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MODELING OF FISSILE MATERIAL DIVERSION IN SOLVENT EXTRACTION CASCADES

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BY

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ABSTRACT

Changes were calculated for measurable parameters of a solvent extraction section of a reprocessing plant resulting from postulated fissile material diversion actions.

The computer program SEPHIS was modified to calculate the time-dependent concentrations of uranium and plutonium in each stage of a cascade. The calculation of the inventories of uranium and plutonium in each contactor was also included. The concentration and inventory histories were computed for a group of four sequential columns during start-up and for postulated diversion conditions within this group of columns. Monitoring of column exit streams or of integrated column inventories for fissile materials could provide qualitative indications of attempted diversions. However, the time delays and resulting changes are complex and do not correlate quantitatively with the magnitude of the initiating event.

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1. Introduction

The reprocessing of spent nuclear fuel has as its aim the separation of fertile and fissile elements from fission products and other radioactive elements generated in nuclear reactors. Some reprocessing schemes provide for the separation and purification of special nuclear materials which could be diverted for the production of nuclear weapons. Many methods have been proposed to prevent such illegal diversions from a reprocessing plant. The availability of suitable techniques for the prompt detection of diversion attempts are essential. Reprocessing plants include a variety of process equipment, interconnecting pipes, and storage vessels. Continuous monitoring of concentrations and volumes would be required for assessing in-process plant inventories. Because of the physical characteristics of some of the streams and the nature of certain process equipment, continuous accountability is difficult or of insufficient accuracy. Thus, it would be of interest to determine whether the continuous monitoring of certain process variables might serve as indicators for all attempted diversion of special nuclear materials from a reprocessing plant.

Solvent extraction is the most frequently used process for the separation of uranium and plutonium from other elements. These separations are done in countercurrent contactors, such as mixer-settlers or pulse columns. On-stream accounting of the plutonium or uranium inventories in such equipment is difficult because of the varying ratios of the immiscible organic and aqueous phases and the variations in concentrations of uranium and plutonium inside the contactors.

The advent of computers which are particularly useful for the rapid solution of "trial-and-error" type problems has greatly facilitate the analysis, design, and optimization of solvent extraction equipment. Programs are available which, given the usual operating and distribution data, calculate the number of stages required for a certain separation and the concentration profiles in a contactor. It is also possible to model changes of time-dependent variables, such as the concentration of streams leaving a contactor or concentration profiles, prior to attainment of steady-state conditions or following a change in input stream characteristics.

One of the objectives of this study was to determine whether monitoring of certain variables in a solvent extraction cascade, such as Pu and U concentrations in contactor exit streams and U and Pu inventories of contactors, could serve as indicators of willful diversion. It was also of interest to determine whether the resulting changes would correlate with the quantities of material diverted and to estimate typical delay times before the indicated changes would appear to be significant.

The SEPHIS (Solvent Extraction Process Having Interacting Solutes) computer program by ORNL* has been particularly useful for U and Pu separations with TBP solvent. The program models the steady-state and the dynamic mass transfer in multi-stage solvent extraction experiment. Though based on the conditions existing in contactor equipment of the mixer-settler type, the program can be used, with certain simplifying assumptions, to represent conditions in differential type contactors such as pulse columns. The columns are divided into equivalent theoretical

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*Groenier, W. S., Report ORNL-4746 (1972)
Watson, S. B. and Rainey, R. H., ORNL-TM-5123 (1975)

stages and the height equivalent of a theoretical stage (HETS) is obtained for a particular system from experimental data.

In the present study, SEPHIS was modified to model the response of a solvent extraction cascade to the removal of U or Pu, by either diverting part of an intermediate stream or by a decrease in heavy metal concentration brought about by partial diversion of a feed stream and substitution of pure solvent for the diverted fraction.

SEPHIS is limited in its utility by its ability to consider only a single column with the feed and scrub streams fully specified at the start of a calculation. The complete evaluation of the effects of a feed diversion requires the evaluation of the consequences of that upset on the entire cascade consisting of several columns, not merely the consequences in a single column. Thus, it was necessary to modify the SEPHIS program to allow it to consider the cascading of columns where the product of one column becomes the feed for the subsequent column. Simultaneously, a second modification was introduced that permitted SEPHIS to evaluate the inventory within each column as a function of time during the transient. These two modifications will permit the application of SEPHIS for the evaluation of the consequences of any diversion of fissionable material from any part of the solvent extraction section of a reprocessing plant. SEPHIS can also be employed to predict the loss rate that is undetectable or the time that elapses between the initiation of an upset and a detectable change in inventory or flow rate at a specified point within the plant.

The development of the program SEPHIS for application in the evaluation of upset conditions is described in the following sections. The next section describes the four sequential columns that were studied and the transport of fissile material from each column to the next. The application of the calculation of the fissile material inventories within these columns is discussed in the third section. The program revisions and the operation of the revised program which includes the ability to evaluate sequential columns is presented in Section 4 and representative calculations of the total impact of an upset are presented in Section 5. The final section delineates the conclusions that have been drawn from the effort. Appendices are included that identify the input to SEPHIS, including the modifications as well as the input for the cases that are presented in this report.

All of the modifications to SEPHIS are exercised by input parameters so that the modifications can be transparent, if desired. However, by selecting the appropriate input parameters all of the modifications can be exercised simultaneously.

Stream	Type	Stage Number	Flow Rate, ℓ/hr	Uranium Concentration, g/ℓ	Plutonium Concentration, g/ℓ	M	°C
				2A Column			
2AS	Aqueous	1	61	0.	0.	1.	38
2AF	Aqueous	7	437	9.52	4.78	3.1	35
2AX	Organic	14	146	0.	0.	0.	31
2AP	Organic	1	146				
2AW	Aqueous	14	498				
				2B Column			
2BX	Aqueous	1	132	0.	0.	0.3	35
2AP	Organic	8	146				
2BP	Aqueous	8	132				
2BW	Organic	1	146				
				Heat Exchanger			
3AFB	Aqueous	–	46	0.	0.	12.	30
2BP	Aqueous	–	132				
3AF	Aqueous	–	178				
				3A Column			
3AS	Aqueous	1	36	0.	0.	1.	30
3AF	Aqueous	7	178				
3AX	Organic	14	83	0.	0.	0.	30
3AW	Aqueous	14	214				
3AP	Organic	1	83				
				3B Column			
3BX	Aqueous	1	34	0.	0.	0.2	30
3AP	Organic	12	83				
3BS	Organic	16	21	0.	0.	0.	30
3BW	Organic	1	104				
3BP	Aqueous	16	34				

Uranium or Plutonium concentrations are not shown for product streams where conditions in previous columns are decisive.

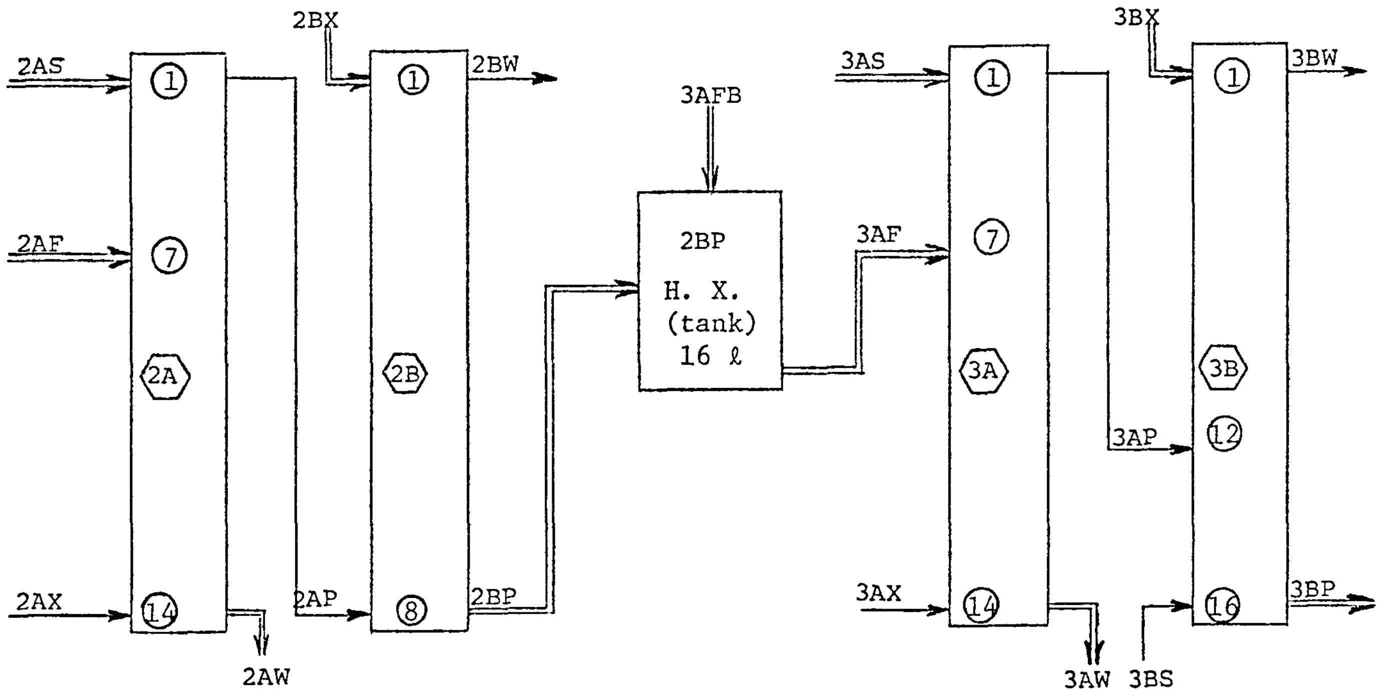

Figure 2.1 Schematic for Sample Calculations

(Circled numbers indicate stage locations)

Table 2.2 Pulse Columns Design and Operating Data

Column	Continuous Phase	Phase Ratio A/O	Stage Volume ℓ	Upper Plenum Volume, ℓ	Lower Plenum Volume, ℓ
2A	ORG.	0.25	25.95	97	217
2B	AQ .	4.00	26.53	263	73
3A	ORG.	0.25	14.81	99	182
3B	AQ .	4.00	19.00(1-12) 12.80(13-18)	178	13

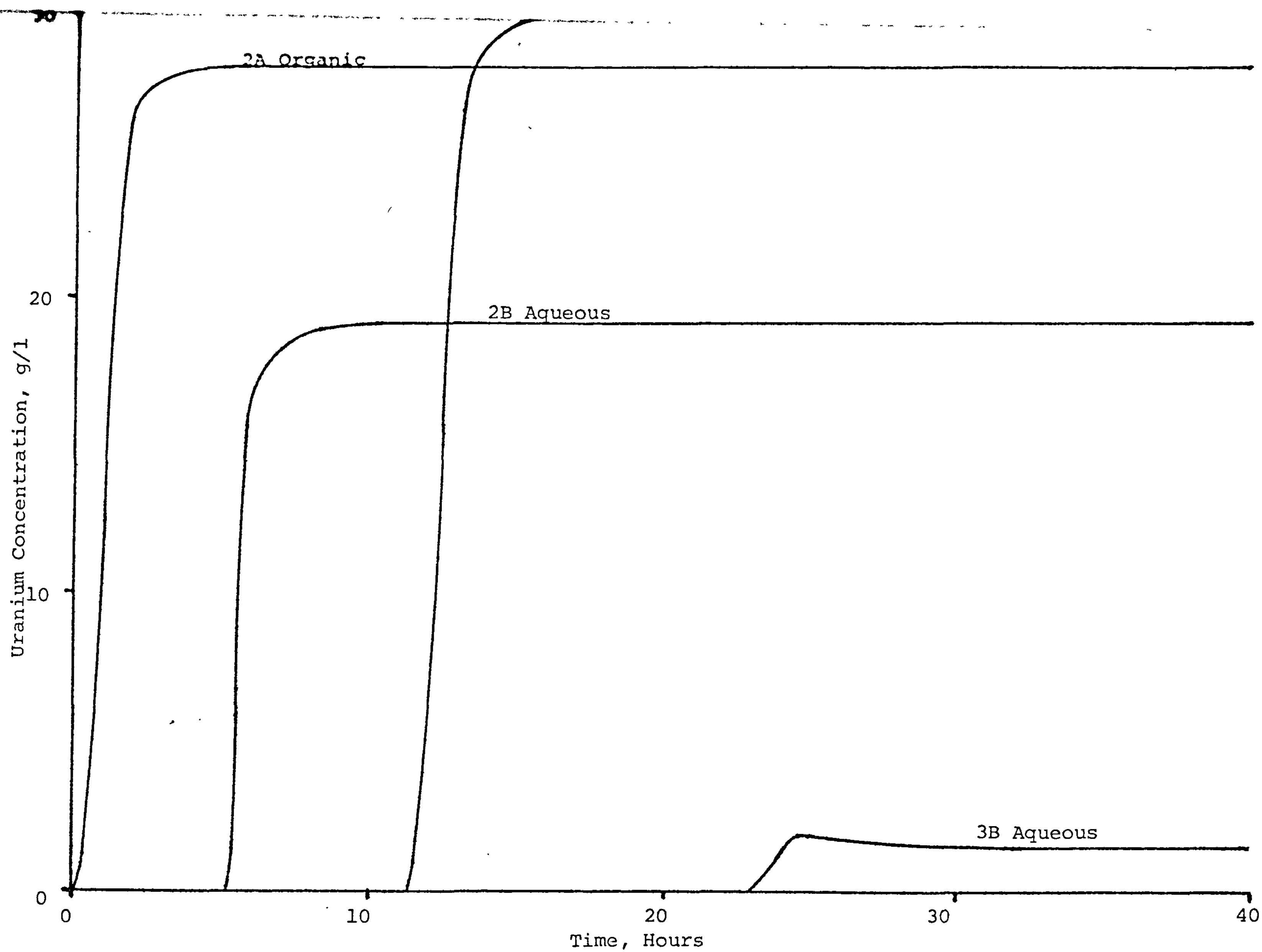

Figure 2.2 Uranium Concentration in Product Streams - Isolated Columns

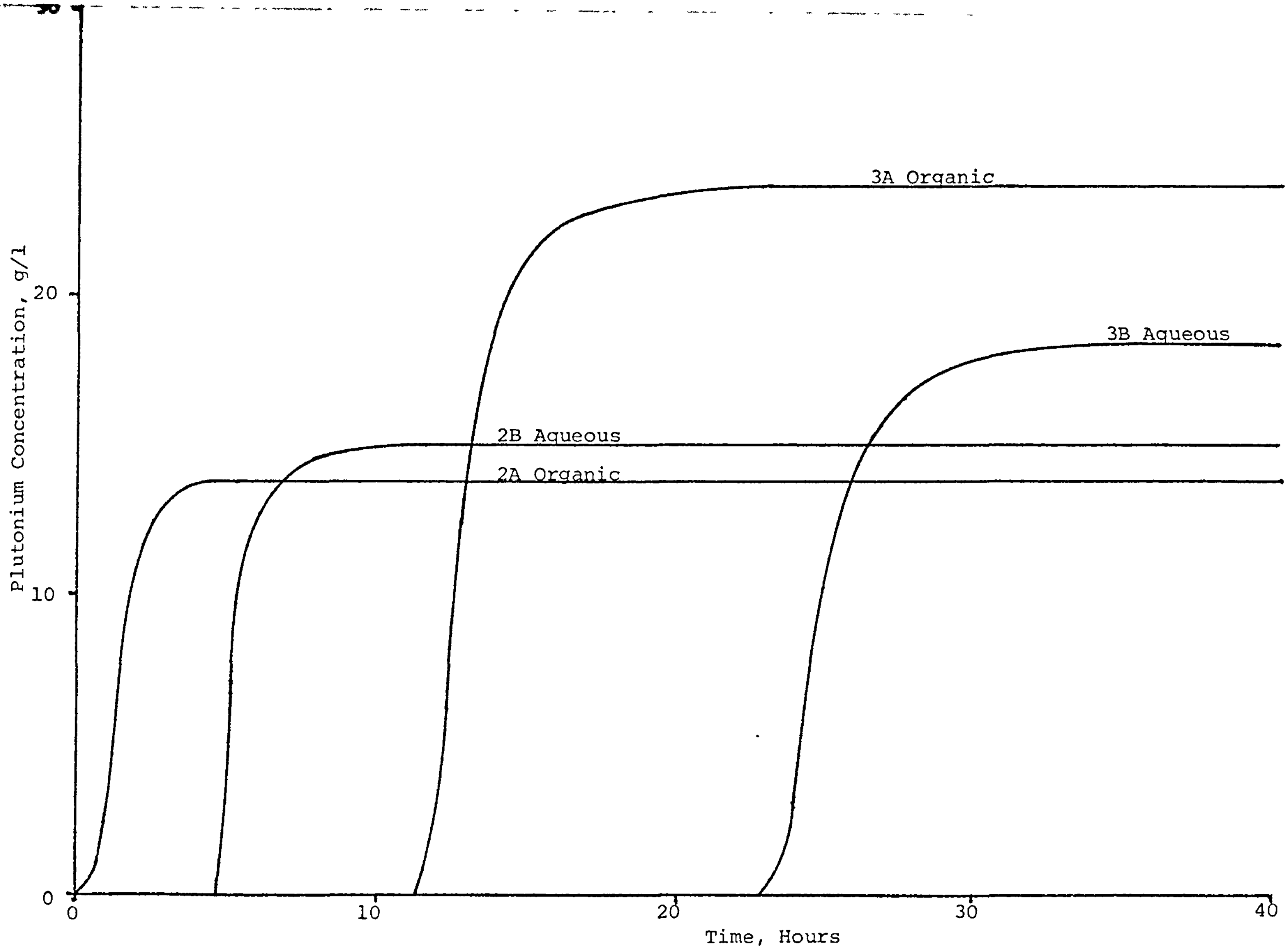

Figure 2.3 Plutonium Concentration in Product Streams - Isolated Columns

2. Reference Case

The evaluation of the impact of an upset requires the evaluation of the conditions within the plant when all systems are operating normally. This section describes the calculations that can be done with the unmodified version of SEPHIS to identify the fundamental characteristics of the reprocessing plant. The data employed are typical of a large reprocessing plant but are not intended to indicate any level of optimization of the parameters to enhance upset detection or any other facet of plant operation.

The section of the plant being modeled throughout this report consists of four columns with the product of each being used as the feed for the following column. A heat exchanger is included between the middle columns to reduce the temperature of the feed material.

The flow rates, feed concentrations and stage volumes for the four columns are presented in Table 2.1 and a schematic representation of the columns is presented in Fig. 2.1. Pertinent column design and operating data are given in Table 2.2.

The first step in the consideration of cascades of columns is to evaluate their characteristics with the current version of SEPHIS, treating each column as if it were independent of the others. This means that each column will be computed separately with its feed to the steady state product of the previous column. A plot of the time history of the uranium and plutonium concentrations in each product-feed stream is presented in Figs. 2.2 and 2.3 which further emphasizes the assumption that each column attains equilibrium before consideration of the next column begins. The time intervals required for each column to reach equilibrium and the time delays between columns are determined from the volumes and flow rates. The

Table 2.3 Time Delays Between Columns

Columns Connected	Upper Plenum Volume, liters	Lower Plenum Volume, liters	Connecting Volume, liters	Flow Rate, ℓ/hr	Time Delay, hours
2A-2B	97		16	146	0.774
2B-3A		73	32	178	0.590
3A-3B	99		16	83	1.193

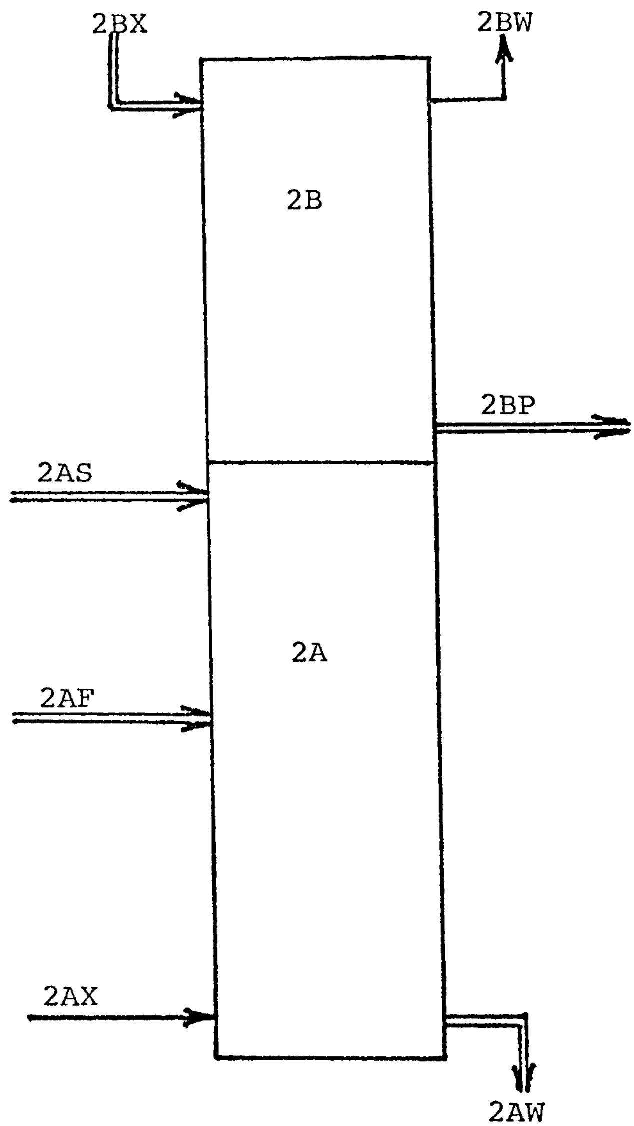

Figure 2.4 Schematic for Calculation of Columns 2A and 2B

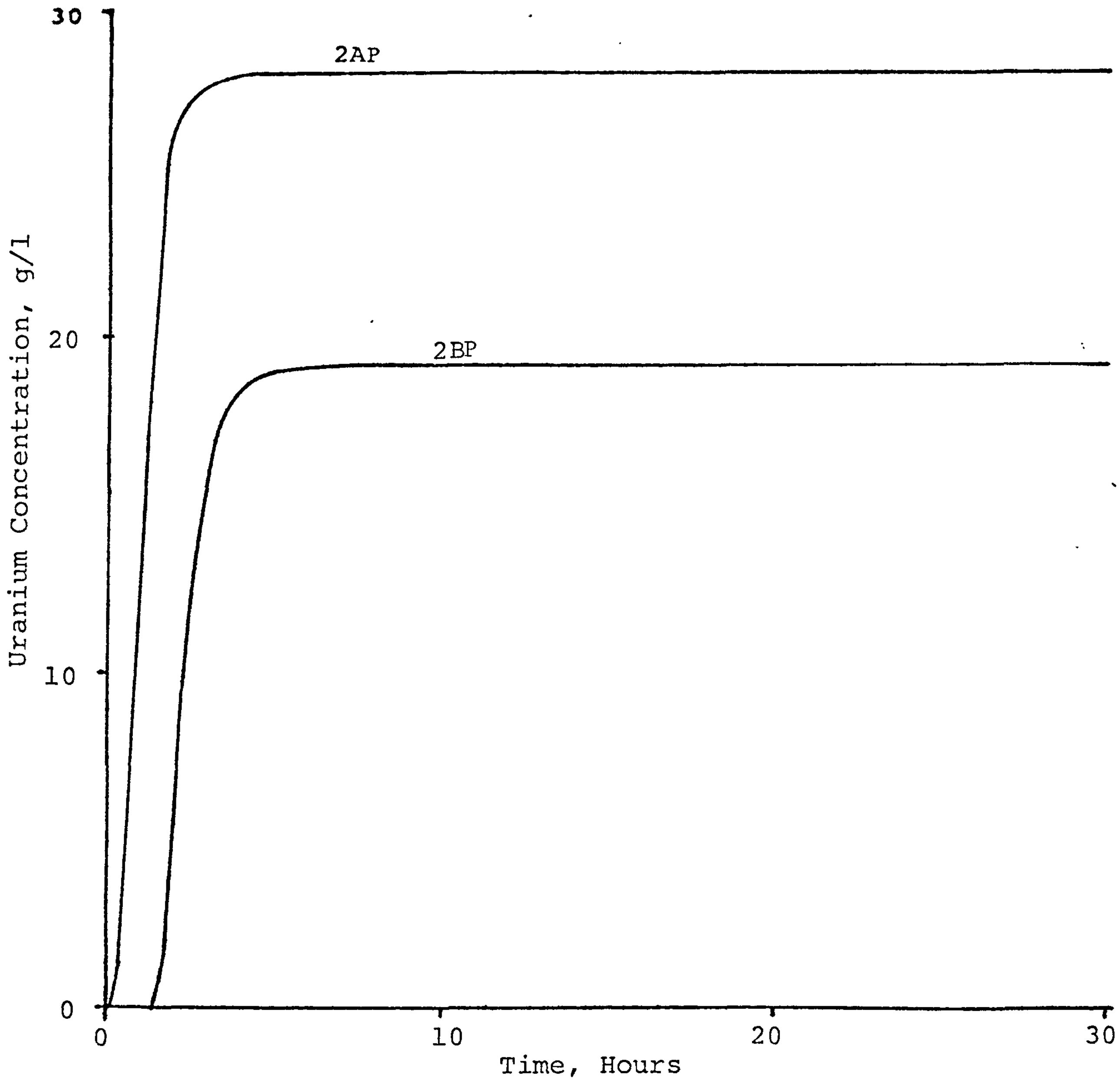

Figure 2.5 Uranium Concentration in Product Streams - 2A and 2B Columns

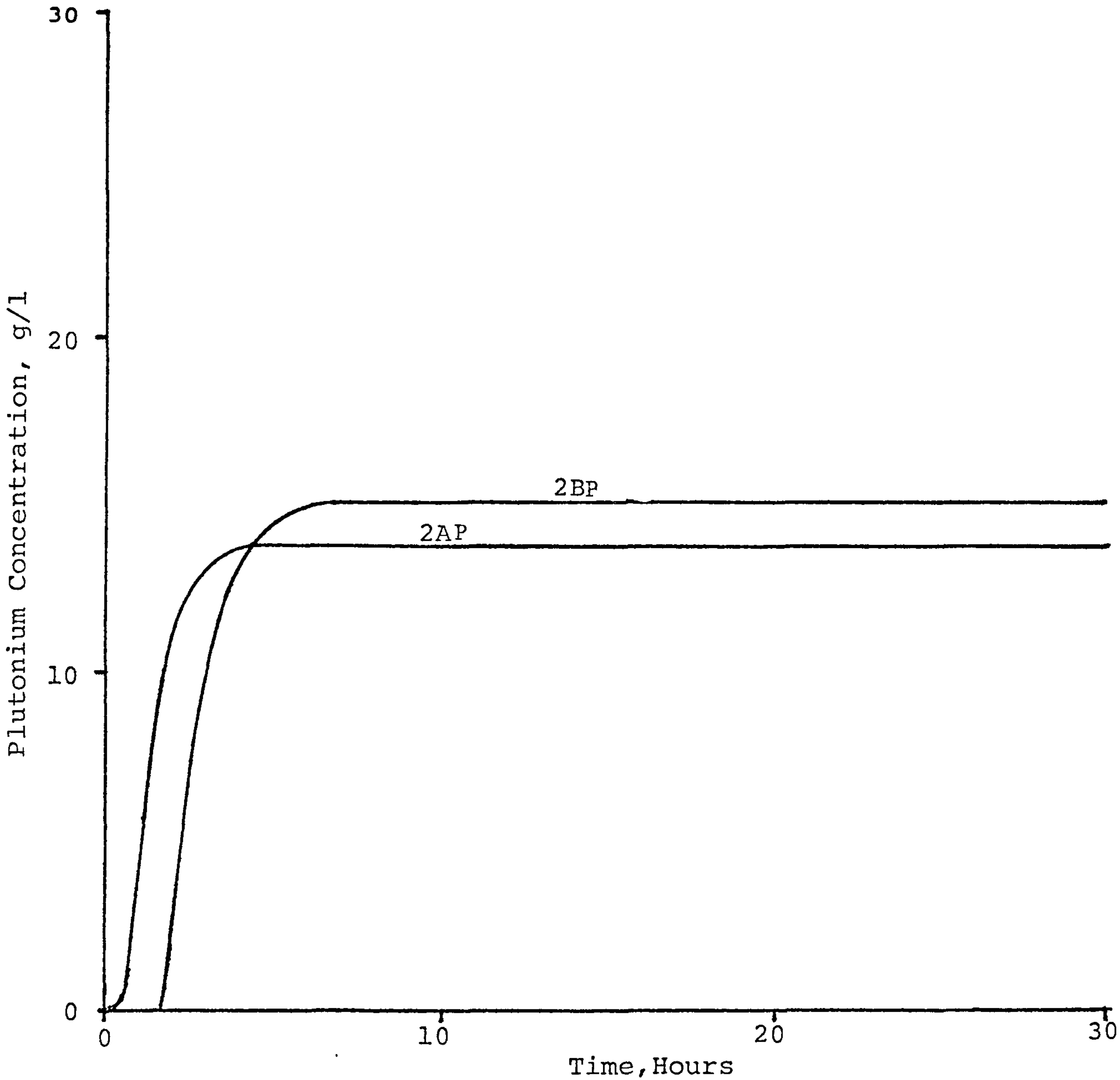

Figure 2.6 Plutonium Concentration in Product Streams - 2A and 2B Columns

necessary volumes, flow rates, and the resulting time intervals are tabulated in Table 2.3. These time intervals have been utilized in Figs. 2.2 and 2.3 to establish the time separation between the columns.

The second step in the investigation of the characteristics of cascading columns was the simultaneous evaluation of the columns by treating them as a single column. The results of this evaluation are complicated by the flow path of the connections between columns. Columns 2A and 2B can be represented in this manner because the output of column 2A and the input to column 2B are adjacent stages. However, columns 3A and 3B are connected to column 2B and to each other in their middle stages requiring reentrant streams for a single analysis.

Consequently, this preliminary evaluation was restricted to columns 2A and 2B as shown in Fig. 2.4. The results of this calculation is presented as histories of the uranium and plutonium concentrations in the product-feed streams in Figs. 2.5 and 2.6. The equilibrium concentrations are identical to those presented in Figs. 2.2 and 2.3, which would indicate that this method of modeling a series of columns introduces no error.

The major limitation of this approach is the need to ignore the existence of the plenums and connecting piping that represents a time delay between the exit of column 2A and the feed to column 2B. This delay amounts to three quarters of an hour and has been introduced into Figs. 2.5 and 2.6 by plotting the results of column 2B delayed by three quarters of an hour.

The preliminary modeling of the remainder of the columns cannot improve on the isolated column cases because of the need to include reentrant feed streems or time-dependent feed concentrations. Neither of these options has been implemented in the current version of SEPHIS.

3. Modifications to Calculate Sequential Columns

Modifying SEPHIS to calculate the characteristics of sequential columns requires the introduction and use of four pieces of information that are not currently utilized in the program. These are: (1) the entering and exiting stages, (2) the flow rate, (3) the time history of the fissile material concentrations, and (4) the time delay. The time history is necessary because a finite amount of time is required for the fluid to flow from the exit of one column to the entrance of the adjacent column. Introduction of a holding tank in the piping between two columns further complicates the process since the tank mixes the flow during the transit through the tank and the mixed concentrations are delivered to the next column.

The changes require a choice of the mode of information transfer. It is possible to store the concentration histories within the memory of the computer or in the slower access information storage devices (disks and magnetic tapes) that are peripheral to the main computer. For this application, disk storage was selected because of its greater flexibility, even though it is slower during execution. Storing the concentration histories in the computer memory would introduce a limitation on either the total number of time steps that could be employed in a given problem or on the detail in the concentration histories. Utilizing the disk avoids these limitations since the storage capacity is virtually limitless for any problems of reasonable size. Also, the concentration histories can be saved to allow a repeat of portions of a problem without the need to repeat portions that were unaltered.

Representation of a heat exchanger with a diluting stream that enters the heat exchanger introduces an additional time delay into the transfer of material from one column to the next. When there is no heat exchanger the time delay is merely the volume of the piping divided by the flow rate between stages columns, which is given by:

$$\Delta t_1 = V_p/\dot{m}$$

The introduction of a holdup tank or heat exchanger into this stream changes the concentration of the stream entering the next column because the exit concentrations changes do not correspond to plug flow. Thus, the concentrations entering the next stage are given by an integral of the form:

$$C = \int_{t}^{t+V/\dot{m}} \lambda(t)dt$$

Assuming the time dependence of the concentration can be approximated linearly, then the concentration entering the next stage is the concentration at the mid time of the time interval required for the fluid to traverse the tank. This is equivalent to a time delay which is given by:

$$\Delta t_2 = V_t/2\dot{m}$$

Consequently, the total time delay is given by:

$$\Delta t = \Delta t_1 + \Delta t_2 = (V_p + V_t/2)\dot{m}$$

Mixing an additional feed stream with the between columns stream requires averaging of the concentrations of the feed stream with the original stream. The flow rates of the two streams are added to give the total flow entering the subsequent column.

These representations of the conditions in the stream entering the subsequent columns were coupled with programming logic which linearly interpolates to determine the flow and concentrations from the data saved on disk. These were included in a new subroutine named TIMEDEP which is called at the start of each time step. The flow rate and concentrations entering the column at the start of each time step are printed to provide a record of the feed entering that column.

SEPHIS has been modified to read concentration histories from disk files and use these with information that defines the time delay between columns to calculate the characteristics of sequential columns. The sample problem described in the previous section was calculated using the modified version. Uranium and plutonium concentrations in the product streams are presented in Figs. 3.1 and 3.2. The results for columns 2A and 2B are essentially identical to the data presented in Figs. 2.5 and 2.6 where these two columns were modeled as one continuous column. However, columns 3A and 3B could not be modeled in this manner so the data in Figs. 3.1 and 3.2 represents the only modeling of this portion of the problem that is correct. The agreement between the two methods of calculating columns 2A and 2B provides reassurance that the modifications have not introduced any errors into the results of the calculations. The steady state conditions for each column are also in agreement with the steady state conditions assuming independent columns, providing further confidence in the modifications.

The modified version of SEPHIS was employed to predict the consequences of a diversion of fissile material from the reprocessing plant. Two cases were evaluated. In the first, ten percent of the feed material in stream 2AP was removed to simulate a diversion or leak with no

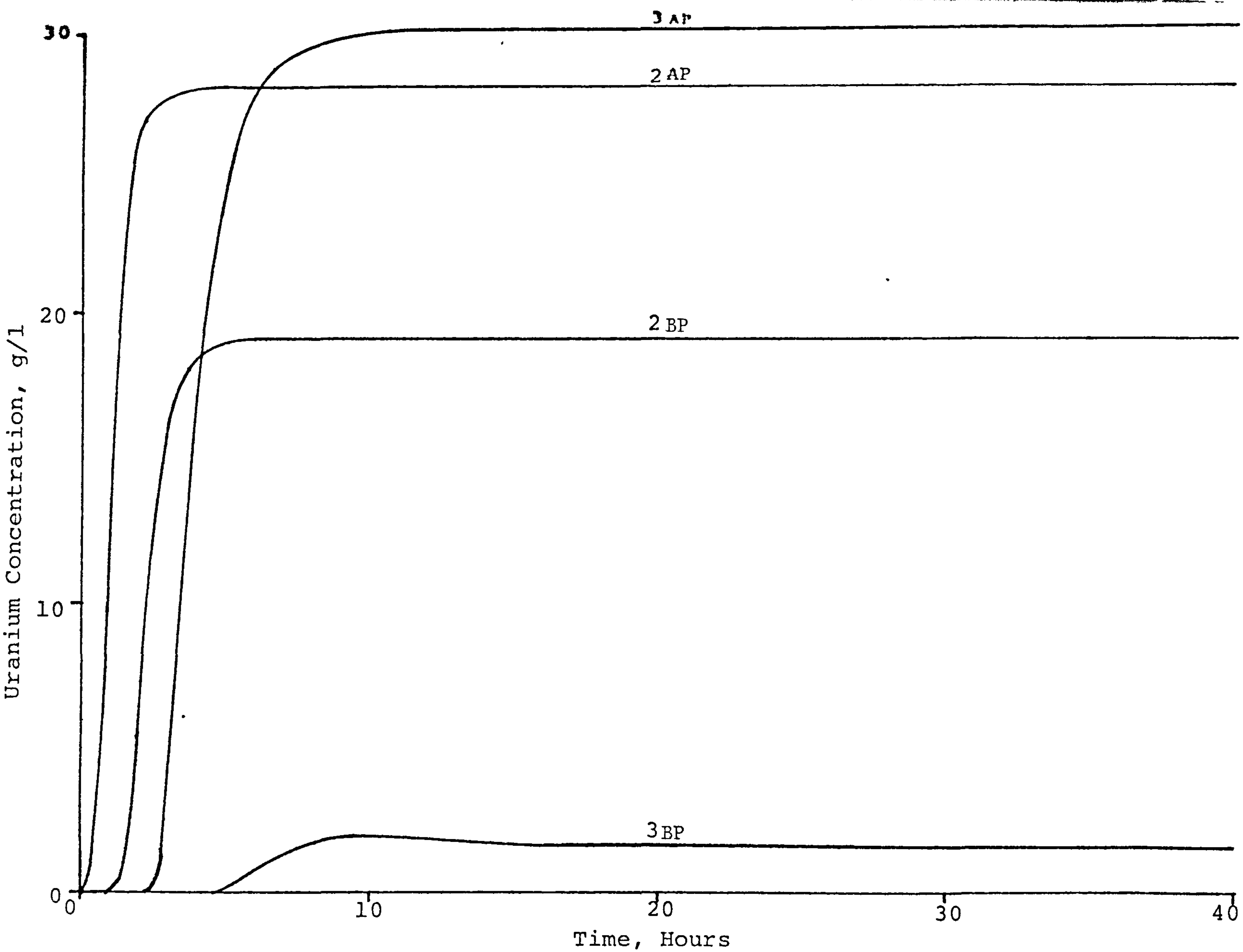

Figure 3.1 Uranium Concentrations in Product Streams - All Columns Sequential

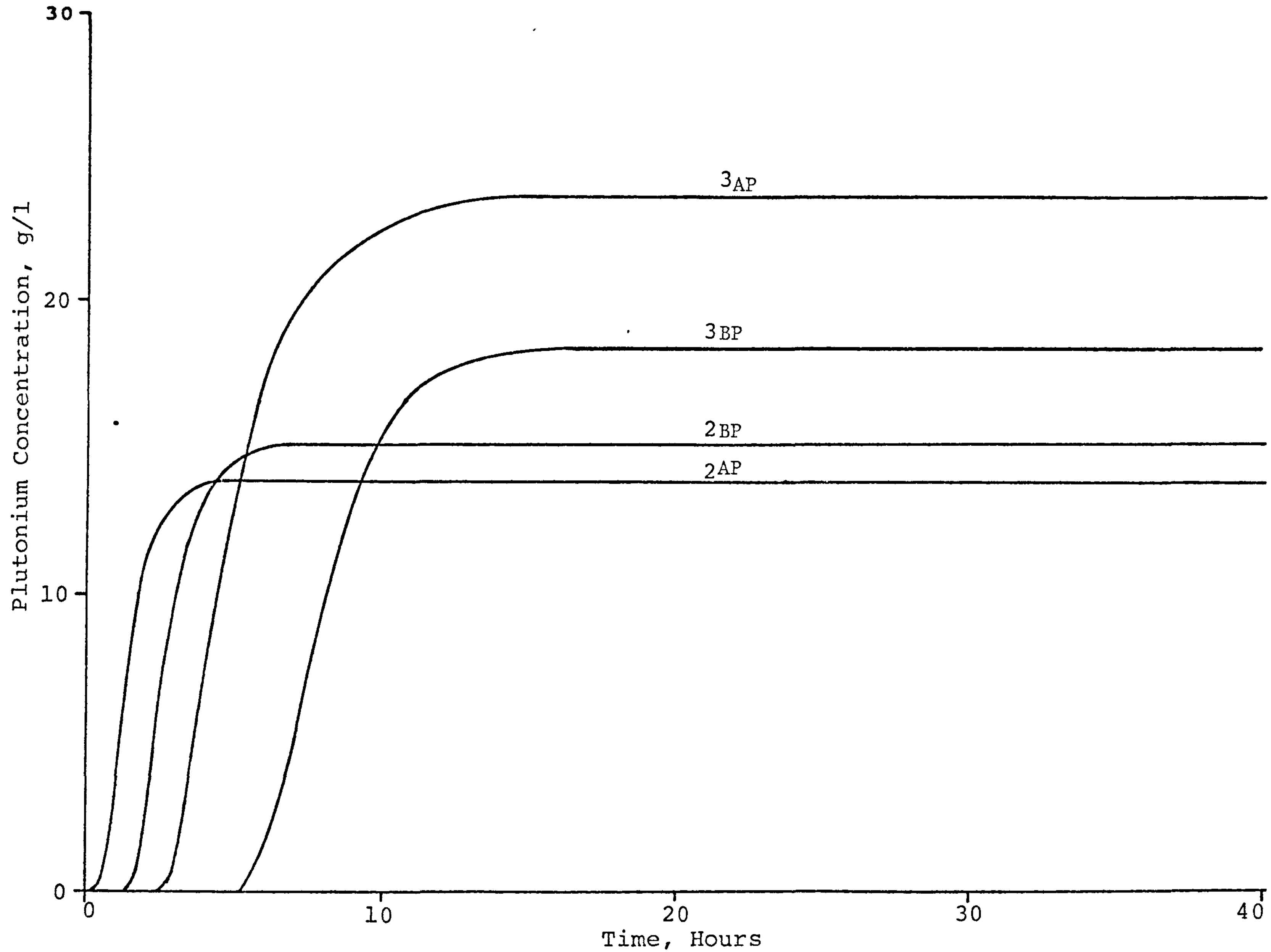

Figure 3.2 Plutonium Concentrations in Product Streams - All Columns Sequential

alteration in the concentration of the fissile materials. The second case involved the reduction of the concentration of uranium and plutonium in the 2AP stream connecting columns 2A and 2B. This simulates the diversion of material and its replacement with clean solvent. The diversion of the flow from the stream is modeled by entering a diluting stream with a negative flow rate and no uranium or plutonium. This reduces the flow rate without altering the concentrations of either the uranium or plutonium. The dilution of the stream was modeled by using a diluting stream with no flow but a negative uranium and negative plutonium concentration. In this manner the concentration was reduced but the flow rate was not altered. The results of these two cases are presented in Figs. 3.3 and 3.4.

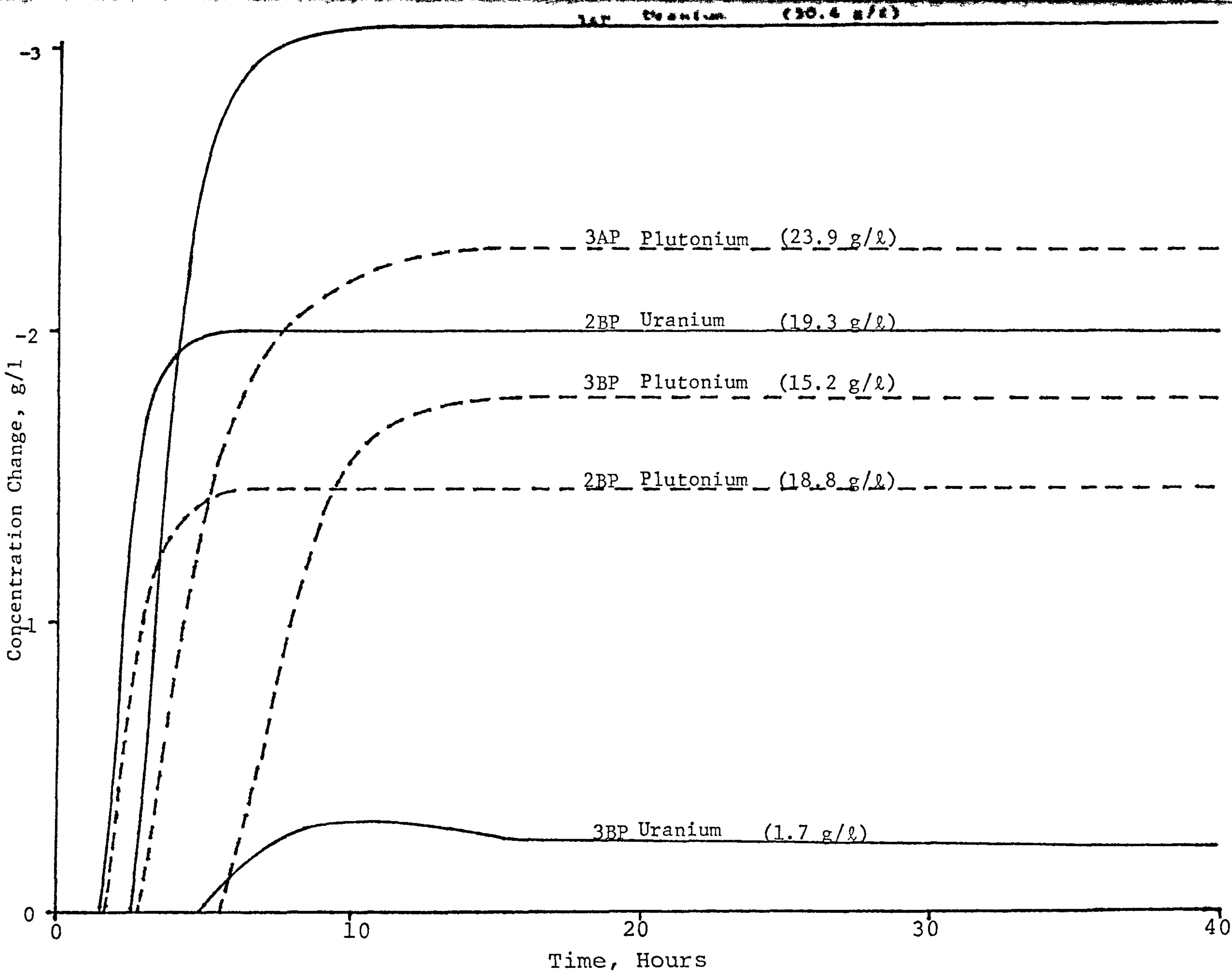

Figure 3.3 Fissile Material Concentration Changes for 10% Flow Reduction in Stream 2AP

(Quantities in Parentheses are Initial Concentrations)

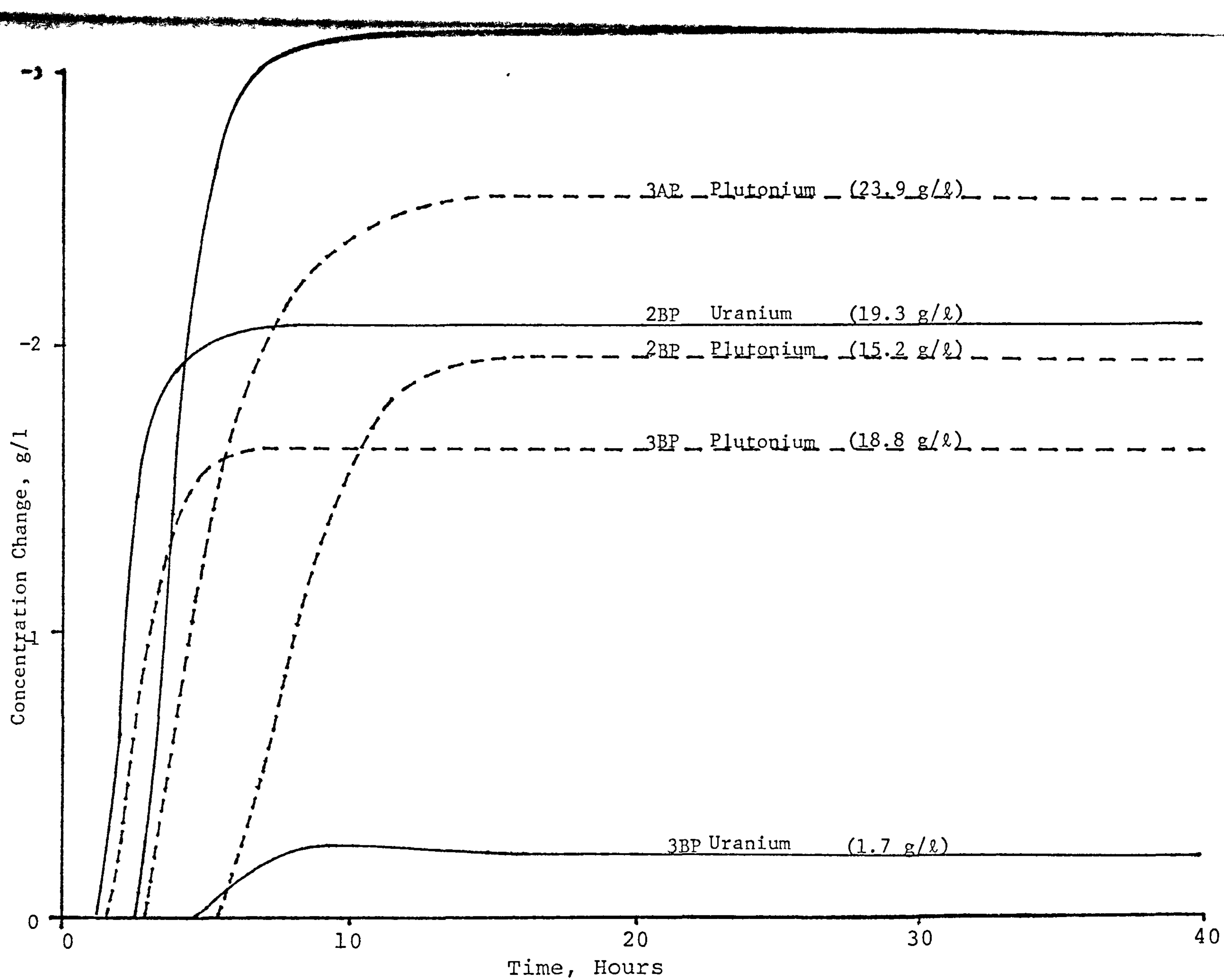

Figure 3.4 Fissile Material Concentration Changes for 10% Concentration Reduction in Stream 2AP (Quantities in Parentheses are Initial Concentrations)

4. Modifications to Calculate Inventories

An important variable in the monitoring of the performance of a separation column is the inventory of fissile material in the column at any time. In practice, this could be measured by determining the weight of the column contents or by integrating the results of scanning determinations. Originally, SEPHIS did not provide this information; it was incorporated into the program by the addition of a subroutine INVEN. Within this subroutine the inventory of plutonium and/or uranium is calculated by summing the product of the concentration and stage volume for all of the stages. The presence of a plenum at the top and bottom of the column is included, using the concentrations in the first and last stages respectively.

The time history of the uranium and plutonium inventories for the cases described in Section 2 is presented in Figs. 4.1 and 4.2.

Figures 4.3 and 4.4 show the changes in U and Pu inventories resulting from the hypothetical diversions described in Section 3.

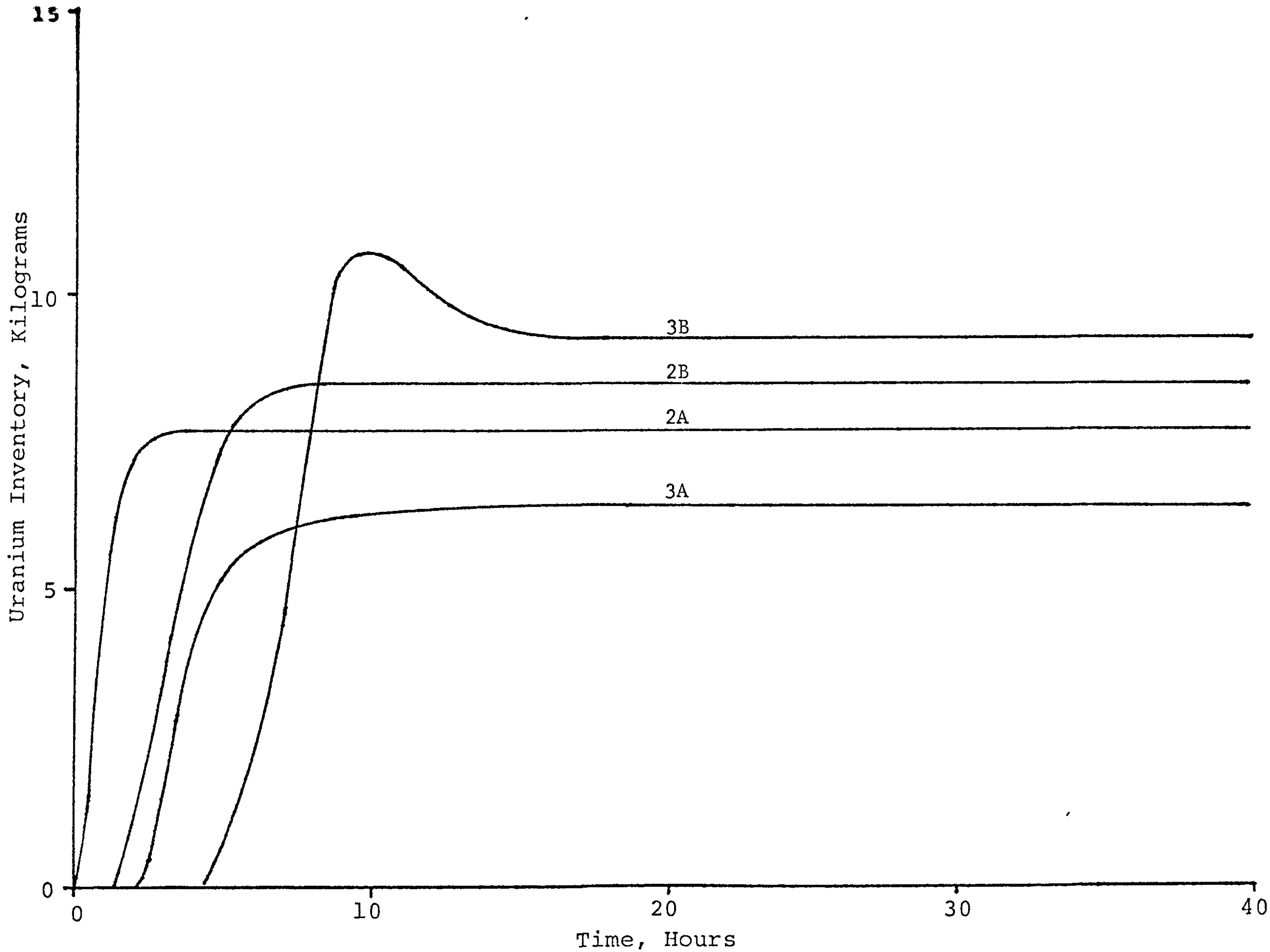

Figure 4.1 Uranium Inventory Histories in All Columns

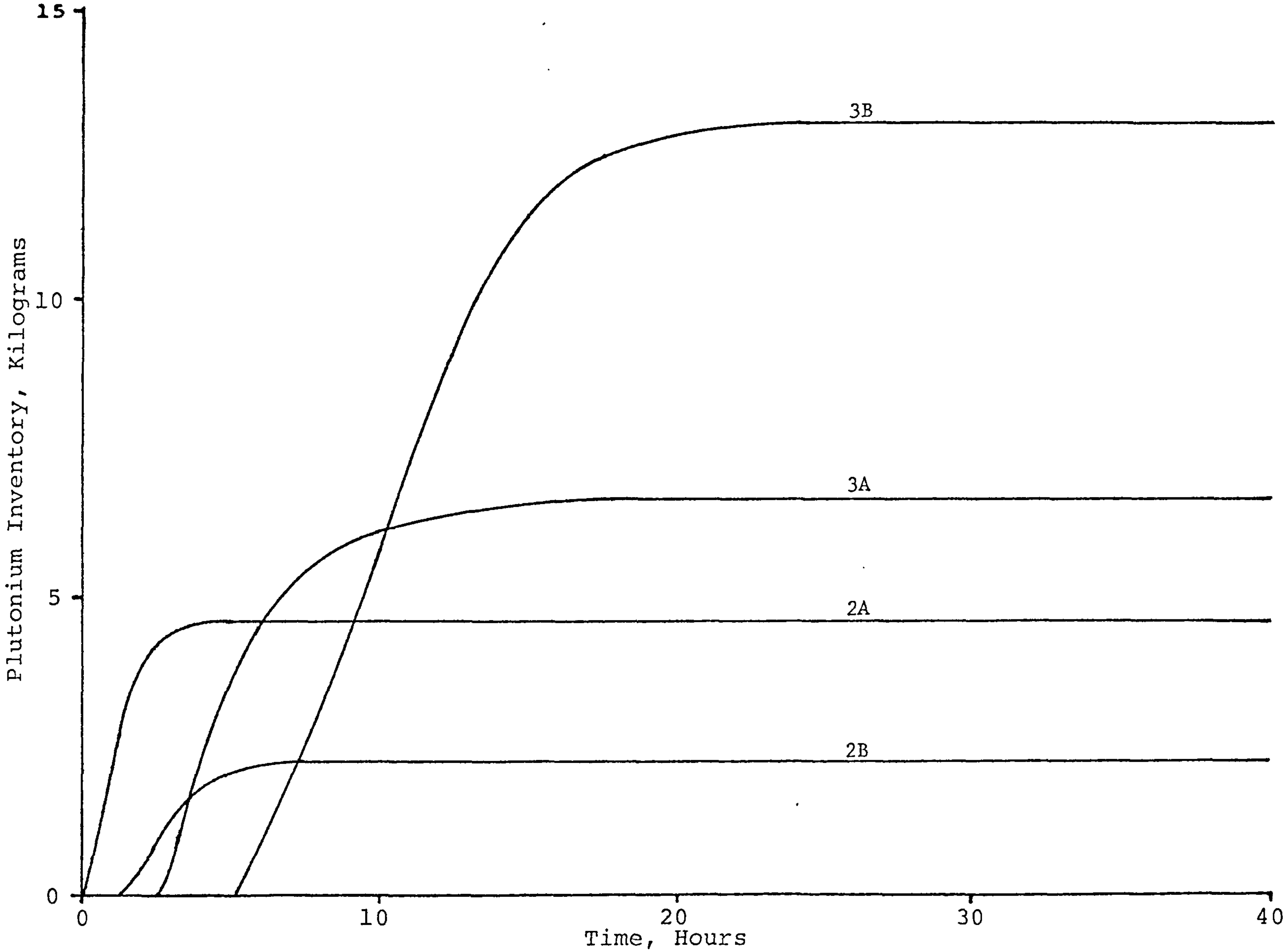

Figure 4.2 Plutonium Inventory Histories in All Columns

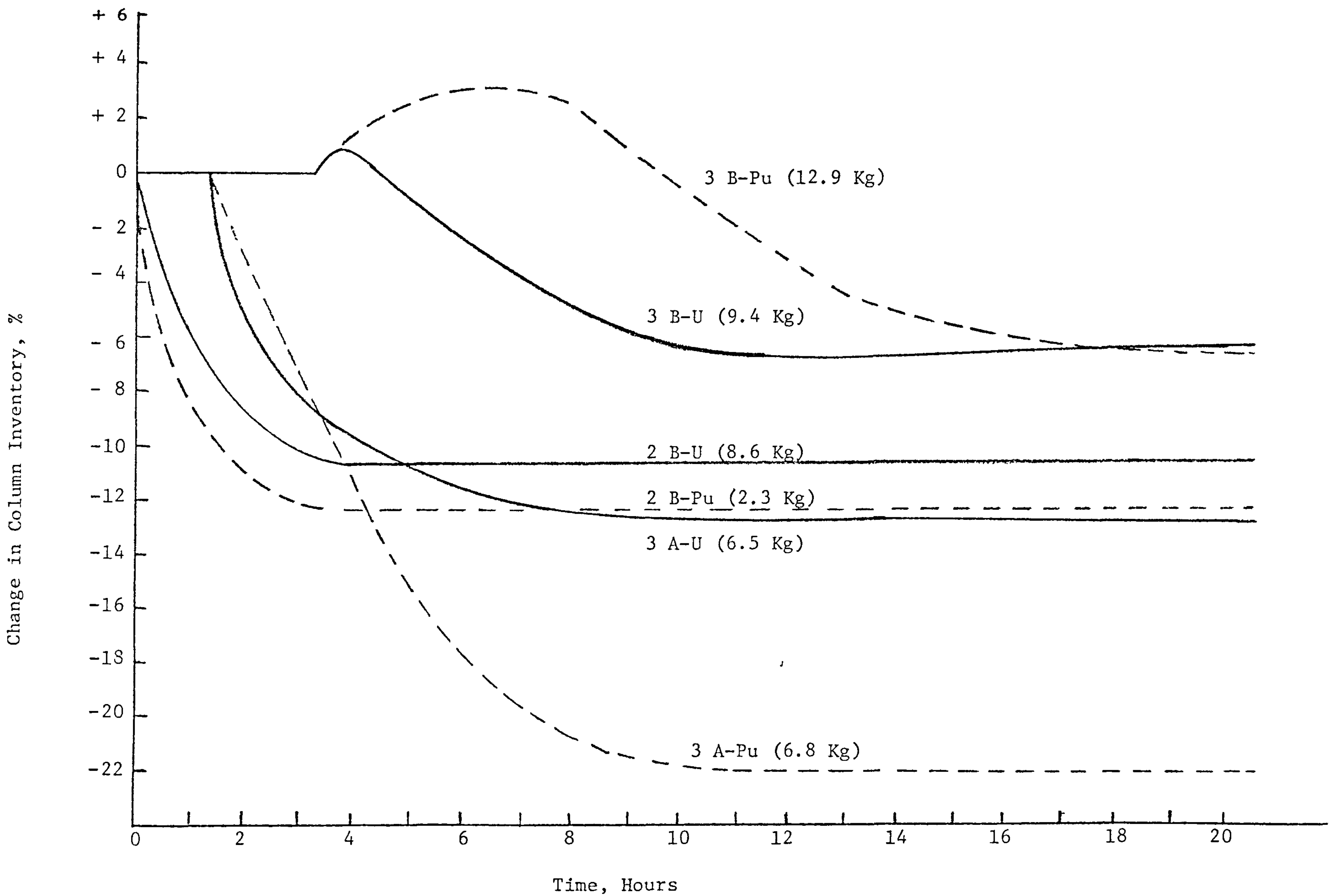

Figure 4.3 Relative Inventory Changes for 10% Concentration Reduction in Stream 2AP
(Quantities in Parentheses are Initial Inventories)

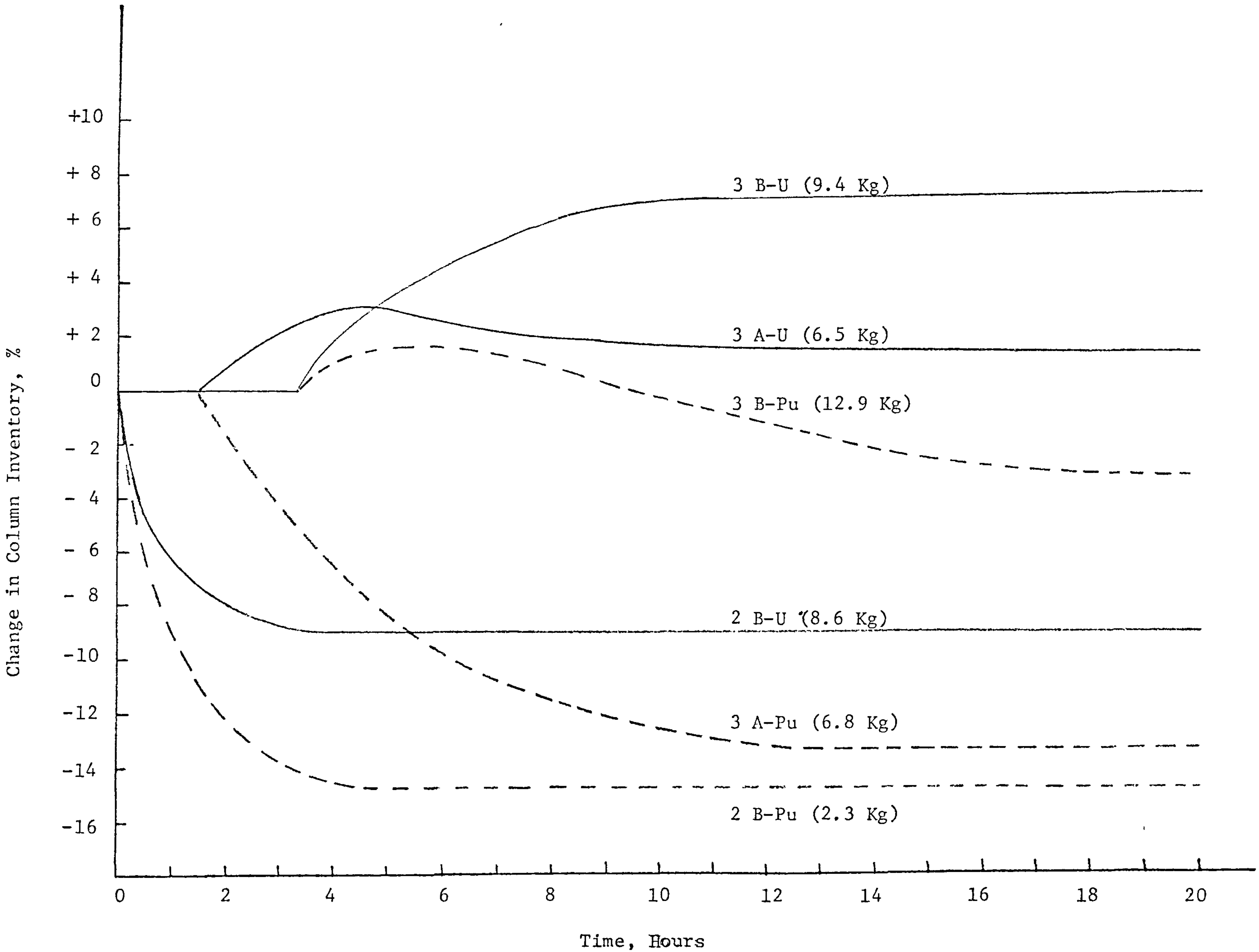

Figure 4.4 Relative Inventory Changes for 10% Flow Reduction in Stream 2AP. (Quantities in Parentheses are Initial Inventories.)

5. Conclusions

The modification of SEPHIS to incorporate the effect of time delays between columns as well as tanks between columns is complete and has not impaired the operation of the other options within SEPHIS. Also the calculation of the fissile material inventories has been incorporated within SEPHIS. The modifications require the inclusion of additional input and a revised tabulation of the input instructions is included as Appendix A and a listing of the input is presented in Appendix B.

The modifications described above have not interfered with the operation of any of the prior options within SEPHIS and the execution time of SEPHIS has not been substantially altered. Execution of a case that represents a sequence of columns with a large number of stages will be increased only by the number of time steps required to reach steady state.

The application of SEPHIS for predicting the consequences of an upset in the operation of a reprocessing plant should now be a task that can be routinely completed without the need for extensive interpretation of the output of SEPHIS or the need for developing arguments that suggest the direction of corrections to compensate for modeling inaccuracies. Routine use of SEPHIS for representing all conditions within a proposed reprocessing plant is now practical.

The results for two hypothetical diversion actions show that detection is feasible by monitoring the concentration of fissile elements of certain column output streams at selected locations. The eventual concentration levels in these streams correlate with the rates at which fissile material is being directed. The delay times will differ for various locations but, for equipment dimensions and operating conditions typical of current reprocessing plants, significant changes in concentration will appear within hours of the start of diversion.

The changes in column fissile material inventories can also be used to indicate the existence of a diversion. The delay times are somewhat more favorable than for concentration monitoring. However, there is no simple correlation between the rate of diversion or quantity of diverted material and the resulting changes in column inventories. This is due to the resulting interactions between multiple solutes distributions which are affected by flow rates, allowable losses in streams which are recycled, and the concentrations of entering streams.

The computational techniques developed in this study hold promise for the evolution of "real time" inventory monitoring in nuclear fuel cycle plants employing solvent extraction.

This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy.

APPENDIX A

Description

Input

The input data are to be prepared in the order shown in Table 1. Referring to Table 1, "Subroutine" indicates the subroutine in which the card is read. "Card Number" denotes the order within the group (Program Cards, Feed Stream Cards, etc.) or quantity of cards for each group to be input. "Columns" refers to the actual columns on the card in which the data must be punched. "Remarks, Variables, etc." gives an explanation as to the variable name, definition, and form of the data to be punched on the cards. The FORMAT descriptor indicates the content and length of the fields on the card. In the FORMAT descriptor the letter "A" denotes alphabetic data; "I" refers to integer data (no decimal point) which must always be right-justified in the field; "F" indicates a real number with or without a signed exponent (decimal point should be punched). The variable names are those used in the FORTRAN program. Two examples of sample input are included in Appendix B.

Output

Two examples of program printout are given in Appendix B. A general explanation of these examples and hence all output is herein described.

The first page of printed output provides a synopsis of input and various initial conditions. Included are the feed stream data, initial profile, phase ratios, and stage flows. The remainder of the printout consists of transient behavior results for each time interval. Printout for each time interval includes aqueous- and organic-phase concentrations, aqueous and organic flows, temperature, and number of iterations required for convergence in the stage calculations; all of which are printed for each stage.

After every time interval which is a multiple of 100 and upon convergence of the transient calculations, the percent steady state and the time intervals at which 90%, 95%, 99%, and 99.5% steady state have been reached are printed.

Table A.1. Input to SEPHIS Code

Subroutine	Card Number	Columns	Remarks, Variables, etc.		
			Program Cards		
MAIN	1		FØRMAT	(10A4)	
		1-40	TITLE	problem title	
	2		FØRMAT	(F8.0,9I2)	
		1-8	CTBP	volume fraction of dry TBP	
		9-10	NTØST	total number of stages - must not exceed 25	
		11-12	IPRØ	0	for a zero initial concentration profile
				1	for a non-zero initial profile
		13-14	IRATIØ	0	if phase ratio = flow ratio
				1	if phase ratio values are to be input
		15-16	ICALC	0	for shutdown calculations (no U or Pu in feed streams)
				1	for start-up or interruption
		17-18	IØUT	0	if there are no extra outgoing streams
				1	if there are outgoing streams in addition to end streams
		19-20	IVØL	0	stage volumes are equal

Table 1. (continued)

Subroutine	Card Number	Columns	Remarks, Variables, etc.
MAIN (cont.)			IVØL 1 stage volumes are unequal but according to total flow 2 stage volumes are independently unequal 3 stage volumes are equal and specified (Options 2 or 3 should be used for hand calculations to correct for stage residence time) (*Hydroxylamine Nitrate - Ref. 3)
		21-22	IPR 0 print out all time intervals 1 print only last interval -1 print every 20th time interval
		23-24	NSTR 0 no unusual routing pattern 1 extra outgoing streams are specified
		25-26	INV 0 no column inventories 1 uranium and plutonium inventories 2 only uranium inventory 3 only plutonium inventory
		27-28	ØUTSTAC stage number of stream to be saved on tape 12 (cannot be zero: use 1 if not using this option)
			Feed Stream Cards
PRØFIL	One card for each input stream		FØRMAT (2I2,5F8.0,I2,F8.0)
		1-2	I - stage number that feed enters

Table 1. (continued)

Subroutine	Card Number	Columns	Remarks, Variables, etc.
PRØFIL (cont.)		3-4	JHAS - 1 for aqueous feed 0 for organic feed
		5-12	FDRT - feed flow rate (volume units)
		13-20	CØN1 - uranium content (g/1)
		21-28	CØN2 - plutonium content (g/1)
		29-36	CØN3 - acid molarity
		37-44	TEMP - temperature in degrees C
		45-46	INDEX - 1 more cards to follow 0 last card
		47-54	CØN4 - nitrate normality from inextractable salts; including the reductant
		55-56	TAPE 0 normal feed stream 1 time dependent feed stream with time dependence on tape 11 (Enter Pu reductant normality as negative Pu concentration)
Initial Profile Cards (required only for non-zero initial profile)			
PRØFIL	One card for each stage		FØRMAT (8F8.0)
		1-8	X(1,J,1) - aqueous-phase uranium concentration in stage J (g/1)
		9-16	X(2,J,1) - aqueous-phase plutonium concentration in stage J (g/1)
		17-24	X(3,J,1) - aqueous-phase nitric acid concentration in stage J (M)

Table 1. (continued)

Subroutine	Card Number	Columns	Remarks, Variables, etc.
PRØFIL (cont.)		25-32	Y(1,J,1) - organic-phase uranium concentration in stage J (g/l)
		33-40	Y(2,J,1) - organic-phase plutonium concentration in stage J (g/l)
		41-48	Y(3,J,1) - organic-phase nitric acid concentration in stage J (M)
		49-56	TPRØF(J,1)- temperature in stage J
		57-64	X(4,J,1) - aqueous-phase nitrate concentration in stage J (M)

<u>Outgoing Stream Data</u>
(only present if IØUT = 1)
(other than aqueous raffinate and organic product)

Subroutine	Card Number	Columns	Remarks, Variables, etc.
FLØWS	One card for each outgoing stream		FØRMAT (2I2,F8.0,I2)
		1-2	I - stage number that stream leaves
		3-4	JHAS - 1 for aqueous stream 0 for organic stream
		5-12	ØTRT - exit flow rate (volume units)
		13-14	INDEX - 1 more cards follow 0 last card
	1	1-5	ISTR
		6-10	JSTR Organic stream from stage ISTR feeds into stage JSTR

Subroutine	Card Number	Columns	Remarks, Variables, etc.
			Phase Ratio Cards (used only if phase ratio ≠ ratio: IRATIØ = 1)
FLØWS	One card for each region of constant phase ratio		FØRMAT (I2,F8.0)
		1-2	I number of stages having phase ratio shown
		3-12	RATIØ - aqueous/organic phase ratio
			Stage Volumes (for IVØL=2 and IVØL=3)
FLØWS			For IVØL=2 stage volumes are unequal and not flow related
	1		FØRMAT (9F8.0)
		1-8	STVØL(1)
		⋮	⋮
		72-80	STVØL(10)
	2		FØRMAT (10A8)
		1-8	STVØL(11)
		⋮	⋮
		72-80	STVØL(20)
	3		FØRMAT (10A8)
		1-8	STVØL(21)
		⋮	⋮
		32-40	STVØL(25)

Only NTØST stage volumes need to be entered; that is, 1 to 3 cards are needed for input.

Table 1. (continued)

Subroutine	Card Number	Columns	Remarks, Variables, etc.
FLØWS			For IVØL=3 stage volumes are equal and specified
	1		FØRMAT (F8.0)
		1-8	VØL - stage volume for all stages
		Plenum Volumes (if IVØL > 0)	
MAIN	1	1-15	VTØP - volume of upper plenum of column (organic, stage 1)
		16-30	VBØT - volume of lower plenum of column (aqueous, last stage)
		Delay Between Columns (only if one stage is time depending)	
MAIN	1	1-8	DELAY - volume of piping between previous column and this column
		9-16	FEED - flow rate of diluent stream
		17-24	VØLUME - volume of heat exchanger or holdup tank
		25-32	CØNC(1)- uranium concentration in diluent stream
		33-40	CØNC(2)-Plutoniumconcentration in diluent stream
		41-48	CØNC(3)- acidity of diluent stream
		49-56	CØNC(4)- temperature of diluent stream
		57-58	J - 0 if diluent stream is independent of time; 1 if diluent stream changes with time as on following cards

Table 1. (continued)

Subroutine	Card Number	Columns	Remarks, Variables, etc.	
			Time Dependence of Diluent Stream	
MAIN	2	1-80	FUNC(1,J),J=1,10	fractional change in uranium concentration of diluent stream
	3	1-80	FUNC(2,J),J=1,10	fractional change in plutonium concentration of diluent stream
	4	1-80	FUNC(3,J),J=1,10	fractional change in molarity of diluent stream
	5	1-80	FUNC(4,J),J=1,10	fractional change in temperature of diluent stream
	6	1-80	FUNC(5,J),J=1,10	fractional change of diluent stream flow rate
	7	1-80	FUNC(6,J),J=1,10	time at which each of the above fractional changes is presented (Note: reference for fractional changes is data on card 1)
			Next Case	
MAIN	1		FØRMAT (2I2)	
		1-2	ICHNGE - 0	next case is new
			1	new Feed Stream Cards and Outgoing Stream Data required for each feed and exit stream - no Program Cards, Initial Profile Cards, Phase Ratio Cards, or Stage Volume Cards are required
			2	stop

Subroutine	Card Number	Columns	Remarks, Variables, etc.
MAIN (cont.)		3-4	IDIF - 0 no changes in Program Card parameters - 1 changes in at least one of these Program Card parameters - ICALC, IØUT, IPR, IPNCH, ICALPL (these parameters are explained in the section Program Cards)

If IDIF = 1, input a card of the following form; if IDIF = 0, omit this card.

Subroutine	Card Number	Columns	Remarks, Variables, etc.
	2		FØRMAT (5I2)
		1-2	ICALC
		3-4	IØUT
		5-6	IPR
		7-8	IPNCH
		9-10	ICALPL
			See Program Cards for explanation of these parameters

APPENDIX B

The input to execute the problem described in Section 2 is presented in Table B.1. This table also includes the CDC control cards that are necessary to execute SEPHIS four times to calculate the performance of all four columns in a single job.

All of the data in Table B.1 is right justified to help define the extremities of each entry field. However, this is only necessary for the integer data. Similarily, each of the floating point entries contains a decimal point which is not strictly necessary but is included for clarity and simplicity.

It should be noted that the data presented in Table B.1 include only the upper and lower plenums as part of a column for purposes of calculating the fissile material inventories. The volume of the piping between columns and the heat exchanger are only present in the time delay terms.

The input data presented in Table B.1 was prepared for one specific problem and does not represent the execution of any of the other options within SEPHIS. Every effort was made to leave the current options totally functional and the testing that was done bears out this statement; however, some combinations of options may have been compromised. Care will have to be exercised in the use of this version of SEPHIS until enough experience has been obtained to give confidence that all options function correctly.

Table B.1

Input for Sample Problem

```
12345678901234567890123456789012345678901234567890123456789O

/JOB
SEPHIS,T777.
USER,user number,password.
GET,SEPHIS.
FTN,I=SEPHIS,GO.
REWIND,TAPE11,TAPE12.
COPYEI,TAPE12,TAPE11.
LGO.
REWIND,TAPE11,TAPE12.
COPYEI,TAPE12,TAPE11.
LGO.
REWIND,TAPE11,TAPE12.
COPYEI,TAPE12,TAPE11.
LGO.
/EOR
 1
          2A PULSE COLUMN
     0.314 0 1 1 0 3-1   0 1 1
 1 1     61.     0.0     0.0     1.0     38. 1     0.0 0
 7 1    437.    9.52    4.78     3.1     35. 1     0.0 0
14 0    146.     0.0     0.0     0.0     31. 0     0.0 0
14    0.25
   25.95
              97.           217.
 2
/EOR
 1
          2B PULSE COLUMN
     0.3 8 0 1 1 0 3-1   0 1 8
 1 1    132.     0.0     0.0     0.3     35. 1     0.0 0
 8 0    146.     0.0     0.0     0.0     35. 0     0.0 1
 8     4.0
   26.53
             263.            73.
    113.     0.0     0.0     0.0     0.0     0.0     0.0 0
 2
/EOR
 1
          3A PULSE COLUMN
     0.314 0 1 1 0 3-1   0 1 1
 1 1     36.     0.0     0.0     1.0     30. 1     0.0 0
 7 1    178.     0.0     0.0     0.0     30. 1     0.0 1
14 0     83.     0.0     0.0     0.0     30. 0     0.0 0
14    0.25
   14.81
              99.           182.

12345678901234567890123456789012345678901234567890123456789O
```

```
123456789012345678901234567890123456789012345678901234567890

     89.       46.       16.       0.0       0.0       12.       30. 0
 2
/EOR
 1
          3B PULSE COLUMN
     0.316 0 1 1 0 2-1   0 116
 1 1      34.       0.0       0.0       0.2       30. 1     0.0 0
12 0      83.       0.0       0.0       0.0       30. 1     0.0 1
16 0      21.       0.0       0.0       0.0       30. 0     0.0 0
16     4.0
    19.0      19.0      19.0      19.0      19.0      19.0      19.0      19.0      19.0
    19.0      19.0      19.0      12.8      12.8      12.8      12.8
           178.                 13.
    115.       0.0       0.0       0.0       0.0       0.0       0.0 0
 2
/EOF

123456789012345678901234567890123456789012345678901234567890
```