

REPORT ON THE INVESTIGATION OF THE REMOVAL
OF IODINE (I¹³¹) AND STRONTIUM (Sr⁸⁹)
FROM WATER BY ION EXCHANGE RESINS

by

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TABLE OF CONTENTS

	Page
LIST OF TABLES	4
LIST OF ILLUSTRATIONS	6
ABSTRACT	8
Chapter	
I. INTRODUCTION	9
Nature of the Problem	9
Object of the Investigation	14
II. REVIEW OF LITERATURE	16
Ion Exchange	16
Iodine (I^{131})	21
Strontium (Sr^{89})	23
III. THE INVESTIGATION	25
Iodine (I^{131})	25
Procedure	25
Results	28
Discussion of Results	28
Conclusions	48
Summary	55
Strontium (Sr^{89})	56
Procedure	56
Results	59
Discussion of Results	59
Conclusions	79
Summary	81
Iodine (I^{131}) and Strontium (Sr^{89})	84
Procedure	84
Results	84
Discussion of Results	84
Conclusions	88
Summary	90

	Page
ACKNOWLEDGEMENT	97
BIBLIOGRAPHY	98
VITA	100

LIST OF TABLES

Table		Page
1.	Maximum Permissible Concentration Under Consideration for Certain Isotopes in Air and Water	10
2.	General Levels of Maximum Permissible Concentration of Radioactive Contaminants Suitable for Use Beyond the Control Area	11
3.	Number of Curies of Radioisotopes Shipped to Non-Project Users - Oak Ridge National Laboratory Data	14
4.	Characteristics of Commercially Available Ion Exchange Materials	22
5.	Analysis of "Grab" Sample of Tap Water at Oak Ridge National Laboratory	26
6.	Removal of Carrier-Free I^{131} by Anion Exchange Resins (Amberlite IRA-400 - Cl)	29
7.	Removal of Carrier-Free I^{131} by Anion Exchange Resins (Amberlite IRA-400 - OH)	33
8.	Removal of Carrier-Free I^{131} by Anion Exchange Resins (Amberlite IRA-400 - OH)	37
9.	Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - H and Amberlite IRA-400 - Cl)	40
10.	Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - Na and Amberlite IRA-400 - Cl)	44
11.	Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - H and Amberlite IRA-400 - OH)	47
12.	Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - Na and Amberlite IRA-400 - OH)	50
13.	Removal of I^{131} - Ion Exchange Resins - Operational Data.	53
14.	Removal of I^{131} - Ion Exchange Resins - Column Results. .	54

Table		Page
15.	Removal of Carrier-Free Sr ⁸⁹ by Cation Exchange Resins (Amberlite IR-120 - Na)	60
16.	Removal of Carrier-Free Sr ⁸⁹ by Cation Exchange Resins (Amberlite IR-120 - H)	64
17.	Removal of Carrier-Free Sr ⁸⁹ by Cation Exchange Resins (Amberlite IR-120 - Ca)	66
18.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - H and Amberlite IRA-400 - Cl)	69
19.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - Na and Amberlite IRA-400 - Cl)	71
20.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - H and Amberlite IRA-400 - OH)	73
21.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IR-120 - Na and Amberlite IRA-400 - OH)	75
22.	Removal of Sr ⁸⁹ - Ion Exchange Resins - Operational Data.	80
23.	Removal of Sr ⁸⁹ - Ion Exchange Resins - Column Results. .	82
24.	Removal of Carrier-Free I ¹³¹ and Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IRA-400 - OH and Amberlite IR-120 - H)	86
25.	Removal of Carrier-Free I ¹³¹ and Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Resins (Amberlite IRA-400 - OH and Amberlite IR-120 - Na)	88
26.	Removal of I ¹³¹ and Sr ⁸⁹ - Ion Exchange Resins - Operational Data	91
27.	Removal of I ¹³¹ and Sr ⁸⁹ - Ion Exchange Resins - Column Results	92

LIST OF ILLUSTRATIONS

Plate	Page
I. View of Apparatus Used in Strontium Runs and in Strontium and Iodine Runs	95
II. Close-Up View, Showing Arrangement of Lucite Column, G-M Tube, and Lead Shield	96
 Figure	
1. Monthly Shipments of Radioisotopes - Oak Ridge National Laboratory	12
2. Number of Radioisotopes Shipped Monthly - Oak Ridge National Laboratory - Non-Project Only	13
3. Removal of Carrier-Free I^{131} by Anion Exchange Column (Amberlite IRA-400 - Cl)	31
4. Removal of Carrier-Free I^{131} by Anion Exchange Column (Amberlite IRA-400 - OH)	35
5. Removal of Carrier-Free I^{131} by Anion Exchange Column (Amberlite IRA-400 - OH)	38
6. Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Column (Amberlite IR-120 - H and Amberlite IRA-400 - Cl)	42
7. Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Column (Amberlite IR-120 - Na and Amberlite IRA-400 - Cl)	46
8. Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Column (Amberlite IR-120 - H and Amberlite IRA-400 - OH)	49
9. Removal of Carrier-Free I^{131} by Mixed Bed Ion Exchange Column (Amberlite IR-120 - Na and Amberlite IRA-400 - OH)	52
10. Cutaway of Lucite Column and G-M Tube	58
11. Removal of Carrier-Free Sr^{89} by Cation Exchange Column (Amberlite IR-120 - Na)	61

Figure		Page
12.	Absorption Curves of the Activity of Influent and Effluent	63
13.	Removal of Carrier-Free Sr ⁸⁹ by Cation Exchange Column (Amberlite IR-120 - H)	65
14.	Removal of Carrier-Free Sr ⁸⁹ by Cation Exchange Column (Amberlite IR-120 - Ca)	67
15.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IR-120 - H and Amberlite IRA-400 - Cl)	70
16.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IR-120 - Na and Amberlite IRA-400 - Cl)	72
17.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IR-120 - H and Amberlite IRA-400 - OH)	74
18.	Removal of Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IR-120 - Na and Amberlite IRA-400 - OH)	76
19.	Plating Out of Y ⁹¹ on Stainless Steel Tank	78
20.	Removal of Carrier-Free I ¹³¹ and Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IRA-400 - OH and Amberlite IR-120 - H)	87
21.	Removal of Carrier-Free I ¹³¹ and Carrier-Free Sr ⁸⁹ by Mixed Bed Ion Exchange Column (Amberlite IRA-400 - OH and Amberlite IR-120 - Na)	89

ABSTRACT

The investigation was conducted to determine the efficiency of ion exchange resins in the removal of carrier-free radioiodine (I^{131}) and carrier-free radiostrontium (Sr^{89}) from tap water. The data collected indicated excellent positive results.

The concentration of the isotope used in this series of tests was approximately 1.70×10^{-2} uc/ml, and the tap water used for dilution was that furnished to the Oak Ridge National Laboratory.

The resins used were the strongly basic type anion resin Amberlite IRA-400 and the strongly acid type cation resin Amberlite IR-120. The anion resin was used on the chloride and hydroxide cycles and the cation resin was used on the hydrogen, sodium and calcium cycles.

The investigation was conducted in three parts: (a) the removal of I^{131} by an anion resin bed and a mixed resin bed; (b) the removal of Sr^{89} by a cation resin bed and a mixed resin bed; and (c) the removal of a mixture of I^{131} and Sr^{89} by a mixed resin bed. The mixed bed was composed of twenty-four inches of anion resin and an equivalent amount (11.25 inches) of cation resin.

In all instances, superior removals were obtained by the mixed resins beds: for the radioiodine, with the anion resin on the hydroxide cycle and the cation resin on the hydrogen cycle; for the radiostrontium, with the cation resin on the sodium cycle and the anion resin on the hydroxide cycle; and for the mixed isotopes, with the anion resin on the hydroxide cycle and the cation resin on the hydrogen cycle.

CHAPTER I
INTRODUCTION

Nature of the Problem

The problem of handling and disposing of liquid wastes containing radioactive materials has increased manifold since the advent of the "Atomic Age." Prior to this time, only those few industries engaged in the manufacture of luminous dials and other such instruments were concerned with this problem. Since 1946, however, radioisotopes have become an important research tool for both industry and medicine, and their use is becoming more widespread each year.

Since its inception, the Atomic Energy Commission has been aware of the hazards created by the production of radioactive materials, and stringent rules for their processing, handling and disposal have been formulated. The ideal situation, set as its goal by the Atomic Energy Commission, is that of no discharge whatsoever of radioactive material to nature. Such an ideal solution is, however, impractical at the present time, and instead maximum permissible concentration (MPC) values (6) have been set up for the different isotopes, in both air and water. Table 1 (6) shows the MPC values for certain isotopes, and Table 2 (6) shows the MPC values for radioactive contaminants in water and air. Both tables refer to usages beyond the control area.

The rapid growth of the use of radioisotopes for industrial, medical, and other research purposes is shown graphically by Straub and Pecsok (13) in Figure 1, which gives the total number of shipments from the Oak

Ridge National Laboratory from August, 1946, to October, 1951. These shipments are broken down into foreign, project, non-project and unspecified groups. The non-project shipments are much greater than those of any other classification, indicating that, although the method of disposal of these isotopes is governed by the Atomic Energy Commission, local facilities must be used.

TABLE 1

MAXIMUM PERMISSIBLE CONCENTRATION UNDER CONSIDERATION FOR CERTAIN RADIOISOTOPES IN WATER AND AIR (MORGAN, 1951) (6)

Element	Half-Life	Microcuries per cc (uc/cc)	
		In Water	In Air
Ra ²²⁶	1,620 years	4×10^{-8}	8×10^{-12}
C ¹⁴ (CO ₂)	5,720 years	3×10^{-3}	5×10^{-7}
P ³²	14.3 days	2×10^{-4}	1×10^{-7}
Sr ⁸⁹	53 days	7×10^{-5}	4.3×10^{-8}
I ¹³¹	8.0 days	3×10^{-5}	3×10^{-9}
Sr ^{90*}	25 years	8×10^{-7}	2×10^{-10}

* in equilibrium with Y⁹⁰ which has a half-life of 61 hours

The number of curies of all radioisotopes shipped from Oak Ridge National Laboratory to non-project users only during the period August, 1946, to October, 1951, is listed in Table 3 (13). The same information is presented graphically in Figure 2 (13), where the amount of I¹³¹ and

P^{32} , the radioisotopes most commonly used, is indicated separately.

TABLE 2

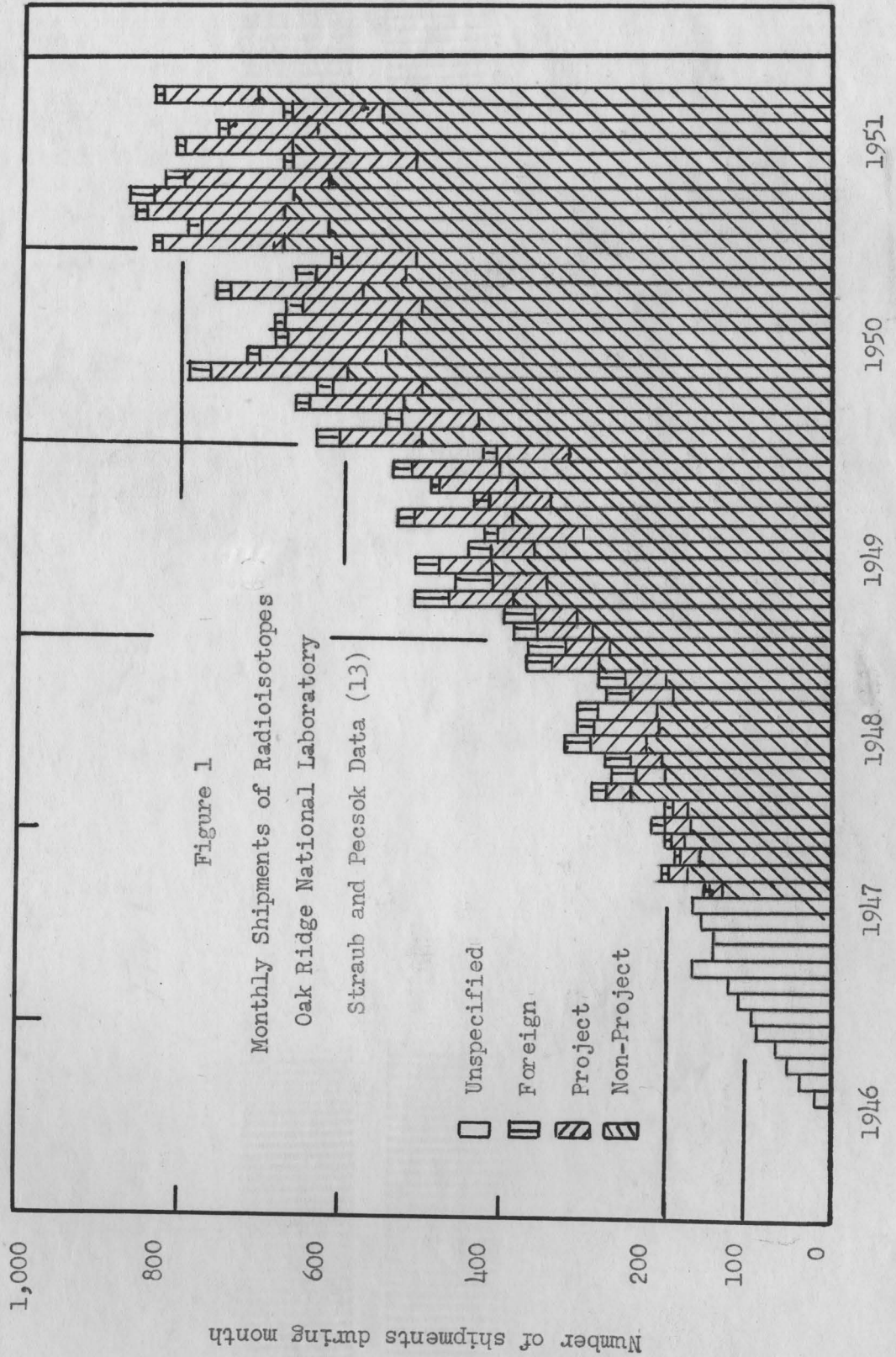
GENERAL LEVELS OF MAXIMUM PERMISSIBLE CONCENTRATION
OF RADIOACTIVE CONTAMINANTS SUITABLE FOR USE
BEYOND THE CONTROL AREA (MORGAN, 1951)* (6)

Medium in Which Contained	Maximum Permissible Concentrations in uc/cc	
	or Emitter	Emitter
Air	10^{-9}	5×10^{-12}
Water	10^{-7}	10^{-7}

* To be considered as safe values until the identity of the isotope is determined and then the recommended value for that particular isotope will be used provided such a value has been established.

The disposal problem occasioned by the quantity of radioisotopes now used presents no great problem. However, as more personnel are trained in the handling and use of these radioactive materials, it is anticipated that this disposal problem will grow, as a result of their increased usage. This problem, moreover, will be nation-wide in its scope, since even now these non-project users are located in every state of the union.

One of the most common methods of disposal of radioisotopes after use is to discharge them in a greatly diluted state into the sewerage system. As a result, some of these may find their way into a natural water system. If this water is used later as a source of water supply by humans and animals, extreme care must be taken to see that any radioactivity present is below the MPC value given for continuous ingestion of any isotope or isotopes present.



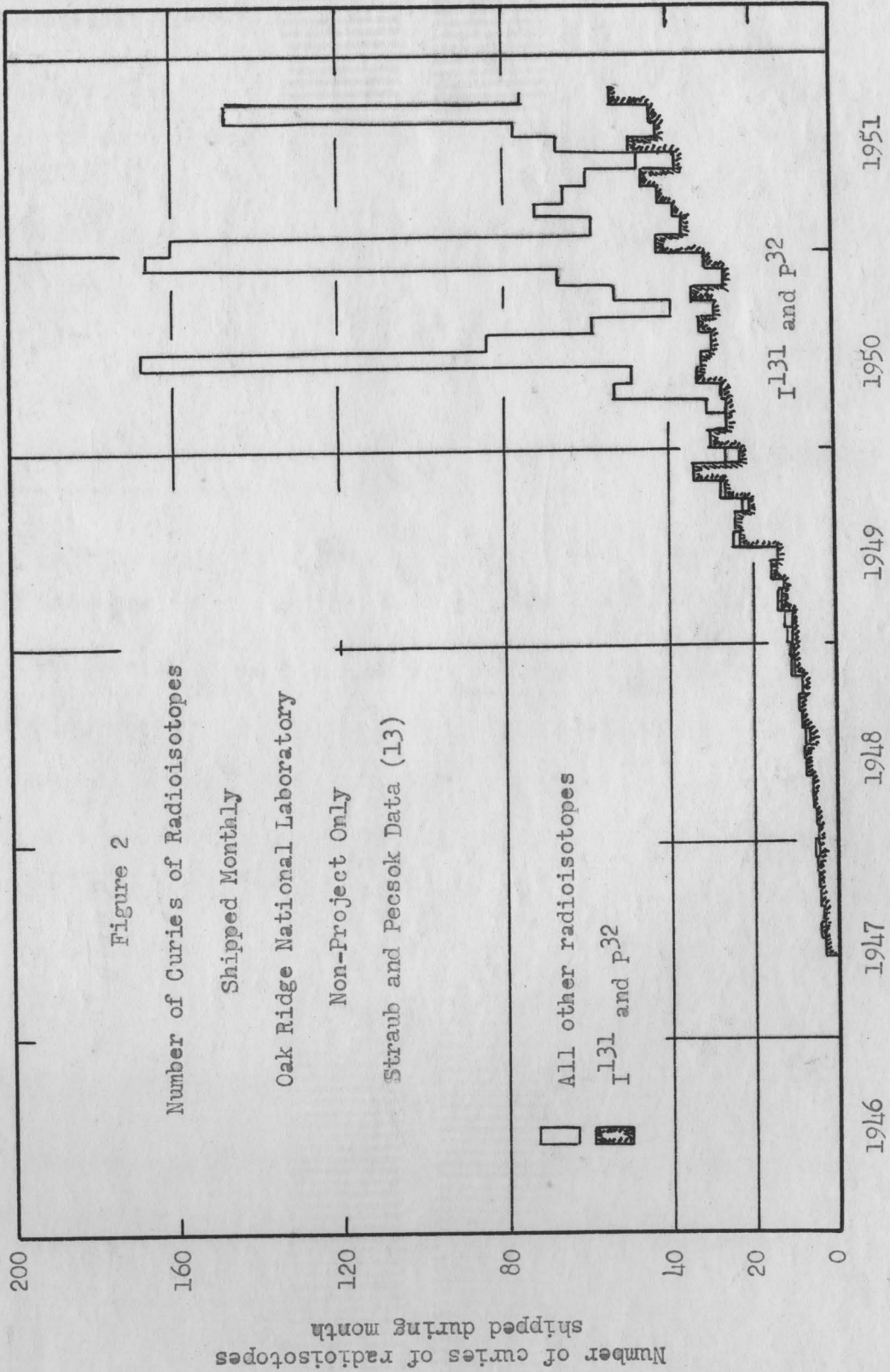


TABLE 3

NUMBER OF CURIES OF RADIOISOTOPES SHIPPED TO NON-PROJECT USERS
OAK RIDGE NATIONAL LABORATORY DATA
(STRAUB AND PECSOK, 1951) (13)

Period of Time	Total Curies Shipped	
	During Interval	Since Start
1946 (a)	4.6	4.6
1947	41.745	46.345
1948	86.313	132.658
1949	271.751	404.409
1950	825.058	1,229.467
1951 (b)	826.75	2,056.217

(a) 5 months

(b) 10 months

Considerable work has been done by waste disposal groups both at the Oak Ridge National Laboratory and elsewhere to evaluate the efficiency of the removal of radioactive materials from waste by sewage treatment methods (2), and from raw water by water treatment methods (3) (5) (12) (13). The present project was therefore carried out to supplement work already accomplished, and to add more knowledge to the field for later use, if the problems anticipated present themselves.

Object of the Investigation

The purposes of this investigation were to evaluate the efficiency of (a) a strongly basic type anion exchange resin in the removal of

carrier-free I^{131} (as iodide) diluted in tap water when used alone on the hydroxide and chloride cycles and when mixed with an equivalent amount of a strongly acid type cation exchanger on the hydrogen and sodium cycles; (b) a strongly acid type cation exchange resin in the removal of carrier-free $Sr^{89}Cl_2$ diluted in tap water when used alone on the hydrogen and sodium cycles and when mixed with an equivalent amount of a strongly basic type anion exchange resin on the hydroxide and chloride cycles; and (c) a mixed bed ion exchange column in the removal of a mixture of I^{131} (as iodide) and $Sr^{89}Cl_2$ diluted in tap water, the resin bed being composed of a strongly basic type anion exchange resin on the chloride and hydroxide cycles and an equivalent amount of a strongly acid type cation exchange resin on the hydrogen and sodium cycles.

CHAPTER II
REVIEW OF LITERATURE

Ion Exchange

The phenomenon of ion exchange was first observed in soil experiments. In 1850, two agricultural chemists, H. W. Thompson and J. Thomas Way (8), reported on the exchange properties of certain soils. In their experiments they had found that certain types of soils were more capable of adsorbing and holding the ammonia in fertilizer than others. Pursuing this phenomenon further, they decided that such an action was due to the complex silicates present in the soils, and concluded that ion exchange was taking place. As George E. Boyd (1) has stated, "their observations that the exchange of ions involved equivalent quantities and that certain ions are more readily exchanged than others have stood the test of time."

The term "zeolite," which is commonly used to cover all inorganic base exchange materials and is sometimes improperly used to cover the entire field of ion exchange, was first used by Eichorn (8), when he observed that the materials he used would swell or boil up when a gas flame was applied to them. The word itself is derived from two Greek words meaning "boiling stone." In 1858 Eichorn further discovered that this ion exchange process was reversible.

The first industrial use of ion exchange was attempted by Harms (8) in 1896. His effort to purify sugar juice by use of base exchange silicates was only partly successful. Robert Gans (8), in 1906, was the first to suggest the use of ion exchange materials for the purpose of

softening water. In 1935, Adams and Holmes (8) developed the first synthetic ion exchange resins, and possibly this has proven to be the most significant step in ion exchange history.

The explanations for the phenomenon of ion exchange may be grouped under three theories: (a) the crystal lattice theory, (b) the double layer theory, and (c) the Donnan membrane theory.

The crystal lattice theory explains ion exchange by assuming that in an ionic solid the constituents are not present as molecules, but as ions. Complete dissociation is consequently assumed, e.g., a crystal of sodium chloride is not made up of sodium chloride molecules, but of sodium ions and chloride ions. Each ion in the crystal is surrounded by a certain number of ions of opposite charge, and since the coulomb attractive force between these ions is dependent upon the charge on the ions and the distance between them, it can be seen that the ions on the surface are bound less closely than those in the interior. When placed in a medium such as water, these surface ions may be easily replaced by ions in solution.

According to Kunin and Myers (4), "the ease with which the surface ions may be replaced by another ion depends therefore on (a) the nature of the forces binding the ion to the crystal, (b) the concentration of the exchanging ion, (c) the charge of the exchanging ion, (d) sizes of the two ions, (e) the accessibility of lattice ions, and (f) solubility effects."

The Helmholtz double layer theory as formulated to explain the electrokinetic properties of colloids is accepted by some scientists to explain ion exchange. The exchange material is imagined as a fixed inner layer of charges surrounded by a diffuse and mobile outer layer of charges

which extends into the external liquid medium. Kunin and Myers (4), in referring to ion exchange, state that "there is no sharp boundary between the ions in the diffuse outer layer and those in the equilibrium external medium, and we may consider the concentration of the ions constituting the diffuse layer as varying continuously and depending upon the concentration and pH of the external solution." Accordingly, any change in the concentration of the ions in the external solution upsets the equilibrium; a new equilibrium is obtained, and some of the new ions will enter into the outer diffuse layer and replace some of the ions held there.

The Donnan membrane theory pertains to the unequal distribution of ions on two sides of a membrane, when one side contains ions too large to diffuse through the membrane. An unequal distribution will occur because of the undiffusible ion and the necessity of maintaining electro-neutrality.

In applying the latter theory to ion exchange, the exchange material is assumed to be the ion too large to diffuse, and although in ion exchange no membrane is used, the interface between the solid and liquid phases is assumed to represent a membrane.

Kunin and Myers (4) tell us that "essentially all the ion exchange theories are quite similar in that the exchange of ions must obey the laws of electroneutrality. The only differences in the various theories then are the position and origin of the exchange site. In all cases this site is essentially an ionic grouping capable of forming an electrostatic bond with an ion of opposite charge."

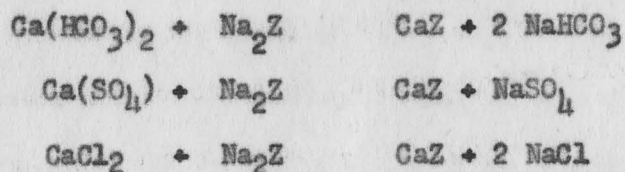
The affinity of an ion for the ion exchanger (cation for the cation

exchanger and anion for the anion exchanger) increases with an increase in valence at low concentration. The following order of affinity can then be made: quadrivalent trivalent bivalent monovalent.

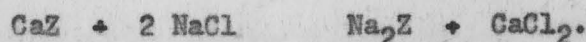
For ions of the same valence, the affinity increases with a decrease in the hydrated ionic radius of the ion or with increasing basicity. Accordingly, the sequence of adsorption among the alkali metals will be Cs⁺ Rb⁺ K⁺ NH₄⁺ Na; for the alkaline earth cations it will be Ba⁺⁺ Sr⁺⁺ Ca⁺⁺ Mg⁺⁺, while for the transition metals the series will be Zn⁺⁺ Cu⁺⁺ Ni⁺⁺ Co⁺⁺ Fe⁺⁺, and for the rare earths La⁺³ Ce⁺³ Pr⁺³ Nd⁺³ Sm⁺³ Eu⁺³ Y⁺³ Sc⁺³ Al⁺³. For the halogen anions it will be I⁻ Br⁻ Cl⁻ F⁻.

Moreover, for ions of the same valence at low concentrations the extent of exchange increases with an increase in atomic weight: Li Na K Rb Cs.

The inorganic exchange materials must be operated in the sodium cycle because the acids used to regenerate for the hydrogen cycle have a detrimental effect on the material. Typical exchange reactions are:

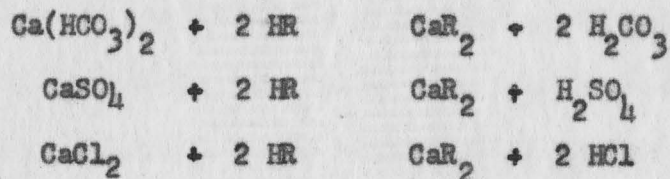


where Z is any inorganic exchange material, and for regeneration as follows, the reaction moving to the right because of the high concentration of the sodium ion on the left:

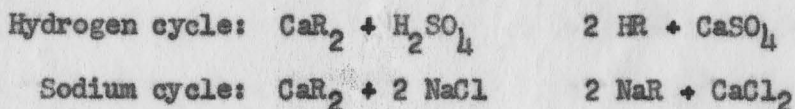


For organic cation exchange resins on the hydrogen cycle the

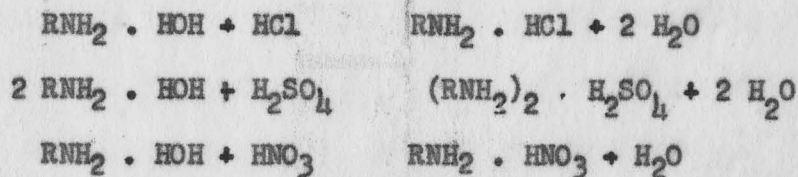
exchange reaction may be written:



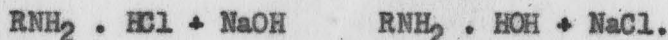
where R is any organic cation exchange resin. For regeneration, the equation is as follows, the reactions moving to the right because of the high concentrations of the hydrogen and sodium ions on the left:



For the organic anion resins the exchange reaction may be written:



where R is any anion exchange resin. For regeneration, the equation is as follows, the reaction moving to the right because of the high concentration of the hydroxide ion on the left:



As the attempts to apply ion exchange reactions to commercial processes advanced, the limitations of the siliceous exchange materials became more evident. It was found that, unless these naturally-occurring zeolites were used between the pH ranges of 6.0 to 8.3, decomposition would occur. The zeolites also tended to decompose through the leaching out of silica by the water being softened. Moreover, their capacities were very small, ranging from about 0.06 to 1.2 milliequivalents per gram, and it was for this reason that the discoveries of Adams and Holmes were

hailed by those working in the ion exchange field. They now had available an exchange resin which would operate over a wide range of pH, e.g., Amberlite IR-120, operating from a pH of 1 to 12. In addition, the resin was very resistant to leaching, had a relatively high capacity (Amberlite IR-120 has a capacity of 4.2 milliequivalents per gram), and could be operated on the hydrogen cycle. Table 4 (h) gives names and capacities of some of the more commonly used exchange materials.

The synthesis of the anion exchange resins greatly enlarged the field of the application of ion exchange. With the use of the proper resins and techniques, all ions can now be removed from a solution; the operation of columns using the hydrogen-hydroxide cycle results in ion-free water which in many ways is equal to or superior to distilled water.

Some of the processes for which ion exchange resins are now being used include:

1. the conditioning of water for boiler feed
2. the conditioning of water for product quality
3. as an analytical material
4. the removal of contaminants
5. the recovery of valuable metals
6. in the pharmaceutical industry
7. as a therapeutic agent, e.g., in order to

exchange the sodium in food after ingestion.

Iodine (I^{131})

I^{131} is one of the most common radioactive isotopes now produced.

TABLE 4

CHARACTERISTICS OF COMMERCIALY AVAILABLE
ION EXCHANGE MATERIALS (4)

Name	Manufacturer	Type	Capacity (milliequivalents per gram)
Cation Exchangers			
Montmorillonite	----	Aluminum silicate	0.8 - 1.2
Kaolinite	----	" "	0.06 - 0.10
Glauconite	----	" "	0.18 - 0.2
Permutit	Permutit	" "	1.0 - 3.0
Amberlite IR-105	Rohm & Haas	Phenolic methylene sulfonic	2.70
Dowex 30	Dow Chemical	" " "	4.00
Duolite C-3	Chemical Process	" " "	3.25
Ionac C-200	American Cyanamid	" " "	2.70
Wofatit K	I. G. Farben	" " "	2.50
Zeo Rex	Permutit	" " "	2.70
Zeo Karb	Permutit	Sulfonated coal	1.62
Amberlite IR-120	Rohm & Haas	Nuclear sulfonic	4.20
Dowex 50	Dow Chemical	" "	4.25
Amberlite IRC-50	Rohm & Haas	Carboxylic	10.00
Duolite CS-100	Chemical Process	"	3.85
Permutit 216	Permutit	"	5.30
Wofatit C	I. G. Farben	"	7.00
Anion Exchangers			
Amberlite IR-4B	Rohm & Haas	Weak base	10.00
Amberlite IRA-400	Rohm & Haas	Strong base	2.50
Duolite A-2	Chemical Process	Weak base	7.00
Wofatit M	I. G. Farben	Weak base	--
Dowex 1	Dow Chemical	Strong base	2.40

Its use in hospitals for treatment and research is widespread. In the event of an atom bomb blast, I^{131} is one of the materials which would be produced, its fission yield being about 2.8%. It has accordingly become a matter of urgency that methods for the removal of this radioactive isotope from water intended for ingestion be studied.

Straub, Morton and Flacak (12) have reported that, when initial concentrations of 3700 to 5600 d/min/ml were employed in pilot plant operation, less than 0.4% of I^{131} was removed by the water treatment techniques of coagulation, sedimentation and filtration. Additions of 4 ppm activated carbon increased removals to 25%.

Straub (11) reported removals of I^{131} in excess of 90% of aerated and stirred activated sludge. This author also reported (11) that raw sewage would remove 17 to 27% of carrier-free I^{131} .

Carter (2), in his studies at the Oak Ridge National Laboratory, found that a laboratory model low-rate trickling filter could be expected to remove in excess of 85% of the carrier-free I^{131} when dosed with settled sewage at the rate of 2 mgad. Straub (11) further investigated the effect of increased flow rates, and found that a removal of 50% could be obtained at dosing rates of 4.1 - 4.45 mgad. The addition of carrier KI reduced removals to as low as 5%.

Strontium (Sr^{89})

Strontium is an element with properties similar to those of calcium. It is classified as a "bone seeker," and is retained in the body for an appreciable length of time. The fission yield of Sr^{89} is

4.6%, and this isotope is one that might cause contamination of a water supply in the event of an atom bomb blast.

Lauderdale (5), in his studies with phosphate precipitation, reported a removal of 97.8% of Sr^{89} in water with a one stage batch treatment. He further reported that coagulation with alum gave a decontamination factor of 1.1; with ferric chloride, of 1.02; with monopotassium phosphate, of 5.3; and with tri-sodium phosphate, of 45.5.

Straub, Morton, and Placak (12) have reported about 20% removal of Sr^{89} from water by addition of 400 ppm turbidity and using a rapid mix. The turbidity used was local soil from the vicinity of the Oak Ridge National Laboratory. The increase of this turbidity to 3400 ppm resulted in removals of about 40%. The same authors further reported no removal of Sr^{89} from water by coagulation with alum and NaOH, but, with the addition of 103 ppm turbidity, removal by this procedure was about 7.4% after coagulation, settling and centrifuging.

During the same investigations (12), coagulation with alum and Na_2CO_3 resulted in removal of Sr^{89} in water of 5.8%. With the addition of 103 ppm turbidity, this removal was increased to 18.7% after centrifuging. In coagulation tests with ferric chloride and NaOH, 20.2% of the Sr^{89} was removed from water after settling. Centrifuging increased this removal to 21.5%.

CHAPTER III

THE INVESTIGATION

Iodine (I^{131})

Procedure. In planning the experiments for the removal of iodine from water it was decided to use tap water mixed with the carrier-free radioactive iodine (as an iodide) as the influent solution to the resin columns, in order to approach as nearly as possible conditions which may be met in the field.

The I^{131} as received from the Operations Division of the Oak Ridge National Laboratory is in the form of an iodide and is in a solution of sodium sulphite (Na_2SO_3), the solution having a pH of 11.

Table 5 shows an analysis of the tap water used. It should be borne in mind, however, that the analysis is that of a "grab" sample, and not of a composite sample collected through the duration of the runs. The analysis of the tap water at the Laboratory will change from day to day depending upon the operation of Norris Dam, the rainfall in the area, and mainly upon the operation of the water treatment plant. The amount of dissolved oxygen in the water affects the state of the iodine, oxidizing it from the iodide form to atomic iodine and possibly to an iodate form I^- I IO^- IO_3^- , while the carbon dioxide dissolved in the water affects the normal carbonate-bicarbonate balance. To restate this point: although the analysis of the tap water in Table 5 is that of a representative sample, the minor changes which might have occurred during the duration of these tests were not taken into account.

TABLE 5

ANALYSIS OF "GRAB" SAMPLE OF TAP WATER
AT OAK RIDGE NATIONAL LABORATORY

Constituents	Concentrations (ppm)
Ppm. Alkalinity as CaCO ₃	0.0
M. O. Alkalinity as CaCO ₃	99.0
Soap Hardness as CaCO ₃ detn.	108.0
Soap Hardness as CaCO ₃ calc.	99.4
Dissolved CO ₂	1.0
Dissolved Solids	142.5
Non-Volatile Solids	73.0
SiO ₂	3.9
Fe	.03
Al	.05
Cu	.05
Ni	.05
Cr	.05
U	-
Ca	27.3
Mg	7.6
Na	4.49
SO ₄	9.0
Cl	3.7
CO ₃	59.4
HCO ₃	120.8
NO ₃	1.75
PO ₄	1.6
F	1.0

pH 7.3

Specific resistance (18° C.) 5.6 x 10³ ohms

The column used for the first three runs in these tests was made from three 18-inch lengths of 1/4 inch. glass tubing. Eight inches of exchange resin were placed in each tube, and all three tubes were connected in series to give a resin bed depth of 24 inches, as recommended by the manufacturer, amounting to about 37 cc. of wet resin. Two-hole stoppers were placed at the bottom of each column, so that a sample could be drawn off for each third of the column. Before being placed in the columns the resin was back-washed and hydraulically graded in a sectional lucite column, so that the first column was representative of the upper third of a resin bed as it would be found in actual use, the second column of the middle third, and the third column of the lower third.

The resin used in Runs 1, 2 and 3 was a strongly basic type anion exchanger, IRA-400, manufactured by Rohm & Haas of Philadelphia.

The column used for the mixed bed runs (Runs 4, 5, 6 and 7) was a 48-inch length of 1/4 inch. glass tubing. All the resins were placed in this one tube, and the samples were drawn off at the bottom of the column only. For each of these runs, 24 inches of anion resin and 11.25 inches of cation resin were used, this ratio corresponding closely to the capacities of the resins (that of the cation being 2.15 milliequivalents per milliliter, that of the anion 1.00 milliequivalent per milliliter). The cation exchange resin used was IR-120, a strongly acid, nuclear sulphonic type exchanger also manufactured by Rohm & Haas.

The flow rate of the influent through the column for all runs except Run 3 was 2.5 gallons per cubic foot per minute. For Run 3 the flow rate was increased 50% to 3.75 gallons per cubic foot per minute, in order

to determine the effect of an increased flow rate upon the removal.

The final effluent from the column discharged into a 50-milliliter beaker in which the electrodes (glass and calomel) of a Beckman pH meter were placed, the overflow passing to the drain. The pH meter was connected to an Esterline-Angus Graphic Ammeter which recorded the pH of the effluent during each run. The pH curves on Figures 3 to 9 inclusive are plotted from data interpolated from the chart of the Esterline-Angus Graphic Ammeter.

All samples collected during these runs were at twenty-minute intervals and two milliliters in quantity, and were dried in aluminum counting dishes. In cases where the pH was above 7 (I^{131} in an iodide form), these samples were dried by use of infra-red heat lamps; in cases of a lower pH they were air-dried at room temperature in a hood.

The samples were counted in a standard end window G-M Tube with a mica window, connected to a 64 scaler.

Results. Results of Runs 1 to 7 inclusive are contained in Tables 6 to 12, and are presented graphically in Figures 3 to 9, inclusive. The pH values presented in these tables and plotted in the figures are interpolated from the Esterline-Angus Graphic Ammeter charts.

Discussion of results. RUN 1 (Table 6, Figure 3). The resin used in this run was placed on the chloride cycle by elution with one liter 6N HCl, this giving about 27 volumes of acid to about one volume of resin.

Because of the low pH at which this run took place, the I^{131} was

TABLE 6

REMOVAL OF CARRIER-FREE I¹³¹ BY ANION EXCHANGE RESINS

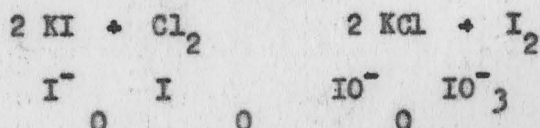
Resin: Amberlite IRA-400 - Cl
 Activity of Influent: 3526 c/min/ml
 Flow Rate: 2.5 gallons/cu. ft./min.
 Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)			pH of Final Effluent
		(upper third)	(middle third)	(lower third)	
1	0.64	261	91	51	6.20
2	1.28	376	86	86	6.00
3	1.92	778	145	76	5.80
4	2.56	936	234	71	5.55
5	3.20	1229	338	96	5.65
6	3.84	1238	463	77	5.80
7	4.48	1635	714	223	5.75
8	5.12	1610	893	254	5.75
9	5.76	1662	1135	336	5.75
10	6.40	1566	1283	526	5.75
11	7.04	1562	1189	732	5.75
12	7.68	1861	1422	750	5.80
13	8.32	1990	1500	887	5.85
14	8.96	1879	1474	1150	5.95
15	9.60	1965	1574	1181	6.15
16	10.24	1843	1262	1321	6.20
17	10.88	2252	1490	945	6.25
18	11.52	2194	1250	1620	6.25
19	12.16	2247	1677	1475	6.30
20	12.80	2417	1705	1334	6.37
21	13.44	2411	1951	1330	6.40
22	14.08	2176	1987	1654	6.46
23	14.72	2722	1788	1705	6.53
24	15.36	2373	1733	1680	6.59
25	16.00	2490	2157	1857	6.61
26	16.64	2543	2035	1777	6.70
27	17.28	2652	1970	1759	6.70
28	17.92	2437	2274	1906	6.75
29	18.56	2737	2367	1586	6.80
30	19.20	2820	2621	1746	6.80
31	19.84	2855	2539	2035	6.82

TABLE 6 - Continued

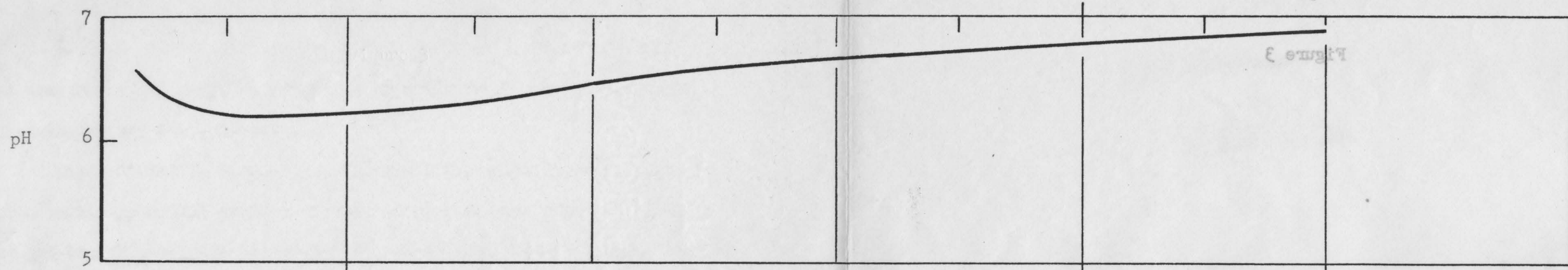
Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)			pH of Final Effluent
		(upper third)	(middle third)	(lower third)	
32	20.48	2547	2523	1822	6.83
33	21.12	2409	1879	2265	6.86
34	21.76	2992	2199	2504	6.90
35	22.40	1982	2638	2939	7.00
36	23.04	2739	2367	1844	7.10
37	23.68	3026	2227	2252	7.15
38	24.32	2412	2378	3014	7.15
39	24.96	2390	2602	2631	7.15
40	25.60	2947	2299	2005	7.20

probably in both the atomic iodine and the iodide states, as it is difficult to retain the iodide state in an acid medium. The removal therefore was accomplished by both ion exchange and either adsorption on the resin or chemical combination with it. In addition, the dissolved oxygen and chlorine in the water would have a tendency to oxidize the iodide to an iodine form:



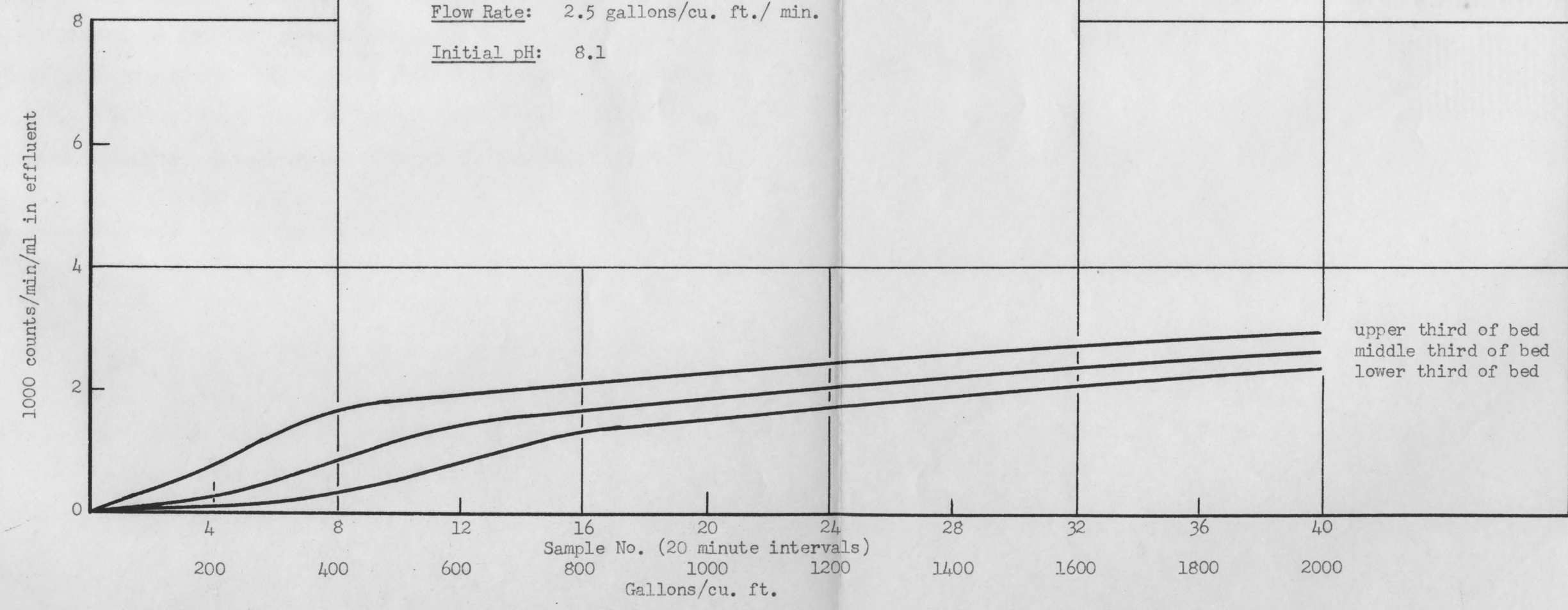
The pH of the influent solution (tap water and carrier-free I^{131}) was 8.1. From Table 6 and Figure 3 it will be seen that the pH quickly dropped to a value of 5.55 at Sample 4 (2.56 liters) and then gradually rose to a value of 7.2 at Sample 40 (25.6 liters). The drop in pH was due to the replacement of the anions in the influent solution by the strongly acid chloride anion.

Figure 3



380-10
 REMOVAL OF CARRIER-FREE I^{131} BY ANION EXCHANGE COLUMN
 380-8

Resin: Amberlite IRA-400 - Cl - 24.0 inches
Activity of Influent: 3526 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./ min.
Initial pH: 8.1



A study of the results from this run (Table 6, Figure 3) shows that considerable leakage* was evident from the first sample, gradually increasing as the run progressed.

RUN 2 (Table 7, Figure 4). For Run 2 the exchange resin was placed on the hydroxide cycle by regeneration with two liters of 6% sodium hydroxide**, this giving about 54 volumes of eluting solution to one volume of resin.

Good removal was accomplished by this resin bed. The data for the run indicate that up to the breakthrough point at Sample 26 (16.7 liters), the decontamination factor*** was 180 for a removal of about 99.45%. The breakthrough occurred when approximately 17 liters of the influent had passed through the bed for an indicated capacity of 2600 gallons per square foot, or 1300 gallons per cubic foot for a two-foot column. For this 17 liters of water, the average count was 17.1 c/min/ml. For an assumed counting efficiency of 10% (geometry), this is equivalent to a concentration of 7.7×10^{-5} microcuries per milliliter (uc/ml), or about 2.5 times the maximum permissible concentration (MPC) for I^{131} in drinking water which is given as 3×10^{-5} uc/ml.

* "Leakage" is the passage of some of the influent ions through the resin bed. It is expressed as a percentage, and is mathematically defined as

$$L = \frac{C}{C_0} \times 100 \quad \text{where } C_0 = \text{concentration of influent, and } C = \text{concentration of effluent}$$

** In this report percentage solutions are calculated by weight

*** Decontamination factor is defined as $\frac{\text{c/min/ml in influent}}{\text{c/min/ml in effluent}}$

TABLE 7

REMOVAL OF CARRIER-FREE I¹³¹ BY ANION EXCHANGE RESINS

Resin: Amberlite IRA-400 - OH
 Activity of Influent: 3082 c/min/ml
 Flow Rate: 2.5 gallons/cu. ft./min.
 Initial pH: 8.1

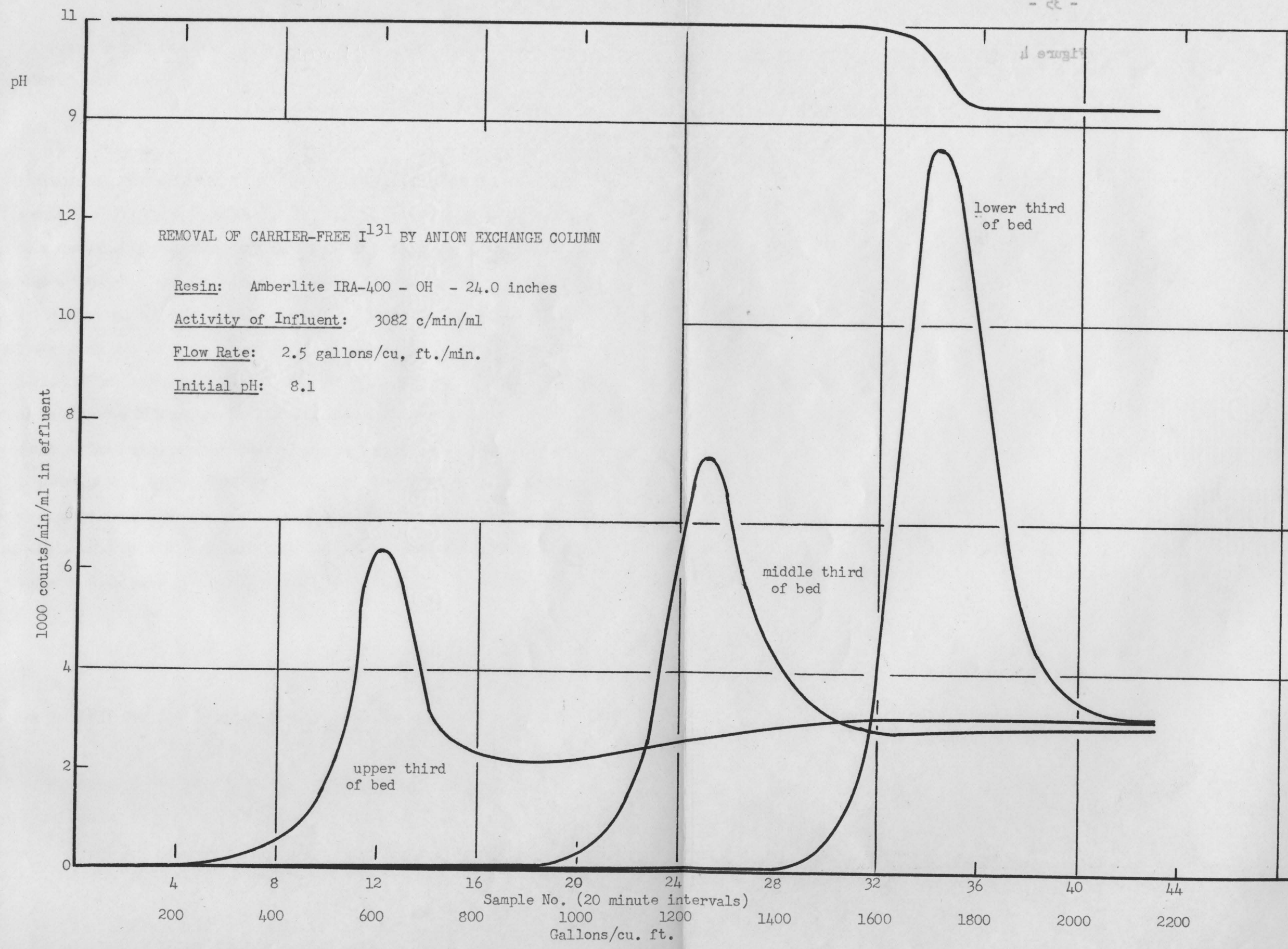
Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)			pH of Final Effluent
		(upper third)	(middle third)	(lower third)	
1	0.64	28	9	7	10.98
2	1.28	28	11	4	10.99
3	1.92	49	9	8	11.00
4	2.56	65	14	8	11.00
5	3.20	86	16	7	11.00
6	3.84	143	15	13	11.00
7	4.48	206	22	9	11.00
8	5.12	514	22	6	11.00
9	5.76	979	16	11	11.00
10	6.40	1887	35	10	11.00
11	7.04	3690	21	13	11.00
12	7.68	6321	24	16	11.00
13	8.32	5336	26	22	11.00
14	8.96	3325	25	16	11.00
15	9.60	2323	36	13	11.00
16	10.24	2283	44	15	11.00
17	10.88	2389	58	17	11.00
18	11.52	2150	87	18	11.00
19	12.16	1948	148	10	11.00
20	12.80	2095	444	22	11.00
21	13.44	2537	762	27	10.95
22	14.08	2420	1818	28	10.95
23	14.72	2273	3796	22	10.95
24	15.36	2717	5587	25	10.95
25	16.00	2632	8289	20	10.95
26	16.64	2675	7205	30	10.95
27	17.28	2465	5136	73	10.95
28	17.92	2465	4125	76	10.95
29	18.56	2886	3759	190	10.95
30	19.20	3157	3111	2385	10.95

TABLE 7 - Continued

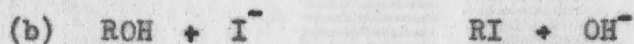
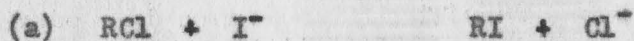
Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)			pH of Final Effluent
		(upper third)	(middle third)	(lower third)	
31	19.84	3189	2979	3070	10.80
32	20.48	3143	3093	4694	10.71
33	21.12	3057	3072	10163	10.59
34	21.76	3023	2828	14257	10.49
35	22.40	3070	2858	14273	9.54
36	23.04	3054	2909	11291	9.40
37	23.68	2779	2911	7166	9.31
38	24.32	2974	2643	4651	9.31
39	24.96	2944	2730	3197	9.31
40	25.60	3090	2822	3667	9.31
41	26.24	2955	2922	3383	9.31
42	26.88	3235	2908	2702	9.31
43	27.52	3263	3007	3181	9.31

The pH of the effluent from the column (Table 7, Figure 4) rose to 11.00 at Sample 3 (1.92 liters) and maintained a high value to Sample 30 (19.2 liters). It then dropped to 9.31 at Sample 37 (23.68 liters), indicating breakthrough of the resin bed. The rise in pH is due to an exchange of the anions in the influent solution for the strongly basic OH anion on the resins.

A study of the curves plotted for Run 2 (anion on the OH cycle) is interesting because of the high peaks reached by the curves. These peaks are the result of the replacement of the iodide ions from the resin, where they had become attached by displacing the weakly held OH ions by the bivalent ions $\text{SO}_4^{=}$ and $\text{CO}_3^{=}$. These peaks are higher than the activity level of the influent because they represent not only the influent activity but also the activity displaced from the resin. The fact that these peaks



did not occur in the runs on the chloride cycle is due to the following equilibrium reactions:



In equation (a), the chloride ion is more tightly bound to the exchange resin than the OH ion in equation (b). Therefore the reaction in equation (a) is a much more reversible reaction than that in equation (b), and the bivalent anions $SO_4^{=}$ and $CO_3^{=}$ are able to displace more of the iodide in the hydroxide runs as more is taken out from the influent solution and is concentrated in a band just below that occupied by the bivalent ions. The elongation of the bivalent band is therefore accomplished by displacing two iodide ions for each bivalent ion. The influent iodide ions pass through the upper portion of the resin bed (that occupied by the bivalent ions), and in passing pick up the displaced ions and move down the bed, where they are exchanged. This continues to the breakthrough point of the bed, where the amount of iodide in solution has reached about a five-fold value of that of the influent. Runs 3, 6 and 7 show this same washout phenomenon.

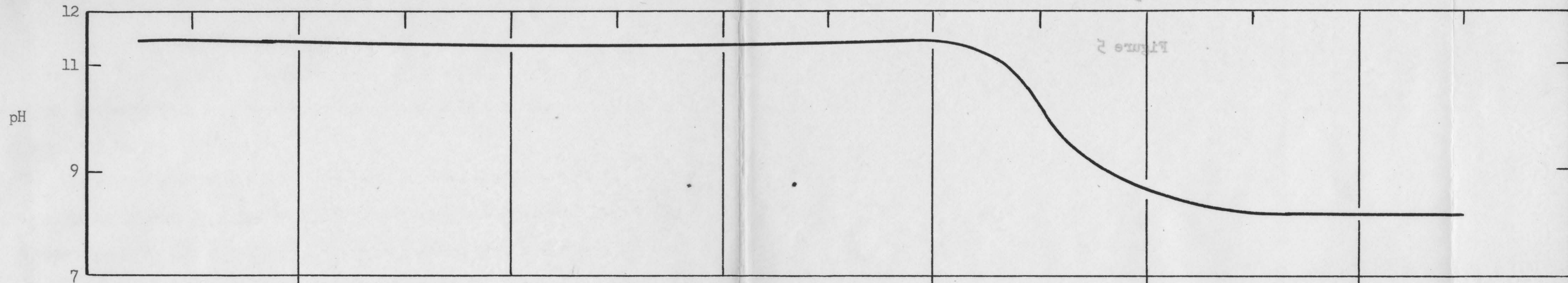
RUN 3 (Table 8, Figure 5). The resins were prepared for this run as for Run 2. The flow rate of the influent through the column was increased from 2.5 to 3.75 gallons per cubic foot per minute (Table 8, Figure 5).

The removal for the run was still high (98.93%), with a decontamination factor of 94, about one-half the value for Run 2. The breakthrough occurred at Sample 13 (about 12.5 liters), corresponding to a

TABLE 8
REMOVAL OF CARRIER-FREE I¹³¹ BY ANION EXCHANGE RESINS

Resin: Amberlite IRA-400 - OH
Activity of Influent: 3096 c/min/ml
Flow Rate: 3.75 gallons/cu. ft./min.
Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)			pH of Final Effluent
		(upper third)	(middle third)	(lower third)	
1	0.48	91	38	17	11.40
2	0.96	171	45	19	11.40
3	1.44	299	48	27	11.40
4	1.92	950	48	27	11.35
5	2.40	2062	60	34	11.30
6	2.88	2836	72	33	11.25
7	3.36	2288	92	38	11.25
8	3.84	1762	137	36	11.20
9	4.32	1795	293	52	11.25
10	4.80	1599	752	41	11.25
11	5.28	1708	2044	61	11.30
12	5.76	1692	3611	70	11.35
13	6.24	1566	3160	96	11.37
14	6.72	1725	2265	191	11.40
15	7.20	1840	1586	421	11.50
16	7.68	1753	1352	900	11.55
17	8.16	1744	1179	2550	11.45
18	8.64	1703	1185	4152	10.75
19	9.12	1726	1164	5854	9.95
20	9.60	1751	1143	2208	9.35
21	10.08	1932	1336	1512	9.30
22	10.56	1952	1427	1400	9.25
23	11.04	2235	1321	1140	9.15
24	11.52	2243	1442	1313	9.14
25	12.00	1979	1402	1249	9.12
26	12.48	2200	1409	1351	9.11



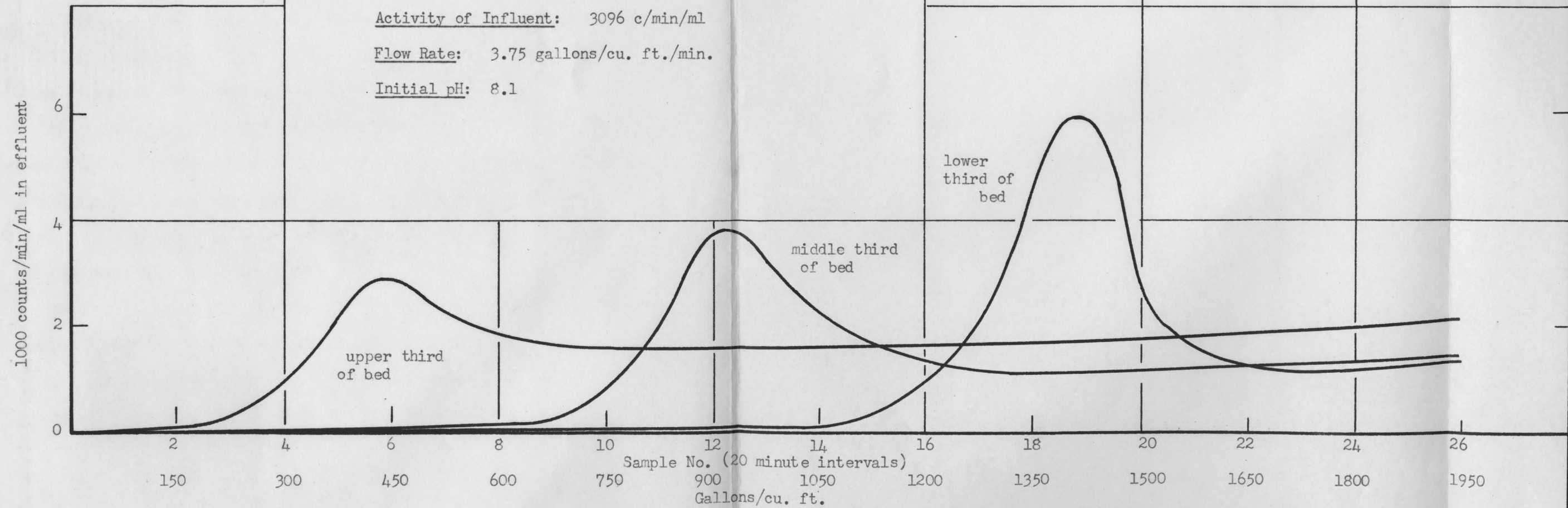
REMOVAL OF CARRIER-FREE I^{131} BY ANION EXCHANGE COLUMN

Resin: Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: 3096 c/min/ml

Flow Rate: 3.75 gallons/cu. ft./min.

Initial pH: 8.1



value of 1000 gallons per square foot, or 500 gallons per cubic foot for a two-foot column. The average activity for this 12.5 liters is 32.4 c/min/ml, corresponding to a concentration of 1.45×10^{-4} uc/ml, or about 4.5 times the MPC for I^{131} .

The curves plotted for Run 3 indicate the same characteristic peaks as those in Runs 2, 6 and 7, but they are lower and broader. The increased flow rate of the influent through the column produced a broader, less concentrated iodide band in the resin bed. Consequently the washout of the resin bed contained less activity per unit volume, but extended over a longer period of time.

MIXED RESIN BED RUNS - RUNS 4, 5, 6 and 7. In all the mixed resin bed runs, the cation and anion resins were regenerated separately and, after having been back-washed, were mixed together as a slurry while still wet and placed in the columns. Twenty-four inches of anion resin (the same amount as in Runs 1, 2 and 3) and 11.25 inches of cation resin were used in each of the mixed bed runs.

The anion resin when used on the chloride cycle was regenerated with one liter of 6N HCl, and when used on the hydroxide cycle was regenerated with two liters of 6% NaOH solution. The cation resin was eluted with 6N HCl when used on the hydrogen cycle and with a 12% solution of NaCl when used on the sodium cycle.

RUN 4 (Table 9, Figure 6). In Run 4, the cation resin was on the hydrogen cycle and the anion resin on the chloride cycle.

The effluent pH quickly dropped to 3.10 at Sample 1 (0.64 liters) and maintained a low pH until 17.92 liters had passed through the column

TABLE 9

REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - H and
 Amberlite IRA-400 - Cl
 Activity of Influent: 3361 c/min/ml
 Flow Rate: 2.5 gallons/cu. ft./min.
 Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	0.64	79	3.10
2	1.28	156	3.15
3	1.92	130	3.20
4	2.56	160	3.15
5	3.20	196	3.15
6	3.84	270	3.15
7	4.48	444	3.15
8	5.12	496	3.15
9	5.76	541	3.15
10	6.40	587	3.10
11	7.04	722	3.10
12	7.68	903	3.10
13	8.32	703	3.05
14	8.96	875	3.05
15	9.60	841	3.04
16	10.24	1455	3.03
17	10.88	877	3.02
18	11.52	1142	3.00
19	12.16	888	3.00
20	12.80	1133	3.00
21	13.44	684	3.00
22	14.08	1535	3.00
23	14.72	817	3.00
24	15.36	1008	3.00
25	16.00	1226	3.05
26	16.64	1013	3.08
27	17.28	1439	3.09
28	17.92	1151	3.10
29	18.56	952	3.15

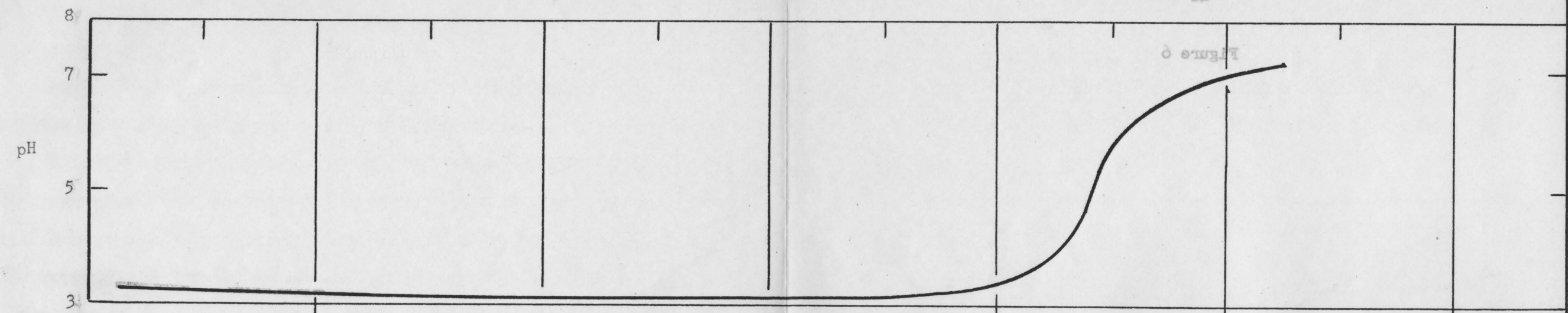
TABLE 9 - Continued

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
30	19.20	1464	3.20
31	19.84	1936	3.30
32	20.48	1570	3.40
33	21.12	1165	3.70
34	21.76	1508	3.95
35	22.40	2299	5.10
36	23.04	2488	6.10
37	23.68	2390	6.45
38	24.32	2315	6.65
39	24.96	2463	7.00
40	25.60	2315	7.15
41	26.24	2446	7.25
42	26.88	2284	7.30

(Sample 28). At this point the column was breaking through and the pH rose rapidly to a value of 7.3 at Sample 42 (27 liters) as shown in Table 9 and Figure 6. The low pH was due to the replacement of the cations and anions in the influent with the strongly acid hydrogen cation and chloride anion in the effluent.

At a pH below 5, it is doubtful if any of the I^{131} remained in the iodide state, all of it existing as atomic or molecular iodine. Therefore the removal in Run 4 was not due to ion exchange, but to either adsorption on the resin or chemical combination with it. This could also account for the wide dispersal of points on the curve, since, although these samples were air-dried, iodine is still volatile at room temperature. (It should be noted here that extreme care must be exercised with the samples from this run in order to prevent contamination of the laboratory and counter

Figure 5



REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE COLUMN

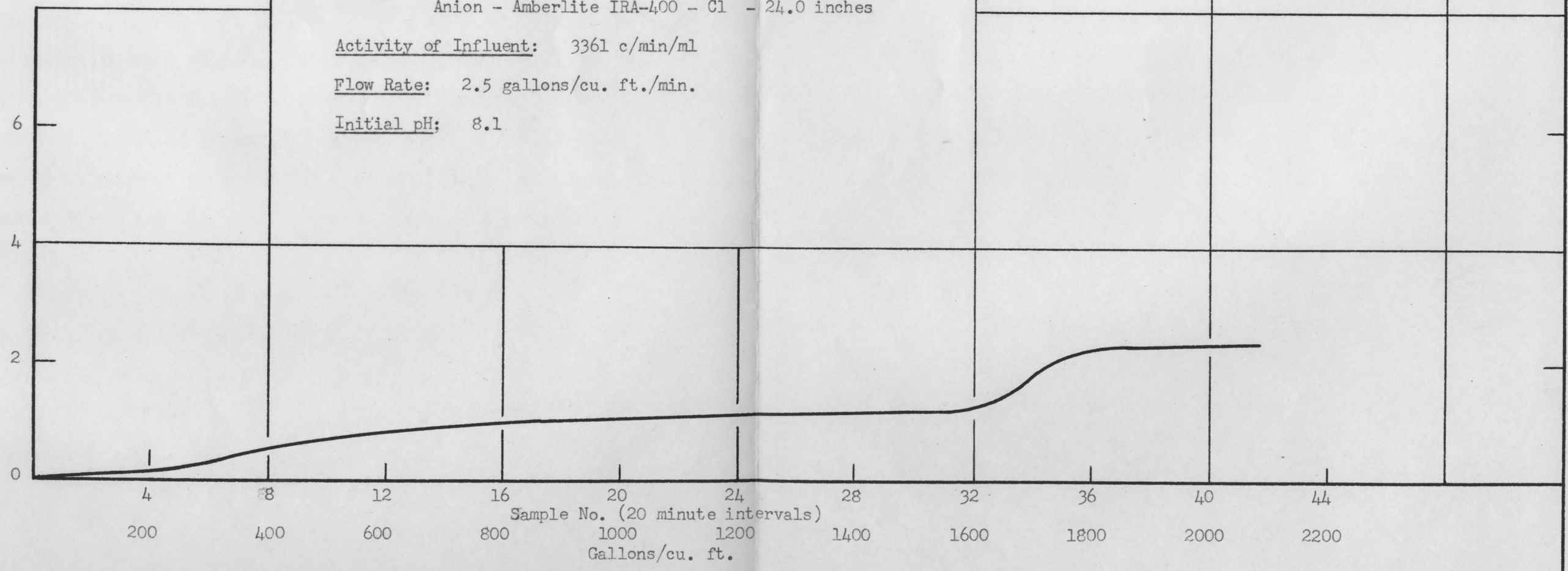
Resins: Cation -Amberlite IR-120 - H - 11.25 inches
Anion - Amberlite IRA-400 - Cl - 24.0 inches

Activity of Influent: 3361 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 8.1

1000 counts/min/ml in effluent



Sample No. (20 minute intervals)

Gallons/cu. ft.

4	8	12	16	20	24	28	32	36	40	44
200	400	600	800	1000	1200	1400	1600	1800	2000	2200

by the iodine vapor.)

RUN 5 (Table 10, Figure 7). In Run 5, the cation resin was on the sodium cycle and the anion resin on the chloride cycle.

Removal by this combination of resins was poor. Leakage through the column prevents this combination from being recommended for water treatment to remove I^{131} , the leakage increasing rapidly from the start of the run until, at Sample 10 (6.5 liters, corresponding to 250 gallons per cubic foot), it reached a value of about one-half the influent value.

The pH of the effluent rose to 9.10 at Sample 1 (0.64 liters) and remained at this value to Sample 33 (21.12 liters). It then gradually dropped to 8.96 at Sample 47 (30 liters).

RUN 6 (Table 11, Figure 8). Run 6 was made using the cation resin on the hydrogen cycle and the anion resin on the hydroxide cycle.

The column gave very good removal of I^{131} . Until the breakthrough point was reached at Sample 35, 22.4 liters, corresponding to 1750 gallons per cubic foot, had passed through the column, with an average of only 5.1 c/min/ml in the effluent. This amounted to a removal of 99.80%, and gave a decontamination factor of 665. The count of 5.1 c/min/ml corresponds to a concentration of 2.32×10^{-5} uc/ml, which is slightly below the MPC value for I^{131} .

Calculating the factors above from the start to Sample 25 where the pH started to rise, for 1250 gallons per cubic foot the average count was 3.16 c/min/ml, giving a removal of 99.91% and a decontamination factor of 1067. The 3.16 c/min/ml corresponded to a concentration of 1.44×10^{-5} uc/ml, which is less than one-half the concentration of I^{131} recom-

TABLE 10

REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - Na and
Amberlite IRA-400 - Cl
Activity of Influent: 4938 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	0.64	223	9.10
2	1.28	502	9.10
3	1.92	833	9.10
4	2.56	1283	9.10
5	3.20	1756	9.10
6	3.84	1996	9.10
7	4.48	2069	9.10
8	5.12	2296	9.10
9	5.76	2292	9.10
10	6.40	2393	9.10
11	7.04	2330	9.10
12	7.68	2075	9.10
13	8.32	2123	9.10
14	8.96	2307	9.10
15	9.60	2514	9.10
16	10.24	2566	9.10
17	10.88	2251	9.10
18	11.52	2680	9.10
19	12.16	2599	9.10
20	12.80	2608	9.10
21	13.44	2499	9.10
22	14.08	2494	9.10
23	14.72	2251	9.10
24	15.36	2336	9.10
25	16.00	2558	9.10
26	16.64	2639	9.10
27	17.28	2675	9.10
28	17.92	2673	9.10
29	18.56	2731	9.10

TABLE 10 - Continued

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
30	19.20	2915	9.10
31	19.84	2604	9.10
32	20.48	2574	9.10
33	21.12	2854	9.10
34	21.76	2583	9.05
35	22.40	2843	9.05
36	23.04	2724	9.05
37	23.68	2871	9.05
38	24.32	2832	9.05
39	24.96	2906	9.05
40	25.60	2764	9.05
41	26.24	3011	9.05
42	26.88	2794	9.05
43	27.56	2786	9.00
44	28.16	3013	8.99
45	28.80	2970	8.98
46	29.44	3080	8.97
47	30.08	3148	8.96

mended for drinking water.

The pH of 7.48 at Sample 1 gradually decreased to 7.20 at Sample 25 (16 liters), whence it rose to a value of 9.85 at Sample 40 (25.6 liters), fell rapidly to a value of 6.7 at Sample 44 (28 liters), and then started to rise again, reaching a value of 7.4 at Sample 47 (30 liters).

RUN 7 (Table 12, Figure 9). Run 7 was made using the cation resin on the sodium cycle and the anion resin on the hydroxide cycle.

Removal of I^{131} by the column was very good, although not as good as that occurring in Run 6. Up to the breakthrough point of the column

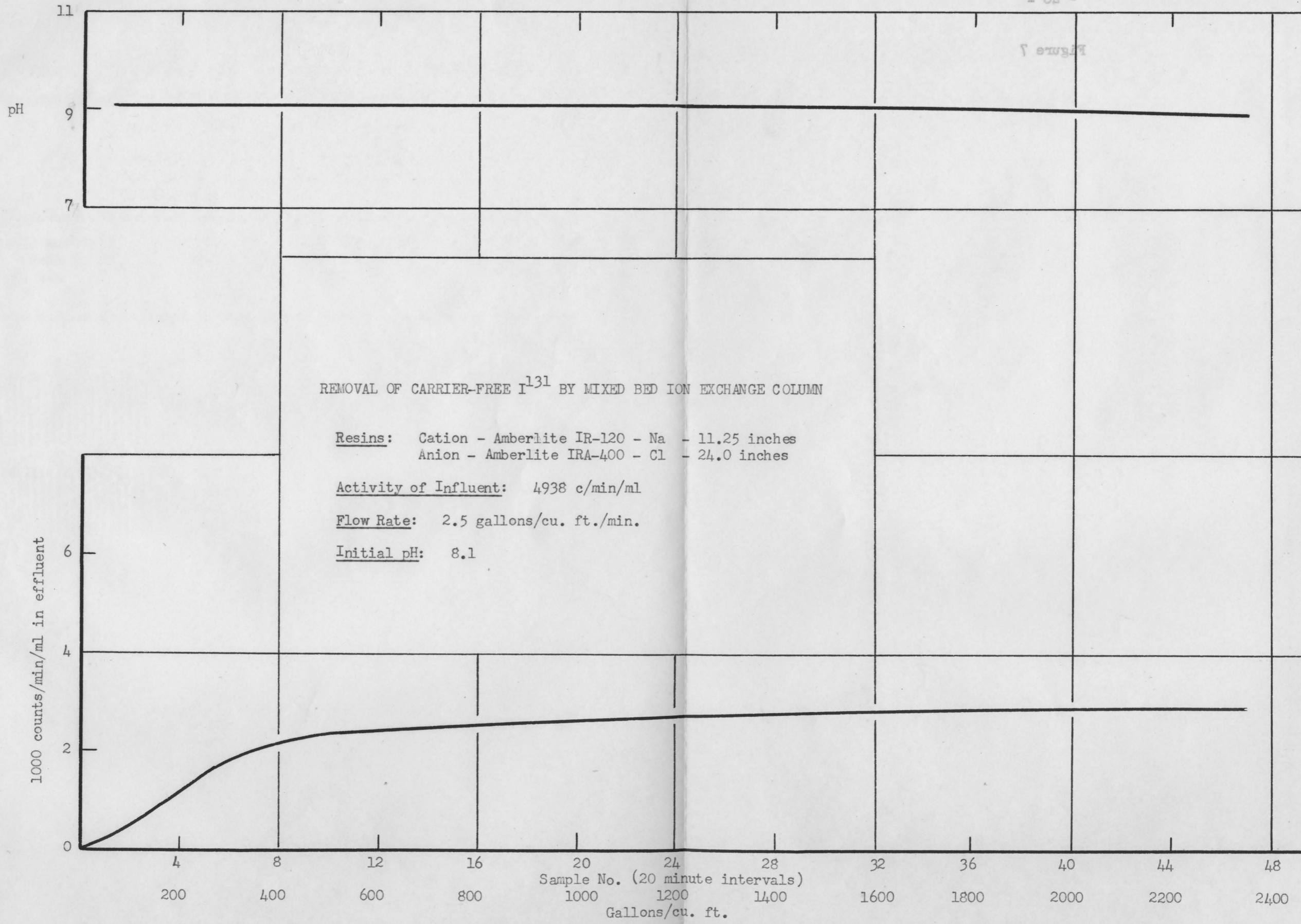


TABLE 11
REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - H and
Amberlite IRA-400 - OH
Activity of Influent: 3380 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	0.64	2	7.48
2	1.28	5	7.45
3	1.92	3	7.40
4	2.56	5	7.40
5	3.20	0	7.40
6	3.84	1	7.40
7	4.48	1	7.35
8	5.12	4	7.35
9	5.76	0	7.35
10	6.40	5	7.35
11	7.04	2	7.30
12	7.68	4	7.30
13	8.32	3	7.25
14	8.96	1	7.25
15	9.60	4	7.25
16	10.24	1	7.20
17	10.88	0	7.20
18	11.52	4	7.20
19	12.16	5	7.20
20	12.80	1	7.20
21	13.44	6	7.20
22	14.08	3	7.20
23	14.72	3	7.20
24	15.36	8	7.20
25	16.00	8	7.20
26	16.64	4	7.25
27	17.28	8	7.25
28	17.92	10	7.28
29	18.56	8	7.58

TABLE 11 - Continued

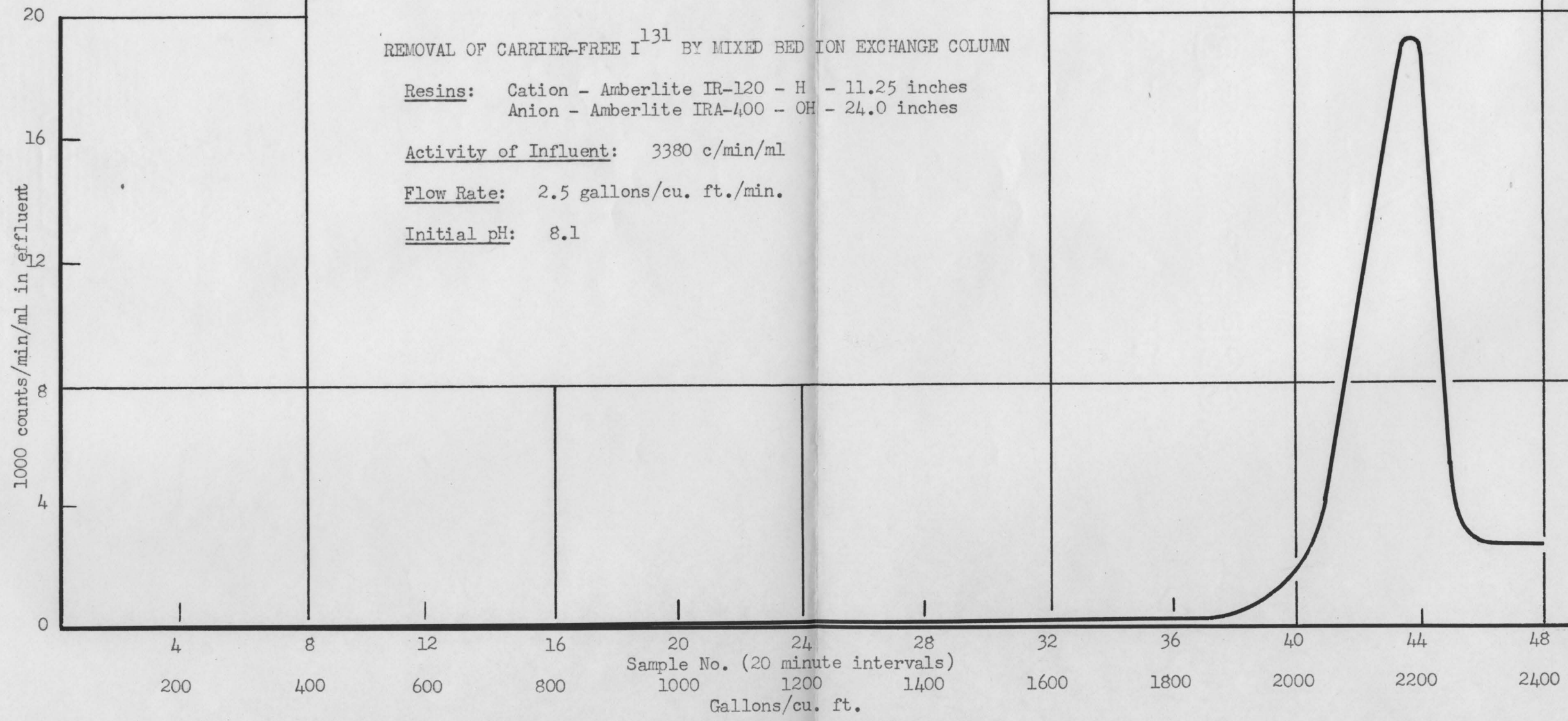
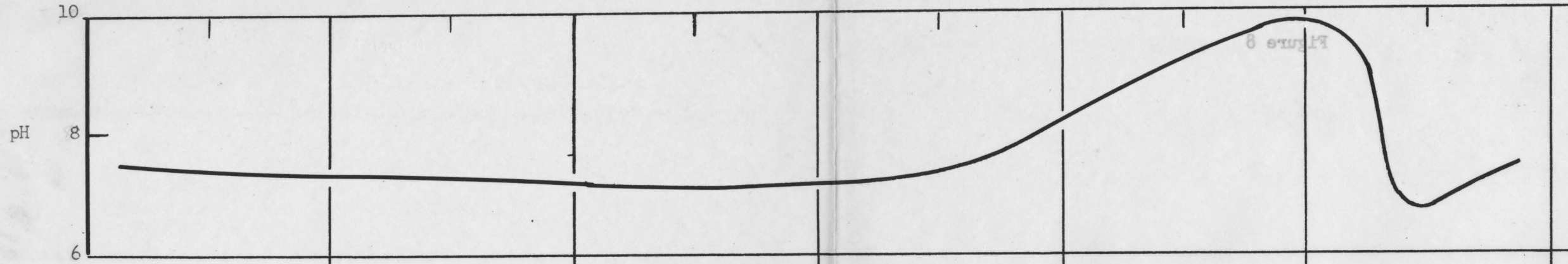
Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
30	19.20	8	7.68
31	19.84	11	7.90
32	20.48	13	8.13
33	21.12	9	8.40
34	21.76	11	8.70
35	22.40	18	8.95
36	23.04	48	9.17
37	23.68	102	9.35
38	24.32	231	9.55
39	24.96	740	9.75
40	25.60	1692	9.85
41	26.24	4086	9.70
42	26.88	10938	9.10
43	27.52	14593	7.00
44	28.16	16984	6.70
45	28.80	5808	6.95
46	29.44	2624	7.20
47	30.08	2495	7.40

(Sample 24), i.e., 15.76 liters or twelve hundred gallons per cubic foot, the average c/min/ml of the effluent was 9.16. This gave a removal of 99.70% and a decontamination factor of 332. The concentration of 9.16 c/min/ml is equal to 4.16×10^{-5} uc/ml, slightly above the recommended MPC value.

The pH in this case dropped from 11.33 at Sample 1 (0.64 liters) to 10.60 at Sample 10 (6.4 liters). From this point it gradually rose to 10.95 at Sample 32 (20.48 liters), where the pH rapidly fell to 8.60.

Conclusions. The following conclusions are drawn from the series of tests with carrier-free I^{131} under the conditions reported herein:

Figure 8



REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - H - 11.25 inches
Anion - Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: 3380 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 8.1

TABLE 12

REMOVAL OF CARRIER-FREE I¹³¹ BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - Na and
 Amberlite IRA-400 - OH
 Activity of Influent: 3042 c/min/ml
 Flow Rate: 2.5 gallons/cu. ft./min.
 Initial pH: 8.1

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	0.64	8	11.33
2	1.28	5	11.20
3	1.92	0	11.10
4	2.56	7	10.95
5	3.20	5	10.77
6	3.84	8	10.65
7	4.48	7	10.65
8	5.12	8	10.64
9	5.76	4	10.62
10	6.40	9	10.60
11	7.04	9	10.60
12	7.68	4	10.60
13	8.32	6	10.60
14	8.96	11	10.60
15	9.60	9	10.60
16	10.24	7	10.60
17	10.88	9	10.60
18	11.52	8	10.70
19	12.16	16	10.82
20	12.80	13	10.81
21	13.44	16	10.81
22	14.08	17	10.81
23	14.72	17	10.81
24	15.36	17	10.83
25	16.00	31	10.85
26	16.64	37	10.87
27	17.28	66	10.88
28	17.92	149	10.90
29	18.56	384	10.91
30	19.20	995	10.92

TABLE 12 - Continued

Sample number at 20-minute intervals	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
31	19.84	2967	10.94
32	20.48	9695	10.95
33	21.12	15549	10.48
34	21.76	12686	9.13
35	22.40	3081	8.90
36	23.04	2060	8.70
37	23.68	1967	8.65
38	24.32	1966	8.60

1. The strongly basic exchange resin Amberlite IRA-400, when used on the hydroxide cycle, will give removals of 98+% of carrier-free I^{131} when diluted in tap water to a concentration of 1.4×10^{-2} uc/ml. The bed capacity for a 24-inch bed depth is 1300 gallons/cu. ft.

2. The addition of an equivalent amount of the strongly acid cation exchanger, Amberlite IR-120, on the hydrogen cycle, increases the removal of carrier-free I^{131} to 99.5+%, and the capacity of the bed by about 450 gallons per cubic foot to 1750 gallons per cubic foot. A lowering of the pH is also accomplished by the mixed bed above.

3. The exchange bed should not be used to the breakthrough point, as a large quantity of the activity is washed out at this point.

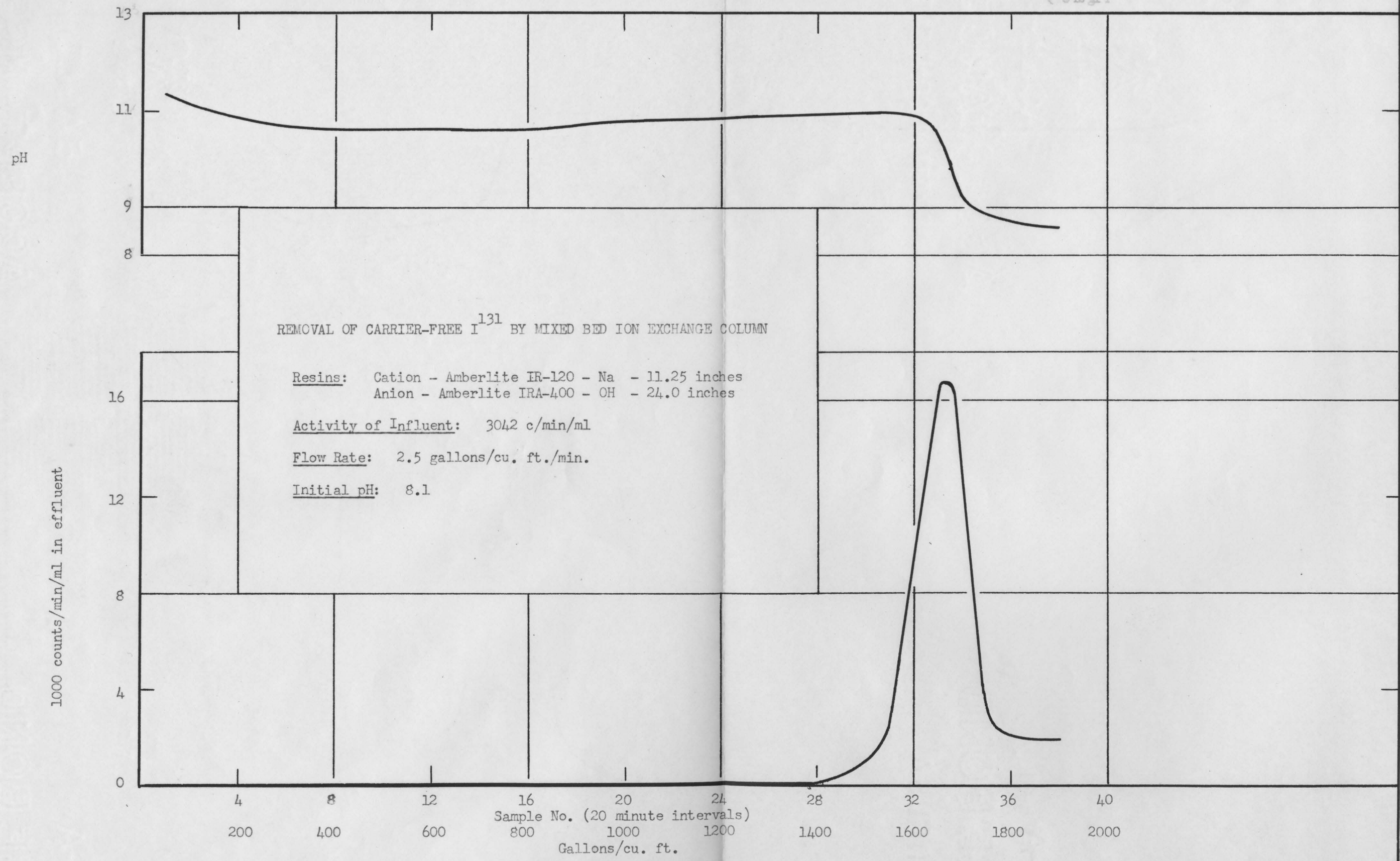


TABLE 13

REMOVAL OF I¹³¹ - ION EXCHANGE RESINS
OPERATIONAL DATA

Run Number	Cation Used in 14mm. Column (inches)	Anion Used in 14mm. Column (inches)	Cycle	Flow Rate (gals./ cu. ft.)	Activity of Influent (uc/ml)	Total volume through Column (liters)
1	-	24	Cl	2.5	1.60×10^{-2}	25.6
2	-	24	OH	2.5	1.40×10^{-2}	27.5
3	-	24	OH	3.75	1.41×10^{-2}	25.0
4	11.25	24	H-Cl*	2.5	1.53×10^{-2}	26.8
5	11.25	24	Na-Cl*	2.5	2.24×10^{-2}	30.1
6	11.25	24	H-OH*	2.5	1.69×10^{-2}	30.1
7	11.25	24	Na-OH*	2.5	1.52×10^{-2}	23.7

* first cation, second anion

TABLE 14

REMOVAL OF I¹³¹ - ION EXCHANGE RESINS
COLUMN RESULTS

Run No.	Cation Used in Column (inches)	Anion Used in Column (inches)	Cycle	Activity of Influent (uc/ml)	Average Activity of Effluent up to Breakthrough (uc/ml)	Volume through Column at Breakthrough (gal./cu.ft.)	Decontamination Factor	Per cent removal
1	-	24	Cl	1.60×10^{-2}	3.45×10^{-4}	300	46	97.84
2	-	24	OH	1.40×10^{-2}	7.70×10^{-5}	1300	180	99.45
3	-	24	OH	1.41×10^{-2}	1.45×10^{-4}	500	94	98.93
4	11.25	24	H-Cl*	1.53×10^{-2}	- **	-	-	-
5	11.25	24	Na-Cl*	2.24×10^{-2}	- **	-	-	-
6	11.25	24	H-OH*	1.69×10^{-2}	2.32×10^{-5}	1750	665	99.80
7	11.25	24	Na-OH*	1.52×10^{-2}	4.16×10^{-5}	1200	332	99.70

* first cation, second anion

** breakthrough point cannot be determined

Summary. The strongly basic anion exchanger, Amberlite IRA-400, when used on the hydroxide cycle, effects a removal of about 98% of the carrier-free I^{131} in tap water at initial concentrations of about 1.40×10^{-2} uc/ml. The addition of an equivalent amount of the strongly acid cation exchanger, Amberlite IR-120, on the hydrogen cycle, increases this removal to 99.5% with an accompanying increase in bed capacity of from 1300 gallons per cubic foot to 1750 gallons per cubic foot. The pH of the effluent is also closer to that desired, falling from approximately 11 to 7.2.

Extreme care must be used in this method of decontamination not to exceed the breakthrough point of the bed, as a study of Figure 8 shows that a large amount of the activity is washed out of the column at the breakthrough point. The critical point at which the run should be halted is where the pH has reached its lowest value and started to rise, at Sample 25 (16 liters), Figure 8.

The use of Amberlite IRA-400, on the chloride cycle, is not recommended for decontamination of drinking water except for emergency use over a period not to exceed ten days, where the MPC is increased to 10^{-2} uc/ml.

The operational data and column results of Runs 1 through 7 are summarized in Tables 13 and 14.

Strontium (Sr⁸⁹)

Procedure. The influent to the column was prepared as for the previous runs for radioiodine, the isotope being diluted in tap water as received at the Oak Ridge National Laboratory. In these runs the isotope used was radiostrontium (Sr⁸⁹). This isotope of strontium was chosen since it has no radioactive daughter product, but decays to stable yttrium (Y⁸⁹).

The Sr⁸⁹ as furnished by the Operations Division of the Oak Ridge National Laboratory is a mixture of Sr⁸⁹, Sr⁹⁰, and Y⁹⁰. In the sample used in these tests, the initial concentration of Sr⁸⁹ was 98.9%, the remaining activity being Y⁹⁰ in equilibrium with Sr⁹⁰.

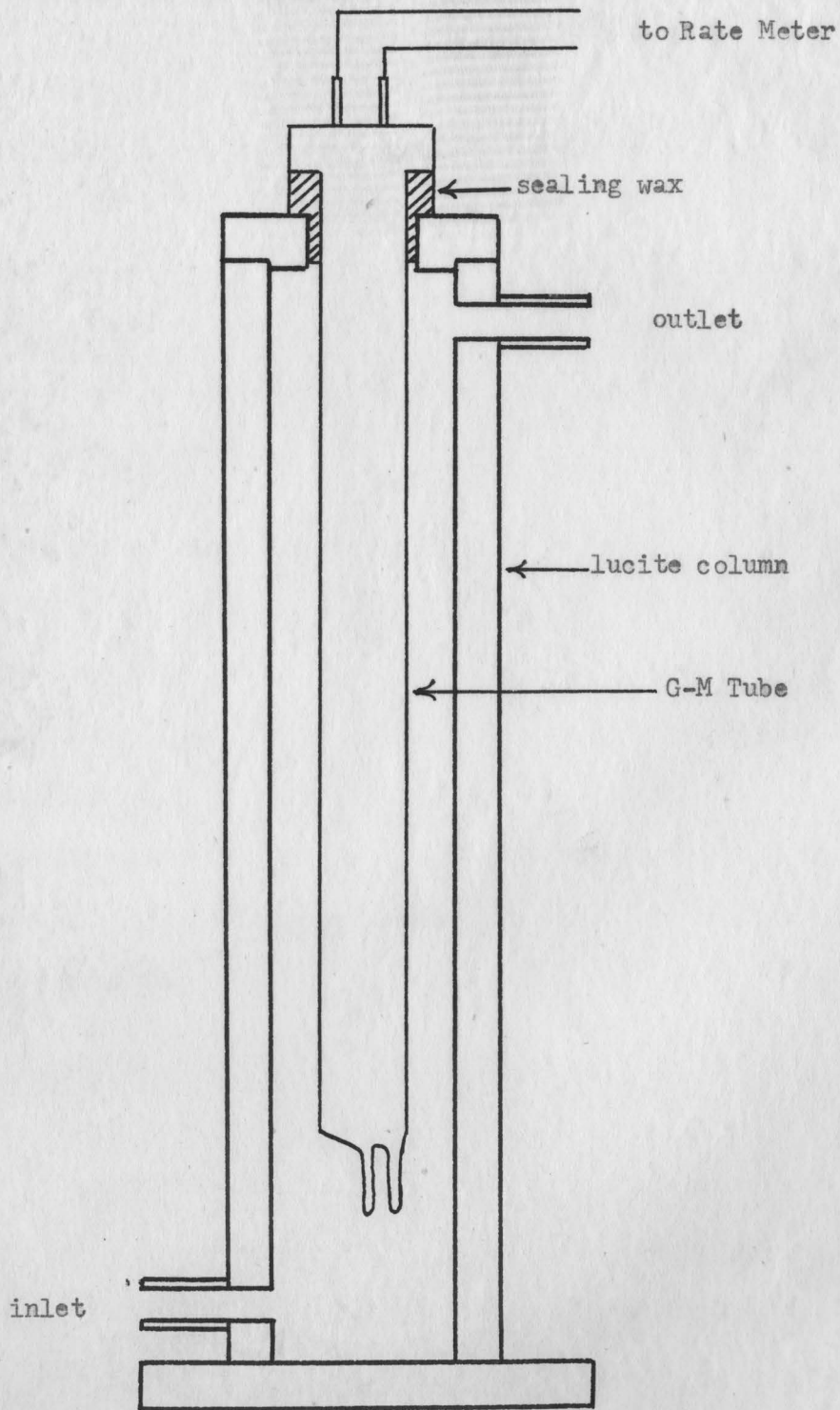
The isotope and tap water were mixed in a 55-gallon stainless steel drum, the inside of which was plastic-coated. The tank was equipped with a glass gauge, so that the volume of liquid in the tank could be noted at any time. A 1/15th horse power centrifugal pump was used to deliver the influent solution to the resin column. The speed of the pump was governed by a Variac, and the rate of flow of the solution was measured by a Flowrater manufactured by Fischer and Porter.

The columns used in the runs were made from a single piece of 1/4 in. glass tubing 48 inches long. The column was fitted at the top with a one-holed rubber stopper and at the bottom with a two-holed rubber stopper. The influent solution was fed in at the top, and effluent taken off from the bottom. One of the bottom holes was used to draw samples for drying and counting. Cation resin (Amberlite IR-120) was placed in the column for a depth of 2 1/4 inches for Runs 8, 9, 10, 15 and 16. For Runs 11, 12, 13 and 14, the resin bed consisted of 2 1/4 inches of anion resin (Amberlite

IRA-400) and an equivalent amount (11.25 inches) of cation resin (Amberlite IR-120). In all the runs the influent solution was passed through the column at the rate of 2.5 gallons per cubic foot per minute.

From the other outlet at the bottom of the column, the effluent was led to a two-inch lucite tube, which was placed on end and fitted with a water-tight bottom. The lucite column was twelve inches high and was fitted with an overflow $3/4$ inches from the top (See Figure 10). A ten-inch G-M* tube was placed in the column so that the effluent solution from the resin column, entering at the bottom of the lucite tube, flowed up and around the G-M tube and out the overflow at the top. A two-inch lead shield made from 2 x 4 x 8-inch lead brick enclosed the lucite column to reduce the background activity to as low a value as possible. The G-M tube was connected to a rate meter, an electronic integrating device manufactured by El-tronics, Inc., which was in turn connected to an Esterline-Angus Graphic Ammeter. By use of this apparatus, a constant monitor of the activity of the effluent from the column was possible. Individual sampling at regular intervals was not considered feasible in these runs, due to the increased capacity of the cation resin over the anion resin used in the previous runs. An attempt to calibrate the chart of the graphic ammeter to read the activity of the effluent direct did not prove feasible; the chart did, however, show any changes in the activity of the effluent. Samples were drawn off from the bottom of the resin column, dried, and counted, and the value noted on the chart when the activity at any time

* Geiger-Müller



Cutaway of lucite column and G-M Tube

Figure 10

was desired (see Plates I and II).

The pH of the effluent was monitored as in the previous runs for radioiodine, the overflow solution from the lucite column being used.

All samples collected were dried and counted as in the previous runs.

The presence of Y^{90} in the Sr^{89} isotope sample as furnished by the Operations Division necessitated Runs 15 and 16. Y^{91} was the isotope used in these two tests, since it has no radioactive daughter product, but decays to stable Zr^{91} .

Results. Results of Runs 8 through 14 inclusive are shown in Tables 15 to 21 inclusive, and in Figure 11 and Figures 13 to 18 inclusive. The data presented in the tables and plotted in the figures for the activity and pH were interpolated from the Esterline-Angus Graphic Ammeter charts.

Results of Runs 15 and 16 are not reported in table and figure form due to the impossibility of getting satisfactory results (See Discussion of Results).

Discussion of Results. RUN 8 (Table 15, Figure 11). The resin used in Run 8 was placed on the sodium cycle by elution with one liter of 4% NaOH, giving about 27 volumes of liquid to one volume of resin.

The column gave good removal of Sr^{89} , the activity of the effluent remaining below the MPC value for the isotope until 138.24 liters had passed through the resin bed. This quantity represents a value of 10,800 gallons per cubic foot. The average activity of Sr^{89} in the effluent

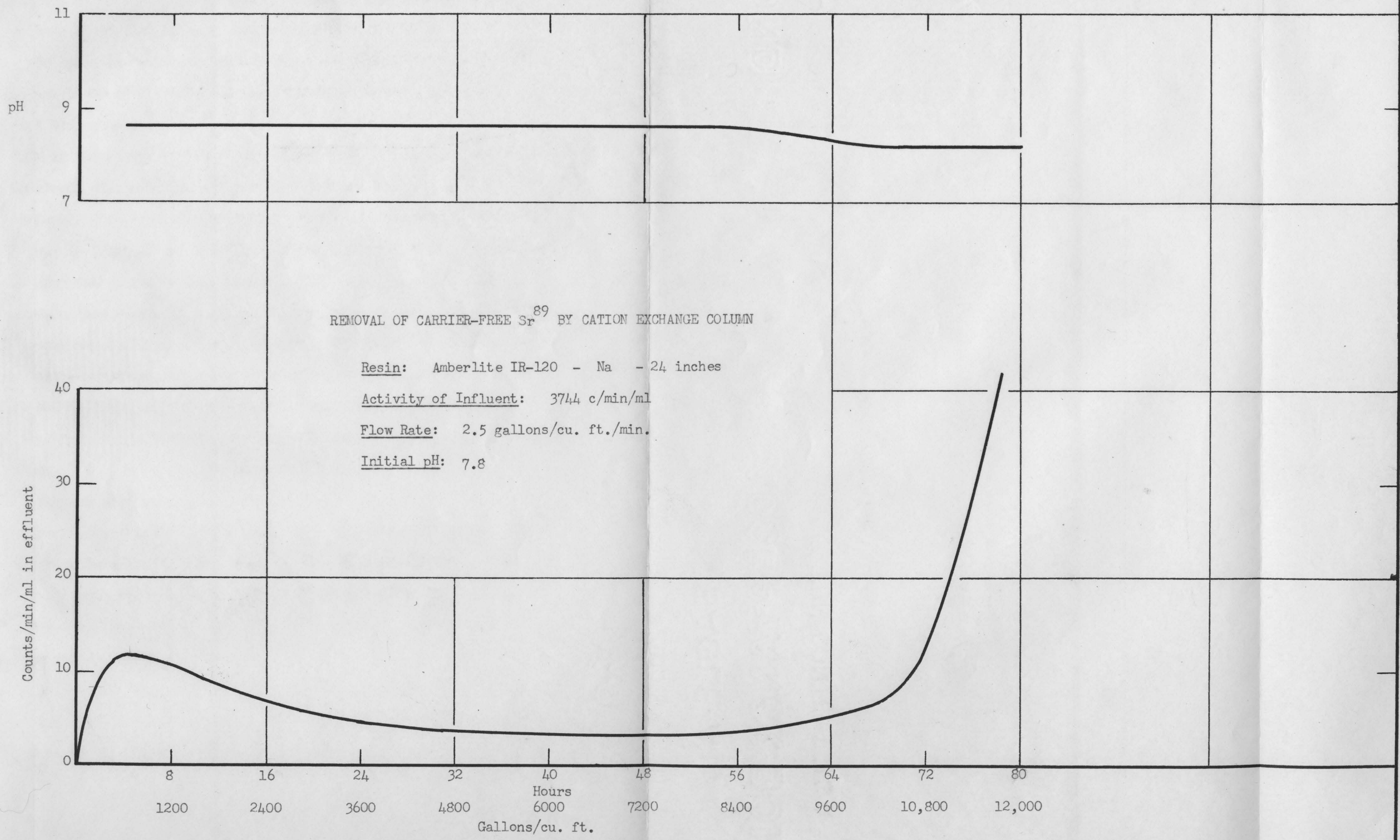
from the column for this period was 6.15 c/min/ml, giving a decontamination factor of 608.8, and a percentage removal of 99.81%.

TABLE 15
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY CATION EXCHANGE RESINS

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
	Resin: Amberlite IR-120 - Na		
	Activity of Influent: 3744 c/min/ml		
	Flow Rate: 2.5 gallons/cu. ft./min.		
	Initial pH: 7.8		
4	7.68	12.0	8.6
8	15.36	10.0	8.6
12	23.04	9.5	8.6
16	30.72	6.2	8.6
20	38.40	6.0	8.6
24	46.08	6.0	8.6
28	53.76	5.8	8.6
32	61.44	4.5	8.6
36	69.12	4.5	8.6
40	76.80	3.5	8.6
44	84.48	3.5	8.6
48	92.16	3.0	8.6
52	99.84	4.1	8.6
56	107.52	4.1	8.6
60	115.20	4.5	8.5
64	122.88	5.5	8.35
68	130.56	6.0	8.2
72	138.24	12.0	8.2
76	145.92	28.3	8.2
80	153.60	49.8	8.2

The initial pH of the feed was raised to 8.6 by the replacement of the cations in the solution by the sodium ions on the resin, and remained at this value until about 107.52 liters had passed through the

Figure 11



column. The pH then fell to a value of 8.2 at 130.56 liters, and remained constant at this value to the completion of the run.

In order to determine the nature of the leakage through the column, one liter of the effluent was taken to dryness. Absorption curves of this sample and of a sample of the feed solution show a great variation in the energy of the particles emitted. A comparison of the half-thickness values of the effluent activity and those of Y^{90} , Sr^{90} and Sr^{89} indicated that the activity was due to Y^{90} , as the half-thicknesses of Sr^{89} and Sr^{90} are 90 and 16 mg/cm² of aluminum respectively, while the half-thicknesses of the effluent sample and Y^{90} are 148 and 170 mg/cm² respectively (see Figure 12). Chemical precipitation verified this fact. It was concluded that yttrium, not completely removed from the solution by the resin, accounted for the major portion of the leakage.

RUN 9 (Table 16, Figure 13). The resin used in this run was placed on the hydrogen cycle by elution with one liter of 6N HCl, giving 27 volumes of acid to one volume of resin.

The run gave excellent results. The average activity in the effluent from the column for 161.28 liters was 3.50 c/min/ml, giving a decontamination factor of 1069.7, and a removal of 99.91%. Also, the capacity of the resin bed was increased from 138.24 liters to 161.28 liters, the latter value representing 12,600 gallons, with an increase over Run 8 (sodium cycle) of 1,800 gallons.

In the run, the pH of the effluent rapidly dropped to a value of 2.9 at 7.68 liters, then rose to 3.2 at 15.36 liters. It remained at this value until 107.32 liters had passed, and then rose rapidly to a value of

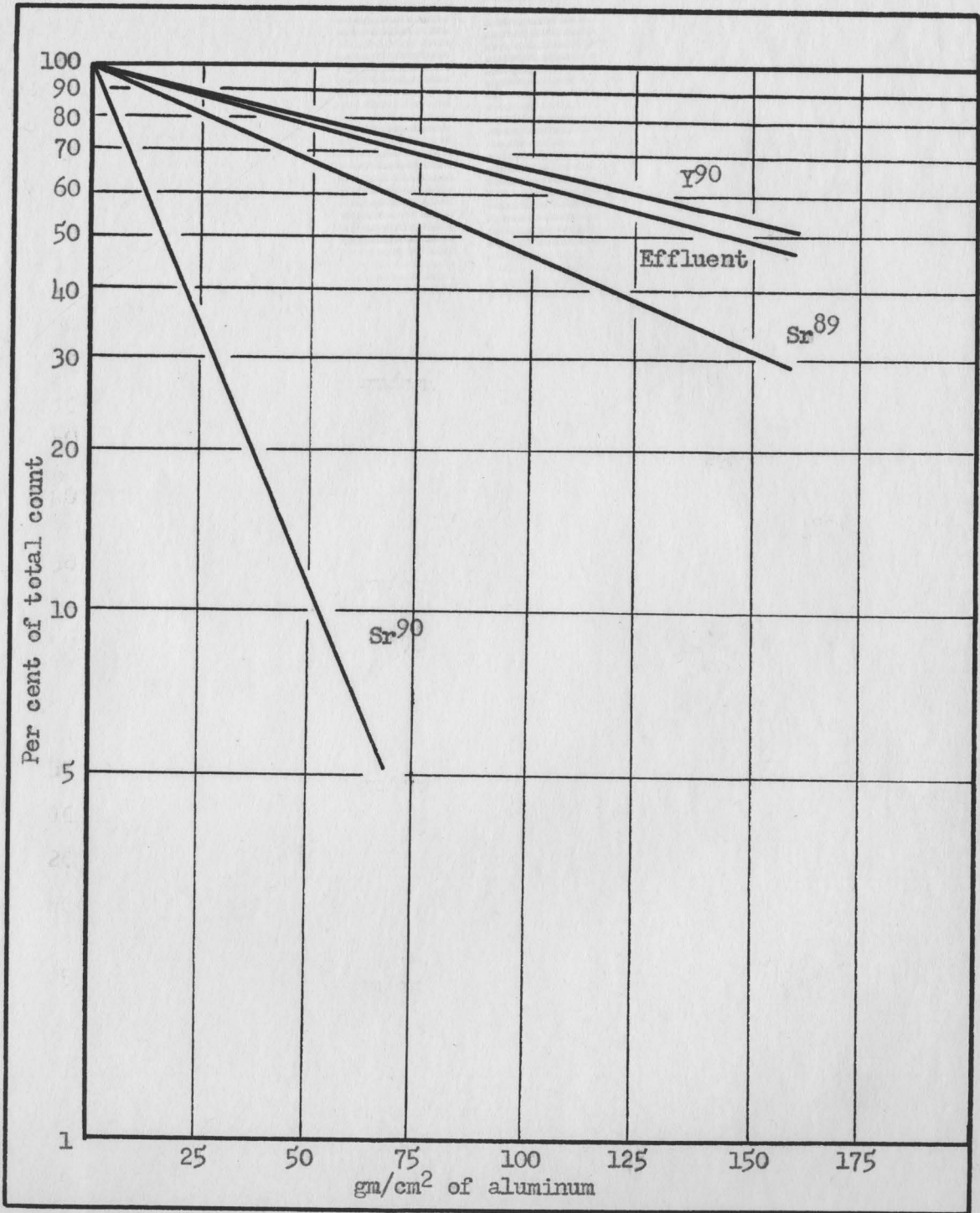


Figure 12

ABSORPTION CURVES OF THE ACTIVITY OF INFLUENT AND EFFLUENT

8.2 when 176.4 liters had been processed.

TABLE 16
REMOVAL OF CARRIER-FREE Sr^{89} BY CATION EXCHANGE RESINS

Resin: Amberlite IR-120 - H
Activity of Influent: 3744 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 7.8

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
4	7.68	0.4	2.95
8	15.36	0.4	3.2
12	23.04	1.0	3.2
16	30.72	1.2	3.2
20	38.40	1.2	3.2
24	46.08	1.3	3.2
28	53.76	1.3	3.2
32	61.44	1.3	3.2
36	69.12	1.3	3.2
40	76.80	1.3	3.2
44	84.48	1.5	3.2
48	92.16	2.2	3.2
52	99.84	2.5	3.2
56	107.52	3.6	3.2
60	115.20	4.6	3.3
64	122.88	5.6	3.5
68	130.56	8.5	5.1
72	138.24	9.7	5.7
76	145.92	10.5	6.3
80	153.60	14.0	6.9
84	161.28	18.0	7.7
88	168.96	21.4	8.2
92	176.64	30.9	8.2

RUN 10 (Table 17, Figure 14). The resin for Run 10 was placed on the calcium cycle by elution with one liter of 20% CaCl_2 solution.



REMOVAL OF CARRIER-FREE Sr⁸⁹ BY CATION EXCHANGE COLUMN

Resin: Amberlite IR-120 - H - 24 inches

Activity of Influent: 3744 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8

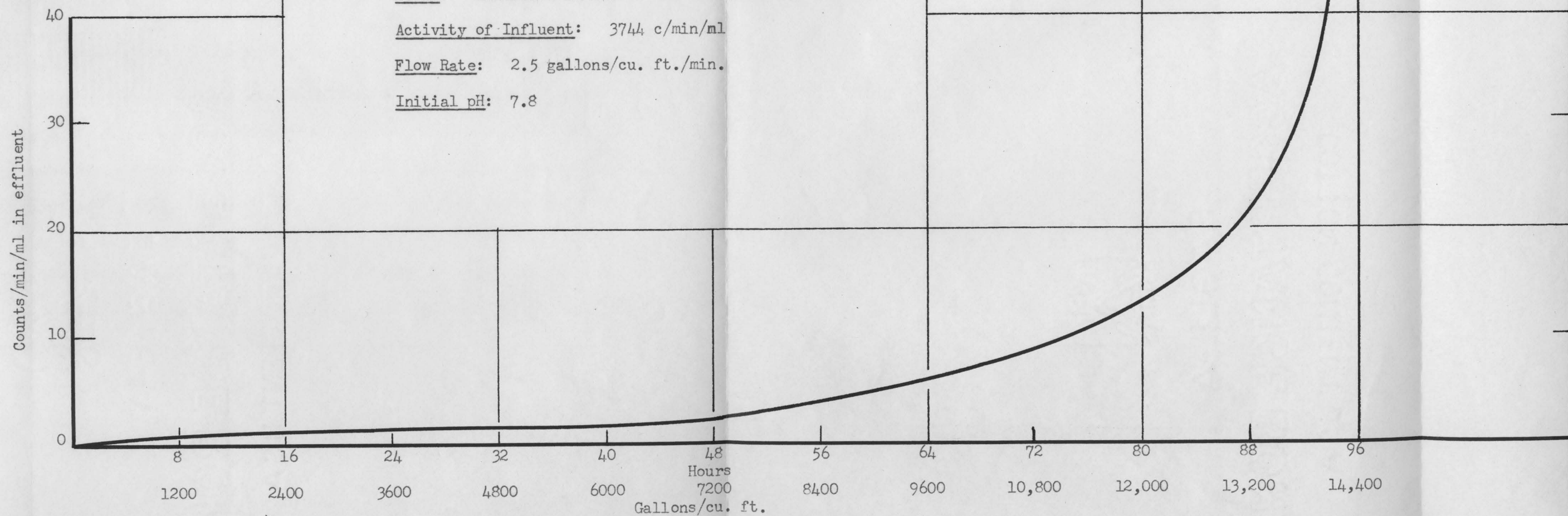
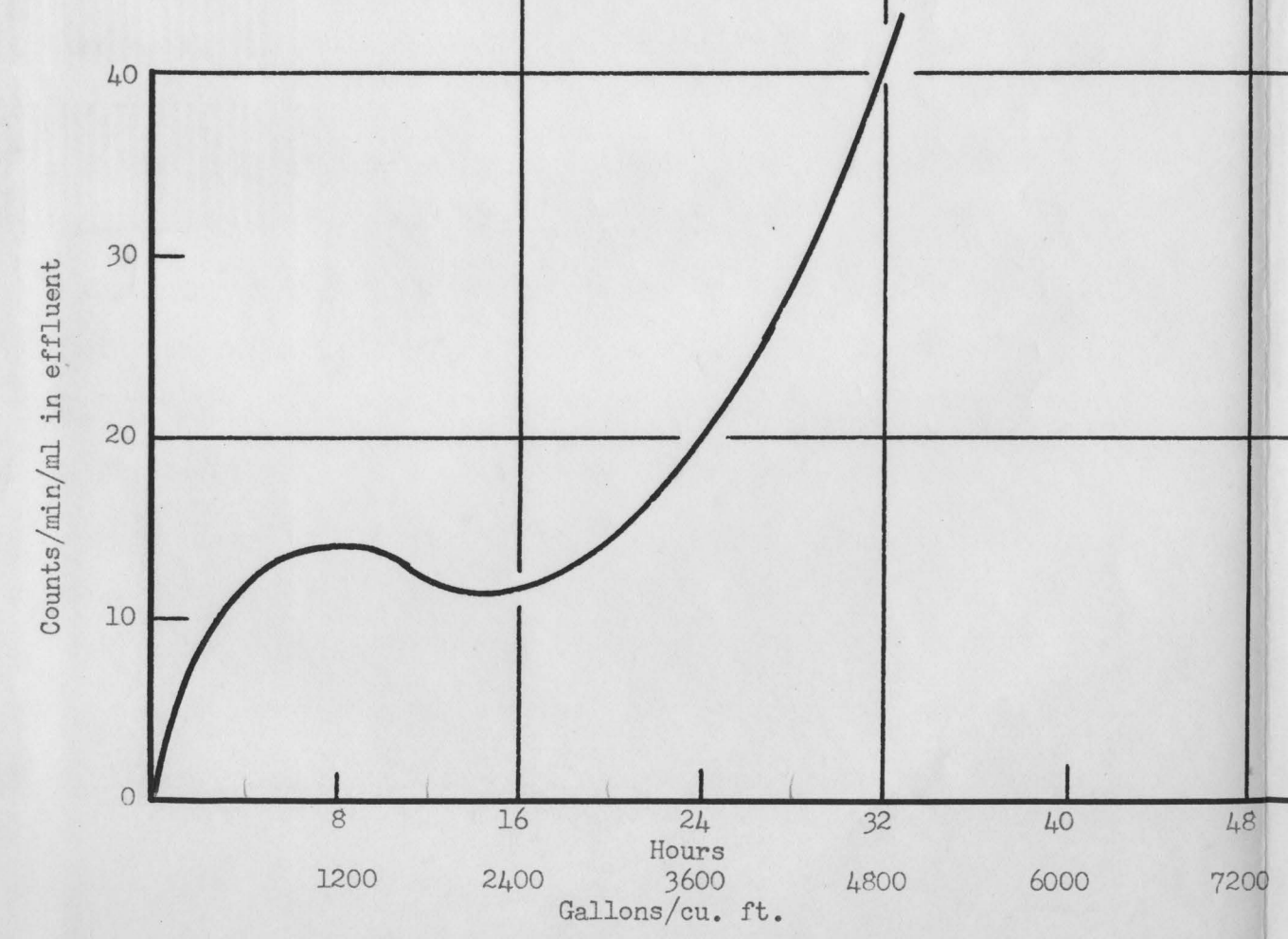
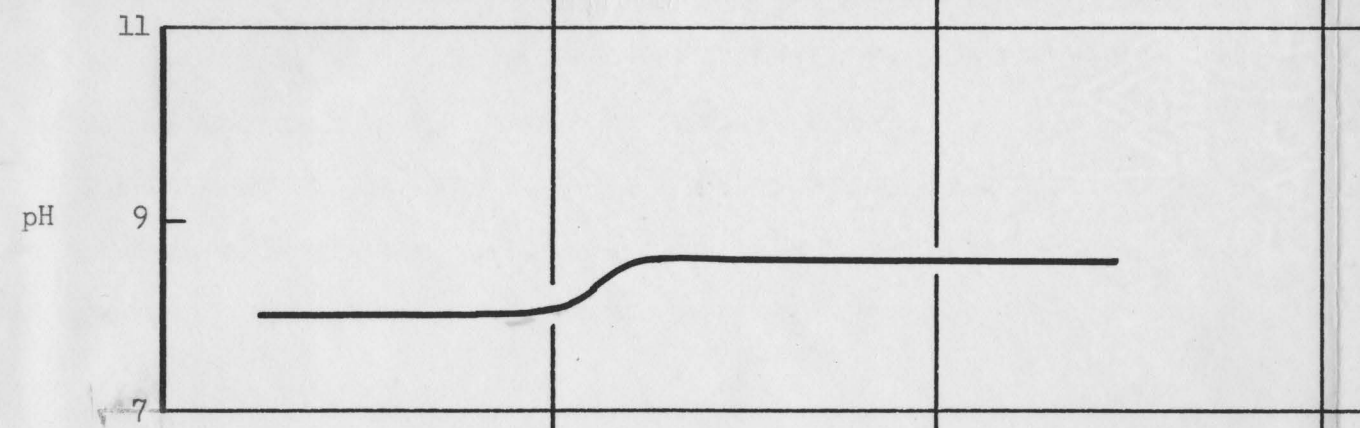


TABLE 17
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY CATION EXCHANGE RESINS

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
4	7.68	12.0	8.0
8	15.36	14.0	8.0
12	23.04	12.0	8.0
16	30.72	11.5	8.0
20	38.40	15.0	8.6
24	46.08	20.0	8.6
28	53.76	27.0	8.6
32	61.44	43.0	8.6
36	69.12	56.0	8.6
38	72.96	64.8	8.6
39	74.88	68.0	8.6

The purpose of the run was to attempt an explanation of the large capacity of the cation resin in the previous run. The concentration of calcium and magnesium in the tap water (Table 5) amounted to 1.68 milliequivalents per liter. The manufacturer indicates the capacity of the resin as 2.15 milliequivalents per milliliter. For the amount of resin used on these runs (36 ml), the indicated capacity is 46.1 liters of tap water. However, the results of Runs 8 and 9 showed a much larger capacity for the resin. A partial explanation of the extended capacity is made by the fact that strontium replaced the calcium that had been exchanged for the sodium and hydrogen on the resin, as the run indicated. Therefore, as



REMOVAL OF CARRIER-FREE Sr^{89} BY CATION RESIN COLUMN

Resin: Amberlite IR-120 - Ca - 24 inches
Activity of Influent: 4087 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 7.8

magnesium has a lesser affinity for the resin than calcium (see page 19), it can be assumed that the strontium replaced both the calcium and magnesium, the magnesium being replaced to a greater degree.

The activity of the effluent from the column averaged 12.9 c/min/ml for 38.4 liters, corresponding to 3000 gallons per cubic foot. This represented a removal of 99.68%, and a decontamination factor of 316.8.

The pH of the effluent was 8.0 after passage of 7.6 liters through the column. The value was constant until 30.72 liters had been processed. The pH then rose to 8.5, and remained constant for the remainder of the run.

MIXED RESIN BED RUNS (Runs 11, 12, 13 and 14). The resins for these runs were prepared in the same manner as for Runs 4, 5, 6 and 7 (see page 39).

RUN 11 (Table 18, Figure 15). In Run 11, the cation was on the hydrogen cycle and the anion on the chloride cycle.

Excellent removals of Sr^{89} were obtained with this combination of resins. The average activity of the effluent from the column was 1.6 c/min/ml. This gave a removal of 99.96% and a decontamination factor of 2337.5. The capacity of the column, measured to the point where the activity of the effluent exceeded the MPC for Sr^{89} , was 46.08 liters, the value corresponding to 3600 gallons per cubic foot.

The pH of the effluent dropped to 2.3 at 7.68 liters, and then rose to 2.8 at 11.52 liters. The pH remained constant at the latter value until a total of 38.4 liters had passed, then rapidly rose to 7.5 at 49.93

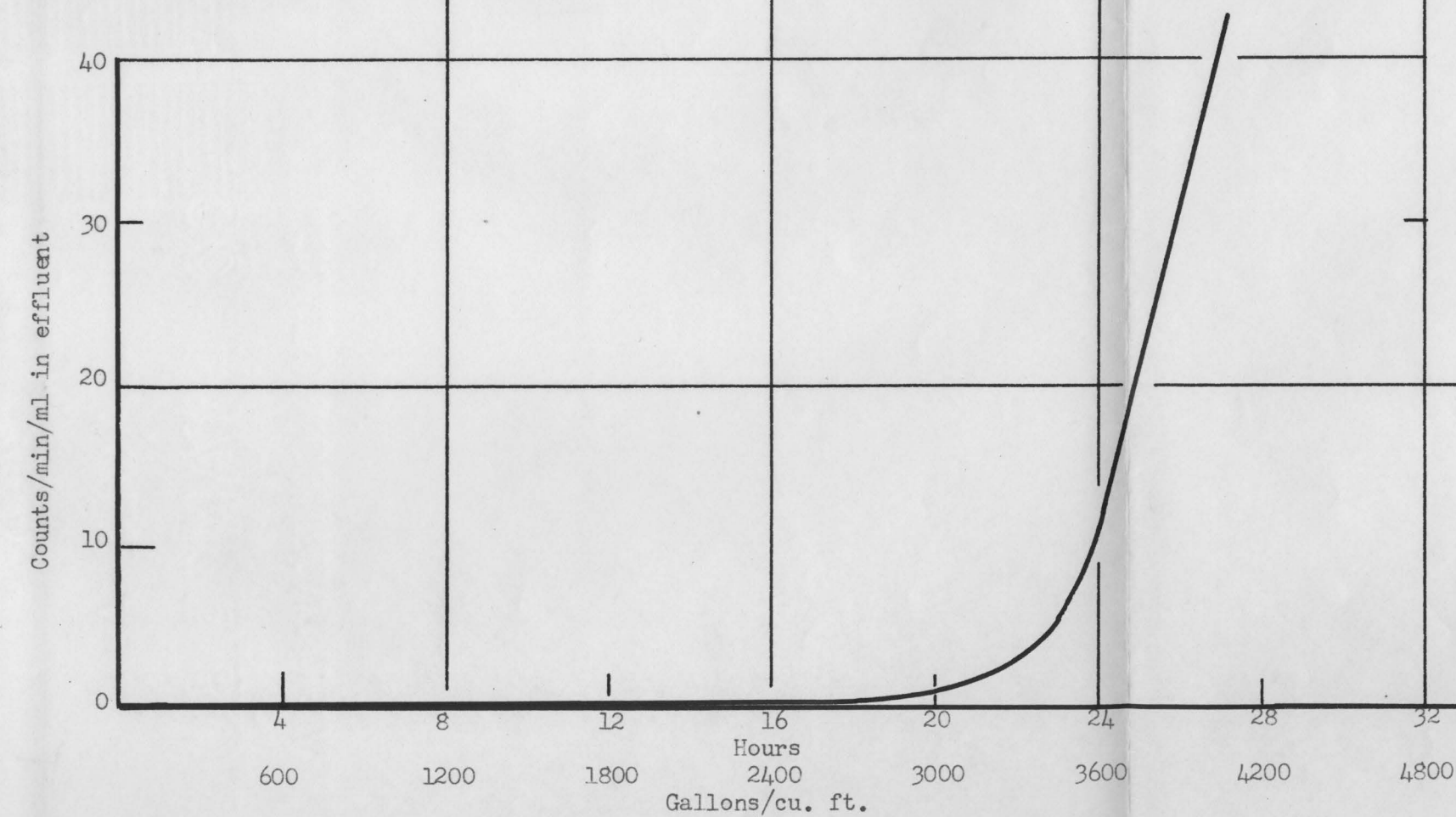
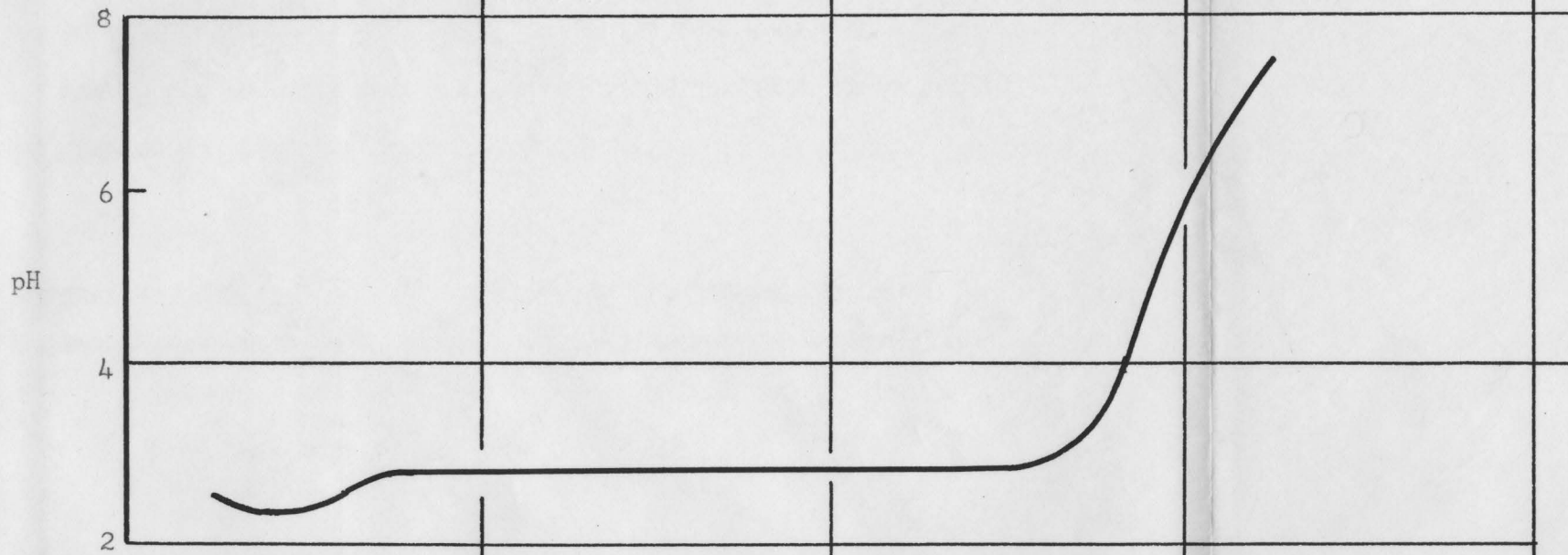
liters. Excess leakage became evident when the pH started to rise from the constant value of 2.8.

TABLE 18
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY MIXED BED ION EXCHANGE RESINS

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
2	3.84	0.3	2.5
4	7.68	0.3	2.3
6	11.52	0.3	2.8
8	15.36	0.3	2.8
10	19.20	0.3	2.8
12	23.04	0.3	2.8
14	26.88	0.3	2.8
16	30.72	0.3	2.8
18	34.56	0.5	2.8
20	38.40	1.0	2.8
22	42.24	2.7	3.2
24	46.08	12.2	5.9
26	49.92	31.2	7.5

RUN 12 (Table 19, Figure 16). In Run 12, the cation was on the sodium cycle and the anion was on the chloride cycle.

This combination of resins resulted in a very good removal of Sr⁸⁹, but was not as effective as the preceding one on the H-Cl cycle. The average activity of Sr⁸⁹ in the effluent was 4.2 c/min/ml for 69.12 liters. This resulted in a removal of 99.89%, and a decontamination



REMOVAL OF CARRIER-FREE Sr⁸⁹ BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - H - 11.25 inches
 Anion - Amberlite IRA-400 - Cl - 24.0 inches

Activity of Influent: 3740 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8

- 10 -
Figure 12

factor of 943.6. The capacity of the bed was extended, however, from a value of 3300 gallons per cubic foot of resin for the previous run, to 5400 gallons. The capacity was measured to the point where the activity in the effluent exceeded the MPC value for Sr⁸⁹.

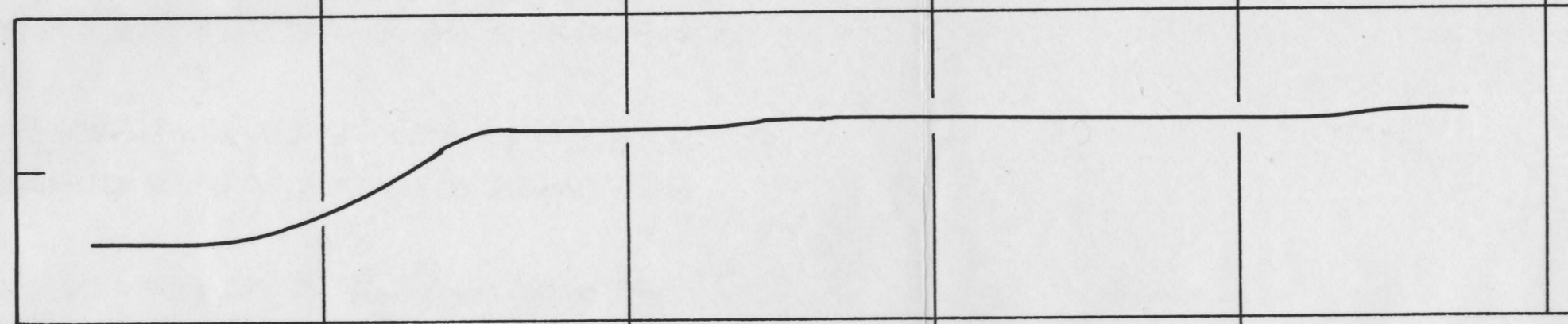
TABLE 19
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - Na and
Amberlite IRA-400 - Cl
Activity of Influent: 3963 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 7.8

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
2	3.84	0.3	6.0
4	7.68	0.9	6.0
6	11.52	1.4	6.0
8	15.36	1.5	6.4
10	19.20	2.0	6.9
12	23.04	2.5	7.5
14	26.88	3.0	7.5
16	30.72	3.2	7.5
18	34.56	3.7	7.5
20	38.40	3.9	7.6
22	42.24	4.0	7.6
24	46.08	4.5	7.6
26	49.92	4.5	7.6
28	53.76	4.5	7.6
30	57.60	6.0	7.6
32	61.44	6.9	7.6
34	65.28	9.5	7.6
36	69.12	12.0	7.7
38	72.96	26.0	7.7

The pH of the effluent from the column was constant at 6 until

pH
8
7
6



REMOVAL OF CARRIER-FREE ⁸⁹Sr BY MIXED BED ION EXCHANGE COLUMN

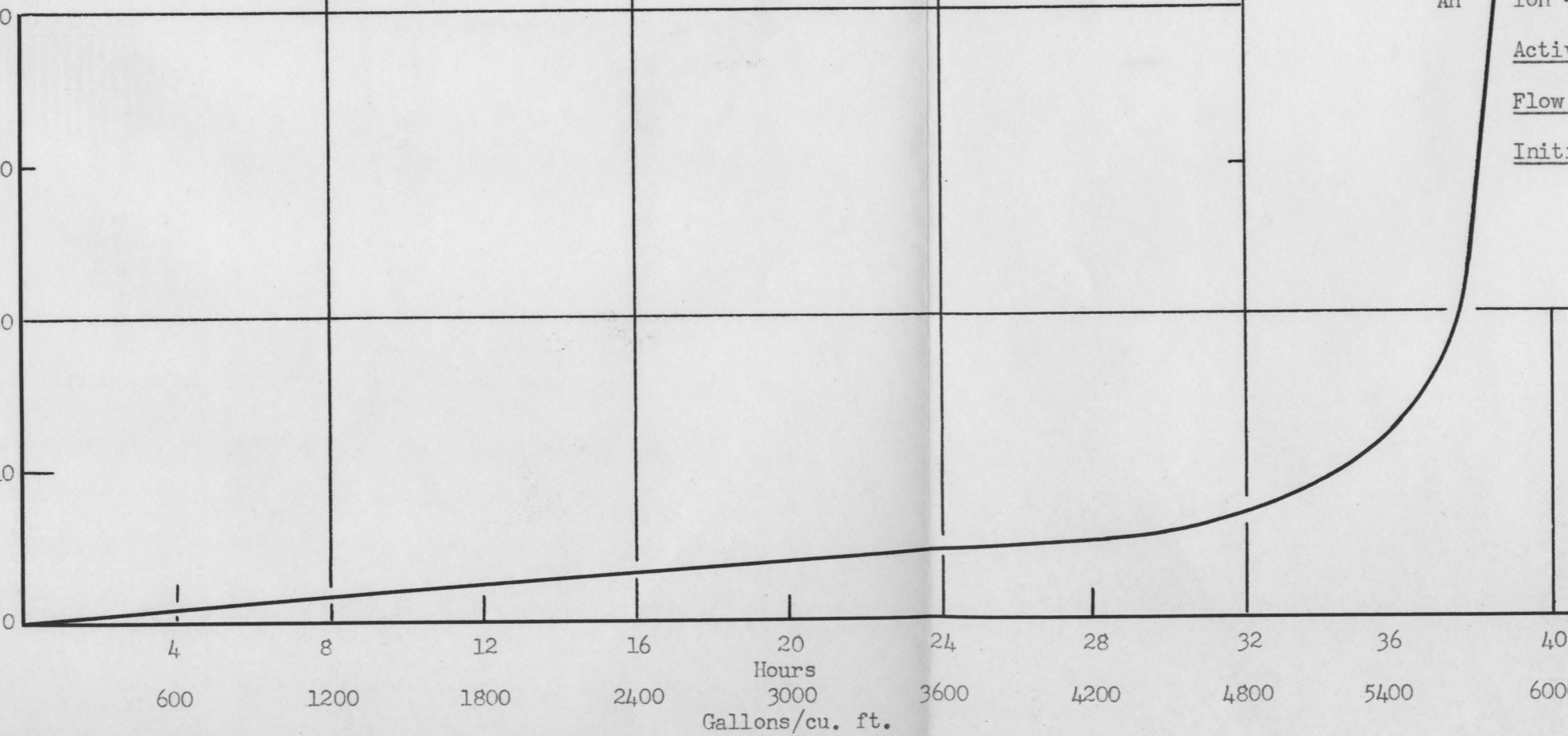
Resins: Cat ion - Amberlite IR-120 - Na - 11.25 inches
An ion - Amberlite IRA-400 - Cl - 24.0 inches

Activity of Influent: 3963 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8

Counts/min/ml in effluent
40
30
20
10
0



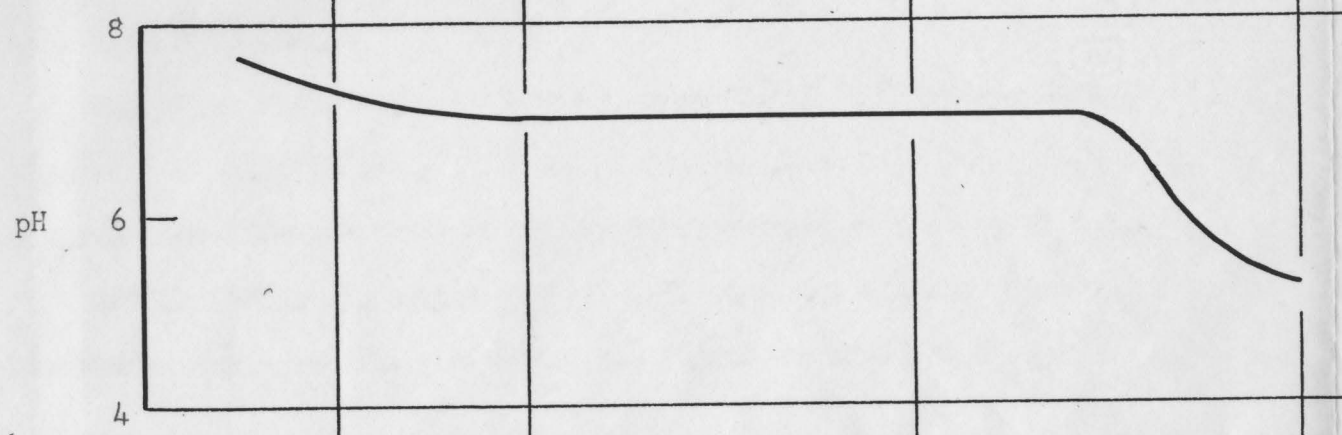
11.52 liters of solution had passed through the column. The pH then rose to a value of 7.5 at 23.04 liters, and then to a value of 7.7 at 72.96 liters.

RUN 13 (Table 20, Figure 17). In Run 13, the cation resin was on the hydrogen cycle and the anion resin on the hydroxide cycle.

TABLE 20
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY MIXED BED ION EXCHANGE RESINS

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
2	3.84	0.2	7.6
4	7.68	0.3	7.3
6	11.52	0.3	7.1
8	15.36	0.3	7.0
10	19.20	0.3	7.0
12	23.04	0.3	7.0
14	26.88	0.3	7.0
16	30.72	2.0	7.0
18	34.56	5.0	7.0
20	38.40	8.9	7.0
22	42.24	19.1	5.6
24	46.08	38.0	5.2

This combination of resins gave an excellent removal for Sr⁸⁹, the average activity of the effluent being 1.79 c/min/ml for 38.4 liters, the value corresponding to 3000 gallons per cubic foot. For the above quantity of water, the percentage removal was 99.96%, and the decontami-



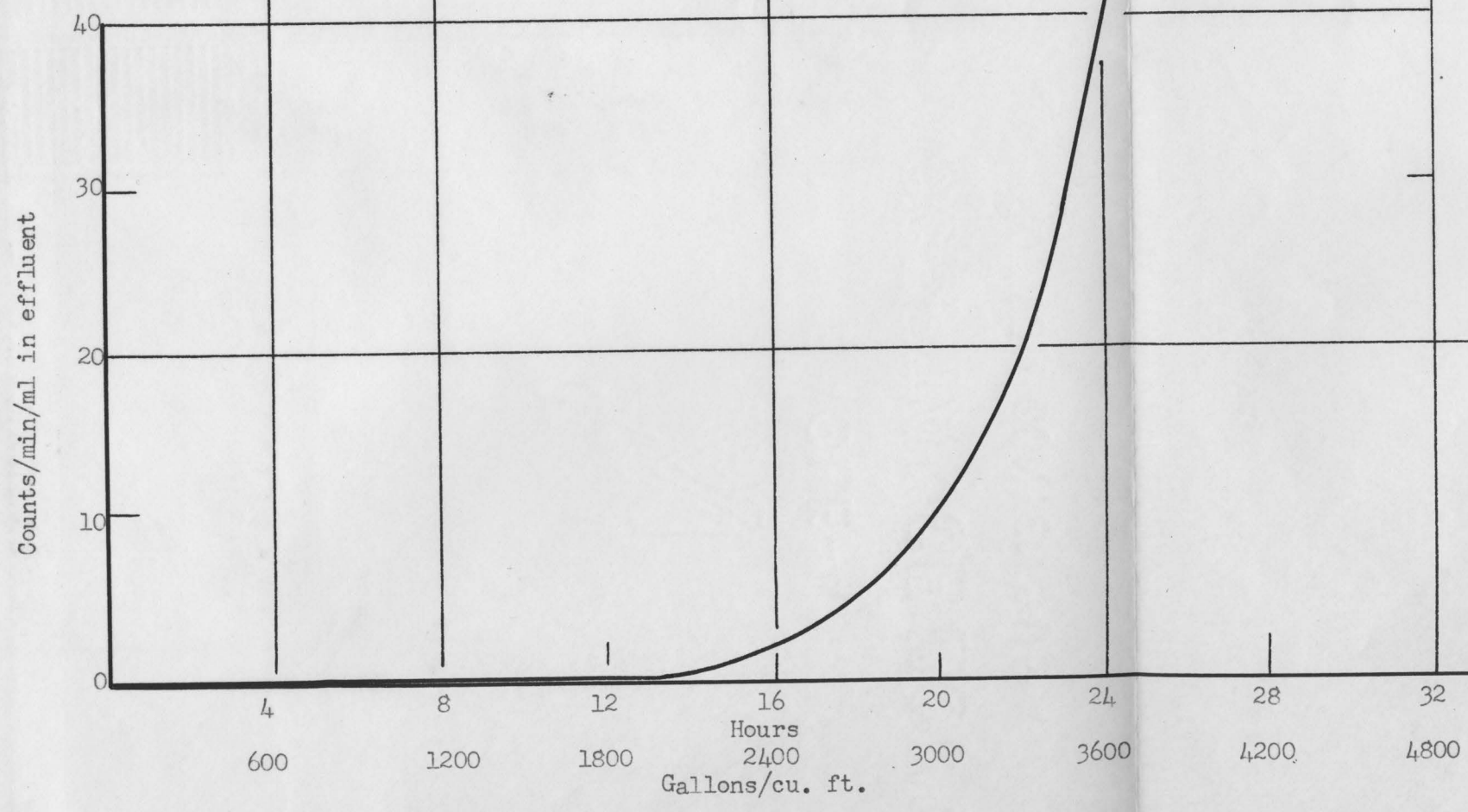
REMOVAL OF CARRIER-FREE Sr⁸⁹ BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - H - 11.25 inches
Anion - Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: 4083 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8



nation factor was 2281. The capacity of the bed as above was 3000 gallons per cubic foot.

The pH of the effluent from the bed was 7.6 at 3.84 liters, and dropped to 7 at 15.36 liters. The pH remained constant at 7 until 38.40 liters had passed through the column, and then dropped to a value of 5.2.

RUN 14 (Table 21, Figure 18). In Run 14, the cation resin was on the sodium cycle and the anion resin was on the hydroxide cycle.

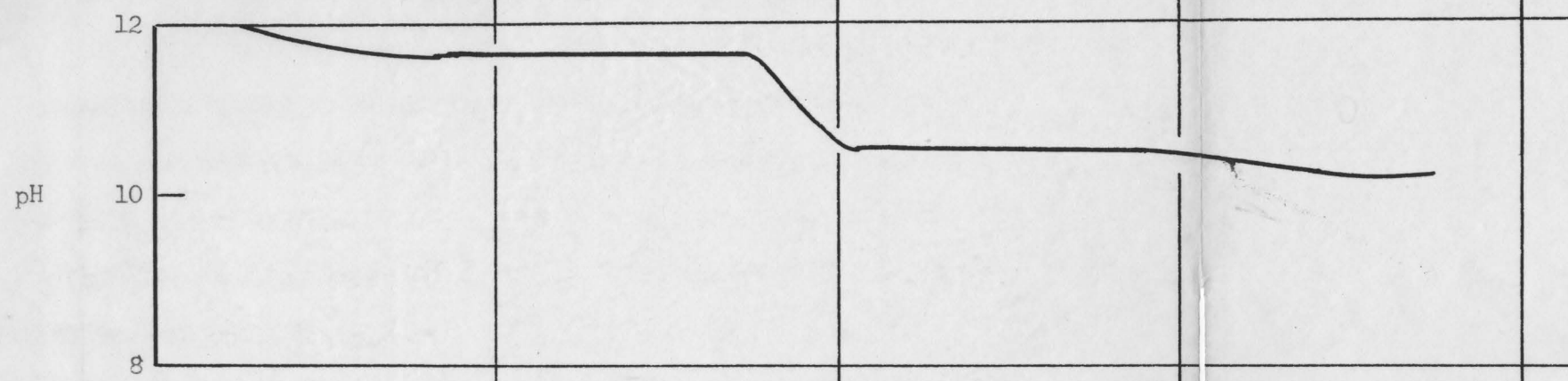
TABLE 21

REMOVAL OF CARRIER-FREE Sr^{89} BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IR-120 - Na and
Amberlite IRA-400 - OH
Activity of Influent: 3761 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 7.8

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
2	3.84	0.5	12.0
4	7.68	0.5	11.8
6	11.52	0.5	11.6
8	15.36	0.6	11.6
10	19.20	0.6	11.6
12	23.04	0.6	11.6
14	26.88	0.7	11.6
16	30.72	0.7	10.5
18	34.56	0.8	10.5
20	38.40	0.8	10.5
22	42.24	1.8	10.5
24	46.08	4.1	10.4
26	49.92	8.1	10.3
28	53.76	16.4	10.2
30	57.60	38.0	10.2

- 18 -
Figure 18



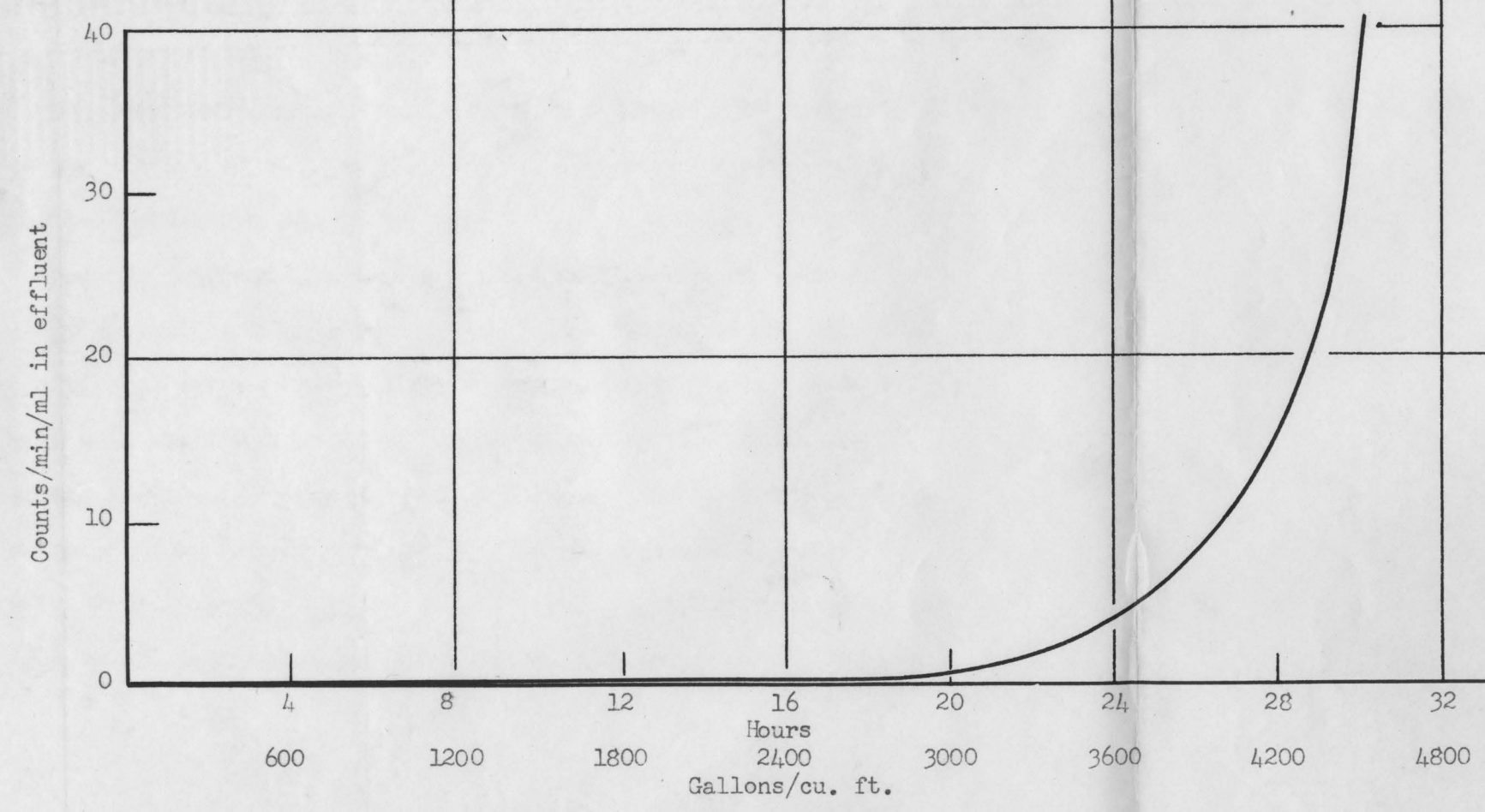
REMOVAL OF CARRIER-FREE Sr^{89} BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - Na - 11.25 inches
Anion - Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: 3761 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8



This combination of resins gave excellent results for the removal of Sr^{89} . The average activity of the effluent for 53.76 liters, corresponding to 4200 gallons per cubic foot, was 1.56 c/min/ml. This resulted in a decontamination factor of 2411, and a removal of 99.96%. The capacity of the column was also large, being approximately 53.76 liters (4200 gallons per cubic foot) before the activity of the effluent exceeded the MPC value for Sr^{89} .

The pH of the effluent from the run was 12 at 3.84 liters, dropped to 11.6 at 11.52 liters, and then was constant until 26.88 liters. At 30.72 liters the pH dropped to 10.5, remained constant at this value to 42.24 liters, and then gradually fell to 10.2 at 57.6 liters.

RUN 15. The results of the runs using Sr^{89} indicated some leakage. Inasmuch as the isotope as received from the Operations Division was a mixture of Sr^{89} , Sr^{90} and Y^{90} , Run 15 was made to determine if the yttrium was removed by the cation resin column on the sodium cycle. The isotope used in the run was Y^{91} , which has no radioactive daughter product, but decays into stable Zr^{91} .

Results obtained were unsatisfactory because the activity of the feed solution could not be maintained at uniform level. These results were due to the fact that yttrium has a tendency to hydrolyze instead of ionize at a pH above 3, and the hydrolyzed particles plated out on the wall of the container. Yttrium, when hydrolyzed, gives a reaction very similar to aluminum hydroxide at an alkaline pH, forming the particle $\text{Y}(\text{OH})_2\text{O}^-$. This accounts for the greater removal of activity by the mixed bed runs, as the negatively-charged particle goes out on the anion resin.

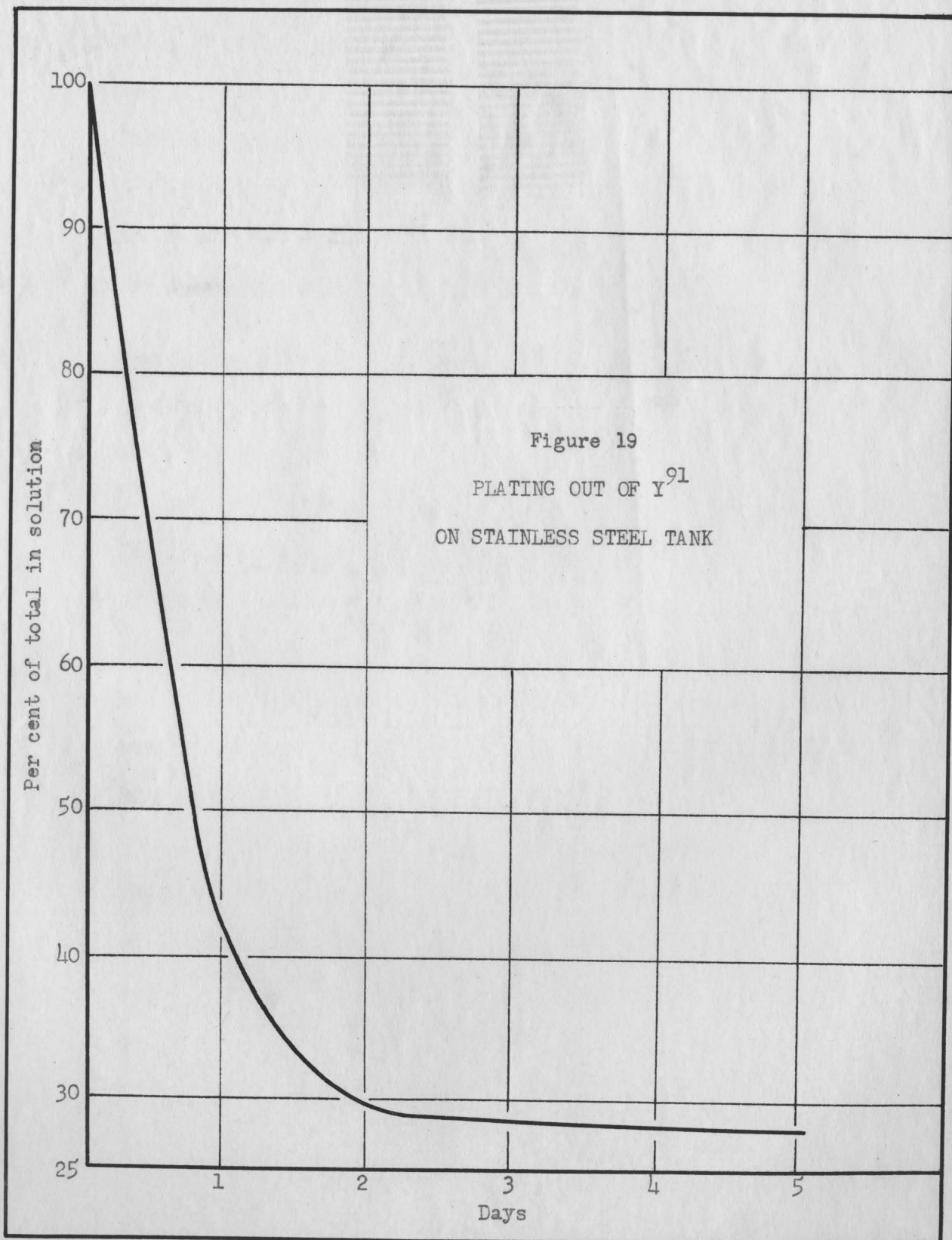


Figure 19
PLATING OUT OF Y^{91}
ON STAINLESS STEEL TANK

The extent of the plating action which took place in the run is shown in Figure 19. Rough approximations of the removal effected by the column gave values of about 75%.

RUN 16. Run 16 was made using the cation resin on the hydrogen cycle, to determine if the lower pH at which the column operated would facilitate the removal of Y^{91} . No determinable change in the results from the preceding run could be found.

Conclusions. The following conclusions are drawn from the series of tests with carrier-free Sr^{89} as received from the Operations Division of the Oak Ridge National Laboratory:

1. The strongly acid cation exchange resin Amberlite IR-120, when used on the sodium cycle, will give removals of 99.8+% of carrier-free Sr^{89} in tap water at a concentration of 1.70×10^{-2} uc/ml, at a flow rate of 2.5 gallons per cubic foot per minute and a bed depth of two feet. The capacity of the resin bed is 10,800 gallons per cubic foot of resin.

2. The addition of an equivalent amount of the strongly basic anion exchange resin Amberlite IRA-400, on the hydroxide cycle, improves the removal to 99.96+% when the column is operated under the same conditions as in 1 above. The capacity of the bed in the run for 11.25 inches of cation resin is 3600 gallons per cubic foot of resin.

3. The use of the cation resin above on the hydrogen

TABLE 22

REMOVAL OF Sr⁸⁹ - ION EXCHANGE RESINS
OPERATIONAL DATA

Run Number	Cation Used in 11mm. Column (inches)	Anion Used in 11mm. Column (inches)	Cycle	Flow Rate (gals/ cu. ft.)	Activity of Influent (uc/ml)	Total volume through Column (liters)
8	24	-	Na	2.5	1.70×10^{-2}	153.60
9	24	-	H	2.5	1.70×10^{-2}	176.64
10	24	-	Ca	2.5	1.85×10^{-2}	74.88
11	11.25	24	H-Cl*	2.5	1.70×10^{-2}	49.42
12	11.25	24	Na-Cl*	2.5	1.80×10^{-2}	72.96
13	11.25	24	H-OH*	2.5	1.85×10^{-2}	46.08
14	11.25	24	Na-OH*	2.5	1.71×10^{-2}	57.60

* first cation, second anion

cycle gives removals of 99.9-% under the same operating conditions, with an increase in bed capacity to 12,000 gallons per cubic foot of resin.

4. The addition of an equivalent amount of the strongly basic type anion exchange resin Amberlite IRA-400, on either the hydroxide or the chloride cycle, increases the removal efficiency to 99.96-% under conditions as in 1 above. The capacity of the resin bed in this run, for 11.25 inches of cation, is 3000 gallons per cubic foot for the anion on the hydroxide cycle, and 3600 gallons per cubic foot for the anion resin on the chloride cycle.

5. The cation resin Amberlite IR-120, when used on the sodium or hydrogen cycle alone, or when used in combination with the anion resin Amberlite IRA-400 on the hydroxide or chloride cycle, for the removal of Sr^{89} , in the concentrations and at the capacities as given in Tables 22 and 23, will furnish a water whose activity is below the MPC value for Sr^{89} (7×10^{-5} uc/ml).

Summary. The strongly acid type cation exchange resin, Amberlite IR-120, when used on the sodium cycle at a two-foot bed depth, will give removals of Sr^{89} in excess of 99.8+% at a flow rate of 2.5 gallons per cubic foot per minute, at an initial feed concentration of 1.70×10^{-2} uc/ml. If the resin is used on the hydrogen cycle under the same conditions as above, the removal can be raised to 99.9+%. When the cation

TABLE 23

REMOVAL OF Sr⁸⁹ - ION EXCHANGE RESINS
COLUMN RESULTS

Run No.	Cation Used in 1 1/2 in. Column (inches)	Anion Used in 1 1/2 in. Column (inches)	Cycle	Activity of Influent (uc/ml)	Average Activity of Effluent up to Breakthrough (uc/ml)	Volume through Column at Breakthrough (gal/cu.ft.)	Decontamination Factor	Per cent Removal
8	24	-	Na	1.70×10^{-2}	2.79×10^{-5}	10,800	608.8	99.84
9	24	-	H	1.70×10^{-2}	1.59×10^{-5}	12,000	1069.7	99.91
10	24	-	Ca	1.85×10^{-2}	5.86×10^{-5}	3,000	316.8	99.68
11	11.25	24	H-Cl*	1.70×10^{-2}	7.27×10^{-6}	3,600	2337.5	99.96
12	11.25	24	Na-Cl*	1.80×10^{-2}	1.91×10^{-5}	5,400	943.6	99.89
13	11.25	24	H-OH*	1.85×10^{-2}	8.13×10^{-6}	3,000	2281.0	99.96
14	11.25	24	Na-OH*	1.71×10^{-2}	7.09×10^{-6}	3,800	2411.0	99.96

* first cation, second anion

resin is used in conjunction with an equivalent amount of strongly basic type anion exchanger, Amberlite IRA-400, the percentage removal can be increased to about 99.96-%. This percentage holds good for all combinations of cycles except the cation on the sodium cycle and the anion on the chloride cycle (see Table 23).

Summaries of the operational data and column results are given in Tables 22 and 23.

Iodine (I^{131}) and Strontium (Sr^{89})

Procedure. The influent solution to the resin column was prepared for these runs (Runs 17, 18, 19 and 20) by diluting carrier-free I^{131} and Sr^{89} in tap water as furnished to the Oak Ridge National Laboratory. The concentration of each isotope was approximately the same and in about the same strength as in the previous runs on I^{131} and Sr^{89} respectively.

The apparatus and method of conducting the investigation were the same as those described in the runs on Sr^{89} (see Plates I and II and Figure 10).

Results. The results for Runs 19 and 20 are reported in Tables 24 and 25 and in Figures 20 and 21.

The results of Runs 17 and 18 are not reported in table and figure form as leakage through the resin column exceeded the MPC value of the isotopes used immediately after commencement of the run in each case (see Discussion of Results).

Discussion of Results. RUN 17. In Run 17 the cation resin was on the hydrogen cycle and the anion resin on the chloride cycle.

The results of the investigation showed almost immediate leakage of activity beyond the MPC value of the isotopes concerned. Fifteen minutes after starting the run, the activity had reached a value of 128 c/min/ml. In order to determine which isotope was responsible for the leakage, 100 ml. of the effluent was taken almost to dryness (after being made alkaline with NaOH). The iodine was precipitated out of the solution

as AgI, and when the precipitate was dried and counted, the iodine was found to account for the major portion of the leakage. The result was to be expected from Run 4 (see page 39).

RUN 18. In Run 18, the anion was on the chloride cycle and the cation was on the sodium cycle.

Results of the run were similar to those in Run 17.

RUN 19 (Table 24, Figure 20). In Run 19, the cation resin was on the hydrogen cycle and the anion resin was on the hydroxide cycle.

This combination of resins gave excellent removals of the isotopes. Up to 28.80 liters through the column, corresponding to 2250 gallons per cubic foot, the average activity of the effluent was 2.2 c/min/ml. This resulted in a percentage removal of 99.97% and a decontamination factor of 3330.

The 2.2 c/min/ml in the effluent is equivalent to 1×10^{-5} uc/ml, a value well below the MPC for either isotope.

The run started at a pH of 7.9, and dropped to a value of 7 at 9.6 liters (750 gallons per cubic foot). The pH remained constant at this value until 23.04 liters had passed through the column. It then dropped rapidly to a value of 4.4 at 28.8 liters, and then gradually rose to 6.3 at 34.56 liters. The latter drop in the pH was probably due to an excess of cation resin, which continued to function after the anion resin had become exhausted.

RUN 20 (Table 25, Figure 21). In Run 20, the cation resin was on the sodium cycle and the anion resin was on the hydroxide cycle.

This combination of resins also gave excellent removal of these

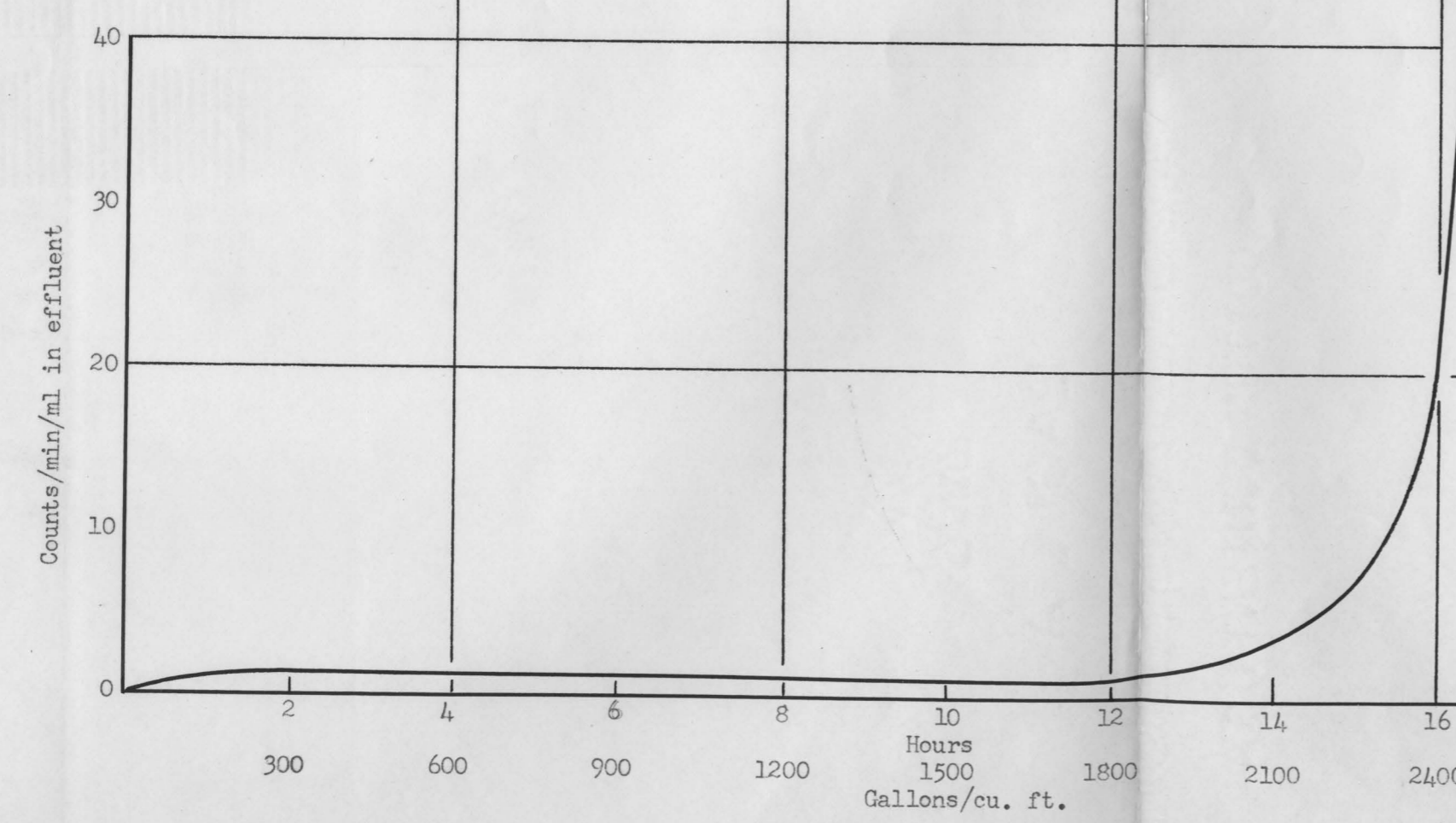
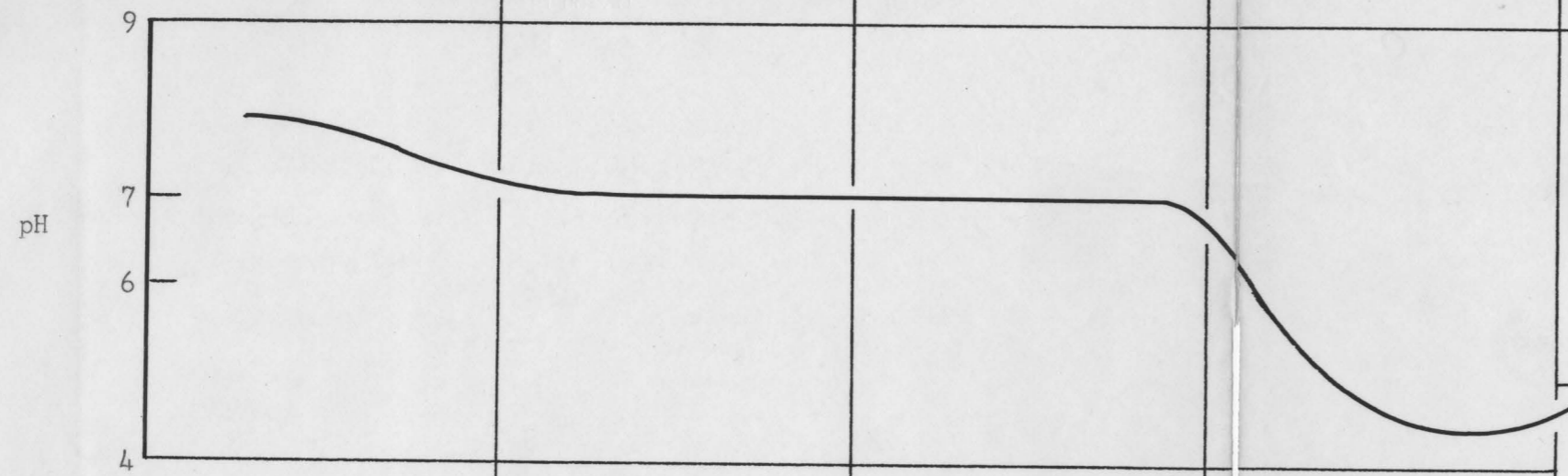
TABLE 24
 REMOVAL OF CARRIER-FREE I¹³¹ AND CARRIER-FREE Sr⁸⁹
 BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IRA-400 - OH and
 Amberlite IR-120 - H
 Activity of Influent: I¹³¹ - 3520 c/min/ml
 Sr⁸⁹ - 3804 c/min/ml
 Flow Rate: 2.5 gallons/cu. ft./min.
 Initial pH: 7.8

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	1.92	1.2	7.9
2	3.84	1.2	7.9
3	5.76	1.2	7.5
4	7.68	1.2	7.3
5	9.60	1.2	7.0
6	11.52	1.2	7.0
7	13.44	1.2	7.0
8	15.36	1.2	7.0
9	17.28	1.2	7.0
10	19.20	1.2	7.0
11	21.12	1.2	7.0
12	23.04	1.5	7.0
13	24.96	2.5	5.5
14	26.88	4.0	4.5
15	28.80	11.8	4.4
16	30.72	20.9	4.6

isotopes, although not as good as in the previous run. The average activity in the effluent was 2.4 c/min/ml for 24.36 liters, the value corresponding to 1950 gallons per cubic foot. The results indicated an average removal of 99.97%, and a decontamination factor of 3067.

The column operated at a pH of 11.3, corresponding to 1200 gallons per cubic foot, for the first 15.36 liters, and then gradually dropped to



REMOVAL OF CARRIER-FREE I^{131} AND CARRIER-FREE Sr^{89}
BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - H - 11.25 inches
Anion - Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: I^{131} - 3520 c/min/ml
 Sr^{89} - 3804 c/min/ml

Flow Rate: 2.5 gallons/cu. ft./min.

Initial pH: 7.8

10.6 at 24.96 liters, corresponding to 1950 gallons per cubic foot.

TABLE 25

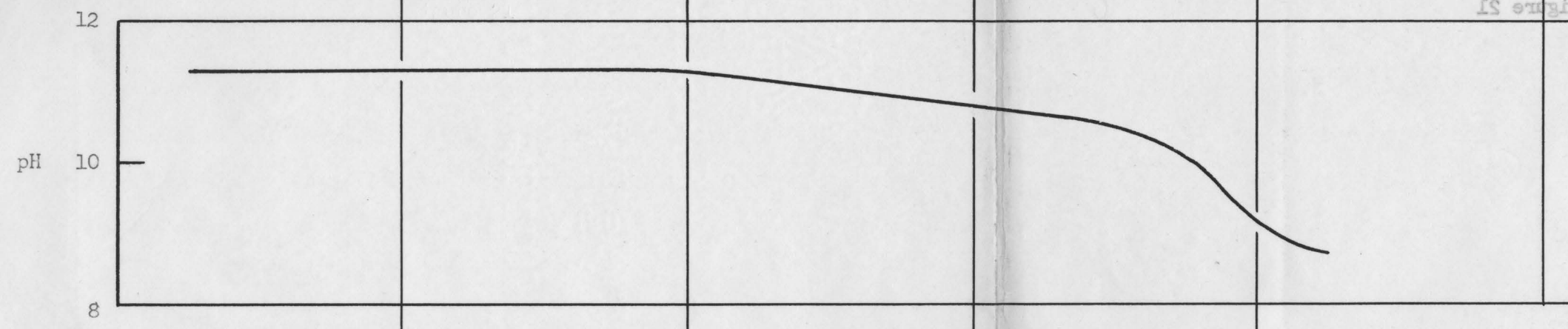
REMOVAL OF CARRIER-FREE I^{131} AND CARRIER-FREE Sr^{89}
BY MIXED BED ION EXCHANGE RESINS

Resins: Amberlite IRA-400 - OH and
Amberlite IR-120 - Na
Activity of Influent: I^{131} - 3700 c/min/ml
 Sr^{89} - 3660 c/min/ml
Flow Rate: 2.5 gallons/cu. ft./min.
Initial pH: 7.8

Hours	Volume through Column (liters)	Activity Level of Effluent (c/min/ml)	pH of Final Effluent
1	1.92	1.2	11.3
2	3.84	1.5	11.3
3	5.76	2.0	11.3
4	7.68	2.0	11.3
5	9.60	2.0	11.3
6	11.52	2.0	11.3
7	13.44	2.0	11.3
8	15.36	2.0	11.3
9	17.28	2.0	11.1
10	19.20	2.0	11.0
11	21.12	2.0	10.9
12	23.04	3.2	10.8
13	24.96	6.5	10.6

Conclusions. The following conclusions are drawn from the series of tests with carrier-free I^{131} and carrier-free Sr^{89} mixed with tap water:

1. The combination of the strongly acid cation exchange resin Amberlite IR-120 on the hydrogen cycle and the strongly basic anion exchange resin Amberlite



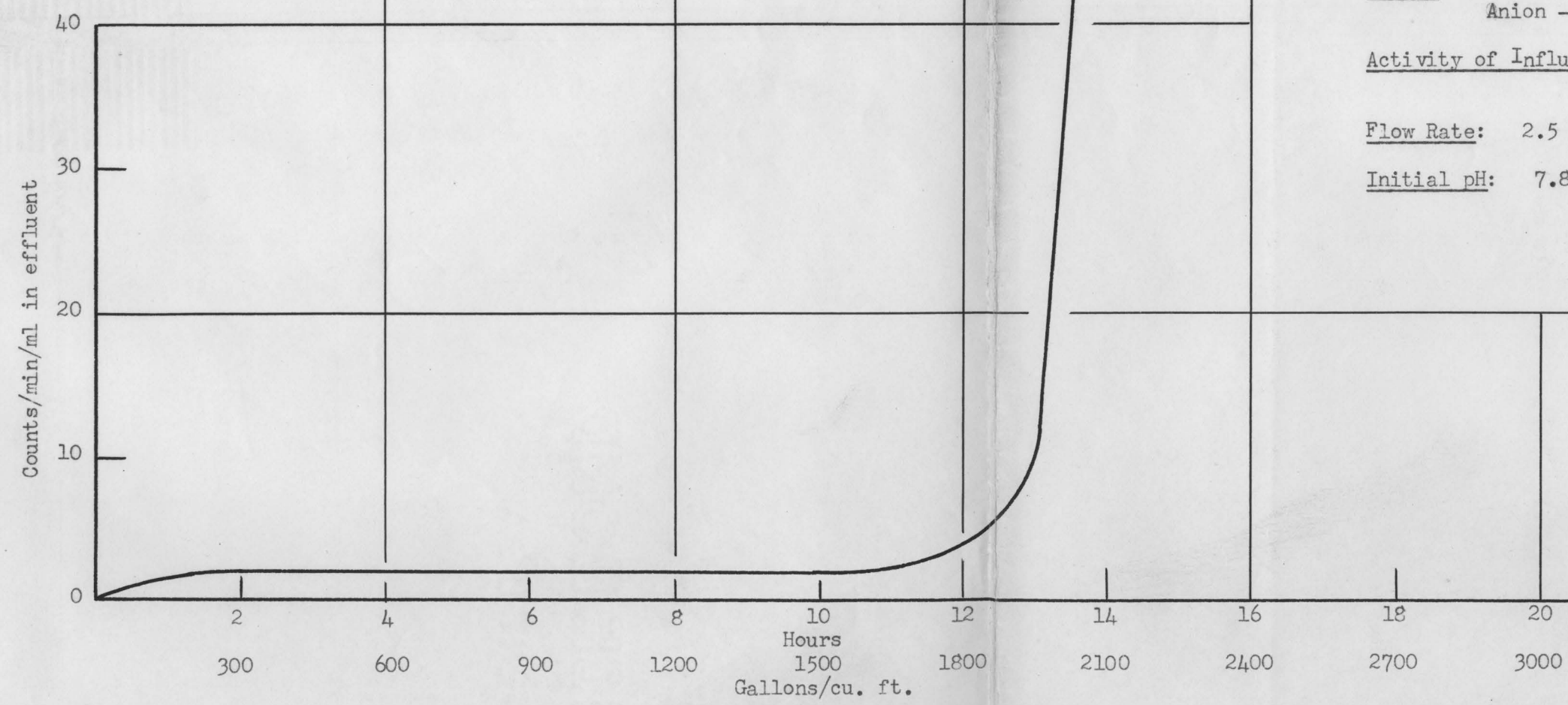
REMOVAL OF CARRIER-FREE I¹³¹ AND CARRIER-FREE Sr⁸⁹
BY MIXED BED ION EXCHANGE COLUMN

Resins: Cation - Amberlite IR-120 - Na - 11.25 inches
Anion - Amberlite IRA-400 - OH - 24.0 inches

Activity of Influent: I¹³¹ - 3700 c/min/ml
Sr⁸⁹ - 3660 c/min/ml

Flow Rate: 2.5 gallons/cu. ft/min.

Initial pH: 7.8



IRA-400 on the hydroxide cycle, mixed in equivalent quantities to a bed depth of approximately 35 inches, will give removals of 99.97% of carrier-free I^{131} and carrier-free Sr^{89} mixed in tap water in concentrations of 1.6×10^{-2} uc/ml and 1.73×10^{-2} uc/ml respectively. The bed capacity of the combination as above is 2250 gallons per cubic foot.

2. The combination of the strongly acid cation exchange resin Amberlite IR-120 on the sodium cycle and the strongly basic anion exchange resin Amberlite IRA-400 on the hydroxide cycle, when mixed in equivalent quantities to a bed depth of approximately 35 inches, will give removals of 99.97% of carrier-free I^{131} and carrier-free Sr^{89} mixed in tap water in concentrations of 1.68×10^{-2} uc/ml and 1.66×10^{-2} uc/ml respectively. The bed capacity for the combination is 1950 gallons per cubic foot.

3. The combination of the resins in 1 and 2 above, with the anion resin on the chloride cycle instead of the hydroxide, shows gross leakage immediately after the start of the run.

Summary. Runs 17 and 18, with the anion on the chloride cycle, showed excess leakage immediately. A chemical analysis of the effluent from the column in Run 17 showed that the greater part of the activity passing through the resin bed was due to the leakage of the I^{131} . The

TABLE 26
REMOVAL OF I¹³¹ AND Sr⁸⁹ - ION EXCHANGE RESINS
OPERATIONAL DATA

Run Number	Cation Used in 1 ^{1/2} mm. Column (inches)	Anion Used in 1 ^{1/2} mm. Column (inches)	Cycle	Flow Rate (gals/ cu. ft.)	Activity of Influent (uc/ml)	Total volume through Column (liters)
19	11.25	24	H-OH [#]	2.5	1.60 x 10 ⁻² * 1.73 x 10 ⁻² **	24.96
20	11.25	24	Na-OH [#]	2.5	1.68 x 10 ⁻² * 1.66 x 10 ⁻² **	30.72

first cation, second anion

* I¹³¹

** Sr⁸⁹

TABLE 27
REMOVAL OF I¹³¹ AND Sr⁸⁹ - ION EXCHANGE RESINS
COLUMN RESULTS

Run No.	Cation Used in Column (inches)	Anion Used in Column (inches)	Cycle	Activity of Influent (uc/ml)	Average Activity of Effluent up to Breakthrough (uc/ml)	Volume through Column at Breakthrough (gal/cu.ft.)	Decontamination Factor	Per cent Removal
19	11.25	24	H-OH [#]	1.60 x 10 ^{-2*} 1.73 x 10 ^{-2**}	1 x 10 ⁻⁵	2250	3300	99.97
20	11.25	24	Na-OH [#]	1.68 x 10 ^{-2*} 1.66 x 10 ^{-2**}	1.1 x 10 ⁻⁵	1950	3067	99.97

first cation, second anion * I¹³¹ ** Sr⁸⁹

results were predicted from a study of Runs 4 and 5.

Runs 19 and 20, with the anion on the hydroxide cycle, gave excellent removals of both isotopes. These results were also expected (see Runs 6, 7, 13 and 14). However, better removals were obtained with the mixture of the two isotopes than in the previous runs where the isotopes were put through the columns separately. The author is at loss as to why this should be so.

In general, it seems that better results can be expected where both an anion and a cation resin are used in equivalent quantities, but the exact effect that the cation resin has on the anion resin, and vice versa, is not fully understood.

Summaries of the operational data and column results are given in Tables 26 and 27.

PLATE I

VIEW OF APPARATUS USED IN STRONTIUM RUNS
AND IN STRONTIUM AND IODINE RUNS

Left to right: Mixing Tank, Variac,
Pump, Resin Column, Flowrator, Rate
Meter and E-A Recorder, Lead Shield
around G-M Tube, pH Meter, E-A Re-
corder for pH Meter.

PLATE II

CLOSE-UP VIEW, SHOWING ARRANGEMENT
OF LUCITE COLUMN, G-M TUBE, AND LEAD SHIELD

PLATE I

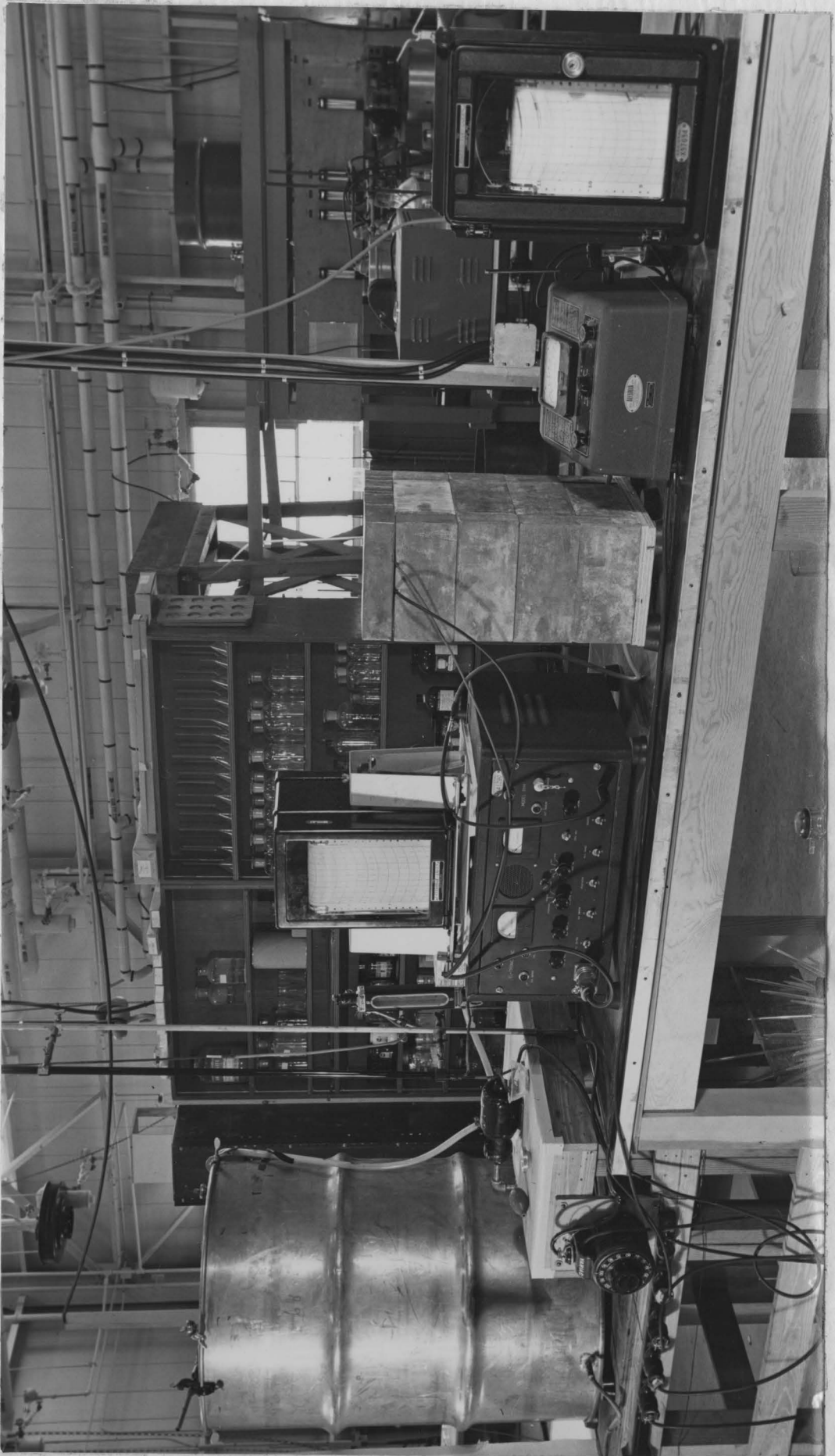
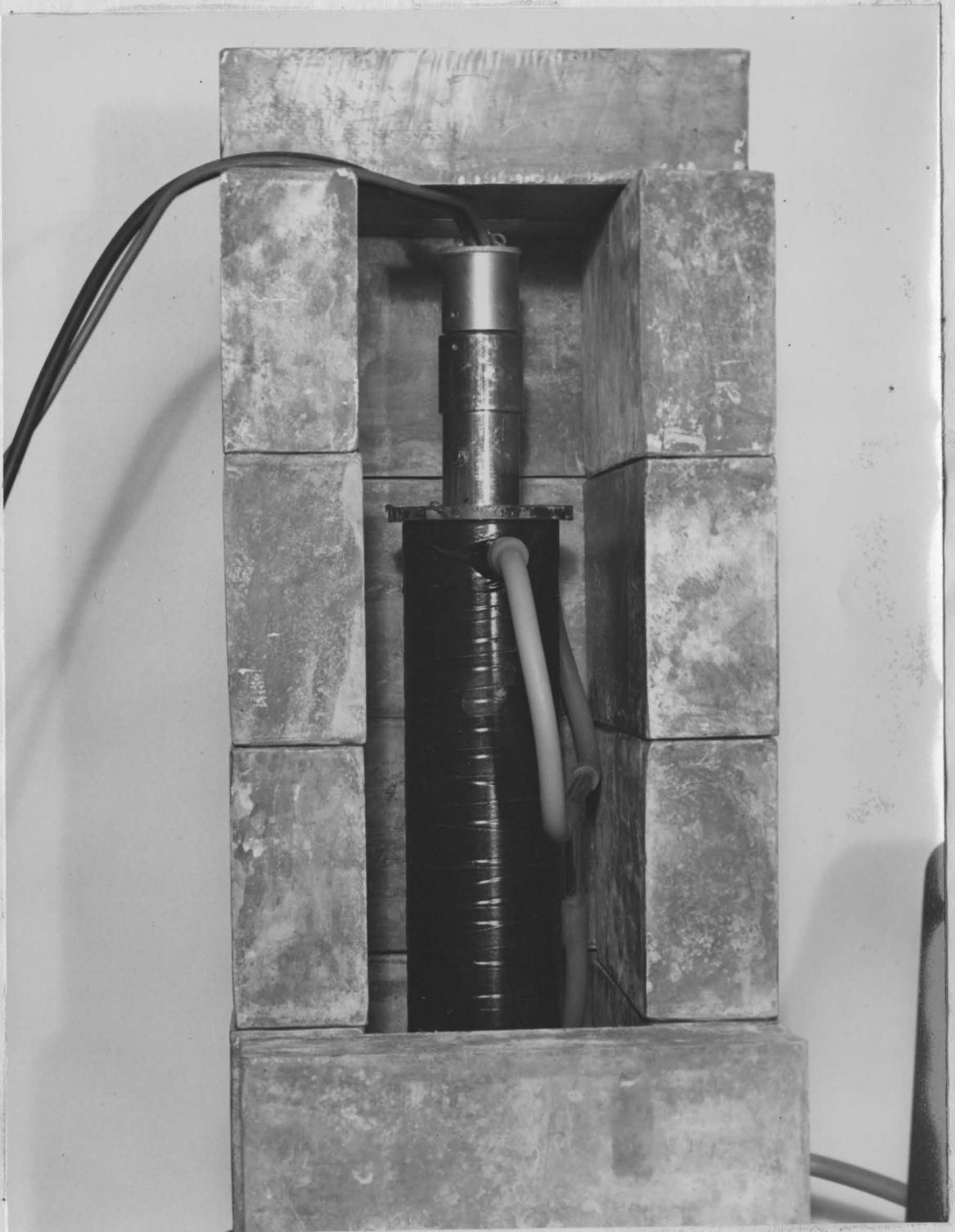


PLATE II



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