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MILK DECONTAMINATION BY ELECTRODIALYSIS

SUMMARY

The removal of the radionuclide contaminants, strontium, barium, cesium, lanthanum, cerium and iodine, from milk by electrodialysis was investigated under contract OCD-OS-62-206 with the Office of Civil Defense from July, 1962 to September, 1963.

The immediate objectives of this investigation were to summarize the existing data on milk decontamination, to review and evaluate methods of decontamination, to define the parameters governing the removal of strontium, iodine, cesium and rare earths by electrodialysis with emphasis on developing a practical adaptation of the electrodialysis method and equipment design criteria, and to indicate possible application of the method to the lower level decontamination problems, such as those associated with reactor and other nuclear accidents.

Ultimately the goal was to achieve a desired degree of decontamination without appreciable changes in nutritional value, palatability, composition and stability of the milk under sanitary conditions.

In the electrodialysis process investigated, radioactive ions, along with other ions normally present in milk are removed electrically through an ion-transfer membrane into a waste solution. These ions are replaced simultaneously through another ion-transfer membrane from an aqueous solution of salts (make-up solution). The salt concentration and composition of the milk can be maintained by controlling the composition and concentration of the make-up solution.

The decontamination tests were made using raw whole milk to which radioactive tracers of Sr^{85}, Cs^{137}, Ce^{139}, Ba^{140} - La^{140}, or I^{131} had been added "in vitro" and also on milk in which Sr^{85} had been added "in vivo" by the Dairy Products Division of the USDA at Beltsville, Maryland.

The electrodialysis stack used in these tests consisted of five three-compartment cells between the two electrodes. The membranes and spacers used measure 5 x 9 inches overall, width and length. The spacers have indentical hydraulic characteristics to those used by Ionics in large scale equipment for demineralization of whey.

The important variables are current density, milk pH, temperature, and composition and concentration of the make-up solution of salts used as a source of replenishment for salts removed from the milk during the process. Within limits another important variable is the type of membrane used.

Previous work on milk decontamination by ion exchange performed at the Dairy Products Division of the USDA and at the Robert A. Taft Engineering Center, USPHS, has been helpful in the development of the electrodialysis decontamination process.

As in the ion exchange process, over 90% removal of strontium is obtained when the pH of the milk is adjusted to 5.1 to 5.3, whereas at the normal milk pH, poor removal is obtained. Following decontamination, the milk is readjusted to its normal pH of 6.6.

The conditions of decontamination which will produce 95% strontium removal "in vitro" by electrodialysis, will produce 90% strontium removal "in vivo".

At 90% removal of strontium, about 80% of the barium and over 99% of the cesium is removed. Very slight removal of lanthanum and no removal of cerium has been observed.

Removal of cationic and anionic contaminants was not performed simultaneously; in separate experiments, 70 to 90% removal of the anionic contaminant iodine has been obtained.

Less than 1% of the lactose in the milk was lost to the waste solution. Therefore, the loss of organics from the milk to the waste solution can be assumed to be negligible.

The capacity of an electrodialysis decontamination plant is proportional to the current density applied, the coulomb or current efficiency of the decontaminating membrane, and the selectivity of the membrane for transfer of the radionuclide ion over the other ions present in milk.

A current density of 42 amperes per square foot is satisfactory. At higher current densities there is a tendency for deposits to form on the membranes. The current efficiency can be maintained at about 90% by a regeneration procedure developed during the program. The selectivity of the membrane for cationic contaminants is enhanced by reducing the potassium content of the milk during decontamination. Potassium can be returned to the milk during the final pH adjustment.

For 90% strontium removal the total investment cost for a 5,000 gallon/hour plant has been estimated to be about $830,000. The operating cost is about 0.5¢ per quart of milk. The economics are based on the decontamination of cold milk at operating conditions considered optimum on the basis of the experimental data.

It is recommended that a pilot plant program be undertaken to test the process in a large scale and to develop information for the design of a full-scale plant. The pilot plant can also be used to provide samples for nutritional studies and acceptance tests.

It is also recommended that certain phases of the experimental program be continued on bench scale. These studies would include membrane life tests, decontamination of skim milk, development of improved techniques of pH adjustment and development of more highly selective membranes, especially for iodine removal.

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REMOVAL OF RADIOACTIVE MATERIAL FROM MILK BY ELECTRODIALYSIS

FINAL REPORT

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1.0 SUMMARY

The removal of the radionuclide contaminants, strontium, barium, cesium, lanthanum, cerium and iodine, from milk by electrodialysis was investigated under contract with the Office of Civil Defense.

Previous work on milk decontamination by ion exchange performed at the Dairy Products Division of the USDA and at the Robert A. Taft Engineering Center, USPHS has been helpful in the development of the electrodialysis process.

As in the ion exchange process, over 90% removal of strontium is obtained when the pH of the milk is adjusted to 5.1 to 5.3, whereas at the normal milk pH poor removal is obtained. Following decontamination, the milk is readjusted to its normal pH of 6.6.

The conditions of decontamination, which will produce 95% strontium removal "in vitro" by electrodialysis, will produce 90% strontium removal "in vivo."

At 90% removal of strontium, about 80% of the barium and over 99% of the cesium is removed. Very slight removal of lanthanum and no removal of cerium has been observed.

Removal of cationic and anionic contaminants was not performed simultaneously; in separate experiments, 70 to 90% removal of the anionic contaminant iodine has been obtained.

For 90% strontium removal the total investment cost for a 5,000 gallon/hour plant has been estimated to be about $830,000. The operating cost is about 0.5¢ per quart of milk. The economics are based on the decontamination of cold milk at operating conditions considered optimum on the basis of the experimental data.

The capacity of an electrodialysis decontamination plant is proportional to the current density applied, the coulomb or current efficiency of the decontaminating membrane, and the selectivity of the membrane for transfer of the radionuclide ion over the other ions

present in the milk. A current density of 42 amperes per square foot has been chosen. At higher current densities there is a tendency for deposits to form on the membranes. The current efficiency can be maintained at about 90% by a regeneration procedure developed during the program. The selectivity of the membrane for cationic contaminants is enhanced by reducing the potassium content of the milk during decontamination. Potassium can be returned to the milk during the final pH adjustment.

In the decontamination process radioactive ions are purged electrically from the milk through an ion transfer membrane along with other ions normally present in milk into a waste solution. The latter ions are replaced simultaneously through another ion-transfer membrane from an aqueous solution of salts (make-up solution). The salt concentration and composition of the milk can be maintained by controlling the composition and concentration of the make-up solution.

Less than 1% of the lactose in the milk was lost to the waste solution. Therefore, the loss of organics from the milk to the waste solution can be assumed to be negligible.

It is recommended that a pilot plant program be undertaken to test the process in a large scale and to develop information for the design of a full-scale plant. The pilot plant can also be used to provide samples for nutritional studies and acceptance tests.

It is also recommended that certain phases of the experimental program be continued on bench scale. These studies would include membrane life tests, decontamination of skim milk, development of improved techniques of pH adjustment and development of more highly selective membranes, especially for iodine removal.

2.0 INTRODUCTION

During July, 1962, the Office of Civil Defense granted a contract to Ionics, Incorporated to study the decontamination of milk polluted with radioactive fallout material. This report presents the results of the work performed under this contract (OCD-OS-62-206) from July, 1962 to September, 1963.

Atmospheric testing of nuclear weapons has resulted in radionuclide contamination of foods, including milk. The radionuclides strontium^{89}, strontium^{90}, barium^{140}, cesium^{137} and iodine^{131} have been detected in milk (3). The soluble contaminants are present in the milk as cations, except for the iodine which is anionic (3, 30). Rare earths such as cerium^{144} and lanthanum^{140} are also present in contaminated milk. The worst offender is Sr^{90} which is deposited with calcium ions in the bone and has a long half-life of 28 years. It may also have long-range somatic effects leading to cancer, such as leukemia. Cesium^{137} distributes itself throughout the body and may produce genetic effects. Iodine^{131} tends to become concentrated in the thyroid gland and is believed to be dangerous only to the smaller and more sensitive glands of children (25). However, the short half-life (8.05 days) of this radionuclide makes it a short range contamination problem.

The National Research Council has published this year a study on "Damage to Livestock from Radioactive Fallout in Event of Nuclear War" (27) in which information is given (Table X, p. 35 of Ref. 27) on the concentration of I^{131}, Sr^{90} and Cs^{137} in milk compared to the acceptable level for man's drinking water. According to this reference, in an immediate emergency situation "if a dairy herd survives the gamma radiation and can give milk...the milk from the herd will not produce an I^{131} dose to the adult human thyroid great enough to preclude drinking the milk." However, this does not apply to young children. Therefore, in such a situation it would be desirable to be prepared to remove I^{131} from milk.

2.1 Scope of Work

This study was initiated to investigate the feasibility and applicability of electrodialysis to the milk decontamination problem, to summarize the existing data on milk decontamination and to review and evaluate methods of decontamination. The parameters governing the removal of strontium, iodine, cesium and rare earths by electrodialysis were to be defined with emphasis on developing a practical adaptation of the electrodialysis method and equipment design criteria. Possible application of the method to the lower level decontamination problems, such as those associated with reactor and other nuclear accidents, was to be indicated.

The objectives of the experimental program were to determine the effect of independent operating variables on the design parameters for an electrodialysis unit to decontaminate milk, to estimate the economics of milk decontamination by electrodialysis on the basis of the experimental data and to ascertain the degree of removal of the various cationic and anionic contaminants and the effect of the process on the mineral and organic composition and concentration of the milk.

The important variables are current density, milk pH, temperature, and composition and concentration of the "make-up" solution of salts used as a source of replenishment for salts removed from the milk during the process. Within limits another important variable is the type of membrane used.

The design parameters to be determined from the laboratory scale experiments to evaluate and design plant scale equipment were: limiting current density, electrical resistance of cells (which determine the energy requirements), ion transfer current efficiencies, separation factors (i.e., relative removal rates for the various important cations and anions), stability of the membranes over continued periods of usage, behavior of the milk in the electrodialysis process and requirements for additional treatment before or after electrodialysis.

Ultimately the goal was to achieve a desired degree of decontamination without appreciable changes in nutritional value, palatability, composition and stability of the milk under sanitary conditions.

2.2 Previous Work

Most of the previous work has been on decontamination by ion exchange using bone preparations, calcium phosphate or synthetic ion-exchange resins. Some laboratory work was reported on electrodialysis for removal of I^{131} by Glueckauf, Cosslett, and Watts (14).

Pulverized inorganic bone preparations and calcium phosphate have been tested in the laboratory for the removal of strontium from milk (29). Using "in vitro" labeled milk, 50 to 70% of removals of strontium have been obtained in the laboratory, but the composition of the milk is altered appreciably.

Synthetic ion-exchange resins have been used for the removal of cationic contaminants such as strontium and cesium (6, 8, 9, 23, 26 and 28) and for the removal of iodine (6, 7, 14). The cation exchange process for strontium removal has undergone pilot plant tests (12).

2.2.1 Iodine Removal

Murthy, Gilchrist and Campbell of the Robert A. Taft Engineering Center, Cincinnati, Ohio, have published extensive data on the removal of I^{131} from milk by ion exchange with Dowex 2-X8 (25). About 95% of the I^{131} was removed from 230 resin bed volumes of milk at temperatures ranging from 1 to 30°C. The iodine was stripped from the bed with 2 N HCl followed by regeneration with a charge aqueous solution containing sodium chloride, citrate and dihydrogen phosphate at pH 6.6. The anionic composition of the charge was designed to maintain the composition of the milk constant during the decontamination. Only the protein-bound I^{131}, which was not available for ion exchange, was not removed. Because of the high decontamination capacity of the resin bed, and the relatively high cost of the acid and salts used for regeneration of the resin, the cost of decontamination consists mainly of the cost of regenerant chemicals. Based on the data published by Murthy et al., this cost can be estimated at about 2¢/quart of milk.

2.2.2 Strontium Removal

A considerable amount of work has been done on the removal of strontium from milk by ion exchange using synthetic cation exchange resin. Nervik et al. (28), Gosslet and Watts (6), and Easterly et al.(8) showed that radio-strontium could be removed from milk by ion exchange using Dowex 50 in the sodium form. Easterly et al.(9, 10) reported removal of strontium^{89} and calcium^{45} from skim milk using Dowex 50 and Duolite C-20. A higher removal of Sr was observed from milk contaminated in vitro 16 hours prior to removal, than from skim milk of dosed cows (in vivo). A higher affinity for Sr than for Ca was reported.

Murthy et al. (26) of the Robert A. Taft Engineering Center and L. F. Edmonson of the Dairy Products Division, USDA, Beltsville, Maryland, improved the ion exchange removal for strontium and barium by adjusting the pH of milk to 5.4 or 5.3 with citric acid before decontamination. To prevent changes in the cationic composition of the milk, the resin was charged with a mixed salt solution of Ca, Mg, K, and Na chlorides in approximately the same relative proportions as in the milk. The pH of the milk was readjusted by batch contacting with Dowex 2-X8 anionic resin in the OH^- cycle. Approximately 90 to 95% of Sr^{85}, 85 to 90% of Ba^{140} and 75% of Cs^{134} were removed from 25 resin-bed volumes of raw whole milk. Similar results were obtained for milk contaminated in vitro with storage of the milk at 4°C. for 72 hours after addition of the tracers and for milk contaminated in vivo. Similar research and development work was done by Edmonson et al. (11) and Landgrebe et al.(20). This culminated in a pilot plant located in Beltsville, Maryland, at the Dairy Products Laboratory of the ARS Eastern Utilization Research and Development Division (12). It is reported that about 90% of the radioactive strontium in milk can be removed. The cost of this process is mainly that of the salts used to regenerate the ion-exchange resins, and the acid and base used to adjust the milk pH. Using citric acid and potassium hydroxide, the cost had been estimated at 2¢ per quart of milk processed, based on USP grade salts and on reuse of part of the salt solution. More recent cost estimates place the cost of the chemicals at about 0.75¢ per quart of milk. Without salt reuse, the cost may be as high as 5¢ per quart of milk.

A plant capable of processing about 1,500 gallons of milk per hour is being built by Producers Creamery Company of Springfield, Missouri, under a joint contract between the U.S. Department of Agriculture and the Health, Education and Welfare Department (31). The purpose of this plant is to scale up the operation, and to determine the feasibility of the process for use in the average dairy plant.

2.3 Electrodialysis Cells for Milk Decontamination

2.3.1 The Electrodialysis Process

In electrodialysis, ions are transferred from one liquid solution to another across selectively permeable membranes under the influence of an electric field. Cation transfer membranes consist of cation exchange resin in sheet form. They permit the passage of cations and restrict the passage of anions. Anion transfer membranes consist of anion exchange resin in sheet form and permit the passage of anions. The current efficiency of the cation membrane is defined as the ratio of cations to total ions transferred through the membrane. The current efficiency depends not only on membrane composition, but also on solution composition and operating conditions. Undissolved solids and dissolved non-ionized materials are prevented from appreciable migration through the membranes because the size of the "pores" in the membranes are in the range of 5 to 10 Å. For the same reason, the membranes are also effective hydraulic barriers so that during electrodialysis practically no liquid flows across the membrane due to differences in hydrostatic head on opposite sides of the membranes.

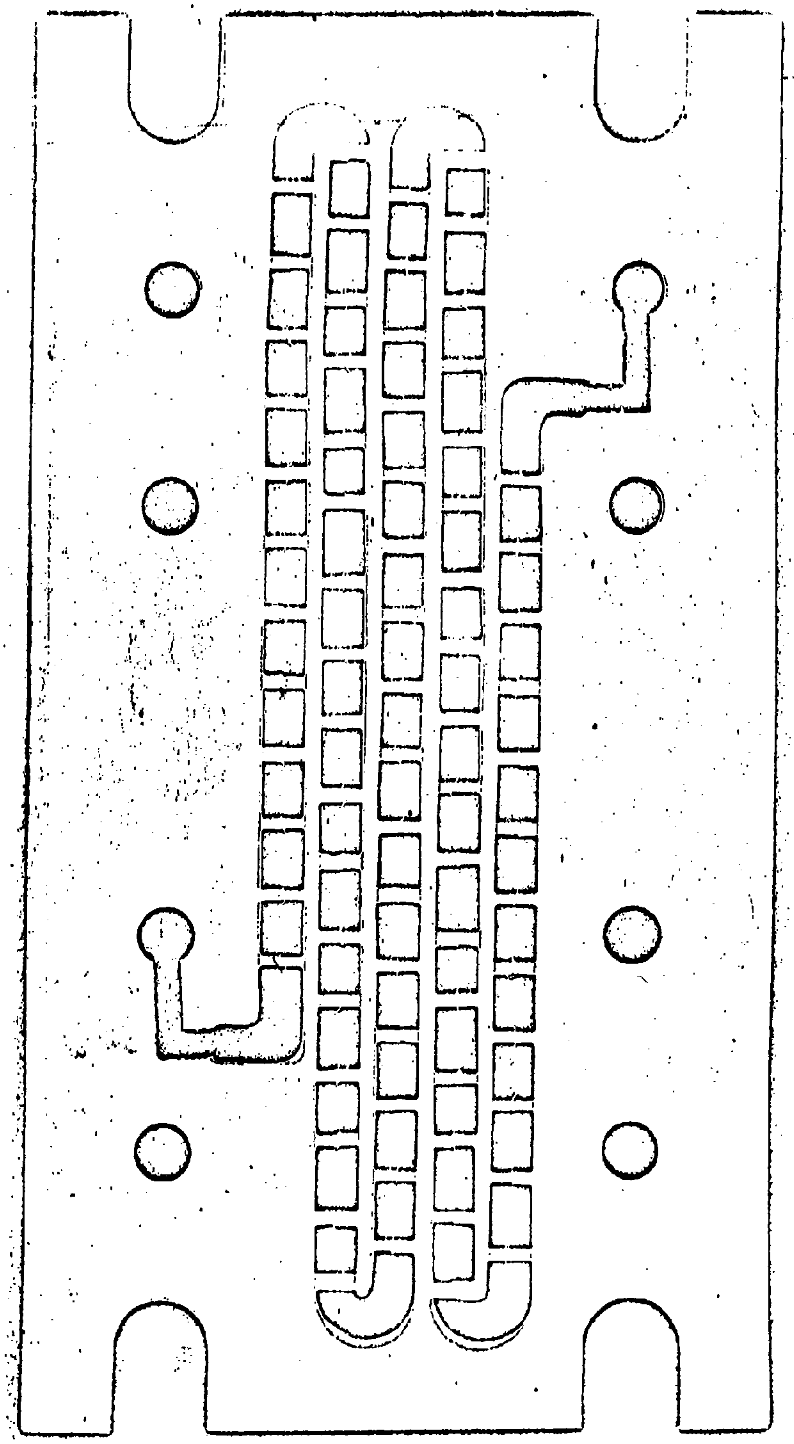
2.3.2 Cell Configuration

The various liquid streams flow into cells bounded on both sides by membranes. The spacing between the membranes is maintained by spacers (sheets of gasketing material) placed between the membranes. Portions of the central area of each spacer are cut out to provide passages for the flow of the liquids between the two membranes (see Figure 1). The

FIGURE I

MEMBRANE SPACER

TYPICAL



spacer dimensions and flow path shape can be varied. An assembly of membranes, spacers and two electrodes formed into a unit having a plurality of cells is referred to as a "membrane stack" (see Figure 2). The electrodes are placed at both ends of the stack.

Ion transfer membranes can be used for decontamination of milk by electrodialysis in several different ways. Examples are shown in Figures 3A, 3B and 3C.

Removal of cationic radioactive species such as Sr^{90}, Cs^{137} and Ce^{144} can be effected using the cell configuration in Figure 3A. Non-radioactive cations are transferred across the cation membrane into the milk from the make-up salt solution, and cations, including radioactive nuclides, are transferred out of the milk into the contaminated solution stream. Hereafter the former membrane will be called the make-up membrane, and the latter membrane will be called the decontaminating membrane. This operation constitutes a purging and replacement of the cations (radioactive and non-radioactive) originally present in the milk with non-radioactive cations from the make-up salt solution. The make-up salt solution consists of salts of the inorganic cations found in milk, such as calcium, magnesium, potassium and sodium. The relative concentrations of these salts in the make-up salt solutions are adjusted so that the salt balance in the milk is maintained during the operation when cations are transferred into and out of the milk. As indicated in Figure 3A, the anions associated with the cations in the make-up salt solution are transferred into the contaminated solution and the anion composition of the milk is not affected. For this reason chlorides can be used as make-up salts.

Where removal of radioactive anionic species (such as I^{131}) is desired, the cell configuration shown in Figure 3B can be employed. The make-up solution would contain the anions found in milk, such as phosphate, citrate, and sulfate in the form of soluble salts (e.g., the sodium salts). Transfer of these anions into the milk through an anion transfer membrane is accompained by simultaneous transfer of the normal milk anions plus the radioactive anions out of the other side of the

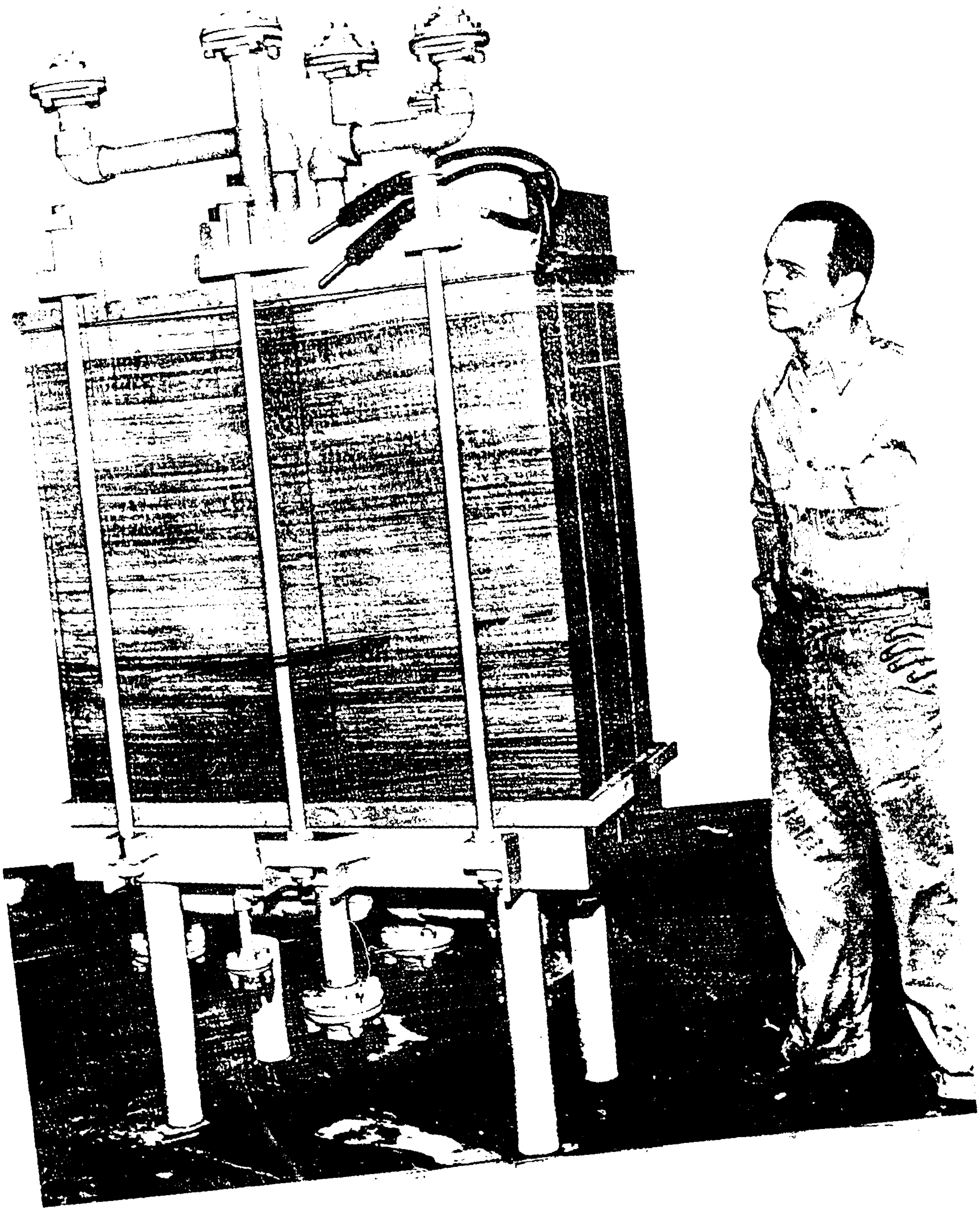
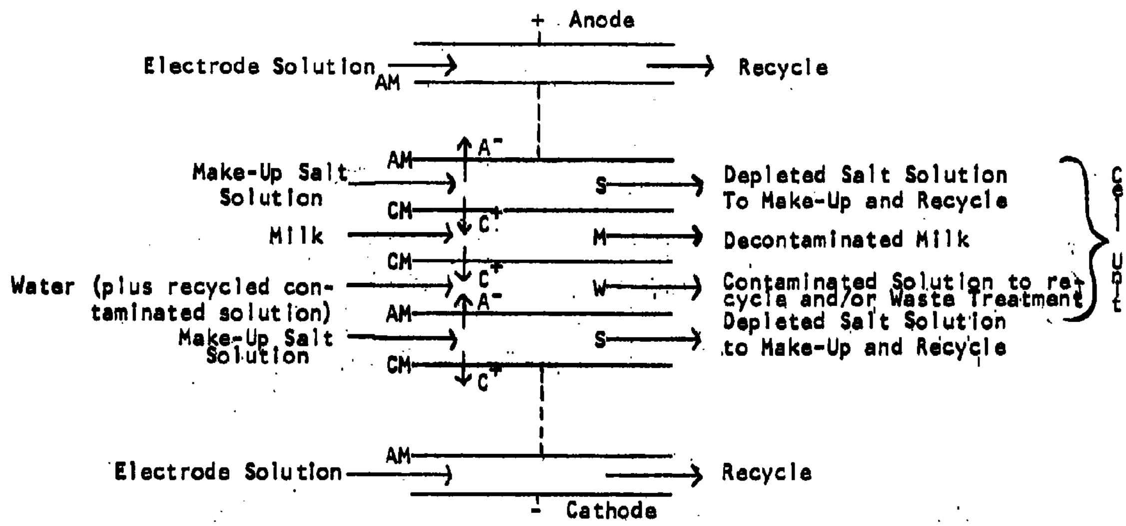


FIGURE 3

Membrane Cell Configurations for Milk Decontamination

A. Three Compartment Cell Unit (Cation Decontamination)

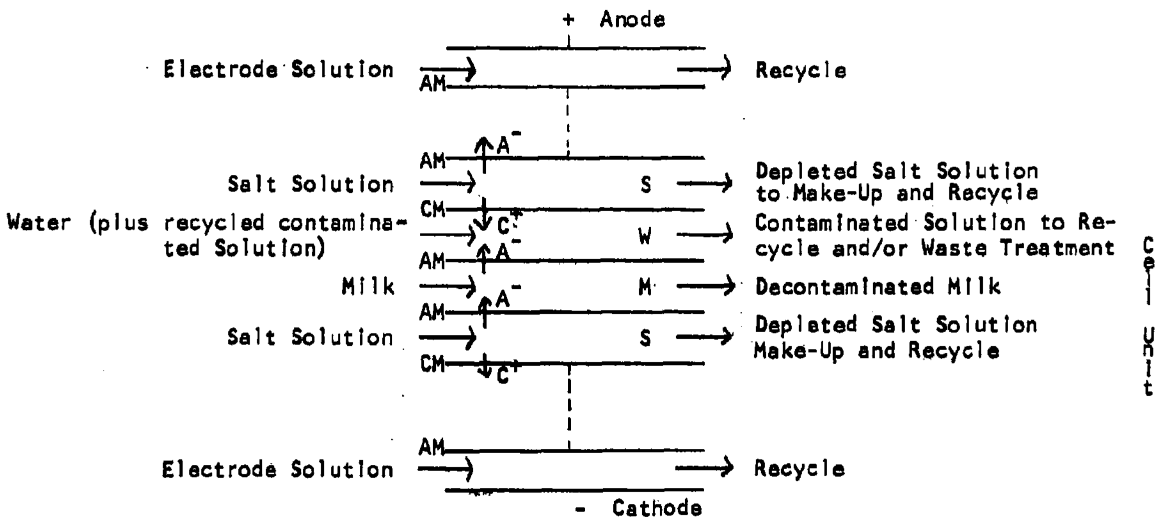


Key:

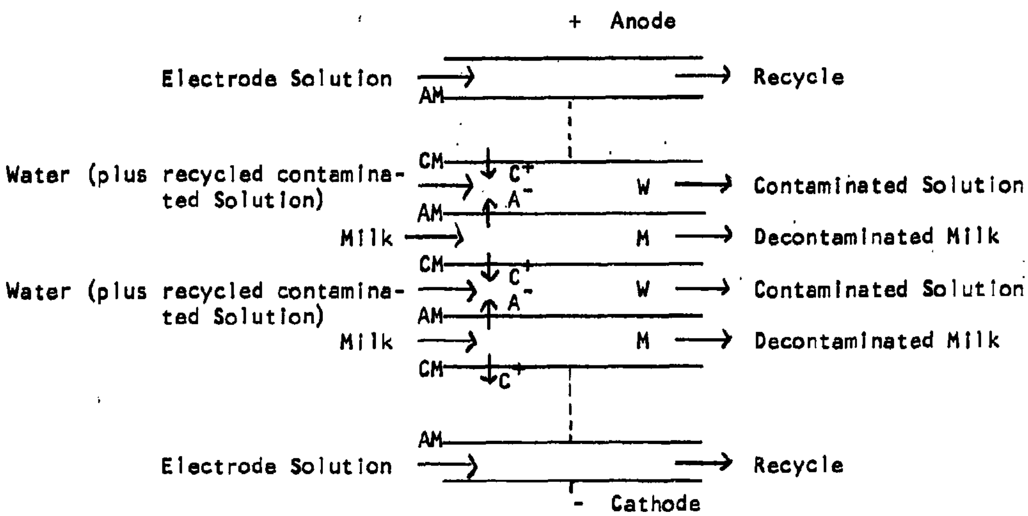
AM	=	Anion Transfer Membrane
CM	=	Cation Transfer Membrane
A^-	=	Any Anion Present in Solution
C^+	=	Any Cation Present in Solution
S	=	Salt Solution Cell
M	=	Milk Cell
W	=	Contaminated Solution Cell

FIGURE 3 (continued)

B. Three Compartment Cell Unit (Anion Decontamination)



C. Conventional Deionization Cell



milk cell. The use of anion transfer membranes on each side of the milk cell prevents the transfer of cations in and out of the milk. The ratio of anions in the make-up stream must be adjusted to maintain the proper ratio of anions in the contaminated milk.

Removal of both radioactive cations and anions can be accomplished by operating the cells shown in Figures 3A and 3B in series or by using the deionization cell shown in Figure 3C. In the latter cell both anions and cations (stable and radioactive) are transferred from the milk into a contaminated water stream. Non-radioactive salts must be added directly to the milk during the decontamination to replenish the salts removed by electrodialysis.

2.3.3 Methods of Cell Operation

There are three different general methods of operation in which the electrodialysis cells described above can be used: feed and bleed, batch, and continuous staging. These are shown schematically in Figure 4.

In the feed and bleed system, the concentration of contaminants in the milk undergoing decontamination is essentially the same as in the decontaminated milk. This has the disadvantage that the ratio of contaminants to other ions is always near its lowest value in the stack during the processing. It results in high energy, equipment and chemical costs per unit of milk treated.

In the second system, a batch of milk to be decontaminated is recirculated through the electrodialysis equipment until the decontamination level has been brought down to the desired point.

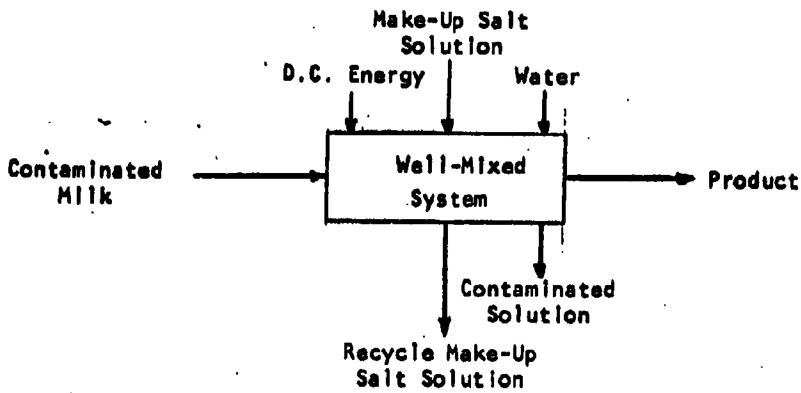
In the third system, the milk flows continuously through as many electrodialysis stages in series as necessary to produce the desired degree of decontamination.

Both the batch and the staged method require essentially the same energy, equipment and chemical costs per unit of milk treated.

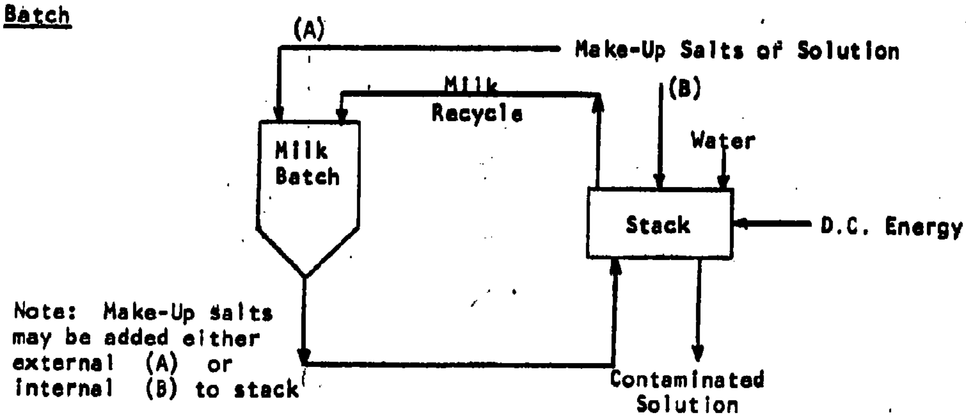
FIGURE 4

Electrodialysis Systems

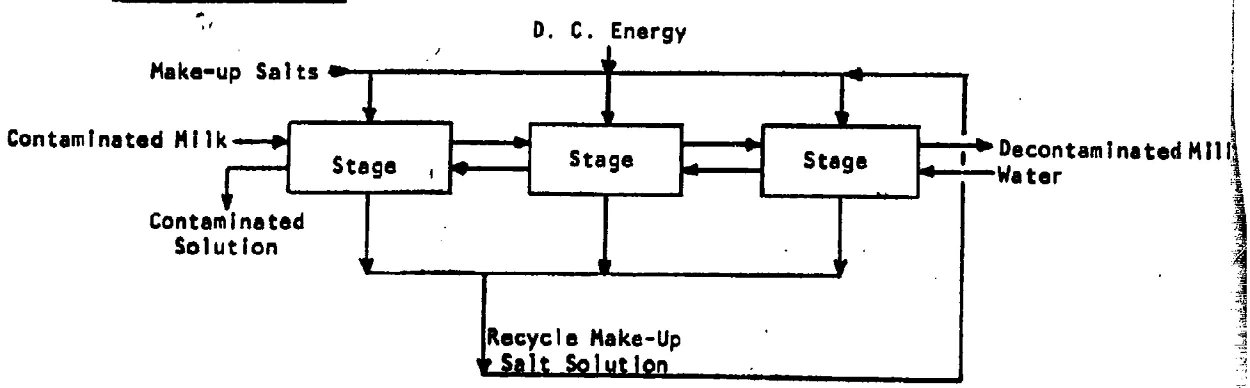
1. Feed and Bleed



2. Batch



3. Continuous Staging



2.4 Experimental Program

The initial program consisted of a series of experiments on uncontaminated whole milk to determine the limiting current density, current efficiency, electrical resistance, and selective transfer of the ions in milk under various conditions of pH, temperature, flow rate, salt concentrations and ratios in the milk, and membrane type. The tendency of milk deposit to form on the membranes was used as the criterion to determine the limiting current density.

After evaluating data from these initial experiments, runs were made using milk to which radioactive tracers of Sr^{85}, Cs^{137}, Ce^{139} and Ba^{140}- La^{140} had been added. The purpose of these preliminary tracer tests was to determine early in the program the levels of salt transfer required to achieve given levels of decontamination.

Later experiments with radioactively contaminated milk were conducted to determine optimum operating values for the process variables studied with a major effort toward achieving maximum removal rates for the contaminants.

Concurrent with these studies, an analysis of the relative rates of transfer of the various milk cations through permselective membranes was made to determine the conditions needed to maintain a constant cationic composition in the milk during decontamination.

A series of runs were made on an all-anion membrane system to determine the limiting current density for the anion membranes at various operating temperatues and pH values. These polarization studies were followed by decontamination runs on milk "spiked" with I^{131} During this phase of the program, studies were made of the removal of radioactive iodine from milk under current and at zero current. In runs where iodine was removed at zero current, the membranes were regenerated electrically.

Experiments were also made to determine: (1) the feasibility of controlling milk pH by electrical addition of hydrogen ions to the milk stream during decontamination, (2) the effect of increased levels of natural strontium in contaminated milk, (3) the loss of organics such as lactose from milk during decontamination, and (4) the possible re-use of a portion of the waste stream as a make-up solution.

Techniques for improving and extending membrane life were studied during the program.

2.5 Composition of Milk

Most of the minerals in milk are present in ionized form and thus are capable of conducting electric current, which makes the electrodialysis of milk or whey feasible. The composition and concentration of the fat, protein, carbohydrate and vitamin components of the milk must be maintained during decontamination.

Milk consists of about 3.9% fat, 3.5% protein, 4.9% lactose and 0.7 to 0.8% ash (33). The ash does not include all the salts, such as citrates and other salts volatile at the temperature of ashing. Typical composition of skim milk, whey, and the calcium caseinate complex are given by Whittier and Webb (34). The composition of the ash in skim milk is also given.

Murthy (24) reported the values given below for the ionic composition of milk as determined by ion exchange:

Composition of Milk By Ion Exchange

Cations	meq/liter	Anions	meq/liter
Ca^{++}	50	$PO_4^{\equiv}$	68
Mg^{++}	14	Total P	103
Na^{+}	35	Citrate	28
K^{+}	44	$SO_4^{=}$	6
TOTAL	143		

Jenness and Patton (18) report the approximate mineral composition of milk as follows:

Mineral Composition of Milk

Cations	grams/liter	meq/liter	Anions	grams/liter	meq/liter
Ca^{++}	1.25	62	Phosphates (as $PO_4^{=}$)	2.10	66
Mg^{++}	0.10	8	Citrates (as citric acid)	2.00	31
Na^{+}	0.50	22	Cl^{-}	1.00	28
K^{+}	1.50	38	HCO_3^{-}	0.20	3
			$SO_4^{=}$	0.10	2
	TOTAL.......	130		TOTAL......	130

Casein is present as a calcium compound associated with a small proportion of calcium phosphate (34). Calcium and phosphate associated with caseinate are known as "organic calcium" and "organic phosphorus." The casein precipitates at pH 4.1 to 4.6 as a weak acid, in which state it is free of the associated calcium and phosphate combined directly with the protein. During electrodialysis the pH of the milk must not be allowed to drop to the coagulation point of the casein.

The particles of casein in milk consist of about six different sizes with multiples of unit diameter 66 millimicrons and molecular weight 33 million (34). The molecular weight of the predominant particles is 530 million, and the largest observed is 15 billion. These particles are too large to penetrate the pores of the ion-transfer membranes used in electrodialysis, but may have a tendency under certain conditions to deposit on the surface of the membranes. The fat particles in the milk may also tend to form deposits.

A discussion of the general ionic equilibria in ion exchange of milk has been given by various authors (2, 4, 5, 13, 15 and 24).

Multivalent ions are preferred over univalent except that the order of exchange of phosphate and chloride are reversed.

3.0 RESULTS AND DISCUSSION

The results on cation decontamination are organized on the basis of the objectives or variables under investigation. To facilitate presentation of data, the cation decontamination runs are separated into two groups. In the runs of Group 1, the decontaminating and make-up membranes were different in that the decontaminating membrane was "tighter" than the make-up membrane. The "tighter" membrane has smaller "pores." In Group 2, the make-up and decontaminating membranes were identical.

The decontamination results given in terms of hours or ampere-hours are based on a lab stack having 5 cell units and a total of 0.30 square feet of active decontaminating membrane area.

3.1 Cation Decontamination

3.1.1 Effect of Milk pH

Since decontamination by electrodialysis and ion exchange both depend on the presence of the radionuclide as a free ion in the milk, the effect of pH in both cases should be similar. Therefore, a pH range from 5.1 to 6.6 was studied to confirm that the degree of removal of Sr^{85} from milk by electrodialysis also increases as the pH decreases, as is the case in ion exchange.

The effect of milk pH is shown in Table 1. A current density of 30 ma/cm^2 was used in these runs, except for Run 12 in which a current density of 60 ma/cm^2 was used. The results are presented graphically in Figure 5.

A pH of 5.4 or less is needed to remove 95% of the strontium from the milk. In all runs at 30 ma/cm^2 and low pH, there was either little or no deposition of solids from the milk on the cation membranes. Any deposits which formed were easily removed by rinsing with water. The colloidal nature of the casein in the milk and the presence of proteins which have charges associated with them was originally considered to be a potential source of membrane fouling due to migration in an electric field. Since, during the course of 95% removal of radioactive strontium

TABLE I

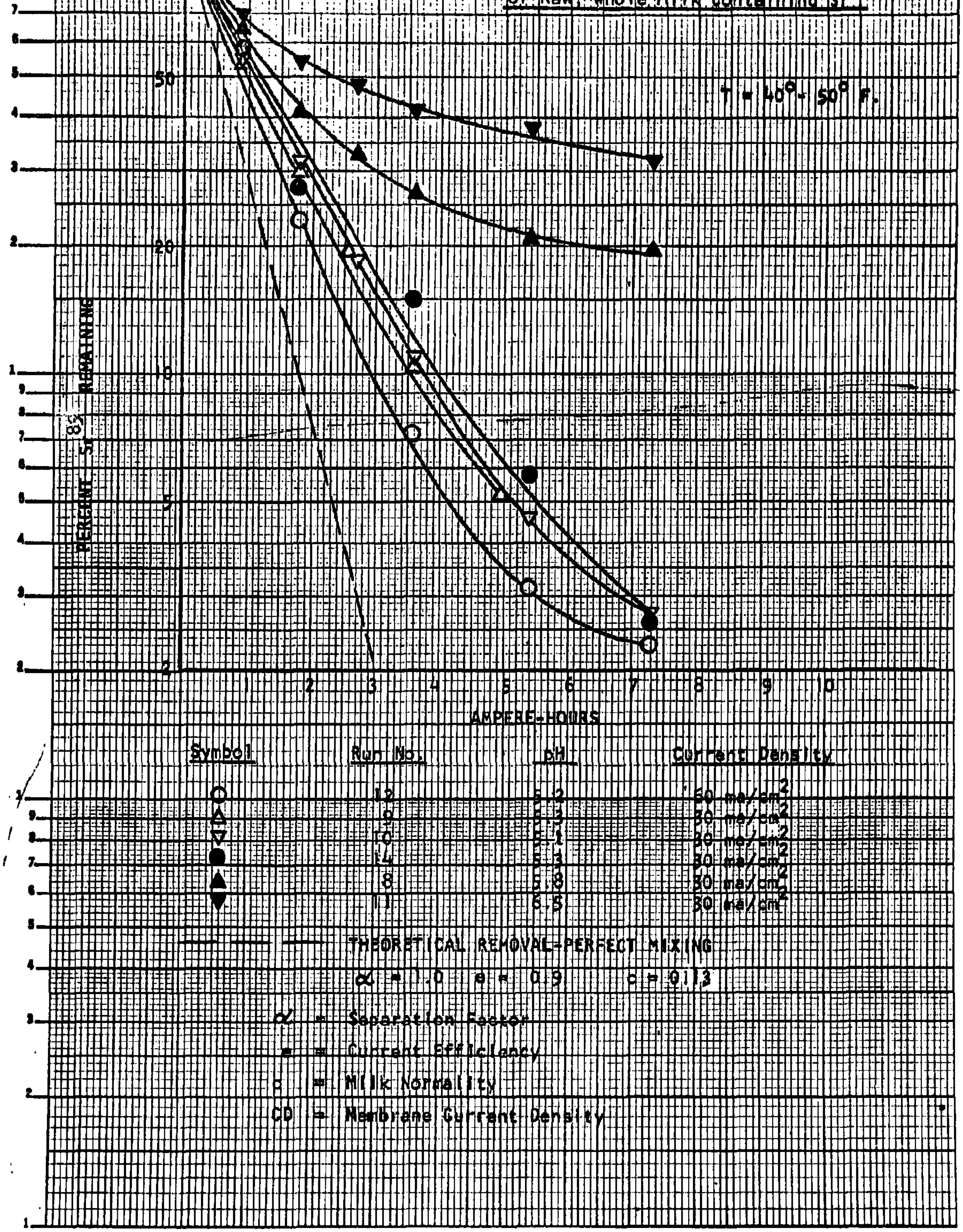
Effect Of Milk pH On Strontium Removal

Run No	Milk pH	Temp. (^{o}F)	Current Density (Ma/cm^2)	Length of Run (Hrs.)	Voltage Drop per 5 cell units (volts)	% Sr^{85} Remvd	*Amp-Hrs/liter to obtain 95% Sr removal
11	6.5	50	30	4		68.3	-
8	5.8	45	30	4	24	80.5	-
9	5.3	47	30	2.66	24	>94.8	5.1
14	5.3	45	30	4	27 - 32	97.4	5.8
12	5.2	45	60	2	58 - 67	97.7	4.3
10	5.1	45	30	4		97.3	5.2

* Stack consisted of 5 cell units.

FIGURE 5

Effect of pH on Decontamination of Raw, Whole Milk Containing Sr^{85}



by electrodialysis, this has had little or no effect on the desired operation, it does not appear to be an area of concern. Some deposition of a creamy material was noted at the end of the milk manifold holes after some of the early electrodialysis runs made between a pH of 5.1 and 5.8. This was overcome in a test stack by feeding the inlet milk manifold at both ends and by drawing milk from the exit manifold at both ends.

When the electrodialysis unit was operated at a pH of 6.5 (Run 11), a dense coherent deposit formed on the milk side of the cation membrane which divided the milk and make-up cells. The heaviest deposits were in the cells closest to the anode. There was some indication that the deposit penetrated the membrane. During this run, the ionic concentration of the milk decreased to 62% of the initial concentration while the conductivity of the milk decreased to about 20% of the original conductivity. These results can be explained as follows:

At a pH of 6.5 certain salts in the milk may be less soluble than they would be after the pH adjustment with citric acid. Therefore, when electrodialysis is performed on the milk at a pH of 6.5, the supersaturation point for these salts may be reached in the liquid film on the milk side of the cation membrane between the milk and make-up streams. This could result in the precipitation of some salts on the membrane, which in turn interferes with the transfer of cations into the milk.

At lower pH's, in Runs 8 to 10, the milk increased in conductivity and ionic concentration during the run. Proportionally, calcium and magnesium showed greater concentration gains than sodium and potassium in these runs. In Run 11 at pH of 6.5, milk lost almost 90% of its sodium and 50% of its potassium ions while the calcium and magnesium were essentially unchanged. The disparity between the percentage change in cationic concentration and the conductivity shows that the electridal conductivity of the milk is due mainly to the univalent cations and not the divalent cations.

Good material balances were obtained for all the cations in Run 11 which shows that the loss of cations from the milk was not due to loss of cations in the deposit or the membrane, but was due to reduced transfer rate of cations into the milk through the membrane effected by the deposit.

3.1.2 Limiting Current Density

The production rate of an electrodialysis stack is proportional to the current density applied. As the current density is increased, a condition termed polarization is reached. At the polarization point, the transfer of ions through the membranes becomes greater than the rate of supply of ions from the bulk of solution to the membrane surface and a solution film depleted in salt is created at the membrane-solution interface. Under these conditions, water dissociates at the interface providing H^+ and OH^- ions to carry any additional current. One of these two ions is transferred through the membrane (depending on the membrane type) and the other builds up in concentration in the solution phase. Operating under polarized conditions may result in salt precipitation in the cells and in increased voltage. Due to the adverse effects of polarization, an electrodialysis unit is usually run at a current density below this point. The determination of this limiting current density is very important in evaluating the economics of the process because of the limitation it imposes on the production rate. The limiting current density increases with increased velocity of fluid past the membrane surface. The laboratory stack was operated at the highest practical flow rate, which is determined by the pressure limitations of the stack.

Several runs were made to determine the effect of current density on decontamination of Sr^{85} from milk. In these runs, current density was varied while all other operating conditions remained unchanged. This investigation covered Runs 12, 16 and 17 of Group 2 which were operated at 60, 30 and 45 ma/cm^2, respectively; Runs 20 and 21 of Group 1, which also were operated at 30 and 45 ma/cm^2; and Runs 22 and 28 of Group 1, which were operated at 52 and 60 ma/cm^2.

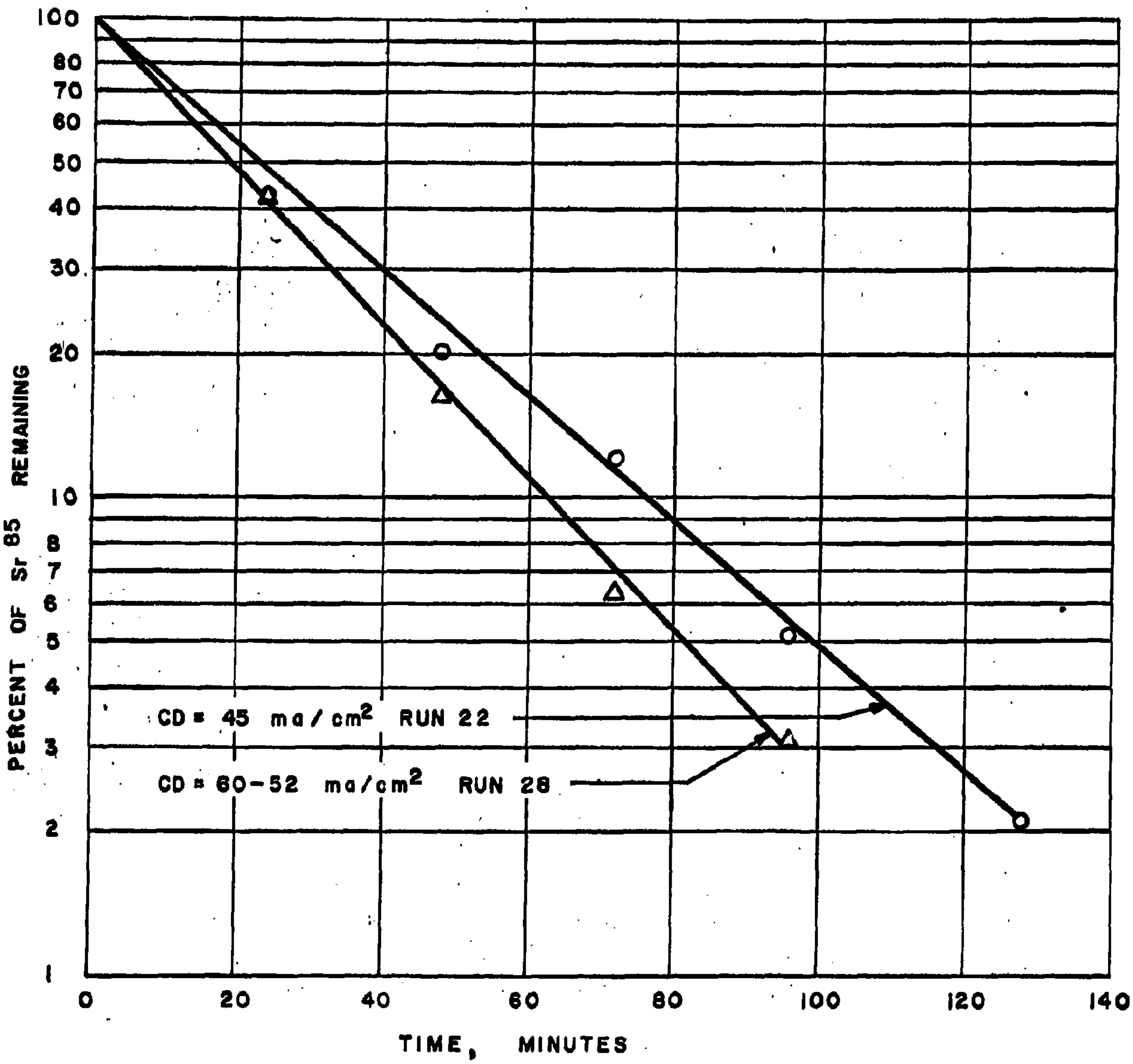
The total salt concentration in the milk increased by 4% in Run 22 and by 8.6% in Run 28. A comparison of the results of these runs (see Figure 6) revealed that the time required to obtain 95% removal of Sr^{85} from one liter of milk with a 5 cell unit was 99 minutes at 45 ma/cm^2 and 81 minutes at 52 to 60 ma/cm^2; therefore, the rate of Sr^{85} removal is proportional to the current density. The increased rate of decontamination at higher current densities is accompanied by an increase in energy consumption. The energy requirement to remove 95% of the Sr^{85} was 217 watt-hours at 45 ma/cm^2 and 386 watt-hours at 52 to 60 ma/cm^2.

The decontamination rates of Run 16 and 17 and of Runs 20 and 21 were not comparable due to large variations in the concentrations of salts in the milk product. In Run 16 the salt concentration increased by 65% and in Run 17, by 79%. The concentration increases in Run 20 and Run 21 were 79% and 92%, respectively. Since the rate of removal of a radionuclide is affected by the salt concentration in the milk, the effect of current density on decontamination could not be ascertained from these runs (see Figure 7).

The electrical resistance of the membrane stack increased progressively in Runs 12 and 28, which were made at the highest current density tried, 60 ma/cm^2. In Run 12, using fresh membranes, it was necessary to increase the stack voltage from 73.5 to 82.5 volts in order to maintain a constant current density during the run. In Run 28, using membranes which had been in use for 20 ampere hours, it was impossible to maintain the current density at 60 ma/cm^2 even though the initial stack voltage of 77 volts was increased to 88 volts (rectifier limit) during the run. By the end of Run 28, the current density had fallen to 52 ma/cm^2. On the basis of these results it was decided that a current density of 60 ma/cm^2 was too high and 45 ma/cm^2 would approach the operating limit for the cation removal system.

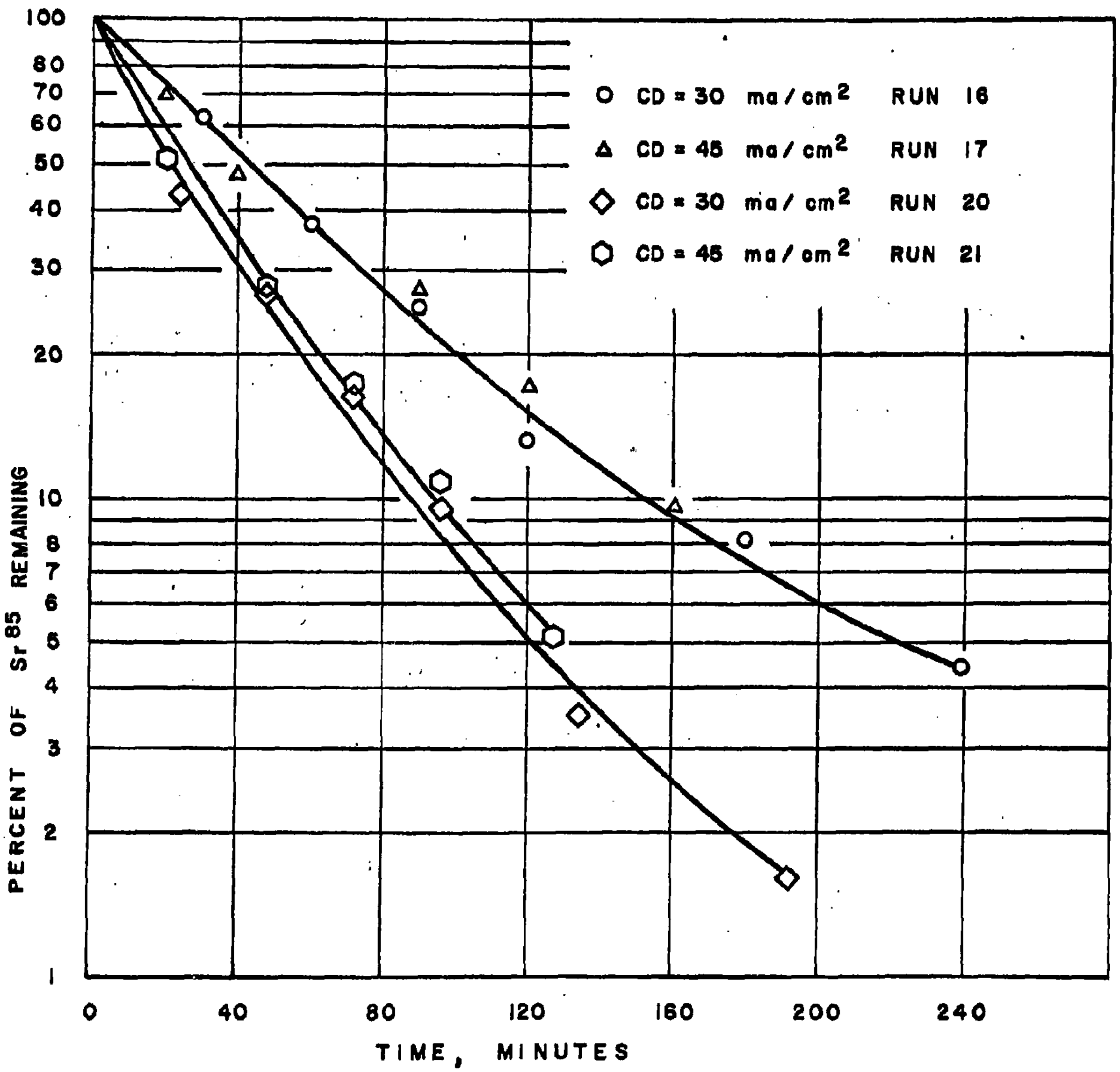
The rate of cesium removal was also proportional to the current density. About one ampere-hour per quart of milk was required for 95% Cs^{137} removal, on the average about 4 times faster than the rate of Sr^{85} removal.

FIGURE 6



REMOVAL OF Sr^{85} FROM RAW MILK
EFFECT OF CURRENT DENSITY

FIGURE 7



REMOVAL OF Sr^{85} FROM RAW MILK
EFFECT OF CURRENT DENSITY

During each of the decontaminating runs a small amount of solid separated from the milk stream and was deposited on the surface of the decontaminating membrane. The amount of deposition of solids from the milk stream onto the membranes increased at the high current density of 60 ma/cm^2. These solids did not adhere to the membrane and were easily wiped away after the run.

3.1.3 Effect of Temperature

Run 23 was made at about 100°F instead of 40 to 50°F., and otherwise at the same conditions as Run 22 (see Figure 8). The higher temperature resulted in a drop in the voltage per unit cell from 13.7 to 7.5, or about 1.2% decrease in voltage per degree F. The energy consumption at a given production rate is decreased proportionately.

3.1.4 Control of Salt Concentration in Milk and the Effect on Decontamination Rate

In the early decontamination runs, a persistent increase in the concentration of salts in milk was observed. This increase in the concentration of salts dilutes the radioactive contaminants and consequently reduces their rate of removal by electrodialysis.

The total concentration of salts in milk may increase or decrease during milk decontamination by electrodialysis if the coulomb or current efficiency for the transfer of cations into the milk through the make-up membrane differs from the current efficiency for the removal of cations from the milk through the decontaminating membrane. When the current efficiency of these two membranes is identical, the total cations entering and leaving the milk stream are equal and the concentration of salts in the milk remains constant. The current efficiency for the decontaminating membrane decreases relative to the current efficiency of the make-up membrane with usage, resulting in an increase in the concentration of salts in milk during the decontamination process. Furthermore, the cations entering through the decontaminating membrane compete with chloride ions entering the milk from the waste stream, whereas the cations entering the milk from the make-up stream compete with relatively slower ions such as citrate and phosphate in the milk.

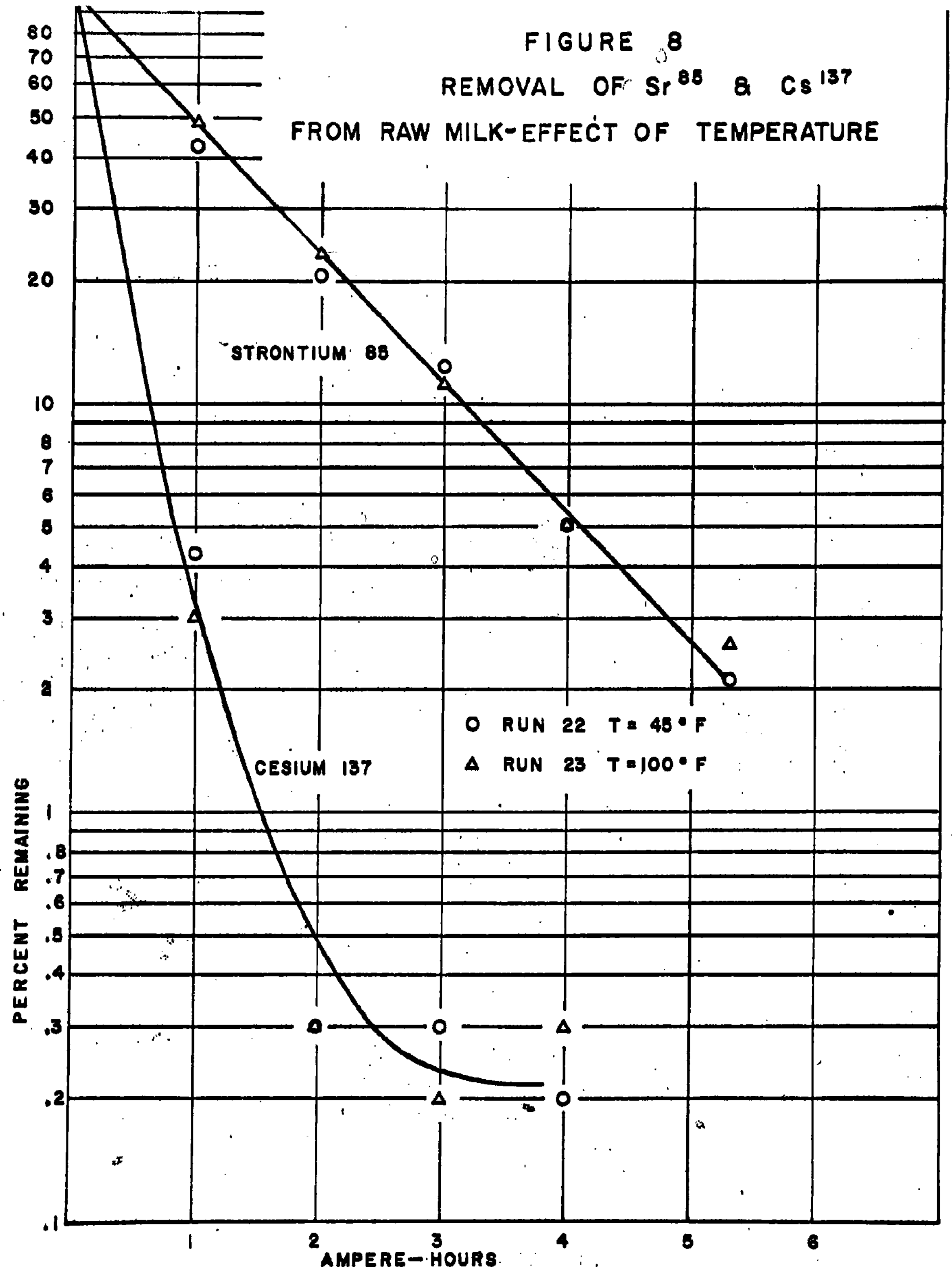


FIGURE 8
REMOVAL OF Sr^{85} & Cs^{137}
FROM RAW MILK-EFFECT OF TEMPERATURE
STRONTIUM 85
CESIUM 137
O RUN 22 T = 45° F
Δ RUN 23 T = 100° F
PERCENT REMAINING
AMPERE—HOURS
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6

Two ways of equalizing the current efficiency have been explored. In one case, the salt concentration in the make-up stream is lowered to a point near polarization, to reduce the cation transfer efficiency in the make-up membrane. In this case only moderately tight membranes (61 CZL 4) were used for both the make-up and decontaminating membrane. This can be accomplished by reducing the make-up concentration to 0.1 N at 45 ma/cm^2 as in Runs 26, 27, 29 and 30, classified as Group 2. A second method is to use a "tighter" membrane (61 DYG) as the decontaminating membrane as in Runs 22, 23, 25 and 28, classified as Group 1. The tight DYG membrane can offset the competition of the chloride ions in the waste stream. The latter system has the disadvantage of allowing an increase in the volume of milk of about 20% due to differences in electrical transfer of water between the DYG membrane and the other membranes. A second objection to the use of the DYG-CZL 4 system is that the tight membrane exhibits a higher degree of electrical resistance to the passage of current than the other membrane, which results in increased energy consumption for milk decontamination and a high voltage drop in the electrodialysis stack. Similar observations were made on a DYG decontaminating membrane and a standard water desalting membrane (61 AZL) as make-up membrane.

The degree of Sr^{85} and Cs^{137} decontamination obtained for Runs 26 and 30, Group 2, is shown in Figure 9. The degree of Sr^{85} and Cs^{137} decontamination obtained for Group 1 is shown in Figure 10. The pH of the milk in Run 25 was 5.5 to 5.6, which explains the slower rate of Sr^{85} decontamination for this run. The decontamination results for Run 24, in which only "tight" cation membranes were used, are given in Figure 11. The decontamination rate was essentially the same as for Group 1.

A comparison of results obtained using the DYG-AZL system and the CZL 4 system is given in Table II. The differences in energy requirements and the changes in milk volume suggest that the best system is the 61 CZL 4 cation membrane as both the decontaminating and make-up membrane. On the average, the salt concentration increases less with the DYG system; however, regeneration of the membrane efficiency by a

TABLE II

Control of Salt Concentration in Milk During Decontamination

Run	Make-up Membrane	Decont. Membrane	Average Normality Make-up Stream	Current Efficiency Make-up Membrane	Current Efficiency Decont. Membrane	Electrical Energy to Obtain 95% Sr Removal, KWH/qt	% Increase in Salt Conc. in Milk	% Increase in Milk Volume
56	61 AZL4	61 DYG	0.123	0.814	0.792	0.442	2.1	18.0
57	"	"	0.138	0.804	0.756	0.538	13.8	16.0
58	"	"	0.140	0.889	0.868	0.247	0.2	18.0
59	"	"	0.146	0.778	0.701	0.425	40.6	21.0
62	"	"	0.141	0.892	0.855	0.336	16.1	16.0
63	"	"	0.141	0.949	0.915	0.194	12.3	19.0
67	"	"	0.152	0.880	0.849	0.261	-0.8	16.0
68	"	"	0.140	0.886	0.857	0.285	0.0	22.0
70	61 AZL4	61 CZL4	0.966	0.840	0.796	0.081	17.7	7.0
64	61 CZL4	61 CZL4	0.105	0.945	0.926	0.105	18.1	2.0
65	"	"	0.096	0.908	0.860	0.124	31.8	2.0
66	"	"	0.105	0.917	0.872	0.124	27.0	2.0
69	"	"	0.104	0.872	0.847	0.108	22.5	2.0

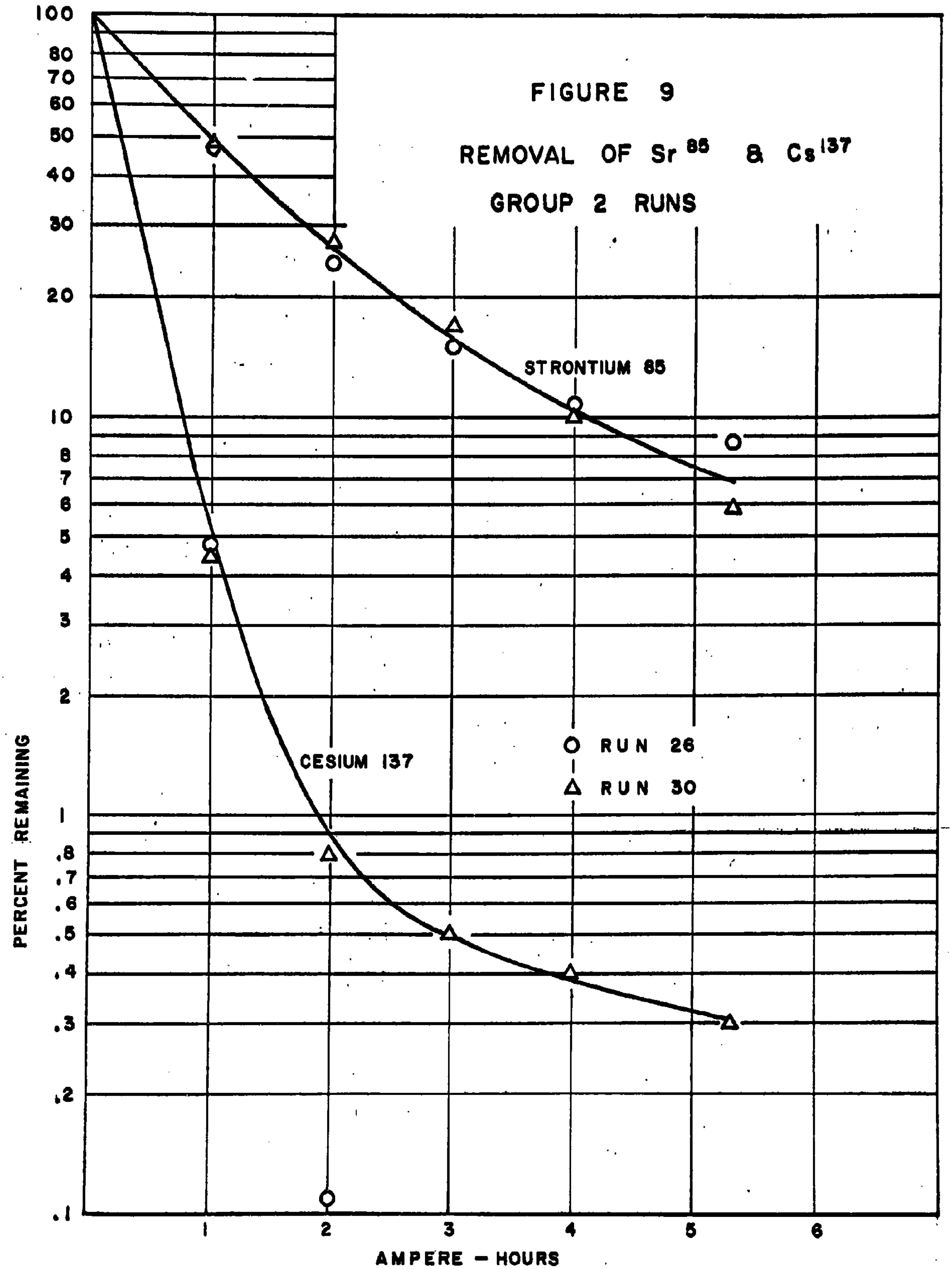


FIGURE 9
REMOVAL OF Sr 85 & Cs 137
GROUP 2 RUNS
STRONTIUM 85
CESIUM 137
RUN 26
RUN 30
PERCENT REMAINING
AMPERE — HOURS
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
.8
.7
.6
.5
.4
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2
3
4
5
6

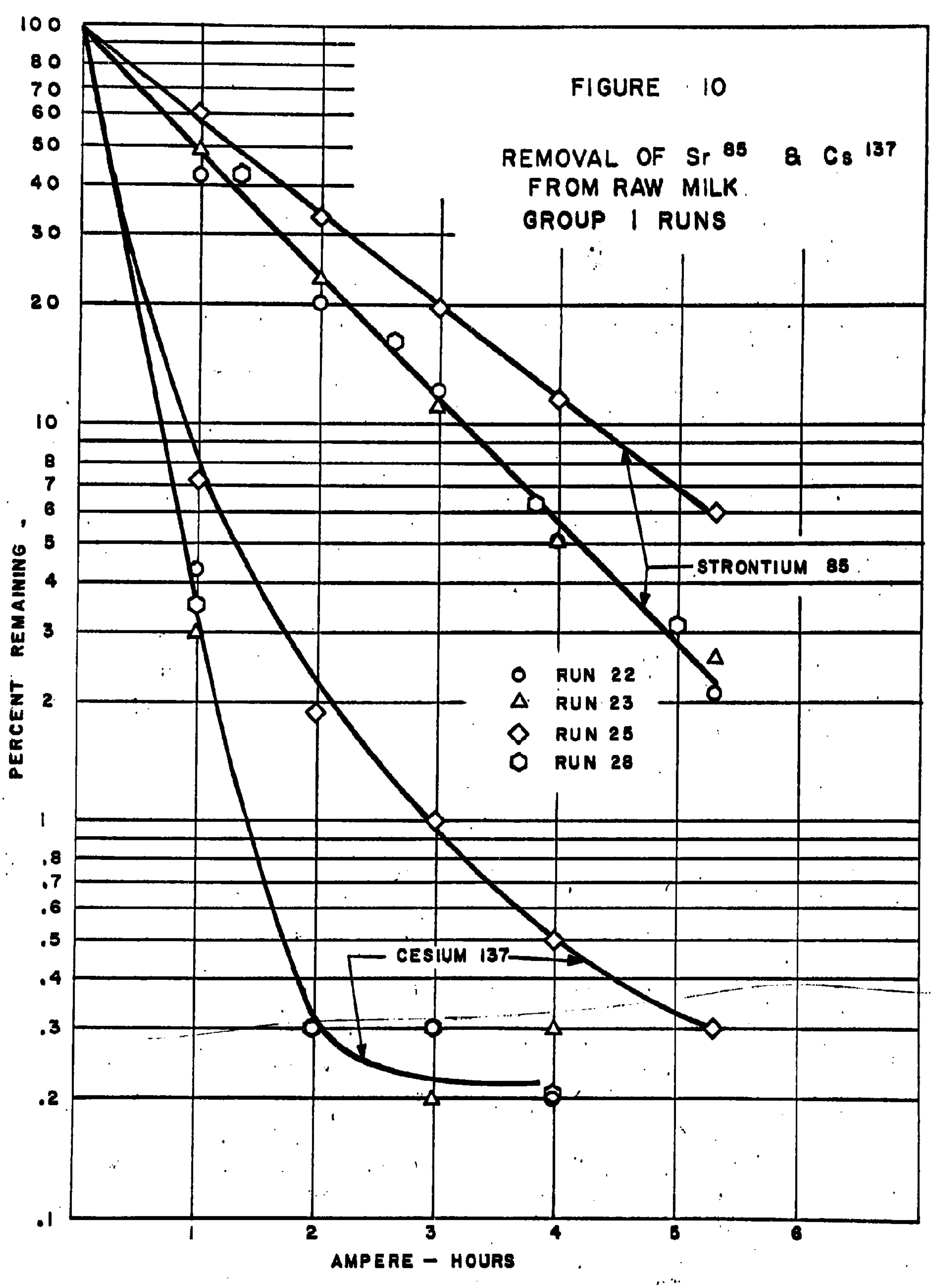
FIGURE 10
REMOVAL OF Sr 85 & Cs 137
FROM RAW MILK
GROUP I RUNS
STRONTIUM 85
CESIUM 137
RUN 22
RUN 23
RUN 25
RUN 28
PERCENT REMAINING
AMPERE — HOURS
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
.8
.7
.6
.5
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1
2
3
4
5
6

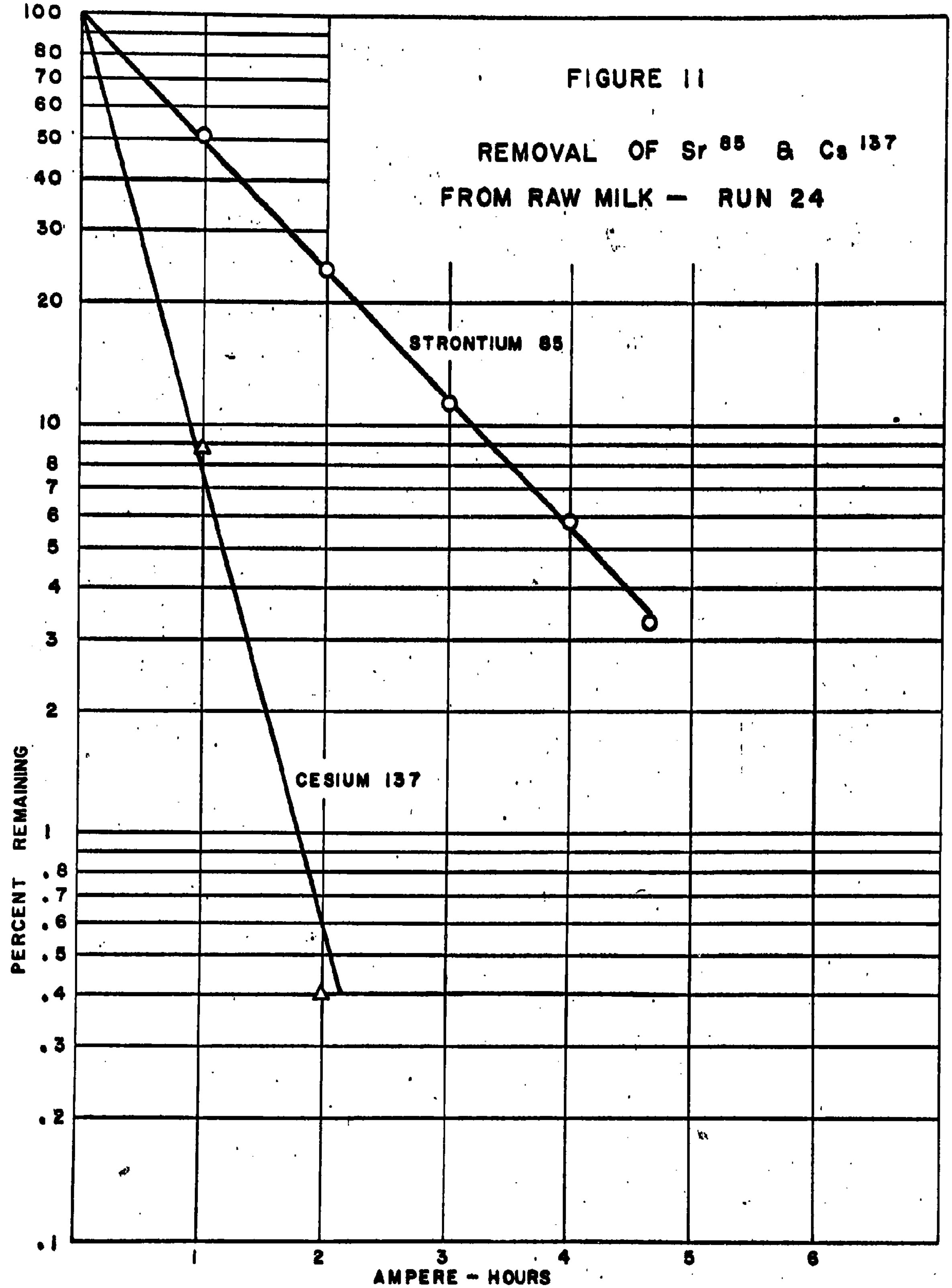


FIGURE 11
REMOVAL OF Sr 85 & Cs 137
FROM RAW MILK — RUN 24
STRONTIUM 85
CESIUM 137
PERCENT REMAINING
AMPERE — HOURS
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6

caustic cleansing step between decontamination batches coupled with close control of the concentration of the make-up stream results in better control of the salt concentration with the 61 CZL 4 system.

The current efficiency of the decontaminating membranes for different runs is shown in Table III-A. The intervening treatments tried to regenerate the current efficiency are also shown. The current efficiency of the make-up membranes is given in Table III-B.

During four decontaminating runs, Runs 26, 27, 29 and 30, the current efficiency of the decontaminating membrane had dropped from about 100% to 88.2% whereas the current efficiency of the make-up membrane had dropped to about 92.1%. The role of the membranes was then reversed for Run 64. Although the current efficiencies increased for both membranes, the current efficiency of the make-up membrane was still higher. Another run, Run 65, was then made which resulted in a further drop in current efficiency of both membranes. The membranes were again reversed in position for Run 66. The current efficiency did not change from Run 65 to Run 66, but Run 69, on the same membranes, showed a further decrease in current efficiency. Therefore, reversing the role of the membranes on the 61 CZL 4 system did not solve the problem of the increase in salt concentration in the milk.

Some success can be reported on the regeneration of the current efficiency of the DYG decontaminating membrane. The current efficiency decreased steadily in four succeeding runs (Runs 22, 23, 26 and 28), from approximately 100% to about 83.2%. The membrane was then treated with a mild caustic wash (Alconox detergent) for thirty minutes and on the succeeding run (Run 56), the further decrease in current efficiency to 79.2% was observed. The same membrane was used again in Run 57 without a caustic wash and the current efficiency showed a further decline to 75.6%. After this run, the membrane was washed in 1 N (~5%) sodium hydroxide for thirty minutes and used in Run 59. The current efficiency declined further to 70.1%. The membrane was then placed in 1 N sodium hydroxide solution overnight and tested again in Run 62.

TABLE III A

CURRENT EFFICIENCIES

Decontaminating and Make-Up Membrane

Decontaminating Membrane	Membrane Treatment	Run	Current Efficiency	Ampere-hours+
61 CZL4	X	8	0.77	18.4
	X	9	0.70	22.6
	X	10	0.80	29.8
	X	11	0.60	37.0
61 CZL4	X	12	0.85	7.2
	X	15	0.908	25.2
	X	16	0.795	32.4
	X	17	0.746	39.0
61 CZL4	X	26	1.04	6.7
	X	27	0.964	13.3
	X	29	0.900	20.0
	X	30	0.882	26.7
	X	66	0.872	33.3
	A	69	0.847	40.0
	X	70	0.796	45.0
61 CZL4 *	X	64	0.926	33.3
	X	65	0.860	40.0
61 CZL4	X	74	0.951	6.7
	A	75	0.998	11.7
	A	76	-	16.7
	A	77	-	21.7
	A	78	0.872	26.7
	A	79	-	31.7
	A	80	0.926	36.7
	A	81	-	41.3
	A	82	0.875	46.3

CODE:

X No Treatment
A 30 Minute Wash in 1N NaOH
* Membrane previously used as a make-up membrane only
+ Denotes total ampere-hours the membrane has been in use.

(Continued)

TABLE III A (Continued)				
Decontaminating Membrane	Membrane Treatment	Run	Current Efficiency	Ampere-hours+
61 DYG	X	22	1.05	6.7
	X	23	0.950	13.3
	X	25	0.968	20.0
	X	28	0.832	26.0
	C	56	0.792	32.7
	X	57	0.756	39.3
	A	59	0.701	46.0
	B	62	0.855	52.7
61 DYG	X	58	0.868	6.7
	X	63	0.915	13.3
	A	67	0.849	20.0
	A	68	0.857	26.7

CODE:

X No Treatment
A 30 Minute Wash in 1N NaOH
B Overnight Wash in 1N NaOH
C Rinse in Alconox Detergent Solution (Mild Caustic)
\+ Denotes total ampere-hours the membrane has been in use.

TABLE III B

CURRENT EFFICIENCIES

Decontaminating and Make-up Membrane

Make-up Membrane	Membrane Treatment	Run	Current Efficiency	Ampere-hours+
61 CZL4	X	15	0.955	25.2
	X	16	0.855	32.4
	X	17	0.819	39.0
61 CZL4	X	26	1.06	6.7
	X	27	0.995	13.3
	X	29	0.947	20.0
	X	30	0.921	26.7
	X	66	0.917	33.3
	A	69	0.872	40.0
61 CZL4*	X	64	0.945	33.3
	X	65	0.908	40.0
61 CZL4	X	74	0.968	6.7
	A	75	0.982	11.7
	A	76	-	16.7
	A	77	-	21.7
	A	78	0.913	26.7
	A	79	-	31.7
	A	80	0.960	36.7
	A	81	-	41.3
	A	82	0.905	46.3
61 AZL4	X	22	1.04	6.7
	X	23	0.953	13.3
61 AZL4	X	56	0.814	6.7
	X	58	0.889	13.3
	X	59	0.778	20.0
	X	62	0.892	26.7
	X	63	0.949	33.3
	A	67	0.880	40.0
	A	68	0.886	46.7
	A	70	0.840	51.7

CODE:

* Membrane previously used as a decontaminating membrane only.

\+ Denotes total ampere-hours the membrane has been in use.

The current efficiency increased to 85.5%. These results indicated that a fairly lengthy equilibration in 1 N sodium hydroxide is required for regeneration of the 61 DYG membrane.

A fresh set of DYG membranes was used in Runs 58, 63, 67 and 68. The current efficiency of these membranes was 86.8% in Run 58 and 91.5% in Run 63. After Run 63, the cation membranes were washed in 1 N sodium hydroxide for 30 minutes and used in Run 67. The current efficiency was 84.9%. The membranes were again equilibrated in 1 N sodium hydroxide for 30 minutes and used in Run 68. The current efficiency was 85.7%. Thus, by treating with 1 N sodium hydroxide for 30 minutes, it was possible to prevent the progressive decrease in current efficiency of the 61 DYG membrane.

New 61 CZL 4 cation membranes were used in Run 74. The same set was used in all following runs to the end of the program. Between each run, these membranes were subjected to a 30 minute rinse in 1 N NaOH. The changes in membrane current efficiencies for both the make-up and decontaminating membrane were very slight between runs and there was no decrease in performance of the membranes. Figure 12 illustrates the performance of these membranes in removing strontium from milk in Run 74 when first used and in Run 82 after having been in use 46.3 ampere hours.

In summary, it appears that there is merit to the sodium hydroxide rinse but the exact conditions of regeneration, contact time, equilibration time, temperature and caustic concentration must be established. Additional study is required on these variables.

The data from a number of runs of Group 2 were collected to illustrate the effect of make-up stream concentration on milk concentration changes during cation decontamination. To lessen outside effects of variables other than make-up concentration, runs were chosen in which the value of those variables was nearly equal in magnitude as indicated in Table IV.

In general, when the make-up stream concentration is increased there is a corresponding increase in salt build-up in the milk during

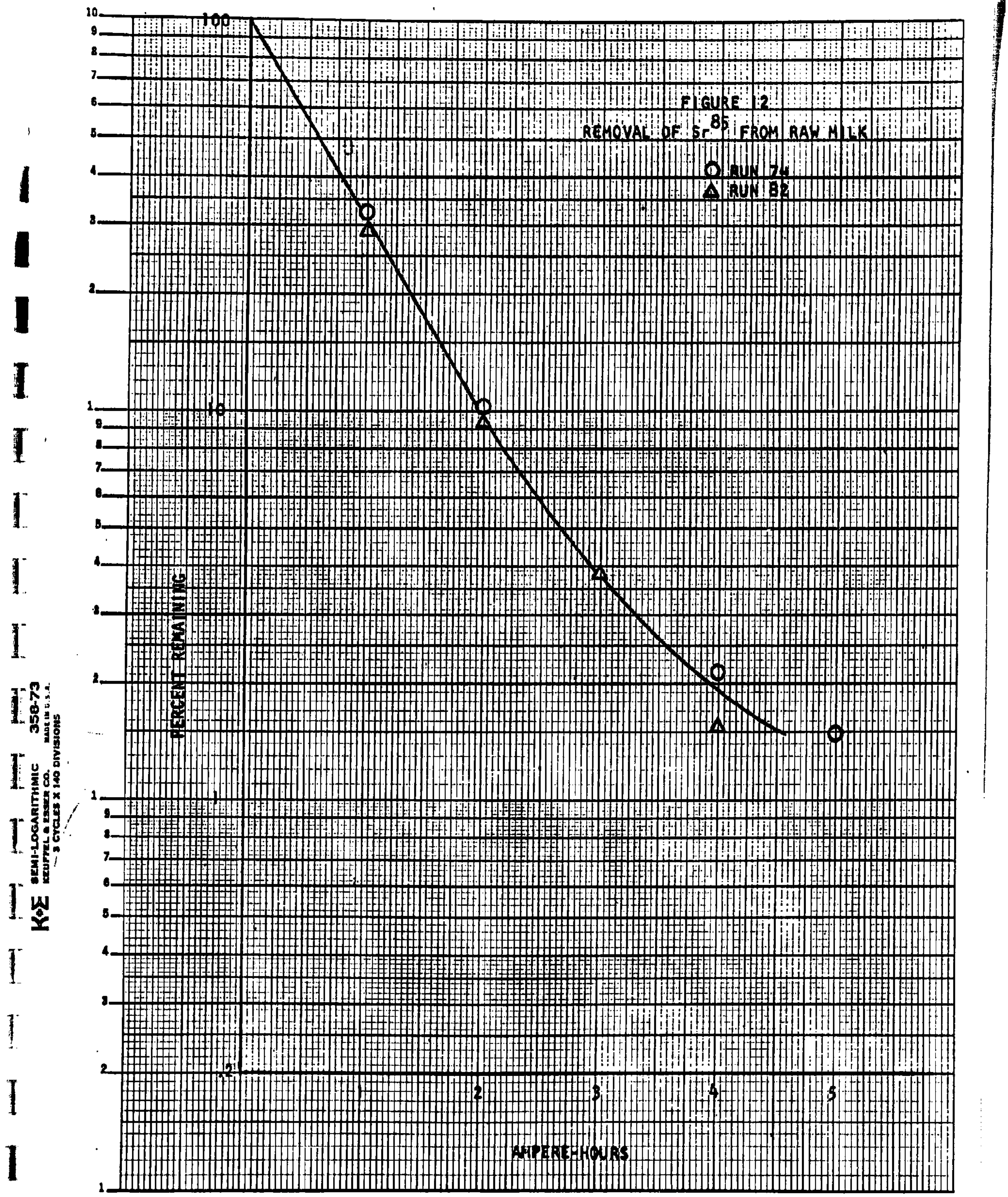


FIGURE 2
REMOVAL OF Sr85 FROM RAW MILK
RUN 74
RUN 82
PERCENT REMAINING
AMPERE-HOURS
100
10
1
.2
1
2
3
4
5
K&E SEMI-LOGARITHMIC 358-73
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 140 DIVISIONS

TABLE IV

Effect of Make-up Stream Concentration on Milk Product

Run No.	Decontaminating Membrane Current Efficiency	Current Density ma/cm^2	Milk pH	Normality Make-up Stream	Equivalent Percent Increase in Milk Concentration
17	0.75	45	5.3	0.65	69.3
12	0.85	60	5.2	0.65→0.065	53.0
15	0.91	30	5.4	0.15	40.4
30	0.88	45	5.2	0.10	47.5
66	0.87	45	5.3	0.10	27.0
78	0.87	45	5.1	0.10	28.3
82	0.87	45	5.2	0.10	27.2
69	0.85	45	5.2	0.10	22.5

the process. This effect, however, is not severe unless the make-up stream concentration is greatly changed.

3.1.5 Control of the Composition of Cations in Milk

The composition of the cations in milk during decontamination depends on the selective transfer of cations through the make-up and the decontaminating membranes, and on the composition of the make-up stream. The composition of the waste stream has little effect on the cation balance in the milk. Therefore, to control this balance in the milk, the separation factors for the various cations must be known for the two membranes, and the composition of the make-up solution must be adjusted accordingly.

It may not be desirable to maintain the cationic composition of the milk constant when the decontamination process is followed by readjustment of the milk pH to 6.6 by the addition of base. For example, the make-up can be adjusted to deplete the milk in sodium, so that sodium hydroxide can be used instead of potassium hydroxide to readjust the milk pH.

The selective electrical transfer of Ca, Mg, Na and K has been defined in terms of separation factors based on the total cation transfer. The separation factor, α , is defined as follows:

$$\alpha = \left(\frac{y}{1-y} \right) \left(\frac{1-x}{x} \right) \qquad (1)$$

Where: y = mole fraction transferred
x = mole fraction in the milk or make-up stream

The separation factor between any two cation species is the ratio of the separation factors for each based on the total cation transfer.

The variables that affect the separation factor significantly are the type of membrane, the composition of the solution which supplies the cations transferred, and the current density. For the make-up membrane, the concentration of the make-up stream and the type of membrane used are the most important variables. For the decontaminating membrane, the type of membrane used is the most important variable since there will be little change in the milk composition. The separation factors obtained for the make-up membrane do not apply to the decontaminating membrane, because the complexing effect of milk on calcium and magnesium reduces their availability for transfer through the decontaminating membrane and consequently enhances the transfer of sodium and potassium.

When the salts in the make-up stream are replenished continuously during a decontamination run, the composition of the feed to the make-up controls the composition of the milk. Referring to Figure 13, if the salt inventory of the make-up stream is small compared to the amount of salts fed during the run as concentrated make-up feed, a condition of steady state is approached in which the composition of the cation flux through the make-up and the decontaminating membranes equals the composition of the cations in the make-up feed. This condition was approached during most of the cation decontamination runs. The amount of salt added as make-up feed was about 5 times the initial amount of salt in the make-up stream; therefore, the condition described above was approached closely. The composition of the make-up feed can be computed from the separation factors for the decontaminating membrane and from the desired milk composition:

$$X_{MUF} = \frac{(\alpha_{MK})(X_{MK})}{\left[1 + (\alpha_{MK}-1)(X_{MK})\right]} \tag{2}$$

Where: X_{MUF} = mole fraction given cation in make-up feed

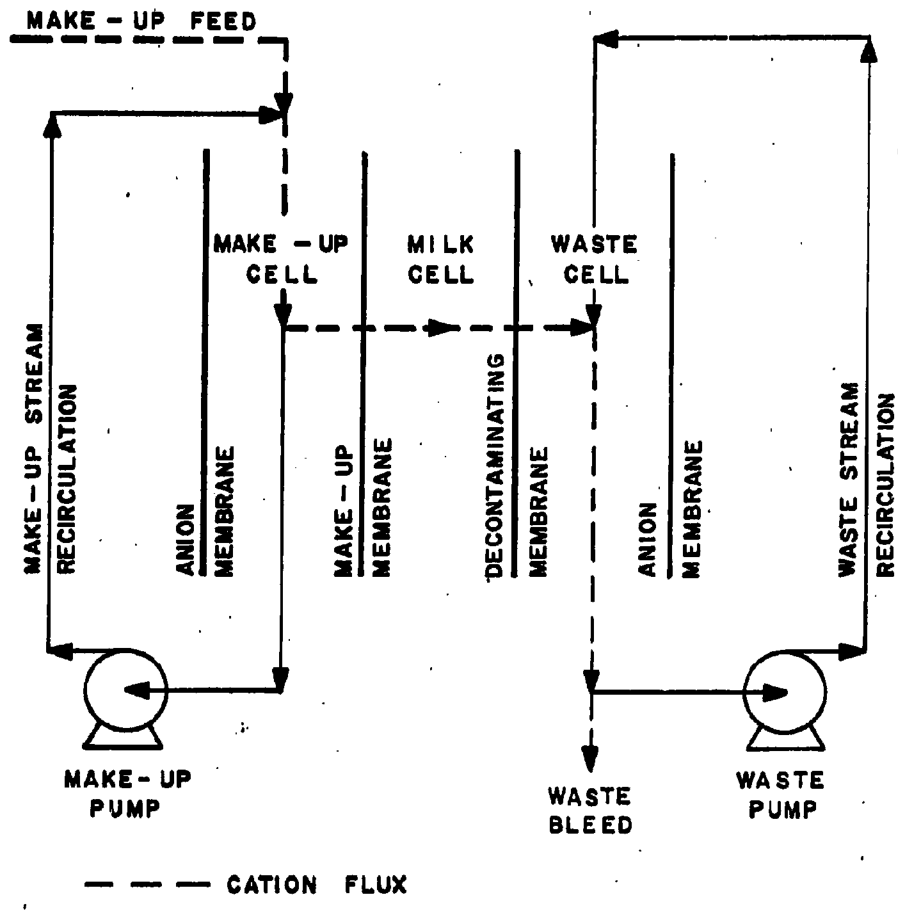
X_{MK} = mole fraction same cation in milk

α_{MK} = separation factor same cation, decontaminating membrane

The initial composition of the make-up stream can be computed from the composition of the make-up feed and the separation factors for the

FIGURE 13

NET CATION FLUX



make-up membrane:

$$X_{MU} = \frac{1}{\left[1 + (\alpha_{MU}) \left(\frac{1 - X_{MUF}}{X_{MUF}}\right)\right]} \tag{3}$$

Where: X_{MU} = Initial composition of make-up stream

It is not strictly necessary to adjust the initial make-up stream too carefully because it will quickly approach its correct composition as the run progresses.

On the basis of the average of the separation factors obtained from Runs 4, 7, 8 and 9 the composition of the make-up stream was adjusted to hold the cationic composition of the milk constant starting with Run 15. To maintain control of the composition and concentration of the make-up stream, it was revised from a closed batch recirculation system to a closed recirculation system with continuous feed of a concentrated solution (2.5 N) of salts. The composition of this feed was designed to replenish the cations transferred from the make-up stream to the milk stream according to Equation (1). The initial composition of the make-up stream was computed from Equation (2).

From Run 17 on, changes in operating conditions, such as current density and concentration of the make-up stream, appear to have caused changes in the selectivity. However, sufficient data were collected in subsequent runs to permit calculation of the separation factors for other operating conditions.

Data on separation factors are given for decontaminating membranes in Table V and for make-up membranes in Table VI. Consistent results were obtained for the separation factors during the runs presented in the tables.

Potassium is the fastest ion leaving through the decontaminating membrane, followed by sodium, calcium and magnesium. This is true for both the 61 DYG and the 61 CZL 4 type membranes.

TABLE V

Separation Factors for Cations
Decontaminating Membranes

A. 61 CZL4

Run	Make-up Feed Composition (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Milk pH	Separation Factor, α_{MK} Ca	Mg	Na	K
4	0.304	0.051	0.244	0.400	30	5.2-5.4	0.37	0.34	1.47	1.65
7						5.4	0.39	0.37	1.40	2.56
8						5.8	0.56	0.37	1.07	1.88
9						5.2-5.4	0.44	0.53	1.18	2.02
						Average:	0.44	0.40	1.28	2.03
15	0.143	0.017	0.305	0.535	30	5.2-5.4	0.38	0.44	1.40	1.65
16					30	5.2-5.7	0.37	0.66	1.46	1.51
17					45	5.1-5.3	0.50	0.85	0.98	1.63
						Average:	0.42	0.65	1.28	1.60
26	0.151	0.018	0.323	0.508	45	5.3-5.6	0.29	0.30	1.41	2.84
27					30	5.4-5.6	0.28	0.32	1.43	2.28
29					45	5.1-5.2	0.36	0.32	0.88	2.08
30					45	5.1-5.3	0.34	0.29	1.22	2.22
						Average:	0.32	0.31	1.24	2.35
64	0.113	0.013	0.232	0.642	45	5.2-5.4	0.210	0.228	0.890	4.12
65						5.1-5.3	0.217	0.246	0.839	3.98
66						5.2-5.3	0.230	0.228	0.842	3.75
69						5.1-5.2	0.204	0.203	0.888	4.14
						Average:	0.215	0.226	0.865	4.00
70	0.085	0.010	0.188	0.717	45	5.2-5.3	0.279	0.201	0.912	2.52
74	0.300	0.037	0.663	None	45	5.0-5.5	0.354	0.435	3.33	
78						5.0-5.2	0.468	0.534	2.36	
79						5.1	0.510	0.423	2.31	
80						5.0-5.1	0.380	0.495	2.98	
82						5.1-5.2	0.396	0.424	2.99	
						Average:	0.422	0.461	2.89	

TABLE V

(Continued)

B. 61 DYG

Run	Make-up Feed Composition (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Milk pH	Separation Factor, α_{MK} Ca	Mg	Na	K
22	0.151	0.018	0.323	0.508	45	5.2-5.4	0.28	0.33	1.19	2.70
23					45	5.3-5.5	0.24	0.16	1.74	3.00
28					52-60	5.0-5.3	0.30	0.28	1.30	2.45
						Average:	0.27	0.26	1.41	2.72
56	0.113	0.013	0.232	0.642	45	5.2-5.3	0.210	0.134	1.23	3.21
57						5.2-5.4	0.157	0.184	1.50	2.38*
58						5.2-5.5	0.189	0.178	1.33	3.42
59						5.2-5.5	0.169	0.251	1.33	3.14
62						5.1-5.2	0.177	0.203	1.52	3.23
63						5.3	0.232	0.225	1.06	2.92
67						5.3-5.4	0.214	0.200	1.16	3.14
68						5.2-5.3	0.197	0.184	1.22	3.30
						Average:	0.196	0.201	1.29	3.19
72	0.074	0.008	0.252	0.666	45	5.1-5.3	0.172	0.144	1.19	2.96
73						5.2-5.3	0.163	0.176	1.08	3.18
						Average:	0.168	0.160	1.14	3.07

C. 61 AZL4

Run	Make-up Feed Composition (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Milk pH	Separation Factor, α_{MK} Ca	Mg	Na	K
20	0.151	0.018	0.323	0.508	30	5.1	0.38	0.40	1.01	2.19
21					45	5.2-5.3	0.41	1.20	0.94	2.05
						Average:	0.40	0.80	0.98	2.12

* Not included in calculated average.

TABLE VI
Separation Factors for Cations
Make-up Membranes

A. 61 CZL4

Run	Make-up Feed Composition (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Make-up Stream Normality	Separation Factor, σ_{MU} Ca	Mg	Na	K
4	0.304	0.051	0.244	0.400	30	0.65→0.10	1.10	0.75	0.61	1.43
7							1.19	0.67	0.56	1.53
8							1.23	0.83	0.61	1.39
9							1.08	0.58	0.57	1.64
						Average:	1.15	0.71	0.59	1.50
15	0.143	0.017	0.305	0.535	30	0.15	0.14	1.64	2.84	5.02
16					30	0.65	0.13	1.51	2.74	5.56
17					45	0.65	0.27	1.00	1.35	2.19
						Average:	0.18	1.38	2.31	4.26
26	0.151	0.018	0.323	0.508	45	0.10	1.37	0.90	0.63	1.34
27					30	0.10	1.23	0.78	0.58	1.54
28					52-60	0.14	1.30	0.78	0.65	1.34
29					45	0.10	0.88	0.66	0.68	1.60
30					45	0.10	0.95	0.52	1.02	1.10
						Average:	1.15	0.73	0.71	1.38
64	0.113	0.013	0.232	0.642	45	0.10	0.943	0.588	0.398	2.39
65							0.840	0.538	0.415	2.47
66							0.865	0.494	0.427	2.36
69							1.050	0.720	0.408	2.16
						Average:	0.925	0.585	0.412	2.35
74	0.300	0.037	0.663	None	45	0.10	1.26	0.80	0.845	
78							3.03	1.33	0.352	
80							2.53	1.12	0.426	
82							2.34	1.33	0.441	
						Average:	2.29	1.15	0.516	

TABLE VI
(Continued)

B. 61 AZL4

Run	Make-up Feed Composition (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Make-up Stream Normality	Separation Factor, α MU Ca	Mg	Na	K
22	0.151	0.018	0.323	0.508	45	0.15	0.45	0.27	0.72	2.99
23							0.22	0.94	0.70	1.13
						Average:	0.34	0.61	0.71	2.06
56	0.113	0.013	0.232	0.642	45	0.15	1.26	0.865	0.574	1.47
57							1.23	0.720	0.589	1.47
58							1.15	0.720	0.652	1.37
59							1.19	0.761	0.634	1.39
62							1.00	0.364	0.670	1.51
63							1.01	0.615	0.638	1.52
67							1.42	0.930	0.548	1.46
68							1.46	0.930	0.597	1.34
						Average:	1.22	0.726	0.613	1.44
70	0.085	0.010	0.188	0.717	45	1.00	1.09	0.691	0.624	1.45
72	0.074	0.008	0.252	0.666	45	0.15	0.86	1.47	0.548	2.15
73							1.38	0.94	0.591	1.00
						Average:	1.12	1.20	0.570	1.63

C. 61 DYG

Run	Make-up Feed Compostion (mole fraction) Ca	Mg	Na	K	Current Density ma/cm^2	Make-up Stream Normality	Separation Factor, α MU Ca	Mg	Na	K
20	0.151	0.018	0.323	0.508	30	0.15	0.40	0.69	1.62	2.15
21					45		0.76	0.40	0.76	1.00
						Average:	0.58	0.55	1.19	1.58

It was possible to increase the rate of removal of all the other ions at a given current density, including radioactive contaminants, by reducing the potassium content of the milk during decontamination by electrodialysis. This was done by eliminating the potassium content of the make-up. The potassium concentration can be brought back up to the initial level during the readjustment of the milk pH by using potassium hydroxide as the neutralizing base.

The selectivity for different cations in the make-up membranes is not as marked as in the decontaminating membranes. Except for adjustments required for control of the composition of the milk, there is no advantage evident in attempting to change the selectivity of the make-up membranes.

Since the 61 CZL 4 system has been suggested as the best system studied to date during this program, it is this set of separation factors that is of most interest. The difference in selectivity between the decontaminating and the make-up membrane is probably due to the complexing action of the milk on the divalent calcium and magnesium ions.

It has been shown above that the composition of the feed make-up can be adjusted to control the composition of the milk when the separation factors for the make-up and the decontaminating membrane are known. The make-up composition was modified according to the new separation data obtained to maintain a constant composition of the cations in the milk. The percentage changes in the concentration of the four cations monitored is shown in Table VII. In general, there is a tendency for the milk to become deficient in sodium and potassium and to gain calcium and magnesium. This is true for both the DYG and the CZL 4 decontaminating systems. The difficulty in assuring control during these runs was due to the fact that there was a tendency for the total concentration of salts in the milk to increase.

3.1.6. Membrane Selectivity for Radionuclide Transfer

The separation factors for the removal of strontium, cesium and barium from milk can be calculated from the following equation, which

TABLE VII

Change in Concentration of Salts in Milk During Decontamination

Cation Removal

Run No.	Membrane: Decontaminating	Membrane: Make-up	Concentration Change, % of Initial Equivalents Per Quart of Milk: Ca	Mg	Na	K	Total Cations	Chlorides+
22	61 DYG	61 AZL4	13.0	25.7	16.0	-43.2	-4.0	- 5.3
67			13.3	38.5	-14.3	-21.2	-0.8	- 7.4
68			17.5	40.5	-16.7	-24.0	0.0	- 9.9
58			15.1	40.5	-21.5	-23.9	0.2	-10.6
23			20.6	--	-11.0	-36.5	0.3	- 9.6
56			20.7	44.2	-19.0	-20.9	2.1	8.6
63			22.5	26.2	8.7	- 4.8	12.3	0.6
57			37.9	50.0	-27.4	- 6.9	13.8	19.0
62			37.1	38.6	- 6.3	-10.8	16.1	24.6
73			52.7	31.0	-14.7	44.5	31.3	12.4
59			72.4	46.5	13.2	9.4	40.6	40.4
72			70.3	66.0	1.2	78.7	55.2	17.9
26	61 CZL4	61 CZL4	21.5	26.2	- 3.8	-34.2	0.4	1.7
74			28.3	34.4	0.5	-97.6*	12.5	4.4
64			36.2	43.9	35.0	-21.7	18.1	6.3
69			41.7	62.5	35.0	-19.8	22.5	5.4
27			47.0	34.8	25.2	-13.2	23.9	13.6
66			46.5	57.2	42.7	-12.5	27.0	25.3
82			77.6	94.6	54.8	-99.9*	27.2	9.7
78			93.4	23.2	99.2	-99.9*	28.2	18.1
80			90.0	66.6	43.5	-99.9*	29.3	12.4
65	61 CZL4	61 CZL4	52.7	50.0	49.8	-10.8	31.8	20.8
29			53.8	52.2	59.7	0.0	37.1	24.9
15			48.6	--	45.3	38.1	46.4	40.4
30			64.3	73.3	79.8	3.1	47.5	35.4
16			66.2	--	67.1	60.4	64.6	--
17			57.0	--	140.0	87.3	69.3	69.3

* Runs made with no potassium ion in make-up solution.

\+ Percent Change based on initial total cations in milk.

is derived in the Appendix:

$$0.0173\ C_{av.}\left(\frac{V}{\theta}\right)\ \ln\left(\frac{X_i}{X_o}\right) = \frac{\alpha\ e\ i\ A}{1.61} \tag{4}$$

For 95% decontamination, $\ln\left(\frac{X_i}{X_o}\right)$ is $\ln\left(\frac{1.00}{0.05}\right)$, or 3, and at a current density, i, of 0.045 amp/cm², the equation for α reduces to:

$$\alpha = 1.855\left(\frac{V}{\theta A}\right)\left(\frac{C_{av.}}{e}\right) \tag{5}$$

Where C_{av} is the average salt normality in the milk during decontamination and e is the current efficiency of the decontaminating membrane, V, θ and A represent the batch volume, the decontamination time, and the total active area of the decontaminating membranes, respectively.

Separation factors for cationic radionuclides were calculated using the data from experimental runs. The results are given in Table VIII. The separation factor for strontium is about twice as high as for calcium and magnesium, and slightly higher for the 61 CZL 4 membranes than for the 61 DYG membranes. It is about 0.5 for the DYG membranes and between 0.6 and 0.7 for the 61 CZL 4 membrane, except for Runs 26 and 30. In Run 26 the pH was high, but the low separation factor for strontium in Run 30 is unexplained. Neither of these two runs were run to 95% decontamination and the separation factor for Sr^{85} was estimated by extrapolation.

The separation factor for barium is of the same order of magnitude as for strontium except in Run 27 at a pH of 5.51 where it was 0.244.

The separation factor for cesium is of the same order of magnitude as for potassium, ranging from a low of 2.38 to a high of 4.12.

3.1.7 Cerium Removal

Essentially no removal of Ce^{139} was obtained in Run 15 at a milk pH between 5.2 and 5.6 and at 30 ma/cm². The results are shown in Figure 14. The decontamination of Cs^{137} proceeded normally during this run. In view of the negative results on cerium, a series of ion exchange

TABLE VIII

Separation Factors for Radioactive Cations

Decontaminating Membranes

Run	Decontaminating Membrane Type	Average Milk pH	$A\theta/V$	C_{av}	e	Separation Factor, α Sr^{85}	Cs^{137}	Ba^{140}
56	61 DYG	5.34	0.70	0.1312	0.792	0.439		
57		5.33	0.81*	0.1383	0.756	0.418	3.33	
58		5.41	0.50	0.1242	0.868	0.530	2.59	
59		5.33	0.86*	0.1576	0.701	0.485	4.08	
62		5.22	0.47	0.1391	0.855	0.633	2.63	
63		5.30	0.50	0.1275	0.915	0.516	2.28	
67		5.35	0.53	0.1243	0.849	0.513	2.32	
68		5.25	0.53	0.1263	0.857	0.516	2.33	
26	61 CZL4	5.48	0.78*	0.1300	1.040	0.297	--	
27		5.51	0.59	0.1516	0.964	--	--	0.244
29		5.18	0.22	0.1555	0.900	--	--	0.584
30		5.25	0.78*	0.1600	0.882	0.431	--	--
64		5.30	0.40	0.1359	0.926	0.680	2.28	--
65		5.20	0.50	0.1494	0.860	0.645	2.71	--
66		5.25	0.52	0.1483	0.872	0.607	2.63	--
69		5.17	0.42	0.1390	0.847	0.725	2.62	--
73**	61 DYG	5.30	0.53	0.1420	0.850	0.372	--	--

* Estimated value (not included in average for comparison with "in vivo" run)

** "in vivo" to 85% decontamination only

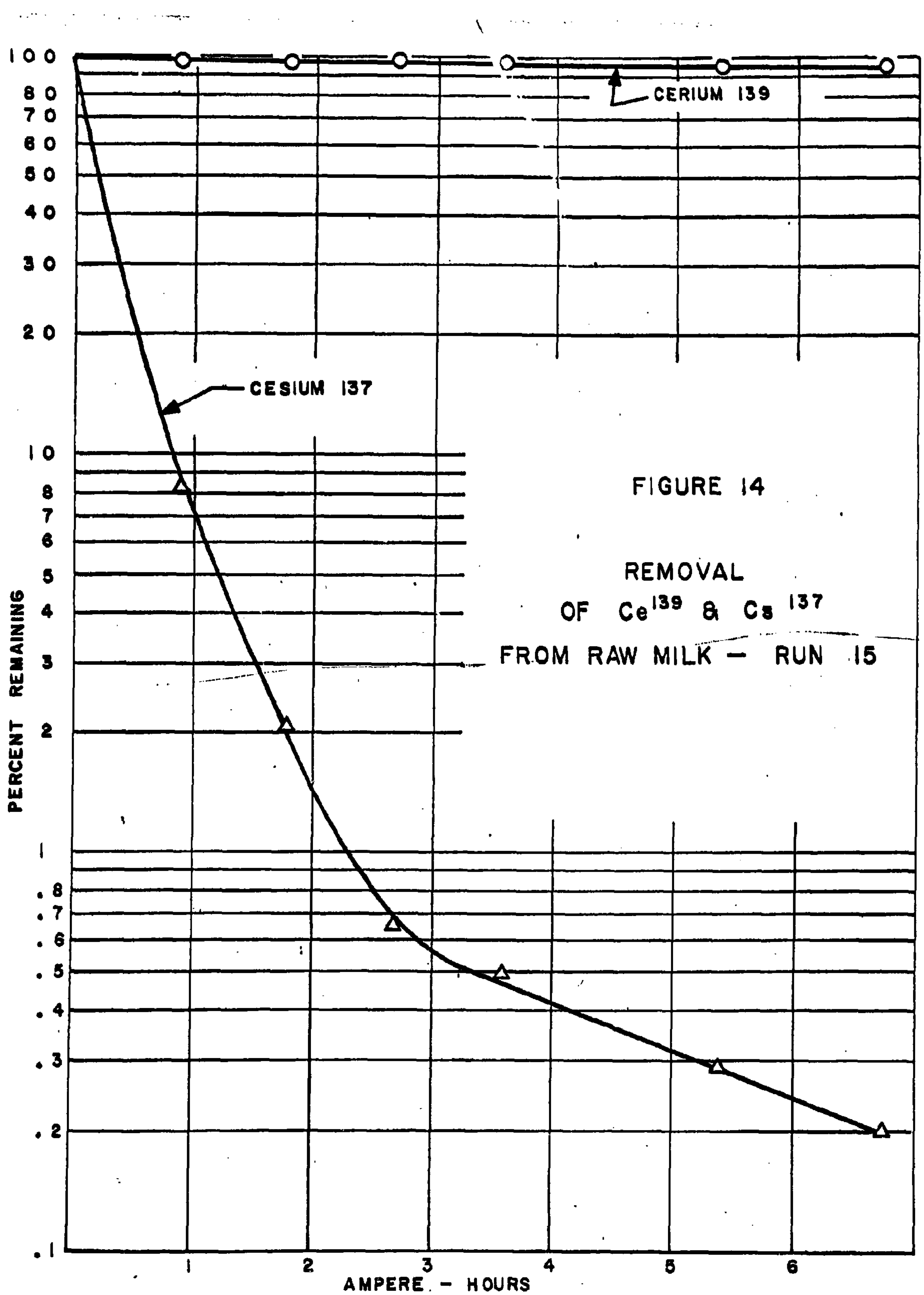


FIGURE 14

REMOVAL OF Ce^{139} & Cs^{137} FROM RAW MILK — RUN 15 tests were run on milk and water contaminated with Ce^{139}. Cerium was removed from water by cation exchange resin but not by anion exchange resin. Tests on milk at pH 5.1 on cation and anion exchange resin were negative. Evidently, the cerium, normally a cation, is complexed by the milk so that it is no longer present as a free ion.

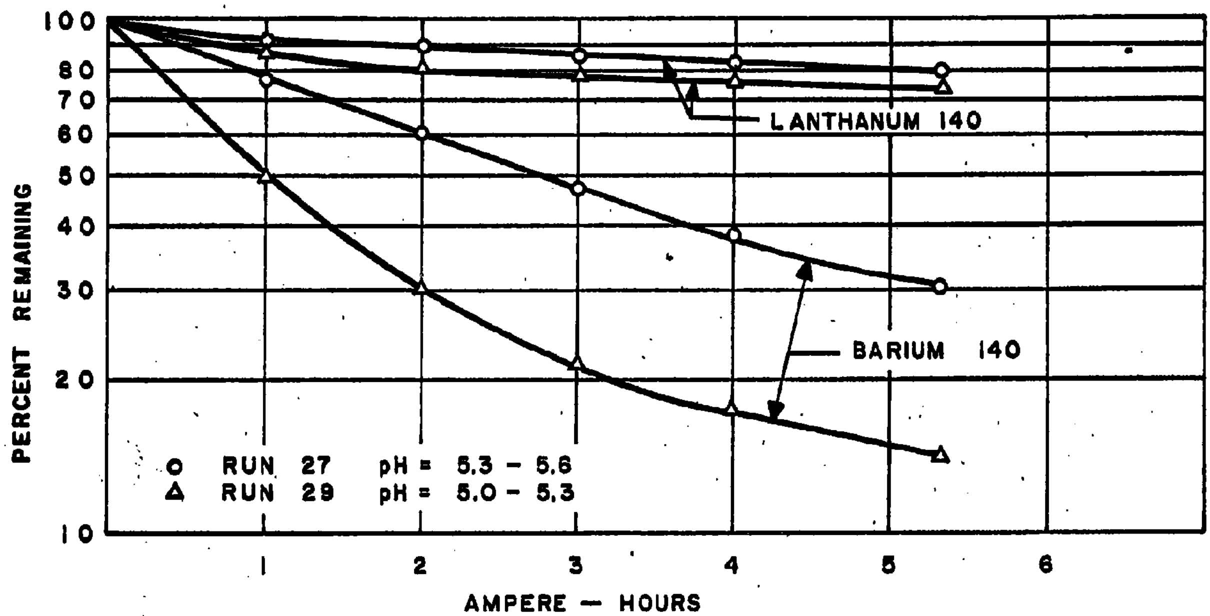
3.1.8 Barium and Lanthanum Removal

As shown in Figure 15, at a milk pH between 5.3 and 5.6 and CD = 45 ma/cm^2 only 70% of the barium was removed in 5 ampere-hours; whereas, at a milk pH between 5.1 and 5.3, 85% of the barium was removed. Twenty and twenty-six per cent of the La^{140} was removed respectively. Normally, under these conditions, at least 90% of the Sr^{85} is removed in 5 ampere-hours. As is the case with strontium, lowering the milk pH aids in barium removal. The partial removal of lanthanum, compared to no removal for cerium indicates that these two rare earths are present in different forms in milk. Lanthanum may not be as strongly complexed as cerium in milk.

3.1.9 Level of Natural Strontium

To determine whether or not changes in the level of natural strontium in milk affect the removal of radiostrontium from milk a run (Run 19) was made in which 10 mg. natural strontium was added to a liter of milk. This is a hundredfold increase over maximum levels of 100 micrograms natural strontium per liter of milk reported by Campbell (3). This level was determined by neutron activation techniques on 50 samples of milk. A comparison of the strontium removal of this run and Runs 24 and 26 from Group 1 and Group 2, respectively, is shown in Figure 16. Although the plot indicates a higher degree of removal for Run 19, the concentration of salt in the milk decreased to about 0.083 N at the beginning of the run; whereas, it averaged 0.11 N and 0.13 N for Runs 24 and 26 up to 90% Sr^{85} removal. Also the pH in Run 26 increased to between 5.3 and 5.6 during the run which slowed the rate of strontium removal. Correcting for the effect of the salt concentration according to Equation (4), the ampere-hours required to 90% Sr^{85} removal at 0.083 N are 2.45, 2.42 and 2.75 for Runs 19, 24 and 26. Up to 95% removal

FIGURE 15



REMOVAL OF Ba^{140} & La^{140}
FROM RAW MILK

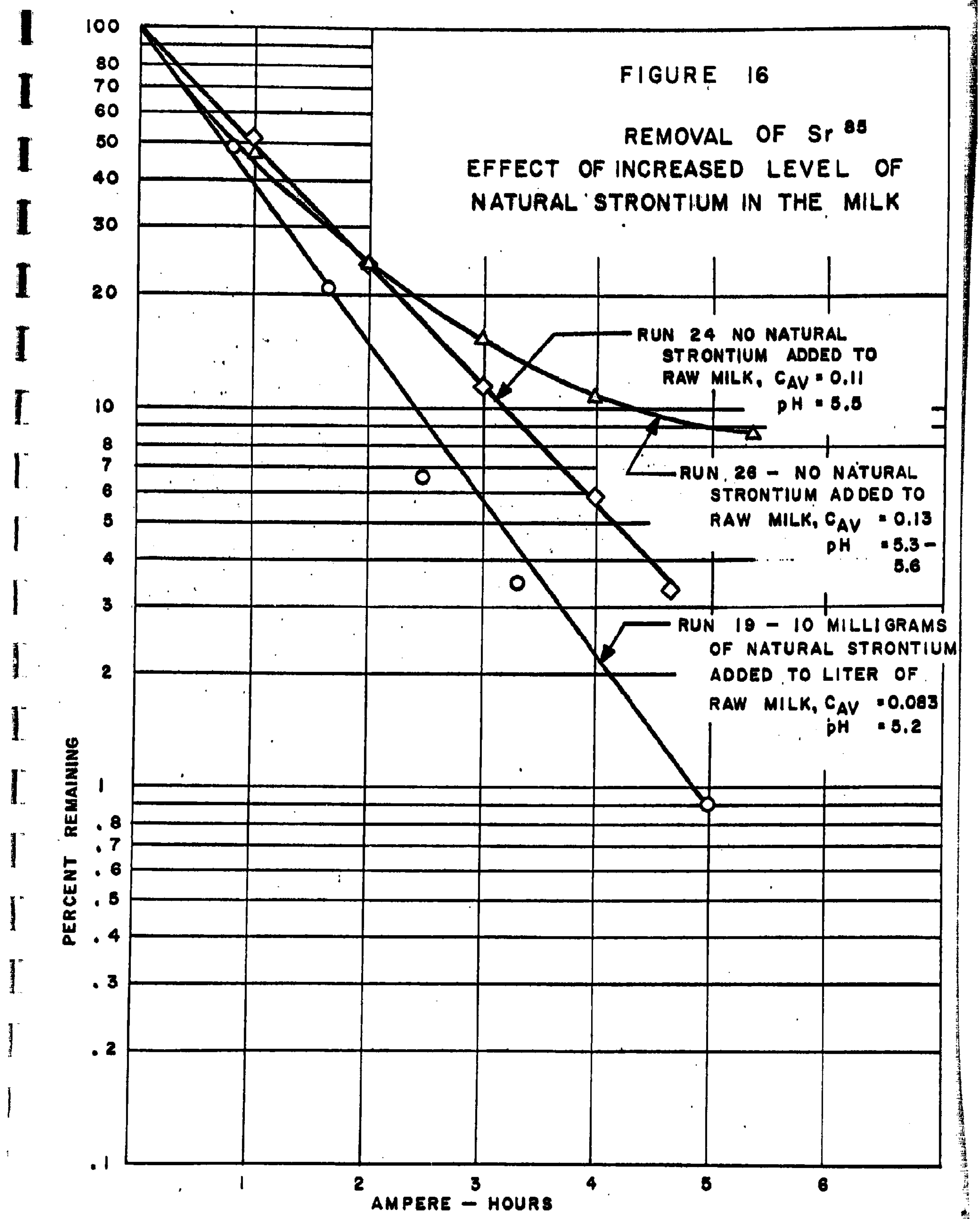


FIGURE 16
REMOVAL OF Sr 85
EFFECT OF INCREASED LEVEL OF NATURAL STRONTIUM IN THE MILK
RUN 24 NO NATURAL STRONTIUM ADDED TO RAW MILK, CAV = 0.11 pH = 5.5
RUN 26 – NO NATURAL STRONTIUM ADDED TO RAW MILK, CAV = 0.13 pH = 5.3 – 5.6
RUN 19 – 10 MILLIGRAMS OF NATURAL STRONTIUM ADDED TO LITER OF RAW MILK, CAV = 0.083 pH = 5.2
PERCENT REMAINING
AMPERE – HOURS
100
80
70
60
50
40
30
20
10
8
7
6
5
4
3
2
1
.8
.7
.6
.5
.4
.3
.2
.1
1
2
3
4
5
6

the milk averaged 0.083 N for Run 19 and 0.103 N for Run 24. Correcting for the salt concentration effect on the basis of Run 19, the ampere-hours required to 95% removal are 3.15 and 3.35 for Runs 19 and 24. Therefore, the addition of natural strontium did not have a significant effect on radiostrontium removal.

3.1.10 Loss of Organics from Milk

Analyses were made of some final make-up and waste stream samples to determine the extent of loss of organics from the milk during decontamination.

Samples of the initial and final make-up and waste stream from Run 15 were analyzed by infrared spectrometer and found to contain only small amounts of amino acids and some sugar residue. The final make-up and waste streams from Runs 22, 26, 27, 28 and 30 were analyzed for lactose. The results indicate that lactose losses from the milk varied between 0.06 and 0.22 per cent of the initial lactose present in these runs (see Table IX).

3.1.11 Waste Stream Contamination

The concentration of contaminants in the waste stream relative to the concentration of contaminants in the original milk batch was monitored to investigate the potential value of utilizing a waste stream recycle to the make-up stream to reduce salt consumption. Table X shows the average concentration for Sr and Cs in the waste stream during the run relative to their concentration in the initial milk batch.

3.1.12 Strontium Removal from Milk Labeled "in vivo"

Runs 72 and 73 in Figure 17 are decontamination runs on milk labeled "in vivo" with strontium^{85} at the Department of Agriculture, Beltsville, Maryland.

For these runs, the make-up membranes were 61 AZL 4 and the decontaminating membranes were 61 DYG. These membranes had been used previously on "in vitro" runs. Consequently, the current efficiency had dropped enough to permit the concentration of salts in the milk to

TABLE IX

Lactose Losses from Milk During Decontamination

Run #	Decontaminating Membrane	Stream Analyzed	Analysis Results Total mg. Lost	Per Cent of Original Lactose in Milk *
22	61DYG	Waste	26.16	0.06
26	61CZL4	Waste	28.3	0.05
27	61CZL4	Waste Make-Up	95.5 <u><2.4</u>	
		Total	97.9	0.22
28	61DYG	Waste	37.3	0.08
30	61CXL4	Waste	87.7	0.20

* Based on average lactose content for milk of 45 grams/liter

TABLE X

Average Waste Stream Contamination During Removal of Radionuclides from Milk

Time (Min)	Ampere Hours	Sr^{85} $\frac{\mu c/l \text{ in waste}}{\mu c/l \text{ in initial milk}}$ *	Cs^{137} $\frac{\mu c/l \text{ in waste}}{\mu c/l \text{ in initial milk}}$ *
0	0	-	-
15	0.5	0.27	0.73
30	1.0	0.49	0.63
60	2.0	0.33	0.21
→ 90	3.0	0.15	0.08
120	4.0	0.07	0.03

* Average of runs 77 to 80, and 82.

→ Indicates the time at which 95% removal of Sr^{85} was attained.

increase. In Run 72 the milk concentration increased by 55% during the run and the pH of the milk rose over 5.3. The increase in milk concentration, combined with the high pH, resulted in poor decontamination results. For Run 73 the DYG decontaminating membranes were immersed in 5% NaOH overnight in an attempt to regenerate some of the lost efficiency. During this run the salt concentration increased by 31% and the pH was kept between 5.1 and 5.3. Because of the increase in concentration the maximum removal of Sr obtained in this run was 87%, as shown in Figure 17.

The separation factor for Sr^{85} removal from milk labeled "in vivo" was lower than from milk labeled "in vitro," as was seen in Table VIII. On the basis of Run 73, the conditions of decontamination which will produce 95% strontium removal "in vitro" by electrodialysis, will produce 90% strontium removal "in vivo."

3.1.13 Electrical Addition of Acid

In an attempt to eliminate or reduce the amount of citric acid added to the milk prior to Sr decontamination, a run was made with the make-up stream acidified to pH 2.2 to 2.9 to supply the hydrogen ions through the make-up membrane. No citric acid was added to the milk. The results were discouraging. The milk pH failed to drop below 6.0 and, as a result, the Sr decontamination was poor (see Figure 18). The Cs decontamination proceeded normally. There was heavy deposition of milk solids on the milk side of the make-up membrane through which the hydrogen ions entered the milk. No additional attempts were made to add acid electrically to the milk. Additional study is required to find the proper make-up pH and current density. The milk pH may have to be reduced somewhat before this is attempted.

FIGURE 17

REMOVAL OF Sr^{85} FROM RAW MILK CONTAMINATED IN VIVO

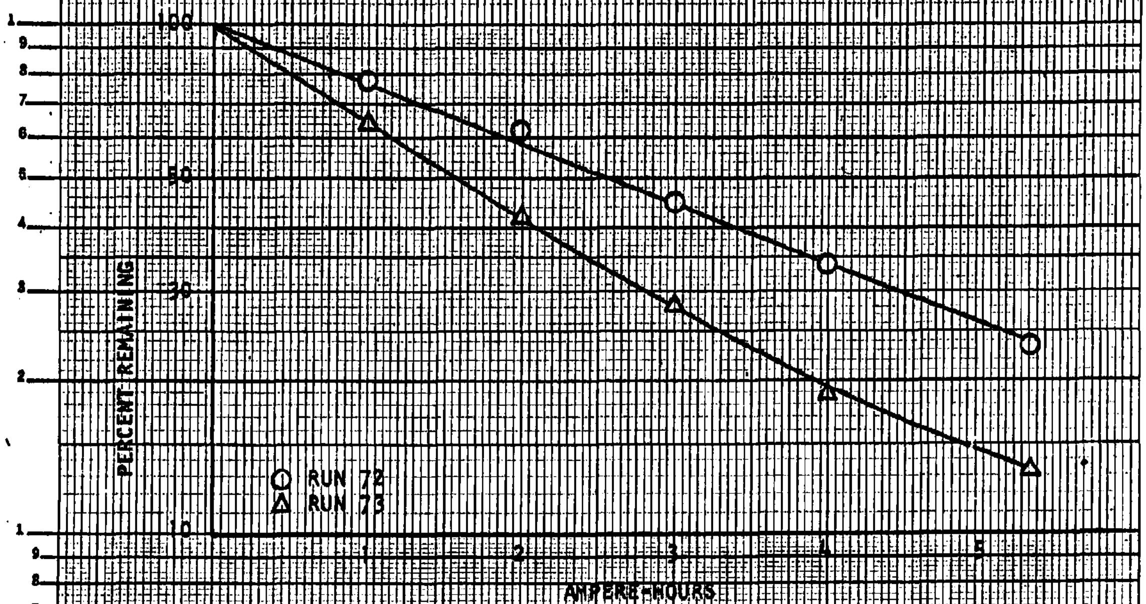
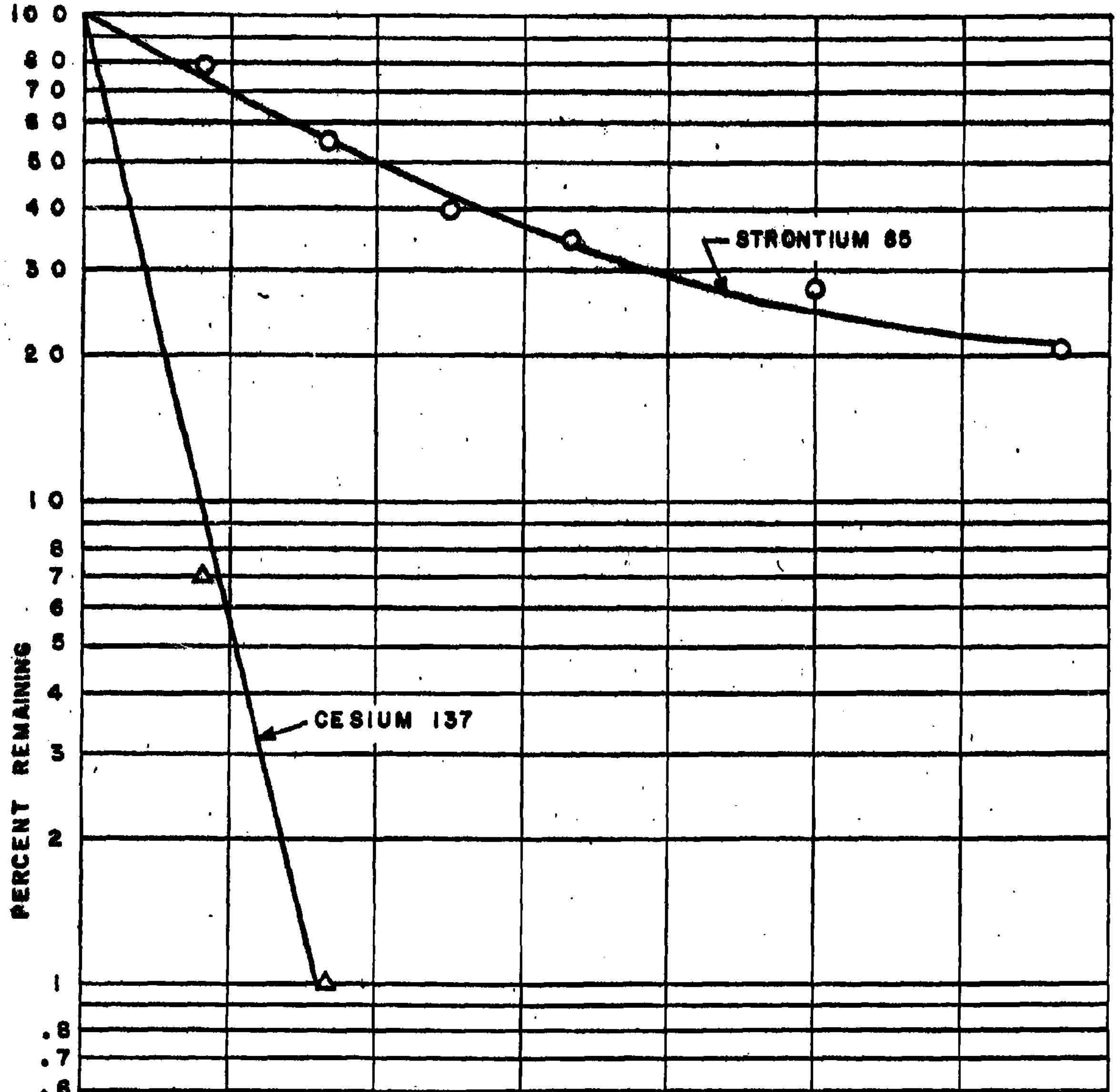


FIGURE 18



REMOVAL OF Sr^{85} & Cs^{137}
FROM RAW MILK
ELECTRICAL ADJUSTMENT OF pH
RUN 18

3.2 Iodine Decontamination Studies

Two different methods were used for the removal of iodine from milk. In one method the iodine was removed under current in a similar manner to the strontium decontamination using a dual anion membrane cell for the milk compartments; while in another method, a demineralizing stack was used. In the latter method the iodine was removed from the milk by contacting under no current, followed by removal of iodine from the membranes under current into a waste stream which was used to replace the milk during the regeneration step. Details of the stack configuration used are given in the section on Apparatus and Procedure.

Initially a series of runs were made to determine the maximum allowable current density for the removal of iodine from milk through anion membranes. The membrane stack was operated at current densities between 10 and 30 milliamperes per square centimeter at milk pH's of 5.2 and 6.6 and at temperatures of 45° and 100°F. The results, given in Table XI, indicate that the allowable current density for iodine removal is less than 20 ma/cm^2 at either pH value or temperature. At the lower pH, 5.2, there appeared to be less tendency toward polarization than at the higher pH. The criteria used to determine the limiting current density in the initial polarization runs was the formation of deposits on the surface of the membrane, the tendency for the milk to curd and the electrical resistance per cell pair, initial and final. Continuously increasing voltage at constant current during the test was interpreted as indicative of polarization.

To facilitate the interpretation of the iodine removal results, a list of the runs made is given in Table XII with the objective of the run, the variables studied and pertinent comments.

In the iodine decontamination runs the first difficulty encountered was the limiting current density. Separation of milk solids occurred at current densities over 10 ma/cm^2, and even at 10 ma/cm^2 some deposits were observed on the membranes. A second difficulty was the rapid rate of exchange of iodine on the membranes. This caused a

TABLE XI

Anion System Polarization Runs

Run No.	Milk Temp °F	Milk pH	Current Density ma/cm²	Voltage Required Per Cell Pair Initial	Voltage Required Per Cell Pair Final	Milk Resistivity Ohm-cm Initial	Milk Resistivity Ohm-cm Final
31	50	5.2	10	1.2	1.4	250	227
32	50	5.2	20	2.9	3.0	225	235
33	54	5.2	30	3.9	7.0	240	235
34	95	5.2	10	0.6	0.7	153	155
35	98	5.2	20	1.4	1.6	138	140
36	98	5.2	30	2.1	4.3	147	133
37	49	6.7	10	1.4	1.7	284	310
38	50	6.6	20	4.0	7.5	300	317
39	98	6.6	10	0.6	0.7	166	154
40	100	6.6	20	1.1	1.8	152	141
41	100	6.0	30	3.3	4.8	150	133

TABLE XII

Iodine Ramoval Runs

Run No.	Objective	Variables Studied and Comments
31 to 41 inclusive	Preliminary polarization studies	Current density, Temperature, pH
42	Polarization run	Current density 20 ma/cm^2 New 111 EZL4 anion membranes (Polarized-Milk separated)
43	Polarization run	Current density 15 ma/cm^2 Same membranes (Same results as Run 42)
44	Polarization run	Current density 10 ma/cm^2 (No polarization - Milk did not separate - Deposits on membranes)
45	Study 111 EZL4 as make-up membranes, 110 CYL4 as decont. membranes	111's from Run 44 110's not equilibrated
46	Decontamination with zero current	Decontamination time
47	Increase I^{131} rate of removal under current	Chloride-free make-up
48	Same as above	Same as above - Hold time* small but not zero
49	Same as above I^{131} - free make-up membrane	Same as above - Hold time 50 seconds
50	Run systems as above to steady state	Zero hold time Chloride-free make-up
51	Run systems as above to steady state	Zero hold time Chloride-free make-up
52	111 EZL4 decont. membranes	Zero hold time Chloride-free make-up
53	Effect of Temperature	Same as Run 52 but at 100°F instead of 45°F
54	Increased current density to increase rate of decontamination	Current density 15 ma/cm^2 (increased deposits on membranes)
55	Decontamination at zero current with electrical regeneration of membrane at 60 ma/cm^2	Fresh 111 EZL4 membranes Chloride-free make-up 10 minute regeneration
60	Same as above	20 minute regeneration
61	Same as above	30 minute regeneration

* Time between start of recirculation and start of current.

significant decontamination of the milk before the current was turned on and resulted in pickup of iodine on the make-up membrane in the time interval between the start of milk recirculation and the start of the current. Consequently, after the current was turned on, some iodine was being introduced into the milk from the make-up membrane. By decreasing the contact time of the milk and the membranes before the start of the current, the decontamination was significantly improved.

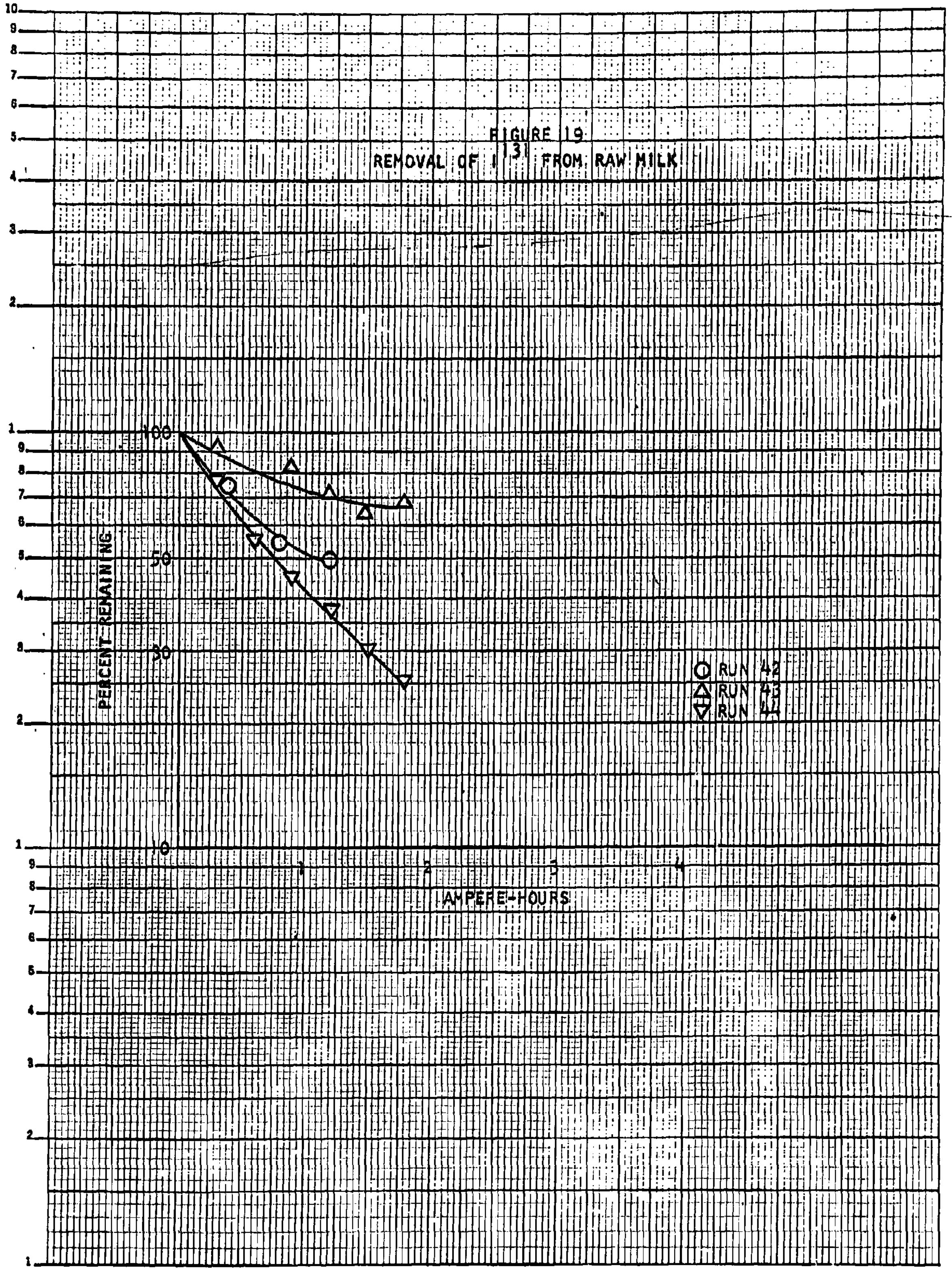
Some of the iodine added to the milk became bound to proteins and, therefore, unavailable for removal. The removal of iodine was expressed in terms of total iodine removed and also in terms of free nonprotein-bound iodine for Runs 52, 53, 54, 55, 60 and 61. For all other runs, it was expressed as per cent of the total iodine. The decontamination rates for Runs 42 to 44 are given in Figure 19. The best decontamination rate was obtained at the lowest current density, 10 ma/cm^2 in Run 44. In runs 42 and 43 at 20 and 15 ma/cm^2, respectively, separation of the solids in milk occurred at the end of the run indicating polarization conditions.

The make-up solution consisted of sodium chloride, citrate and phosphate in the same ratio as in milk, except in some runs where no chloride was used. The make-up pH was adjusted to 6.0. The effect of chloride-free make-up is shown in Figure 20. Almost 90% removal was achieved in Run 47 with no chloride in the make-up.

In Run 45 the decontamination leveled off at about 80% removal of iodine. The rate of decontamination was increased by decreasing the interval between the time of the recirculation of the milk in the stack and the start of the current to minimize pickup of iodine on the make-up membrane. This is shown in Figure 21. In these two runs the make-up was also chloride free.

Run 46 was made under no current (see Figure 22). Surprisingly about 80% decontamination was achieved, indicating that the rate of exchange for pickup of iodine on the anion membrane is exceedingly fast. In view of this observation, it was decided to try to decontaminate the

FIGURE 19
REMOVAL OF I^{131} FROM RAW MILK



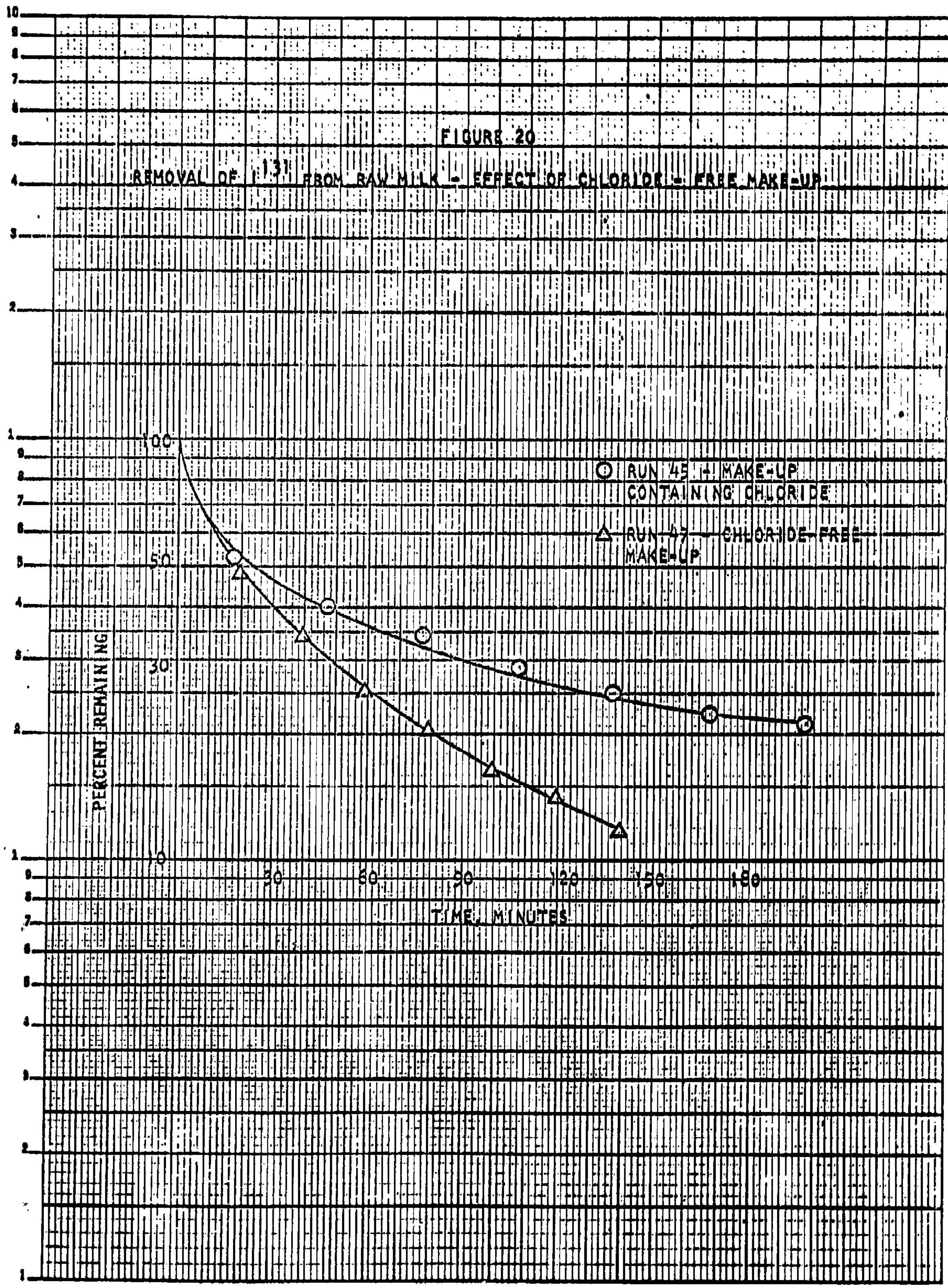


FIGURE 20
REMOVAL OF I 131 FROM RAW MILK - EFFECT OF CHLORIDE - FREE MAKE-UP
RUN 45 - MAKE-UP CONTAINING CHLORIDE
RUN 47 - CHLORIDE-FREE MAKE-UP
PERCENT REMAINING
TIME, MINUTES
100
50
30
10
30
60
90
120
150
180
K&E SEMI-LOGARITHMIC 358-73
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 140 DIVISIONS

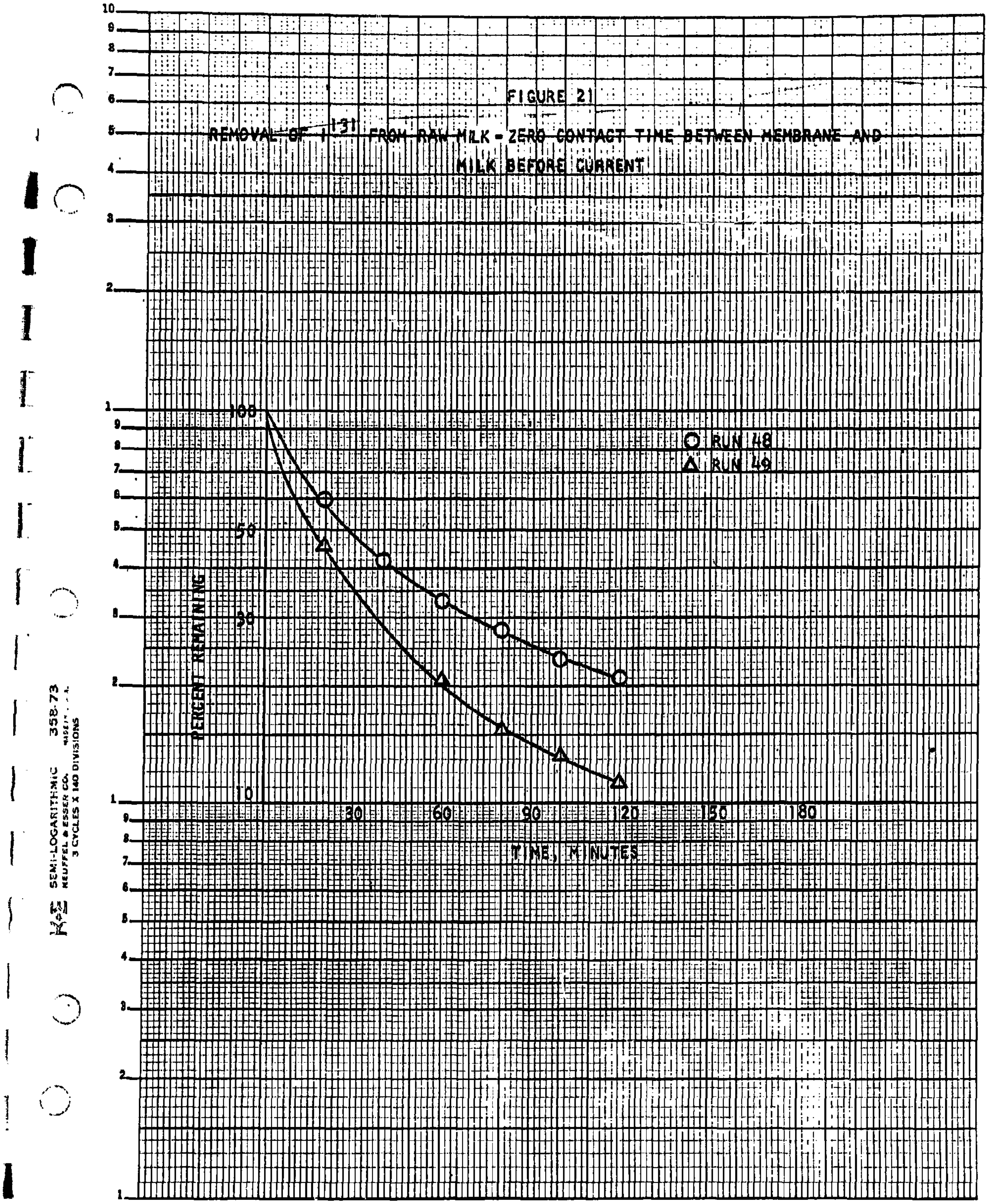


FIGURE 21
REMOVAL OF I^{131} FROM RAW MILK - ZERO CONTACT TIME BETWEEN MEMBRANE AND MILK BEFORE CURRENT
PERCENT REMAINING
TIME, MINUTES
RUN 48
RUN 49
100
50
30
10
30
60
90
120
150
180
SEMI-LOGARITHMIC 358-73
KEUFFEL & ESSER CO.
3 CYCLES X 140 DIVISIONS

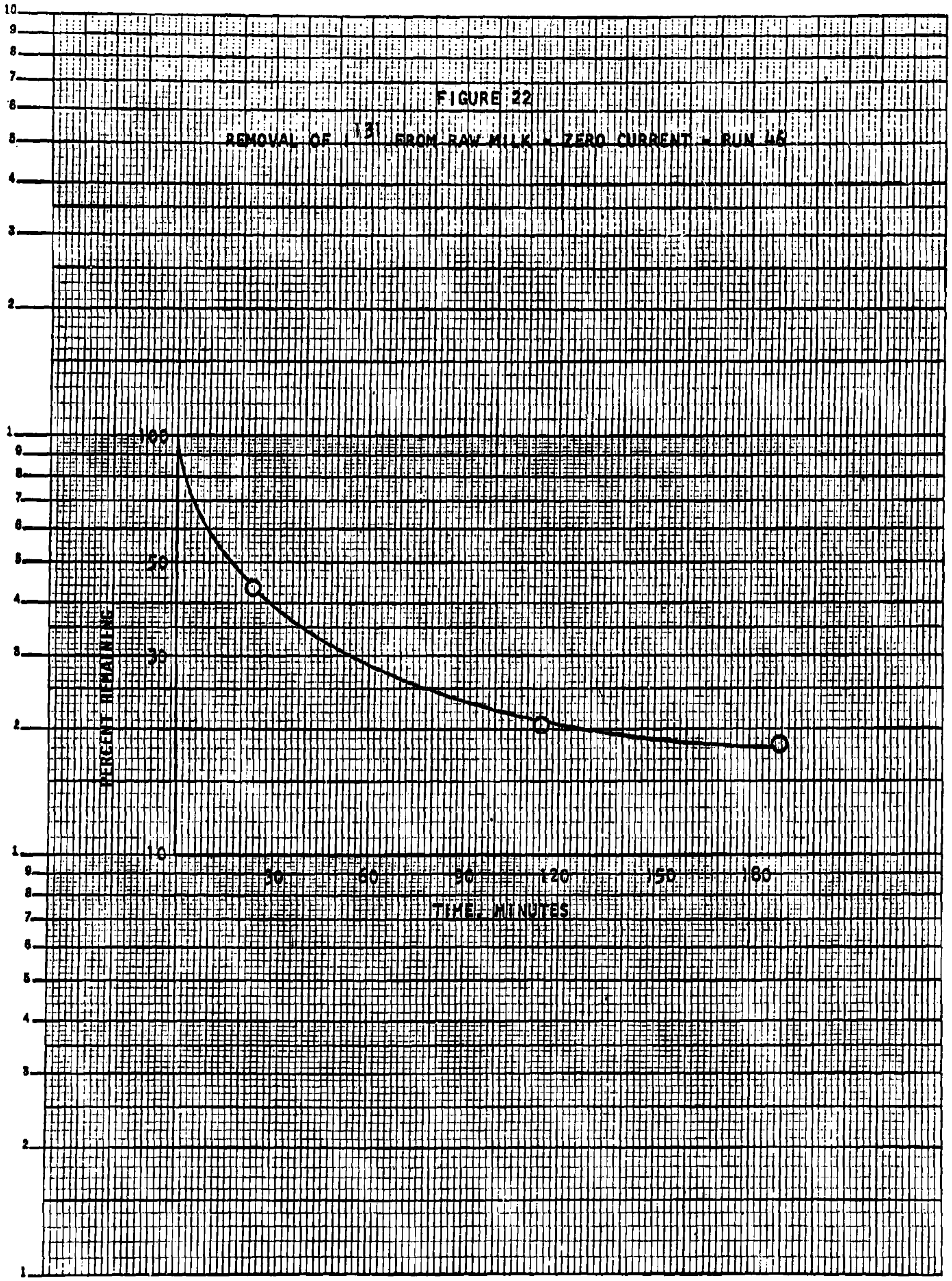


FIGURE 22
REMOVAL OF I 131 FROM RAW MILK - ZERO CURRENT - RUN 46
100
50
30
10
PERCENT REMAINING
30
60
90
120
150
180
TIME, MINUTES

milk without current followed by regeneration of the anion membranes contaminated with iodine under current when the milk is not in the stack. This was done with a demineralizing stack configuration in which the milk cells are bound by a cation and an anion membrane. Runs 55, 60 and 61 were run under this new scheme. Since the milk is not in the stack when the current is applied, a high current density can be used for regeneration of the membrane without causing deposits on the membrane. After the milk is removed from the stack, the waste stream which is to receive the iodine is recirculated in the milk cells, the make-up solution is recirculated through the adjacent cells and the current is applied. A current density of about 60 ma/cm^2 was used in the regeneration step without the formation of any deposits on the surface of the membrane. The contacting of the milk was done in two steps with a regeneration step in between. Three consecutive runs were made to bring the membranes to a steady state condition in order to determine the steady state removal of iodine. Per cent removal for the conditions of the experiment steadied at about 70% of the total iodine present, or about 75% of the free iodine. This compares with about 96 to 98% removal of the free iodine under current at 10 or 15 ma/cm^2 for Runs 52 to 54. The results of Runs 55, 60 and 61 are given in Figures 23, 24 and 25. In Figures 24 and 25 the iodine pickup in the waste stream during the regeneration step is also shown. In Run 60 the regeneration was carried out for 20 minutes, whereas, in Run 61 it was carried out for 30 minutes. A comparison of per cent total iodine and per cent free iodine removal is given in Table XIII.

The protein-bound iodine normally involved is 10% of the total iodine in the milk. It cannot be removed from the milk unless the protein is destroyed and, therefore, is not removable if the milk is to retain its protein value. However, in market milk only about 5% of the iodine is protein-bound (25).

The change in the concentration of the individual anions and of the total anions in the milk for the iodine decontamination runs is given in Table XIV.

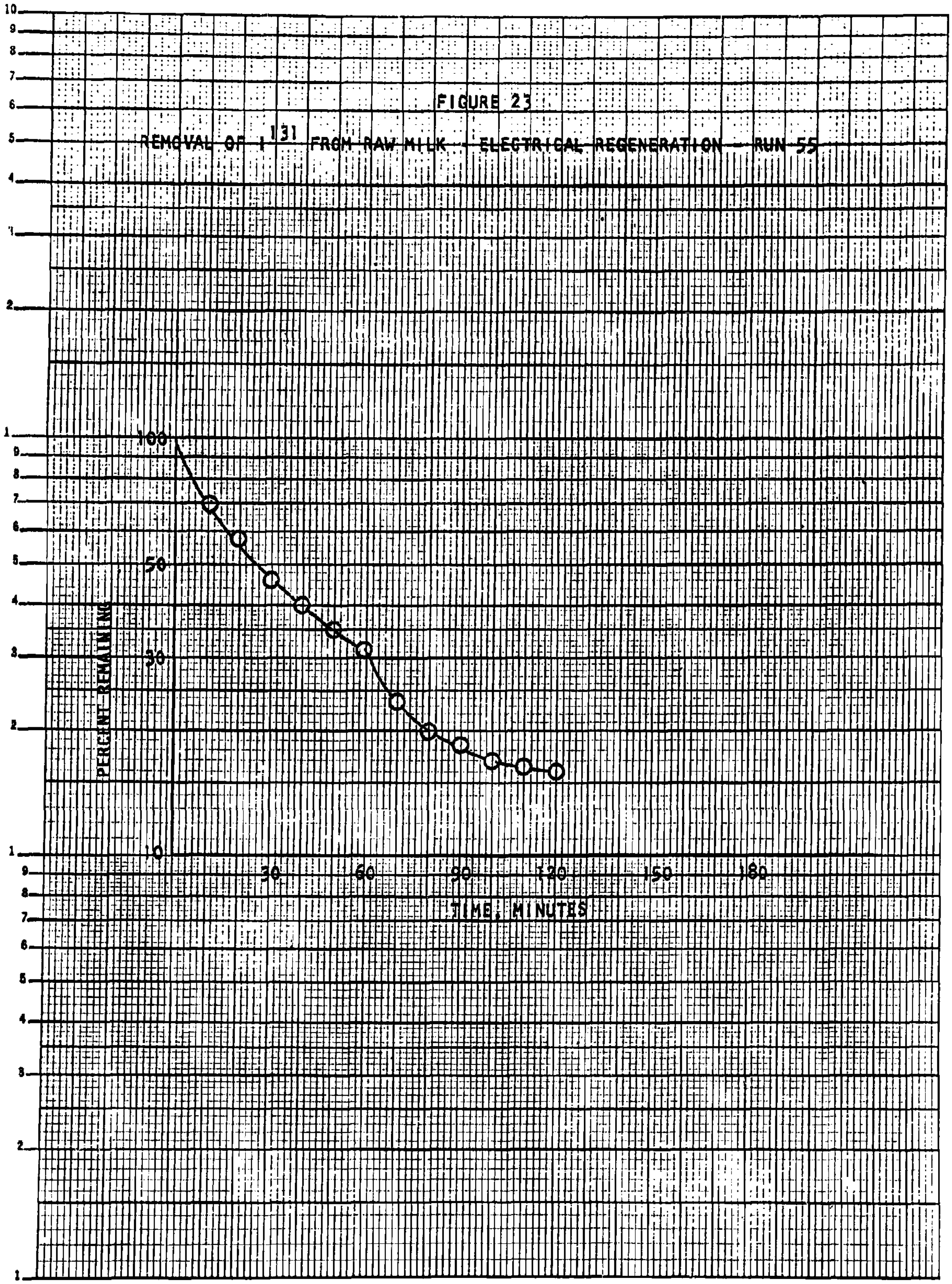


FIGURE 23
REMOVAL OF I 131 FROM RAW MILK - ELECTRICAL REGENERATION - RUN 55
PERCENT REMAINING
100
50
30
10
30
60
90
120
150
180
TIME, MINUTES

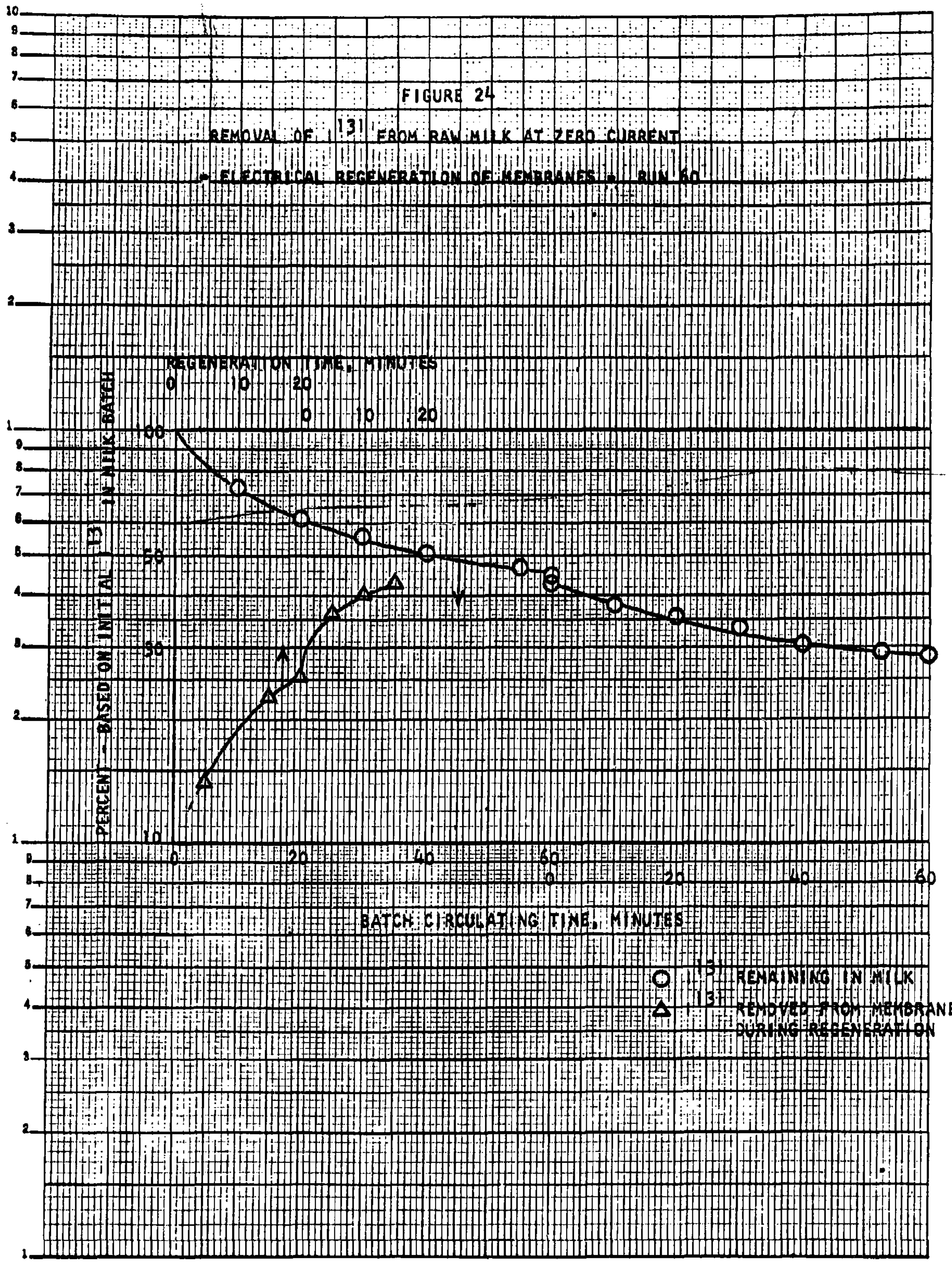


FIGURE 24
REMOVAL OF I131 FROM RAW MILK AT ZERO CURRENT
- ELECTRICAL REGENERATION OF MEMBRANES - RUN 60
REGENERATION TIME, MINUTES
PERCENT - BASED ON INITIAL I131 IN MILK BATCH
BATCH CIRCULATING TIME, MINUTES
I131 REMAINING IN MILK
I131 REMOVED FROM MEMBRANE DURING REGENERATION

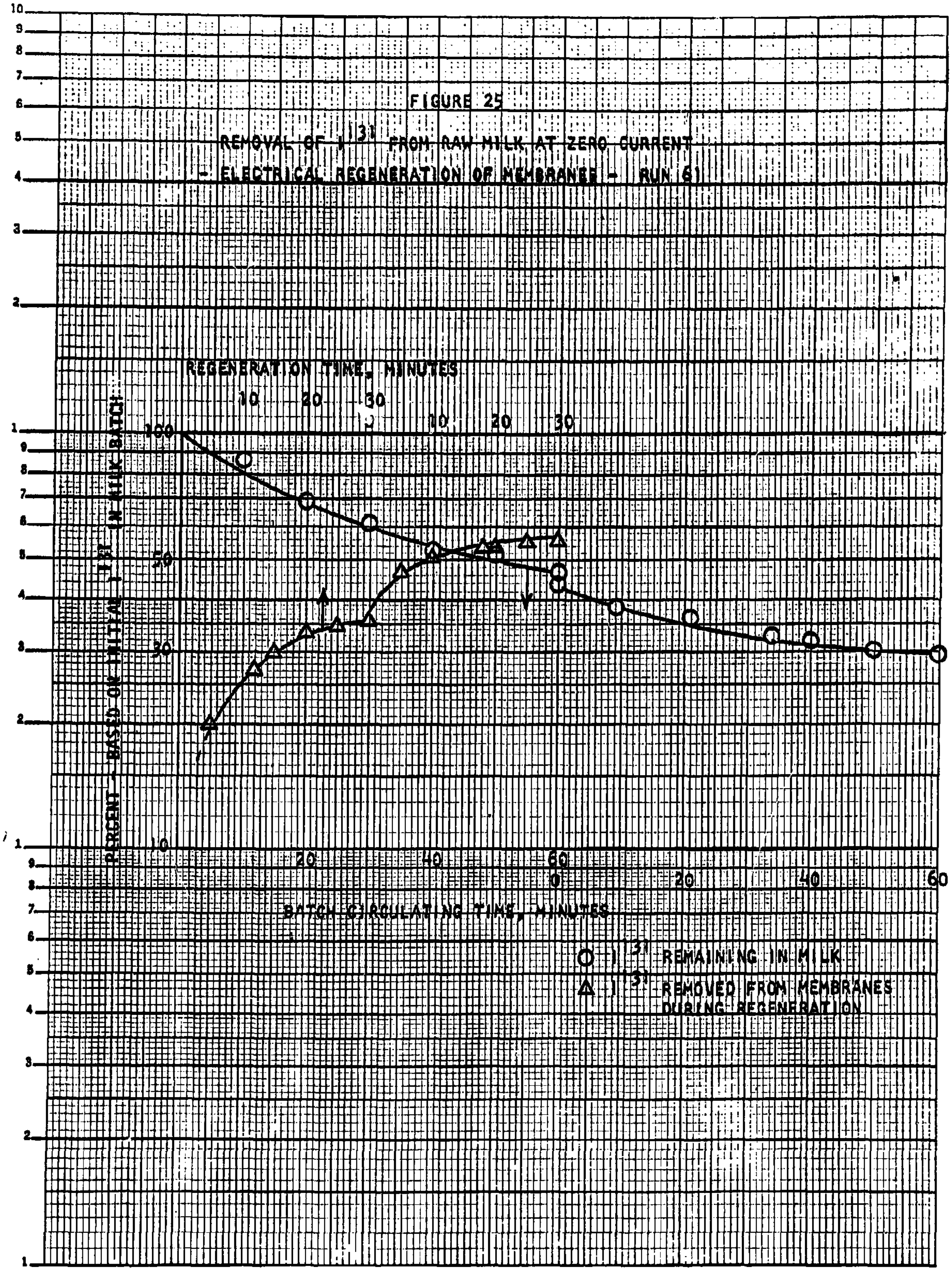


FIGURE 25
REMOVAL OF I 131 FROM RAW MILK AT ZERO CURRENT
- ELECTRICAL REGENERATION OF MEMBRANES - RUN 61
REGENERATION TIME, MINUTES
10
20
30
0
10
20
30
100
50
30
10
20
40
60
0
20
40
60
PERCENT - BASED ON INITIAL I 131 IN MILK BATCH
BATCH CIRCULATING TIME, MINUTES
I 131 REMAINING IN MILK
I 131 REMOVED FROM MEMBRANES DURING REGENERATION

TABLE XIII

Removal of I^{131} from Raw Milk

Run No.	Current Density	Total μc/liter I^{131}	Protein Bound I^{131} μc/liter	% Total I^{131} Removed	% Free I^{131} Removed
Current 52	15	4.18	0.056	97.0	98.2
" 53	10	3.22	0.378	86.0	97.5
" 54	15	3.22	0.334	86.3	96.3
*Zero Current 55	60	4.39	0.108	83.8	86.0
" 60	60	4.00	0.225	71.7	76.0
" 61	60	3.68	0.225	70.4	75.0

*In zero current runs, current density listed is that used to electrically regenerate the membranes.

TABLE XIV

IODINE REMOVAL

Change in Concentration of Salts in Milk During Decontamination

	Concentration Change, Per Cent of Initial Equivalents/qt. Milk					
	Run	Citrate	PO_4	SO_4	Cl	Total Anions
A	44	-27.6	-36.4	-35.6	- 9.4	-26.2
	45	-12.0	-34.2	-45.5	- 2.7	-23.1
	43	17.5	-37.3	-75.0	45.3	5.8
	42	21.6	-10.3	-33.3	14.4	11.2
B	48	-34.7	20.2	-12.7	-91.2	-37.8
	49	34.8	-26.6	-20.1	-94.4	-11.0
	47	44.2	21.2	-10.3	-92.4	3.2
	54	71.6	31.6	-13.1	-98.4	17.0
	53	104.8	45.3	-32.7	-97.4	25.3
C	55	- 4.2	2.7	2.8	-18.0	- 5.3
	60	36.0	- 1.1	4.8	-21.8	7.6
	61	35.1	2.2	12.0	-25.8	8.6

A Chlorides Present in Make-up Solution

B Chloride-Free Make-up Solution

C Electrical Regeneration Chloride-Free Make-up Solution

Generally, in the runs where chloride was present in the make-up solution, there was a decrease in citrate, sulfate and phosphate ions in the milk and an increase in chloride ions. For runs where no chloride was present in the make-up solution, the citrate and phosphate concentration increased and the sulfate and chloride concentration decreased. When the milk was circulated through the stack under no current, the total anionic concentration of the milk remained relatively constant.

As in the case of the cation removal system, control of the make-up stream composition can be used to control the anionic composition of the milk in the iodine removal system.

4.0 ECONOMICS OF STRONTIUM AND IODINE DECONTAMINATION BY ELECTRODIALYSIS

Estimates of the cost of decontaminating milk by electrodialysis to 67% and 90% removal of Sr^{90} and to 70% removal of I^{131} have been made. The estimates for Sr^{90} removal are based on the separation factor obtained for Sr^{90} in the "in vivo" run. Estimates were made for plants of a capacity of 1,000, 5,000 and 10,000 gallons per hour of milk operating for ten hours per day. The operating cost of Sr^{90} decontamination is about 0.5¢ per quart for 90% removal. Amortization and membrane replacement add about 0.25¢ per quart.

At 90% removal of Sr^{90} about 80% of the barium and over 99.5% of the Cs^{137} will have been removed. At 67% removal of Sr^{90} about 67% of the barium and about 99% of the Cs^{137} will have been removed.

4.1 Strontium Decontamination

The results of the cost estimates are summarized in Table XV. The conditions of decontamination assumed for these estimates are given in the table. Table XV is based on the CZL 4 system using a make-up with no potassium salt. The use of a potassium-free make-up solution increases the decontamination rate by about 35% over the rate achieved when potassium is present in the make-up. During decontamination the milk loses its potassium, but the use of potassium hydroxide to readjust the milk pH to 6.6 after decontamination will return the potassium content of the milk to its original value.

For 90% Sr^{90} removal the total investment cost ranges from $213,000 for 1,000 gallons per hour capacity to $1,460,000 for 10,000 gallons per hour capacity. At 67% Sr^{90} removal the total investment cost is slightly over half of that for 90% Sr^{90} removal. The cost per quart to remove Sr^{90} from milk does not vary significantly with capacity over 1,000 gallons per hour. The total investment cost consists of the membrane stacks (and associated hydraulic system), rectifier and instrumentation. A breakdown of the operating cost is given in Table XV.

A plot of the investment cost versus capacity for 90% and 67% Sr^{90} removal with potassium-free make-up is given in Figure 26. The

TABLE XV

Decontamination of Milk

Cost Analysis

Basis: CZL4 System (Basis, 78,79,80,&82)
i, 45 ma/cm^2
t, 45°F
10 hr/day, 300 day/year

(Make-up with no pot ium salt)

Decontamination rate: 3.01 (qt/hr)/sq ft effective cell trio area, to 90% R.

	90% Sr Removal		67% Sr Removal	
Capacity Gal/hr Milk	Effective Cell Trio Area, sq ft	Total Investment Cost	Effective Cell Trio Area, sq ft	Total Investment Cost
1,000	1,260	213,000	600	115,000
5,000	6,400	830,000	3,000	440,000
10,000	12,600	1,460,000	6,000	790,000

	Decontamination Cost, cents/qt milk					
	90% Sr Removal, Capacity, gal/hr			67% Sr Removal, Capacity, gal/hr		
	1,000	5,000	10,000	1,000	5,000	10,000
Make-up salts (comml grade)	0.133			0.067		
Acid and Base (USP) (Citric acid and potassium hydroxide)	0.211			0.211		
Energy, 7 mil/KWH	0.112			0.056		
Subtotal	0.456			0.334		
Membrane Replacement*	0.075			0.037		
Maintenance	0.020			0.020		
Subtotal	0.551	0.551	0.551	0.391	0.391	0.391
Amortization (10% per year)	0.18	0.14	0.12	0.097	0.075	0.069
Operating Labor	0.04	0.03	0.03	0.03	0.02	0.02
Total	0.771	0.721	0.701	0.518	0.486	0.480

* Decontaminating Membrane - 100% per year
Other Membranes - 33% per year

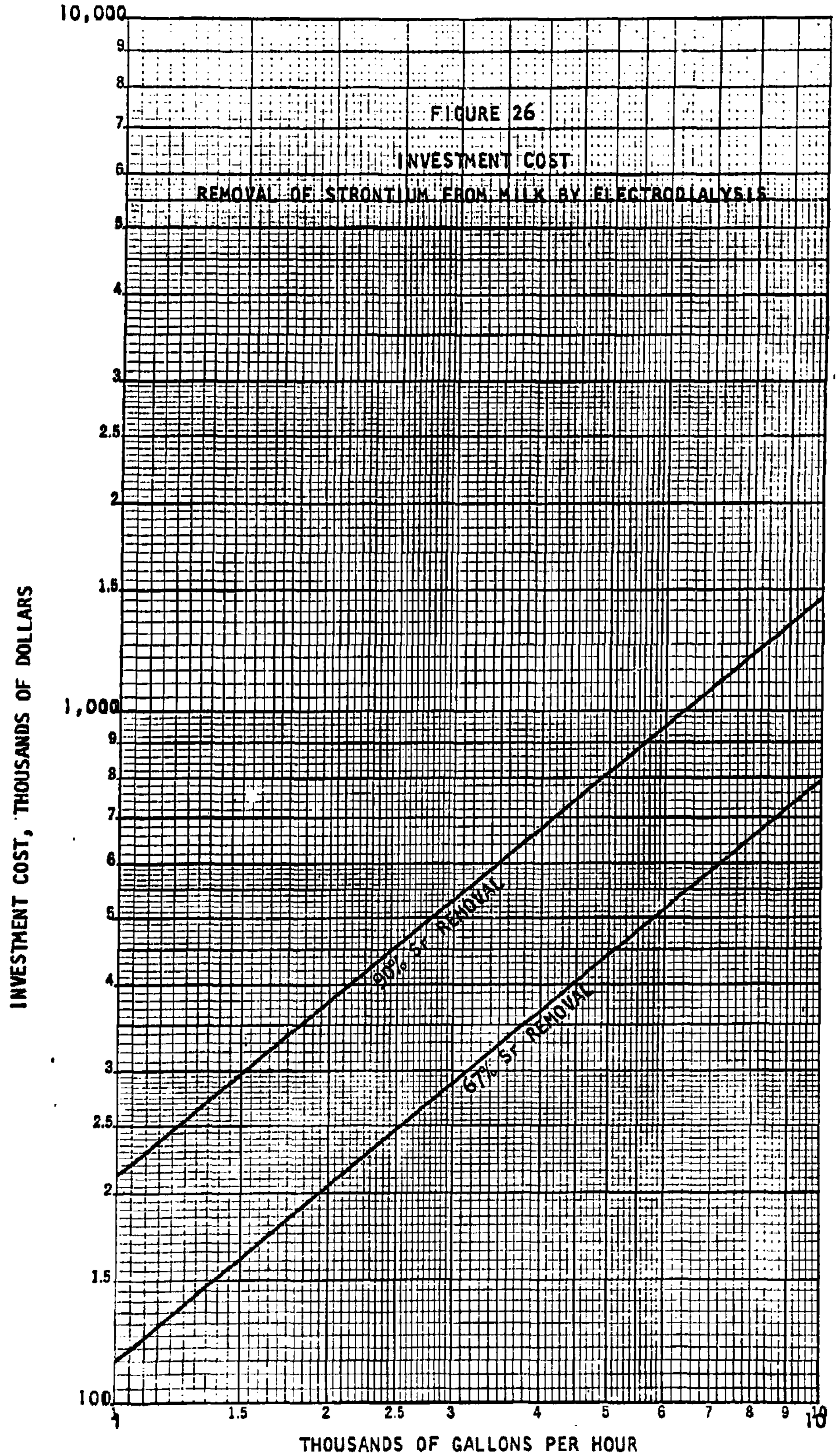


FIGURE 26
INVESTMENT COST
REMOVAL OF STRONTIUM FROM MILK BY ELECTRODIALYSIS
INVESTMENT COST, THOUSANDS OF DOLLARS
THOUSANDS OF GALLONS PER HOUR
90% Sr REMOVAL
67% Sr REMOVAL
10,000
1,000
100
1
1.5
2
2.5
3
4
5
6
7
8
9
10

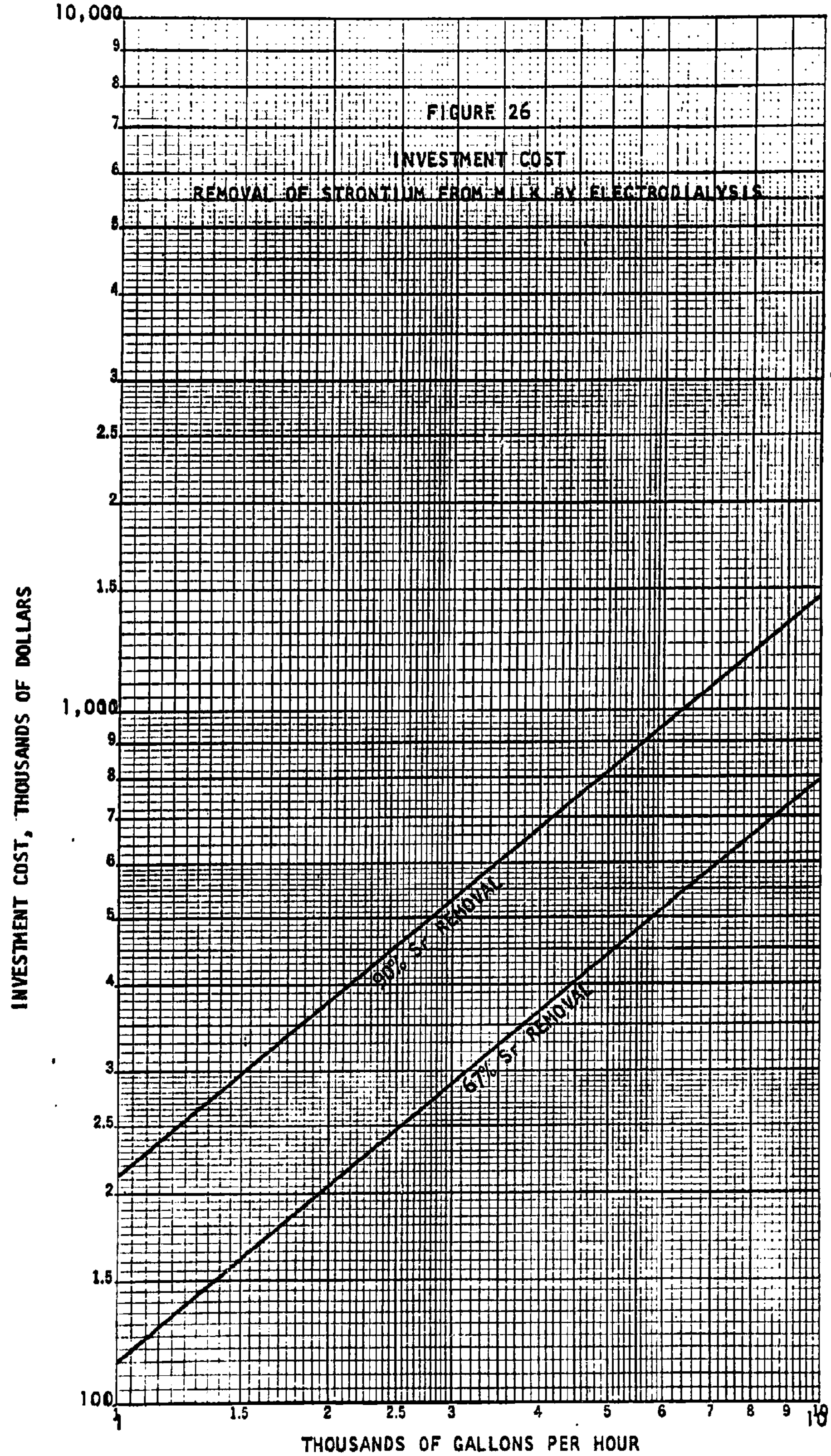


FIGURE 26
INVESTMENT COST
REMOVAL OF STRONTIUM FROM MILK BY ELECTRODIALYSIS
INVESTMENT COST, THOUSANDS OF DOLLARS
THOUSANDS OF GALLONS PER HOUR
90% Sr REMOVAL
67% Sr REMOVAL
10,000
1,000
100

variation of the operating cost as a function of capacity is slight.

The make-up salts consist of calcium chloride, sodium chloride and magnesium chloride. These salts are added to the make-up stream. The cations of these salts are introduced into the milk electrically through the cation transfer membranes. Since the make-up salts are not added directly to the milk, commercial grade salts would be satisfactory. The acid and base used in the estimates are U.S.P. citric acid and U.S.P. potassium hydroxide. The amounts consumed, and the cost of salts, acid, base and energy at 45°F., are given in Table XVI. Use of U.S.P. grade hydrochloric acid would reduce the cost per quart by 0.07¢. Use of commercial grade hydrochloric acid would reduce the cost by 0.17¢ per quart. The energy cost is based on the voltage per cell trio observed at 45°F. and 45 ma/cm^2. The energy required for pumping is less than 10% of the energy requirements. At 100°F. instead of 45°F. the energy requirements are reduced by about a factor of 2.

The membrane replacement cost is based on an average replacement of 55% of all the membranes in one year, and a membrane cost of $2.80 per square foot. At 67% effective membrane area and three membranes per cell trio, the cost is $12.50 per effective square foot cell trio. The life of the membranes remains to be checked out in a pilot plant life test. Our estimates are based on the life of membranes in similar plants. The maintenance and operating-labor costs are estimated from our experience in electrodialysis plants on water and other applications.

The size of the decontamination plant and the energy and salt requirements for 90% Sr^{90} removal "in vivo" are equivalent to those for 95% Sr^{90} removal "in vitro." This was estimated from the separation factor for Sr^{85} on the "in vivo" run compared with the six runs on the same system on "in vitro" spiked milk shown in Table VIII. On the average 95% removal of Sr^{85} "in vitro" corresponds to 90% removal of Sr^{85} removal "in vivo" probably because of the increased amount of Sr^{85} bound by the milk proteins in "in vivo" milk.

The cost of decontaminating milk may be reduced by devising a

TABLE XVI

Energy Requirements and Salt Consumption During 90% Removal of Sr^{85} from Raw Milk

(Same Basis as Table XV)

Make-up Salt Consumption

Salt	Grade	lbs/qt Milk	¢/lb	¢/qt Milk
$CaCl_2$	Commercial	2.87×10^{-2}	1.72	0.049
$MgCl_2 \cdot 6H_2O$	"	0.654×10^{-2}	2.75	0.018
NaCl	"	3.34×10^{-2}	1.97	0.066
			Total	0.133

Adjustment of Milk ph

Chemical	Grade	lbs/qt Milk	¢/lb	¢/qt Milk		
Citric Acid	U.S.P.	0.64×10^{-2}	30.0	0.192		
KOH	U.S.P.	0.37×10^{-2}	5.0	.019	0.019	0.019
			Total	0.211		
HCL	U.S.P.	0.73×10^{-2}	17.0		0.124	
			Total		0.143	
	Commercial		3.0			0.022
			Total			0.041

D.C. Energy Requirement

Current Density = 45 ma/cm^2, Temp = 45°F

Decontaminating Membrane	Voltage Per Cell Trio	KWH/qt Milk
61 CZL4	13.4	0.160

membrane which has a higher selectivity for Sr. Another way of reducing the decontamination cost is to operate at a higher temperature than 45°F. This not only reduces the energy cost but also it would reduce the investment cost of the electrical power supply and rectifier.

The difference in cost between the case of 90% and the case of 67% Sr^{90} removal results from the shorter batch time required for 67% removal. The lower decontamination is reached with 40 to 50% of the area required for the higher decontamination at the same production rate. The cost of make-up salt, membrane replacement and energy consumption are affected proportionally. The cost of acid and base for pH adjustment is unchanged, as the milk must be adjusted to the same pH in each case. Other costs are reduced, but not in direct proportion.

A cost estimate was made for the removal of 70% I^{131} from milk by electrodialysis and by the method of absorption on anion membranes followed by electrical regeneration of the membranes. The total investment cost for 70% removal of I^{131} is in the same order of magnitude as that for 67% Sr^{90} removal. The result of the cost analysis is shown in Table XVII. The cost per quart of milk is less than 1¢ per quart. In the case of I^{131} removal the cost of make-up salts and the membrane replacement is the major component of the cost. Since there is no need to adjust the milk pH during I^{131} removal there is no cost of acid or base for pH adjustment.

The electrical regeneration method is considerably more expensive than the electrodialysis removal of I^{131}. Even though the electrodialysis stack itself is less complicated for the electrical regeneration system, substantially more membrane area is required. The energy consumption and salt consumption are also substantially higher. The costs per quart of milk would be over 3¢.

The electrodialysis case is based on 10 ma/cm^2, at which current density there was some evidence of deposits from the milk adhering to the membranes. At a slightly lower current density the problem of adherent deposits may be solved without increasing the decontamination costs significantly.

TABLE XVII

Decontamination of Milk (I^{131})

Cost Analysis

10 hr/day, 300 day/yr

70% Removal of Iodine

Capacity Gal/hr Milk	Electrodialysis 10 ma/cm² Effective Cell Trio Area, sq ft	Electrodialysis 10 ma/cm² Total Investment Cost	Electrical Regneration Effective Cell Pair Area, sq ft	Electrical Regneration Total Investment Cost
1,000	610	$116,000	3,400	$ 350,000
5,000	3,050	445,000	17,000	1,300,000
10,000	6,100	800,000	34,000	2,400,000

Electrodialysis 10 ma/cm² Decontamination Cost, cents/qt Milk	Capacity, gal/hr 1,000	5,000	10,000
Make-up salts (comml grade)	0.73		
Energy, 7 mil/KWH	0.01	—	—
Subtotal	0.74		
Membrane Replacement*	0.04		
Maintenance	0.02	—	—
Subtotal	0.80	0.80	0.80
Amortization (10% per year)	0.10	0.08	0.07
Operating Labor	0.03	0.02	0.02
Total	0.93	0.90	0.89

* Decontaminating membrane - 200% per year

Other membranes - 100% per year

A strontium removal plant can be used for iodine removal during emergencies by changing the membranes in the stacks.

5.0 PILOT PLANT

A flow sheet of 100 gallons per hour Sr^{90} removal pilot plant is given in Figure 27. The rectifier and the power supply are not shown in the figure. The flow sheet is based on a batch cycle with a timer controlling the length of the batch processing time. Provisions are made for cooling the milk during processing.

The cold, raw milk is first introduced into the acid adjustment tank where a fixed acid charge is added with stirring to bring the milk pH close to the point required for efficient Sr removal. From the acid adjustment tank, the milk is pumped into the milk batch tank. Additional acid required to bring the pH to the exact value desired is added automatically as requested by the pH control system. The pH is then adjusted automatically throughout the duration of the decontamination batch run.

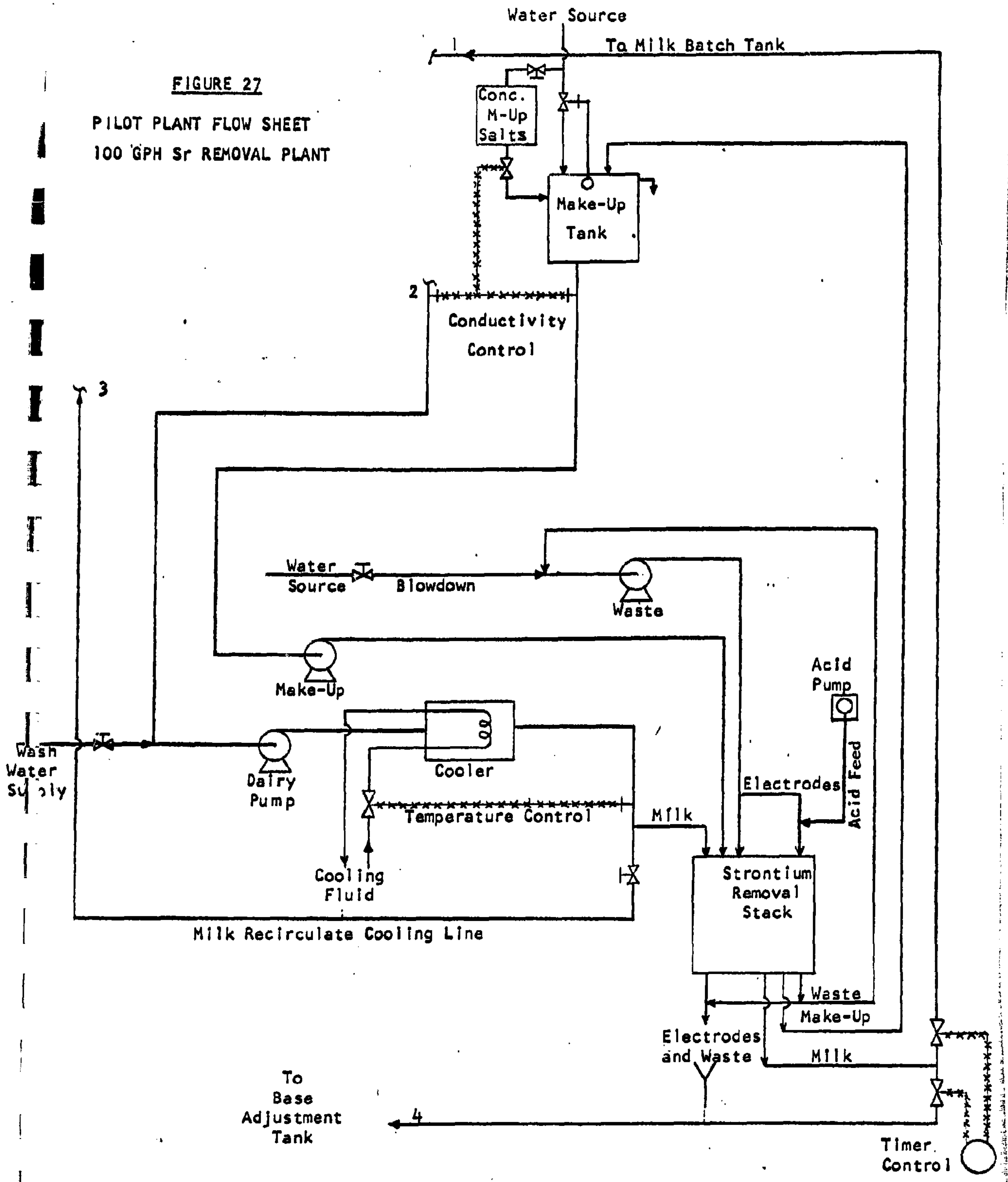
During decontamination the milk is recirculated through a cooler, the electrodialysis stack and back into the milk batch tank.

The make-up salts are introduced into the make-up tank as a concentrated solution. Water is introduced into the make-up tank as required to maintain a constant level. The rate of make-up salts fed into the make-up tank is controlled by the conductivity of the milk and the conductivity of the make-up recirculation stream. If the milk conductivity increases, the conductivity control will reduce the rate of addition of salts to the make-up tank. A conductivity cell on the make-up recirculation stream will override the request for addition of fewer salts if the make-up stream conductivity drops to a certain limiting value This provides a make-up stream concentration low enough to prevent an increase in the concentration of salts in the milk. However, the make-up stream concentration must not be allowed to decrease to the point where "polarization" occurs.

The waste stream is recirculated through a feed and bleed system in which water is fed into the stream at a given rate to maintain the desired concentration of salts in the waste stream.

FIGURE 27

PILOT PLANT FLOW SHEET
100 GPH Sr REMOVAL PLANT



The electrode cells are fed from the waste recirculation stream, with acid fed to the cathode cell input to prevent scaling at the cathode.

When the processing of the batch is completed the milk is transferred into the milk product tank where the pH is adjusted back to 6.6 by the addition of base. This is shown in detail A in Figure 28. It shows the three tanks required for milk; the acid adjustment tank, the milk batch tank and the base adjustment tank from which the milk is sent to further dairy processing.

By reducing the number of cell trios in the stack, this plant could be operated at less than 100 gallons per hour; for example, by using about 10 to 15 cell trios, it would be operated at 20 to 25 gallons per hour.

A schematic of the energy and chemical consumption for the pilot plant is shown in Figure 29.

FIGURE 28

MILK pH ADJUSTMENT AREA

Detail A

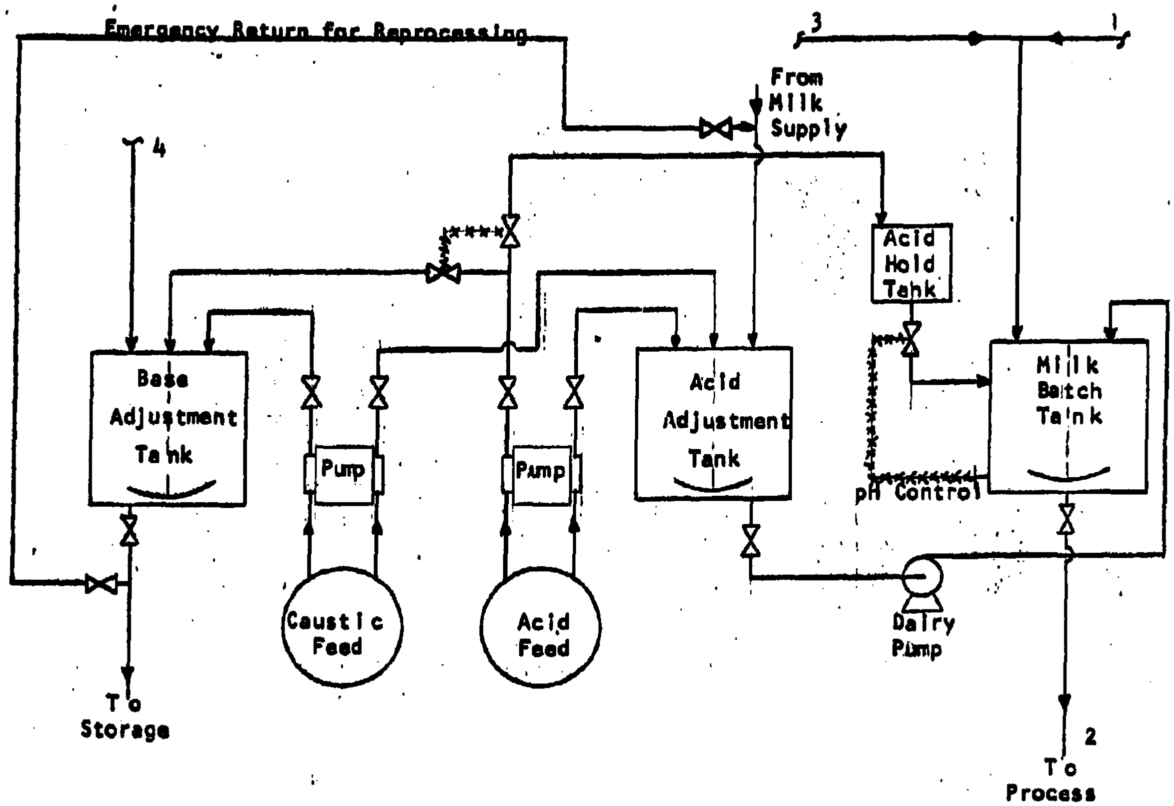
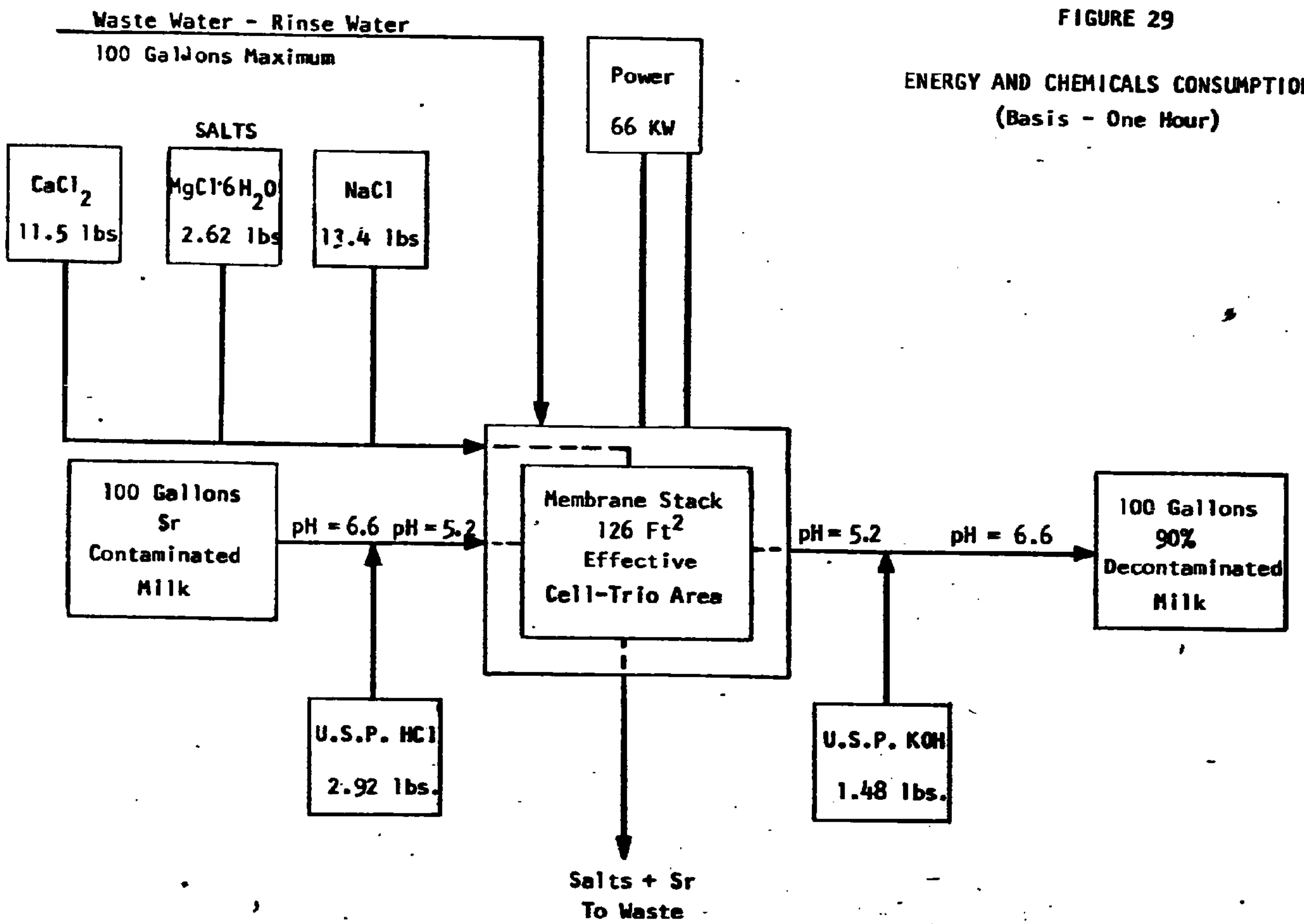


FIGURE 29

ENERGY AND CHEMICALS CONSUMPTION
(Basis - One Hour)



6.0 APPARATUS AND PROCEDURE

6.1 Laboratory Equipment

The laboratory electrodialysis unit was designed to handle four separate hydraulic streams--milk, salt make-up, contaminated waste, and electrode. Figure 30 is a schematic flow diagram of the laboratory unit.

The membranes and spacers used in the electrodialysis stack measure 5 inches by 9 inches overall, width and length. The spacers have flow paths similar, but shorter, to those used successfully by Ionics in large plant scale equipment for water desalting and for demineralization of whey.

Two of the four pumps (Eastern Industries, Model D-11) included in the apparatus are made of Hastelloy-C for extreme corrosion resistance and two are made of stainless steel. The connecting lines are principally polyethylene and Tygon tubing. The batch solution tanks have a capacity of two liters each. Cooling coils have been provided so that the temperature of the milk can be controlled.

For cation decontamination, the stack membrane configuration used is shown in Figure 31. The basic cell unit in this system consists of two cation membranes, decontaminating and make-up, and one anion membrane. The milk stream passes between the two cation membranes and the flow of current is perpendicular to the milk flow. This results in a gradual electrical flushing of the milk with a supply of uncontaminated cations through the make-up membrane and a gradual purging of the radioactive cations present in the milk through the decontaminating membrane.

For iodine decontamination, two different stack configurations were used. In the initial iodine decontamination runs, the stack configuration was the same as that of Figure 31, except that cation membranes were used instead of anion membranes and vice versa. In the electrical regeneration runs (Runs 55, 60 and 61), the cell configuration consisted of alternating anion membranes and cation membranes throughout the stack.

FIGURE 30

Flow Sheet of Laboratory Electrodialysis Unit

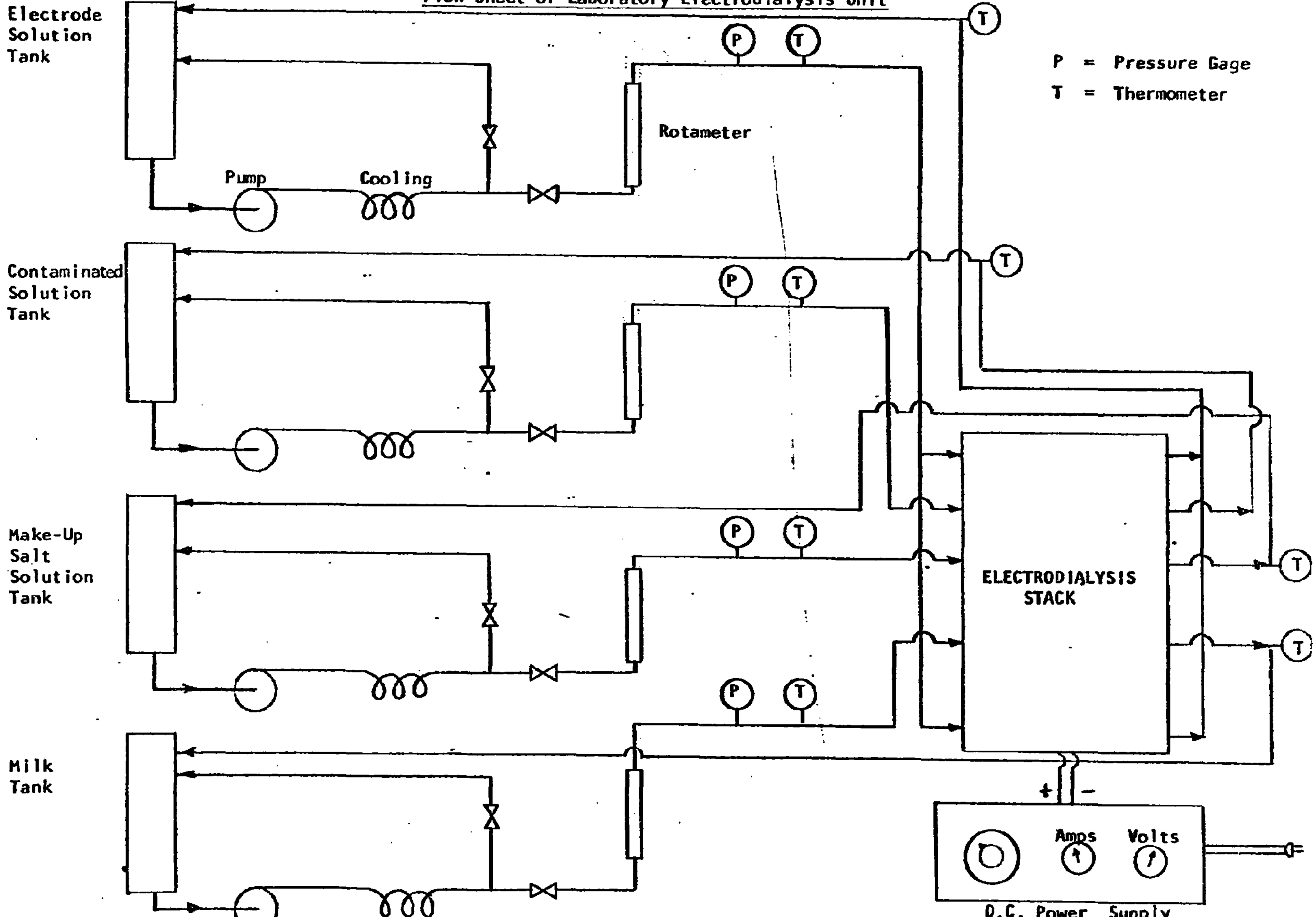
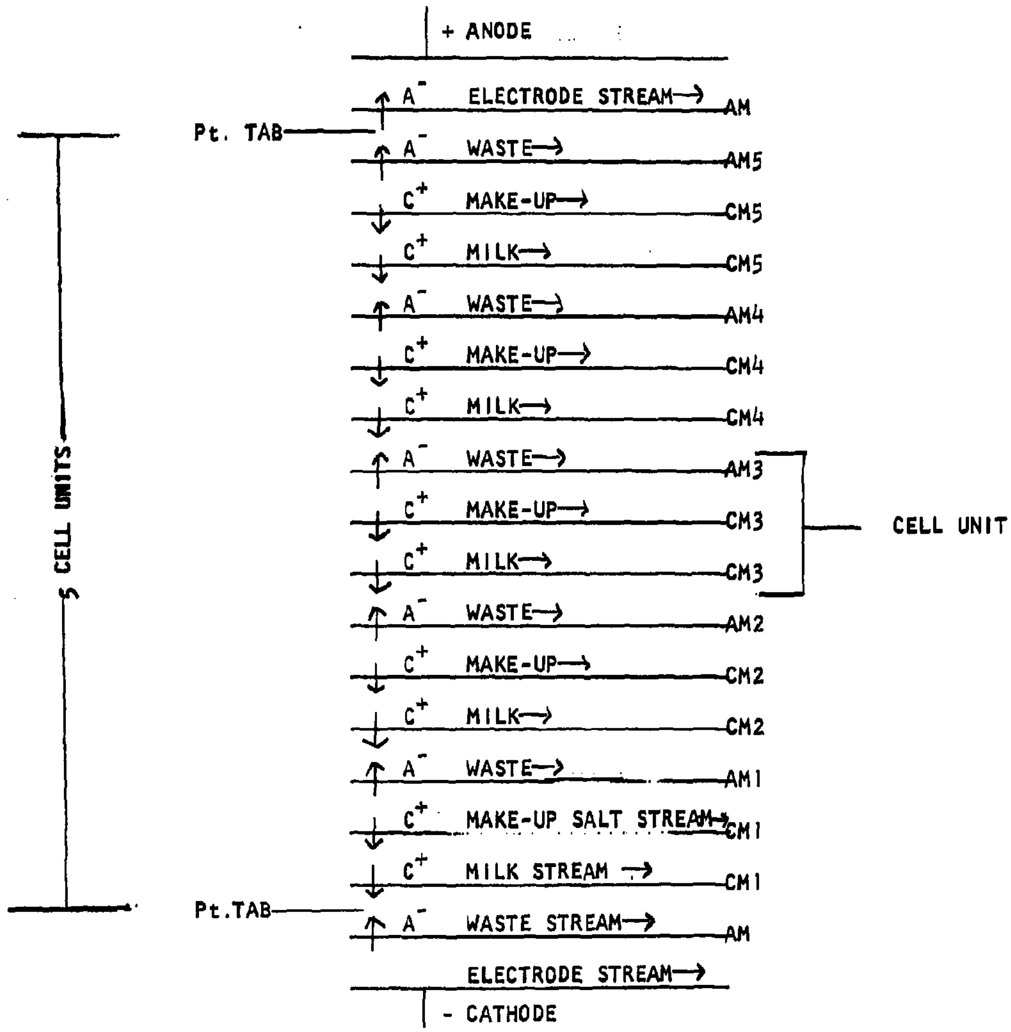


FIGURE 31

STACK CONFIGURATION FOR CATION DECONTAMINATION OF MILK (FIVE THREE-COMPARTMENT CELL UNITS)



LEGEND

AM = ANION MEMBRANE

CM = CATION MEMBRANE

A^- = ANIONS PRESENT IN SOLUTION

C^+ = CATIONS PRESENT IN SOLUTION

Two separate sets of cells are thus formed which are separated from each other by an anion membrane on one side and a cation membrane on the other. The same stream can be passed through every other cell. In the decontamination step, milk containing radioactive iodine was passed through one set of cells at approximately 5 psig. For this step no other stream was circulated through the other set of cells, and no current was applied to the stack. Radioactive iodine in the milk was picked up by the anion membranes. The decontamination step was followed by an electrical regeneration step in which the milk stream was replaced by a waste stream and a make-up stream was circulated through the other set of cells. The make-up stream contained phosphate, citrate and sulfate ions in the same ratio as they are found in milk. Using a current density of 60 ma/cm^2, radioactive iodine was driven from the surface of the anion membrane into the waste stream solution. The iodine driven from the anion membrane was replaced by phosphate, citrate and sulfate from the make-up streams.

6.2 Experimental Procedure

6.2.1 Preparation of Milk

A one liter batch of raw milk was contaminated with approximately five microcuries of tracer solution. The tracers used for contamination were carrier free solutions of Sr^{85}, Cs^{137}, Ba^{140}- La^{140}, Ce^{139} and I^{131} as their chlorides in 0.1 M HCl. The total volume of tracer solution added was about 0.1% of the total milk volume.

The contaminated milk batch was equilibrated for 72 hours to allow ample time for divalent cation contaminants to undergo association with anions like citrate and phosphate and to complex with casein in the milk. This time period had been found satisfactory by the Department of Agriculture in their work in decontamination of milk using "in vitro" spiked milk. When running at a pH other than the normal pH of milk, the milk was acidified by the addition of 1 M citric or 1.0 N hydrochloric acid immediately before the start of a decontaminating run.

6.2.2 Preparation of Make-Up, Waste and Electrode Streams

The composition of the initial make-up and concentrated feed make-up solutions was based on the average of the separation factors obtained in early runs and was changed as data were accumulated during the program. The composition of these streams for all the runs is reported in the Appendix.

Since the composition of the waste stream has no significant effect on the composition of the milk, the initial waste stream was prepared by diluting make-up solution with deionized water. The concentrated feed make-up, the make-up and the waste solutions were then adjusted to a pH of 6.0 by the addition of hydrochloric acid.

The electrode stream was a 0.2 N solution of NaCl acidified to pH of 2.0 by the addition of HCl.

6.2.3 Decontamination Runs

Batch volumes of one liter of milk, two liters of make-up, two liters of waste and one liter of electrode stream solution were placed in their respective batch tanks. The streams were allowed to circulate through the stack for approximately 15 minutes while final pH adjustments were made and initial samples taken for analyses.

The velocity of the milk stream was held at 40 cm/sec. in the spacer flow path. The volumetric flow rate of milk through a five cell unit at this velocity was 850 cc/min. The inlet pressure at the stack was 15 psig. The flow rates of the make-up, waste and electrode stream were adjusted so that their inlet pressure at the stack was approximately one psi less than the milk stream inlet pressure.

When all streams were flowing properly and the adjustments had been completed, the rectifier was turned on and the time was noted as the start of the run.

During the run, the concentrated feed make-up solution was fed automatically to the batch make-up solution to maintain a constant salt concentration in the make-up stream. The concentration of the waste stream was monitored with a flow-through conductivity cell.

Batch volumes, flow rates, stack inlet pressures, electrical resistance, pH values and batch temperatures of each stream were recorded periodically. The current was held at a constant value during each run. Total stack voltages and voltages across the cell units were recorded periodically.

Samples of the milk stream, make-up stream and waste stream were taken at the start, the mid-point and the termination of each run. These samples were analyzed for Na^+, K^+, Ca^{++}, and Mg^{++} and for chloride. A 5 ml sample of milk was pipetted from the batch every 30 minutes to be analyzed for cationic tracer contamination.

After each decontamination run, the stack was flushed with distilled water, disassembled and cleaned. After examination, the membranes were wiped clean, rinsed with distilled water and then placed in a solution having the same composition as the make-up stream or subjected to a cleansing step with aqueous NaOH.

New membranes were equilibrated with make-up solution before use in the stack.

A similar procedure was followed for the runs on iodine removal, except that the make-up and the waste streams were run on a batch basis.

6.2.4 Analytical Procedure

The milk samples were analyzed for their radioactive contents, using a single channel scintillation spectrometer with a well type detector manufactured by Radiation Instrument Development Laboratory. Gamma ray scintillation spectrometry was used to determine Ce^{139}, Sr^{85} and Cs^{137} simultaneously. Experiments involving Ba^{140}- La^{140} and I^{131} were carried out using a single tracer.

Analyses were carried out using a differential method of counting, even when only a single tracer was present. The various radionuclides were determined by counting their photopeak at the following MEV values:

	MEV
Sr^{85}	0.51
Cs^{137}	0.66
Ba^{140}	0.54
Ce^{139}	0.166
La^{140}	1.60
I^{131}	0.364

Analyses for calcium, magnesium, sodium, potassium, phosphorus, sulfate, citrate and lactose were carried out on a clear casein-free serum produced using the precipitation procedure of Wenner (32). Chloride analyses were made on milk serum after precipitation of the casein with dilute nitric acid. The following procedures were used for these analyses:

Sodium and potassium were determined by flame photometry using the method of Wenner (32).

Calcium and magnesium were determined volumetrically using a slightly modified version of the EDTA titration procedure of Kamel (19) or the direct EDTA titration procedure of Jenness (17).

Chloride was determined volumetrically using the classical Volhard method.

Citrate, phosphate and lactose were determined by spectrophotometry.

Citrate was determined using the pyridine-acetic anhydride method of Marier and Boulet (21). Phosphate was determined using the molybdenum blue method of Harris and Popat (16). This procedure gives the total inorganic phosphorous content of milk. Lactose was determined using the phenol-sulfuric acid method of Marier and Boulet (22).

Sulfate was determined by turbidimetry (1).

7.0 CONCLUSIONS

1. The feasibility of milk decontamination by electrodialysis has been demonstrated.
2. The pH of the milk must be adjusted to between 5.1 and 5.3 to achieve 90 to 95% strontium removal.
3. The removal of barium is somewhat less rapid than the removal of strontium and is affected by pH in a similar manner.
4. The rate of removal of cesium is about four times faster than the rate of removal of strontium and does not seem to be affected by pH.
5. At the pH of 5.1 to 5.3 required for satisfactory strontium removal, cerium was not removed from milk by electrodialysis. Lanthanum, another rare earth, was removed less readily than barium.
6. Changes in the level of natural strontium in the milk up to 10 mg per liter have no significant effect on the rate of removal of radiostrontium.
7. In the range of 30 to 60 ma/cm^2 the rate of decontamination is proportional to the current density, but the milk is less stable at the higher current densities.
8. Increasing the operating temperature reduces the voltage required at a given current density, but does not affect the rate of decontamination at a given current density.
9. The concentration and composition of the salts in the milk can be controlled by controlling the concentration and composition of the make-up stream.
10. The loss of organics, such as lactose, from milk during electrodialysis is less than 1%.

11. Univalent ions such as K, Na and Cs are transferred selectively from milk by electrodialysis over divalent cations such as Ca, Mg, Sr and Ba. This is due to the complexing action of the milk on divalent cations.

12. Some electrochemical properties of the cation membranes are impaired during decontamination of milk. A regular cleansing step with aqueous NaOH is effective in preventing loss in performance.

13. The rate of cation decontamination can be increased by using a potassium free make-up stream to make the milk deficient in potassium.

14. Conditions which yield 95% strontium removal from milk contaminated "in vitro" result in 90% strontium removal from milk contaminated "in vivo."

15. Removal of iodine from milk by electrodialysis may be accomplished under current or alternatively with no current applied followed by removal of iodine from the membranes under current.

16. The allowable current density for iodine removal under current is about 10 ma/cm^2 for whole milk.

17. The rate of exchange of iodine from milk in the presence of anion membranes is extremely rapid.

18. Some iodine (approximately 10%) in milk is bound to proteins and unavailable for removal.

19. The total cost of 90% Sr^{90} removal by electrodialysis is less than 3/4¢ per quart of milk.

20. The total cost of 70% I^{131} removal by electrodialysis is less than 1¢ per quart of milk.

8.0 RECOMMENDATIONS

8.1 Pilot Plant Studies

A pilot plant program on a scale of 100 gallons of milk per hour capacity is recommended. The major objectives of this program are: (1) to provide information which can be used with confidence for the design of a full-scale plant; (2) to establish with reliability the operating costs such as electrical energy, chemicals, supplies and labor costs; (3) to provide samples of treated milk for nutritional and acceptance tests; and (4) to establish sanitation procedures.

The pilot plant should be designed for both cation and anion decontamination, so that either strontium or iodine decontamination tests can be made by changing the membranes in the stack.

A 100 gallon per hour pilot plant capacity is recommended because a full-scale plant would consist of several membrane stacks, each having the same capacity as the pilot plant stack. The pilot plant could be operated at a minimum capacity of 20 gallons per hour for membrane life tests to reduce the consumption of milk during prolonged test periods.

The operating conditions to be studed in the pilot plant are:

a. Temperature
b. Current Density
c. Milk pH
d. Recirculation Flow Rate
e. Duration of Decontamination Cycle
f. Concentration and Composition of the Make-Up and Waste Streams

The nutritional study will encompass analysis of the mineral, vitamin, fat and protein composition of the milk. It should be supported by tests on animals.

The sanitation study will be concerned with bacterial contamination and flavor. It is related to the conditions of operation and to the cleansing of the stack between runs to maintain optimum performance.

In addition to the pilot plant it is recommended that research and development be continued.

8.2 Research and Development

Additional studies in the laboratory or bench scale are recommended as follows:

1. Life test of membranes - The cost of membrane replacement is an important factor in the economics of milk decontamination by electrodialysis. A bench scale life test is recommended to determine the useful life of the membranes.

2. Decontamination of skim milk - The studies on decontamination by electrodialysis have been confined to whole milk. It may be possible to reduce the decontamination cost by processing skim milk instead. Most of the radionuclide contaminants should be present in the skim milk after the fat is separated out. The absence of the fat may result in increased decontamination rates without problems of solids deposition, especially in iodine^{131} removal, and should simplify the sanitation procedures. Following decontamination, whole milk could be reconstituted from decontaminated skim milk.

3. Development of improved techniques for pH adjustment of the milk before and after decontamination - The use of a weak acid ion-exchange resin, such as IRC50, in the hydrogen cycle may be used to lower the milk pH to 5.2 by batch contacting. If feasible, this is preferable to the direct addition of acid because the salt concentration of the milk is not increased. The spent resin could be regenerated easily with inexpensive hydrochloric or sulfuric acid.

   The use of a weak base anion exchange resin to readjust the pH of the decontaminated milk to 6.6 would eliminate the addition of base directly to the milk. Inexpensive sodium hydroxide could be used to regenerate the spent resin.

4. Nutritional Studies - The protein composition and the vitamin B-6 (pyridoxine) and vitamin B-2 (riboflavin) content of the milk can be studied in a bench scale unit.

5. Development of improved membranes - The rate of decontamination depends on the selectivity of the membrane for the ionic form of the radionuclide. It would be worthwhile to develop membranes which have higher selectivity for transfer of strontium and barium and for iodine. Especially so in the case of iodine, where the membranes tested absorbed iodine from the milk, but did not readily transport it electrically to the waste stream.

9.0 APPENDIX

9.1 References

9.1.1 Literature References

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9.2 Derivation of Electrodialysis Equations

9.2.1 Feed and Bleed System

In this system the milk undergoing electrodialysis is of essentially the same composition as the decontaminated milk. For purposes of the derivation, it can be assumed that they are of the same composition. The case of cationic contaminants will be considered. The contaminating ions enter the cell in the milk feed. They leave the cell in the decontaminated milk and electrically through the cation membrane. The fraction of cationic contaminants in the electric flux of cations is proportional to the fraction of contaminants in the milk and to the separation factor, if the membrane discriminates between the contaminants and the other cations. A material balance yields:

$$X_i cF = X_o cF + 60 X_o \frac{\alpha e i A}{(\mathcal{F}/1000)} \qquad (1)$$

where $\mathcal{F}/1000$ is 96.5 coulomb/milliFaraday and $\frac{\mathcal{F}}{60 \times 1000} = 1.61 \frac{\text{amp-min}}{\text{milliFaraday}}$ (please refer to the nomenclature at the end of this section.)

Solving the A/F, the area requirement per unit volume of milk processed per unit time is:

$$\frac{A}{F} = 1.61 \left(\frac{X_i - X_o}{X_o} \right) \left(\frac{c}{\alpha e} \right) \left(\frac{1}{i} \right) \qquad (2)$$

The D.C. energy requirement per unit volume of milk is:

$$\frac{E}{F} = \frac{R_p i^2 A}{F} = 1.61 \left(\frac{X_i - X_o}{X_o} \right) \left(\frac{c}{\alpha e} \right) i R_p \qquad (3)$$

9.2.2 Continuous Staging

In this system the milk is passed in series through as many decontamination stages as required to reach the desired decontamination level. The decontamination achieved is a function of the total membrane area available for the passage of ions.

A material balance based on a cell bound by a differential area dA yields:

$$xcF = (x + dx)\,cF + x\alpha \frac{eidA}{1.61} \tag{4}$$

Rearranging and integrating between X_i and X_o,

$$-cF \int_{X_i}^{X_o} \frac{dx}{x} = \frac{\alpha ei}{1.61} \int_{0}^{A} dA \tag{5}$$

$$cF \ln \frac{X_i}{X_o} = \frac{\alpha eiA}{1.61} \tag{6}$$

$$\frac{A}{F} = 1.61 \left[\ln \frac{X_i}{X_o}\right] \left(\frac{c}{\alpha e}\right) \left(\frac{1}{i}\right) \tag{7}$$

The D.C. energy requirements are derived as in equation (3):

$$\frac{E}{F} = 1.61 \left[\ln \frac{X_i}{X_o}\right] \left(\frac{c}{\alpha e}\right) iR_p \tag{8}$$

These equations differ from equations (2) and (3) in the ln term.

9.2.3 Batch System

In this case a batch of milk is recirculated through an electrodialysis unit until the batch contaminants drop to the desired level. The rate of contaminant removal is equal to the change of contaminant concentration in the batch with time:

$$-cVdx = \frac{X\alpha eiA}{1.61}\,d\theta \tag{9}$$

where V is the batch volume and θ is the time. Integrating between X_o and X_i and rearranging:

$$-cV\int_{X_i}^{X_o}\frac{dx}{x} = \frac{\alpha eiA}{1.61}\int_{o}^{\theta} d\theta \tag{10}$$

$$c\left(\frac{V}{\theta}\right)\ln\frac{X_i}{X_o} = \frac{\alpha eiA}{1.61} \tag{11}$$

Since $\frac{V}{\theta}$ is the same as F in equation (6), identical expressions for energy and area requirements are obtained for this system as for the continuous staged system.

To convert the equations to square feet/(qt./hr.) and KWH/qt., the following conversion factors can be used:

sq. ft./(qt./hr.) = (0.0173 sq. cm./(ml./min)
KWH/qt. = 0.0161 watt-min/ml.

<u>Nomenclature</u>

A = Total effective area of membranes transferring radioactive ions decontaminating membrane (cm^2).

F = Flow rate of milk through cells (cm^3/min.).

c = Total ionic concentration in milk, (meq/cm^3).

E = D.C. power (watts).

e = Cationic or anionic transport number for cation and anion membranes respectively, or current efficiency (meq/milliFaraday).

i = Current density (amp/sq. cm.)

R_p = Electrical resistance of a square centimeter of unit cell ($ohms\text{-}cm^2$/cell unit).

V = Batch volume (cm^3).

X_i = Initial fraction of contaminating ion.

X_o = Final fraction of contaminating ion.

α = Separation factor for the contaminating ion over other ions in the milk (determined by the membrane).

$\mathcal{F}$ = Coulombs/Faraday (96,500).

θ = Time (minutes).

n = Number of cell units.

a = effective area of cell unit (decontaminating membrane).

A = na

9.2.4 Separation Factor Calculations

The mole fraction of cations transferred electrically through a cation membrane differs from the mole fraction of cations in the solution in contact with the membrane. This selectivity among ions of the same charge can be defined by a separation factor, α, as follows:

$$\alpha = \left(\frac{y}{1 - y}\right)\left(\frac{1 - x}{x}\right)$$

where,

x = mole fraction of particular ion in solution.

y = mole fraction of particular ion transferred.

In the cation decontamination of milk, the final ionic composition of the milk is determined by the separation factor for each cation and the cationic composition of the make-up stream. The separation factor for each cation passing from the make-up stream during a batch run was calculated as follows:

$$\alpha_{MU} = \frac{\ln \left[\left(\frac{C_i}{C_f}\right)\right]\left[\left(\frac{X_i}{X_f}\right)\right]}{\ln \left[\left(\frac{C_i}{C_f}\right)\left(\frac{1 - X_i}{1 - X_f}\right)\right]}$$

where,

C_i = Total initial moles in make-up stream.

C_f = Total final moles in make-up stream.

X_i = Initial mole fraction of ion in make-up stream.

X_f = Final mole fraction of ion in make-up stream.

The separation factor for each cation passing from the milk stream to the waste stream was calculated as follows:

$$\alpha_{MK} = \frac{\left(\frac{\Delta C}{\Delta C_T}\right)\left(\frac{1 - Xav}{Xav}\right)}{\left(1 - \frac{\Delta C}{\Delta C_T}\right)}$$

where,

Xav = The average mole fraction of ion in the milk stream during run.

ΔC = Moles of cation gained in waste stream during run.

ΔC_T = Total moles of all cations gained by waste stream during run.

Where a continuous make-up feed was used, steady state conditions were approached in which constant composition was approached for all three streams. In this case the proportions of the cations transferred through both cation membranes approached closely the proportion of cations in the make-up feed; therefore, the following equations were used to calculate α_{MU} and α_{MK}:

$$\alpha_{MU} = \left(\frac{Y_{MUF}}{1 - Y_{MUF}}\right)\left(\frac{1 - X_{MU}}{X_{MU}}\right)$$

$$\alpha_{MK} = \left(\frac{Y_{MUF}}{1 - Y_{MUF}}\right)\left(\frac{1 - X_{MK}}{X_{MK}}\right)$$

where,

Y_{MUF} = Mole fraction of ion in make-up feed solution.

X_{MU} = Mole fraction of ion in make-up stream.

X_{MK} = Mole fraction of ion in milk stream.

9.3 Tables of Basic Data

The following is a list of the tables included in this section:

(1) TABLE A-1 - EXPERIMENTAL DATA, CATION DECONTAMINATION

(2) TABLE A-2 - EXPERIMENTAL DATA, ANION DECONTAMINATION

(3) TABLE A-3 - EXPERIMENTAL DATA, ANION MEMBRANE POLARIZATION

(4) TABLE A-4 - RADIOACTIVITY COUNTING RESULTS

(5) TABLE A-5 - COMPOSITION OF MAKE-UP AND CONCENTRATED FEED MAKE-UP SOLUTIONS FOR DECONTAMINATION RUNS

TABLE A-1

EXPERIMENTAL DATA - CATION DECONTAMINATION

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 3

Stack Velocity: 40 cm/sec. Stack Amperage: 1.8 amps.

Stack Voltage: 20 volts Current Density: 30 ma/cm^2

Stream A - Simulated Milk Stream - 0.1N NaCl

Stream B - Simulated Make-Up Stream - 0.5 N NaCl

Stream C - Simulated Waste Stream - 0.1 N NaCl

Stream D - Electrode Stream - 0.2N NaCl

	STREAM A--MILK		STREAM B--MAKE-UP		STREAM C--WASTE	
	Initial	Final	Initial	Final	Initial	Final
pH	5.2	4.9	6.1	4.3	6.1	5.2
Temp. °F.	40	46	42	47	41	46
Resistivity, ohm-cm	132	125	30.5	47.0	91.8	51.2
Flow Rate, cc/min	850	850	1000	1000	760	760
Pressure, psig	10.75	10.75	10.50	10.50	10.25	10.25

Duration of Run: 1 Hour

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 4

Stream Velocity: 40 cm/sec

Stack Voltage: 16.5 volts

Stack Amperage: 1.8 amps

Current Density: 30 ma/cm^2

Voltage/5 Cell Units: 18 volts

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1336	0.1968	0.675	0.283	0.135	0.378
K^+ Ion, g/l	1.56	1.77	7.80	2.60	1.56	5.63
Ca^{++} Ion, g/l	1.17	1.86	6.11	2.40	1.22	2.40
Na^+ Ion, g/l	0.60	0.88	2.81	1.60	0.56	2.30
Mg^{++} Ion, g/l	0.11	0.25	0.61	0.33	0.12	0.22
Volume, liters	1.0	1.0	2.0	1.8	2.0	2.2
pH	5.4	5.2	6.0	3.4	6.0	4.0
Temp. ^oF.	45	45	45	44	44	42
Resistivity, ohm-cm	242	112	26.5	55.0	92.0	44.2
Flow Rate, cc/min.	850	850	900	1000	1200	1200
Pressure, psig	11.0	13.0	10.75	12.5	10.5	11.7

Duration of Run: 1.25 Hours

(Runs No. 5 and No. 6 were incomplete)

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 7

Stream Velocity: 40 cm/sec   Stack Amperage: 1.8 amps

Stack Voltage: 27 volts   Current Density: 30 ma/cm^2

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1316	0.1778	0.675	0.1623	0.135	0.5812
K^+ Ion, g/l	1.60	0.85	7.80	1.15	1.56	8.00
Ca^{++} Ion, g/l	1.18	2.20	6.11	1.20	1.22	4.65
Na^+ Ion, g/l	0.48	0.59	2.81	1.20	0.56	2.50
Mg^{++} Ion, g/l	0.10	0.25	0.61	0.25	0.12	0.38
Volume, liters	1.0	1.0	2.0	1.6	2.0	2.4
pH	5.4	5.4	5.2	6.0	5.7	6.0
Temp. ^{o}F.	53	50	52	50	51	52
Resistivity, ohm-cm	272	158	24.9	88.0	92.0	26.0
Flow Rate, cc/min	850	850	1300	1320	1320	1320
Pressure, psig	14.75	16.5	14.3	15.5	14.0	15.0

Duration of Run: 4 Hours

TABLE A-1
EXPERIMENTAL DATA
Cation Decontamination

Run # 8

Stream Velocity; 40 cm/sec
Stack Voltage: 23 volts

Stack Amperage: 1.8 amps.
Current Density: 30 ma/cm^2

Voltage/5 cell units: 24 volts

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1343	0.2134	0.629	0.1144	0.2102	0.5908
K^+ Ion, g/l	1.59	0.88	7.10	0.86	2.65	7.77
Ca^{++} Ion, g/l	1.17	2.60	5.42	0.76	1.63	4.70
Na^+ Ion, g/l	0.56	0.69	2.93	0.95	1.05	2.80
Mg^{++} Ion, g/l	0.12	0.36	0.62	0.16	0.19	0.41
Volume, Liters	1.0	1.0	2.0	1.6	2.0	2.4
pH	5.6	5.9	6.6	7.4	6.1	3.5
Temp. °F.	45	47	45	48	45	48
Resistivity, ohm-cm	270	160	30.0	128	75.0	25.5
Flow Rate, cc/min	850	760	1000	1150	1250	1400
Pressure, psig	11.5	17.0	10.75	14.25	10.2	14.25

Duration of Run: 4 Hours

Cation Membrane Current Efficiency = e = 0.77

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 9

Stream Velocity: 40 cm/sec — Stack Amperage: 1.8 amps — Voltage/5 cell units: 24 volts

Stack Voltage: 34.5 volts — Current Density: 30 ma/cm^2

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1268	0.1725	0.6754	0.4141	0.1341	0.3894
K^+ Ion, g/l	1.50	0.95	7.80	3.85	1.56	5.42
Ca^{++} Ion, g/l	1.20	2.12	6.11	3.63	1.22	3.03
Na^+ Ion, g/l	0.46	0.61	2.81	2.16	0.56	1.77
Mg^{++} Ion, g/l	0.10	0.19	0.61	0.49	0.12	0.27
Volume, liters	1.0	1.0	2.0	1.73	2.0	2.27
pH	5.3	5.4	6.1	6.0	6.1	3.0
Temp. $^{\circ}$F.	46	50	47	50	48	50
Resistivity, ohm-cm	283	205	25.0	37.0	91.0	36.0
Flow Rate, cc/min	850	850	1000	1100	1200	1400
Pressure, psig	12.5	17.5	12.0	14.75	11.5	15.0

Duration of Run: 2.66 Hours

Cation Membrane Current Efficiency = 0.70

TABLE A-1
EXPERIMENTAL DATA
Cation Decontamination

<u>Run # 10</u>

Stream Velocity: 40 cm/sec Stack Amperage: 1.8 amps

Stack Voltage: 35 volts Current Density: 30 ma/cm^2

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1305	0.1684	0.2389	0.6474	0.4157	0.1462	0.1396	0.3904	0.5647
K^+ Ion, g/l	1.59	1.13	0.68	7.40	3.00	0.83	1.55	6.17	7.65
Ca^{++} Ion, g/l	1.22	2.17	3.32	5.70	4.12	1.20	1.21	2.56	4.50
Na^+ Ion, g/l	0.48	0.43	0.44	2.98	2.00	1.00	0.71	2.03	2.82
Mg^{++} Ion, g/l	0.10	0.15	0.45	0.60	0.55	0.26	0.12	0.20	0.33
Volume, liters	1.0	1.0	1.0	2.0	1.8	1.6	2.0	2.2	2.4
pH	5.0	5.1	5.2	6.1	8.7	6.8	6.1	3.6	2.7
Temp. °F.	43	50	47	44	50	48	45	51	52
Resistivity, ohm-cm	260	205	150	28.0	38.5	91.0	106	36.0	27.0
Flow Rate, cc/min	850	850	850	1000	1120	1100	1100	1300	1300
Pressure, psig	12.5	17.5	17.5	12.0	15.25	14.75	11.5	14.75	15.0

Duration of Run: 4 Hours

Cation Membrane Current Efficiency = 0.80

TABLE A-1

EXPERIMENTAL DATA
Cation Decontamination

Run # 11

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1331	0.1068	0.0826	0.5726	0.4101	0.2110	0.1373	0.3142	0.4524
K^+ Ion, g/l	1.45	0.33	0.18	6.70	4.07	1.75	1.55	4.60	5.85
Ca^{++} Ion, g/l	1.21	1.49	1.13	4.90	3.55	1.80	1.14	2.43	3.75
Na^+ Ion, g/l	0.63	0.29	0.29	2.57	2.10	1.19	0.71	1.30	2.03
Mg^{++} Ion, g/l	0.10	0.14	0.11	0.55	0.46	0.30	0.12	0.23	0.33
Volume, liters	1.0	1.0	1.0	2.0	1.8	1.6	2.0	2.2	2.4
pH	6.5	6.5	6.4	5.5	6.5	5.0	5.3	5.2	3.5
Temp. °F.	62	42	51	63	52	55	61	54	57
Resistivity, ohm-cm	185	580	855	24.5	39.0	61.0	85.0	42.0	29.0
Flow Rate, cc/min	850	850	850	875	1000	1050	925	1250	1400
Pressure, psig	11.25	16.5	17.5	10.5	15.0	16.0	10.5	15.0	16.0

Stream Velocity: 40 cm/sec
Stack Voltage: 29-82 volts

Stack Amperage: 1.8 amps
Current Density: 30 ma/cm^2

Duration of Run: 4 Hours

Cation Membrane Current Efficiency: = 0.60

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 12

Stream Velocity: 40 cm/sec.
Stack Voltage: 73.5 volts

Stack Amperage: 3.6 amps.
Current Density: 60 ma/cm^2

Voltage Drop/5 Cell
Units: 58-67 volts

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	.1232	.3172	.6492	.0639	.1456	.5950
K^+ Ion, g/l	1.41	0.56	7.40	0.40	1.70	7.95
Ca^{++} Ion, g/l	1.24	2.55	5.85	0.50	1.19	4.85
Na^+ Ion, g/l	0.43	0.70	2.82	0.48	0.73	2.90
Mg^{++} Ion, g/l	0.08	0.20	0.55	0.09	0.13	0.40
Volume, liters	1.0	1.0	2.0	1.6	2.0	2.4
pH	5.2	5.3	6.0	6.1	5.9	5.25
Temp. ^{o}F.	46	47	44	46	48	47
Resistivity, ohm-cm	290	170	27.5	230	98	26.0
Flow Rate, cc/min	850	850	1100	1220	1250	1300
Pressure, psig	12.75	17.5	12.5	16.0	12.5	15.0

Duration of Run: 2 Hours

Cation Membrane Current Efficiency = .845

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 13

Stream Velocity: 40 cm/sec. Stack Amperage: 1.8 amps.

Stack Voltage: 40 volts Current Density: 30 ma/cm^2

	MILK*		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality			0.55	.42	0.18	0.33
K^+ Ion, g/l	0.81	0.75	6.13	4.07	3.00	5.13
Ca^{++} Ion, g/l			4.90	3.95	1.51	2.60
Na^+ Iôn, g/l	0.27	0.29	2.37	1.92	0.83	1.30
Mg^{++} Ion, g/l			0.50	0.40	0.12	0.20
Volume, liters	1.0	1.0	2.0	1.8	2.0	2.2
pH	5.2	5.4	6.0	5.7	6.0	3.2
Temp. $^{\circ}$F.	44	57	42	54	45	55
Resistivity, ohm-cm	270	210	30	37	115	42
Flow Rate, cc/min	850	690	1100	1080	1200	1300
Pressure, psig	13.5	17.5	13.0	14.5	12.0	15.5

Duration of Run: 2 Hours

* Some separation of milk occurred during this run due to souring.

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 14

Stream Velocity (initial): 40 cm/sec. Stack Amperage: 1.8 amps.

Stack Voltage: 38 volts Current Density: 30 ma/cm^2

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
pH	5.2	5.4	5.0	6.0	5.2	3.6
Temp. ^{o}F.	43	50	40	46	44	48
Resistivity, ohm-cm	290	190	27	75	210	90
Flow Rate, cc/min	850	190	930	1230	1270	1400
Pressure, psig	10.0	20.0	11.0	15.0	12.0	16.5

Duration of Run: 4 Hours

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 15,

Stream Velocity: 40 cm/sec.
Stack Voltage: 35 volts

Stack Current: 1.8 amps
Current Density: 30 ma/cm^2

Voltage/Cell Trio: 4.8 volts
No. of Cell Units: 5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1342	0.1734	0.1965	0.151	0.172	0.310	0.159	0.100	0.182
Cl^- g/l.	0.95	2.26	2.87	5.37	6.10	10.70	5.65	3.53	5.98
K^+ Ion, g/l.	1.58	1.55	2.18	2.37	2.45	4.65	2.00	2.33	3.40
Ca^{++} Ion, g/l.	1.24	1.85	1.85	0.84	0.75	1.55	1.43	0.81	0.82
Na^+ Ion, g/l.	0.58	0.72	0.84	1.36	1.59	2.42	0.76	0.78	1.05
Mg^{++} Ion, g/l.	0.08	0.12	0.14	0.125	0.118	0.193	0.148	0.035	0.06
Volume, liters	1.0	1.0	1.0	-	-	-	-	-	-
pH	5.2	5.5	5.7	6.0	5.3	5.9	6.0	3.6	4.2
Temp. $^\circ$ F.	43	46	49	41	43	45	43	44	46
Resistivity, ohm-cm	270	210	160	85	80	47	110	110	110
Flow Rate, cc/min.	850	850	850	1100	1220	1220	900	1030	1000

Duration of Run = 4 Hours

Contaminants: Cs^{137} - 4.71 μc/liter
Ce^{139} - 9.95 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 16.

Stream Velocity: 40 cm/sec. Stack Current: 1.8 amps Voltage/Cell Trio: 4.2 volts

Stack Voltage: 28 volts Current Density: 30 ma/cm^2 No. of Cell Units: 5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	-	-	-	0.6448	0.5996	0.6628	0.0872	0.1796	0.2935
Cl^- g/l.	1.05	3.28	4.80	-	-	-	-	-	-
K^+ Ion, g/l.	1.56	2.01	2.50	9.50	9.00	9.00	0.93	3.40	8.25
Ca^{++} Ion, g/l.	1.23	1.71	2.05	2.82	2.39	3.40	0.78	0.69	0.66
Na^+ Ion, g/l.	0.53	0.94	0.89	5.35	5.11	5.23	0.35	1.12	1.12
Mg^{++} Ion, g/l.	-	-	-	0.336	0.346	0.433	0.087	0.107	0.008
Volume, liters	1.0	1.0	1.0	-	-	-	-	-	-
pH	5.3	5.1	5.3	4.6	4.1	4.1	4.6	3.2	2.9
Temp. °F.	50	54	48	40	50	41	43	53	44
Resistivity, ohm-cm	250	134	113	27	29	25	230	135	128
Flow Rate, cc/min.	850	850	850	980	1100	1200	1150	1050	1100

Duration of Run = 4 Hours

Contaminants: Sr^{85} - 3.06 uc/liter
Cs^{137} - 4.0 uc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 17.

Stream Velocity: 40 cm/sec.
Stack Voltage: 33 volts

Stack Current 2.8 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 4.8 volts
No. of Cell Units: 5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1257	0.1940	0.2248	0.6323	0.6318	0.5579	0.0994	0.1424	0.1419
Cl^- g/l.	1.02	3.24	4.11	-	-	-	-	-	-
K^+ Ion, g/l.	1.42	2.40	2.66	10.0	7.3	12.6	1.18	3.07	2.93
Ca^{++} Ion, g/l.	1.17	1.46	1.84	2.80	3.26	3.37	0.80	0.48	0.406
Na^+ Ion, g/l.	.550	1.21	1.32	4.80	5.33	1.32	0.51	0.85	1.03
Mg^{++} Ion, g/l.	.085	.085	.090	0.33	0.59	0.09	0.086	0.034	0.022
Volume, liters	1.0	1.0	1.0	-	-	-	-	-	-
pH	5.4	5.1	5.3	4.7	10.7	10.5	4.3	3.0	2.7
Temp. °F.	47	50	52	42	47	57	43	50	58
Resistivity, ohm-cm	285	142	106	27	25	24	148	88	76
Flow Rate, cc/min.	850	850	850	1150	1150	1150	1270	1270	1270

Duration of Run = 160 Minutes

Contaminants: Sr^{85} - 2.90 μc/liter
Cs^{137} - 4.17 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 18,

Stream Velocity:	40 cm/sec.	Stack Current	2.5 amps	Voltage/Cell Trio:	9.0-16.4 v.
Stack Voltage:	54.0 - 90.0 volts	Current Velocity:	30 ma/cm^2	No. of Cell Units:	5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1243	0.0867	0.0728	0.299	0.1477	0.2316	0.0881	0.1295	0.1043
Cl^- g/l.	1.13	0.28	0.20	-	-	-	-	-	-
K^+ Ion, g/l.	1.48	0.52	0.42	4.52	2.00	3.60	0.94	2.18	2.00
Ca^{++} Ion, g/l.	1.06	1.11	1.03	1.29	0.535	0.91	0.796	0.725	0.51
Na^+ Ion, g/l.	0.58	0.26	0.15	2.46	1.44	1.94	0.42	0.75	0.59
Mg^{++} Ion, g/l.	0.10	0.08	0.05	0.133	0.086	0.111	0.073	0.058	0.024
Volume, liters	1.0	1.0	1.0	-	-	-	-	-	-
pH	6.7	6.0	6.6	2.2	2.9	2.7	4.3	2.4	2.3
Temp. $^\circ$ F.	42	51	62	40	43	44	40	45	49
Resistivity, ohm-cm	305	590	695	90	68	48	240	140	140
Flow Rate, cc/min.	850	520	420	1100	1100	1080	1250	1250	1200

Duration of Run = 160 Minutes

Contaminants: Sr^{85} - 3.77 μc/liter
Cs^{137} - 3.78 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 19.

Stream Velocity: 40 cm/sec.
Stack Voltage: 43-88 volts

Stack Current: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 6.6-15.8 v.
No. of Cell Units: 5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1190	0.0830	0.0832	0.1446	0.1637	0.2168	0.0794	0.1140	0.1023
Cl^- g/l.	1.07	0.227	0.141	-	-	-	-	-	-
K^+ Ion, g/l.	1.33	0.49	0.59	2.10	2.50	3.30	0.93	2.04	1.88
Ca^{++} Ion, g/l.	0.97	0.97	1.00	0.561	0.665	0.848	0.696	0.557	0.470
Na^+ Ion, g/l.	0.66	0.32	0.27	1.30	1.40	1.90	0.40	0.68	0.58
Mg^+ Ion, g/l.	0.094	0.10	0.078	0.070	0.068	0.090	0.041	0.053	0.065
Volume, liters	1.0	1.0	1.0	-	-	-	-	-	-
pH	5.4	5.4	5.4	2.4	4.0	3.5	4.8	2.4	2.4
Temp. °F.	48	55	56	40	42	42	42	48	44
Resistivity, ohm-cm	270	490	585	88	88	65	250	150	150
Flow Rate, cc/min.	850	570	550	1040	1080	1080	1300	1350	1370

Duration of Run = 160 Minutes

Contaminants: Sr^{85} - 3.21 μc/liter
Cs^{137} - 3.77 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 20,

Stream Velocity: 40 cm/sec.
Stack Voltage: 29 volts

Stack Current: 1.8 amps
Current Density: 30 ma/cm^2

Voltage/Cell Trio: 5.5 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1198	-	0.2072	0.1906	0.1727	0.1422	0.0846	0.0992	0.1280
Cl^- g/l.	-	-	-	-	-	-	-	-	-
K^+ Ion, g/l.	1.42	-	1.91	3.88	2.28	1.85	0.99	1.75	2.32
Ca^{++} Ion, g/l.	1.05	-	1.93	0.543	0.609	0.470	0.702	0.450	0.632
Na^+ Ion, g/l.	0.56	-	1.12	1.31	1.77	1.50	0.42	0.66	0.74
Mg^+ Ion, g/l.	0.08	-	0.16	0.094	0.085	0.075	0.073	0.039	0.058
Volume, liters	1.0	1.0	0.96	-	-	-	-	-	-
pH	5.1	5.1	5.1	4.7	5.7	5.9	4.3	3.3	3.3
Temp. °F.	46	50	46	39	43	42	42	44	43
Resistivity, ohm-cm	290	210	165	110	100	88	235	150	210
Flow Rate, cc/min.	800	650	650	900	880	880	1180	1240	1240

Duration of Run = 4 Hours

Contaminants: Sr^{85} - 3.19 μc/liter
Cs^{137} - 3.71 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 21.

Stream Velocity: 40 cm/sec.
Stack Voltage: 34 volts

Stack Current: 2.5 amps
Current Density: 4.5 ma/cm^2

Voltage/Cell Trio: 6.5 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1247	0.1870	0.2396	0.1339	0.1650	0.1494	0.0755	0.0943	0.1534
Cl^- g/l	1.29	2.76	4.37	-	-	-	-	-	-
K^+ Ion, g/l	1.55	2.40	2.42	1.88	1.88	1.50	1.28	2.02	3.00
Ca^{++} Ion, g/l	1.09	1.60	2.22	0.60	1.06	0.99	0.386	0.311	0.640
Na^+ Ion, g/l	0.52	0.86	1.41	1.14	1.20	1.15	0.47	0.58	0.96
Mg^{++} Ion, g/l	0.095	0.099	0.065	0.075	0.143	0.139	0.036	0.022	0.036
Volume, liters	1.0	-	0.90	-	-	-	-	-	-
pH	5.30	5.20	5.18	3.8	5.0	4.9	3.9	3.0	2.8
Temp. °F	50	53	55	44	43	43	47	45	44
Resistivity, ohm-cm	260	153	116	103	90	103	220	185	120
Flow Rate, cc/min.	790	600	600	850	860	820	1200	1200	1210

Duration of Run = 160 min.

Contaminants: Sr^{85} - 3.32 c/liter
Cs^{137} - 4.25 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 22.

Stream Velovity:	40 cm/sec.	Stack Current:	2.5 amps	Voltage/Cell Trio:	7.9-13.7 volts
Stack Voltage:	40 - 62 volts	Current Density:	45 ma/cm^2	No. of Cell Units:	4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1255	0.1291	0.1203	0.0544	0.1562	0.1181	0.0788	0.1641	0.1030
Cl^- g/l	1.19	0.85	0.71	-	-	-	-	-	-
K^+ Ion, g/l	1.60	1.12	0.90	2.50	1.85	0.88	1.33	3.19	1.96
Ca^{++} Ion, g/l	1.14	1.29	1.29	0.605	0.960	0.991	0.410	0.558	0.354
Na^+ Ion, g/l	0.48	0.58	0.55	1.23	1.17	0.80	0.50	1.24	0.75
Mg^{++} Ion, g/l	0.085	0.093	0.107	0.075	0.121	0.136	0.031	0.039	0.031
Volume, liters	1.0	-	1.12	-	-	-	-	-	-
pH	5.4	5.2	5.3	4.6	4.3	3.9	4.3	2.5	2.5
Temp. °F.	48	51	45	39	41	41	43	43	44
Resistivity, ohm-cm.	280	305	330	110	100	115	220	120	165
Flow Rate, cc/min.	850	750	780	-	-	-	-	-	-

Duration of Run = 160 min.

Contaminants: Sr^{85} - 3.53 c/liter
Cs^{137} - 4.63 c/liter

TABLE A-I

EXPERIMENTAL DATA

Cation Decontamination

RUN # 23.

Stream Velocity: 40 cm/sec.
Stack Voltage: 35 volts

Stack Current: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 7.5 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	intermed.	Final	initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1255	0.1309	0.1259	0.1558	0.1447	0.1624	0.0829	0.1136	0.1005
Cl^- g/l	1.08	0.71	0.65	-	-	-	-	-	-
K^+ Ion, g/l	1.55	0.75	0.83	2.25	2.32	2.71	1.50	2.03	1.90
Ca^{++} Ion, g/l	1.15	1.53	1.39	0.673	0.462	0.574	0.382	0.569	0.454
Na^+ Ion, g/l	0.46	0.43	0.41	1.34	1.31	1.35	0.51	0.70	0.62
Mg^{++} Ion, g/l	0.10	0.20	0.21	0.076	0.063	0.068	0.039	0.031	0.027
Volume, liters	1.0	-	1.11	-	-	-	-	-	-
pH	5.3	5.5	5.4	3.8	4.4	3.9	3.5	2.5	2.4
Temp. °F.	97	100	90	95	95	95	96	98	95
Resistivity, ohm-cm	178	227	242	47	50	48	120	90	90
Flow Rate, cc/min.	800	800	800	690	1070	680	1100	1050	1000

Duration of Run: = 158 min.

Contaminants: Sr^{85} - 3.10 c/liter
Cs^{137} - 4.31 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 24,

Stream Velocity: 40 cm.sec.
Stack Voltage: 74-89 volts

Stack Current: 2.5 - 2.0 amps
Current Density: 45 - 35 ma/cm^2

Voltage/Cell Trio: 16.5 - 20 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1250	0.0940	0.0813						
Cl^- g/l.	1.09	0.360	0.17						
K^+ g/l.	1.50	0.64	0.41						
Ca Ion, g/l	1.15	1.13	1.07	(No analysis)			(No analysis)		
Na^+ Ion, g/l.	0.49	0.34	0.29						
Mg^{++} Ion, g/l.	0.094	0.076	0.057						
Volume liters	1.0	-	1.03						
pH	5.3	5.2	5.4	4.6	3.9	3.6	3.9	2.7	2,3
Temp ^oF.	44	52	51	44	44	44	44	47	46
Resistivity, ohm-cm	283	420	485	100	95	100	225	195	180
Flow Rate, cc/min.	750	560	520	670	710	710	1050	1010	1010

Duration of Run = 140 min.

Contaminants: Sr^{85} - 3.46 c/liter
Cs^{137} - 3.85 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 25,

Stream Velocity: 40 cm/sec.
Stack Voltage: 70 volts

Stack Current: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 15.5 v.
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Fianl	Initial	Intermed.	Final
Normality	0.1277	0.1545	-	0.1472	0.1408	0.1316	0.0844	0.0969	0.1143
Cl^- g/l.	1.09	1.70	2.01	-	-	-	-	-	-
K^+ Ion, g/l.	1.55	1.28	-	2.10	2.19	1.97	1.56	1.87	2.22
Ca^{++} Ion, g/l.	1.15	1.62	-	0.574	0.542	0.494	0.389	0.418	0.490
Na^+ Ion, g/l.	0.65	0.51	-	1.32	1.21	1.19	0.52	0.58	0.68
Mg^{++} Ion, g/l	0.10	0.15	-	0.090	0.060	0.058	0.029	0.036	0.039
Volume, liters	1.0	-	1.09	-	-	-	-	-	-
pH	5.6	5.5	5.6	5.2	4.2	3.9	4.2	2.6	2.6
Temp. ^oF	46	50	52	47	45	44	44	48	47
Resistivity, ohm-cm	290	222	196	100	109	102	250	180	165
Flow Rate, cc/min.	770	660	670	680	700	700	1040	1100	1100

Duration of Run = 160 min.

Contaminants: Sr^{85} - 2.96 c/liter
Cs^{139} - 4.43 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 26.

Stream Velocity: 40 cm/sec.
Stack Voltage: 41 volts

Stack Current: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 8.5 v.
No. of Cell Units: 4

	MILK			MAKE-UP			WASTER		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1322	0.1261	0.1317	0.1055	0.0768	0.1080	0.0869	0.1230	0.1035
Cl^- g/l.	1.13	1.02	1.05	-	-	-	-	-	-
K^+ Ion, g/l.	1.66	1.02	1.09	1.37	1.00	1.62	1.67	2.30	2.44
Ca^{++} Ion, g/l.	1.15	1.34	1.40	0.418	0.342	0.437	0.382	0.525	0.581
Na^+ Ion, g/l.	0.55	0.55	0.53	0.99	0.71	0.94	0.53	0.79	0.19
Mg^{++} Ion, g/l.	0.10	0.12	0.13	0.079	0.039	0.046	0.036	0.041	0.044
Volume, liters	1.0	-	0.98	-	-	-	-	-	-
pH	5.37	5.6	5.3	4.0	5.0	5.0	4.3	3.1	2.8
Temp. ^oF	55	58	53	50	52	50	52	54	51
Resistivity, ohm-cm	255	282	300	128	140	128	200	145	135
Flow Rate, cc/min	850	850	810	670	710	700	1010	1030	1060

Duration of Run = 160 min.

Contaminants: Sr^{85} - 3.40 c/liter
Cs^{137} - 4.20 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN 27.

Stream Velocity: 40 cm/sec.
Stack Voltage: 38 volts

Stack Current: 2.5 amps
Current Density: 30 ma/cm^2

Voltage/Cell Trio: 7.5 v.
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1322	0.1589	0.1638	0.1111	0.0884	0.1158	0.0844	0.1329	0.1309
Cl^- g/l	1.16	1.48	1.77	-	-	-	-	-	-
K^+ Ion, g/l.	1.60	1.74	1.39	1.58	1.00	1.58	1.55	2.25	2.40
Ca^{++} Ion, g/l.	1.19	1.57	1.75	0.470	0.398	0.509	0.386	0.506	0.569
Na^+ Ion, g/l.	0.52	0.59	0.65	1.00	0.90	1.04	0.53	1.06	0.85
Mg^{++} Ion, g/l.	0.11	0.14	0.15	0.044	0.046	0.056	0.029	0.046	0.049
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.45	5.4	5.6	5.3	4.6	3.9	5.0	2.8	2.4
Temp. °F.	47	52	51	49	46	46	46	48	48
Resistivity, ohm-cm	293	250	225	130	140	112	228	160	140
Flow Rate, cc/min	800	770	680	730	770	770	1070	1100	1110

Duration of Run = 160 min.

Contaminants: B_2^{140} - 4.68 c/liter
L_2^{140} - 4.68 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 28.

Stream Velocity: 40 cm/sec.
Stack Voltage: 77 - 88 volts

Stack Current: 3.33 -.2.88 amps
Current Density: 60 - 52 ma/cm^2

Voltage/Cell Trio: 16.8-19.5 v.
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1310	0.1364	0.1478	0.1376	0.1386	0.1512	0.0886	0.1208	0.0716
Cl^- g/l.	1.16	1.19	1.30	-	-	-	-	-	-
K^+ Ion, g/l.	1.63	1.18	1.19	1.90	1.88	2.25	1.62	2.25	1.31
Ca^{++} Ion, g/l.	1.12	1.38	1.55	0.601	0.612	0.632	0.406	0.490	0.310
Na^+ Ion, g/l.	0.55	0.59	0.63	1.23	1.25	1.29	0.57	0.81	0.47
Mg^{++} Ion, g/l.	0.11	0.14	0.15	0.065	0.068	0.073	0.036	0.044	0.027
Volume, liters	1.0	-	1.16	-	-	-	-	-	-
pH	5.0	5.3	5.0	4.2	4.6	6.0	4.3	2.7	2.5
Temp. °F.	50	50	49	42	44	44	43	50	46
Resistivity, ohm-cm	305	265	265	102	102	100	215	140	225
Flow Rate, cc/min	890	820	710	700	700	710	1090	1070	1060

Duration of Run = 120 min.

Contaminants: Sr^{85} - 2.90 c/liter
Cs^{137} - 4.40 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 29.

Stream Velocity:	40 cm/sec.	Stack Current:	2.5 amps	Voltage/Cell Trio:	7.0 v.
Stack Voltage:	36 volts	Current Density:	45 ma/cm2	No. of Cell Units:	4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1292	0.1683	0.1771	0.0953	0.0970	0.0969	0.0831	0.1028	0.1093
Cl^- g/l.	1.21	1.92	2.35	-	-	-	-	-	-
K^+ Ion, g/l.	1.58	1.55	2.18	2.37	2.45	4.65	2.00	2.33	3.40
Ca^{++} Ion, g/l.	1.24	1.85	1.85	0.84	0.75	1.55	1.43	0.81	0.82
Na^+ Ion, g/l.	0.52	0.71	0.83	0.85	0.83	0.76	0.53	0.67	0.72
Mg^{++} Ion, g/l.	0.10	0.16	0.17	0.041	0.059	0.060	0.034	0.041	0.039
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.25	5.1	5.1	4.2	4.9	3.8	4.2	2.9	2.6
Temp. °F.	49	49	50	46	44	50	49	46	53
Resistivity, ohm-cm	275	215	188	140	140	130	222	190	140
Flow Rate cc/min	850	880	700	750	740	730	1080	1060	1080

Duration of Run: = 160 min.

Contaminants: B^{140} - 5.76 c/liter

L^{140} - 6,30 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

RUN # 30

Stream Velocity: 40 cm/sec. Stack Current: 2.5 amps Voltage/Cell Trio: 6.5 v.

Stack Voltage: 34 volts Current Density: 45 ma/cm^2 No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1291	0.1603	0.1905	0.0946	0.0893	0.1378	0.0851	0.1179	0.0995
Cl^- g/l.	1.13	2.08	2.75	-	-	-	-	-	-
K^+ Ion, g/l.	1.65	1.46	1.70	1.25	1.00	1.87	1.60	2.34	1.55
Ca^{++} Ion, g/l.	1.13	1.60	1.86	0.422	0.525	0.629	0.386	0.465	0.446
Na^+ Ion, g/l.	0.49	0.71	0,88	0.85	0.74	0.73	0.52	0.73	0.79
Mg^{++} Ion, g/l.	0.10	0.15	0.19	0.054	0.063	0.082	0.027	0.036	0.036
Volume, liters	1.0	-	1.04	-	-	-	-	-	-
pH	5.2	5.1	5.3	3.9	4.3	4.2	3.8	2.7	2.6
Temp. °F.	50	52	60	48	48	54	51	50	56
Resistivity, ohm-cm	275	190	160	135	140	115	210	150	140
Flow Rate, cc/min	900	840	760	700	720	700	1060	1050	1070

Duration of Run = 160 min.

Contaminants: Sr^{85} - 2.62 c/liter
C^{137} - 4.09 c/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #56

Stream Velocity: 40 cm/sec.
Stack Voltage: 66 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 14.0
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1309	0.1302	0.1337	0.1416	0.1109	0.1159	0.0912	0.0838	0.0877
Cl^-, g/l	1.11	-	1.51	-	-	-	-	-	-
K^+, g/l	1.63	0.94	1.29	0.850	2.00	2.35	2.00	1.37	1.75
Ca^{++}, g/l	1.16	1.62	1.40	1.73	0.462	0.382	0.370	0.637	0.494
Na^+, g/l	0.52	0.29	0.42	0.535	0.74	0.83	0.43	0.30	0.35
Mg^{++}, g/l	0.104	0.153	0.150	0.123	0.053	0.039	0.034	0.044	0.036
Volume, liters	1.0	-	1.18	-	-	-	-	-	-
pH	5.3	5.2	5.3	6.0	3.2	3.1	5.7	2.5	2.5
Temp. $^\circ$F	51	60	58	52	53	52	52	58	56
Resistivity, ohm-cm	270	240	230	96	100	105	180	180	160
Flow Rate, cc/min.	910	890	810	1190	1100	1100	1040	1050	1050

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 300 ml.

Contaminants: Sr^{85}- 3.96 μc/liter
Cs^{137}- 4.75 μc/liter

TABLE A-1
EXPERIMENTAL DATA

Cation Decontamination

Run #57

Stream Velocity: 40 cm/sec.
Stack Voltage: 69 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 14.7 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1274	0.1426	0.1450	0.1433	0.1394	0.1299	0.0822	0.0821	0.1207
Cl^- g/l	1.11	-	1.97	-	-	-	-	-	-
K^+, g/l	1.60	1.04	1.49	0.81	2.50	2.50	1.75	1.24	2.25
Ca^{++}, g/l	1.16	1.78	1.60	1.75	0.648	0.442	0.350	0.648	0.442
Na^{++}, g/l	0.47	0.32	0.34	0.56	0.86	0.91	0.40	0.34	0.84
Mg^{++} g/l	0.098	0.156	0.146	0.130	0.068	0.051	0.030	0.039	0.053
Volume, liters	1.0	-	1.16	-	-	-	-	-	-
pH	5.2	5.3	5.4	4.0	3.1	3.0	3.6	2.5	2.4
Temp. ^oF	51	55	50	51	50	47	53	54	50
Resistivity, ohm-cm	250	218	195	96	92	100	190	175	172
Flow Rate, cc/min.	920	830	770	1210	1200	1200	1100	1090	1080

Duration of Run: 160 min.

Volume of 2.5N Salt Solution Used: 305 ml.

Contaminants: Sr^{85} - 4.34 μc/liter
Cs^{137} - 5.19 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #58

Stream Velocity: 40 cm/sec.
Stack Voltage: 54 Volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 11.0 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1252	0.1219	0.1255	0.1375	0.1251	0.1568	0.0937	0.1048	0.1526
Cl^-, g/l	1.15	-	0.675	-	-	-	-	-	-
K^+, g/l	1.50	0.87	1.14	0.75	2.08	3.10	2.00	2.12	3.00
Ca^{++} g/l	1.17	1.49	1.37	1.71	0.648	0.561	0.374	0.725	0.855
Na^+, g/l	0.46	0.28	0.35	0.52	0.78	1.02	0.49	0.46	0.64
Mg^{++} g/l	0.100	0.133	0.143	0.136	0.068	0.061	0.031	0.051	0.063
Volume, liters	1.0	-	1.18	-	-	-	-	-	-
pH	5.2	5.5	5.4	3.7	5.2	3.6	4.6	2.4	2.1
Temp. ^oF	56	59	55	54	54	54	55	56	54
Resistivity, ohm-cm	257	308	325	92	98	84	178	142	105
Flow Rate, cc/min.	890	850	790	1250	1250	1200	1120	1100	1100

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 360 ml.

Contaminants: Sr^{85} - 3.33 μc/liter
Cs^{137} - 4.31 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run # 59

Stream Velocity: 40 cm/sec.
Stack Voltage: 54 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 11.0 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1288	0.1624	0.1816	0.1450	0.1535	0.1407	0.0825	0.0968	0.1375
Cl^-, g/l	1.11	-	3.01	-	-	-	-	-	-
K^+, g/l	1.62	1.28	1.77	0.77	2.77	2.77	1.75	1.62	2.75
Ca^{++}, g/l	1.17	2.02	2.01	1.82	0.729	0.490	0.362	0.685	0.80
Na^+ g/l	0.47	0.40	0.53	0.55	0.92	0.94	0.39	0.35	0.51
Mg^{++}, g/l	0.103	0.133	0.148	0.126	0.073	0.053	0.032	0.070	0.058
Volume, liters	1.0	-	1.21	-	-	-	-	-	-
pH	5.5	5.3	5.2	3.9	5.9	5.7	4.3	2.5	2.3
Temp. $^{\circ}$F	53	58	55	48	53	51	53	57	54
Resistivity, ohm-cm	265	175	148	98	88	92	180	159	115
Flow Rate cc/min.	920	830	800	1250	1210	1200	1120	1110	1140

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 300 ml

Contaminants: Sr^{85} - 3.75 μc/liter
Cs^{137} - 3.78 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #62

Stream Velocity: 40 cm/sec.
Stack Voltage: 75 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 16.0 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1272	0.1424	0.1477	0.1564	0.1240	0.1437	0.0853	0.0897	0.1026
Cl^-, g/l	1.07	-	2.21	-	-	-	-	-	-
K^+, g/l	1.56	1.08	1.39	0.81	2.01	2.65	1.75	1.38	1.88
Ca^{++}, g/l	1.22	1.83	1.67	1.93	0.703	0.565	0.417	0.716	0.662
Na^+, g/l	0.49	0.34	0.46	0.53	0.70	0.89	0.38	0.33	0.41
Mg^{++}, g/l	0.107	0.136	0.148	0.196	0.082	0.107	0.038	0.052	0.043
Volume, liters	1.0	-	1.16	-	-	-	-	-	-
pH	5.1	5.2	5.2	4.4	4.1	3.5	5.3	2.6	2.5
Temp. ^oF	54	59	54	51	52	51	55	56	53
Resistivity, ohm-cm	259	217	209	100	102	87	205	155	148
Flow Rate, cc/min.	840	730	700	940	950	900	1080	1080	1100

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 340 ml

Contaminants: Sr^{85} - 3.52 μc/liter

Cs^{137} - 4.56 μc/liter

TABLE A-1
EXPERIMENTAL DATA
Cation Decontamination

Run #63

Stream Velocity: 40 cm/sec.
Stack Voltage: 45 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 8.7
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1212	0.1251	0.1361	0.1391	0.1390	0.1458	0.0811	0.0869	0.1043
Cl^-, g/l	1.10	-	1.13	-	-	-	-	-	-
K^+, g/l	1.46	1.18	1.39	2.70	2.60	2.70	1.75	1.90	2.35
Ca^{++}, g/l	1.12	1.32	1.37	0.464	0.458	0.602	0.364	0.376	0.375
Na^{++}, g/l	0.45	0.42	0.47	0.97	0.94	0.95	0.35	0.40	0.53
Mg^{++}, g/l	0.101	0.140	0.142	0.058	0.045	0.065	0.035	0.025	0.028
Volume, liters	1.0	-	1.19	-	-	-	-	-	-
pH	5.3	5.3	5.3	4.5	4.9	3.7	4.3	2.6	2.4
Temp.^{o}F	59	58	55	57	53	52	57	57	55
Resistivity,ohm-cm	240	250	243	82	85	85	180	152	135
Flow Rate,cc/min.	920	820	720	1180	1140	1140	1140	1120	1100

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 377 ml

Contaminants: Sr^{85} - 3.39 μc/liter
Cs^{137} - 4.73 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #64

Stream Velocity: 40 cm/sec.
Stack Voltage: 33 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 5.8
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1247	0.1357	0.1472	0.1014	0.0998	0.1128	0.0716	0.1001	0.1154
Cl^-, g/l	1.14	-	1.42	-	-	-	-	-	-
K^+, g/l	1.55	1.08	1.21	1.45	1.40	1.65	1.13	1.68	2.00
Ca^{++}, g/l	1.14	1.44	1.55	0.427	0.424	0.472	0.385	0.501	0.545
Na^+, g/l	0.46	0.58	0.62	0.88	0.89	0.98	0.46	0.65	0.76
Mg^{++}, g/l	0.098	0.132	0.142	0.057	0.049	0.053	0.035	0.045	0.046
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.2	5.4	5.2	3.8	5.5	4.5	3.7	2.8	2.6
Temp. ^oF	55	55	56	51	51	51	53	53	53
Resistivity, ohm-cm	255	253	233	123	118	115	210	159	142
Flow Rate, cc/min	690	730	650	1330	1300	1300	1170	1140	1200

Duration of Run: 160 min.

Volume of 2.5 N salt solution used: 385 ml

Contaminants: Sr^{85} - 3.30 μc/liter
Cs^{137} - 4.74 μc/liter

TABLE A-I

EXPERIMENTAL DATA
Cation Decontamination

Run #65

Stream Velocity: 40 cm/sec.
Stack Voltage: 32 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 5.5 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1269	0.1541	0.1672	0.0967	0.0901	0.1020	0.0709	0.1175	0.1039
Cl^-, g/l	1.11	-	2.05	-	-	-	-	-	-
K^+, g/l	1.59	1.28	1.42	1.40	1.25	1.45	1.12	1.87	1.87
Ca^{++}, g/l	1.14	1.62	1.74	0.416	0.385	0.465	0.392	0.486	0.465
Na^+, g/l	0.48	0.64	0.72	0.82	0.80	0.86	0.46	0.96	0.58
Mg^{++}, g/l	0.101	0.151	0.151	0.053	0.048	0.051	0.032	0.044	0.037
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.2	5.3	5.1	4.0	5.7	4.2	3.8	2.6	2.5
Temp. ^oF	56	56	56	52	53	51	52	55	54
Resistivity, ohm-cm	253	208	178	125	138	125	210	128	150
Flow Rate, cc/min	850	770	750	1290	1280	1260	1140	1100	1120

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 375 ml

Contaminants: Sr^{85} - 3.62 μc/liter
Cs^{137} - 5.33 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #66

Stream Velocity: 40 cm/sec.
Stack Velocity: 31 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 5.3 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1281	0.1541	0.1627	0.0996	0.0953	0.1205	0.0740	0.1039	0.1496
Cl^-, g/l	1.11	-	2.26	-	-	-	-	-	-
K^+, g/l	1.66	1.28	1.46	1.46	1.35	1.61	1.12	1.75	2.62
Ca^{++}, g/l	1.12	1.63	1.64	0.423	0.420	0.493	0.385	0.472	0.70
Na^+, g/l	0.49	0.64	0.70	0.84	0.82	0.91	0.54	0.73	1.00
Mg^{++}, g/l	0.101	0.151	0.159	0.054	0.05	0.06	0.03	0.04	0.049
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.3	5.2	5.2	5.3	5.2	5.2	3.8	2.5	2.4
Temp. ^oF	54	52	55	53	50	51	55	52	54
Resistivity, ohm-cm	259	222	183	125	128	120	210	168	110
Flow Rate, cc/min	870	880	850	1310	1260	1240	1140	1110	1110

Duration of Run: 60 min.

Volume of 2.5 N Salt Solution Used: 381 ml

Contaminants: Sr^{85} - 4.30 μc/liter
Cs^{137} - 4.69 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #67

Stream Velocity: 40 cm/sec
Stack Voltage: 54 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 11.0 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1253	0.1236	0.1243	0.1480	0.1552	0.1539	0.0845	0.0772	0.1073
Cl^-, g/l	1.13	-	0.80	-	-	-	-	-	-
K^+, g/l	1.55	1.19	1.22	2.77	3.07	3.00	1.75	1.75	2.28
Ca^{++}, g/l	1.14	1.28	1.29	0.50	0.462	0.455	0.374	0.211	0.406
Na^+, g/l	0.48	0.41	0.41	1.08	1.14	1.14	0.43	0.45	0.60
Mg^{++}, g/l	0.095	0.137	0.135	0.062	0.049	0.045	0.028	0.027	0.032
Volume, liters	1.0	-	1.16	-	-	-	-	-	-
pH	5.4	5.3	5.3	5.8	7.1	5.8	5.6	2.6	2.3
Temp. $^{\circ}$F	57	57	54	52	54	51	54	57	54
Resistivity, ohm-cm	242	268	307	82	80	83	180	152	135
Flow Rate, cc/min	870	920	850	1210	1200	1160	1120	1110	1130

Duration of Run: 160 minutes

Volume of 2.5 N Salt Solution Used: 350 ml

Contaminants: Sr^{85} - 4.12 μc/liter
Cs^{137} - 5.05 μc/liter

TABLE A-1
EXPERIMENTAL DATA
Cation Decontamination

Run #68

Stream Velocity: 40 cm/sec. | Stack Amperage: 2.5 amps | Voltage/Cell Trio: 12.0 Volts
Stack Voltage: 58 volts | Current Density: 45 ma/cm^2 | No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1271	0.1264	0.1273	0.1426	0.1323	0.1446	0.0925	0.0972	0.1017
Cl^-, g/l	1.09	-	0.74	-	-	-	-	-	-
K^+, g/l	1.58	1.18	1.20	2.70	2.60	2.95	2.00	2.00	2.12
Ca^{++}, g/l	1.15	1.35	1.35	0.510	0.385	0.423	0.374	0.420	0.410
Na^+, g/l	0.48	0.40	0.40	1.01	0.985	1.02	0.475	0.515	0.562
Mg^{++}, g/l	0.100	0.137	0.142	0.051	0.045	0.042	0.025	0.033	0.030
Volume, liters	1.0	-	1.22	-	-	-	-	-	-
pH	5.2	5.3	5.2	5.5	3.8	3.5	5.4	2.5	2.4
Temp. °F	59	62	63	55	56	59	57	59	61
Resistivity, ohm-cm	241	272	278	89	92	81	178	140	125
Flow Rate, cc/min	810	860	850	1110	1070	1050	1110	1100	1100

Duration of Run: 160 min.

Volume of 2.5 N Salt Solution Used: 348 ml

Contaminants: Sr^{85} - 3.78 μc/liter
Cs^{137} - 4.85 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #69

Stream Velocity: 40 cm/sec.
Stack Voltage: 34 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 6.0 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1253	0.1383	0.1535	0.1044	0.1010	0.1080	0.0791	0.1007	0.1222
Cl^-, g/l	1.08	-	1.35	-	-	-	-	-	-
K^+, g/l	1.56	1.08	1.25	1.55	1.55	1.70	1.40	1.92	2.25
Ca^{++}, g/l	1.15	1.49	1.63	0.450	0.385	0.406	0.410	0.534	0.575
Na^+, g/l	0.46	0.55	0.62	0.874	0.895	0.940	0.46	0.50	0.74
Mg^{++}, g/l	0.095	0.149	0.157	0.051	0.038	0.041	0.034	0.038	0.043
Volume, liters	1.0	-	1.02	-	-	-	-	-	-
pH	5.2	5.1	5.2	5.3	5.6	4.3	5.1	2.7	2.4
Temp. °F	58	55	58	56	53	53	57	55	56
Resistivity, ohm-cm	247	257	227	118	125	120	190	140	122
Flow Rate, cc/min	900	870	830	1150	1130	1130	1140	1130	1120

Duration of Run: 160 min

Volume of 2.5 N Salt Solution Used: 350 ml.

Contaminants: Sr^{85} - 3.32 μc/liter
Cs^{137} - 5.14 μc/liter

TABLE A-1
EXPERIMENTAL DATA

Cation Decontamination

Run # 70

Stream Velocity: 40 cm/sec
Stack Voltage: 23 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 3.25 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1309	0.1444	0.1541	1.000	0.975	0.922	0.0951	0.0972	0.1327
Cl^-, g/l	1.08	-	1.68	-	-	-	-	-	-
K^+, g/l	1.64	2.11	2.32	23.0	22.5	21.0	2.38	2.42	2.98
Ca^{++}, g/l	1.19	1.18	1.18	2.66	2.78	2.64	0.298	0.259	0.284
Na^+, g/l	0.48	0.47	0.55	5.4	5.25	5.24	0.40	0.48	0.48
Mg^{++}, g/l	0.103	0.132	0.143	0.298	0.382	0.308	0.023	0.017	0.017
Volume, liters	1.0	-	1.07	-	-	-	-	-	-
pH	5.3	5.2	5.3	5.3	8.3	8.7	4.6	3.0	2.8
Temp. $^{\circ}F$	56	57	65	52	57	66	56	59	68
Resistivity,ohm-cm	238	192	170	15	15	14	160	140	115
Flow Rate,cc/min	890	870	870	1220	1150	1100	1100	1060	1080

Duration of Run: 120 min.

Volume of 2.5 N Salt Solution Used: 180 ml

Contaminants: Sr^{85} - 5.37 μc/liter
Cs^{137} - 5.00 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #72

Stream Velocity: 40 cm/sec
Stack Voltage: 42 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 7.8 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1292	0.1725	0.2005	0.1470	0.1520	0.0924	0.0827	0.1100	0.1233
Cl^-, g/l	1.08	-	1.94	-	-	-	-	-	-
K^+, g/l	1.28	1.98	2.29	2.85	3.30	1.75	1.87	2.50	2.76
Ca^{++}, g/l	1.09	1.76	1.86	0.475	0.322	0.290	0.248	0.288	0.388
Na^+, g/l	0.735	0.684	0.744	1.07	1.11	0.740	0.485	0.700	0.725
Mg^{++}, g/l	0.12	0.17	0.20	0.045	0.026	0.010	0.017	0.015	0.022
Volume, liters	1.0	-	1.35	-	-	-	-	-	-
pH	5.1	5.2	5.3	7.5	4.8	4.1	2.5	3.1	2.5
Temp. $^{\circ}F$	57	55	57	53	50	50	56	54	55
Resistivity, ohm-cm	250	200	172	98	120	92	190	240	170
Flow Rate, cc/min	920	820	790	1310	1300	1350	1150	1100	1100

Duration of Run: 160 Min.

Contaminants: Sr^{85} - 0.634 μc/liter (IN VIVO)

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #73

Stream Velocity: 40 cm/sec
Stack Voltage: 51 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 10.2 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1223	0.1471	0.1606	0.0950	0.0995	0.1134	0.1000	0.0947	0.1263
Cl^-, g/l	1.13	-	1.67	-	-	-	-	-	-
K^+, g/l	1.21	1.67	1.75	1.78	2.08	2.40	2.24	2.05	2.90
Ca^{++}, g/l	1.07	1.31	1.54	0.301	0.217	0.234	0.258	0.227	0.273
Na^+, g/l	0.75	0.65	0.64	0.73	0.78	0.89	0.65	0.68	0.85
Mg^{++}, g/l	0.10	0.128	0.133	0.032	0.018	0.020	0.019	0.015	0.017
Volume, liters	1.0	-	1.27	-	-	-	-	-	-
pH	5.3	5.2	5.2	4.8	6.7	6.5	5.6	2.6	2.3
Temp. ^oF	58	60	69	54	55	54	56	57	56
Resistivity, ohm-cm	265	210	192	158	160	130	219	177	140
Flow Rate, cc/min	840	830	810	1260	1240	1240	1180	1180	1200

Duration of Run: 160 min.

Contaminants: Sr^{85} - 0.550 μc/liter (IN VIVO)

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #74

Stream Velocity: 40 cm/sec
Stack Voltage: 37 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 7.2 volts
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Normality	0.1475	0.1524	0.1659	0.0975	0.1503	0.1505	0.1291	0.1594	0.1377
Cl^-, g/l	1.68	-	1.83	-	-	-	-	-	-
K^+, g/l	0.49	0.02	0.01	-	-	-	0.38	0.23	0.75
Ca^{++}, g/l	1.74	2.10	2.23	0.72	1.06	1.17	0.96	1.27	0.76
Na^+, g/l	0.83	0.93	0.87	1.28	2.00	1.86	1.48	1.88	1.72
Mg^{++}, g/l	0.146	0.08	0.199	0.073	0.125	0.129	0.086	0.095	0.069
Volume, liters	1.00	-	1.01	-	-	-	-	-	-
pH	5.1	5.5	5.0	6.3	8.0	8.3	5.8	3.3	5.4
Temp. °F	61	58	63	59	59	61	63	59	61
Resistivity, ohm-cm	223	250	255	120	90	95	130	100	110
Flow Rate, cc/min	850	790	780	1250	1200	1200	1200	1200	1200

Duration of Run: 160 Min

Contaminants: Sr^{85} - 3.06 μc/liter
Cs^{137} - 1.38 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #75

Stream Velocity: 40 cm/sec
Stack Voltage: 41 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 8.0 volts
No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1276	0.1205	0.1644	0.1188	0.1147	0.1675
Cl^-, g/l	1.42	2.36	-	-	-	-
K^+, g/l	1.07	0.004	-	-	0.08	0.06
Ca^{++}, g/l	1.39	1.62	1.30	0.62	0.92	1.47
Na^+, g/l	0.62	0.79	2.05	1.87	1.37	1.78
Mg^{++}, g/l	0.045	0.063	0.123	0.077	0.086	0.120
Volume, liters	1.00	1.01	-	-	-	-
pH	5.8	5.5	6.0	4.3	6.5	3.1
Temp. ^oF	61	64	65	64	61	64
Resistivity,ohm-cm	225	184	115	102	132	75
Flow Rate,cc/min	800	800	1500	1500	1200	1200

Duration of Run: 120 min

Contaminants: Sr^{85} - 4.08 μc/liter
Cs^{137} - 2.77 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #76

Stream Velocity: 40 cm/sec
Stack Voltage: 42 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 4.2 volts
No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	(NO ANALYSES REQUESTED)					
Cl^-, g/l						
K^+, g/l						
Ca^{++}, g/l						
Na^+, g/l						
Mg^{++}, g/l						
Volume, Liters	1.0	1.02	-	-	-	-
pH	5.1	5.3	6.5	4.2	6.5	4.0
Temp. °F	64	63	64	60	69	65
Resistivity, ohm-cm	250	250	130	150	108	78
Flow Rate, cc/min	800	800	1200	1200	1200	1200

Duration of Run: 120 Min

Contaminants: Sr^{85} - 3.39 μc/liter
Cs^{137} - 3.33 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #77

Stream Velocity: 40 cm/sec | Stack Amperage: 2.5 amps | Voltage/Cell Trio: 6.6 volts

Stack Voltage: 35.2 volts | Current Density: 45 ma/cm^2 | No. of Cell Units: 4

	MILK Initial	MILK Final	MAKE-UP Initial	MAKE-UP Final	WASTE Initial	WASTE Final
Normality	(NO ANALYSES REQUESTED)					
Cl^-, g/l						
K^+, g/l						
Ca^{++}, g/l						
Na^+, g/l						
Mg^{++}, g/l						
Volume, liters						
pH	5.3	5.3	6.5	4.0	6.5	4.2
Temp. ^oF	59	50	59	57	64	64
Resistivity, ohm-cm	180	152	78	135	80	80
Flow Rate, cc/min	850	850	1200	1200	1200	1200

Duration of Run: 120 min

Contaminants: Sr^{85} - 2.68 μc/liter

Cs^{137} - 2.73 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #78

Stream Velocity: 40 cm/sec
Stack Voltage: 36.4 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 6.9 volts
No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1241	0.1592	0.0850	0.1181	0.0850	0.2191
Cl^-, g/l	2.36	3.16	-	-	-	-
K^+, g/l	1.50	0.01	-	-	-	1.08
Ca^{++}, g/l	1.02	1.97	0.810	0.505	0.810	1.22
Na^+, g/l	0.542	1.48	0.890	2.00	0.890	2.84
Mg^{++}, g/l	0.134	0.166	0.070	0.070	0.070	0.088
Volume, liters	1.00	1.02	-	-	-	-
pH	5.0	5.2	5.7	3.7	5.7	2.5
Temp. ^oF	62	61	76	60	76	59
Resistivity,ohm-cm	168	149	120	135	120	75
Flow Rate,cc/min	850	850	1200	1200	1200	1200

Duration of Run: 120 min

Contaminants: Sr^{85} - 3.77 μc/liter
Cs^{137} - 3.96 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #79

Stream Velocity:	40 cm/sec	Stack Amperage:	2.5 amps	Voltage/Cell Trio:	10.2 v
Stack Voltage:	51.4 volts	Current Density:	45 ma/cm^2	No. of Cell Units:	4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1268	0.1658	-	-	-	-
Cl^-, g/l	1.18	1.63	-	-	-	-
K^+, g/l	1.38	0.03	-	-	-	-
Ca^{++}, g/l	1.06	1.97	-	-	-	-
Na^+, g/l	0.636	1.14	-	-	-	-
Mg^{++}, g/l	0.132	0.214	-	-	-	-
Volume, liters	1.00	1.02	-	-	-	-
pH	5.1	5.1	5.9	3.8	5.9	2.5
Temp. ^oF	58	60	78	56	78	62
Resistivity, ohm-cm	244	215	93	149	93	77
Flow Rate, cc/min	850	850	1200	1200	1200	1200

Duration of Run: 120 min

Contaminants: Sr^{85} - 4.20 μc/liter

Cs^{137} - 4.62 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #80

Stream Velocity: 40 cm/sec

Stack Voltage: 49 volts

Stack Amperage: 2.5 amps

Current Density: 45 ma/cm^2

Voltage/Cell Trio: 9.6 v

No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1110	0.1435	0.0729	0.0946	0.0729	0.1636
Cl^-, g/l	1.13	1.62	-	-	-	-
K^+, g/l	1.11	-	-	-	-	0.68
Ca^{++}, g/l	1.00	1.90	0.553	0.588	0.553	1.16
Na^+, g/l	0.57	0.82	0.90	1.35	0.90	1.75
Mg^{++}, g/l	0.094	0.156	0.072	0.079	0.072	0.147
Volume, liters	1.0	1.02	-	-	-	-
pH	5.0	5.1	5.7	3.7	5.7	2.3
Temp. ^oF	52	56	45	52	56	58
Resistivity, ohm-cm	250	240	180	152	85	73
Flow Rate, cc/min	850	850	1200	1200	1200	1200

Duration of Run: 120 min.

Contaminants: Sr^{85} - 2.32 μc/liter
Cs^{137} - 2.94 μc/liter

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #81

Stream Velocity: 40 cm/sec   Stack Amperage: 2.5 amps   Voltage/Cell Trio: 10.2 volts

Stack Voltage: 50 volts   Current Density: 45 ma/cm^2 No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1260	0.1500	0.0695	0.0673	0.0695	0.1390
Cl^-, g/l	1.20	1.52	-	-	-	-
K^+, g/l	1.23	0.00	-	-	-	0.430
Ca^{++}, g/l	1.05	2.46	1.13	1.10	1.13	2.02
Na^+, g/l	0.736	0.222	-	-	-	0.230
Mg^{++}, g/l	0.121	0.210	0.157	0.149	0.157	0.206
Volume, liters	1.00	1.01	-	-	-	-
pH	5.0	5.1	5.2	3.7	5.2	2.5
Temp ^oF	53	53	77	61	77	62
Resistivity, ohm-cm	250	288	140	163	140	92
Flow Rate, cc/min	850	850	1200	1200	1200	1200

Duration of Run: 110 min

Contaminants: None

TABLE A-1

EXPERIMENTAL DATA

Cation Decontamination

Run #82

Stream Velocity: 40 cm/sec.
Stack Voltage: 57 volts

Stack Amperage: 2.5 amps
Current Density: 45 ma/cm^2

Voltage/Cell Trio: 11.3 v
No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Normality	0.1096	0.1394	0.1367	0.0987	0.1367	0.1799
Cl^-, g/l	1.19	1.57	-	-	-	-
K^+, g/l	1.13	0.00	-	-	-	0.68
Ca^{++}, g/l	1.02	1.81	0.785	0.752	0.785	1.50
Na^+, g/l	0.513	0.792	2.12	1.25	2.12	1.84
Mg^{++}, g/l	0.089	0.174	0.063	0.081	0.063	0.091
Volume, liters	1.0	1.02	-	-	-	-
pH	5.1	5.2	4.5	3.7	4.5	2.5
Temp. $^{\circ}F$	50	52	49	50	59	59
Resistivity, ohm-cm	280	265	158	140	85	78
Flow Rate, cc/min	850	850	1200	1200	1200	1200

Duration of Run: 120 min.

Contaminants: Sr^{85} - 2.30 μc/liter
Cs^{137} - 2.72 μc/liter

TABLE A-2

EXPERIMENTAL DATA - ANION DECONTAMINATION

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #42

Stream Velocity: 40 cm/sec   Stack Amperage: 1.2 amps   Voltage/Cell Trio: 6.1 volts

Stack Voltage: 30.3 volts   Current Density: 20 ma/cm^2 No. of Cell Units: 4

	MILK		MAKE-UP		WASTE	
	Initial	Final	Initial	Final	Initial	Final
Citrate as citric acid, g/l	4.50	5.48	3.76	1.64	2.16	0.012
Phosphate as P, g/l	0.544	0.488	0.480	0.360	0.376	0.260
$SO_4^{=}$, g/l	0.062	0.041	0.096	0.023	0.042	0.113
Cl^-, g/l	0.99	1.10	1.85	0.213	1.14	3.06
Ca^{++}, g/l	1.11	1.18	-	-	-	-
Mg^{++}, g/l	0.102	0.108	-	-	-	-
Na^+, g/l	0.52	0.48	-	-	-	-
K^+, g/l	1.44	1.66	-	-	-	-
Normality	0.1214	0.1223	-	-	-	-
Volume, liters	1.0	1.02	-	-	-	-
pH	5.2	5.2	6.1	6.1	6.0	6.3
Temp. $^{\circ}$F	43	50	43	43	47	48
Resistivity, ohm-cm	300	280	180	500	340	170
Flow Rate, cc/min	850	580	800	790	970	980

Duration of Run: 1 hour

Contaminant: I^{131} - 5.82 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #43

Stream Velocity: 40 cm/sec

Stack Voltage: 21.3

Stack Amperage: 0.9

Current Density: 20 ma/cm^2

Voltage/Cell Trio: 3.9 volts

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.92	4.12	4.60	12.15	11.65	11.60	1.95	0.95	1.46
Phosphate as P, g/l	0.596	0.420	0.376	1.92	1.90	1.90	0.408	0.566	0.662
$SO_4^{=}$, g/l	0.08	0.02	0.02	0.355	0.306	0.261	0.040	0.063	0.124
Cl^-, g/l	1.02	1.27	1.48	-	-	-	-	-	-
Ca^{++}, g/l	1.13	-	1.16	-	-	-	-	-	-
Mg^{++}, g/l	0.100	-	0.108	-	-	-	-	-	-
Na^+, g/l	0.48	-	0.52	-	-	-	-	-	-
K^+, g/l	1.59	-	1.46	-	-	-	-	-	-
Normality	0.1265	-	0.1268	-	-	-	-	-	-
Volume, liters	1.00	-	1.04	-	-	-	-	-	-
pH	5.2	5.1	5.0	6.1	5.9	6.0	6.4	6.3	6.4
Temp. $^\circ$F	45	48	48	45	47	45	48	49	48
Resistivity, ohm-cm	300	272	265	58	68	80	295	173	130
Flow Rate, cc/min	880	570	550	780	800	800	1000	1020	1040

Duration of Run: 2 hours

Contaminant: I^{131} - 7.80 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #44

Stream Velocity: 40 cm/sec

Stack Voltage: 11.8–17.9 volts

Stack Amperage: 0.6

Current Density: 10 ma/cm^2

Voltage/Cell Trio: 1.9–3.2 v

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.76	4.35	4.80	11.75	10.90	10.20	2.29	0.008	0.014
Phosphate as P, g/l	0.590	0.424	0.368	1.98	1.92	1.86	0.392	0.536	0.646
$SO_4^{=}$, g/l	0.097	0.064	0.062	0.282	0.247	0.220	0.044	0.089	0.084
Cl^-, g/l	1.13	1.10	1.02	5.57	3.85	2.65	1.13	2.66	3.90
Volume, liters	1.0	-	0.985	2.0	-	-	2.0	-	-
pH	5.1	5.2	5.2	6.1	6.0	6.2	6.2	6.0	6.1
Temp. $^{\circ}F$	47	46	47	48	43	43	51	47	47
Resistivity, ohm-cm	267	282	290	53	68	78	295	180	133
Flow Rate, cc/min	890	600	460	780	790	800	910	910	950

Duration of Run: 3 hours

Contaminant: I^{131} - 4.53 μc/liter

TABLE A-2
EXPERIMENTAL DATA
Anion Decontamination

Run #45

Stream Velocity: 40 cm/sec
Stack Voltage: 14 volts

Stack Amperage: 0.6 amps
Current Density: 10 ma/cm^2

Voltage/Cell Trio: 2.4
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.20	2.80	2.80	11.7	11.6	7.6	1.8	0.004	0.005
Phosphate as P, g/l	0.716	0.544	0.472	2.04	2.04	2.00	0.329	0.468	0.553
$SO_4^{=}$, g/l	0.107	0.087	0.06	0.307	0.260	0.220	0.250	0.13	0.130
Cl^-, g/l	1.05	1.24	1.02	5.56	3.78	2.32	0.95	2.83	4.40
Volume, liters	1.00	-	1.00	-	-	-	-	-	-
pH	5.2	5.2	5.2	5.9	6.2	6.0	6.3	6.1	6.1
Temp. °F	46	48	48	45	48	46	50	50	50
Resistivity ohm-cm	280	272	290	57	68	78	350	170	128
Flow Rate, cc/min	920	770	620	820	820	810	1000	1000	1020

Duration of Run: 3 hours
Contaminant: I^{131} - 4.43 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #46

Stream Velocity: 40 cm/sec

Stack Voltage: 0

Stack Amperage: 0

Current Density: 0

Voltage/Cell Trio: 0

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.56	3.52	2.64	11.60	11.60	11.30	1.88	1.78	1.58
Volume, liters	1.0	-	1.0	2.0	-	-	2.0	-	-
pH	5.2	5.1	5.1	5.9	6.1	5.9	6.3	6.2	6.2
Temp. ^{o}F	51	47	47	50	46	45	53	49	48
Resistivity, ohm-cm	248	255	260	50	54	57	332	345	350
Flow Rate, cc/min	900	750	670	730	740	740	900	900	900

Duration of Run: 3 hours

Contaminant I^{131} - 2.11 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run # 47

Stream Velocity: 40 cm/sec
Stack Voltage: 22 volts

Stack Amperage: 0.6
Current Density: 10 ma/cm^2

Voltage/Cell Trio: 4.2
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.72	4.64	5.26	10.30	9.20	5.80	1.66	0.036	0.018
Phosphate as P, g/l	0.688	0.836	0.832	1.96	1.62	1.31	0.312	0.504	0.764
$SO_4^{=}$, g/l	0.111	0.133	0.10	0.282	0.234	0.181	0.039	0.112	0.178
Cl^-, g/l	1.10	0.141	0.085	0.00	0.00	0.00	0.00	0.88	1.17
Volume, liters	1.00	-	1.02	-	-	-	-	-	-
pH	5.2	5.2	5.2	5.9	5.8	5.9	6.0	6.2	6.3
Temp. °F	49	46	48	47	43	44	50	47	48
Resistivity, ohm-cm	261	325	429	105	127	139	620	320	245
Flow Rate, cc/min	750	590	490	780	790	780	890	890	900

Duration of Run: 2 hours
Contaminant: I^{131} - 4.06 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #48

Stream Velocity: 40 cm/sec

Stack Voltage: 15-35 volts

Stack Amperage: 0.6

Current Density: 10 ma/cm^2

Voltage/Cell Trio: 2.3-5.5

No. of Cell Units: 5

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	5.15	5.28	3.36	10.80	9.70	6.20	0.36	0.018	0.004
Phosphate as P, g/l	0.720	0.856	0.864	1.84	1.45	1.06	0.336	0.592	0.920
$SO_4^{=}$, g/l	0.129	0.127	0.103	0.306	0.198	0.136	0.052	0.120	0.20
Cl^-, g/l	0.96	0.085	0.085	0.00	0.00	0.00	0.00	0.89	1.05
Volume, liters	1.00	-	1.01	-	-	-	-	-	-
pH	5.5	5.2	5.2	6.1	6.1	5.9	6.3	6.2	6.5
Temp. °F	68	47	49	63	45	48	64	49	51
Resistivity, ohm-cm	220	295	448	83	120	142	450	285	218
Flow Rate, cc/min	1050	890	660	1030	1000	990	1150	1170	1170

Duration of Run: 2 hours

Contaminant: I^{131} - 5.41 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #49

Stream Velocity: 40 cm/sec

Stack Voltage: 15-30

Stack Amperage: 0.6

Current Density: 10 ma/cm^2

Voltage/Cell Trio: 2.5-6.4

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	3.80	5.32	5.12	10.60	8.9	5.4	1.83	0.00	0.00
Phosphate as P, g/l	0.664	0.564	0.488	1.8	1.68	1.6	0.256	0.440	0.608
$SO_4^{=}$, g/l	0.129	0.127	0.103	0.360	0.270	0.22	0.058	0.114	0.116
Cl^-, g/l	0.99	0.17	0.057	0.00	0.00	0.00	0.00	0.82	1.05
Volume, liters	1.00	-	1.03	-	-	-	-	-	-
pH	5.1	5.4	5.1	6.2	6.1	5.9	6.3	6.2	6.3
Temp. °F	48	47	48	46	45	46	50	48	50
Resistivity, ohm-cm	265	290	395	108	122	138	575	330	240
Flow Rate, cc/min	830	610	490	800	790	770	1000	1020	1000

Duration of Run: 2 hours

Contaminant: I^{131} - 6.94 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #50

Stream Velocity: 40 cm/sec | Stack Amperage: 0.6 | Voltage/Cell Trio: 2.5-5.4

Stack Voltage: 14.2-26.2 volts | Current Density: 10 ma/cm^2 | No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Volume, liters	1.0	-	1.0	2.0	-	-	2.0	-	-
pH	5.3	5.2	5.1	5.9	5.9	5.8	5.8	6.0	6.3
Temp. °F	52	47	51	50	47	50	55	50	53
Resistivity, ohm-cm	272	400	400	110	130	142	512	315	230
Flow Rate, cc/min	890	790	670	800	800	790	1010	1010	1010

Duration of Run: 2 hours

Contaminant: I^{131} - 4.18 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #51

Stream Velocity: 40 cm/sec
Stack Voltage: 16.0 - 27.7

Stack Amperage: 0.6
Current Density: 10 ma/cm^2

Voltage/Cell Trio: 2.8-5.8
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Volume, liters	1.0	-	1.0	2.0	-	-	2.0	-	-
pH	5.4	5.1	5.1	5.8	5.8	5.9	6.2	6.1	6.2
Temp. °F	52	49	47	50	47	47	55	50	49
Resistivity, ohm-cm	280	410	440	108	125	142	560	325	250
Flow Rate, cc/min	930	800	650	810	800	800	980	1000	1000

Duration of Run: 2 hours

Contaminant: I^{131} - 4.24 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #52

Stream Velocity: 40 cm/sec

Stack Voltage: 27-54 volts

Stack Amperage: 0.9

Current Density: 15 ma/cm^2

Voltage/Cell Trio:5.0-12.0 v

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	1.0	4.4	5.52	11.1	2.7	0.0	0.0	0.0	0.0
Phosphate as P, g/l	0.710	0.786	0.67	1.97	1.42	1.38	0.314	0.580	0.936
$SO_4^=$, g/l	0.142	0.123	0.087	0.278	0.166	0.093	0.054	0.163	0.230
Cl^-, g/l	0.85	0.085	0.028	0.0	0.0	0.0	1.65	0.84	0.99
Volume, liters	1.00	-	1.00	2.0	-	-	2.0	-	-
pH	5.4	5.3	5.3	6.0	6.0	5.8	6.2	6.5	6.5
Temp. °F	48	48	50	45	46	47	49	49	50
Resistivity,ohm-cm	262	420	428	110	130	167	600	275	200
Flow Rate,cc/min	830	600	470	790	750	750	1000	1000	1000

Duration of Run: 2 hours

Contaminant: I^{131} - 4.18 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run # 53

Stream Velocity: 40 cm/sec

Stack Voltage: 9.6-19.0

Stack Amperage: 0.6

Current Density: 10 ma/cm^2

Voltage/Cell Trio: 1.5-3.6 v

No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	2.76	3.88	5.67	9.4	4.1	0.0	0.0	0.0	0.0
Phosphate as P, g/l	0.670	0.670	0.980	1.85	1.61	1.20	0.291	0.641	0.913
$SO_4^=$, g/l	0.110	0.084	0.074	0.302	0.168	0.074	0.040	0.178	0.248
Cl^-, g/l	0.94	0.028	0.028	0.0	0.0	0.0	0.0	0.98	1.36
Volume, liters	1.0	-	0.97	2.0	-	-	2.0	-	-
pH	-	5.3	5.1	-	6.1	6.1	-	6.4	6.4
Temp. °F	100	97	-	101	97	100	100	98	100
Resistivity, ohm-cm	142	210	-	52	70	105	310	129	88
Flow Rate, cc/min	910	820	400	770	700	690	1010	999	940

Duration of Run: 4 hours

Contaminant: I^{131} - 3.22 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #54

Stream Velocity: 40 cm/sec
Stack Voltage: 13.2-29.0

Stack Amperage: 0.9
Current Density: 15 ma/cm^2

Voltage/Cell Trio: 2.0-6.0 v
No. of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citrate as citric acid, g/l	2.84	6.08	4.88	10.75	7.90	5.6	1.80	1.35	1.52
Phosphate as P, g/l	0.71	1.02	0.97	2.22	2.08	1.81	0.394	0.618	0.890
$SO_4^{=}$, g/l	0.103	0.111	0.089	0.269	0.161	0.070	0.058	0.170	0.275
Cl^-, g/l	0.88	0.028	0.014	0.0	0.0	0.0	0.0	0.905	1.16
Volume, liters	1.0	-	1.0	2.0	-	-	2.0	-	-
pH	5.3	5.2	5.2	6.3	6.2	6.2	6.5	6.7	6.6
Temp. ^oF	100	99	102	101	99	102	101	100	103
Resistivity, ohm-cm	142	200	202	52	62	80	290	142	100
Flow Rate, cc/min	890	680	530	990	850	820	1000	980	940

Duration of Run: 2 hours

Contaminant: I^{131} - 3.22 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #55

Milk Stream Velocity: 18 cm/sec

Regenerating Stream Velocity: 40 cm/sec

No. of Cell Units: 5

Current Desnity for Regeneration: 60 ma/cm^2

Stack Voltage: 40 volts

Stack Amperage: 3.3 amps

	MILK		MAKE-UP				WASTE			
			A		B		A		B	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Citrate as citric acid, g/l	2.76	2.66	6.0	0.0	4.75	2.30	1.38	0.0	1.40	0.0
Phosphate as P, g/l	0.685	0.702	1.22	0.20	1.10	0.50	0.142	0.96	0.160	0.881
$SO_4^{=}$, g/l	0.102	0.105	0.166	0.028	0.148	0.038	0.04	0.183	0.041	0.187
Cl^-, g/l	1.12	0.92	0.10	0.10	0.10	0.10	0.0	0.467	0.10	1.60
Volume, liters	1.0	1.0	1.0	0.95	2.0	1.93	1.0	1.05	2.0	2.07
pH	5.1	5.3	6.3	6.0	6.1	6.2	6.3	-	6.2	6.4
Temp. °F	70	53	50	53	57	75	45	-	58	73
Resistivity, ohm-cm	213	265	180	690	125	256	280	-	420	134
Flow Rate, cc/min	460	400	1550	1500	1600	-	750	780	810	-

Duration of Milk Run: 2 hours

Duration of Regeneration: A-13 min
B-20 min

Contaminants: I^{131}- 4.39 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run # 60

Milk Stream Velocity: 18 cm/sec

Regenerating Stream Velocity: 40 cm/sec

No. of Cell Units: 5

Current Density for Regeneration: 60 ma/cm^2

Stack Voltage: 40 volts

Stack Amperage: 3.3 amps

	MILK		MAKE-UP				WASTE			
			A		B		A		B	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Citrate as citric acid, g/l	3.24	4.4	4.3	-	7.2	4.2	0.0	0.0	3.1	0.0
Phosphate as P, g/l	0.709	0.701	1.34	0.59	1.18	u.67	0.139	0.811	0.472	0.680
$SO_4^=$, g/l	0.101	0.106	0.195	0.06	0.191	0.106	0.053	-	-	-
Cl^-, g/l	1.11	0.890	0.0	0.10	0.0	0.10	0.0	0.524	0.0	0.269
Volume, liters	1.0	1.0	2.0	1.85	2.0	1.9	1.0	1.15	1.0	1.1
pH	5.3	5.2	6.1	6.3	6.2	6.4	6.2	6.5	6.3	6.4
Temp. °F	56	56	56	75	79	84	49	-	68	82
Resistivity, ohm-cm	238	250	118	172	89	148	670	85	249	74
Flow Rate, cc/min	410	400	1550	-	1600	-	770	-	800	-

Duration of Milk Run: 2 hours

Duration of Regeneration: A-20 min
B-20 min

Contaminant: I^{131} - 4.00 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #61

Milk Stream Velocity: 18 cm/sec

Regenerating Stream Velocity: 40 cm/sec

No. of Cell Units: 5

Current Density for Regeneration: 60 ma/cm^2

Stack Voltage: 30 volts

Stack Amperage: 3.3 amps

	MILK		MAKE-UP				WASTE			
			A		B		A		B	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Citrate as citric acid, g/l	3.52	4.76	14.2	6.2	14.7	6.2	2.38	0.18	2.44	0.0
Phosphate as P, g/l	0.694	0.709	2.24	1.34	2.40	1.18	0.361	1.01	0.378	1.02
$SO_4^=$, g/l	0.122	0.135	0.29	0.140	0.30	0.120	0.020	0.101	0.023	0.111
Cl^-, g/l	1.07	0.816	0.0	0.10	0.0	0.10	0.0	0.298	0.0	0.212
Volume, liters	1.0	1.0	2.0	1.9	2.0	1.9	1.0	1.1	1.0	1.1
pH	5.4	5.2	6.2	6.4	6.2	6.4	6.3	6.5	6.3	6.4
Temp. °F	58	51	68	92	67	85	61	89	66	82
Resistivity, ohm-cm	247	251	66	63	65	92	322	55	300	59
Flow Rate, cc/min	420	400	1570	-	1520	1470	900	-	840	810

Duration of Milk Run: 2 hours

Duration of Regeneration: A-30 min
B-30 min

Contaminant: I^{131} - 3.68 μc/liter

TABLE A-2

EXPERIMENTAL DATA

Anion Decontamination

Run #71

Stream Velocity: 40 cm/sec

Stack Voltage: 20 volts

Stack Amperage: 0.6

Current Density: 10 ma/cm^2

Voltage/Cell Trio: 2.5 volts

No of Cell Units: 4

	MILK			MAKE-UP			WASTE		
	Initial	Intermed.	Final	Initial	Intermed.	Final	Initial	Intermed.	Final
Citric Acid,g/l	4.64	7.52	7.52	11.6	-	8.0	1.80	2.74	3.80
Volume, liters	1.0	-	1.08	2.0	-	1.96	2.0	-	2.06
pH	5.2	5.3	5.2	6.4	6.4	6.5	6.6	6.4	6.5
Temp. ^{o}F	57	54	54	55	52	52	58	53	54
Resistivity,ohm-cm	238	345	380	85	105	130	529	275	205
Flow Rate, cc/min	920	800	610	1220	1250	1240	1070	1100	1120

Duration of Run: 120 minutes

Contaminants: None

TABLE A-3

EXPERIMENTAL DATA - ANION MEMBRANE POLARIZATION

TABLE A 3

EXPERIMENTAL DATA - ANION MEMBRANE POLARIZATION

Run # 31

Stream Velocity: 40 cm/sec
Current Density: 10 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	pH	Resistivity ohm-cm	Temp. °F
0	11.0	1.2	0.6	1380	5.2	250	49
20	12.4	1.4	0.6	1380	5.3	245	50
40	12.1	1.4	0.6	1380	5.2	243	52
60	11.9	1.4	0.6	1360	5.2	227	53

Run # 32

Stream Velocity: 40 cm/sec
Current Density: 20 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	pH	Resistivity ohm-cm	Temp. °F
0	21.0	2.9	1.2	1380	5.1	225	51
20	22.5	2.9	1.2	1380	5.2	245	48
40	22.5	2.9	1.2	1380	5.2	237	51
60	24.0	3.0	1.2	1380	5.1	235	48

Run # 33

Stream Velocity: 40 cm/sec
Current Density: 30 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	pH	Resistivity ohm-cm	Temp. °F
0	28.0	3.9	1.8	1380	5.2	240	55
20	44.0	6.2	1.8	1305	5.2	238	56
40	48.5	7.0	1.8	1050	5.2	243	52
55	49.0	7.0	1.8	1020	5.2	235	52

TABLE A-3

EXPERIMENTAL DATA - ANION MEMBRANE POLARIZATION

Run #34

Stream Velocity: 40 cm/sec
Current Density: 10 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	7.0	0.6	0.6	1380	5.2	153	96
20	7.8	0.7	0.6	1340	5.3	152	96
40	8.0	0.7	0.6	1350	5.2	153	94
60	8.0	0.7	0.6	1290	5.2	155	93

Run # 35

Stream Velocity: 40 cm/sec
Current Density: 20 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	12.2	1.4	1.2	1320	5.2	138	100
20	13.8	1.7	1.2	1240	5.2	139	100
40	13.0	1.5	1.2	1230	5.2	139	98
60	13.3	1.6	1.2	1225	5.2	140	96

Run # 36

Stream Velocity: 40 cm/sec
Current Density: 30 ma/cm^2
No.of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	18	2.1	1.8	1380	5.6	147	96
20	30	4.2	1.8	1330	5.1	136	99
40	31	4.3	1.8	1300	5.2	133	99

TABLE A-3

EXPERIMENTAL DATA - ANION MEMBRANE POLARIZATION

Run # 37

Stream Velocity: 40 cm/sec
Current Density: 10 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	11.8	1.4	0.6	1310	6.5	284	53
20	12.7	1.5	0.6	1250	6.8	330	46
40	13.6	1.6	0.6	1220	6.7	324	47
60	13.9	1.7	0.6	1190	6.7	310	49

Run # 38

Stream Velocity: 40 cm/sec
Current Density: 20 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	27	4.0	1.2	1210	6.7	300	50
20	48	7.5	1.2	1140	6.5	317	50

Run # 39

Stream Velocity: 40 cm/sec
Current Density: 10 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per Cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. °F
0	6.8	0.6	0.6	1350	6.6	166	96
20	7.0	0.6	0.6	1315	6.6	160	98
40	7.2	0.7	0.6	1310	6.6	159	98
60	7.0	0.7	0.6	1310	6.5	154	100

TABLE A-3

EXPERIMENTAL DATA - ANION MEMBRANE POLARIZATION

Run # 40

Stream Velocity: 40 cm/sec
Current Density: 20 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per Cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. ^oF
0	13.4	1.1	1.2	1330	6.7	152	100
20	16.0	1.8	1.2	1280	6.6	152	100
40	16.0	1.8	1.2	1180	6.5	147	100
60	15.0	1.8	1.2	1160	6.4	141	101

Run # 41

Stream Velocity: 40 cm/sec
Current Density: 30 ma/cm^2
No. of Cell Pairs: 4

Time (min.)	Stack Voltage	o.c. volts per Cell pair	Stack Amps.	MILK Flow Rate cc/min	MILK pH	MILK Resistivity ohm-cm	MILK Temp. ^oF
0	--	3.3	1.8	1270	6.3	150	100
20	30	4.2	1.8	1040	6.0	140	101
40	38	5.7	1.8	1020	5.9	136	100
60	40	4.8	1.8	900	5.8	133	99

TABLE A-4

RADIOACTIVITY COUNTING RESULTS

TABLE A-4

RADIOACTIVITY COUNTING RESULTS

	Time (min.)	Ampere Hours	μc Sr^{85} per Liter Milk	% Sr^{85} Remaining
Run # 8	0	0	4.41	100
	30	0.9	2.88	66
	60	1.8	1.82	41
	90	2.7	1.49	33.5
	120	3.6	1.18	26.5
	180	5.4	.93	21.0
	240	7.2	.855	19.5
Run #9	0	0	4.34	100
	30	0.9	2.48	56.0
	60	1.8	1.30	29.5
	85	2.55	.775	19.5
	120	3.6	.463	10.5
	165	4.95	.326	5.2
Run # 10	0	0	5.55	100
	30	0.9	3.00	55.0
	60	1.8	1.73	31.0
	90	2.7	1.05	18.5
	120	3.6	.685	11.0
	180	5.4	.261	4.6
	240	7.2	.153	2.7
Run # 11	0	0	4.21	100
	30	0.9	2.90	69.0
	60	1.8	2.29	54.3
	90	2.7	1.99	47.3
	120	3.6	1.76	41.7
	180	5.4	1.56	37.0
	240	7.2	1.33	31.7

TABLE A-4

RADIOACTIVITY COUNTING RESULTS

	Time (min.)	Ampere Hours	$\mu c\ Sr^{85}$ per Liter Milk	% Sr^{85} Remaining
Run # 12	0	0	3.51	100
	30	1.8	.815	23.0
	60	3.6	.253	7.2
	90	5.4	.106	3.1
	120	7.2	.083	2.3
Run # 14	0	0	3.44	100
	30	0.9	1.87	54.4
	60	1.8	.947	27.5
	120	3.6	.513	14.9
	180	5.4	.198	5.8
	240	7.2	.090	2.6

	Time (min.)	Ampere Hours	$\mu c\ Cs^{137}$ per Liter Milk	% Cs^{137} Remaining
Run # 13	0	0	5.5	100
	30	0.9	0.928	16.9
	60	1.8	0.243	4.4
	90	2.7	0.072	1.3
	120	3.6	0.090	1.6

TABLE A-4

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	c Sr^{85} Liter Milk	% Sr^{85} Remaining	c Cs^{137} Liter Milk	% Cs^{137} Remaining
Run # 16						
CO=30 ma/cm^2	0	0	3.06	100	4.0	100
	30	0.9	1.91	62.4	0.685	17.1
	60	1.8	1.15	37.6	0.091	2.5
	90	2.7	0.766	25.0	0.032	0.8
	120	3.6	0.442	13.2	0.017	0.4
	180	5.4	0.252	8.2	0.013	0.3
	240	7.2	0.135	4.4	0.013	0.3
Run # 17						
CO=45 ma/cm^2	0	0	2.90	100	4.17	100
5 Cell Unit	20	0.83	2.04	70.2	0.852	20.5
	40	1.66	1.39	47.8	0.189	4.6
	60	2.50	1.09	37.6	0.094	2.2
	80	3.34	0.784	27.0	0.061	1.5
	120	5.00	0.477	16.5	0.056	1.3
	160	6.67	0.281	9.7	0.041	1.0
Run # 18						
CO=45 ma/cm^2			3.77	100	3.78	100
5 Cell Unit			2.97	78.8	0.265	7.0
	(same as Run 17)		2.09	55.5	0.038	1.0
			1.51	40.0	0.038	1.0
			1.30	34.5	0.038	1.0
			1.03	27.4	0.038	1.0
			0.766	20.3	0.038	1.0
Run # 19						
CO=45 ma/cm^2			3.21	100	3.77	100
5 Cell Unit			1.57	48.7	0.27	7.2
			0.657	20.8	0.43	1.1
	(same as Run 17)		0.214	6.6	0.015	0.4
			0.113	3.5	0.012	0.3
			0.315	0.9	0.010	0.2
			0.180	0.6	0.005	0.1
Run # 20						
CO=30 ma/cm^2	0	0	3.19	100	3.71	100
4 Cell Unit	30	0.72	1.53	43.0	0.356	9.6
	60	1.44	0.848	26.6	0.082	2.2
	90	2.16	0.568	16.3	0.027	0.7
	120	2.88	0.304	9.5	0.025	0.7
	180	4.32	0.111	3.5	0.010	0.3
	240	5.76	0.052	1.6	0.013	0.3

* Based on 5 Cell Unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	c Sr^{85} Liter Milk	% Sr^{85} Remaining	c Cs^{137} Liter Milk	% Cs^{137} Remaining
Run # 21						
CO=45 ma/cm^2	0	0	3.32	100	4.25	100
4 Cell Unit	30	1.0	1.72	51.8	0.321	7.6
	60	2.0	0.919	27.6	0.066	1.6
	90	3.0	0.578	17.4	0.032	0.8
	120	4.0	0.364	10.9	0.025	0.6
	160	5.32	0.168	5.1	0.021	0.5
Run # 22						
CO=45 ma/cm^2			3.53	100	4.63	100
4 Cell Unit	(Same as Run 21)		1.50	42.4	0.198	4.3
			0.715	20.3	0.153	0.3
			0.429	12.2	0.135	0.3
			0.181	5.1	0.081	0.2
			0.076	2.1	0.036	0.1
Run # 23						
CO=45 ma/cm^2			3.10	100	4.31	100
4 Cell Unit			1.54	49.7	0.129	3.0
			0.73	23.6	0.013	0.3
	(Same as Run 21)		0.346	11.2	0.010	0.2
			0.157	5.1	0.015	0.3
			0.079	2.6	0.005	0.1
Run # 24						
CO=45 ma/cm^2			3.46	100	3.85	100
4 Cell Unit			1.79	51.8	0.341	8.9
	(Same as Run 21)		0.83	24.0	0.015	0.4
			0.398	11.5	0.015	0.4
			0.202	5.8	0.015	0.4
	140	4.65	0.115	3.3	0.015	0.4
Run # 25						
CO=45 ma/cm^2			2.96	100	4.43	100
4 Cell Unit			1.83	61.7	0.321	7.2
			0.982	33.3	0.083	1.9
	(Same as Run 21)		0.589	19.9	0.046	1.0
			0.349	11.7	0.023	0.5
			0.177	6.0	0.013	0.3

* Based on 5 Cell Unit

TABLE A-4 (Continued)

TITLE: RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	c Sr^{85} Liter Milk	% Sr^{85} Remaining	c Cs^{137} Liter Milk	% Cs^{137} Remaining
Run # 26						
CO=45 ma/cm^2			3.40	100	4.20	100
4 Cell Unit			1.60	47.2	0.171	4.8
	(same as Run 21)		0.829	24.2	0.004	0.1
			0.514	15.1	-	-
			0.432	10.8	-	-
			0.295	8.7	-	-
Run # 28						
CO=60 ma/cm^2	0	0	2.90	100	4.44	100
4 Cell Unit	30	1.34	1.24	42.7	0.156	3.5
	60	2.62	0.472	16.3	0.135	0.3
	90	3.82	0.185	6.4	0.117	0.3
	120	4.99	0.094	3.2	0.008	0.2
Run # 30						
CO=45 ma/cm^2	0	0	2.62	100	4.09	100
4 Cell Unit	30	1.0	1.30	49.4	0.204	4.5
	60	2.0	0.724	27.5	0.032	0.8
	90	3.0	0.447	17.0	0.019	0.5
	120	4.0	0.263	10.0	0.015	0.4
	160	5.32	0.155	5.9	0.014	0.3

* Based on 5 Cell Unit

TABLE A-4 (Cont.)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Sr^{85} per Liter Milk	% Sr^{85} Remaining	μc Cs^{137} per Liter Milk	% Cs^{137} Remaining
Run # 56						
CO=45 ma/cm^2	0	0	3.96	100	4.75	100
4 cell unit	30	1.0	1.44	36.4	0.05	1.1
	60	2.0	0.82	20.8	0.01	0.2
	90	3.0	-	-	-	-
	120	4.0	0.34	8.5	-	-
	160	5.32	0.24	6.2	-	-
Run # 57						
CO=45 ma/cm^2	(Same as Run 56)		4.34	100	5.19	100
4 cell unit			2.06	47.7	0.21	4.1
			1.07	24.8	0.01	0.2
			0.67	15.4	-	-
			0.50	11.4	-	-
			0.36	8.3	-	-
Run # 58						
CO=45 ma/cm^2			3.33	100	4.31	100
4 cell unit	(Same as Run 56)		1.31	39.2	0.18	4.1
			0.61	18.2	0.01	0.2
			0.35	10.5	-	-
			0.16	4.8	-	-
			0.15	4.6	-	-
Run # 59						
CO=45 ma/cm^2			3.75	100	3.78	100
4 cell unit	(Same as Run 56)		1.80	48.0	0.13	3.4
			1.01	26.9	0.01	0.2
			0.67	17.7	-	-
			0.49	13.0	-	-
			0.34	9.0	-	-
Run # 62						
CO= 45 ma/cm^2			3.52	100	4.56	100
4 cell unit	(Same as Run 56)		1.55	44.0	0.21	4.6
			0.65	18.6	0.01	0.2
			0.37	10.6	-	-
			0.19	5.5	-	-
			0.11	3.1	-	-

* Based on a 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Sr^{85} per Liter Milk	% Sr^{85} Remaining	μc Cs^{137} per Liter Milk	% Cs^{137} Remaining
Run # 63 CO=45 ma/cm^2 4 Cell unit			3.39	100	4.73	100
			1.71	50.4	0.26	5.5
	(Same as Run 56)		0.94	27.6	0.02	0.4
			0.50	14.6	-	-
			0.23	6.9	-	-
			0.13	3.7	-	-
Run # 64 CO=45 ma/cm^2 4 cell unit			3.30	100	4.74	100
			1.38	41.8	0.26	5.5
	(Same as Run 56)		0.59	17.8	0.02	0.4
			0.26	7.9	-	-
			0.12	3.6	-	-
			0.04	1.4	-	-
Run # 65 CO=45 ma/cm^2 4 cell unit			3.62	100	5.33	100
	(Same as Run 56)		1.74	48.0	0.33	6.2
			0.86	23.9	0.02	0.3
			0.44	12.2	-	-
			0.23	6.5	-	-
			0.13	3.5	-	-
Run # 66 CO=45 ma/cm^2 4 cell unit			4.30	100	4.69	100
	(Same as Run 56)		2.14	50.0	0.27	5.7
			1.08	25.2	0.02	0.4
			0.58	13.4	-	-
			0.30	6.9	-	-
			0.15	3.6	-	-
Run # 67 CO=45 ma/cm^2 4 cell unit			4.12	100	5.05	100
	(Same as Run 56)		2.02	49.0	0.25	5.0
			1.06	25.8	0.02	0.4
			0.56	13.6	-	-
			0.32	7.9	-	-
			0.16	3.9	-	-

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Sr^{85} per Liter Milk	% Sr^{85} Remaining	μc Cs^{137} per Liter Milk	% Cs^{137} Remaining
Run # 68						
CO—45 ma/cm^2			3.78	100	4.85	100
4 cell unit	(Same as Run 56)		1.87	49.5	0.19	4.0
			0.96	25.2	0.01	0.2
			0.53	14.0	-	-
			0.42	11.1	-	-
			0.13	3.4	-	-
Run # 69						
45 ma/cm^2			3.32	100	5.14	100
4 cell unit	(Same as Run 56)		1.33	40.2	0.32	6.1
			0.62	18.5	0.03	0.5
			0.32	9.5	0.01	0.2
			0.15	4.6	-	-
			0.07	2.2	-	-
Run # 70						
45 ma/cm^2	0	0	5.37	100	5.00	100
4 cell unit	30	1.0	2.92	54.4	0.36	7.2
	60	2.0	1.39	25.8	0.14	2.7
	90	3.0	0.95	17.8	0.05	1.0
	120	4.0	0.55	10.2	0.05	1.0
Run # 72						
45 ma/cm^2	0	0	0.632	100	-	-
4 cell unit	30	1.0	0.494	78.0	-	-
	60	2.0	0.395	62.4	-	-
	90	3.0	0.286	45.1	-	-
	120	4.0	0.215	34.0	-	-
	160	5.32	0.150	23.8	-	-
Run # 73						
45 ma/cm^2			0.550	100	-	-
4 cell unit	(Same as Run 72)		0.350	63.8	-	-
			0.232	42.2	-	-
			0.155	28.2	-	-
			0.105	19.2	-	-
			0.072	13.1	-	-

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	$\mu c\ Sr^{85}$ per Liter Milk	% Sr^{85} Remaining	$\mu c\ Cs^{137}$ per Liter Milk	% Cs^{137} Remaining
Run # 74, 45 ma/cm^2, 4 cell unit	(Same as Run 72)		3.06	100	1.38	100
			1.00	32.8	0.04	2.6
			0.31	10.3	0.02	1.3
			0.22	7.3	0.04	2.6
			0.07	2.2	0.01	0.7
			0.05	1.5	0.01	-
Run # 75, 45 ma/cm^2, 4 cell unit	0	0	4.08	100	2.77	100
	30	1.0	2.26	55.5	0.10	3.6
	60	2.0	1.51	37.0	0.01	0.4
	90	3.0	0.58	14.2	-	-
	120	4.0	0.35	8.7	-	-
Run # 76, 45 ma/cm^2, 4 cell unit	(Same as Run 75)		3.39	100	3.33	100
			1.22	36.2	0.39	11.6
			0.73	21.5	0.19	5.6
			0.49	14.6	0.11	3.2
			0.33	9.7	0.06	1.7
Run # 77, 45 ma/cm^2, 4 cell unit	(Same as Run 75)		2.68	100	2.73	100
			0.90	33.5	0.11	4.1
			0.36	13.5	0.02	0.6
			0.20	7.7	0.01	0.4
			0.13	4.7	-	-
Run # 78, 45 ma/cm^2, 4 cell unit	(Same as Run 75)		3.77	100	3.96	100
			1.20	31.8	0.19	4.8
			0.45	11.8	0.03	0.7
			0.21	5.6	0.03	0.6
			0.12	3.3	0.02	0.4

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Sr^{85} & Cs^{137} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Sr^{85} per Liter Milk	% Sr^{85} Remaining	μc Cs^{137} per Liter Milk	% Cs^{137} Remaining
Run # 79 45 ma/cm^2 4 cell unit	(Same as Run 75)		4.20	100	4.62	100
			1.26	30.0	0.11	2.5
			0.46	11.0	0.04	0.9
			0.20	4.7	0.03	0.6
			0.09	2.2	0.01	0.3
Run # 80 45 ma/cm^2 4 cell unit	(Same as Run 75)		2.32	100	2.94	100
			0.74	30.4	0.09	3.6
			0.22	9.3	0.03	0.8
			0.10	4.4	0.02	0.5
			0.05	2.1	0.01	0.4
Run # 82 45 ma/cm^2 4 cell unit	(Same as Run 75)		2.30	100	2.72	100
			0.67	29.0	0.07	2.4
			0.21	9.1	0.02	0.9
			0.09	3.8	0.02	0.7
			0.04	1.6	0.01	0.5

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

I^{131} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc I^{131} per Liter Milk	% I^{131} Remaining
Run # 42 CO=20 ma/cm^2 4 cell unit	0	0	5.82	100
	20	0.32	4.61	79.3
	40	0.64	3.16	54.4
	60	0.96	2.86	49.2
Run # 43 CO= 15 ma/cm^2 4 cell unit	0	0	7.80	100
	20	0.24	7.21	92.5
	60	0.72	6.40	82.1
	80	0.96	5.59	70.7
	120	1.20	5.06	65.0
	160	1.44	5.40	69.5
Run# 44 CO= 10 ma/cm^2 4 cell unit	0	0	4.53	100
	30	0.24	3.21	70.6
	60	0.48	2.50	55.0
	90	0.72	2.04	45.0
	120	0.96	1.69	37.3
	150	1.20	1.40	30.7
	180	1.44	1.16	25.6
Run # 45 CO= 10 ma/cm^2 4 cell unit	(Same as Run 44)		2.40	100
			1.76	76.5
			1.49	64.7
			1.27	55.4
			1.09	47.5
			0.98	42.8
			0.94	40.8
Run # 46 No Current 4 cell unit	0	-	2.11	100
	90	-	0.98	46.6
	180	-	0.89	42.3

* Based on 5 cell unit

TABLE A-4 (Continued)

RAIDOACTIVITY COUNTING RESULTS

I^{131} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc I^{131} per Liter Milk	% I^{131} Remaining
Run # 47 CO= 10 ma/cm^2 4 cell unit	0	0	1.96	100
	20	0.16	1.39	70.6
	40	0.32	1.04	52.8
	60	0.48	0.84	43.2
	80	0.64	0.68	34.9
	100	0.80	0.58	29.4
	120	0.96	0.49	24.8
Run # 48 CO= 10 ma/cm^2 5 cell unit	0	0	5.41	100
	20	0.2	3.30	60.4
	40	0.4	2.29	41.9
	60	0.6	1.81	33.2
	80	0.8	1.52	27.9
	100	1.0	1.31	23.9
	120	1.2	1.15	21.0
Run # 49 CO= 10 ma/cm^2 4 cell unit	0	0	6.93	100
	20	0.16	3.19	46.0
	60	0.48	1.45	20.9
	80	0.64	1.08	15.6
	100	0.80	0.94	13.5
	120	0.96	0.81	11.7
Run # 50 CO= 10 ma/cm^2 4 cell unit	(Same as Run 47)		4.18	100
			1.90	45.5
			1.09	26.1
			0.79	18.9
			0.63	15.1
			0.54	12.9
			0.50	12.0
Run # 51 CO= 10 ma/cm^2 4 cell unit	(Same as Run 47)		4.24	100
			1.74	41.0
			1.04	24.6
			0.73	17.2
			0.59	13.9
			0.49	11.6
			0.46	10.8

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

I^{131} Radioactivity Counting Results

	Time (min.)	Ampere * Hours	$\mu c\ I^{131}$ per Liter Milk	% I^{131} Remaining
Run # 52 CO= 15 ma/cm^2 4 cell unit	0	0	4.18	100
	20	0.24	1.00	24.0
	40	0.48	0.48	11.4
	60	0.72	0.23	5.6
	80	0.96	0.18	4.3
	100	1.20	0.14	3.4
	120	1.44	0.13	3.0
Run # 53 CO= 10 ma/cm^2 4 cell unit	0	0	3.22	100
	44	0.35	0.73	22.7
	60	0.48	0.58	18.0
	90	0.72	0.47	14.6
	120	0.96	0.44	13.7
	150	1.20	0.43	13.4
	180	1.44	0.44	13.7
	210	1.68	0.46	14.3
	240	1.92	0.45	14.0
Run # 54 CO= 15 ma/cm^2 4 cell unit	(Same as Run 52)		3.22	100
			1.13	35.1
			0.77	23.9
			0.60	18.6
			0.51	15.8
			0.48	14.9
			0.44	13.7
Run # 55 No Current 5 cell unit	0	-	4.39	100
	11	-	3.13	71.3
	20	-	2.60	59.3
	31	-	2.03	46.2
	40	-	1.78	40.5
	50	-	1.57	35.8
	60	-	1.40	31.9
	Membrane Regeneration Step:			
	0	-	1.28	29.2
	10	-	1.06	24.2
	30	-	0.85	19.4
	40	-	0.77	17.6
	50	-	0.74	16.9
	60	-	0.71	16.2

* Based on 5 cell unit

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

I^{131} Radioactivity Counting Results

	Time (min.)	Ampere Hours	μc I^{131} per Liter Milk	% I^{131} Remaining
Run # 60 No Current 5 cell unit	0	-	4.00	100
	10	-	2.92	73.0
	20	-	2.46	61.5
	30	-	2.25	56.2
	40	-	2.05	51.2
	55	-	1.86	46.5
	60	-	1.80	45.0
	Membrane Regeneration Step:			
	0	-	1.71	42.7
	10	-	1.54	38.5
	20	-	1.42	35.5
	30	-	1.33	33.3
	40	-	1.23	30.8
	53	-	1.16	29.0
	60	-	1.13	28.3
Run # 61 No Current 5 cell unit	0	-	3.68	100
	10	-	3.22	87.5
	20	-	2.56	69.5
	30	-	2.28	62.0
	40	-	1.94	52.7
	55	-	1.89	51.4
	60	-	1.76	47.8
	Membrane Regeneration Step:			
	0	-	1.62	44.0
	10	-	1.42	38.6
	21	-	1.35	36.7
	34	-	1.23	33.4
	40	-	1.18	32.1
	50	-	1.12	30.5
	60	-	1.09	29.6

TABLE A-4 (Continued)

RADIOACTIVITY COUNTING RESULTS

Ba^{140} - La^{140} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Ba^{140} per Liter Milk	% Ba^{140} Remaining	μc La^{140} per Liter Milk	% La^{140} Remaining
Run # 27 CO=45 ma/cm^2 4 cell unit	0	0	4.68	100.0	4.68	100.0
	30	1.0	3.56	76.1	4.38	93.5
	60	2.0	2.84	60.7	4.25	90.8
	90	3.0	2.17	46.4	3.99	85.3
	120	4.0	1.78	38.0	3.89	83.1
	160	5.32	1.42	30.4	3.75	80.1
Run # 29 CO=45 ma/cm^2 4 cell unit	(Same as Run 27)		5.76	100.0	6.30	100.0
			2.95	51.3	5.63	89.5
			1.73	30.0	5.15	81.7
			1.24	21.6	4.98	79.0
			0.99	17.2	4.79	76.0
			0.81	14.1	4.77	75.6

* Based on 5 Cell Unit

RADIOACTIVITY COUNTING RESULTS

Cs^{137} & Ce^{139} Radioactivity Counting Results

	Time (min.)	Ampere* Hours	μc Cs^{137} per Liter Milk	% Cs^{137} Remaining	μc Ce^{139} per Liter Milk	% Ce^{139} Remaining
Run # 15 CO=30 ma/cm^2 5 cell unit	0	0	4.72	100.0	9.90	100.0
	30	0.9	0.387	8.2	9.63	100.0
	60	1.8	0.099	2.1	9.73	100.0
	90	2.7	0.030	0.6	9.63	100.0
	120	3.6	0.023	0.5	9.46	100.0
	180	5.4	0.013	0.3	9.46	100.0
	240	7.2	0.008	0.2	9.63	100.0

* Based on 5 cell unit

TABLE A-5

<u>Composition of Make-Up and Concentrated Feed Make-Up Solutions for Decontamination Runs</u>

TABLE A-5

Composition of Make-up and Concentrated Feed Make-up Solutions for Decontamination Runs

A. CATION DECONTAMINATION

	Concentrated Feed Make-up			Make-up Stream	
	Cation	Eq/l	Mol Fraction	Eq/l	Mole Fraction
Run # 1-14	Na			0.121	0.242
	K			0.200	0.400
	Ca			0.051	0.052
	Mg			0.304	0.306
				0.676	1.000
Run # 15	Na	0.656	0.305	0.054	0.435
	K	1.160	0.535	0.051	0.411
	Mg	0.075	0.017	0.006	0.024
	Ca	0.614	0.143	0.032	0.130
		2.505	1.000	0.143	1.000
Run # 16, 17	Na	0.656	0.305	0.246	0.435
	K	1.160	0.535	0.232	0.411
	Mg	0.075	0.017	0.027	0.024
	Ca	0.614	0.143	0.145	0.130
		2.505	1.000	0.650	1.000
Run # 18-30	Na	0.658	0.323	0.054	0.417
	K	1.037	0.508	0.057	0.439
	Mg	0.074	0.018	0.006	0.020
	Ca	0.616	0.151	0.032	0.124
		2.385	1.000	0.149	1.000
Run # 56-59, 62	Na	0.515	0.232	0.025	0.250
	K	1.422	0.642	0.022	0.224
	Mg	0.058	0.013	0.012	0.059
	Ca	0.502	0.113	0.093	0.467
		2.497	1.000	0.152	1.000

TABLE A-5
(Continued)

Composition of Make-up and Concentrated Feed Make-up Solutions for Decontamination Runs

A. CATION DECONTAMINATION (continued)

	Concentrated Feed Make-up			Make-up Stream	
	Cation	Eq/l	Mol Fraction	Eq/l	Mole Fraction
Run # 63,67,68	Na	(Same as Run 56-59,62)		0.047	0.348
	K			0.073	0.540
	Mg			0.005	0.018
	Ca			0.025	0.094
				0.150	1.000
Run # 64-66, 69	Na	(Same as Run 56-59,62)		0.031	0.348
	K			0.048	0.540
	Mg			0.003	0.018
	Ca			0.017	0.094
				0.099	1.000
Run # 70	Na	0.428	0.188	0.244	0.264
	K	1.638	0.717	0.593	0.647
	Mg	0.048	0.010	0.028	0.015
	Ca	0.386	0.085	0.136	0.074
		2.500	1.000	0.991	1.000
Run # 72	Na	0.578	0.252	0.047	0.347
	K	1.532	0.666	0.073	0.538
	Mg	0.040	0.008	0.005	0.018
	Ca	0.342	0.074	0.025	0.097
		2.492	1.000	0.150	1.000

TABLE A-5 (Continued)

Composition of Make-up and Concentrated Feed Make-up Solutions for Decontamination Runs

A. CATION DECONTAMINATION (continued)

	Concentrated Feed Make-up			Make-up Stream	
	Cation	Eq/l	Mol Fraction	Eq/l	Mole Fraction
Run # 73	Na	(Same as Run 72)		0.031	0.347
	K			0.049	0.538
	Mg			0.003	0.018
	Ca			0.017	0.097
				0.100	1.000
Run # 74-80, 82	Na	1.24	0.663	0.049	0.663
	Ca	1.12	0.300	0.045	0.300
	Mg	0.14	0.037	0.006	0.037
		2.50	1.000	0.100	1.000
Run # 81	Ca	2.24	0.896	0.090	0.896
	Mg	0.26	0.104	0.010	0.104
		2.50	1.000	0.100	1.000

TABLE A-5 (Continued)

Composition of Make-up and Concentrated

Feed Make-up Solutions for Decontamination Runs

B. ANION DECONTAMINATION

	Anion	Make-Up Eq/l	Make-Up Mole Fraction
Run 42-46	$C_6H_5O_7$	0.203	0.221
	PO_4	0.200	0.220
	SO_4	0.006	0.009
	Cl	0.170	0.550
		0.579	1.000
Run # 46-55,60,61	$C_6H_5O_7$	0.203	0.493
	PO_4	0.200	0.485
	SO_4	0.006	0.022
		0.409	1.000

Note: In all runs the initial waste stream was prepared by diluting the concentrated make-up feed to a 0.1N solution.

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