

TITLE: REMOVAL OF RADIOACTIVE CONTAMINANTS FROM AQUEOUS LABORATORY WASTES BY CHEMICAL TREATMENT

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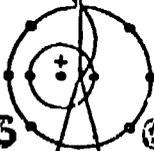
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REMOVAL OF RADIOACTIVE CONTAMINANTS FROM
AQUEOUS LABORATORY WASTES BY CHEMICAL TREATMENT

by

Joseph A. Drago and J. R. Buchholz

INTRODUCTION

Low level, aqueous radioactive wastes generated at the Los Alamos Scientific Laboratory (LASL) are collected in an industrial waste sewer system and are delivered to a separate technical area, TA-50, for treatment. The major radionuclides in this waste are 238-plutonium and 239-plutonium with some 241-ameridium, 90-strontium and 137-caesium. Typical values for the concentrations of these radionuclides in the raw waste, along with their half-lives, major decay modes and concentration guides for water, uncontrolled areas,¹ (CG's) are summarized in Table I. Additional aqueous radioactive wastes are also generated and treated at the LASL plutonium and uranium processing area, TA-21, but these wastes will not be considered in this paper.

The LASL waste management philosophy is to concentrate and contain the radioactivity to produce an effluent which reduces the radioactivity to the lowest practicable levels. The treatment plant used to accomplish these objectives, shown schematically in Figure 1, has been described in detail elsewhere^{2,3} and only the liquid treatment train will be dis-

cussed further. Raw wastes are received in holding tanks which are sized to handle overnight and weekend flows.

The liquid treatment train provides a high pH (above 11.0) chemical precipitation-flocculation process similar to the one first described by Christenson, et al.⁴ Cation exchange for removal of beta-gamma emitters, including ⁹⁰Sr and ¹³⁷Cs, is an in-line process for additional treatment.

Raw feed is pumped from the waste holding tanks and routed to either or both of the two chemical treatment trains, which can be operated in parallel (normal mode) or series at design rates of 250 gpm (total) and 125 gpm, respectively. These two treatment trains provide flash mixing of reactant chemicals (2 minutes), flocculation (40 minutes) and sedimentation (2.5 hours) in combined flocculator-clarifier units. A small fraction of the sludge produced is normally recycled to the flash mixers to aid in the floc formation.

The settling tank effluents (STE's) are combined (parallel operation) and recarbonated before filtration (3 gpm/ft²) with graded anthracite to remove any fine particles carried over from the settling units. The filtrate passes through two hydrogen form cation exchange columns and is routed to a treated-waste holding tank. If the alpha activity in the filtrate is less than about 2,000 pCi/l, it is discharged to a canyon through an outfall; if not the filtrate is re-treated. Normally the alpha activity in the filtrate will average less than 400 pCi/l.

Sludge is drawn from the bottom of the flocculation-clarification tanks and dewatered by vacuum filtration. Filter backwash water is returned to the raw waste storage tanks. The spent ion exchange regenerant is chemically treated; the sludge is then dewatered and the supernatant is returned to the raw waste holding tanks. Handling of these sludges has been discussed elsewhere.⁵

The current chemical reactants used at the LASL normally include ferric sulfate (about 100 mg/l), hydrated lime (about 400 mg/l), trisodium phosphate (about 100-200 mg/l) and a nonionic or anionic polyelectrolyte (about 1 mg/l). These produce a voluminous floc containing ferric hydroxide, calcium carbonate and basic calcium phosphate at high pH (>11.0). Christenson, et al.⁴ found that a high pH (with calcium present) was necessary in addition to the ferric hydroxide to provide adequate plutonium removals when citrates and polyphosphates were present. Drago⁶ found that these conditions were also necessary to obtain satisfactory plutonium removals in wastes containing EDTA (disodium ethylenediamine tetraacetate). Nevertheless, excess chelating agents or unknown contaminants in the raw waste occasionally caused plant upsets since the Fe was complexed and plutonium removal efficiencies sharply decreased. The effluent required re-treatment before it could be discharged.

The high pH conditions and iron complexing problems indicated that Mg(II) might minimize this problem because a

metal hydroxide floc would still be formed, but the magnesium would be less sensitive to complexing than Fe(III).

The current treatment normally provides only limited amounts of ^{90}Sr and ^{137}Cs removal. Trisodium phosphate (TSP) is used to help aid in removing ^{90}Sr , but the high TSP:lime ratios which Lauderdale⁷ found were necessary (ratios over 2.2 to provide greater than 90 percent removal) can not be achieved in the TA-50 plant; significant floc carryover and increased alpha in the settling tank effluent occurred when the TSP:lime was much greater than 0.5.

Clays have been used as coagulant aids to remove ^{90}Sr and ^{137}Cs from radioactive wastes with varying degrees of success.⁸ Clinoptilolite, a natural zeolite with a high selectivity for cesium and a lesser one for strontium ($\text{Cs}^+ > \text{Rb}^+ > \text{NH}_4^+ > \text{Ba}^{2+} > \text{Sr}^{2+} > \text{Na}^+ > \text{Ca}^{2+} > \text{Fe}^{3+} > \text{Al}^{3+} > \text{Mg}^{2+} > \text{Li}^+$) has been used in a column form to remove ^{137}Cs and ^{90}Sr from aqueous wastes. A powdered form of clinoptilolite was selected for this study to determine its effectiveness as a coagulant aid.

EXPERIMENTAL

Procedures - The investigations in this study included batch experiments and full scale plant tests of various chemical treatments.

Batch Experiments - These consisted of standard jar tests using a 6-multi-paddle stirring apparatus (Phipps and Bird, Richmond, Virginia) and one-liter samples in 1500 ml

beakers. The samples were rapid-mixed while the chemicals were added and for one additional minute at 100 RPM, flocculated for 20 minutes at 20 RPM, then allowed to settle for at least 30 minutes. At this time, at least 150 ml of the supernatant were filtered through a Whatman No. 541 filter paper. Samples were taken before and after filtration for appropriate radioactivity measurements.

Plant Tests - These directly used the parallel chemical treatment trains in the TA-50 plant to provide side-by-side comparisons between the modified and the current chemical treatments. The plant sampling system was used to take daily and weekly composite samples for analyses.

Waste Solutions - The batch experiments were performed with LASL tap water containing a ^{238}Pu - ^{239}Pu spike in 2N HNO_3 , a ^{137}Sr spike in 2N HCl . The spiked solutions contained approximately 68×10^6 pCi/l of the ^{238}Pu - ^{239}Pu (76 percent ^{238}Pu by alpha activity) and approximately 2×10^7 pCi/l of ^{137}Cs and 1.5×10^7 pCi/l of ^{85}Sr as appropriate (^{85}Sr , a gamma emitter, was used in place of ^{90}Sr , a beta emitter, to simplify the radioactivity determinations). The acid added by the spikes was neutralized by 6N NaOH .

Table II provides a comparison of selected chemical constituents in the TA-50 raw feed and LASL tapwater. The addition of the acids and bases to the spiked solutions raised the specific conductance to around 1100-1200 $\mu\text{mho/cm}$, which is similar to the raw feed. The powdered clinoptilolite used in some experiments helped simulate the suspended solids

found in the raw feed.

Chemicals - The chemicals used in the batch test were all reagent grade except for the clinoptilolite; those used in the plant tests were commercial grade. The clinoptilolite used in the batch test was obtained as 50 mesh zeolex, (Double Eagle Petroleum and Mining Company, Casper, Wyoming). This was ball milled and sieved through a 325 mesh sieve to produce a fine powder. The clinoptilolite used in the plant was Zeolex 725 (Double Eagle), with an NH_4^+ exchange capacity of 2.0 meq/g and with over 95 percent of the particles passing a 200 mesh sieve.

Analyses - The alpha activity of the plutonium was determined with an internal proportional counter, ^{137}Cs and ^{85}Sr by gamma spectrometry, ^{238}Pu and ^{239}Pu by alpha spectrometry and ^{90}Sr with a beta proportional counter. Radiochemical separations, using accepted methods, were made of plant samples for ^{238}Pu , ^{239}Pu , ^{90}Sr , and ^{137}Cs before the gross radioactivity determinations were made.

RESULTS

Batch Experiments - Preliminary screening tests were conducted with magnesium sulfate to determine the dosage required for further testing. Six different chemical treatments were compared in jar tests so that the effects of Mg(II) , Fe(III) , lime, and trisodium phosphate on plutonium removal could be made. Table III summarizes the treatments tested and the dosages used.

A screening test was made for sorption of ^{238}Pu - ^{239}Pu , ^{137}Cs and ^{85}Sr on powdered clinoptilolite (<325 mesh), using spiked tapwater (pH=11.6) with 100 ml portions containing various concentrations of clinoptilolite (0, 10, 20, 50, 100, 200, 500, and 1000 mg/l). The samples were mixed with wrist action shakers for 30 minutes, then removed and filtered through Whatman No. 2 filter paper before counting. Figure 2 shows a plot of percent radionuclide sorbed (corrected for losses in filtering the portion without clinoptilolite) as a function of clinoptilolite concentration. Based on these results, it appeared that dosages around 100 mg/l might be suitable for the jar test experiments.

Plutonium removals in jar tests - The results of a series of jar tests using the six chemical treatments and 0, 50, and 100 mg/l clinoptilolite are shown in Table IV. The unfiltered supernatant results indicate that the presence of a metal hydroxide $[\text{Mg}(\text{OH})_2 \text{ or } \text{Fe}(\text{OH})_3]$ in the floc improves the plutonium removals as compared to the lime-only treatment. This effect is significantly reduced when trisodium phosphate is added, although the magnesium-lime-TSP and ferric-lime-TSP provided better results than the lime-TSP treatment. The general trend of these tests indicate that the presence of suspended matter (clinoptilolite) improves the plutonium removal.

The results of another series of jar tests, using 100 mg/l

clinoptilolite and various concentrations of EDTA, are summarized in Table V. These tests indicate that increasing the EDTA concentration generally resulted in poorer removals of plutonium. Note that the treatments without a metal hydroxide in the floc were affected more by the EDTA concentration. This puts a practical limit on the use of lime-TSP treatment because the TA-50 raw feed frequently contains chelating agents.

Additional tests were run with the magnesium and ferric treatments on raw feed and other spiked tapwater samples containing chelating agents which showed that comparable results for the magnesium-lime-TSP and ferric-lime-TSP treatments were obtained.

Strontium and cesium removals - The removal of ^{85}Sr and ^{137}Cs in the first series of jar tests in which 0, 50, and 100 mg/l clinoptilolite were used are shown in Table VI along with similar results from spiked raw feed samples. The ^{85}Sr removals ranged from 25-75% and generally were better where trisodium phosphate was used. Slightly better results were obtained with 50 mg/l clinoptilolite than with 100 mg/l clinoptilolite.

The ^{137}Cs removals improved from zero removal without clinoptilolite up to over 80% with 100 mg/l clinoptilolite for the spiked tapwater and over 60% with the spiked raw feed. Slightly better removals were obtained when the chemical treatment did not contain trisodium phosphate. This appears to be related to the amounts of sodium present in the solution; the sodium may compete with the Cs for sorption sites on the clinoptilolite. Figures 3 and 4 show the

relationship between ^{137}Cs removal versus residual calcium concentration and specific conductance (an indirect measure of sodium). For simplicity, only the distinction of whether TSP was used is made on these plots.

Plant Test - Full scale plant tests were conducted to determine the effectiveness of (1) magnesium sulfate-lime-trisodium phosphate treatment and (2) powdered clinoptilolite in conjunction with ferric sulfate-lime trisodium phosphate treatment. In both cases, ferric sulfate-lime-trisodium phosphate treatment was established as a control using the parallel chemical treatment trains in the TA-50 plant.

(1) Magnesium Sulfate vs Ferric Sulfate - Table VII provides a summary of the chemical usage and the performance of each treatment based on alpha activity of daily composite samples during 24 operating days. Variation of the alpha activity in the raw feed and the settling tank effluents (STE) for a 39 day period is shown in Figure 5.

The results of this test indicate that the magnesium sulfate-lime-trisodium phosphate treatment performed adequately, but not as well as the ferric sulfate-lime-trisodium phosphate treatment. Note that, except for a few points, both methods of treatment reduced the alpha activity well below the CG for plutonium, and that the variability of the unfiltered STE samples was much greater for the magnesium treatment.

This variability is illustrated better in Figure 6, which contains plots of the probability of the unfiltered STE alpha activity being less than or equal to a given value for each treatment over the entire test period. The values for the magnesium treatment are consistently higher, suggesting that routine replacement of the ferric sulfate with magnesium sulfate could not be justified.

On operating day number 20, a waste known to contain EDTA and other chelating agents was processed with the magnesium treatment with significantly better results (250 pCi/l in the unfiltered STE compared to 950 pCi/l for the ferric control). Since that time, magnesium sulfate has been added with ferric sulfate and increased lime doses during occasions of non-typical plant influents.

(2) Clinoptilolite Test - Table VIII provides a summary of the chemical usage and the performance of the ferric sulfate-lime-trisodium phosphate treatment with and without clinoptilolite over a 9 week period. For this test, the performance data are based on radiochemical analyses for ^{238}Pu , ^{239}Pu , ^{90}Sr , and ^{137}Cs in weekly composites of the raw feed and STE's. Variations in the total plutonium ($^{238}\text{Pu} + ^{239}\text{Pu}$), on both a specific activity and a mass basis, ^{90}Sr and ^{137}Cs during the test period are shown in Figures 7, 8, 9, and 10 respectively. Note that the total plutonium ($^{238}\text{Pu} + ^{239}\text{Pu}$) and ^{90}Sr removals were relatively unaffected by the addition of clinoptilolite while a significant improvement was noted in the ^{137}Cs removals.

On Figure 7, the alpha activity for STE-1 for week #5 is not included because a spurious "hot sample" was detected. The authors have occasionally found such non-typical particles in the suspended solids of raw feed samples filtered with a 0.45 μm millipore (Type HA) filter by using autoradiographic techniques.

CONCLUSIONS

The following conclusions can be drawn from these studies:

1. The presence of suspended matter (i.e., clay) in the spiked tapwater solution improved the plutonium removals; however, the addition of clinoptilolite to the plant raw feed did not provide any noticeable improvement for plutonium removal.
2. The addition of powdered clinoptilolite to the regular treatment in the plant significantly improved the removal of ^{137}Cs , but had little effect on plutonium or ^{90}Sr removal.
3. Magnesium sulfate-lime-TSP treatment in the plant performed adequately, but not as well as the regular ferric sulfate-lime-TSP treatment. However, magnesium appears to be an adequate alternate during occasions of non-typical influents.
4. A large portion of the plutonium is associated with the suspended solids matter in the waste. Autoradiographs indicate that the plutonium is generally evenly distributed, with some occasional hot spots.

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TABLE I

MAJOR RADIONUCLIDES IN TA-50 RAW WASTE

Radionuclide	t _{1/2} (yr)	Major Decay Mode	Concentration, pCi/l Typical TA-50 Waste	Uncontrolled Area(CG)
²³⁸ Pu	87	Alpha	140,000	5,000
²³⁹ Pu	24,400	Alpha	5,800	5,000
²⁴¹ Am	458	Alpha	6,000	4,000
⁹⁰ Sr	29	Beta	1,100 (a)	100
¹³⁷ Cs	30	Beta, Gamma	5,100	20,000

(a) ⁸⁹Sr - ⁹⁰Sr combined

TABLE II

CHEMICAL COMPOSITION OF LOS ALAMOS
TAPWATER AND TA-50 RAW FEED(*)

<u>Constituent</u>	<u>Los Alamos Tapwater</u>	<u>TA-50 Raw Feed</u>
Total Hardness, mg/l CaCO_3	25	30-130
Total Alkalinity, mg/l CaCO_3	60	180-1720
Total Dissolved Solids, mg/l	203	245-1360
Conductivity, $\mu\text{mhos/cm}$	116	647-6240
pH, mg/l	8.2	8.6-12.0
Na, mg/l	50	75-750
Ca, mg/l	9	10-26
Mg, mg/l	0.5	1-17
Suspended Solids	-	74-1580

(*) Based on 9 weekly composites November 1975-January 1976

TABLE III

CHEMICAL COAGULANT SYSTEMS EVALUATED

CHEMICAL TREATMENT COMBINATION	CHEMICAL DOSAGES, mg/l			
	Ca(OH)_2	$\text{Fe}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$
Lime	400	-	-	-
Lime-TSP	400	-	-	200
Magnesium-Lime	400	-	200	-
Magnesium-Lime-TSP	400	-	200	200
Ferric-Lime	400	100	-	-
Ferric-Lime-TSP	400	100	-	200

TABLE IV
EFFECT OF CLINOPTILOLITE ON REMOVAL OF PLUTONIUM
BATCH EXPERIMENTS WITH VARIOUS CHEMICAL TREATMENTS (a)

<u>Chemical Treatment</u>	<u>Clinoptilolite Concentration, mg/l</u>	<u>Supernatant Alpha Activity, pCi/l Unfiltered</u>	<u>Alpha Activity, pCi/l Filtered (b)</u>	<u>Alpha Activity Removal, % Unfiltered</u>	<u>Alpha Activity Removal, % Filtered</u>
Lime	0	551,000	49,600	69.4	97.2
	50	370,000	77,600	79.4	95.7
	100	316,000	300	82.4	99.9+
Lime-TSP	0	14,200	1,560	99.2	99.9
	50	6,880	520	99.6	99.9+
	100	3,460	140	99.8	99.99
Magnesium-Lime	0	21,600	5,480	98.8	99.7
	50	6,920	2,420	99.6	99.9
	100	5,310	1,610	99.7	99.9
Magnesium-Lime-TSP	0	7,400	1,610	99.6	99.9
	50	3,320	660	99.8	99.9+
	100	3,030	1,040	99.8	99.9
Ferric-Lime	0	23,600	3,560	98.7	99.8
	50	3,840	3,570	99.8	99.8
	100	12,300	2,370	99.3	99.9
Ferric-Lime-TSP	0	4,360	810	99.8	99.9+
	50	4,360	280	99.8	99.9+
	100	1,420	95	99.9	99.99

(a) Initial Alpha Activity = $1.8 \cdot 10^6$ pCi/l of ^{238}Pu - ^{239}Pu in tapwater

(b) Filtered through Whatman No. 541 filter paper

TABLE V
EFFECT OF EDTA ON REMOVAL OF PLUTONIUM
BATCH EXPERIMENTS WITH VARIOUS CHEMICAL TREATMENTS (a)

Chemical Treatment	EDTA Conc., mg/l	Supernatant Alpha Activity, pCi/l		Alpha Activity Removal, %	
		Unfiltered	Filtered (b)	Unfiltered	Filtered (b)
Lime	0	316,000	300	82.4	99.9+
	100	387,000	2,750	78.5	99.8
	500	344,000	26,400	80.9	98.5
	1,000	353,000	94,400	80.4	94.8
Lime-TSP	0	3,460	140	99.8	99.99
	100	15,600	3,800	99.1	99.8
	500	21,800	2,990	98.8	99.6
	1,000	45,000	15,300	97.5	99.1
Magnesium-Lime	0	5,310	1,610	99.7	99.9
	100	11,700	4,930	99.4	99.7
	500	18,000	9,500	99.0	99.5
	1,000	34,600	17,700	98.1	99.0
Magnesium-Lime-TSP	0	3,030	1,040	99.8	99.9
	100	3,460	2,420	99.8	99.9
	500	14,700	4,360	99.2	99.8
	1,000	14,700	4,700	99.2	99.7
Ferric-Lime	0	12,300	2,370	99.3	99.9
	100	10,700	2,660	99.4	99.8
	500	9,100	2,510	99.5	99.9
	1,000	13,000	3,420	99.3	99.8
Ferric-Lime-TSP	0	1,420	95	99.9	99.99
	100	4,130	900	99.8	99.9+
	500	4,080	1,280	99.8	99.9
	1,000	12,700	2,230	99.3	99.9

(a) Tapwater containing $1.8 \cdot 10^6$ pCi/l of ^{238}Pu - ^{239}Pu spike and 100mg/l clinoptilolite
(b) Filtered through Whatman No. 541 paper

TABLE VI

EFFECT OF CLINOPTILOLITE ON REMOVAL OF ^{85}Sr AND ^{137}Cs
 BATCH EXPERIMENTS WITH VARIOUS CHEMICAL TREATMENTS

<u>Chemical Treatment</u>	<u>Clinoptilolite Concentration, mg/l</u>	^{85}Sr Removal		^{137}Cs Removal	
		<u>Spiked Tapwater</u>	<u>Spiked Raw Feed</u>	<u>Spiked Tapwater</u>	<u>Spiked Raw Feed</u>
Lime	0	-	-	-	-
	50	39.1	64.4	74.0	48.1
	100	36.9	-	84.0	-
Lime-TSP	0	-	-	~0	-
	50	51.3	72.0	70.4	49.2
	100	43.2	60.2	82.1	64.0
Magnesium-Lime	0	-	-	~0	-
	50	43.4	68.3	78.4	59.1
	100	-	-	89.3	-
Magnesium-Lime-TSP	0	-	-	~0	-
	50	39.3	75.1	72.2	56.0
	100	-	-	84.4	-
Ferric-Lime	0	-	-	-	-
	50	25.6	68.6	75.7	55.6
	100	39.8	-	86.9	-
Ferric-Lime-TSP	0	-	65.2	~0	7.3
	50	54.0	74.2	71.1	49.5
	100	44.6	64.5	82.8	63.1

TABLE VII

SUMMARY OF TYPICAL PLANT DATA FOR
MAGNESIUM SULFATE VS. FERRIC SULFATE TEST (a)

Parameter	Process Train-1		Process Train-2	
	Average	Range	Average	Range
Flow rate, gpm	113	56-165	113	56-165
Coagulant Dosage, mg/l				
Ferric Sulfate	210	47-579	-	-
Magnesium Sulfate	-	-	177	10-274
Lime	500	96-985	500	96-985
Trisodium Phosphate	94	62-266	94	62-266
Alpha Activity, pCi/l				
Raw Feed	154,200	29,800-706,100	154,200	29,800-706,100
Unfiltered STE	730	100-2430	1600(b)	60-8510
Filtered STE (c)	70	5-150	240(b)	6-890
Filtered effluent (b)	670	130-2680	670	130-2680
Alpha Activity Removal, %				
Unfiltered STE	99.5	97.8-99.8	99.0	88.9-99.9
Filtered STE (c)	99.9+	99.8-99.98	99.8	99.5-99.99

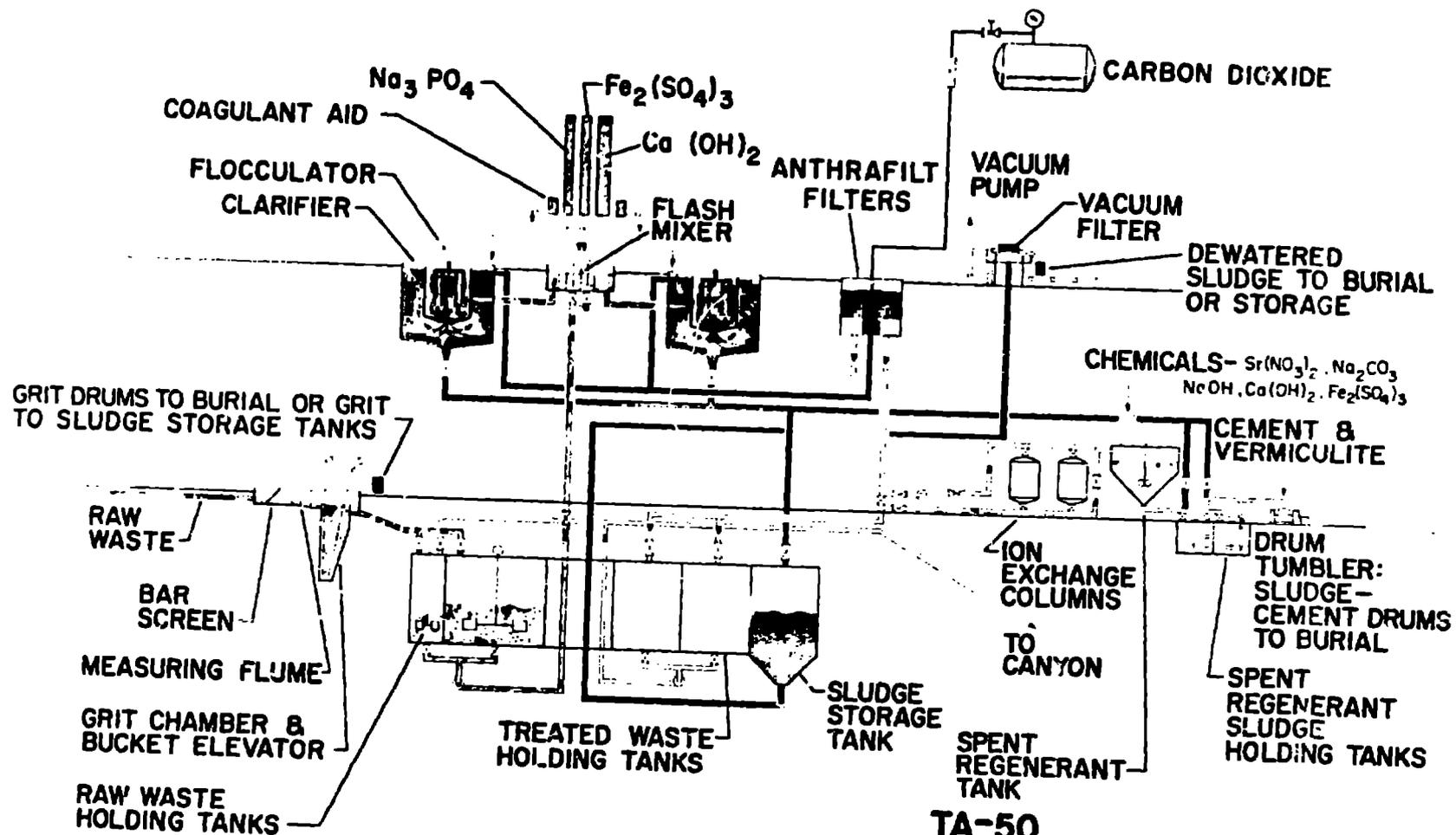
(a) Based on 24 operating days.

(b) Based on 23 operating days

(c) Filtered through Whatman No. 2 paper.

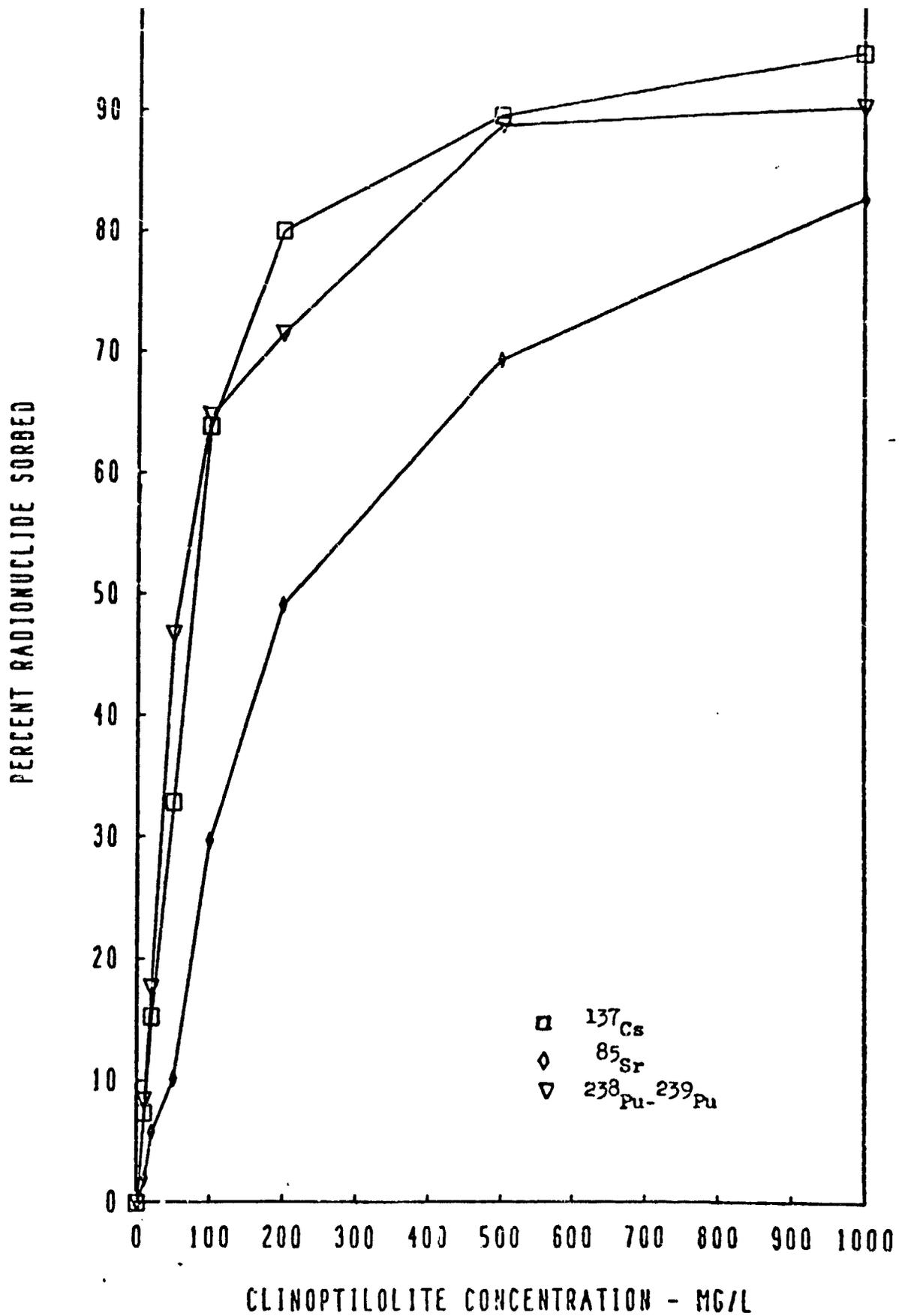
TABLE VIII
SUMMARY OF PLANT DATA FOR CLINOPTILOLITE TEST

Parameter	Process Train-1		Process Train-2	
	Average	Range	Average	Range
Flow rate, gpm	92.3	84.2-97.5	92.3	84.2-97.5
Coagulant Dosage, mg/l				
Ferric Sulfate	179	128-242	179	116-242
Lime	474	359-596	474	359-596
Trisodium Phosphate	122	57-284	122	57-284
Clinoptilolite	0	0	181	116-248
Total Pu, pCi/l				
Raw Feed	60,600	45,600-87,400	60,600	45,600-87,400
Unfiltered STE	730	70-2450	630	90-1860
Percent Removal	98.8	97.2-99.9	99.0	95.9-99.9
Total Pu, pg/l				
Raw Feed	195,900	105,100-276,700	195,900	105,100-276,700
Unfiltered STE	1210	4-469	1030	12-381
Percent Removal	99.4	98.2-99.9 ⁺	99.5	97.0-99.9
¹³⁷ Cs, pCi/l				
Raw Feed	3710	2780-5140	3710	2780-5140
Unfiltered STE	2080	1630-3740	1220	950-1990
Percent Removal	43.9	0-60.1	67.0	43.5-76.8
⁸⁷⁻⁹⁰ Sr, pCi/l				
Raw Feed	1850	870-4220	1850	870-4220
Unfiltered STE	340	130-550	380	97-760
Percent Removal	81.8	54.0-93.1	79.6	44.7-92.6



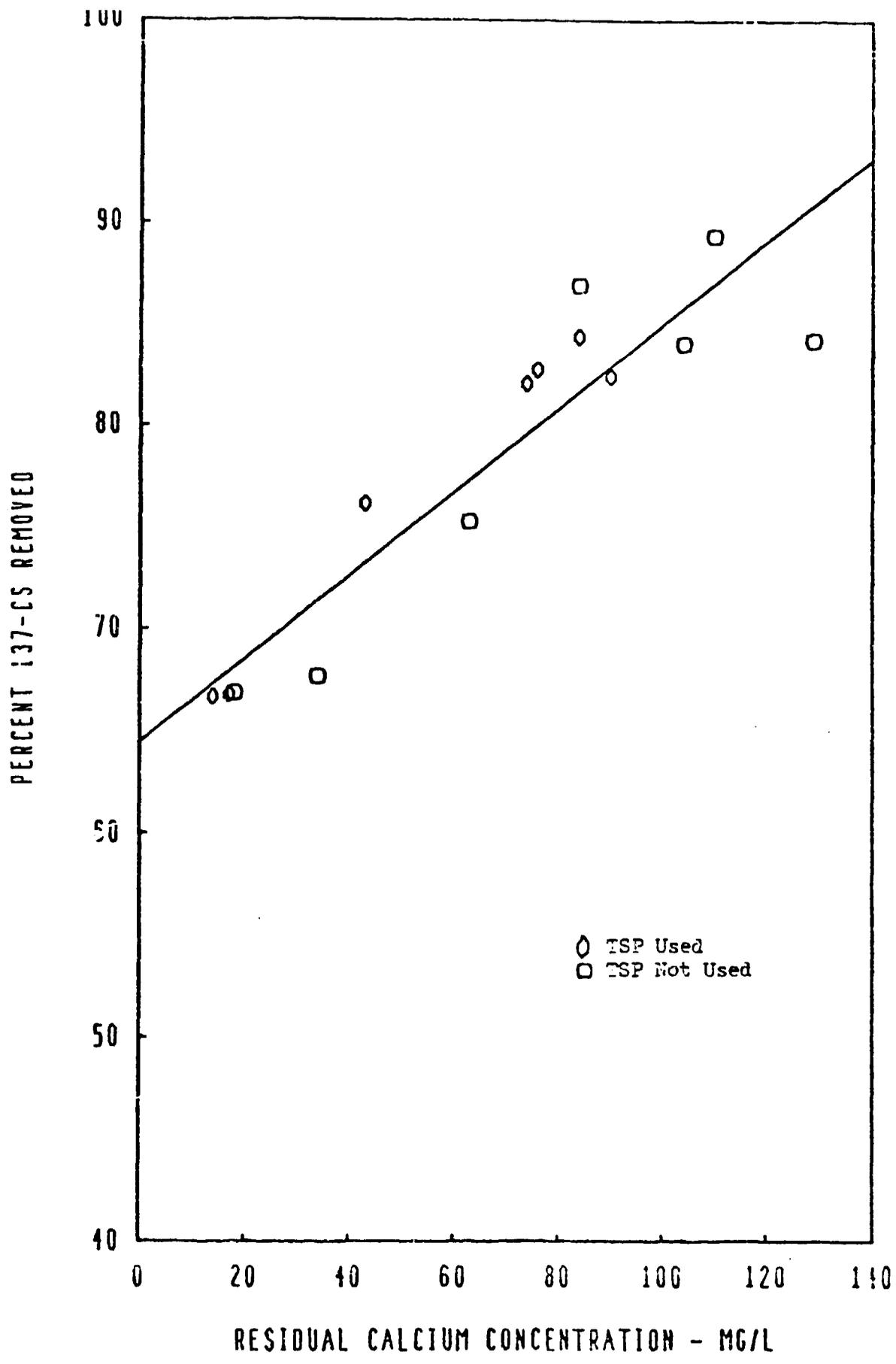
TA-50
SCHEMATIC FLOW DIAGRAM
 NORMAL METHOD OF OPERATION

- β - γ ACTIVITY
- α ACTIVITY
- FILTERED
- UNFILTERED



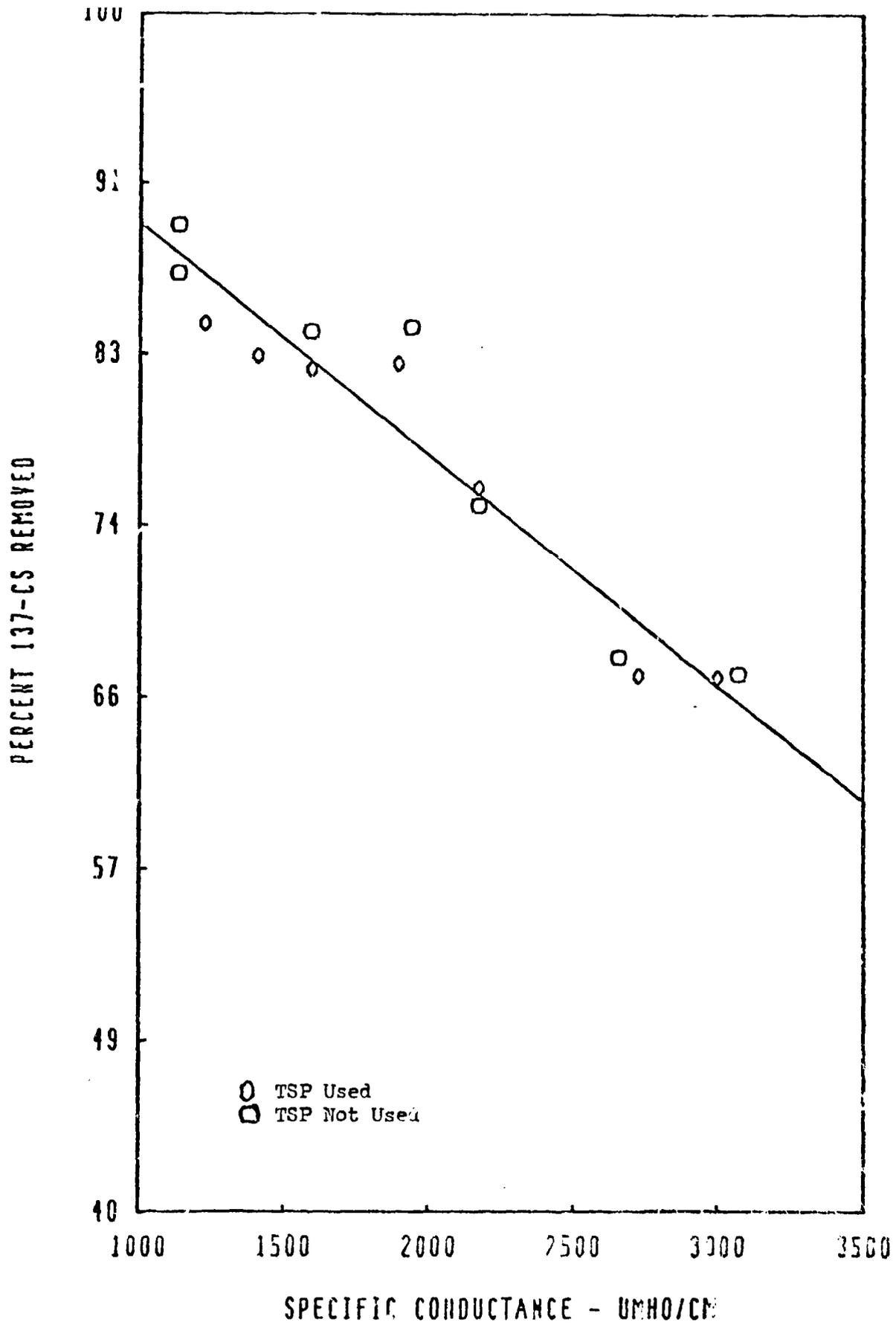
EFFECT OF CLINOPTILOLITE CONCENTRATION
ON SORPTION OF CS , SR AND PU

FIGURE 2



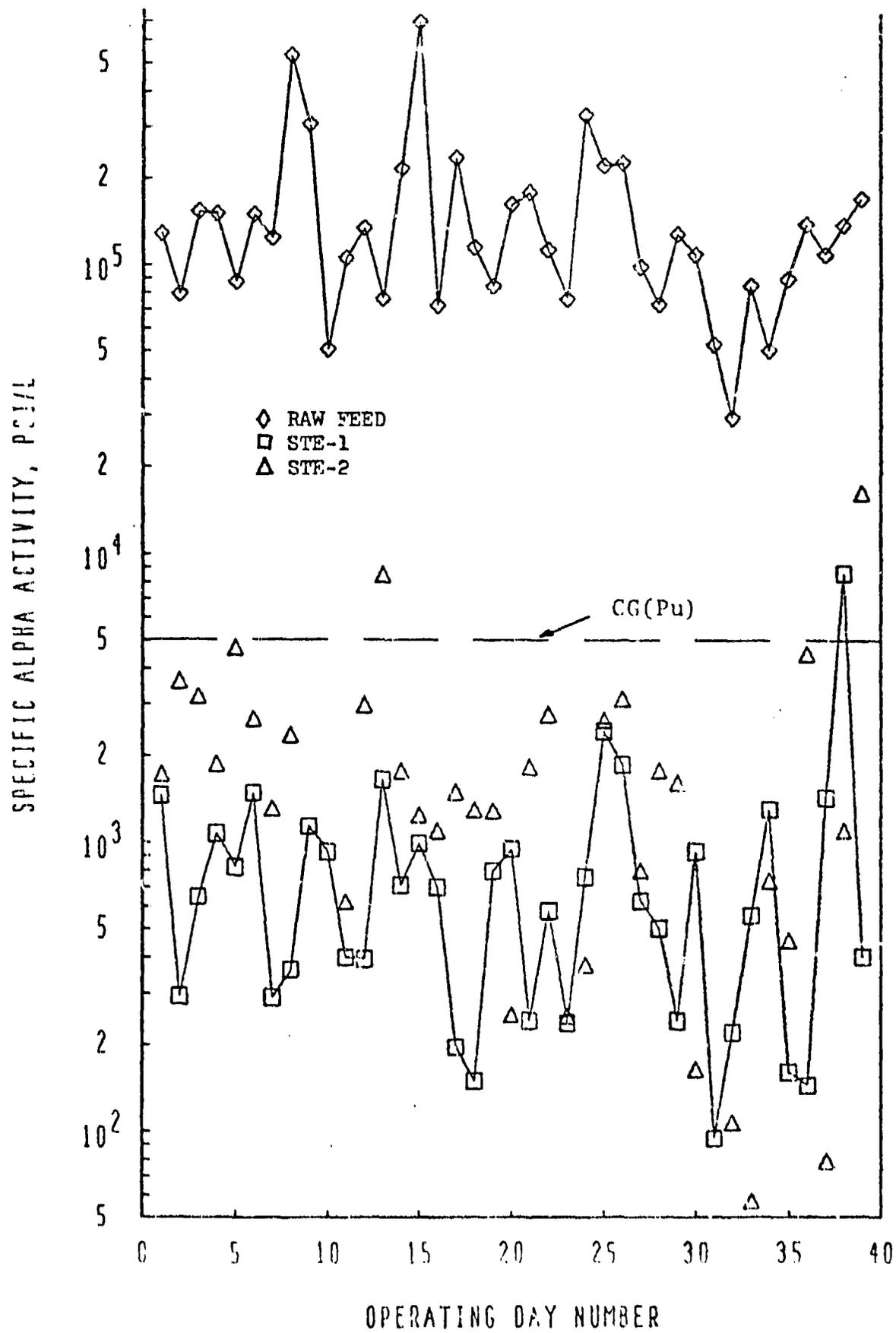
EFFECT OF RESIDUAL CALCIUM ON CESIUM REMOVAL
 100 MG/L CLINOPTILOLITE IN TAPWATER

FIGURE 3



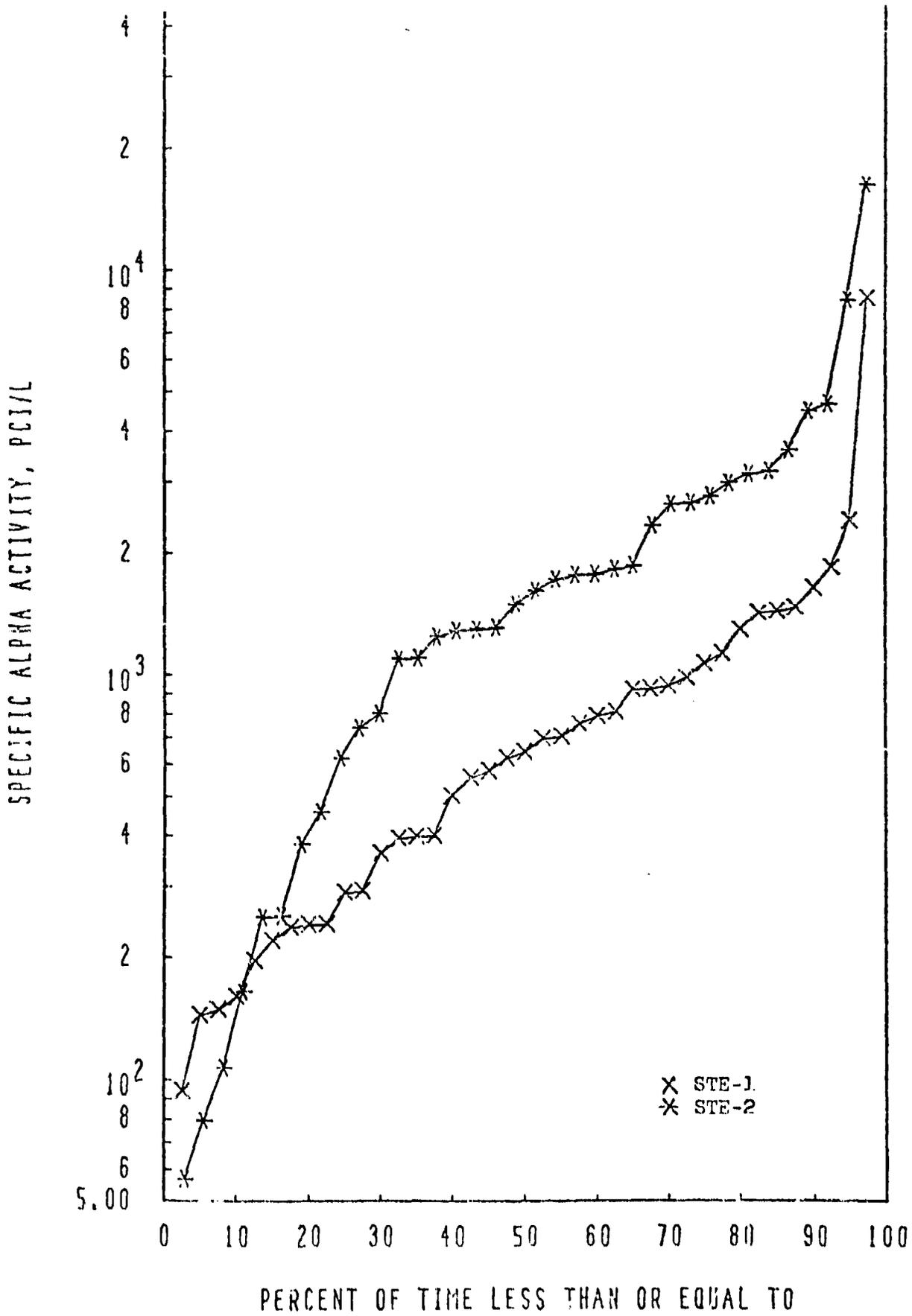
EFFECT OF CONDUCTIVITY ON CESIUM REMOVAL
 100 MG/L CLINOPTILOLITE IN TAPWATER

FIGURE 4



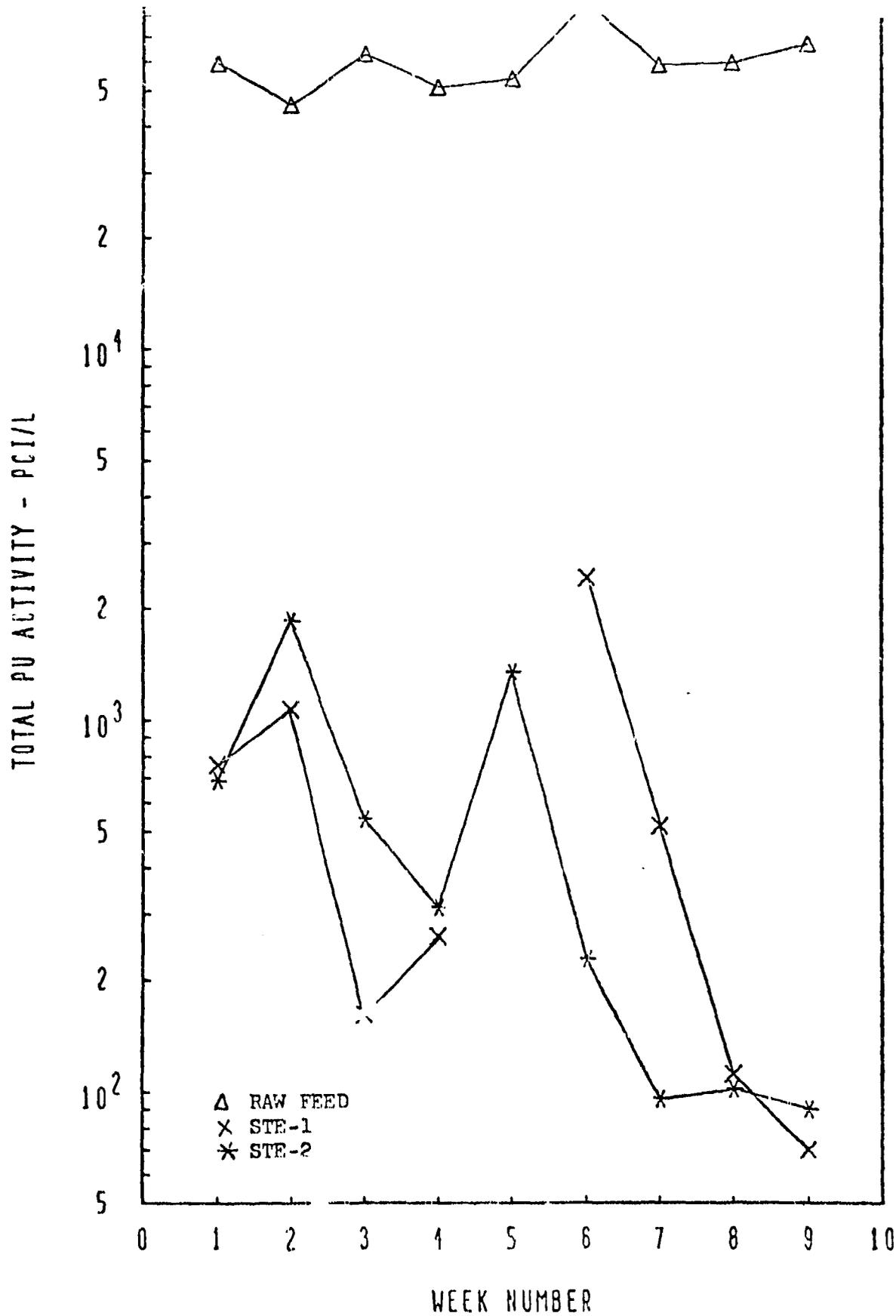
VARIATION OF SPECIFIC ALPHA ACTIVITY
OF TA-50 RAW FEED AND SETTLING TANK EFFLUENTS

FIGURE 5



PROBABILITY OF UNFILTERED STE ALPHA ACTIVITY
BEING LESS THAN OR EQUAL TO GIVEN VALUE

FIGURE 6

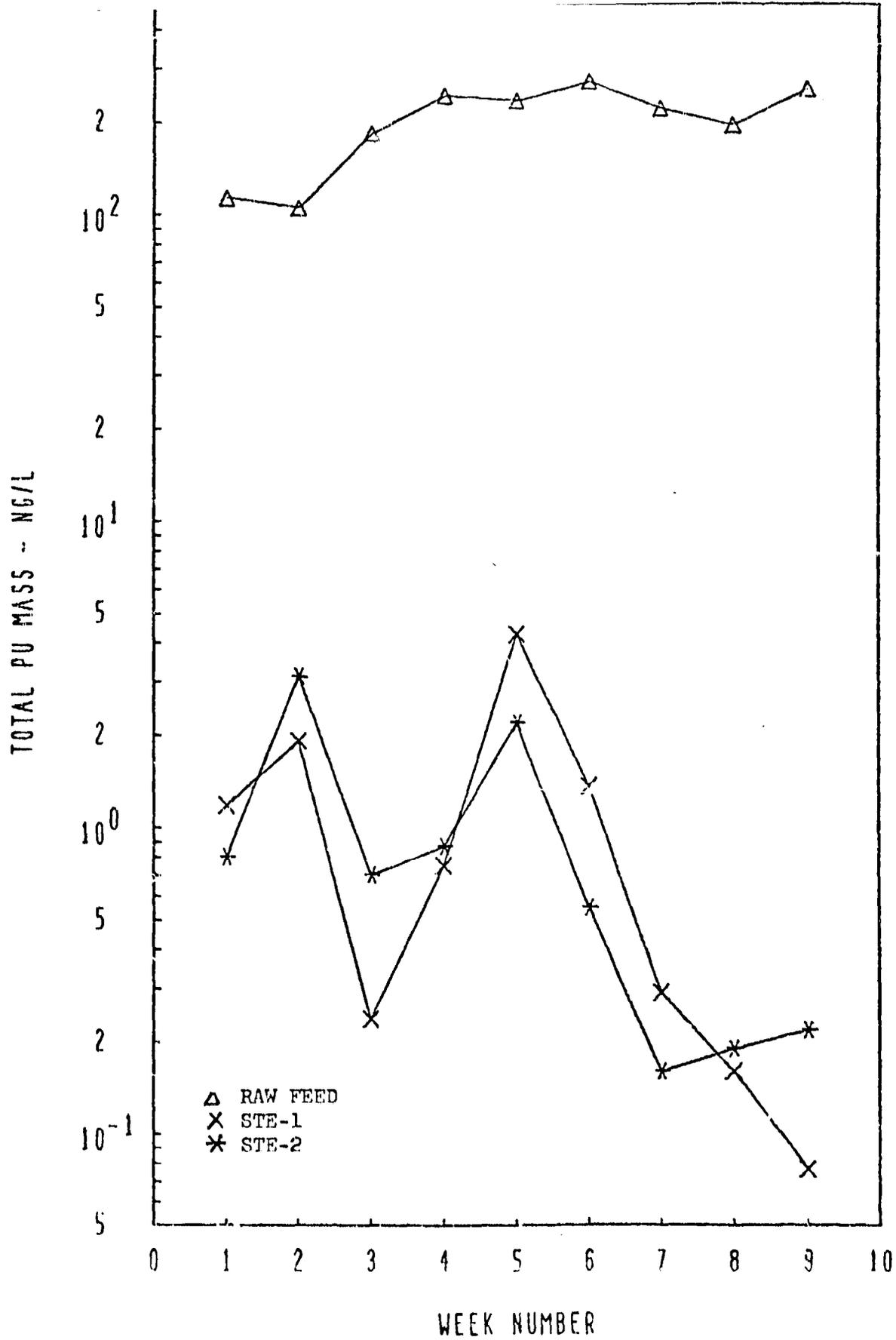


TOTAL PLUTONIUM ACTIVITY VS WEEK OF TEST

TA-50 PLANT - LASL

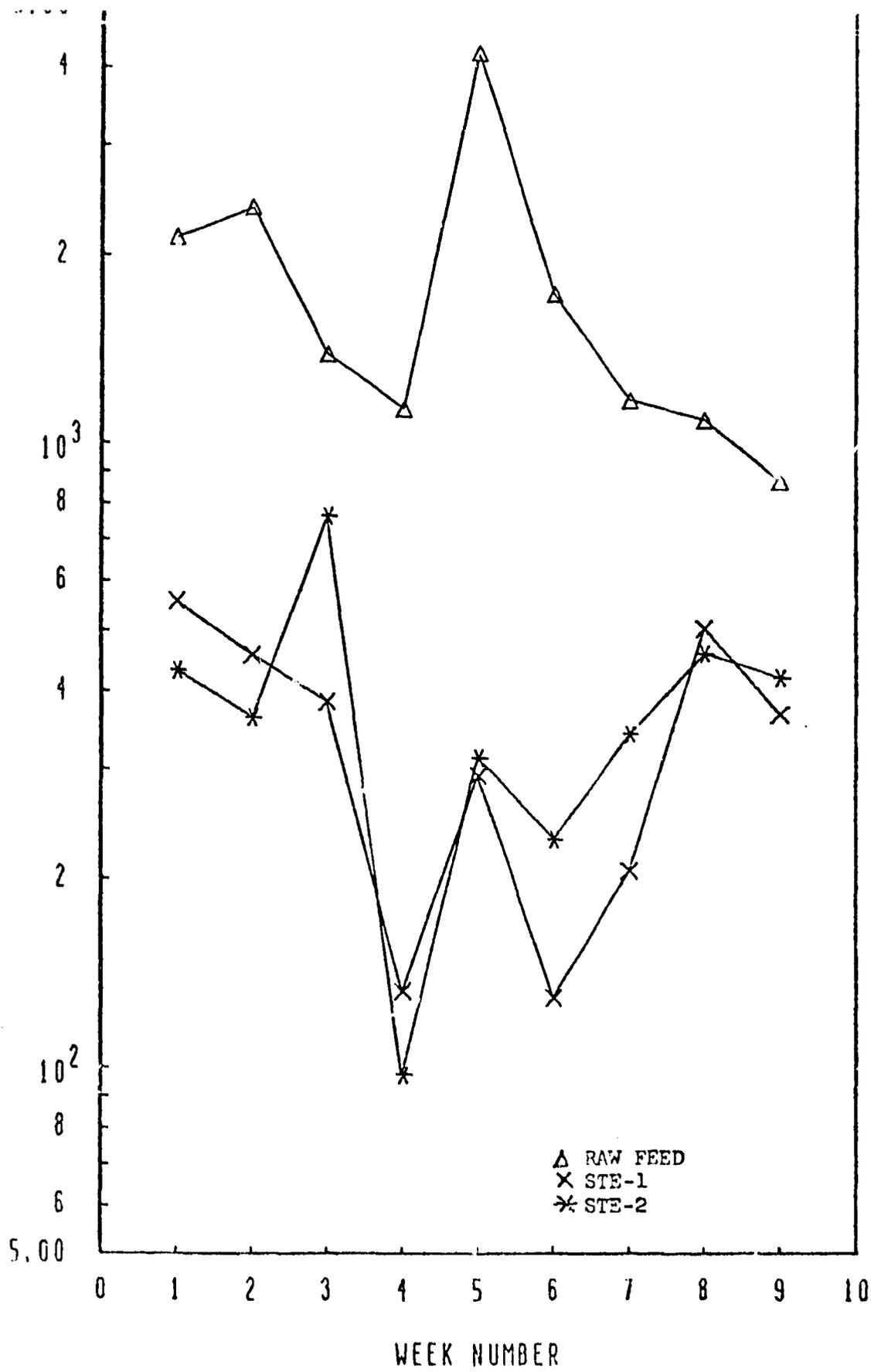
FIGURE 7



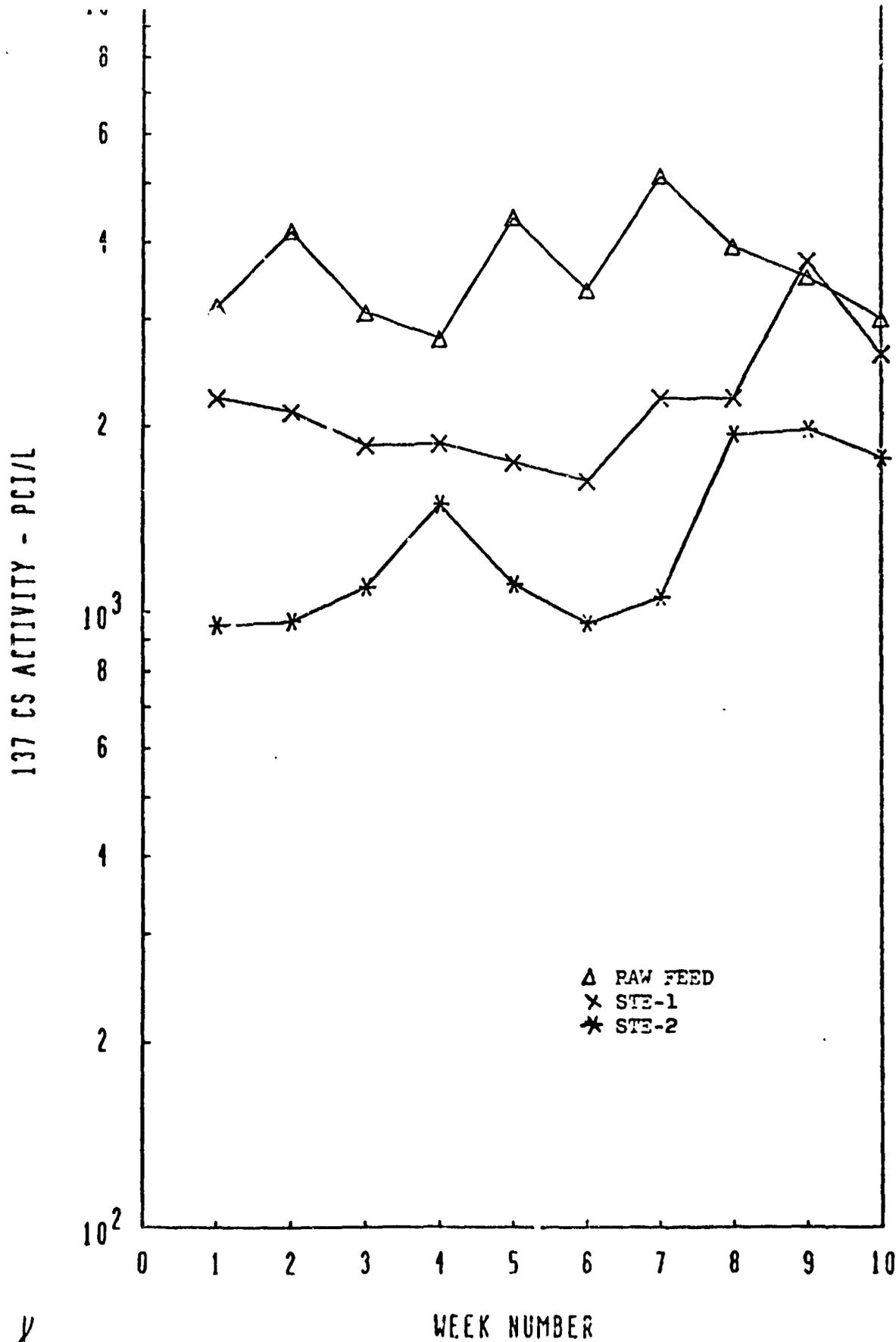


TOTAL PLUTONIUM MASS VS WEEK OF TEST
TA-50 PLANT

FIGURE 8



STRONTIUM ACTIVITY VS WEEK OF TEST
 TA-50 PLANT - LASL
 FIGURE 9



CESIUM ACTIVITY VS WEEK OF TEST
TA-50 PLANT - LASL

FIGURE 10