Research and Development Command and other Army officials; to members of a human use Committee as defined in USAMRDC Regulation 70-25, paragraph 2-4-1; and to prospective human test subjects for a clinical trial. At least preliminary estimates of acceptable engineering configurations and performance characteristics of suitable wastewater treatment systems should be specified, including a target value for the extent of water recycle.

(2) Preparation of an assessment of acceptable risks associated with short-term shower and laundry water reuse in a combat situation. Topics covered might include digestive tract irritation due to accidental ingestion, skin irritation, and eye irritation.

(3) Preparation of criteria defining acceptable risks for human test subjects in clinical trials of water reuse. Acceptable (and unacceptable) toxic symptoms should be defined together with the minimum professional qualifications to be possessed by the person or persons responsible for evaluation of toxic responses in human test subjects.

(4) Preparation of a protocol for animal studies designed to assess the possibility of human toxic response to shower and laundry water reuse. The protocol must specify the composition of products to be used during showering or laundering, the wastewater treatment system to be used and its mode of operation, chemical analysis to be performed, and responses to be monitored. It should also specify criteria for test adequacy, i.e., criteria for cessation of animal tests and for consideration of human clinical trials.

(5) Preparation of a protocol for human clinical trials of short-term shower and laundry water reuse. It is assumed that human clinical trials would be proposed only after assessments have been completed for: benefits to be expected, acceptable risks in a combat situation, acceptable risks for human test subjects, and likely risks for test subjects as projected from animal studies. The human use protocol should then focus on early detection and treatment of toxic symptoms which might arise during the course of the clinical trials.

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OBJECTIVE

The objective of the present program has been to evaluate health effects related to the reuse of shower and laundry waters by field Army units. Walden Division of Abcor, Incorporated has performed this evaluation in a four task program.

(1) A list of ingredients used in shower and laundry operation has been prepared which includes a range of products of each type.

(2) An engineering evaluation has been made of the treatability of each ingredient by five different wastewater treatment systems.

(3) Ocular, dermal and oral toxicity data availability and adequacy were assessed for each ingredient.

(4) Previous Army-sponsored studies related to shower and laundry water reuse have been assessed.

APPROACH

The health effects of short-term shower and laundry water reuse have been assessed by investigating wastewater composition, wastewater treatability, the toxicity of wastewater components, and previous Army-sponsored research. This has led to a consideration of other factors affecting reuse including esthetics and the engineering state-of-the-art for systems compatible with field Army operations. Finally, it has become apparent that health effects evaluations cannot be performed without considering details of the reuse scenario.

TASK I - COMPOSITION OF SHOWER AND LAUNDRY WASTEWATERS

The composition of shower and laundry wastewaters was estimated by determining the constitutents of cleansing and health care products. Information was obtained through telephone contacts, computerized data base searches, and assessment of books and printed reports.

Calculations of wastewater component concentrations were based on USAMBRDL-supplied lists (Tables 1 and 2) of products present in shower and laundry wastewater and the concentration of each type after a single use of the water. For each of the product types noted, composition data were obtained for several types or brands of products. Constituent concentrations were calculated for each product, corresponding to product concentrations. The highest concentration of each constitutent was selected for each product type, and these were summed by product. Final concentrations of constituents in wastewaters were calculated for shower wastewaters, laundry wastewaters, and a mixture of the two. Ingredient concentrations for laundry, shower, and mixed (55% shower, 45% laundry) wastewater are given in Tables 5, 6, and 7.

Product List

Lists of products present in shower and laundry wastewaters were supplied by the U.S. Army Medical Bioengineering Research and Development Laboratory. The concentrations of each product after a single use are indicated in Tables 1 and 2. In a previous study by Tardiff and Mullaney, a single brand of each product was chosen and the composition of each of these products was used to estimate the compositions of a typical wastewater. In the present study, the compositions of five brands of each product were sought and used to predict a composition range for shower wastewater, laundry wastewater, and a mixed wastewater. The objective has been to include a broad range of product brands in the health effects assessment.

Literature Search: Telephone Contracts

Several agencies and organizations were contacted by telephone and requested to supply any information they might have regarding shower or laundry product compositions and health effects. Details of these contacts are provided in Tables 3 and 4.

TABLE 1

SHOWER WASTEWATER PRODUCTS

Product	Concentration mg/l
Shower Cleaner	100-220
Salt	60-180
Soap, Deodorant	50-150
Hair Oil	25-150
Soil (Kaolinite)	20-50
Talc	20-50
Hair Shampoo	10-50
DEET	1-20
Epithelium	18
Lactic Acid	5
Urea	1-3
Toothpaste	2
Hair	2
Potassium	1.5
Shaving Preps	1
Disinfectant	1
Lotions	1
Mouthwash	1
Deodorant	1
Suntan Preps	1

TABLE 2

LAUNDRY WASTEWATER PRODUCTS

Product	Concentration mg/l
Sodium Carbonate	499
Detergent Type I	433
Detergent Type II	172
Vegetable Oil	166
Kaolinite Clay	133
Sour (Downey)	116
Urea	13
DEET	12

TABLE 3

SUCCESSFUL TELEPHONE CONTACTS

No.	Organization	Person	Information
1.	Food and Drug Administration (FDA) Division of Cosmetics Technology 200 C St., NW Washington, DC 20240	Dr. Kokoski (202) 472-5767	Suggested looking at a cosmetic text for formulation information: Recommended <u>CTFA Cosmetics Ingredient Dictionary</u>. 7/13/78.
		Dr. Earl Richardson (202) 245-1094	Works with voluntary cosmetic regulatory program. Informed Walden of a computer file containing 24,000 individual formulations. Sent list of 83 genral cosmetic categories. 7/13/78.
2.	Consumer Products Safety Commission (CPSC) 1750 K St., NW Washington, DC 20207	Mr. Van Seabaugh Division of Toxicology (202) 245-1445	Informed Walden of a detergent toxicity survey they prepared; he sent a copy of that report to Walden.
			Called concerning detergent report Walden had received. Requested composition data on detergent. Mr. Seabaugh indicated there may be a legality complication. Offered to send what information he could. 7/19/78.
3.	Soap & Detergent Association 475 Park Avenue South New York, NY 10016	Dr. Bowman Technical Director (212) 725-1262	Gave Walden direction in getting formulation information; laundry detergents: they can help. Sent data on laundry detergent composition for a range of concentrations. 7/17/78.

TABLE 3 (CONTINUED)

SUCCESSFUL TELEPHONE CONTACTS

No.	Organization	Person	Information
4.	Cosmetic, Toiletry & Fragance Association (CTFA) 1133 15th St., NW Washington, DC 20005	Ralph Wands Director of Cosmetic Ingredient Review (202) 331-0651	CTFA recently compiled a list of 189 top priority cosmetic ingredients for safety purposes. Mr. Wands sent Walden a copy of that report. 7/12/78.
		Mr. Haynes (202) 331-1770	Advised Walden that nobody has a list of exactly what goes into each product. The packaging act of 1976 allowed each manufacturer to voluntarily list the constituents in a product. However, not all did Mr. Haynes cited two "excellent" cosmetic formuation texts for reference. Mr. Haynes is in charge of the Cosmetic, Toiletry and Fragrance Association dictionary and suggested it may be of use. He indicated manufacturers may be reluctant to supply formulation data, but suggested that manufacturers may have had Army contracts in the past and that the Army might help get more specifics from the manufacturer. 7/13/78
5.	United States Environmental Protection Agency (USEPA) Pesticides Office 4th and M St.,SW Waterside Mall Washington, DC 20410	Robert Rose (202) 755-8930	For pesticides formulation, go to the Army. They will have specifications. 7/13/78.

TABLE 3 (CONTINUED)

SUCCESSFUL TELEPHONE CONTACTS

No.	Organization	Person	Information
5.	United States Environmental Protection Agency (USEPA) Pesticides Office 4th and M St.,SW Waterside Mall Washington, DC 20410	James Stone Product Manager Insect Repellents (202) 426-9425	"Army uses straight DEET". J. Stone DEET formulation: N,N- Diethyl-m-Toluamide. 7/13/78.
6.	USEPA National Environmental Research Center 26 W. St. Clair St. Cincinnati, OH	Dr. Dwight Ballinger (513) 684-7301	They monitor water quality in waste treatment plants. They can't help Walden in formulation or composition data, but suggest that Walden contact them when Walden has specific compound to be evaluated. The Research Center can advise with various measurement techniques. Dr. Ballinger, off the top of his head, thinks surfactants in wastewater will pose foaming problems. 7/13/78.
7.	International Joint Commission Windsor, Ontario	Dr. Watson Head of Health Effects of Non-Phosphate Detergent Task Force (313) 963-9041	Supplied Walden with over-the-phone information concerning basic constitutents of laundry detergents. Dr. Watson warns that anything containing phosphates will adversely affect water treatment units. Sent article on perfumed shampoos. Offered to lend any further assistance when needed. 7/13/78.

TABLE 3 (CONTINUED)

SUCCESSFUL TELEPHONE CONTACTS

No.	Organization	Person	Information
8.	Geigy Industry, Inc. P.O. Box 11422 Greensboro, N.C. 27409	Mr. Mike Caruso (800)334-9481	Sent laundry detergent brightener formulation. 7/13/78.
9.	American Society for Testing and Materials 1916 Race Street Philadelphia, PA 19103	Gloria Collier (215) 299-5400	Sent booklet listing soap and detergent documents. 7/19/78.
10.	Chemicals Industry Institute of Technology (CIIT) Research Triangle Park,N.C. 27711	Mr. Bob Beacham (919) 876-8100	Supplied information on computer services and data bases. 7/19/78.
11.	U. S. Army Natick Research & Development Command Natick, MA 01760	Mr. William Montori (617)653-2175	Walden called Natick concerning possible Army specifications regarding cleaning compounds, biological materials, and personal health care items. Mr. Montori stated that Mr. Englehoff and Mr. Eaton from Ft. Detrick had called earlier about the same. Mr. Montori and Mr. Frank Kane are going to get together Monday, July 24 to supply the requested information.

TABLE 4

UNSUCCESSFUL TELEPHONE CONTACTS

No.	Organization	Person	Information
1.	Division of Water Pollution Control Boston, MA	Mr. Thomas McMahon, Director (617)727-3855	Don't deal with formulation information. If it's not a specific law, they aren't concerned with it. 7/13/78.
2.	National Bureau of Standards	Dr. Carrie Gravatt, Chief of Environment Measurements	Involved with water characteristics of clean groundwater and riverwater. Don't deal with wastewater. 7/13/78
3.	Cosmetic Industry Buyers and Suppliers Almay, Inc. 562 Fifth Avenue New York, N.Y. 10036	Joy Spoke, Secretary to President Underwood. (212) 869-0500	President Underwood's secretary, after conferring with the president, stated they did not wish to lend any assistance. She suggested Walden try again in a month, when employees are back from vacation. 7/12/78
4.	U. S. Navy, Washington, D.C.	Lt. Commander Haig (202) 697-1997	Upon inquiring about water reuse on nuclear submarines, Walden discovered the Navy does not reuse water, they make it. 7/12/78.

Literature Search

Sixteen computerized data bases were searched with keyword terms specified below:

Chemical Data Base (*Chemical Abstracts*)

Keywords:

Soap	Fabric	All Lotion
All Detergent	All Softener	Suntan
All cosmetic	All Rinse	Hair
All Deodorant	Sizing	All Spray
Insect	Spray	
All Repellant	Starch	

The keywords were crossed with toxicity or composition.

NTIS Data Base

Keywords:

Soap	All Fabric	All Lotion
All Detergent	All Softener	Suntan
All Cosmetic	All Rinse	Creme
All Deodorant	Sizing	
Insect	Spray	
All Repellant	Starch	

The keywords were crossed with toxicity or composition or all ingredients.

Toxline Data Base

Keywords:

Soap	Fabric Softeners	Sizing
Detergent	Creme Rinse	Lotion
Cosmetics	Creme or Cremes	
Deodorant	Gels	
Insect Repellant	Spray Starch	

The keywords were crossed with wash or laundry or shower.

The keywords were also crossed with composition or ingredients.

The following data bases all employed the same keyword strategy:

Chemical Abstracts. Chemical Abstracts Service.
Government Reports Announcements and Index. National Technical Information Service.
Technical Report Program - Past Research. Defense Documentation Center.
Research and Technology Work Unit Information System, Defense Documentation Center.
Environment Index. Environment Information Center, Inc.
Pollution Abstracts. Environment Information Center, Inc.
Biological Abstracts. Biological Sciences Information Service.
Engineering Index. Engineering Index, Inc.
Energy Index. Environmental Information Center, Inc.
Nuclear Science Abstracts. Atomic Energy Commission.
Atomindex. International Atomic Energy Commission, Vienna.
Selected Water Resources Abstracts. U.S. Department of the Interior, Office of Water Research and Technology.
Energy Info Data Base. U.S. Department of Energy.

Keywords:

Ultrafiltration	Laundry
Hyperfiltration	Laundr?
Reverse Osmosis	Shower?
Membrane?	Wash?
	Domestic

? = truncation

Literature Obtained

The following textbooks, identified in telephone contacts or literature searches, were obtained:

De Navarre, The Chemistry and Manufacture of Costmetics, Van Nostrand, 1941.

Cosmetics, Science and Technology, Wiley-Interscience, M.S. Brasam, Edward Sagarin. (Vol 1 and Vol 2).

Winter, Ruth, A Consumer's Dictionary of Cosmetic Ingredients, 1976.

Synthetic Detergents, 6th Ed., A. Davidsohn and B. M. Milmosky, 1978.

Jellinek, J.S., Formulation and Function of Cosmetics, Wiley-Interscience, 1970.

Niven, Wm. W., Fundamentals of Detergency.

The following reports or literature were mailed to Walden as a result of telephone conversations.

From:	FDA Cosmetics Division
Title or Topic:	Instructions and General Information for the Voluntary Cosmetic Regulatory Program.
Comments:	Contains product code list for 83 cosmetic categories. Walden has written for formulations for specific categories.
From:	C.P.S.C.
Title or Topic:	Detergent Survey Toxicity Testing (1971-1976).
Comment:	A survey of 145 detergent products involving biological testing, chemical analyses and product label reviews.
From:	CTFA
Title or Topic:	Grouping of Ingredients for Literature Searching.
Comment:	List includes 189 ingredients on CFTA's final first pricing list.
From:	NASA
Title or Topic:	2 Reports (1) Reports of the Panel on Potable Water Quality in Manned Spacecraft, August 1972. (2) Recommended Tentative Standards for Wash Water in Manned Spacecraft, December 1971.
Comment:	Walden has contacted NASA requesting more recent data.
From:	Union Carbide
Title or Topic:	Product information on surfactant, Tergitol.
Comments:	Contains chemical composition, biodegradable low-foam surfactant information and properties.
From:	Soap & Detergent Association
Title or Topic:	Letter listing range of combinations for phosphate and non-phosphate detergents.
From:	Soap & Detergent Association
Title or Topic:	Human Safety and Environmental Aspects of Major Surfactants.
Comments:	546 page report prepared by Arthur D. Little for the Soap and Detergent Association.
From:	ASTM
Title or Topic:	ASTM publications 1977-1978.

Concentrations of Wastewater Components

For each of the product types noted, composition data were obtained for several types or brands of product. Component concentrations were calculated for each product corresponding to product concentrations given in Tables 1 and 2. The highest concentration of each constituent was selected for each product type and these were summed by product. Final concentrations of constituents in wastewaters were calculated for shower wastewaters (Table 5), laundry wastewaters (Table 6) and a mixture of the two (Table 7). Concentration ranges are specified for constituents of products with concentration ranges.

TABLE 5

SHOWER WASTEWATER CONSTITUENTS

	mg/l
Silica Flour	100 - 210
Sodium chloride	60 - 180
Castor oil	20 - 130
Isopropyl alcohol	18 - 105
Ethanol	15 - 85
Kaolinite	20 - 50
Oleic acid	16 - 50
Talc	41
Tallow	13 - 38
Stearic acid	11 - 31
Coconut oil	9 - 30
Castor oil, sulfonated (75%)	6 - 30
Ultrawet 60-L	5 - 25
Ammonium lauryl sulfate	5 - 25
Sodium lauryl sulfate	5 - 22
Epithelium cells	18
N,N-Diethyl-m-toluamide	1 - 15
Sodium dodecylbenzenesulfonate	3 - 13
Sodium tripolyphosphate	5 - 11
Olive oil, sulfonated (75%)	2 - 10
Tannic acid	1 - 8
Triethanolamide alkylbenzene sulfonate (60%)	1 - 7
Potassium oleate (20%)	1 - 6
Kaloin, colloidal	5
Lactic acid	5
Triethanolamine	1 - 5
Urea	1 - 3
Glycerol	1 - 3
Potassium hydroxide	0.7 - 3
Zinc stearate	3
Coconut diethanolamine (92%)	0.5 - 3
Hair	2
Mineral oil	0.5 - 2
Potassium	1.5
Calcium carbonate	0.9
Aluminum hydroxide	0.9
Sorbitol	0.7
Dicalcium phosphate	0.6
Sodium-ortho-phenylphenolate	0.6
Sodium-4-chloro-2-phenylphenolate	0.5
Sodium metaphosphate	0.4
Aluminum formate solution	0.4
Propylene glycol	0.3
Tricalcium phosphate	0.2
Volatile silicone	0.2
Tegacid	0.2
Aluminum chlorhydrate	0.2
Tween 80	0.2

The following compounds present at <0.2 mg/l

Alumina
Aluminum chloride
Aluminum sulfate
Ammonium alum
Beeswax
Boric acid
Cetyl alcohol
Corn starch
Bentonite
Hexachlorophene
Isopropyl myristate
Jamaican rum
Magnesium carbonate
Magnesium oxide
Glycerol monostearate
Methyl paraben
Lanolin
Petrolatum
PABA
Isopropyl palmitate
Polyethylene sorbitan monostearate
Saccharin sodium
Sodium-6-chloro-2-phenyl-phenolate
Sodium hydroxide
Sorbitol
Spermaceti
Sorbitan monostearate
Stannous fluoride
Veegum
Zinc chloride
Sodium stearate

TABLE 6

LAUNDRY WASTEWATER CONSTITUENTS

	Concentration mg/l
Sodium carbonate	530
Vegetable oil	170
Kaolinite	130
Sodium alkylbenzenesulfonate	120
Sodium sulfate	110
Sodium tripolyphosphate	90
Sodium silicate	80
Sodium fluosilicate	80
Ethoxylated alcohol	60
Urea	13
N, N-Diethyl-m-toluamide	9
Sodium carboxymethylcellulose	6
Protease	3
Fluorescent whitening agents	3
Ethanol	3

TABLE 7

CONSTITUENTS OF MIXED WASTEWATER*

	mg/l
Sodium carbonate	240
Silica flour	50-110
Sodium chloride	33-100
Kaolinite	70-90
Vegetable oil	75
Castor oil	12-70
Isopropyl alcohol	10-60
Sodium alkyl-benzenesulfonate	55
Sodium sulfate	51
Ethanol	10-50
Sodium tripoly-phosphate	40-45
Sodium silicate	35
Sodium fluosilicate	35
Ethoxylated alcohol	30
Oleic acid	10-30
Talc	20
Tallow	1-21
Stearic acid	6-17
Coconut oil	5-16
Castor oil, sulfonated	3-16
Ultrawet 60L	3-14
Ammonium lauryl sulfate	3-14
N,N-Diethyl-m-toluamide	5-12
Sodium lauryl sulfate	2-12
Epithelium cells	10
Urea	6-8
Sodium dodecyl benzenesulfonate	1-7
Olive oil, sulfonated	1-5
Tannic acid	0.7-5
Triethanolamide alkyl-benzenesulfonate	0.7-4
Potassium oleate	0.7-3
Kaolin, colloidal	3
Sodium carboxymethyl-cellulose	3
Lactic acid	3
Triethanolamine	0.5-2
Glycerol	0.8-2
Potassium hydroxide	0.4-1
Zinc Stearate	1
Coconut diethanol-amine	0.3-1
Fluorescent whitening agents	1
Hair	1
Mineral oil	0.2-0.9
Potassium	0.8

	mg/l
Calcium carbonate	0.5
Aluminum hydroxide	0.5
Sorbitol	0.4
Dicalcium phosphate	0.3
Sodium ortho-phenyl-phenolate	0.3
Sodium 4-chloro-2-phenylphenolate	0.3
Sodium meta-phosphate	0.2

Compounds present at <0.2 mg/l

Alumina
Aluminum chlorhydrate
Aluminum chloride
Aluminum formate
Aluminum sulfate
Ammonium alum
Beeswax
Boric acid
Cetyl alcohol
Corn starch
Bentonite
Hexachlorophene
Isopropyl myristate
Isopropyl palmitate
Jamaican rum
Magnesium carbonate
Magnesium oxide
Glycerol monostearate
Methyl paraben
Lanolin
Petrolatum
PABA
Propylene glycol
Polyethylene sorbitan monostearate
Saccharin sodium
Sodium-6-chloro-2-phenylphenolate
Sodium hydroxide
Sodium stearate
Spermaceti
Sorbitan monostearate
Stannous fluoride
Tegacid
Tricalcium phosphate
Tween 80
Veegum
Volatile silicone
Zinc chloride

*55% shower water, 45% laundry water

TASK II - ENGINEERING EVALUATION

A. INTRODUCTION

The primary objective of the engineering evaluation is to evaluate the efficiency of several wastewater treatment systems for the removal of chemical contaminants from shower and laundry wastewaters. Given the low toxicity of these wastewaters and the constraints imposed by field Army operations, it was a further objective to assess the relative merits of treatment systems for various levels of treatment.

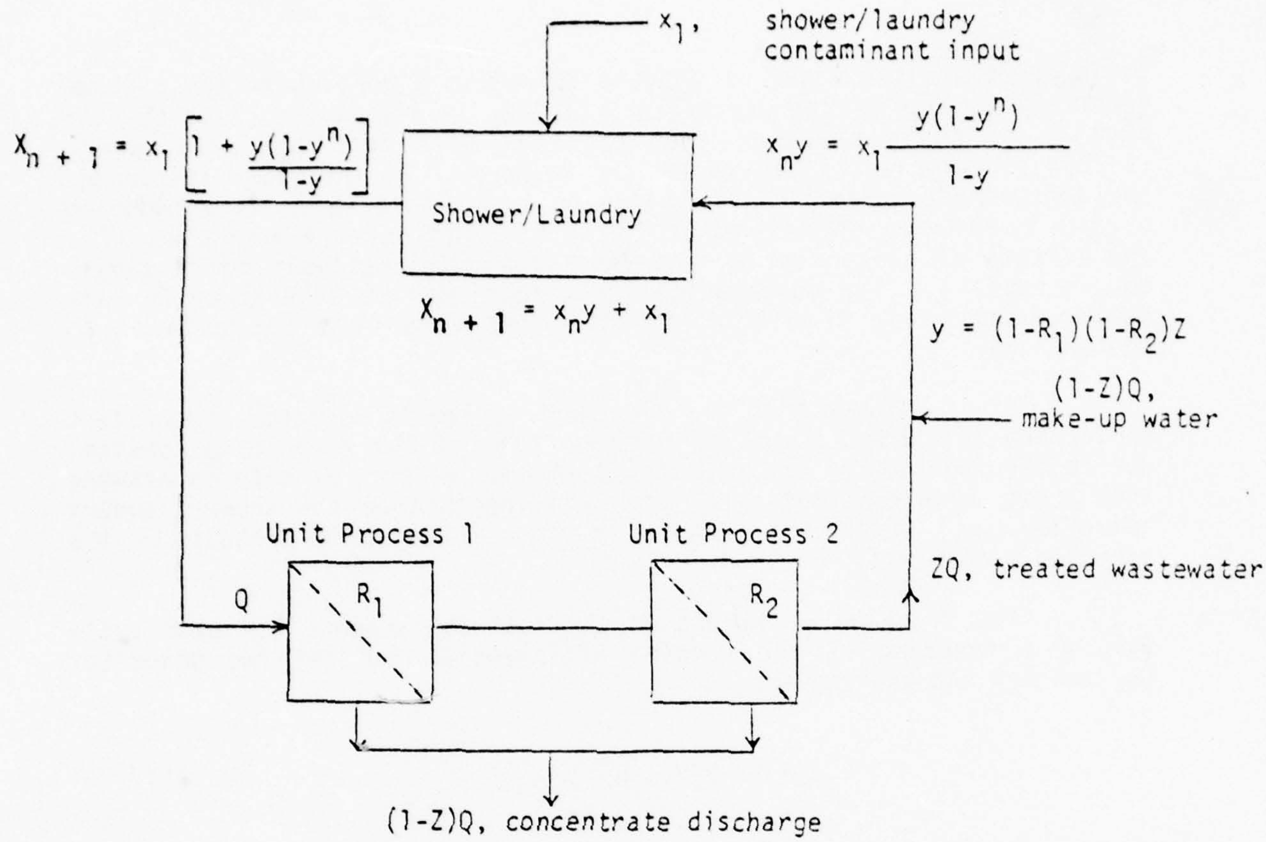
On the basis of a literature survey and relevant experience, five representative wastewater treatment systems were evaluated which appeared to be particularly promising for treating shower and laundry wastewaters generated by field Army units. The relative system performances at 70-90% conversion were estimated from calculations of the concentrations of nine problem contaminants present in treated wastewater which had been recycled an infinite number of times. The problem contaminants consisted of six organic chemicals rank-ordered from the list of total contaminants based on high concentration, low removal efficiency, and toxicity; and three inorganic chemicals selected from the list of total contaminants based on high concentration. Of the five systems evaluated, the system producing the highest purity water was a system which included an ultrafiltration unit followed by a reverse osmosis unit. A system which may be more practical for the given application was dilution, filtration and disinfection.

B. WASTEWATER TREATMENT SYSTEMS

The five wastewater treatment systems considered in this engineering evaluation all incorporate treatment and recycle of 70 to 90% of the shower and laundry wastewaters. This recycle, in effect, multiplies the available water supply three and one-third to ten-fold for shower and laundry purposes. The characteristics of the treatment systems are considered in terms of: recycle mathematics, treatment systems, and unit process characteristics.

1. Recycle Model

A generalized flow schematic for a wastewater treatment system with partial recycle is shown in Figure 1. Wastewater enters the system at a volumetric flow rate of Q liters per minute with a contaminant concentration X_1 mg/liter. This concentration, X_1, is, for shower wastewater, the concentration of a particular substance in the shower water due to the initial use of fresh water. It is the contaminant concentration as the water enters the shower drain. The water passes to Treatment Process 1 (Unit Process 1) and to Treatment Process 2. In



x_1 = chemical contaminant concentration in wastewater resulting from shower/laundry operation, mg/liter.

Q = volumetric flow rate of wastewater, liter/min.

R_1 = removal efficiency for process 1.

R_2 = removal efficiency for process 2.

Z = conversion, fraction of wastewater recycled.

$x_n y$ = chemical contaminant concentration in recycled water prior to reuse after n recycles.

x_{n+1} = chemical contaminant concentration in wastewater following n recycles.

y = fraction of unremoved chemical contaminant following each cycle.

FIGURE 1

WASTEWATER TREATMENT SYSTEM FLOW SCHEMATIC these processes the water is treated to remove a portion of the contaminant. A portion of the wastewater, (1-Z)Q, is discharged. The treated portion of the wastewater, ZQ, together with fresh make-up water, (1-Z)Q, is recycled to the shower (or laundry). As the water is reused, the contaminant concentration builds up to a limit which is a function of the treatment efficiencies (R_1 & R_2) and water conversion (Z). The effects of these factors are described quantitatively for a single contaminant, X. The mathematical treatment applies separately to each contaminant since treatment efficiencies vary from contaminant to contaminant.

It is assumed that the treatment system is operated at constant conversion (Z) and that the circulation rate of the recycle is constant due to the addition of uncontaminated make-up water. It also is assumed that there is a constant input of contaminants from the shower/laundry operation (x_1) which is additive to the contaminants present in the recycled water (x_n).

The fraction of unremoved chemical contaminant for each cycle (y) is a function of the removal efficiencies for the two processes (R_1 and R_2) and the conversion:

$$y = (1-R_1)(1-R_2)Z \qquad (1)$$

The contaminant concentrations after an infinite number of recycles may be expressed as the convergent infinite series.

$$x_\infty = x_1(1 + \frac{y}{1-y}) \qquad (2)$$

Thus, there is an upper limit on the concentration build-up of wastewater contaminants. See Appendix I, p. 55 , for the derivation of equation (2). As will be demonstrated below, for 80% water recycle the system with zero treatment efficiency gives a five-fold buildup in contaminant concentration and the system with highest treatment efficiency shows virtually no build-up.

2. Treatment System

Five wastewater treatment systems were selected for evaluation:

- ultrafiltration, reverse osmosis
- ultrafiltration
- activated carbon adsorption, ion exchange

• ERDLator

• dilution

Two of the systems were chosen on the premise that a system consisting of processes for removing suspended solids followed by processes for removing dissolved solutes would be required for reliable system performance. The other three systems were selected on the premise that satisfactory performance would be obtained by employing only processes typically used for removing suspended solids. A final step in each of the systems would be some form of disinfection (e.g., hypochlorination, ultraviolet radiation, ozonation, UV-activated ozonation). Certain methods of disinfection (e.g., hypochlorination) have the added advantage of destroying problem chemical contaminants (viz., urea).

An objective of this program is to determine the effectiveness of the representative wastewater treatment systems for removing specific chemical contaminants from wastewaters. Data are available on the specific removal efficiencies for unit processes designed for removing dissolved solids (e.g., IX, ACA, and RO). However, no such chemical-specific data are available for unit processes generally employed for removing suspended solids (e.g., DEF, UF, and DAF), and these data are required for evaluating the wastewater treatment systems. For this reason, an approach was developed for estimating removal efficiencies which was based on comparing removal efficiencies for a suspended solids removal process to those for a dissolved solids removal process. The removal efficiencies which were compared generally were total organic carbon and total dissolved solds. The removal efficiency for a suspended solids removal process was expressed in terms of a percentage of the removal efficiency for a dissolved solids removal process. This percentage was then applied on an individual chemical basis to supply the data required for the evaluation of each system.

a. UF-RO System

This system would consist of ultrafiltration (UF) unit for removing suspended solids followed by a reverse osmosis (RO) unit for removing dissolved solids. The UF unit would function principally to pretreat the wastewater for satisfactory operation of the RO unit. Because free chlorine destroys polyamide RO membranes, a method of disinfection other than chlorination may be required for operation in a recycle mode. On the basis of studies with shower and laundry wastewaters[5,6], it was estimated that the dissolved solids removal for UF would be 40% of that for RO. The rejection of dissolved species by UF is primarily a result of the adsorption of these species onto suspended particulates.

Ultrafiltration (UF) and reverse osmosis (RO) are pressure-driven membrane separation processes in which water selectively permeates through a semi-permeable membrane while suspended and dissolved species are rejected at the membrane surface. The mechanisms by which rejection occurs are the following:

-- the "sieving" mechanism, in which constituents larger than the membrane pore diameter are rejected, and

-- the "solution-diffusion" mechanism, in which the permeability of the membrane to any constituent is proportional to the product of its solubility in the membrane and its diffusivity through the membrane.

Rejection by UF membranes occurs predominantly by the sieving mechanism, whereas rejection by RO membranes occurs predominantly by the solution-diffusion mechanism. For UF membranes the degree of rejection is determined solely by the size of the rejected species. For RO membranes, as the size of the rejected solute increases, its diffusivity through the membrane decreases resulting in a higher degree of rejection. On the other hand, small solutes with hydrogen-bonding tendencies are poorly rejected by RO membranes because of their high diffusivity and high solubility in the membrane. Ionic species are highly rejected by interaction with fixed charges on the membrane surface. In general, ionic species and large organics will be highly rejected by RO membranes; small hydrogen-bonding organics and non-ionized acids and bases will be poorly rejected.

There are three basic types of commercially available membrane modules: tubular, spiral-wound, and hollow-fiber. Spiral-wound and hollow-fiber modules are more compact and less expensive than tubular modules, but tubular modules are less susceptible to plugging by particulates and can be easily cleaned if fouled. In a practical membrane module there are several factors which influence the concentration of feed at the membrane surface and thereby influence both the flux (volume of effluent produced per unit membrane area per unit time) and rejection. If a module is operated at a significant conversion, the feed, in passing through the module, becomes progressively concentrated. The higher the cnversion, the higher the average feed concentration and the lower the average module flux and rejection.

b. UF System

This system would consist of a UF unit containing membranes having a smaller porosity (i.e., they are "tight") than the UF membranes which would be included in the UF-RO system. On the basis of results of studies with "tight" UF membranes[2, 4. 6], it was estimated that the rejection of all contaminants by the UF system would be 50% of that for an RO unit.

c. Pretreat-ACA-IX System

This system would consist of a suspended solids removal, pretreatment unit (viz., diatomaceous earth filtration (DEF) or dissolved air flotation (DAF)) followed by an activated carbon adsoprtion (ACA) unit to remove dissolved organic chemicals and an ion exchange (IX) unit to remove dissolved inorganic chemicals. Because the pretreatment requirements for ACA-IX are not as strict as those for RO, it was reasoned that a unit less expensive and efficient than a UF unit would be adequate. Based on studies with such units[3,7], it was estimated that 30% of the RO rejection would be obtained by the pretreatment method.

Diatomaceous earth filtration (DEF) is a physical straining process which is used to remove suspended solids by virtue of physical restrictions at the surface of a filter which has no appreciable thickness in the direction of flow. A thin layer of precoat formed around a porous septum is utilized in DEF to strain out the suspended solids in the wastewater which passes through the filter cake and septum. The driving force can be imposed by vacuum from the product side or pressure from the feed side. As filtration proceeds, headloss through the cake increases due to solids deposition until a maximum is reached. The cake and associated solids are then removed by flow reversal and the process is repeated. Generally, the DE filtration process is capable of removing suspended solids, but not colloidal matter.

Dissolved air flotation (DAF) is used as a sludge thickening method, frequently in treating laundry wastewater[10]. The objective of DAF is to concentrate suspended substances in a floating layer which can be skimmed. The principal advantage of DAF is the formation of a single layer for removal irrespective of suspended material density. Difficult-to-settle particles are first flocculated and then carried to the surface by large numbers of small air bubbles. Bubble formation is caused by air saturation of a portion of the waste stream using compressed air followed by bubble nucleation when the stream is released to atmospheric pressure.

Ion exchange (IX) involves a solid phase containing bound groups that carry on ionic charge in conjunction with free ions of opposite charge which can be displaced. Ion-exchange resins are insoluble solid materials which carry exchangeable positive or negative ions. These ions can be exchanged for a soichiometrically equivalent amount of other ions of the same sign when the resin is in contact with an electrolytic solution. The exchange process is reversible.

The characteristic properties of ion-exchange resins are due to their structure. They consist of a crosslinked polyelectrolytic framework which is held together by chemical bonds. This framework forms a hydrophobic matrix which is an irregular, macromolecular, three-dimensional network of hydrocarbon chains. The resins are made insoluble by the introduction of crosslinks which interconnect the hydrocarbon chains. The matrix carries hydrophillic ionic groups, such as carboxyl groups,. which give it a net surplus charge. This charge is compensated by ions of opposite sign called counter-ions. The counter-ions are free to move within the framework and are the ions that are replaced by other ions of the same sign from the solution. The ion-exchange capacity of a resin, expressed in milliequivalents per gram of resin, is a measure of its counter-ion content at equilibrium. This capacity is a constant and is determined by the magnitude of the matrix charge.

The degree of crosslinking of the matrix and the character and number of the fixed ionic groups enable ion-exchange resins to adsorb certain counter-ions preferentially, based on their size, valence, or electrostatic interactions. Because of this ability selectively to adsorb charged substances from feed streams, ion-exchange resins have been employed in various separation processes. However, the nature of this adsorption process precludes continuous operation of a fixed bed of resins unless a resin regeneration period is included as part of the process.

Activated carbon adsorption (ACA) is used for removing organic chemicals from water. There are a number of factors which influence the extent to which organics adsorb on activated carbon. These include the carbon surface area, the nature of the organics, interactions with other solutes, the pH, the temperature, and the nature of the carbon. Of these the most critical factor is generally the nature of the organics present in the water. As a rule, the more insoluble (hydrophobic) a contaminant, the better it is adsorbed by activated carbon.

A number of sequential steps are involved in the adsorption of organic molecules. First, molecules in the bulk of the solution must migrate to the carbon particle. Then they must migrate across a liquid film surrounding the particle, and thus into a pore. Thereafter they migrate through the pore to finally come to rest on the ultimate adsorption site. When all of the available sites are occupied, the carbon particle is in equilibrium with the surrounding solution, and its capacity for further adsorption is exhausted.

Three principal factors affect the ease with which organic compounds are adsorbed: polarity, structure, and molecular weight. Highly polar molecules are generally more water soluble and poorly adsorbed. Molecular structure affects the ease with which the molecules attach to the surface of the carbon particle (e.g., aromatic rings are conducive to adsorption). Molecular weight affects the ease of adsorption through two effects: solubility and surface attraction. The high molecular weight compounds are generally less soluble, and

and consequently more easily adsorbed. In addition, the surface attraction is generally greater for large molecules, so that they are more easily adsorbed.

The extent of the adsorption is influenced by the equilibrium adsorption capacity and the rate of adsorption, which can be determined from adsorption isotherm and column tests. The two major parameters for designing an adsorption system are:

(1) Contact time - which indicates the amount of carbon required at any given time, and thus, determines the size of the equipment and the capital cost.

(2) Carbon usage rate - which indicates the rate at which the carbon must be replaced, and thus defines the operating costs of the system. Once the contact time is determined, the carbon usage rate can be determined through a column test.

d. ERDLator System

This Army system, an upflow clarifier, originally designed for solids removal has also been used for removal of organic compounds from water by sorption onto activated carbon. For the present application this system would consist of powdered carbon plus polyelectrolyte addition followed by hypochlorination and a pressure diatomite filter. On the basis of removal efficiencies using such a unit for total organic carbon, hexane solubles, detergents, salts, and suspended solids[1], it was estimated that the rejections of individual chemical contaminants would be 75% of those for ACA.

e. Dilution System

The fifth treatment system is simply a dilution system wherein a portion of the wastewater is discarded and fresh make-up water is added. A sand filter is assumed for removal of gross particulates and a chlorination unit for disinfection.

C. WASTEWATER COMPONENTS AND TREATABILITY

Wastewater components and treatability are considered in four sections: Wastewater components, chlorination and ozonation products, treatability for each unit process, and system performances for challenge contaminants.

1. Wastewater components

Wastewater components are listed in Tables 5, 6, and 7 with concentrations expected to be present after a single water use.

2. Chlorination and Ozonation Products

Chemicals could be created during the disinfection of treated wastewaters. Chlorination could result in the formation of chlorinated organic chemicals, and ozonation could result in the formation of partially oxidized organic chemicals.

Hypochlorination is an attractive method for disinfection, especially in this application, because it offers the added feature of destroying a difficult-to-remove contaminant, urea. Total removal of urea can be accomplished in practice by using twice the stoichiometric quantity of hypochlorite, according to the following equation:

$$(NH_2)_2CO + 3HOCl \rightarrow N_2 + 2H_2O + CO_2 + 3HCl$$

For the predicted urea concentration of 13 ppm in laundry and 3 ppm in shower wastewaters, the concentration of OCl^- required for complete urea destruction would be 67 and 15.5 ppm, respectively. One half, or 33.5 and 8 ppm, of the OCl^- would remain in solution. Since in a saturated solution of chlorine, the concentration of HOCl is one half of that for Cl_2, the equivalent concentrations of Cl_2 would be 92 and 21 ppm. These concentrations of Cl_2 would be available to react with the organic chemicals present in the wastewaters. The concentrations of the created chemicals would be determined by the chemical reaction kinetics, and limited by either the concentration of the precursor chemical or the concentration of Cl_2.

Chemical groups likely to be chlorinated include:

- Alkanes
- Aromatics and alkyl aromatics
- Carbonyl compounds
- Amines and amides
- Carboxylic acids

A limited number of chemicals were selected for the engineering evaluation. Of primary concern here are those organic chemicals which are likely to be chlorinated and are poorly removed by RO and ACA. Some of these chemicals which could be formed by chlorination of laundry and shower wastewaters are listed in Table 8.

Ozonation is an attractive method of disinfection, especially for membrane systems operated in a recycle mode in which the membranes could be destroyed by free chlorine. Incomplete ozonation, however, can produce partially oxidized organic chemicals. Some of these (e.g., epoxides and diols) could be carcinogenic.

Treatment efficiencies for chlorination and ozonation products were not considered in the present report.

3. Wastewater Treatability - Unit Processes

The efficacy of the unit processes and systems for removing the shower and laundry contaminants from wastewaters is discussed in this section. Several simplifying assumptions were made:

- Insoluble chemicals which are solid at room temperature would be 100% removed by any of the seven unit processes. This applies to 19 contaminants.

- Insoluble chemicals which are liquid at room temperature would be 100% removed by both ACA and RO. These chemicals plus the large organics (i.e., C_n, $n > 8$) account for 35 chemicals. Both types would be 100% removed by ACA and RO.

- Inorganic salts would be approximately 100% removed by RO and IX, but 0% removed by ACA. This applies to 18 contaminants.

- Organic chemicals would be 0% removed by IX. The IX removal efficiencies for inorganic chemicals are the same as the RO removal efficiencies for inorganic chemicals.

- The most important group of chemical contaminants consists of water soluble organic chemicals which are small and polar. These chemicals are poorly removed by both RO and ACA, and are discussed in detail below. This applies to 12 contaminants.

Because it is assumed that the removal efficiencies for all of the unit processes can be expressed as a function of the removal efficiencies for RO and ACA, estimates were made of the RO and ACA removal efficiencies for each of the contaminants in shower and laundry wastewaters. These removal efficiencies were estimated on the basis of published data[7,9] and related practical experience. The removal efficiencies are listed in Table 9.

TABLE 8

CHEMICALS FORMED BY CHLORINATION

Precursor	Chemical Created
Ethanol	$Cl-CH_2-CH_2-OH$ 2-chloroethanol (ethylene chlorohydrin)
Isopropyl alcohol	$Cl-CH_2-CH(OH)-CH_3$ 1-chloro-isopropyl alcohol
Urea	$Cl-HN-C(=O)-NH_2$, $Cl_2-N-C(=O)-NH_2$ mono and di-N-chloroamides
Lactic acid	$CH_3-CH(OH)-C(=O)Cl$ acid chloride $Cl-CH_2-CH(OH)-C(=O)OH$ chloro acid
Triethanolamine	$Cl-N(CH_2CH_2OH)-CH_2CH_2OH$ diethanolchloroamine
Propylene glycol	$Cl-CH_2-CH(OH)-CH_2(OH)$ 3-chloro propylene glycol

TABLE 9

PREDICTED ACA AND RO REMOVAL EFFICIENCIES

Substance	Removal Efficiencies (%) ACA	Removal Efficiencies (%) RO
Alumina	*	*
Aluminum chlorohydrate	0	98
Aluminum chloride	0	98
Aluminum formate	40	80
Aluminum hydroxide	*	*
Aluminum sulfate	0	98
Ammonium alum	0	98
Ammonium lauryl sulfate	100	98
Bees wax	*	*
Bentone gel	0	98
Boric acid	40	65
Calcium carbonate	*	*
Castor oil	100	100
Cetyl alcohol	100	100
Coconut diethanolamide	100	100
Coconut oil	100	100
Dicalcium phophate	0	98
N,N-diethyl-m-toluamide	100	100
Epithelium	*	*
Ethanol	10	30
Ethoxylated lauryl alcohol	100	100
Fluorescent whitening agents	-	-
Glycerol	25	80
Glycerol monostearate	100	100
Hair	*	*
Hexachlorophene	100	100
Isopropyl alcohol	40	85
Isopropyl myristate	100	100
Jamaican rum	100	100
Kaolin, colloidal	10	30

* Insoluble in water, would be removed during pretreatment step if solid; if liquid, would be removed 100% by ACA or RO.

- Not enough information for a prediction.

TABLE 9 (Continued)

PREDICTED ACA AND RO REMOVAL EFFICIENCIES

Substance	Removal Efficiencies (%)	
	ACA	RO
Kaolinite	*	*
Lactic acid	60	60
Lanolin	100	100
Magnesium carbonate	*	*
Magnesium oxide	*	*
Methyl paraben	100	100
Mineral oil	100	100
Oleic acid	100	100
Petrolatum	100	100
Polyethylene sorbitan monostearate	100	100
Potassium	0	100
Potassium hydroxide	0	100
Potassium oleate	80	100
Propxylated PABA	100	75
Propylene glycol	35	80
Protease	100	100
Silica flour	*	*
Sodium alkylbenzene sulfonate	100	100
Sodium carbonate	0	100
Sodium carboxymethyl cellulose	100	100
Sodium chloride	0	98
Sodium 4-chloro-2-phenylphenolate	100	100
Sodium 6-chloro-2-phenylphenolate	100	100
Sodium dodecyl benzene sulfonate	100	92
Sodium fluosilicate	*	*
Sodium hydroxide	0	98
Sodium hypochlorite	0	Destroys most membranes
Sodium lauryl sulfate	100	92
Sodium-ortho-phenylphenolate	100	100
Sodium saccharin	100	100

* Insoluble in water, would be removed during pretreatment step if solid; if liquid, would be removed 100% by ACA or RO.

- Not enough information for a prediction.

TABLE 9 (Continued)

PREDICTED ACA AND RO REMOVAL EFFICIENCIES

Substance	Removal Efficiencies (%)	
	ACA	RO
Sodium silicate	0	98
Sodium stearate	100	100
Sodium sulfate	0	98
Sodium tripolyphosphate	0	98
Sorbitan monostearate	100	100
Sorbitol	75	85
Spermaceti	-	-
Stannous fluoride	0	98
Sulfonated castor oil	100	100
Sulfonated olive oil	100	100
Talc	*	*
Tallow	*	*
Tannic acid	100	100
Tegacid	-	-
Tricalcium phosphate	70	90
Triethanolamine	70	90
Triethanolamine alkylbenzene-sulfonate	100	100
Tween 80	-	-
Ultra-wet 60L	100	100
Urea	5	35
Veegum	0	98
Vegetable oil	100	100
Volatile silicone	*	*
Zinc chloride	0	98
Zinc stearate	*	*

* Insoluble in water, would be removed during pretreatment step if solid; if liquid, would be removed 100% by ACA or RO.

- Not enough information for a prediction.

4. System Performance for Challenge Contaminants

By applying simplifying assumptions, the removal efficiencies for the wastewater treatment systems (RE_S) can be expressed in terms of the reverse osmosis rejection (R), the activated carbon adsorption removal efficiency (A), and the combined effect of activated carbon adsorption removal for organics and ion exchange removal (assumed equal to RO) for inorganics (AR). The expressions for RE_S are given as follows:

$$\text{In general, } RE_S = \frac{C_I - C_O}{C_I} = 1 - \frac{C_O}{C_I}$$

where C_I = initial concentration of chemical contaminant in wastewater
C_O = final concentration of chemical contaminant in treated effluent

For the UF-RO system,

$$RE_{S1} = 1 - [(1-0.4R)(1-R)] = 1.4R-0.4R^2 \quad (3)$$

For the UF system,

$$RE_{S2} = 1 - [(1-0.5R)] = 0.5R \quad (4)$$

For the Pretreat-ACA-IX system,

$$RE_{S3} = 1 - [(1-0.3R)(1-AR)] = 1.3R - 0.3R^2 \text{ for inorganic compounds} \quad (5)$$
$$= A + 0.3R - 0.3AR \text{ for organic compounds} \quad (6)$$

For the ERDLator system,

$$RE_{S4} = 1 - [(1-0.75A)] = 0.75A \quad (7)$$

The RE_S values apply to concentration prior to the addition of make-up water. The corresponding fraction of contaminant not removed is $1-RE_S$. Including the effect of dilution with make-up water one obtains

$$y = (1-RE_S)Z \quad (8)$$

where y and Z are the variables given in equation 1 and Figure 1.

of the many contaminants of shower and laundry wastewaters, the evaluation was based on removal efficiencies for nine problem contaminants which would pose a challenge to the five systems. The shower and laundry wastewater contaminants were rank ordered based on:

- high concentration of water soluble chemicals in wastewater
- low removal efficiency for both RO and ACA
- high toxicity at the wastewater concentration

These three factors were weighted equally to give a list of nine chemicals which would pose a challenge to the wastewater treatment system:

1 - ethanol
2 - urea
3 - isopropyl alcohol
4 - lactic acid
5 - triethanolamine
6 - sodium carbonate
7 - sodium chloride
8 - sodium sulfate
9 - glycerol

The treatment efficiencies of Table 10, together with equations 2-8, can be used to calculate contaminant concentrations in wastewater for an infinite number of recycles. Concentrations of these nine challenge contaminants were calculated. The chemical concentrations in treated, recycled water prior to reuse for an infinite number of recycles (x y) were calculated for the five systems at 70, 80, and 90% conversion and are given in Tables 11, 12, and 13, respectively. Data used to prepare these tables are shown in Appendix III.

TABLE 10

PREDICTED ACA AND RO REMOVAL EFFICIENCIES
FOR CHALLENGE CONTAMINANTS

Substance	Removal Efficiencies (%)	
	ACA	RO
Ethanol	10	30
Glycerol	25	80
Isopropyl alcohol	40	85
Lactic acid	60	60
Sodium carbonate	0	100
Sodium chloride	0	98
Sodium sulfate	0	98
Triethanolamine	70	90
Urea	5	35

TABLE 11

CONCENTRATIONS OF CHALLENGE/PROBLEM CONTAMINANTS IN TREATED WASTEWATER PRIOR TO REUSE FOR AN INFINITE NUMBER OF RECYCLES (70% CONVERSION)

			x_∞ y (mg/liter)				
Wastewater Source	Contaminant	x_1 (mg/liter)	UF-RO	UF	Pretreat - ACA-IX	ERDLator	Dilution
Shower	Ethanol	84	64	130	110	160	200
	Isopropanol	105	7.8	70	48	100	245
	Glycerol	2.8	0.3	2.0	1.9	3.7	6.5
	Lactic acid	5.0	1.4	4.8	1.5	3.2	12
	Triethanolamine	7.5	0.4	4.8	1.4	3.7	18
	Urea	3.0	1.9	4.1	4.4	6.1	7
	Sodium chloride	180	1.6	100	1.8	420	420
Laundry	Ethanol	1.4	1.1	2.1	1.9	2.6	3.3
	Urea	13	8.4	18.0	19	26	30
	Sodium carbonate	533	0.0	290	0.0	1,200	1,200
	Sodium sulfate	112	1.0	63	1.1	260	260
Composite	Ethanol	47	36	71	63	87	110
	Isopropanol	57	4.2	38	26	55	130
	Glycerol	1.5	0.2	1.1	1.0	2.0	3.5
	Lactic acid	2.7	0.7	2.6	0.8	1.7	6.3
	Triethanolamine	4.8	0.2	3.1	0.9	2.4	11
	Urea	7.5	4.8	9.9	11	15	18
	Sodium chloride	98	0.9	55	1.0	230	230
	Sodium carbonate	242	0.0	130	0.0	570	570
	Sodium sulfate	51	0.5	28	0.5	120	120

TABLE 12

CONCENTRATIONS OF CHALLENGE/PROBLEM CONTAMINANTS IN TREATED WASTEWATER PRIOR TO REUSE FOR AN INFINITE NUMBER OF RECYCLES (80% CONVERSION)

Wastewater Source	Contaminant	x_1 (mg/liter)	x_y (mg/liter) UF-RO	UF	Pretreat - ACA-IX	ERDLator	Dilution
Shower	Ethanol	84	82	180	160	240	340
	Isopropanol	105	9.0	89	59	130	420
	Glycerol	2.8	0.3	2.6	2.4	5.2	11
	Lactic acid	5.0	1.6	6.4	1.8	3.9	20
	Triethanolamine	7.5	0.4	5.9	1.6	4.6	30
	Urea	3.0	2.4	5.8	6.4	10	12
	Sodium chloride	180	1.8	130	2.0	720	720
Laundry	Ethanol	1.4	1.3	3.0	2.7	4.0	5.6
	Urea	13	11	25	28	44	52
	Sodium carbonate	533	0.0	360	0.0	2,100	2,100
	Sodium sulfate	112	1.1	78	1.3	450	450
Composite	Ethanol	47	46	100	89	130	190
	Isopropanol	57	4.9	49	32	73	230
	Glycerol	1.5	0.2	1.4	1.3	2.8	6.0
	Lactic acid	2.7	0.9	3.4	1.0	2.1	11
	Triethanolamine	4.8	0.3	3.8	1.0	2.9	19
	Urea	7.5	6.1	15	16	25	30
	Sodium chloride	98	1.0	68	1.1	390	390
	Sodium carbonate	242	0.0	160	0.0	960	960
	Sodium sulfate	51	0.5	35	0.6	200	200

TABLE 13

CONCENTRATIONS OF CHALLENGE/PROBLEM CONTAMINANTS IN TREATED WASTEWATER PRIOR TO REUSE FOR AN INFINITE NUMBER OF RECYCLES (90% CONVERSION)

Wastewater Source	Contaminant	x_1 (mg/liter)	x y (mg/liter)				
			UF-RO	UF	Pretreat - ACA-IX	ERDLator	Dilution
Shower	Ethanol	84	100	280	240	410	760
	Isopropanol	105	10	114	71	180	950
	Glycerol	2.8	0.4	3.3	3.0	7.6	11
	Lactic acid	5.0	1.9	8.5	2.1	5.0	45
	Triethanolamine	7.5	0.5	7.5	1.8	5.7	68
	Urea	3.0	3.0	8.5	9.8	20	27
	Sodium chloride	180	2.0	150	2.4	1,600	1,600
Laundry	Ethanol	1.4	1.7	4.7	3.9	6.8	13
	Urea	13	13	37	42	87	120
	Sodium carbonate	533	0.0	436	0.0	4,800	4,800
	Sodium sulfate	112	1.3	95	1.5	1,000	1,000
Composite	Ethanol	47	58	160	130	230	420
	Isopropanol	57	5.6	62	38	97	510
	Glycerol	1.5	0.2	1.8	1.6	4.1	14
	Lactic acid	2.7	1.0	4.6	1.1	2.7	24
	Triethanolamine	4.8	0.3	4.8	1.2	3.6	43
	Urea	7.5	7.6	21	24	50	68
	Sodium chloride	98	1.1	84	1.3	880	880
	Sodium carbonate	242	0.0	200	0.0	2,200	2,200
	Sodium sulfate	51	0.6	43	0.7	460	460

D. DISCUSSION AND CONCLUSIONS

Engineering aspects of treatment and reuse of water for non-potable purposes have been reviewed and sufficient data are available to allow the choice of a prototype wastewater treatment system for short-term field Army use. However, choice of such a system depends not only on engineering factors but also on: supply and support logistics, tactical requirements, toxicology and esthetics. Given that toxicity appears to be a minor factor, it would seem that logistics, tactical requirements and esthetics will be the dominant factors in system specification.

Requirements for short-term use (7 days or less) may be such that making do with a very limited water supply may be preferable to transporting and maintaining a wastewater treatment system to provide high quality water. Alternatively, short-term reuse of wastewater with minimal treatment may be the best tactical choice in situations where esthetics are secondary to function.

If logistics and tactical requirements are the dominant factors governing the choice of a wastewater treatment system, one may consider engineering and procedural solutions to the problem of getting maximum use from limited supplies of water. Six topics bear on a wastewater treatment system for short-term use:

- General considerations
- Engineering systems versus conversion ratio
- Special product formulations
- Pre-rinse
- Simplest system
- Sophisticated treatment systems

1. General Considerations

The most important procedural factor which should be considered is the possible danger of using treated laundry wastewaters for shower use. Several types of materials potentially present on clothes could present serious risks to the health (combat readiness) of Army personnel. These materials include: biological agents, chemical agents, lubrication products, solvents, fuels, and septic wastes. It is recommended that treated laundry wastewaters not be used for showers. Treated shower waters might, however, be used for laundering. It seems likely that conservation of water in laundries may be limited to the normal practice of counter-current flow of laundered items and water, with the cleanest water being used for final rinsing of laundered products.

2. Engineering Systems Versus Conversion Ratio

Data of Tables 6-8 were assessed to determine, for each treatment system, the poorest removal efficiencies. These poor removal efficiencies and similar data for conversion ratios below 70% are plotted in Figure 2. This figure can be used to assess the effects of various conversion ratios and treatment systems on the build-up of difficult-to-treat wastewater contaminants.

A hypothetical case is considered in which health, esthetic, or cleansing criteria dictate that wastewater contaminant build-up be limited to a 3-fold concentration increase. For either the UF-RO or the ACA-IX systems this presents no problem since at all conversion ratios, buildup is no greater than 1.2. For the UF system, the contaminant build up is less than 3-fold for conversion ratios below 0.87.

For the ERDLator or Dilution systems, conversion ratios are limited to 0.75 or less. Thus, if 75% conversion ratio is adequate, any of the systems would do in this hypothetical case. If 85% conversion ratio is required, only three of the five systems qualify.

3. Special Product Formulation

An alternative means of improving water reuse would be to use specially formulated products in showers or laundries. Concentrations of potentially toxic substances could be lowered. Products could be reformulated to function at higher levels of total dissolved solids. Such products are presently available for such applications as washing with saline water.

4. Pre-rinse

An operational procedure which could be implemented as required would be to require a shower pre-rinse and/or laundry pre-wash. These pre-rinse and pre-wash waters would be the waters marked concentrate discharge in Figure 1, which in the case of the "dilution system" would be as clean as the treated wastewater. After use, the pre-rinse and pre-wash waters would be discarded without treatment.

5. Simplest Treatment System

If it meets health and esthetic criteria (yet to be specified), a simple dilution system with a sandfilter and chlorination would be an eminently practical system for maximizing use of limited water supplies. Such a system, consisting of a sand filter, flow splitter and chlorination unit could be constructed as a lightweight, very reliable unit possibly as a part of a portable shower or laundry unit. It would be not so much a system but rather a means of replumbing existing showers and laundries to allow for water reuse as necessary.

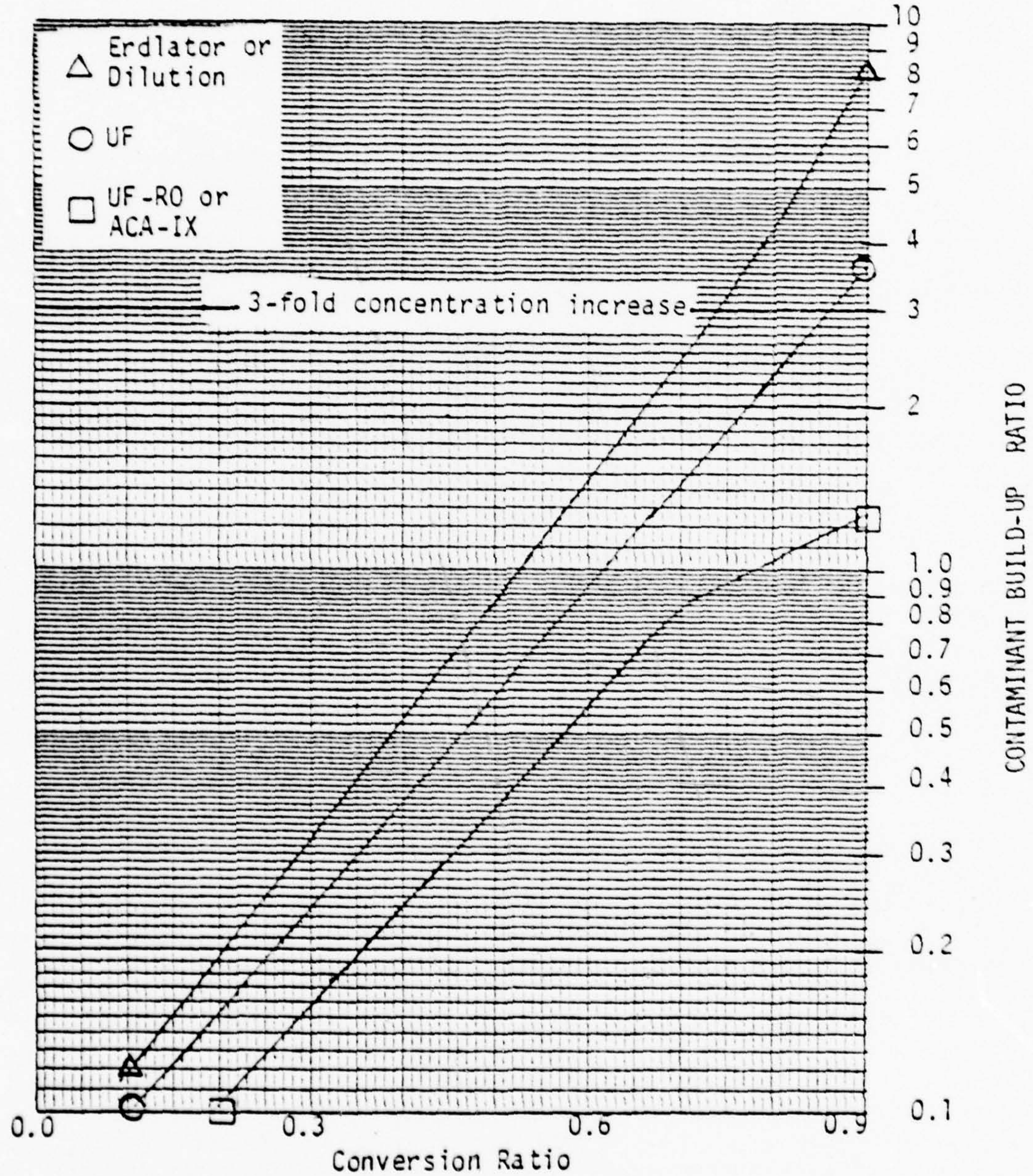


FIGURE 2

COMPARISON OF TREATMENT SYSTEMS
FOR VARIOUS CONVERSION RATIOS

6. Sophisticated Treatment Systems

Sophisticated systems for wastewater treatment are not likely to be chosen for applications involving short-term reuse for non-potable uses such as showers and laundries of field Army units. Apparently, the logistical factors are such that, for the short time periods involved (7 days or less) field Army units will use existing systems; use simple treatment systems; or do without showers and laundries. For larger periods of time, the options are supplying water by pipeline with only a single quality water (potable) or installing and operating wastewater treatment systems to supply water for non-potable uses.

In conclusion, many factors will affect the choice of a wastewater treatment system to provide water for short-term reuse in showers and laundries by field Army units. Toxicity data from the companion report entitled "Health Effects Data on the Reuse of Shower and Laundry Waters by Field Army Units: Toxicology Data on Individual Components," indicate that these wastewaters are not expected to produce toxic effects. The present engineering evaluation provides sufficient data for choice of a treatment system to meet any particular health or esthetic criteria and water reuse goal. The more stringent these criteria are, the more complex the required treatment system is likely to be.

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TASK III - TOXICITY EVALUATION

APPROACH

Toxicity data were sought for each of the compounds predicted to be present in shower or laundry waters (Tables 5, 6, 7 and 14). Oral, dermal and ocular toxicity were considered. The factors most strongly influencing the toxicity of particular compounds were assumed to be: inherent chemical reactivity, chemical formulation (e.g., powder, suspension, emulsion, solution), transformation products (e.g., products of chlorination), concentration, and exposure time. References listed in the bibliography were consulted for toxicity data. Data were assembled on a compound-by-compound basis. Notations of test compound concentration, test duration, etc. were made.

It is essential to point out that toxicity data are not available in a specified set of tables. Rather they are an amorphous body of approximations of the averaging of millions of observations in many species of animals under a great variety of experimental conditions.

The data presented here have been culled from the published observations of physicians, chemists and biologists. They have been the results of research sponsored by private industry, research organizations and governmental agencies. Data have often been presented with entirely different bias and objectives. Differences in experimental protocols and design, contradictions in terminology and interpretation as well as gross omissions are rife and ever-present. The greater part of the data has been accumulated through animal experimentation. Much of it has not been directly correlated or corroborated with human exposure. Despite these deficiencies, steady improvement over the past few decades is very evident and this effort is made to reveal the data gaps and to show how they might be eliminated.

Human or animal toxicity can be described as unwanted, harmful or adverse effects on the individual. There are more than 20 factors that can influence the toxicity of a chemical or compound. Factors which may influence the toxicity of recycled shower and laundry wastewater include:

(1) Inherent chemical reactivity of each compound. Some compounds such as kaolin are relatively inert while others such as sodium hydroxide are very active in their interaction with animal tissue or other chemicals.

(2) The chemical formulation of a compound may often determine how active the product might be. The compound might take the form of a powder, solution, suspension of particles or an emulsion. It may also be made more or less reactive by virtue of the solvent used.

TABLE 14

LIST OF INDIVIDUAL COMPONENTS

Alkyl aryl sulfonate	Kaolin, colloidal	Sodium lauryl sulfate
Alumina (powder)	Kaolinite	Sodium ortho phenylphenolate
Aluminum chlorhydrate	Lactic acid	Sodium saccharin
Aluminum chloride	Lanolin	Sodium silicate
Aluminum formate	Linear alkylbenzene sulfonate	Sodium stearate
Aluminum hydroxide gel	Magnesium carbonate	Sodium sulfate
Aluminum sulfate	Magnesium oxide	Sodium tripolyphosphate
Ammonium alum	Methyl paraben	Sorbitan monostearate
Ammonium lauryl sulfate	Mineral oil	Sorbitol
Bees wax	Nitrilotriacetate	Spermaceti
Bentonite	Oleic acid	Stannous fluoride
Boric acid	Petrolatum	Stearic acid
Calcium carbonate	Polyethlene sorbitan monostearate	Sulfonated castor oil
Castor oil	Potassium	Sulfonated olive oil
Cetyl alcohol	Potassium hydroxide	Talc
Coconut diethanolamide	Potassium oleate	Tallow
Coconut oil	Propoxylated PABA	Tannic acid
Corn starch	Propylene glycol	Tegacid
Dicalcium phosphate	Protease	Tricalcium phosphate
N,N-Diethyl-m-toluamide	Silica flour	Triethanolamine
Epithelium	Sodium alkylbenzene sulfonate	Triethanolamine alkylbenzene-sulfonate
Ethanol	Sodium carbonate	Tween 80
Ethoxylated lauryl alcohol	Sodium carboxymethyl cellulose	Ultrawet 60L
Glycerol	Sodium chloride	Urea
Glycerol monostearate	Sodium-4-chloro-2-phenylphenolate	Veegum
Hair	Sodium-6-chloro-2-phenylphenolate	Vegetable oil
Hexachlorophene	Sodium dodecyl benzene sulfonate	Volatile silicone
Isopropyl alcohol	Sodium fluosilicate	Whitening agents
Isopropyl myristate	Sodium hydroxide	Zinc chloride
Isopropyl palmitate		Zinc stearate
Jamaican rum		

(3) Chemicals may interact with each other. For example, chlorine bleach and complex organic compounds can react to form transformation products with entirely different physical and physiological activities than the starting compounds.

(4) Finally, toxicity is markedly influenced by increased concentrations of most chemicals and by increase in the time of exposure.

RESULTS

The toxicity data for individual wastewater components did not indicate that human toxic responses would be expected from short-term shower or laundry water reuse by field Army units. However, at least some data were lacking for 36 compounds. Previous Army-sponsored toxicology testing of shower and laundry wastewaters gives further evidence that no toxic responses are expected for the wastewaters.

Literature survey results are presented in detail in Appendix II. For the concentrations of substances expected in shower, laundry, or mixed wastewaters, available data do not indicate that toxic responses are to be expected for shower and laundry water reuse. Compounds for which toxicity were not found are indicated in Table 15.

From an appraisal of toxicity data, it would appear that ocular toxicity is probably the most sensitive human endpoint of toxicity. It is discouraging to note that in the compilation of toxicity data, the greatest data gap occurs in ocular toxicity in regard to activity of the pure chemical, at different concentrations and for various times of exposure.

Another area which may be very troublesome is the paucity of data concerned with dermal sensitization and photosensitization. The following list of compounds is illustrative of chemicals that have been shown to cause dermal sensitization. Some of these are further activated when skin so exposed is subjected to bright light such as sunlight:

nickel	propylene glycol
protease	triethanolamine
parabens	sorbic acid
lanolin	hexachlorophene

TABLE 15

COMPOUNDS FOR WHICH TOXICITY DATA WERE LACKING

Compound	Oral	Skin	Eyes
Aluminum chloride			X
Aluminum formate			X
Aluminum hydroxide			X
Aluminum sulfate			X
Bentonite			X
Castor oil			X
Cetyl alcohol	X		
Corn starch			X
Dicalcium phosphate			X
Ethoxylated lauryl alcohol	X	X	X
Glycerol monostearate	X	X	X
Isopropyl myristate			X
Isopropyl palmitate	X		X
Lanolin			X
Magnesium carbonate			X
Magnesium oxide			X
Methyl paraben			X
Potassium oleate			X
Polyethylene sorbitol monostearate			X
Propoxylated PABA			X
Sodium-4-chloro-2-phenyl phenolate	X		X
Sodium-6-chloro-2-phenyl phenolate	X		X
Sodium dodecyl benzene sulfonate	X		X
Sodium ortho-phenyl phenolate	X		X
Sodium saccharin			X
Sodium silicate			X
Sodium stearate			X
Sodium sulfate			X
Sorbitol			X
Spermaceti	X	X	X
Sulfonated castor oil	X	X	X
Tegacid	X	X	X
Tricalcium phosphate			X
Veegum	X	X	X
Whitening agents	X	X	X
Zinc stearate			X

CONCLUSIONS

No protocol has been established specifically for the assessment of health effects due to shower and laundry water reuse. The present assessment is based on the following assumptions:

(1) toxicity data are required for compounds at concentrations expected in treated, recycled wastewaters.

(2) ocular and dermal exposures of several minutes duration are to be expected,

(3) oral exposures will be minimal, amounting to only a few milliliters of recycled water per shower.

Since the consequences of ocular toxicity can be very serious to the individual and to a unit's combat readiness, good estimates of human ocular toxicity (based on animal tests) are important. Dermal irritation and sensitization data can be acquired through animal testing or with human volunteers. Due to the minimal oral exposure, highly precise data may not be required.

Available toxicity data are incomplete. Neither complete data for individual wastewater components nor complete data for well characterized wastewaters (synthetic or actual) are available. Such data as are available indicate that no toxic effects are to be expected from short-term reuse of shower and laundry waters by field Army units.

TASK IV - EVALUATION OF ARMY SPONSORED RESEARCH

Four reports of Army-sponsored research were evaluated to determine the extent to which they provided information applicable to an assessment of the health effects of shower and laundry water reuse by field Army units. These reports are considered below in chronological order.

R.G. Tardiff and J. L. Mullaney prepared a report on "The Compounds in the 'Must' Waste Water as They Relate to Hazards in the Product Water: A Toxicity Evaluation", (1973). Industrial product identities and their concentrations were furnished by the U.S. Army Medical Research and Development Command. Tardiff and Mullaney determined the concentrations of product components, performed a literature search and provided lists of: (1) compounds requiring no further study, (2) compounds requiring control (treatment) in product (recycle) water, and compounds requiring additional study. The report was extremely concise but adequately documented with references and appendices. There was no discussion of the basis for compound classification, no discussion of the effects of compound concentration or exposure time on toxic responses, no discussion of the applicability of retrieved data to water reuse, and no discussion regarding the specification of a toxicology protocol for wate reuse evaluation. Such matters were left to the judgement of the sponsor. Much of the data presented in the appendices applies to the compounds in concentrated form and is thus not applicable to evaluations of water reuse.

Of the 104 compounds studied, three which appear in the present report were found to require treatment: boric acid, hexachlorophene, and tripolyphosphates. Three compounds were found to require further study, N,N-diethyl-m-toluamide, isopropyl myristate, and oleic acid.

Bernard P. McNamara prepared a report, "Toxicology Program on Certain MUST Wastewater Components," (1974). Included in his tests of nine compounds (or mixtures) were tests of two substances found in shower wastewaters: pyrogallol and isopropyl myristate. The tests of dermal absorption, skin irritancy, eye irritancy, and skin sensitization were carefully performed according to accepted protocols. The first three tests were performed with pure compounds according to protocols not necessarily applicable to the evaluation of health effects of water reuse. Isopropyl myristate was shown to be not toxic by dermal sorption, not a skin irritant, not an eye irritant, and not a skin sensitizing agent. At the low concentrations expected in shower wastewaters it would be expected to be non-toxic by these tests. Pyrogallol was shown to be not toxic by dermal sorption, not a primary skin irritant, a positive eye irritant, and a possible skin sensitizer. At the low concentrations present in shower wastewaters, pyrogallol might or might not be an eye irritant.

Robert B. Grieves and Dibakar Bhattacharyya prepared a report on "Membrane Ultrafltration to Treat Non-Sanitary Military Wastes," (1976). Their tests of synthetic and actual shower and laundry wastewaters demonstrated that ultrafiltration can be used to effectively treat these wastewaters to provide recyclable water up to at least 90% water conversion. They provided wastewaters, ultrafiltrate (permeate) of treated wastewaters, and concentrates of treated wastewaters to Witherup and Emmett for toxicological investigations.

Sylvan Witherup and Edward A. Emmett prepared a report on "The Toxicity and Irritancy of Ultrafiltrates of Non-Sanitary Military Wastes," (1977). Witherup and Emmett tested the samples provided by Grieves and Bhattacharyya as well as freeze-dry concentrates of the samples. Except when the freeze-dry concentrates were used, no toxic effects were noted in ocular, dermal, or oral toxicity tests. The freeze-dry concentrates with solids contents in the range of 2 to 9% did produce toxic responses as might be expected of many substances. Though strictly applicable only to the wastewaters tested, the results of Witherup and Emmett tend to confirm that at least for some wastewaters, neither the untreated nor treated wastewaters produce toxic responses at concentrations expected in field Army situations.

SUMMARY AND CONCLUSIONS

In attempting to assess health effects of water reuse, we have learned that at least under certain conditions, limited water reuse is likely to benefit the soldier. Benefits of water reuse can be maximized if, for a carefully defined reuse scenario, we delineate the basis for health effects criteria. What kinds of tests under which conditions, and on which test groups, need to be performed to assess the health effects of water reuse?

Of all possible kinds of water reuse, consideration has been limited to short-term shower and laundry water reuse by field Army units. These are high-volume uses under field Army conditions which can be readily segregated from other uses. Both the wastewaters and the users of the recycled water are well-defined and subject to a degree of control which will minimize health impacts. One need worry neither about septic wastes nor about unusually sensitive water users (e.g., infants, elderly persons, or medical patients). Concern may be focused on possible acute effects, since exposure would be too short to produce chronic effects.

Results achieved to date indicate that it should be possible to treat and reuse shower and laundry waters without any significant health effects. Literature studies have uncovered no data to indicate adverse health effects. Animal and human (skin patch) tests of wastewater and wastewater concentrates indicate no adverse health effects (oral, dermal or ocular) at concentrations up to several times those expected in treated, recycled water.

Since the present evaluation suggests there will be no adverse effects, what further tests are required to establish the safety, without question, of shower and laundry water reuse by field Army units? If the answer is to be obtained under conditions other than battlefield conditions, human clinical trials must be performed.

U.S. Army Medical Research and Development Command Regulation No. 70-25, "Use of Human Subjects in Research Development, Test, and Evaluation," establishes procedures for conduct of human clinical trials. This regulation specifies three conditions which must be satisfied before and during the conduct of human clinical trials: adequate scientific justification, adoption of appropriate measures to minimize risk, and adoption of administrative review procedures.

A human clinical trial is scientifically justified if the benefits of the study (importance of the knowledge to be obtained) outweigh the risks to test subjects, and if the results are not obtainable except by means of a human clinical trial. This is phrased in various ways in paragraphs 1-5-2a, 1-5-2e, and 2-4-2a of the regulation.

Measures to minimize risk to human test subjects include provisions for: qualified personnel to conduct the study (paragraph 1-5-2g and 2-3a); consent of human test subjects (1-5-1); adequate facilities for conducting the test and for administration of any medical treatment that might be necessary (1-5-2f, 2-3b, 2-3d); sufficient animal or laboratory experiments or other evaluations to give assurance of acceptable risk prior to use of human subjects (1-5-2d); a written research proposal to be reviewed either by HQDA (SGRD-RP) in the case of civilian contractors or by HQDA (DASG-RDZ-H) in the case of USAMRDC laboratories (1-12); and research protocols (2-5, 3-4a, 3-8). Of these measures to minimize risk to human test subjects, conditions pertaining to subject consent are covered in the most detail. Consent must be voluntarily given and the subject must be fully informed of the value of the tests and the risks associated with the tests. The subject must be free to withdraw his consent at any time prior to or during the study without penalty. "It should be emphasized that the essence of voluntary, informed consent is a full discussion of the nature of the study by a scientifically competent person with the prospective human subject, in the presence of a witness not directly involved in the project." Thus, the scientific justification for the study and the risks of the study are assessed by: the planners of the study, the qualified persons conducting the study, and the subjects of the study.

Administrative review procedures have been specified to insure that the spirit and letter of the regulations are followed. These procedures include: Surgeon General approval of all studies before they may commence (paragraph 1-6), filing of assurances and certificates prior to study commencement (3-4, 3-5); establishment of a human use committee with continuing review responsibilities (2-4-1, 2-4-2, Appendix D); and detailed procedures for record-keeping to verify compliance with regulations (1-13).

It is recommended that consideration be given to:

(1) Preparation of an assessment of the benefits of short-term shower and laundry water reuse by field Army units. This assessment should be phrased in terms meaningful to members of the U. S. Army Medical Research and Development Command and other Army officials; to members of a human use Committee as defined in USAMRDC Regulation 70-25, paragraph 2-4-1; and to prospective human test subjects for a clinical trial. At least preliminary estimates of acceptable engineering configurations and performance characteristics of suitable wastewater treatment systems should be specified, including a target value for the extent of water recycle.

(2) Preparation of an assessment of acceptable risks associated with short-term shower and laundry water reuse in a combat situation. Topics covered might include digestive tract irritation due to accidental ingestion, skin irritation, and eye irritation.

(3) Preparation of criteria defining acceptable risks for human test subjects in clinical trials of water reuse. Acceptable (and unacceptable) toxic symptoms should be defined together with the minimum professional qualifications to be possessed by the person or persons responsible for evaluation of toxic responses in human test subjects.

(4) Preparation of a protocol for animal studies designed to assess the possibility of human toxic response to shower and laundry water reuse. The protocol must specify the composition of products to be used during showering or laundering, the wastewater treatment system to be used and its mode of operation, chemical analysis to be performed, and responses to be monitored. It should also specify criteria for test adequacy, i.e., criteria for cessation of animal tests and for consideration of human clinical trials.

(5) Preparation of a protocol for human clinical trials of short-term shower and laundry water reuse. It is assumed that human clinical trials would be proposed only after assessments have been completed for: benefits to be expected, acceptable risks in a combat situation, acceptable risks for human test subjects, and likely risks for test subjects as projected from animal studies. The human use protocol should then focus on early detection and treatment of toxic symptoms which might arise during the course of the clinical trials.

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APPENDIX I

MATHEMATICAL DERIVATION OF EQUATIONS FOR CONCENTRATION BUILD-UP OF WASTEWATER CONTAMINANTS

It is assumed that the treatment system is operated at constant conversion (Z) and that the circulation rate of the recycle is constant due to the addition of uncontaminated make-up water. It also is assumed that there is a constant input of contaminants from the shower/laundry operation (x_1) which is additive to the contaminants present in the recycled water (x_n).

The fraction of unremoved chemical contaminant for each cycle (y) is a function of the removal efficiencies for the two processes (R_1 and R_2) and the conversion:

$$y = (1-R_1)(1-R_2)Z \qquad (1)$$

The contaminant concentrations after one cycle (x_2, n= 1), two cycles (x_3, n= 2), and three cycles (x_4, n= 3) are given as

$$x_2 = x_1y+x_1$$

$$x_3 = x_2y+x_1$$

$$x_4 = x_3y+x_1$$

The equation for x_4 as a function of x_1 and y is

$$x_4 = [(x_1y+x_1)y+x_1]\ y+x_1$$
$$= x_1 + x_1(y^3+y^2+y)$$

By induction, the contaminant concentration after n cycles (x_{n+1}) is given as

$$x_{n+1} = x_1(1+S_n)$$

where $S_n = \sum_{k=1}^{n} y^k$

The series S_n is a geometrical progression with common ratio y which is also given as

$$S_n = \frac{y(1-y^n)}{1-y}$$

Therefore,

$$X_{n+1} = X_1\left[1 + \frac{y(1-y^n)}{1-y}\right] \qquad (2)$$

For an infinite number of recycles, the expression simplifies as follows:

Since $y < 1$ and $$S_n + \frac{y(1-y^n)}{1-y} \quad \frac{y}{1-y} \quad \frac{y^{n+1}}{1-y}$$

as $n \quad \infty$, $y^{n+1} \quad 0$ and $S_n \quad \frac{y}{1-y}$

Therefore, for the convergent infinite series

$$x_\infty = x_1\left(1 + \frac{y}{1-y}\right) \quad \frac{x_1}{1-y} \qquad (3)$$

Thus, there is an upper limit on the concentration build-up of wastewater contaminants. In the worst case, where the contaminant passes unaffected through the treatment system (or where there is no treatment other than dilution with make-up water), the fraction of unremoved contaminant per cycle becomes equal to the recycle ratio:

$$_\infty = \frac{x_1}{1-z}$$

For 80% recycle and zero removal efficiency

$$x_\infty = \frac{x_1}{1-0.80} = 5\ x_1$$

Systems with the highest treatment efficiencies for particular contaminants show virtually no build-up of those contaminants. An example is the effectiveness of the UF-RO system in removing dissolved salts such as sodium chloride and sodium sulfate.

APPENDIX II

DATA ON CHEMICALS FORMED BY CHLORINATION

Chemical created:

Cl - CH_2 - CH_2 - OH
2-chloroethanol
(ethylene chlorohydrin)

MW 80.51
vp 10 ton @ 30°C
mp -89°C
bp 129°C
p 1.2
∞ sol. H_2O
∞ sol. ethanol

Precursor:

Ethanol

Concentration of precursor:

>100 ppm

Predicted concentration of created chemical:

limited by Cl_2 concentration*, 25 ppm max.

Biological effects data for created chemical:

TLV skin	TWA 1 ppm 3 mg/m^3	STEL 1 ppm 3 mg/m^3	skin effects

Has produced fatal poisonings. Is especially dangerous because is not irritating in inhale, and is rapidly absorbed through the skin either as pure liquid or from water solution. The lethal dose for man is <5 ml when held in contact with skin. Inhalation of 2 ppm for 1 hour was fatal for rats.

LDL_0 = 5000 mg/kg (skin-human), LD_{50} = 580 μg/kg (oral-rat)
LCL_0 = 32 ppm/4 hour (inhl rat).

Effects of created chemical at predicted concentration : **Could be a serious problem even in trace amounts.**

Carcinogen analog: epichlorohydrin, vinyl chloride

Chemical created:

$Cl - CH_2 - CH - CH_3$

$\qquad\qquad\quad |$

$\qquad\qquad\; OH$

1-chloro-isopropyl alcohol

Precursor:

Isopropyl alcohol

Concentration of precursor:

>100 ppm

Predicted concentration of created chemical:

limited by Cl_2 concentration*, 25 ppm max.

Biological effects data for created chemical:

Presumed similar to ethylene chlorohydrine

For 2-chloro-1-propanol (UA89250)

LD_{50} = 220 mg/kg (oral-rat)

LCL_0 = 500 ppm/4 h (inhl-rat)

LDL_0 = 200 mg/kg (oral-dog)

LD_{50} = 480 mg/kg (skin-rabbit)

LD_{50} = 720 mg/kg (guinea pig-oral)

Effects of created chemical at predicted concentration: No data available.

Chemical created:

$$Cl - HN - \overset{\displaystyle O}{\overset{\|}{C}} - NH_2, \quad Cl_2 - N - \overset{\displaystyle O}{\overset{\|}{C}} - NH_2$$

mono and di-N-chloramides

Precursor:

urea

Concentration of precursor:

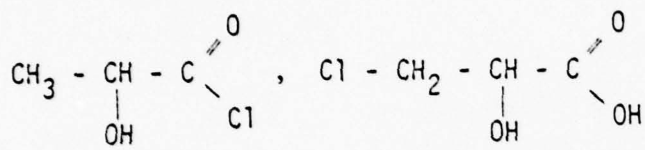
10 ppm

Predicted concentration of created chemical:

>90% should be destroyed by Cl_2; 1 ppm max. remains

Biological effects data for created chemical: **No data available.**

Chemical created:



acid chloride chlor acid

Precursor:

Lactic acid

Concentration of precursor:

3 ppm

Predicted concentration of created chemical:

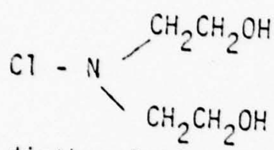
1 ppm

Biological effects data for created chemical:

For 3 - chloropropionic acid (UE87500)

LDL_0 = 1,040 mg/kg (skin-mouse)

Chemical created:



diethanolchloroamine

Precursor:

Triethanolamine

Concentration of precursor:

5 ppm

Predicted concentration of created chemical:

2 ppm

Chemical created:

$$Cl - CH_2 - \underset{\displaystyle OH}{\underset{|}{CH}} - \underset{\displaystyle OH}{\underset{|}{CH_2}}$$

3-chloro propylene glycol
1-chloropropane-2,3-diol

Precursor:

Propylene glycol

Concentration of precursor:

<200 ppb

Predicted concentration of created chemical:

<100 ppb

Biological effects data for created chemical:

For 1-chloropropane-2,3-diol (TY40250)

LD_{50} = 150 mg/kg (oral-rat)
LCL_o = 125 ppm/4 hr (inhl-rat)
LDL_o = 10 mg/kg (ipr-rat)
LD_{50} = 160 mg/kg (oral-mouse)
LD_{50} = 73 mg/kg (ipr-mouse)

APPENDIX III

DATA ON WASTEWATER TREATMENT SYSTEM PERFORMANCE IN A RECYCLE MODE

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, X_1 (mg/liter)	(RO rej = R UF rej = 0.4R) Process Removal Efficiencies R	Fraction of unremoved contaminant, $y = 0.7 - .98R + .28R^2$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.431	147.6	63.6
	Isopropanol	105	0.85	0.069	112.8	7.8
	Glycerol	2.8	0.80	0.095	3.1	0.3
	Lactic acid	5.0	0.60	0.213	6.4	1.4
	Triethanolamine	7.5	0.90	0.045	7.9	0.4
	Urea	3.0	0.35	0.391	4.9	1.9
	Sodium chloride	180	0.98	0.009	181.6	1.6
Laundry	Ethanol	1.4	0.30	0.431	2.5	1.1
	Urea	13	0.35	0.391	21.4	8.4
	Sodium carbonate	533	1.00	0.000	533	0.0
	Sodium sulfate	112	0.98	0.009	113	1.0
Composite	Ethanol	47	0.30	0.431	82.6	35.6
	Isopropanol	57	0.85	0.069	61.2	4.2
	Glycerol	1.5	0.80	0.095	1.7	0.2
	Lactic acid	2.7	0.60	0.213	3.4	0.7
	Triethanolamine	4.8	0.90	0.045	5.0	0.2
	Urea	7.5	0.35	0.391	12.3	4.8
	Sodium chloride	98	0.98	0.009	99	0.89
	Sodium carbonate	242	1.00	0.000	242	0.0
	Sodium sulfate	51	0.98	0.009	51.5	0.5

System: UF-RO

Conversion: 70%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R UF rej = 0.4R) Process Removal Efficiencies R	Fraction of unremoved contaminant $y = 0.8 - 1.12R + 0.32R^2$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.493	166	82
	Isopropanol	105	0.85	0.079	114	9
	Glycerol	2.8	0.80	0.108	3.1	0.3
	Lactic acid	5.0	0.60	0.243	6.6	1.6
	Triethanolamine	7.5	0.90	0.050	7.9	0.4
	Urea	3.0	0.35	0.447	5.4	2.4
	Sodium chloride	180	0.98	0.010	182	1.8
Laundry	Ethanol	1.4	0.30	0.493	2.7	1.3
	Urea	13	0.35	0.447	23.6	10.5
	Sodium carbonate	533	1.00	0.000	533	0.0
	Sodium sulfate	112	0.98	0.010	113	1.1
Composite	Ethanol	47	0.30	0.493	93	46
	Isopropanol	57	0.85	0.079	62	4.9
	Glycerol	1.5	0.80	0.108	1.7	0.2
	Lactic acid	2.7	0.60	0.243	3.6	0.9
	Triethanolamine	4.8	0.90	0.05	5.1	0.3
	Urea	7.5	0.35	0.447	13.6	6.1
	Sodium chloride	98	0.98	0.010	99	1.0
	Sodium carbonate	242	1.00	0.000	242	0.0
	Sodium sulfate	51	0.98	0.010	52	0.5

System: UF-RO

Conversion: 80%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R UF rej = 0.4R) Process Removal Efficiencies R	Fraction of unremoved contaminant, $y = 0.9 - 1.26R + .36R^2$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.554	188	104
	Isopropanol	105	0.85	0.089	115	10.3
	Glycerol	2.8	0.80	0.122	3.2	0.4
	Lactic acid	5.0	0.60	0.274	6.9	1.9
	Triethanolamine	7.5	0.90	0.058	8.0	0.5
	Urea	3.0	0.35	0.503	6.0	3.0
	Sodium chloride	180	0.98	0.011	182	2.0
Laundry	Ethanol	1.4	0.30	0.554	3.1	1.7
	Urea	13	0.35	0.503	26.2	13.2
	Sodium carbonate	533	1.00	0.000	533	0.0
	Sodium sulfate	112	0.98	0.011	113.3	1.3
Composite	Ethanol	47	0.30	0.554	105	58.4
	Isopropanol	57	0.85	0.089	62.6	5.6
	Glycerol	1.5	0.80	0.122	1.7	0.2
	Lactic acid	2.7	0.60	0.274	3.7	1.0
	Triethanolamine	4.8	0.90	0.058	5.1	0.3
	Urea	7.5	0.35	0.503	15.1	7.6
	Sodium chloride	98	0.98	0.011	99.1	1.1
	Sodium carbonate	242	1.00	0.000	242	0.0
	Sodium sulfate	51	0.98	0.011	51.6	0.6

System: UF-RO

Conversion: 90%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R UF rej = 0.5R) Process Removal Efficiencies R	Fraction of unremoved contaminant, $y = 0.7 - 0.35R$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.60	210.0	126
	Isopropanol	105	0.85	0.40	175.0	70
	Glycerol	2.8	0.80	0.42	4.8	2.0
	Lactic acid	5.0	0.60	0.49	9.8	4.8
	Triethanolamine	7.5	0.90	0.39	12.3	4.8
	Urea	3.0	0.35	0.58	7.1	4.1
	Sodium chloride	180	0.98	0.36	281	101
Laundry	Ethanol	1.4	0.30	0.60	3.50	2.1
	Urea	13	0.35	0.58	31.0	18.0
	Sodium carbonate	533	1.00	0.35	820	287
	Sodium sulfate	112	0.98	0.36	175	0.5
Composite	Ethanol	47	0.30	0.60	117.5	70.5
	Isopropanol	57	0.85	0.40	95.0	38
	Glycerol	1.5	0.80	0.42	2.6	1.1
	Lactic acid	2.7	0.60	0.49	5.3	2.6
	Triethanolamine	4.8	0.90	0.39	7.9	3.1
	Urea	7.5	0.35	0.57	17.4	9.9
	Sodium chloride	98	0.98	0.36	153	55.1
	Sodium carbonate	242	1.00	0.35	372	130
	Sodium sulfate	51	0.98	0.36	79.7	27.9

System: UF

Conversion: 70%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R UF rej = 0.5R) Process Removal Efficiencies R	Fraction of unremoved contaminant, $y = 0.8 - 0.4R$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 \left(1 + \frac{y}{1-y}\right)$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.68	263	179
	Isopropanol	105	0.85	0.46	194	89
	Glycerol	2.8	0.80	0.48	5.4	2.6
	Lactic acid	5.0	0.60	0.56	11.4	6.4
	Triethanolamine	7.5	0.90	0.44	13.4	5.9
	Urea	3.0	0.35	0.66	8.8	5.8
	Sodium chloride	180	0.98	0.41	305	125
Laundry	Ethanol	1.4	0.30	0.68	4.4	3.0
	Urea	13	0.35	0.66	38	25
	Sodium carbonate	533	1.00	0.40	888	355
	Sodium sulfate	112	0.98	0.41	190	78
Composite	Ethanol	47	0.30	0.68	147	100
	Isopropanol	57	0.85	0.46	106	49
	Glycerol	1.5	0.80	0.48	2.9	1.4
	Lactic acid	2.7	0.60	0.56	6.1	3.4
	Triethanolamine	4.8	0.90	0.44	8.6	3.8
	Urea	7.5	0.35	0.66	22	14.5
	Sodium chloride	98	0.98	0.41	166	68
	Sodium carbonate	242	1.00	0.40	403	161
	Sodium sulfate	51	0.98	0.41	86	35

System: UF

Conversion: 80%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R UF rej = 0.5R) Process Removal Efficiencies R	Fraction of unremoved contaminant, $y = 0.9 - 0.45R$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.77	365	281
	Isopropanol	105	0.85	0.52	219	114
	Glycerol	2.8	0.80	0.54	6.1	3.3
	Lactic acid	5.0	0.60	0.63	13.5	8.5
	Triethanolamine	7.5	0.90	0.50	15.0	7.5
	Urea	3.0	0.35	0.74	11.5	8.5
	Sodium chloride	180	0.98	0.46	333	153
Laundry	Ethanol	1.4	0.30	0.77	6.1	4.7
	Urea	13	0.35	0.74	50	37
	Sodium carbonate	533	1.00	0.45	969	436
	Sodium sulfate	112	0.98	0.46	207	95
Composite	Ethanol	47	0.30	0.77	204	157
	Isopropanol	57	0.85	0.52	118.8	61.8
	Glycerol	1.5	0.80	0.54	3.3	1.8
	Lactic acid	2.7	0.60	0.63	7.3	4.6
	Triethanolamine	4.8	0.90	0.50	9.6	4.8
	Urea	7.5	0.35	0.74	28.9	21.4
	Sodium chloride	98	0.98	0.46	182	83.5
	Sodium carbonate	242	1.00	0.45	440	198
	Sodium sulfate	51	0.98	0.46	94.4	43.4

System: UF

Conversion: 90%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R, Filter rej = 0.3R, Organics ACArej = A, Salts IX rej = R) Process Removal Efficiencies R	A	Fraction of unremoved contaminant, $y = 0.7 - .21R - .7(AR) + .21(R)(AR)$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.10	0.573	197	113
	Isopropanol	105	0.85	0.40	0.313	153	47.8
	Glycerol	2.8	0.80	0.25	0.399	4.7	1.9
	Lactic acid	5.0	0.60	0.60	0.230	6.5	1.5
	Triethanolamine	7.5	0.90	0.70	0.153	8.9	1.4
	Urea	3.0	0.35	0.05	0.595	7.4	4.4
	Sodium chloride	180	0.98	-	0.010	182	1.8
Laundry	Ethanol	1.4	0.30	0.10	0.573	3.3	1.9
	Urea	13	0.35	0.05	0.595	32.0	19.1
	Sodium carbonate	533	1.00	-	0.000	533	0.0
	Sodium sulfate	112	0.98	-	0.010	113	1.13
Composite	Ethanol	47	0.30	0.10	0.573	110	63
	Isopropanol	57	0.85	0.40	0.313	83	26
	Glycerol	1.5	0.80	0.25	0.399	2.5	1.0
	Lactic acid	2.7	0.60	0.60	0.230	3.5	0.8
	Triethanolamine	4.8	0.90	0.70	0.152	5.7	0.9
	Urea	7.5	0.35	0.05	0.595	18.5	11.0
	Sodium chloride	98	0.98	-	0.010	99	.99
	Sodium carbonate	242	1.00	-	0.000	242	0.0
	Sodium sulfate	51	0.98	-	0.010	51.5	0.5

System: Filter - ACA/IX

Conversion: 70%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R Filter rej = 0.3R Organics ACArej = A Salts:IX rej = R) Process Removal Efficiencies R	A	Fraction of unremoved contaminant, $y = 0.8 - 0.24R - 0.8(AR) + 0.24(R)(AR)$	Chemical concentration in wastewater for an infinite number of cycles $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.10	0.655	247	163
	Isopropanol	105	0.85	0.40	0.358	163.6	58.6
	Glycerol	2.8	0.80	0.25	0.456	5.2	2.4
	Lactic acid	5.0	0.60	0.60	0.262	6.8	1.8
	Triethanolamine	7.5	0.90	0.70	0.175	9.1	1.6
	Urea	3.0	0.35	0.05	0.680	9.4	6.4
	Sodium chloride	180	0.98	-	0.011	182	2.0
Laundry	Ethanol	1.4	0.30	0.10	0.655	4.1	2.7
	Urea	13	0.35	0.05	0.680	40.6	27.6
	Sodium carbonate	533	1.00	-	0.000	533	0.0
	Sodium sulfate	112	0.98	-	0.011	113.3	1.3
Composite	Ethanol	47	0.30	0.10	0.655	136	89.2
	Isopropanol	57	0.85	0.40	0.358	88.8	31.8
	Glycerol	1.5	0.80	0.25	0.456	2.8	1.3
	Lactic acid	2.7	0.60	0.60	0.262	3.7	1.0
	Triethanolamine	4.8	0.90	0.70	0.175	5.8	1.0
	Urea	7.5	0.35	0.05	0.680	23.4	15.9
	Sodium chloride	98	0.98	-	0.011	99.0	1.1
	Sodium carbonate	242	1.00	-	0.000	242	0.0
	Sodium sulfate	51	0.98	-	.011	51.6	0.6

System: Filter - ACA/IX

Conversion: 80%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(RO rej = R Filter rej = 0.3R Organics ACArej = A Salts IX rej = R Process Removal Efficiencies) R	A	Fraction of unremoved contaminant, $y = 0.9 - .27R - .9(AR) + .27 R(AR)$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.30	0.10	0.737	319.4	235
	Isopropanol	105	0.85	0.40	0.402	175.6	70.6
	Glycerol	2.8	0.80	0.25	0.513	5.8	3.0
	Lactic acid	5.0	0.60	0.60	0.295	7.1	2.1
	Triethanolamine	7.5	0.90	0.70	0.197	9.3	1.8
	Urea	3.0	0.35	0.05	0.765	12.8	9.8
	Sodium chloride	180	0.98	-	0.013	182	2.4
Laundry	Ethanol	1.4	0.30	0.10	0.737	5.3	3.9
	Urea	13	0.35	0.05	0.765	55.3	42.3
	Sodium carbonate	533	1.00	-	0.000	533	0.0
	Sodium sulfate	112	0.98	-	0.013	113.5	1.5
Composite	Ethanol	47	0.30	0.10	0.737	178.7	131.7
	Isopropanol	57	0.85	0.40	0.402	95.3	38.3
	Glycerol	1.5	0.80	0.25	0.513	3.1	1.6
	Lactic acid	2.7	0.60	0.60	0.295	3.8	1.1
	Triethanolamine	4.8	0.90	0.70	0.197	6.0	1.2
	Urea	7.5	0.35	0.05	0.765	31.9	24.4
	Sodium chloride	98	0.98	-	0.013	99.3	1.3
	Sodium carbonate	242	1.00	-	0.000	242	0.0
	Sodium sulfate	51	0.98	-	0.013	51.7	0.7

System: Filter - ACA/IX

Conversion: 90%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(ACA rej = A) (ERD rej = 0.75A) Process Removal Efficiencies A	Fraction of unremoved contaminant, y = 0.7 - .525A	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 (1 + \frac{y}{1-y})$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.10	0.65	240	156
	Isopropanol	105	0.40	0.49	206	101
	Glycerol	2.8	0.25	0.57	6.5	3.7
	Lactic acid	5.0	0.60	0.39	8.2	3.2
	Triethanolamine	7.5	0.70	0.33	11.2	3.7
	Urea	3.0	0.05	0.67	9.1	6.1
	Sodium chloride	180	0.00	0.70	600	420
Laundry	Ethanol	1.4	0.10	0.65	4.0	2.6
	Urea	13	0.05	0.67	39.4	26.4
	Sodium carbonate	533	0.00	0.70	1777	1244
	Sodium sulfate	112	0.00	0.70	373	261
Composite	Ethanol	47	0.10	0.65	134	87.3
	Isopropanol	57	0.40	0.49	112	54.8
	Glycerol	1.5	0.25	0.57	3.5	2.0
	Lactic acid	2.7	0.60	0.39	4.4	1.7
	Triethanolamine	4.8	0.70	0.33	7.2	2.4
	Urea	7.5	0.05	0.67	22.7	15.2
	Sodium chloride	98	0.00	0.70	327	229
	Sodium carbonate	242	0.00	0.70	807	565
	Sodium sulfate	51	0.00	0.70	170	119

System: ERDlator

Conversion: 70%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(ACA rej = A) (ERD rej = 0.75A) Process Removal Efficiencies A	Fraction of unremoved contaminant, $y = 0.8 - 0.6A$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 \left(1 + \frac{y}{1-y}\right)$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.10	0.74	323	239
	Isopropanol	105	0.40	0.56	239	134
	Glycerol	2.8	0.25	0.65	8.0	5.2
	Lactic acid	5.0	0.60	0.44	8.9	3.9
	Triethanolamine	7.5	0.70	0.38	12.1	4.6
	Urea	3.0	0.05	0.77	13.0	10.0
	Sodium chloride	180	0.00	0.80	900	720
Laundry	Ethanol	1.4	0.10	0.74	5.4	4.0
	Urea	13	0.05	0.77	56.5	43.5
	Sodium carbonate	533	0.00	0.80	2670	2136
	Sodium sulfate	112	0.00	0.80	560	448
Composite	Ethanol	47	0.10	0.74	181	134
	Isopropanol	57	0.40	0.56	130	73
	Glycerol	1.5	0.25	0.65	4.3	2.8
	Lactic acid	2.7	0.60	0.44	4.8	2.1
	Triethanolamine	4.8	0.70	0.38	7.7	2.9
	Urea	7.5	0.05	0.77	32.6	25
	Sodium chloride	98	0.00	0.80	490	392
	Sodium carbonate	242	0.00	0.80	1200	960
	Sodium sulfate	51	0.00	0.80	255	204

System: ERDlator

Conversion: 80%

Wastewater Source	Chemical Contaminant	Concentration in wastewater resulting from shower/laundry operation, x_1 (mg/liter)	(ACA rej = A) (ERD rej = 0.75A) Process Removal Efficiencies A	Fraction of unremoved contaminant, $y = 0.9 - .675(A)$	Chemical concentration in wastewater for an infinite number of cycles, $x_\infty = x_1 \left(1 + \frac{y}{1-y}\right)$	Chemical concentration in treated, recycled water prior to reuse for an infinite number of cycles $x_\infty y$
Shower	Ethanol	84	0.10	0.83	494	410
	Isopropanol	105	0.40	0.63	284	179
	Glycerol	2.8	0.25	0.73	10.4	7.6
	Lactic acid	5.0	0.60	0.50	10	5.0
	Triethanolamine	7.5	0.70	0.43	13.2	5.7
	Urea	3.0	0.05	0.87	23.1	20.1
	Sodium chloride	180	0.00	0.90	1800	1620
Laundry	Ethanol	1.4	0.10	0.83	8.2	6.8
	Urea	13	0.05	0.87	100	87
	Sodium carbonate	533	0.00	0.90	5330	4797
	Sodium sulfate	112	0.00	0.90	1120	1008
Composite	Ethanol	47	0.10	0.83	276	229
	Isopropanol	57	0.40	0.63	154	97
	Glycerol	1.5	0.25	0.73	5.6	4.1
	Lactic acid	2.7	0.60	0.50	5.4	2.7
	Triethanolamine	4.8	0.70	0.43	8.4	3.6
	Urea	7.5	0.05	0.87	57.7	50.2
	Sodium chloride	98	0.00	0.90	980	882
	Sodium carbonate	242	0.00	0.90	2420	2178
	Sodium sulfate	51	0.00	0.90	510	459

System: ERDlator

Conversion: 90%

APPENDIX IV

TOXICOLOGY DATA ON INDIVIDUAL COMPONENTS

Alkyl aryl sulfonate AZ 84000*

Human Body Use: Synthetic anionic detergent

Toxicity:

Oral:	Rats:	LD_{50}	2320 mg/kg
	Mouse:	LD_{50}	2010 mg/kg
	Rabbit:	LD_{50}	1730 mg/kg
	Hamster:	LD_{50}	1131 mg/kg

Skin: Mild irritant

Eyes: Probably irritating

Alumina (powder) Al_2O_3

[1344-28-1] A071-9664

Human Body Surface Use: Toothpaste

Toxicity:

Oral: None

Skin: None

Eyes: Insoluble mechanical irritant

Aluminum chloride BD 05250* $AlCl_3$

Aluminum trichloride

Human Body Use: Antiperspirant

Toxicity:

Oral:	Rats:	LD_{50}	3700 mg/kg
	Mouse:	LD_{50}	3800 mg/kg
	Human:	Highly toxic	

Skin: Slight irritation

Eyes: ?

Inhalation: -

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Aluminum chlorhydrate   BD 05250* $AlCl_3.H_2O$

Human Body Use: Antiperspirant

Toxicity:

Oral: Rats: LD_{50} 3700 mg/kg
Human: Subacetate Sol. "Ingestion of large doses may cause severe nausea, vomiting, diarrhea, melena, hematuria" - Merck Index.

Skin: Solutions of 10 - 25% are used as deodorants. "Irritating to sensitive skin" - Merck Index.

Eyes: Irritant

Aluminum formate $Al(CHO_2)_3$

Human Body Use: Antiperspirant

Toxicity: "These compounds have little or no toxicity" (Sax)

Skin: None

Eyes: ?

Aluminum hydroxide gel   BD 09400*

Human Body Use: Water purification
Gastric antacids
Antiperspirant

Toxicity:

Oral: Human: > 2.4g will cause constipation

Skin: None

Eyes: ?

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Aluminum sulfate   BD 17000* $Al_2(SO_4)_3$

Human Body Use: Water purification

Toxicity:

Oral: None (Sax)

Skin: None (Merck Index)

Eyes: ?

Ammonium alum $AlNH_4(SO_4)_2$

Human Body Use: Astringent, styptic, water and sewage treatment.

Toxicity: "Ingestion of large quantities may cause burning in mouth and pharynx, vomiting and diarrhea" (Merck Index)

Skin: Slightly irritating if concentrated

Eyes: *Used for conjunctivitis in weak solutions*

Ammonium lauryl sulfate

Probably made from Ammonium laurate anhydrous $C_{11}H_{23}COONH_4$

Human Body Use: Production of oil in water emulsions with high oil content; cosmetics

Toxicity:

Oral: Irritating to mucous membranes

Skin: Low toxicity

Eyes: Irritant

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Bees wax

Human Body Use: Cosmetics, lipstick

Toxicity:

Oral: None

Skin: None

Eyes: None

Bentonite CT 94500* $Al_2O_3 . 4 SiO_2 . H_2O$

Human Body Use: As emulsifier for oils, as a bulk laxative

Toxicity:

Oral: None

Skin: None

Eyes: ?

Boric acid ED 45500* H_3BO_3

Human Body Use: Mild astringent, antiseptic

Toxicity:

Oral: less than 5 grams may be fatal for infants, lethal to adults in doses of 5-20 grams.

Skin: External chronic use may cause borism (dry skin, eruptions and gastric disturbances)(Merck index)

Eyes: Boric acid can be used as a saturated solution for topical treatment of inflammed eyes. Its toxicity is negligible if only used two or three times a day for several days.

Inhalation: "Experimental animals shows no deleterious effects from the daily ingestion of moderate amounts of the compound (Frost & Richards 1945)"(Goodmand & Gilman)

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Calcium carbonate EV 95800* $CaCO_3$

Human Body Use: Dentifrice, cosmetics, gastric antacids
Oral dose - 1 gram

Toxicity:

Oral: practically nil - may cause constipation

Skin: None

Eyes: Mild irritant

Castor oil FI 41000* $C_{17}H_{32}OHCOOH$

Human Body Use: Skin emollient, hair tonics (10% in alcohol)
Medical: Carthartic from 4 - 60 ml orally. (Merck index)

Toxicity:

Oral: Only toxic in very large doses of the pure oil. (Goodman and Gilman)

Skin: Not toxic but can be absorbed to cause catharsis

Eyes: ?

Inhalation: Would cause a severe pulmonary edema and pneumonia

---

Cetyl alcohol

Alcohol C-16

Human Body Use: Perfumes, emollients, cosmetics, lipsticks

Toxicity:

Oral: ?

Skin: None

Eyes: ?

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Coconut diethanolamide 97% $C_{14}H_{29}NO_2$

[142-78-9] A454-6429

Human Body Use: Shampoo

Toxicity:

Oral: -

Skin: -

Eyes: -

Coconut oil GG 60400*

Human Body Use: In soaps, ointments and hair dressings

Toxicity:

Oral: None (Merck index)

Skin: None

Eyes: Very slight irritant

Inhalation: Severe irritant

Corn starch $(C_6H_{10}O_5)_n$

Human Body Use: Medicinal products and dusting powders

Toxicity:

Oral: None

Skin: None

Eyes: ?

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Dicalcium phosphate

Calcium phosphate dibasic $CaHPO_4$

Human Body Use: In dental products

Toxicity:

Oral: None

Skin: None

Eyes: ?

N,N-Diethyl-m-toluamide XS 36750*

m-Toluamide, N-N-diethyl-; DEET
Molecular formula $CH_3C_6H_4CON(C_2H_5)_2$

Human Body Use: Insect repellant, redsin solvent

Toxicity:

Oral: Rat: LD_{50} 2000 mg/kg

Skin: Rabbit: LD_{50} 3180 mg/kg

Eyes: Irritating

INV: Rabbit: LD_{20} 75 mg/kg
Condensed Chemical Dictionary
Mucuous Membrane - Irritating

Epithelium

The epithelium found in laundry and shower wastewater are the surface cells of the body that are no longer living and form the keratinized layer on the surface of the skin. It is in the form of flakes (dander) and of shriveled flattened cells. They do contain some protein and oils from the sebaceous glands.

There is no toxicity associated with this material but it will support the growth of bacteria and mold.

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Ethanol Ethyl alcohol KQ 63000* C_2H_5OH

Human Body Use: Topical antiseptic

Toxicity:

Oral: Rat: LD_{50} 14 g/kg
Human: TDL_o 50 mg/kg

Skin: None

Eyes: Irritating above 10%
Necrosis above 90%

Air: 1000 ppm. TLV

Inhalation: ?

Ethoxylated lauryl alcohol JR 59,600 - 900*

Dodecyl alcohol condensed with ethylene oxide.
A nonionic surfactant, controls sudsing.

Human Body Contact Use: Detergent Type I (Foam depressant)

Toxicity:

Oral: Mouse: LD_{50} 1170-3500 mg/kg
Ethoxylated alcohol
Ethoxylated alkyl phenols
Ethoxylated amines or amides
Ethoxylated fatty acids
Fatty amine oxides

Glycerol MA 80500* $HOCH_2CHOHCH_2OH$ ($C_3H_8O_3$)

Human Body Use: Solvent, humectant, emollient, antiseptic, in soaps, used in cough medicine

Toxicity:

Oral: Mouse: LD_{50} 470 mg/kg
Human: Very low toxicity

Skin - None

Eye - Irritation. Irritant in concentrated solution (Tardiff)

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Glycerol monostearate RG 19250* $(C_{17}H_{35})COOCH_2CHOHCH_2OH$

Human Body Use: Cosmetics

Toxicity: Unknown

Hair

Since it is an epithelial derived structure it has protein and is particulate and not readily soluble.

It can only act as an irritant if small pieces get into the eye.

There is no toxicity associated with hair. Skin sensitivity of humans to human hair would be unusual.

Hexachlorophene SM 07000*

Phenol, 2,2 methylene bis 3,4,6-trichloro

Human Body Use: Antiseptic, bactericide, cosmetics, dentifrice

Toxicity:

Oral:	Human:	LD_{Lo}	50 ug/kg
	Rat:	LD_{50}	60 mg/kg
	Dog:	LD_{50}	40 mg/kg
Skin -	Child	TDL_{o}	300 mg/kg
	Rat	LD_{20}	600 mg/kg

Eye - Non-toxic in doses up to 2%

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Isopropyl alcohol | NT 80500* | $CH_3CHOHCH_3$

Human Body Use: Solvent, toiletries
(Perfumes, after-shave lotions, antiseptics)

Toxicity:

Oral: Human: 100 ml can be lethal
Mouse: LDL_{50} 192 mg/kg
Rat: LD_{50} 5840 mg/kg

Skin: Very low to skin

Eyes: Would irritate at concentrations over 10%.

Isopropyl myristate | $C_{27}H_{34}O_2$

Human Body Use: Cosmetics, Skin medications

Toxicity:

Oral: Non-toxic

Skin: Very low with continued use a hyperkeratosis may evolve.

Eyes: ? unknown (Tardiff)

Isopropyl palmitate | RT 49000*

Palmitic acid, isopropyl ester

Human Body Use: used in soaps

Toxicity:

Oral: ?

Skin - None

Eyes: ?

Interperitoneal: Mouse - LDL_0 - 100 mg/kg
Very low toxicity in any other mode

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Jamaican Rum

There is no special toxicity to Jamaican Rum over the toxicity of a 30% to 50% ethyl alcohol solution. There are some special flavors and odors but these have no inherent toxic activities. Jamaican or Bay Rum is used as an odor enhancement in after shave lotions. It would certainly irritate the eye.

Kaolin colloidal $H_2Al_2Si_2O_8.H_2O$

China clay

Human Body Use: An adsorbent

Toxicity:

Oral: None

Skin: None

Eyes: Insoluble mechanical irritant

Kaolinite

Clay or soil

Human Body Use: Picked up as dust, etc.

Toxicity:

Oral: None

Skin - None

Eyes: Mechanical irritation

Inhalation: ?

Lactic Acid — OD 28000* — $C_3H_5O_3$

Human Body Use: This material is part of sweat and sebaceous secretions. It is not used on the body but is a result of muscular activity and glandular secretions.

Toxicity:

Oral: Rat: LD_{50} 3730 mg/kg
G.Pig: LD_{50} 1810 mg/kg

Skin: None

Eyes: None (Unless concentrated)

Inhalation: ?

Lactic acid in nature never reaches a high percentage of purity. It is found in fermented milk products most commonly.

Lanolin

Wool fat

Human Body Use: Soaps, Cosmetics, Hair set preparations

Toxicity:

Oral: None

Skin: None

Eyes: Unknown - (Tardiff)

Inhalation: Foreign body pneumonia

Linear alkylbenzene sulfonates (LAS)

Human Body Use: Detergents and surfactants

Toxicity:

Acute Oral: Rats LD_{50} 404-1525 mg/kg
Mice: 1575-1850 mg/kg
Rats: .5% in food for 12 weeks - no response.

Skin powder: G.P. 30% sol - 10' to 2 hrs - irritating
G.P. .4% - non-irritating

Rabbit eyes: - Powder - irritating
1% sol - non-irritating
>5% - irritating

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Magnesium carbonate   OM 24700* $MgCO_3$

Human Body Use: costmetics
dentifrices
antacids

Toxicity:

Oral: Human: low toxicity
used as laxative
Skin: none
Eyes: ?

Magnesium oxide   OM 38500* MgO

Magnesia

Human Body Use: antacid - dose, 250 mg
laxative - 4 g

Toxicity:

Oral: low toxicity
skin: - none
eyes: - ?
inhalation: ?

Methyl paraben   DH 24500* $C_8H_8O_3$

Human Body Use: cosmetics
lotions

Toxicity:

Oral: very low; greater than 500 mg/kg
skin: very low; chronic use can cause sensitization
eyes: ?

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Mineral oil

Petroleum

Human Body Use: cosmetics
laxatives
rubbing oils

Toxicity:

Oral: excessive laxative
low toxicity
Skin: none
Eyes: none

Inhalation: Foreign body pneumonia

Nitrilotriacetate, NTA AJ 01750*

Human Body Use: detergent

Toxicity:

Oral: Chronic Rat: - 20,000 ppm in food caused slight kidney damage
Rabbit: - no absorption
Dogs: - good clearance through urine no toxicity
Skin: - none
Eyes: -

Oleic acid RG 22750* $C_{18}H_{34}O_2$

9 Octadecenoic Acid

Human Body Use: in soaps

Toxicity:

Oral: low oral toxicity
Skin: mild irritant
Eyes: low
Mouse: LD_{50} 230 mg/kg

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

<u>Petrolatum</u>

Mineral Wax, Petroleum Jelly

Human Body Use: As a base for ointments
Cosmetics

Toxicity:

Oral: none (large doses as laxative)
Skin: none
Eyes: none
Inhalation: almost impossible

<u>Polyethylene sorbitan monostearate</u> WG 29310, 25, 30, 40*

This compound is one of the "Tween" compounds that is a surfactant. They are polyoxyethylene derivations of fatty acids partial esters of sorbital anhydrides.

This is a class of compounds usually of low toxicity.

<u>Potassium</u>

Dces not occur in nature as a pure element.

Some salts that are commonly encountered are:

pot. carbonate	pot. chloride
alum. pot. sulfate	pot. chromate
pot. phosphate	pot. eyenate
pot. aluminate	pot. glutamate
pot. bicarbonate	pot. glycerophosphate

Human Body Use: manufacture of soaps ?

Toxicity: depending on the salt complex

Potassium hydroxide   TT 21000*   KOH

Caustic potash

Human Body Use: in soap manufacture

Toxicity:

Oral: Rat - LD_{50} - 365 mg/kg

Skin: Highly caustic - injury directly proportional to concentration and duration of contact.

Eyes: Same as skin but much lower concentration and time duration will bring about severe eye damage

---

Potassium oleate

Human Body Use: textile soaps
emulsifying agent
detergent

Toxicity:

Oral: unkwnon

Skin: none

Eyes: ?

Inhalation: ?

Propoxylated PABA   DG 14000* $C_7H_7NO_2$

para amino benzoic acid

Human Body Use: as a sun screen - in conjunction with local anesthetics

Toxicity:

Oral:

Skin:

Eyes:

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Propylene glycol — TY 200000* — $C_3H_8O_2$

1,2 propanedial

Human Body Use: drug solvent
ointments
antiseptics

Toxicity:

Oral: very low
Rat: LD_{50}; 30 g/kg
Skin: none
Eyes: very low

Protease

A class of enzymes which hydrolyze peptide linkages into peptides and proteins. The subgroup of enzymes are:
peptidases
proteinases
They solubilize proteins and are used along with and in economical washing powders.

Human Body Use: laundry presoak

Toxicity:

Rat: LD_{50} - 2.9 g/kg
Oral: none
Eyes: 100% enzyme mod. conjunction - mild irritant
Skin: 0-90% no reaction - not inherently toxic but can set up skin sensitization. Enzymes increase the dermal toxicity of detergents.

Silica flour — VV 73300* — SiO_2

powder

Human Body Use: water filtration, filler in cosmetics and insecticide

Toxicity:

Oral: Rat LD_{50}; - 3160 mg/kg
Skin: none
Eyes: only as a mechanical irritant

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Sodium alkylbenzene sulfonate   DB 45500*

alkylbenzene sulfonate (ABS)

Human Body Use: detergent (resistant to biodegradation)

Toxicity:

Oral: Fish - 5-20 mg/l
Rat - LD_{50} 260-20,000 mg/Kg (Tardiff)
Skin: 1% sol occluded patches cause primary irritant
Eyes: Rabbit - very slight reaction at 1% sol.
marked irritation at 10% sol.

Sodium carbonate   VZ 40500* Na_2CO_3

soda ash

Human Body Use: ingredient of cleaners
solubilized calcium
used toxically for dermatitis

Toxicity:

Oral: Rat LD_{Lo} 4000 mg/Kg
Skin: low toxicity - chronic use may cause sensitization
Eyes: concentrated solution may cause necrosis.
Inhalation: ?

Sodium carboxymethyl cellulose   FJ 59500*

Human Body Use: as a suspending agent
hair dressings

Toxicity:

Oral: Rat LD_{50}: 27 g/Kg very low toxicity
Guinea Pig LD_{50}: 16 g/Kg very low toxicity
Skin: none
Eyes: none
Inhalation: ?

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Sodium chloride VZ 47250* $NaCl$

common table salt

Human Body Use: manufacture of soap

Toxicity:

Oral: Rats LD_{50} 2.5 g/Kg
Humans: very low 1 gram is well tolerated by adults
Skin: none below 3% sol
above 3% pickling and dehydration occurs.
Eyes: no toxicity up to 1%
increased concentration causes increased
dehydration and necrosis.

Sodium 4-chloro-2-phenylphenolate DV 68250*

4 chloro 2 phenylphenol sod. salt
2 B. phenylol, 5 chloro sod. salt

Human Body Use: fungicide
disinfectent

Toxicity:

Oral: LD_{50} 3500 mg/Kg
Skin: ?
Eyes: ?
Inhalation: ? DOW

Sodium 6-chloro-2-phenylphenolate DV 7000*

2 B1 phenylol, 6 chloro- sod. salt

Human Body Use: fungicide
disinfectent

Toxicity:

Oral: Rat LD_{50} 3500 mg/Kg
Skin: ?
Eyes: ?

Dow

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Sodium dodecyl benzene sulfonate   DB 68250*

benzene sulfonic acid, dodecyl sod. salt
detergent HD-90

Human Body Use: detergent

Toxicity:

Oral: rat - LD_{50} 1260 mg/Kg
mouse - LD_{50} 2000 mg/Kg
Intravenous: - mouse - LD_{50} 105 mg/Kg
Skin: ?
Eyes: irritant

Sodium fluosilicate   VV 84100* Na_2SiF_6

Human Body Use: water fluoridization
laundry use

Toxicity:
Oral: rat - LD_{50} 125 mg/kg

in its pure form it is highly toxic by ingestion and inhalation, and is irritating to skin and eyes.

Sodium hydroxide   WB 49000*   NaOH

caustic soda

Human Body Use: cleaning ingredient

Toxicity:

Oral: Rabbit LD_{Lo} 500 mg/Kg
Skin: very corrosive even with chronic dilute solutions
Eyes: severe irritation and necrosis
Inhalation: lungs - air - tolerance 2 mg/m^3 (TLV)

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Sodium lauryl sulfate WT 10500* $C_{12}H_{25}NaO_4S$

dodecyl sodium sulfate

Human Body Use: wetting agent
detergent
toothpaste

Toxicity:

Oral: Rat LD_{50} 1288 mg/Kg
Skin: slight irritation depending on time and concentration
Eyes: irritant

Sodium ortho phenylphenolate DV 77000* $C_6H_4(C_6H_5)ONa.4H_2O$

sodium ortho phenylphenate

Human Body Use: bactericide and antifunge

Toxicity:

Oral: Rat LD_{50} 1160 mg/Kg
Rat LD_{50} 530 mg/Kg
Cat LD_{50} 2.7 g/Kg Tardiff
Skin: ?
Eyes: ?
Inhalation: ?

Sodium saccharin DE 45500*

Human Body Use: dentrifice sweetener

Toxicity:

Oral: very low
Skin: none
Eyes: ?
Inhalation: ?

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

<u>Sodium silicate</u> VV 92750* $2Na_2O_1S_1O_2$

water glass

Human Body Use: in soaps and bleaches

Toxicity:

Oral: very low to none
Skin: none
Eyes: ?
Inhalation: ?

<u>Sodium stearate</u> WI 42750* $C_{18}H_{35}NaO_2$

stearic acid, sod. salt

Human Body Use: soap manufacture
tooth paste
topically in some skin __?_

Toxicity: generally unknown

Oral: mouse LD_{Lo} 400 mg/K
Skin: very low
Eyes: ?
Inhalation: ?

<u>Sodium sulfate</u> WE 16500* Na_2SP_4

Human Body Use: in the manufacture of detergents

Toxicity:

Intravenous: Rabbit - LD_{50} 4470 mg/Kg
Oral: low - used as a cathartic
Skin: none
Eyes: ?
Inhalation: ?

---

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

<u>Sodium tripolyphosphate</u>   YK 49000* $Na_5P_3O_{10}$

triphosphoric acid sod. salt

Human Body Use: detergent
water softener

Toxicity:

Oral: violent catharsis in human
esophageal stricture in human
Skin: moderate irritant
Eyes: irritant
Intrapert - mouse LD_{50} 700 mg/K

<u>Sorbitan monostearate</u>   WG 29340*

sorbitan fatty acid esters

Human Body Use: emulsifiers in cosmetics

Toxicity:

Oral: probably low
Skin: " "
Eyes: " "
Inhalation: probably low

<u>Sorbitol</u>   LZ 42900* $C_6H_6(OH)_5$

sorbo, or D-Sorbitol

Human Body Use: cosmetics, lotions, and toothpaste

Toxicity:

Oral: none -mild cathartic. used for potential elimination
Skin: none
Eyes: ?
Inhalation: ?

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Spermaceti

whale oil, spermateceti

Human Body Use: ointment bases, emollient
soaps
laundry wax

Toxicity:

Oral: unknown; probably low
Skin: unknown; probably low
Eyes: unknown; probably low
Inhalation: unkwnon; probably low

Stannous fluoride SnF_2

flouristan

Human Body Use: dentifrice
2% oral topical, to prevent cavities

Toxicity:

Oral: highly toxic
Skin: strong irritant
Eyes: strong irritant
Inhalation: tolerance 2 mg per cubic meter of air

Stearic acid WI 28000* $CH_3(CH_2)_{16}CO_2H$

n-octadecanoic acid

Human Body Use: soaps
cosmetics

Toxicity:

Oral: very low to none
Intravenous: Rat - LD_{50} 22 mg/Kg
Mouse - LD_{50} 23 mg/Kg
Cat - LD_{50} 5 mg/Kg
Skin: none
Eyes: very little

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Sulfonated castor oil

[8002-33-3] B637-9037

Human Body Surface Use: shampoo

Sulfonated olive oil

Human Body Use: shampoo

Toxicity:

Oral: none
Skin: none
Eyes: none

probably a sulfonated oil used in the preparation of soap

Talc $Mg_3Si_4O_{10}(OH)_2$

talcum powder

Human Body Use: dusting powder

Toxicity:

Oral: none
Skin: none
Eyes: mild irritant
Air: chronic inhalation can cause pulmonary fibrosis
tolerance 20 million particles per cu ft of air

Tallow

animal body fat

Human Body Use: in soap
cosmetics

Toxicity:

Oral: none

Skin: none

Eyes: none

Inhalation: ?

Tannic Acid WW 50750*

Human Body Use: astringent?

Toxicity: none except by inhalation used orally as an anti diarrhea med. used topically for burns

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Tegacid

Human Body Contact Use: Anti-perspirant

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Tricalcium phosphate $Ca_3(PO_4)_2$

calcium phosphate tribasic

Human Body Use: toothpaste

Toxicity:

Oral: none

Skin: none

Eyes: ? (possibly only mechanical irritant)

Inhalation: ?

Triethanolamine KL 92750* $(HOCH_2CH_2)_3N$

ethanol 2,2,2, nitrilotris

Human Body Use: soap manufacture
detergents
insecticides

Toxicity:

Oral: G.P: LD_{50} 8000 mg/k

Skin: slight irritant

Eyes: slight irritant

Inhalation:

Triethanolamine alkylbenzene sulfonate

Human Body Use: surfactants

Toxicity:

Oral: moderate

Skin: moderate

Eyes: moderate

* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Tween 80 WG 29325*

This is one representative of a class of surface active compounds - similar to polyethylene sorbitan monostearate.

Tween 80 has been used extensively as a depressant for drugs given orally on the skin and parentally. This compound has a very low toxicity when it is used in very dilute solutions.

Ultra Wet 60L DB 68250*

Trademark for a series of biodegradable linear alkylate sulfonate (LAS) anionic detergents or surface active agents.
Condensed Chemical Directionary
see "Linear Alkylbenzene Sulfonates".

Toxicity:

Oral: very low

Skin: slight

Eyes: irritant

Urea YR 62500* $CO(NH_2)_2$

Human Body Use: major constitutent of urine

Toxicity:

Oral: Rat - none up to about 10 grams/Kg
Dog - LD_{Lo} 3000 mg/Kg

Skin: none (acute exposure)

Eyes: none at low concentration

Inhalation: ?

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

Veegum

[1327-43-1]   B 790-4224

Bentonite family - (mag + aluminum silicates)

Human Body Use: after shave lotion

Toxicity:

Oral:
Skin: ?
Eyes:

Vanderbilt Co. - Norwalk, CT

Vegetable oil

(cotton seed, linseed, tung, peanut)

Human Body Use: soap manufacture
shampoo

Toxicity:

Oral: none (high dose laxative)

Skin: none

Eyes: none

Inhalation: foreign body pneumonia

Volatile silicone 7207

A group of organo siloxane polymers of silicon and oxygen atoms with various organic radicals attached to the silicone. (Diethyl cyclic tetramer)

Human Body Use: antiperspirant emollient

Toxicity:

Oral: rat LD_{50} > 64 ml/Kg non-toxic

Skin: rabbit LD_{50} > 16 ml/Kg non-toxic
human sensivitity - no reaction to patch test in 200 volunteers

Eyes: not an irritant by FHSA procedure

Union Carbide

Whitening Agents

No information available

Zinc chloride   ZH 14000* $ZnCl_2$

butter of zinc

Human Body Use: dentifrices
mouth washes
antiseptic

Toxicity:

Oral: 2-5% mouth rinse well tolerated

Skin: O.K. 1-2% sol topically. Irritant if stronger

Eyes: irritant

Inhalation: Tolerance 1 mg per cu meter of air

Zinc stearate   ZH 52000* $Zn(C_{18}H_{35}O_2)_2$

Human Body Use: cosmetics

Toxicity:

Oral: very low

Skin: very low

Eyes: ?

Inhalation: ?

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* Accession No., Registry of Toxic Effects of Chemical Substances, 1977.

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SUPPLEMENTARY

INFORMATION

AD-A076302

Revised Page

For an infinite number of recycles, the expression simplifies as follows:

Since $y < 1$ and $S_n + \frac{y(1-y^n)}{1-y} \quad \frac{y}{1-y} \quad \frac{y^{n+1}}{1-y}$

as $n \rightarrow \infty$, $y^{n+1} \longrightarrow 0$ and $S_n \longrightarrow \frac{y}{1-y}$

Therefore, for the convergent infinite series

$$x_\infty = x_1\left(1 + \frac{y}{1-y}\right) = \frac{X_1}{1-y} \qquad (3)$$

Thus, there is an upper limit on the concentration build-up of wastewater contaminants. In the worst case, where the contaminant passes unaffected through the treatment system (or where there is no treatment other than dilution with make-up water), the fraction of unremoved contaminant per cycle becomes equal to the recycle ratio:

$$x_\infty = \frac{x_1}{1-z}$$

For 80% recycle and zero removal efficiency

$$x_\infty = \frac{x_1}{1-0.80} = 5\ x_1$$

Systems with the highest treatment efficiencies for particular contaminants show virtually no build-up of those contaminants. An example is the effectiveness of the UF-RO system in removing dissolved salts such as sodium chloride and sodium sulfate.