SOLVENT EXTRACTION STUDY OF THE SYSTEM MONAZITE RARE EARTH NITRATES - NITRIC ACID - WATER - TRIBUTYL PHOSPHATE

by

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NOMENCLATURE

The following three paragraphs are explanatory notes on the nomenclature used in this thesis.

(1) All molalities are expressed in terms of the nitrate group associated with the solute in question. For example, a solution containing one kilogram of water and one molecular weight (324.9 gms.) of $La(NO_3)_3$ would be three molal $La(NO_3)_3$.

(2) For a doubly subscripted quantity, the first subscript is the solute subscript and the second subscript is a "location" subscript, referring to the phase, stream, or stage with which the quantity is associated.

(3) If used as a subscript S, R, and F denote that the quantity subscripted refers to a stream in an extraction cascade. If used as a variable S, R, and F denote the solvent flow rate in a stream in an extraction cascade. In the text, a reference to stream R_n or S_n denotes a reference to the stream as a whole.

M - molality, moles of a solute per kilogram of solvent

K - distribution coefficient, ratio of molality of a solute in an organic phase to molality of the solute in the equilibrium aqueous phase

β - separation factor, ratio of two distribution coefficients

X - ratio of molality of a solute in aqueous solution to total molality of the solution

x - ratio of molality of a rare earth solute in aqueous solution to total rare earth molality of the solution

Y - ratio of molality of a solute in organic solution to total molality of the solution

y - ratio of molality of a rare earth solute in organic solution to total rare earth molality of the solution

S - flow rate of solvent in an organic stream, kgm. TBP/ unit time

R - flow rate of solvent in an aqueous stream, kgm. H_2O/ unit time

F - flow rate of solvent in a feed stream, kgm. H_2O/unit time

T - total number of solutes

α - flow rate ratio, S/R

Subscripts

i,j - arbitrary solute

t - total solutes present, expressed as equivalents of nitrate

RE - total rare earth nitrate solutes present

La - lanthanum nitrate

Pr - praseodymium nitrate

Nd - neodymium nitrate

Sm - samarium nitrate

HNO_3 - nitric acid

n - arbitrary stage in extraction cascade

org. - organic phase

aq. - aqueous phase

SUMMARY

Using single stage equilibrium data for the systems shown below, plus the assumption of mutual immiscibility of water and tributyl phosphate (TBP), a calculation method was developed to give the stagewise conditions in a cascade of equilibrium stages with all species present in the flow streams.

I $La(NO_3)_3$ - HNO_3 - TBP - H_2O

II $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

III $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O

IV $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O

V $La(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

VI $Nd(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

VII $Sm(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

The calculation method was checked via a series of simulated column experiments. The agreement between predicted and experimental stagewise conditions was considered reasonable, and the calculation is considered useful for engineering work.

As the calculation is tedious and time consuming, digital computor programs were written for the IBM 7074 to calculate the stagewise conditions in cascades of interest. It is hoped these programs will be useful in design and optimization studies.

INTRODUCTION

The elements of atomic number 57 to 71 are commonly known as the rare earths or lanthanides. They occur in nature as rather complex mixtures, and due to their chemical similarity are quite difficult to separate. The term rare earths is a misnomer, and these elements represent a potentially rich source of metals. The abundance, industrial potential, physical properties, and chemistry of the rare earths have been discussed extensively in the recent literature (1,2,3,4, 5,6,7) and will not be elaborated on here.

Spedding and Powell (8) have developed ion exchange techniques which have been used at the Ames Laboratory of the Atomic Energy Commission and by several chemical companies to prepare the pure lanthanides in industrial quantities. The work discussed in this thesis is a continuation of a long term project sponsored by the Chemical Engineering Division of Ames Laboratory to investigate the application of solvent extraction to the separation of the rare earths. It is thought that either a solvent extraction process or a combination of solvent extraction and ion exchange might possess certain advantages over the present process, such as more continuous operation and larger throughputs per dollar of capital investment.

Specifically, the purpose of this research was to propose and verify a calculation method to give the stagewise conditions

in a multistage cascade operating with the system $La(NO_3)_3$ - $Pr(NO_3)_3$ - $Nd(NO_3)_3$ - $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O. If considered desirable, as was the case, the method was to be programmed for digital computor calculation.

The basic problem in this project, as in many projects of this type, was to develop a method of calculating the conditions in one equilibrium phase with the contacting equilibrium phase completely specified. Because of the large number of solutes present it is practically impossible to systematically investigate the equilibrium of the system of interest over the range of composition and concentration encountered in a solvent extraction cascade. Therefore the basic approach was to use experimentally determined equilibrium data for contributing systems to predict the equilibrium of the more complex system of interest.

The function of the nitric acid is threefold. The solvent, TBP, has a relatively high viscosity and a specific gravity approximately equal to that of water (about 0.98 at 20°C.). These characteristics have led to slow phase separation and emulsion formation in the past. The inclusion of nitric acid promotes rapid phase separation and inhibits emulsion formation. Also, the separation factors between the rare earth nitrates have been found to increase with increasing nitrate concentration of the system. The inclusion of nitric acid allows high nitrate concentrations without the

phase separation and emulsion problems mentioned above. On the debit side of the discussion, nitric acid is also extracted by TBP and complicates the system as an extra solute which must be considered.

PREVIOUS WORK

The first study of solvent extraction separation of the rare earths was made in 1937 by Fischer et al. (9). Since that time a large number of systems have been investigated, primarily by single stage "shakeups", and often using radioactive rare earth tracers. Typical studies are (10,11,12,13, 14,15). The field has also been reviewed extensively (16,17, 18,19).

In recent years most workers have followed one of two distinct approaches. The more fundamental approach has been based on the thermodynamic equilibrium constants for postulated complexing reactions between the solutes in the aqueous phase and the organic extractant. In contrast, several workers have approached the problem from a pragmatic point of view, obtaining equilibrium data for simple systems and then making approximations to extrapolate the available data to systems of interest. These two approaches are considered in more detail in the following sections.

Thermodynamic Equilibrium Constant Approach

Many thermodynamic studies have been reported in the literature, typical studies being (20,21,22,23,24,25). In general, the conclusions were that the extraction of many

solutes such as nitric acid and rare earth nitrates from aqueous solution by TBP may be considered the result of a reaction of the type

$$M^{+a}_{(aq.)} + aX^{-}_{(aq.)} + bTBP_{(org.)} \rightleftharpoons MX_a \cdot bTBP_{(org.)} \qquad (1)$$

where b is the solvation number, that is, the number of TBP molecules complexed with one molecule of the extracted compound. For the rare earth nitrates b has been established to be three, and for nitric acid b is usually taken as one, although for nitric acid solubility considerations show such a simple picture to be impossible. That is, the solubility of nitric acid in TBP grossly exceeds the theoretical maximum as given by complete formation of $HNO_3 \cdot TBP$ in the organic phase. The present trend (26,27,28) is to consider the nitric acid extraction as an initial formation of $HNO_3 \cdot TBP$ followed by solubility of excess acid in the complex.

Rozen and Khorkhorina (29) have approached the equilibrium of the system $UO_2(NO_3)_2$ - HNO_3 - TBP plus diluent - H_2O by a consideration of the proposed complexing reactions

$$UO^{++}_{2(aq.)} + 2NO^{-}_{3(aq.)} + 2TBP_{(org.)} \rightleftharpoons UO_2(NO_3)_2 \cdot 2TBP_{(org.)} \qquad (2)$$

and

$$H^{+}_{(aq.)} + NO^{-}_{3(aq.)} + TBP_{(org.)} \rightleftharpoons HNO_3 \cdot TBP_{(org.)} \quad . \qquad (3)$$

The equilibrium constant values for these reactions plus

material balances make possible a calculation of the equilibrium organic concentrations if the aqueous concentrations are known. Several questionable assumptions are, however, necessary. No activity data are available for the reactants in the organic phase and so the activity coefficients of all organic constituents (the free TBP and the solvated complexes) are assumed to be unity. Activity measurements of uranyl nitrate in aqueous solution and of nitric acid in aqueous solution are available (30), but no justification is given by the authors for their use of these activity data for mixtures of uranyl nitrate and nitric acid. Also, as pointed out previously, the proposed reaction involving nitric acid is inadequate over the allowable nitric acid concentration range.

Jury and Whatley (31) have written a digital computor subroutine based on the equations of Rozen and Khorkhorina to calculate equilibrium points in the system discussed above. They do not compare their results with distribution data. Referring to their calculated distribution curves the authors conclude "Beyond the insipid observation that these curves seem to follow the behavior of what is known about the system, there is no quantitative criteria available for evaluating their accuracy". Although many of their calculated distributions appear reasonable, it is to be noted that under some conditions such as low values of the TBP concentration and high

values of the uranyl nitrate concentration the equations predict negative values of the solvent phase nitric acid concentration, which is, of course, impossible.

Olander (32) has written a digital computor program for multistage, multicomponent cascade design making use of equations of the form of Equation 1 alternating with material balance calculations. He assumed:

(1) unit activity coefficients for all species,

(2) complete dissociation of the solutes in the aqueous phase, and

(3) no competing side reactions.

The first two assumptions are certainly in error to some undetermined extent, and the third is open to question. His program is for a center fed cascade and involves a multiple trial and error, the extract and raffinate conditions first being assumed and then working toward the center stage by stage from both ends with a match at the feed point the criteria of correct choice of the end streams. He states that it is impossible at present to estimate activity coefficients of mixed electrolytes containing more than two solutes and also to estimate the activity coefficients of the complexes and the unbound TBP in the organic phase. Consequently his calculation must be regarded solely as an order of magnitude approximation to the true number of theoretical stages.

Empirical Approach

Weaver et al. (33) produced better than a kilogram of 95% pure gadolinium oxide starting with a mixture of rare earth oxides containing about 30% gadolinium oxide. They used a 60:40 mixture of TBP in a hydrocarbon diluent and extracted a highly acidified solution of the rare earth nitrates many times in both batch extractions and counter-current extractions in a York Scheibel column. Their approach was primarily trial and error, empirically adjusting the operating conditions from extraction to extraction.

Peppard and Mason (34) report several simulated column extractions of milligram quantities of mixed rare earths. The aqueous phases were either acidified chloride or nitrate solutions and the organic extractant was TBP either undiluted or mixed with a light hydrocarbon diluent. No design procedure was given. In each case they obtained two enriched fractions, the light rare earths preferring the aqueous and the heavies preferentially extracting into the organic.

A series of reports by Michigan Chemical Corporation (35, 36,37,38,39,40,41,42,43) describe the bench and pilot plant scale separation of yttrium from the rare earths and the division of the rare earths into a light enriched and a heavy enriched fraction. Some work was also done in attempting to strip lanthanum from a rare earth and yttrium mixture. The

solvent used in the latter study was monododecyl phosphoric acid plus hydrocarbon diluent and the aqueous phase acidified chloride or acetate solutions of the rare earths. In some cases a chelating agent was added to the aqueous strip. Yttrium of 98% purity was obtained.

At Ames Laboratory of the Atomic Energy Commission Bochinski (44) demonstrated the partial separation of the rare earths. He distributed the acid free nitrates between undiluted, water equilibrated TBP and water. He developed a design procedure based on two assumptions concerning the equilibrium distribution of the system. They are:

(1) an average equilibrium curve may be used for all mixtures of the rare earths and

(2) the separation factors between the rare earths are independent of the composition of the rare earth solutes and a function only of the total concentration of solutes present in an equilibrium stage.

Bochinski then "pinched" the total solute concentration, thus by assumption 2 holding the separation factors constant. He based his calculations on an oxides per liter basis.

Using Bochinski's method Schoenherr (45) set up a pilot plant separation run. Because of the aforementioned phase separation and emulsion formation problems he acidified the system with nitric acid. The stages were preloaded with a fixed nitric acid concentration, the feed and strip were also

at this acid concentration, and the organic was pre-equilibrated with an aqueous of the specified acidity. Under these conditions it was hoped that the acid concentration in the system would remain constant and Bochinski's method could be used to predict the stagewise rare earth compositions and concentrations. This condition was not realized and it was found that the acid, if included, must be considered as a solute. Schoenherr (46), Sharp (47), and Dinnin (48) then collected distribution data for various acidified systems, the object being to predict the equilibrium of the complex acidified systems of interest.

The project described in this thesis is essentially a continuation of this work carried out at the Ames Laboratory. After a consideration of the state of development of the field of thermodynamic chemistry applied to concentrated, multicomponent ionic solutions, it was the opinion of the author that an empirical approach of this type was more likely to yield a realistic design procedure than the thermodynamic equilibrium constant approach.

METHOD OF CALCULATION

In this section the proposed calculation method will be discussed in detail. The data used in the calculation method are single stage "shake-up" distributions for the systems

I	$La(NO_3)_3$ - HNO_3 - TBP - H_2O	,
II	$Pr(NO_3)_3$ - HNO_3 - TBP - H_2O	,
III	$Nd(NO_3)_3$ - HNO_3 - TBP - H_2O	,
IV	$Sm(NO_3)_3$ - HNO_3 - TBP - H_2O	,
V	$La(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O	,
VI	$Nd(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O	,
VII	$Sm(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O	.

The data for systems I, II, V, VI, and VII were collected by the author by the method described in detail by Sharp (47). The bulk of the data for systems III and IV were taken from the work of Schoenherr (46), supplemented to a small degree by work of the author. A complete compilation of the equilibrium data used is given in Appendix B.

Equilibrium Phase Calculation

The method to be discussed in this section is the calculation of all concentrations of one equilibrium phase with all concentrations of the contacting phase specified. The general procedure was:

(1) to obtain values of K_t and K_{HNO_3} by interpolation using data obtained from the contributing two solute systems and then use the defining equations

$$K_t = (M_t)_{org.}/(M_t)_{aq.} \quad , \qquad (4)$$

$$K_{HNO_3} = (M_{HNO_3})_{org.}/(M_{HNO_3})_{aq.} \quad , \qquad (5)$$

$$M_{RE} = M_t - M_{HNO_3} \quad , \qquad (6)$$

to calculate the total molality, HNO_3 molality, and the rare earth molality of the unspecified phase, followed by

(2) the use of separation factors between the rare earths obtained from data for the contributing three solute systems in one of the equations

$$(M_i)_{org.} = \frac{(M_{RE})_{org.} \times \beta_{i\text{-}Pr} \times (M_i)_{aq.}}{\sum_{i=1}^{T} (\beta_{i\text{-}Pr} \times (M_i)_{aq.})} \quad , \qquad (7)$$

$$(M_i)_{aq.} = \frac{(M_{RE})_{aq.} \times (M_i)_{org.}}{\beta_{i\text{-}Pr} \times \sum_{i=1}^{T} ((M_i)_{org.}/\beta_{i\text{-}Pr})} \quad , \qquad (8)$$

to calculate the rare earth molalities of the unspecified phase. Equations 7 and 8 follow directly from the definition of separation factor and are applicable, of course, only to the rare earths present.

Considering this calculation in more detail, the data from systems I, II, III, and IV were processed to give a series of plots of K_t and K_{HNO_3} versus the composition of an equilibrium phase with the total molality of the same phase as parameter. Typical plots are shown in Figures 1 through 8. A complete compilation of the values from these plots is given in Appendix D.

The separation factors from systems V, VI, and VII were plotted versus the total molality of the organic phase as shown in Figure 9. In each case the rare earth separation factors are seen to be, to a good approximation, a function of the total nitrate molality of the equilibrium organic phase and relatively independent of the phase composition. This observation parallels Bochinski's (44) observation of the acid free system. The curves of Figure 9 were fitted to straight lines by the least squares method to give

$$\beta_{La\text{-}Pr} = 0.8187 - 0.1106(M_t)_{org.} \quad , \qquad (9)$$

$$\beta_{Nd\text{-}Pr} = 1.0448 + 0.09874(M_t)_{org.} \quad , \qquad (10)$$

$$\beta_{Sm\text{-}Pr} = -0.3795 + 0.9214(M_t)_{org.} \quad . \qquad (11)$$

These correlations were assumed to hold with $(M_t)_{org.}$ greater than 1.75.

At this point a gross assumption was made. It was assumed that Equations 9, 10, and 11 would hold also in the five

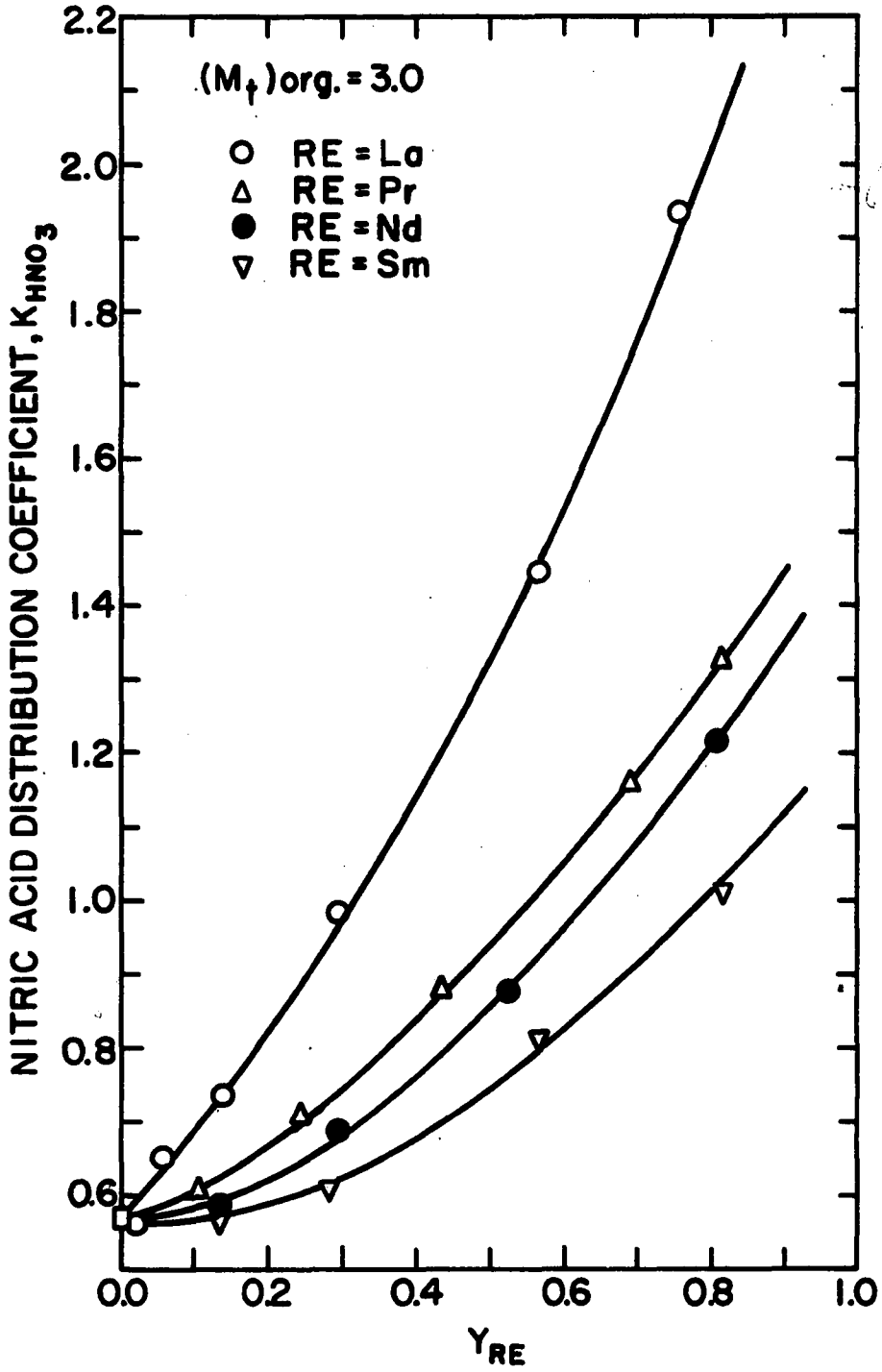


Figure 1. Nitric acid distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the organic phase at $(M_t)_{org.}$ equal to 3.0

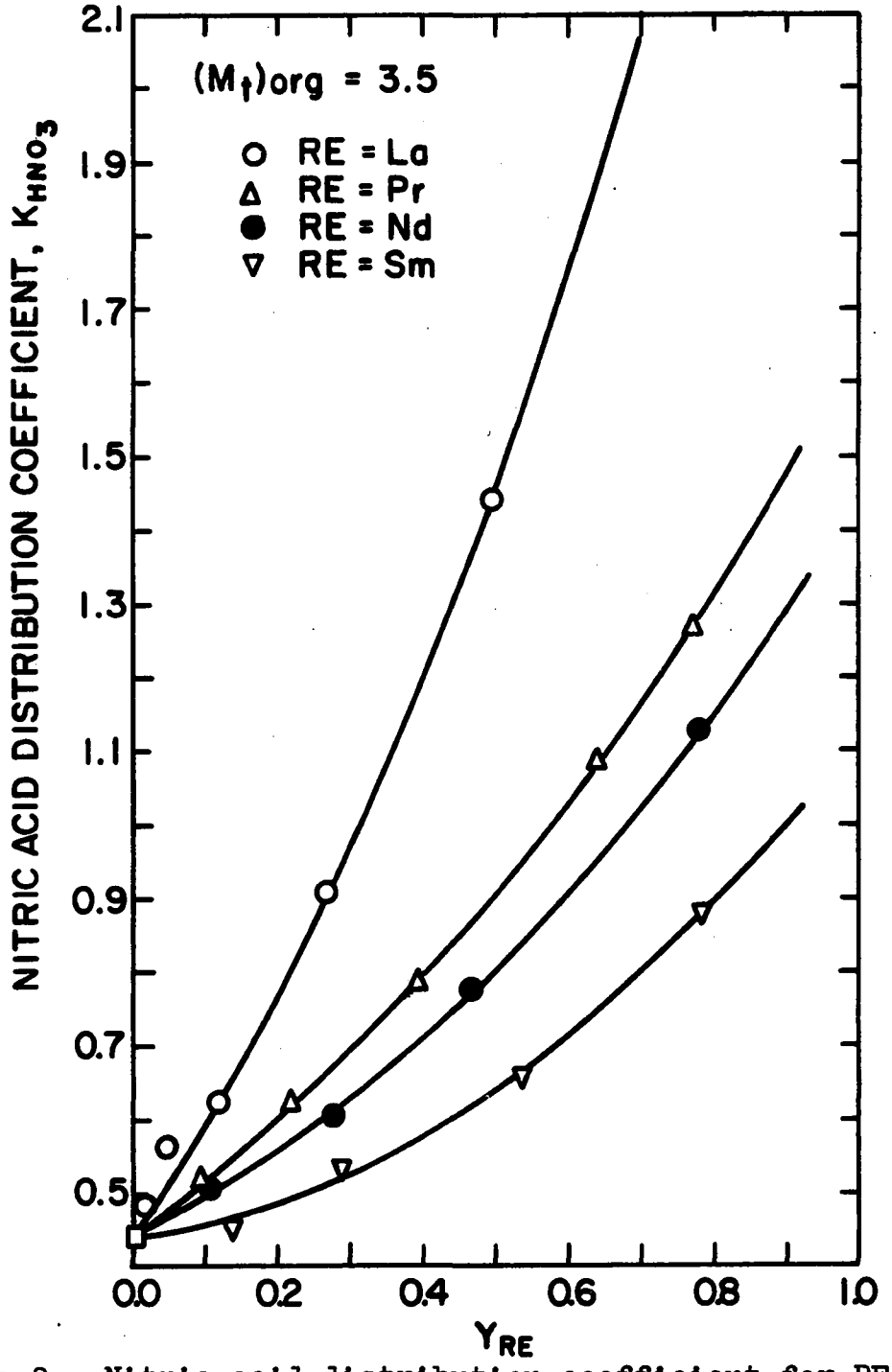
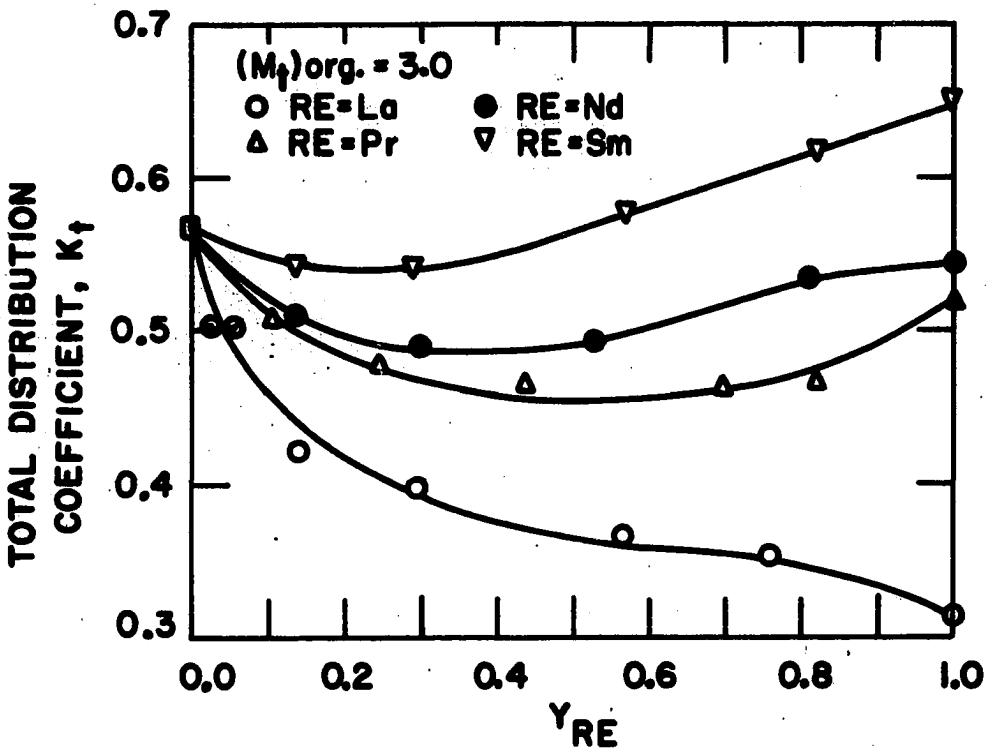
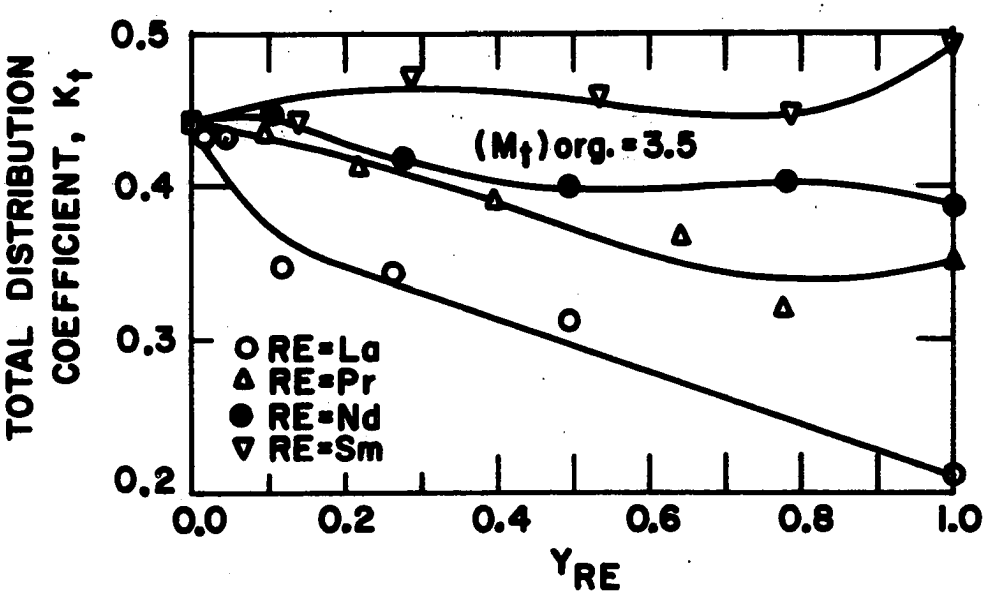


Figure 2. Nitric acid distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the organic phase at $(M_t)_{org.}$ equal to 3.5

Figure 3. Total distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the organic phase at $(M_t)_{org.}$ equal to 3.0

Figure 4. Total distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the organic phase at $(M_t)_{org.}$ equal to 3.5


(Mf)org. = 3.0
RE=La
RE=Nd
RE=Pr
RE=Sm
TOTAL DISTRIBUTION COEFFICIENT, Kf
0.7
0.6
0.5
0.4
0.3
0.0
0.2
0.4
0.6
0.8
1.0
YRE


(Mf)org. = 3.5
RE=La
RE=Pr
RE=Nd
RE=Sm
TOTAL DISTRIBUTION COEFFICIENT, Kf
0.5
0.4
0.3
0.2
0.0
0.2
0.4
0.6
0.8
1.0
YRE

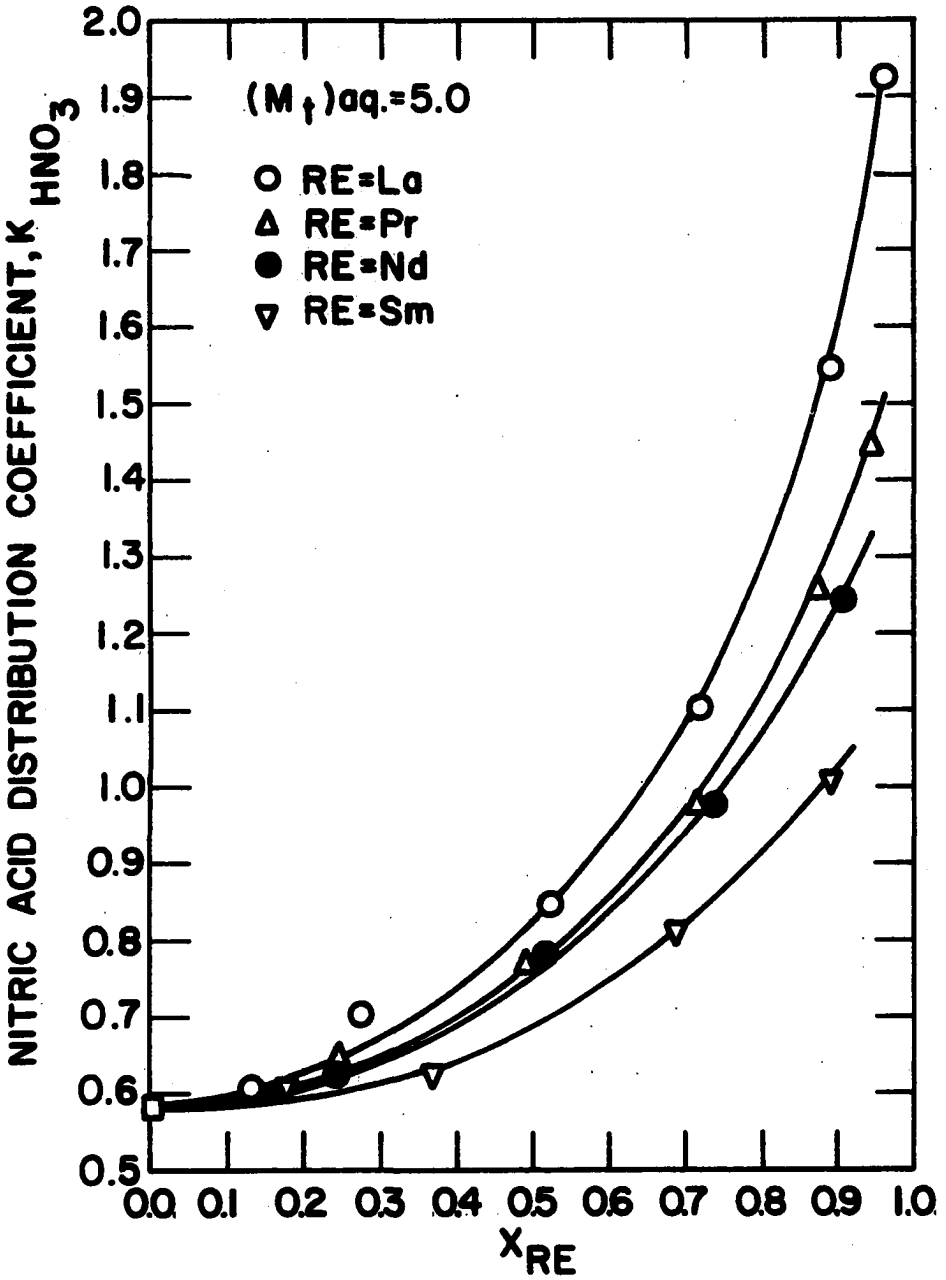


Figure 5. Nitric acid distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the aqueous phase at $(M_t)_{aq.}$ equal to 5.0

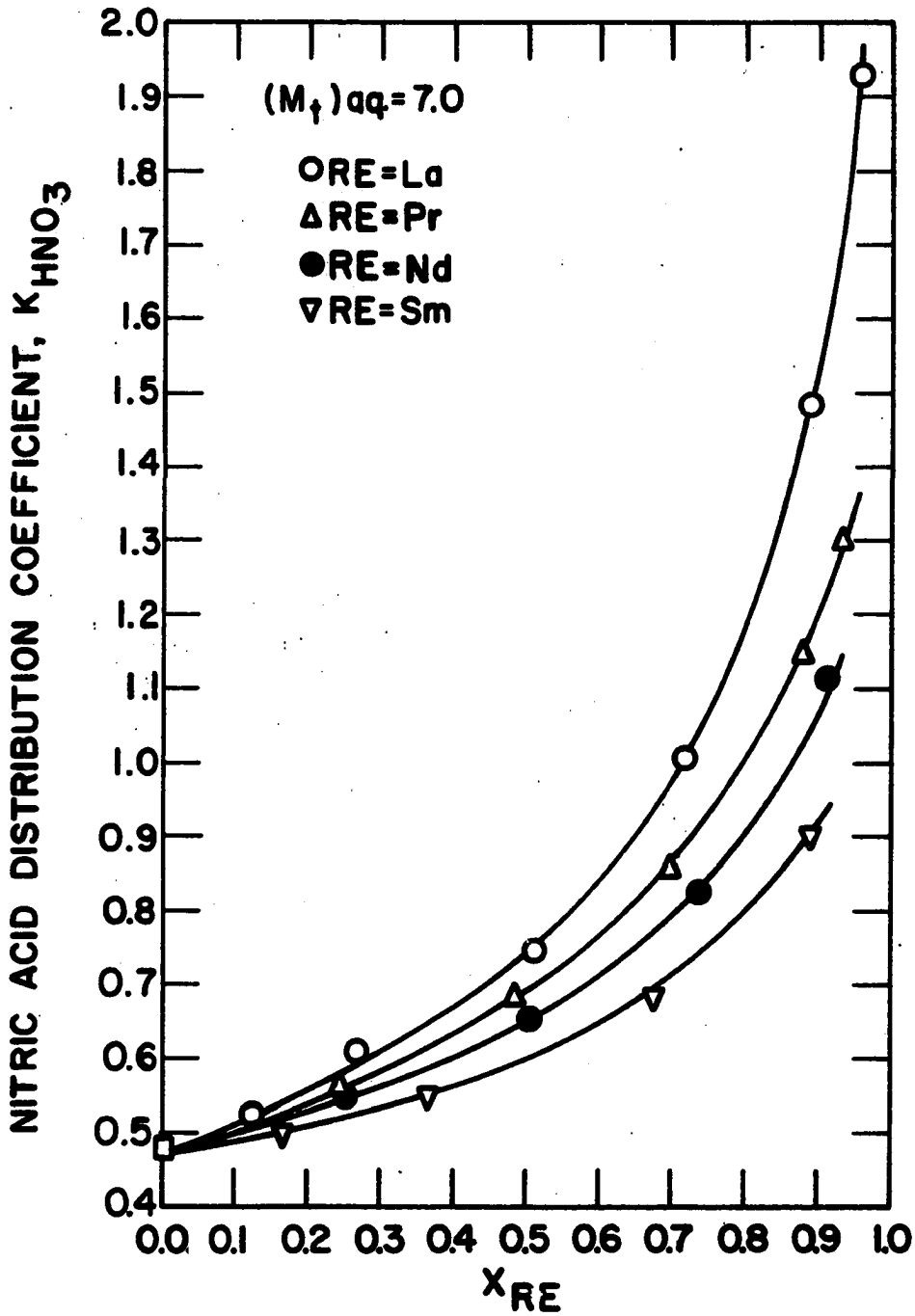
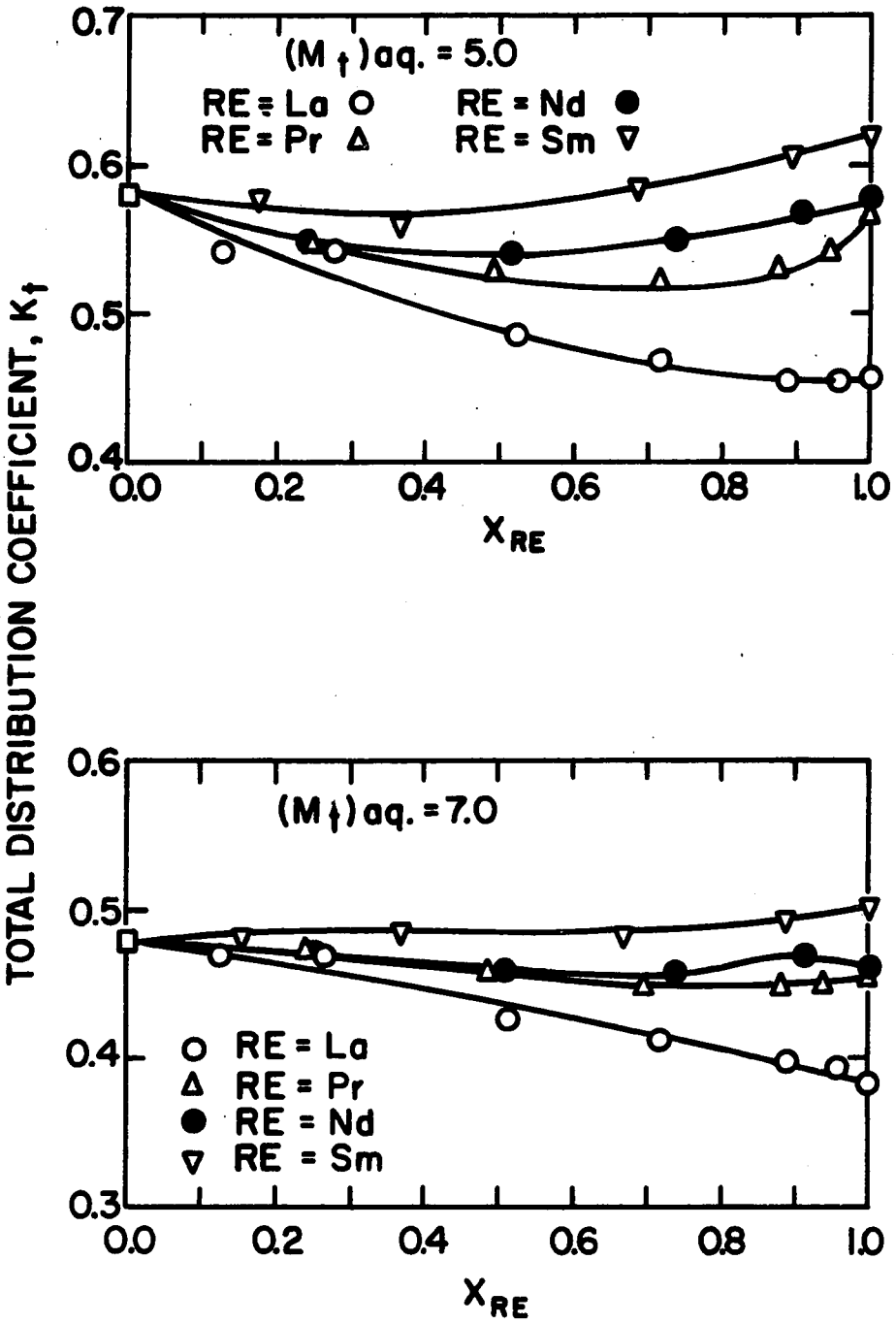


Figure 6. Nitric acid distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the aqueous phase at $(M_t)_{aq.}$ equal to 7.0

Figure 7. Total distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the aqueous phase at $(M_t)_{aq.}$ equal to 5.0

Figure 8. Total distribution coefficient for $RE(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of the composition of the aqueous phase at $(M_t)_{aq.}$ equal to 7.0


(M f) aq. = 5.0
RE = La O
RE = Nd ●
RE = Pr Δ
RE = Sm ▽
0.7
0.6
0.5
0.4
0.0
0.2
0.4
0.6
0.8
1.0
X RE
TOTAL DISTRIBUTION COEFFICIENT, Kf
(Mf) aq. = 7.0
O RE = La
Δ RE = Pr
● RE = Nd
▽ RE = Sm
0.6
0.5
0.4
0.3
0.0
0.2
0.4
0.6
0.8
1.0
X RE

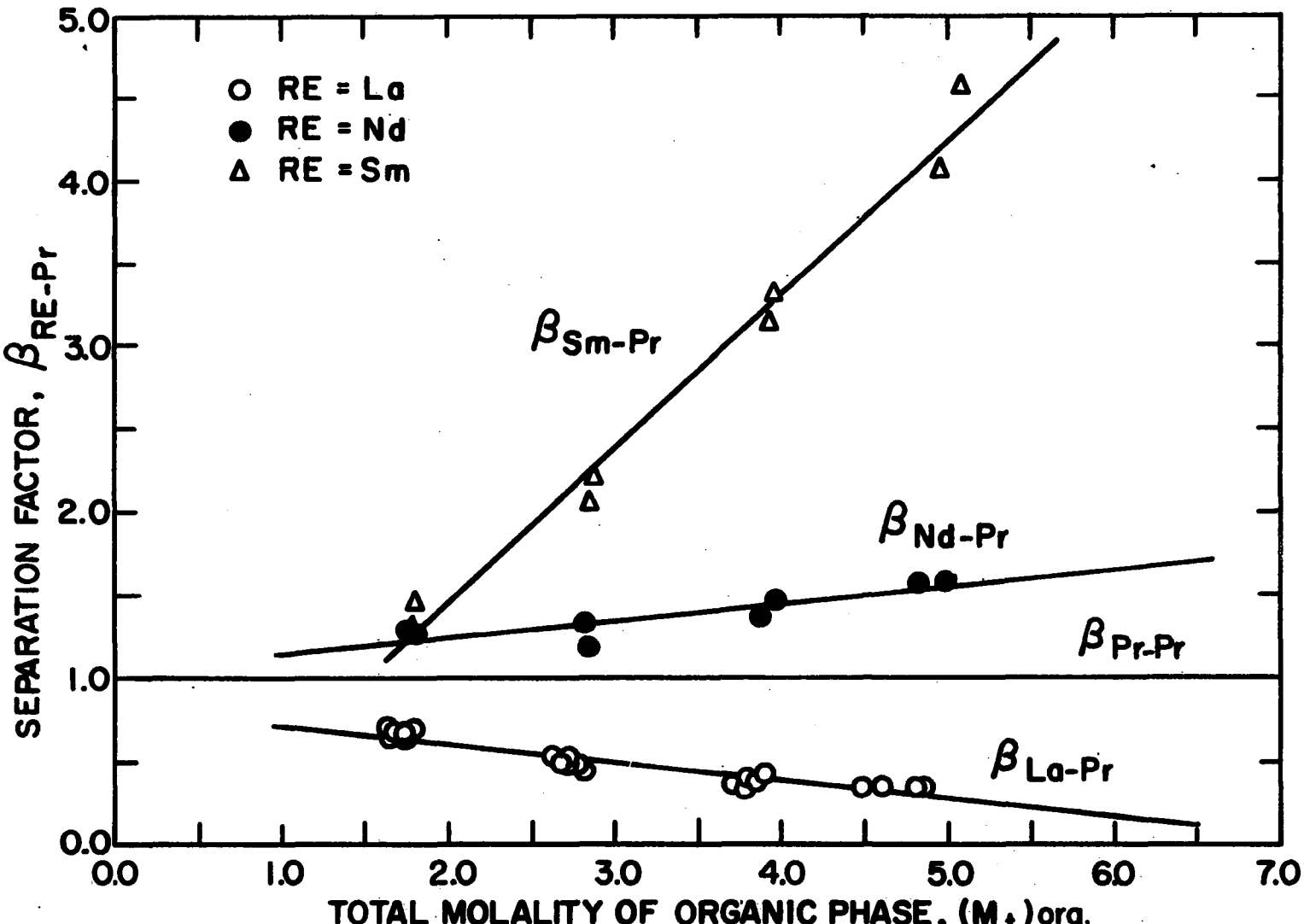


Figure 9. Separation factor between $RE(NO_3)_3$ and $Pr(NO_3)_3$ for $RE(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O systems as a function of concentration of the organic phase

solute system $La(NO_3)_3$ - $Pr(NO_3)_3$ - $Nd(NO_3)_3$ - $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O. The limitations of such a sweeping assumption may only be ascertained empirically, therefore the usefulness of the approximation must be judged by the comparison with experimental results in the Verification of Model section.

Sample calculation

A sample calculation is now given to illustrate this method. It was assumed that an equilibrium organic phase has the following concentrations:

$$(M_t)_{org.} = 3.0261 \quad ,$$

$$(M_{HNO_3})_{org.} = 2.3590 \quad ,$$

$$(M_{La})_{org.} = 0.0397 \quad ,$$

$$(M_{Pr})_{org.} = 0.0460 \quad ,$$

$$(M_{Nd})_{org.} = 0.0706 \quad ,$$

$$(M_{Sm})_{org.} = 0.5108 \quad ,$$

$$(M_{RE})_{org.} = 0.6671 \quad .$$

From these data were calculated

$$Y_{HNO_3} = (M_{HNO_3})_{org.}/(M_t)_{org.} = 2.3590/3.0261 = 0.7796 \quad ,$$

$$Y_{RE} = (M_{RE})_{org.}/(M_t)_{org.} = 0.6671/3.0261 = 0.2204 \quad ,$$

$$y_{La} = (M_{La})_{org.}/(M_{RE})_{org.} = 0.0397/0.6671 = 0.0595 \quad ,$$

$y_{Pr} = (M_{Pr})_{org.}/(M_{RE})_{org.} = 0.0460/0.6671 = 0.0690$,

$y_{Nd} = (M_{Nd})_{org.}/(M_{RE})_{org.} = 0.0706/0.6671 = 0.1058$,

$y_{Sm} = (M_{Sm})_{org.}/(M_{RE})_{org.} = 0.5108/0.6671 = 0.7657$.

To obtain the value of K_t it was first assumed that all the rare earth nitrates present were $La(NO_3)_3$. That is, $Y_{RE} = Y_{La} = 0.2204$. Then, by straight line interpolation between the total molality parameters of Figures 3 and 4, a value of K_t was obtained that would hold for the case of $(M_t)_{org.} = 3.0261$ and $Y_{RE} = Y_{La} = 0.2204$. This was $K_t = 0.4031$. Exactly the same procedure was then followed to get values for K_t assuming, in succession, that all the rare earths present were $Pr(NO_3)_3$, $Nd(NO_3)_3$, and $Sm(NO_3)_3$. To then get the K_t used in the calculation each K_t derived from the assumption of only one rare earth solute was multiplied by the fraction of the rare earths present as that particular solute. In other words, the contribution from the $La(NO_3)_3$ system to the final value of K_t was assumed to be equal to the value of K_t for the $La(NO_3)_3 - HNO_3 - TBP - H_2O$ system multiplied by y_{La}. Or arithmetically, the contribution was $(0.4031) \times (0.0595) = 0.0240$. The sum of the four contributions was then the value of K_t used.

Exactly the same procedure, using Figures 1 and 2 was then used to get a value of K_{HNO_3} for the case in question.

The values so obtained were

$$K_t = 0.5200 \quad ,$$

$$K_{HNO_3} = 0.6114 \quad .$$

The values of $(M_t)_{aq.}$, $(M_{HNO_3})_{aq.}$, and $(M_{RE})_{aq.}$ were then calculated from Equations 4, 5 and 6 to be

$$(M_t)_{aq.} = (M_t)_{org.}/K_t = 3.0261/0.5200 = 5.8194 \quad ,$$

$$(M_{HNO_3})_{aq.} = (M_{HNO_3})_{org.}/K_{HNO_3} = 2.3590/0.6114 = 3.8584 \quad ,$$

$$(M_{RE})_{aq.} = (M_t)_{aq.} - (M_{HNO_3})_{aq.} = 5.8194 - 3.8584 = 1.9610 \quad .$$

Using $(M_t)_{org.} = 3.0261$ the separation factors were calculated as

$$\beta_{La-Pr} = 0.4840 \quad ,$$

$$\beta_{Nd-Pr} = 1.3436 \quad ,$$

$$\beta_{Sm-Pr} = 2.4087 \quad .$$

Note that, by definition, β_{Pr-Pr} is equal to 1.0.

The rare earth molalities of the aqueous phase were then calculated by Equation 8 as follows:

$$\sum_{i=1}^{T}((M_i)_{org.}/\beta_{i-Pr}) = (M_{La})_{org.}/\beta_{La-Pr} + (M_{Pr})_{org.}/\beta_{Pr-Pr} + (M_{Nd})_{org.}/\beta_{Nd-Pr} + (M_{Sm})_{org.}/\beta_{Sm-Pr} \quad ,$$

$$\sum_{i=1}^{T}((M_i)_{org.}/\beta_{i-Pr}) = 0.0397/0.4840 + 0.0460/1.0000 + 0.0706/1.3436 + 0.5108/2.4087 \quad ,$$

$$\sum_{i=1}^{T} ((M_i)_{org.}/\beta_{i\text{-}Pr}) = 0.3926 \quad ,$$

$$(M_{La})_{aq.} = \frac{(M_{RE})_{aq.} \times (M_{La})_{org.}}{\beta_{La\text{-}Pr} \times \sum_{i=1}^{T} ((M_i)_{org.}/\beta_{i\text{-}Pr})}$$

$$= \frac{(1.9610)(0.0397)}{(0.4840)(0.3926)} = 0.4097$$

and in exactly the same manner

$$(M_{Pr})_{aq.} = 0.2298 \quad ,$$

$$(M_{Nd})_{aq.} = 0.2625 \quad ,$$

$$(M_{Sm})_{aq.} = 1.0592 \quad .$$

If the reverse calculation had been desired, the same procedure would have been followed, first using plots of the type portrayed in Figures 5, 6, 7, and 8 to get K_t and K_{HNO_3}, calculating then $(M_t)_{org.}$, $(M_{HNO_3})_{org.}$, and $(M_{RE})_{org.}$, and then, after calculating the separation factors, using Equation 7 to calculate the rare earth molalities.

Application to Multistage Calculations

It was desired to apply the model to the calculation of the stagewise conditions in an ideal multistage cascade. Referring to Figures 10 and 11 it is seen that if any point on

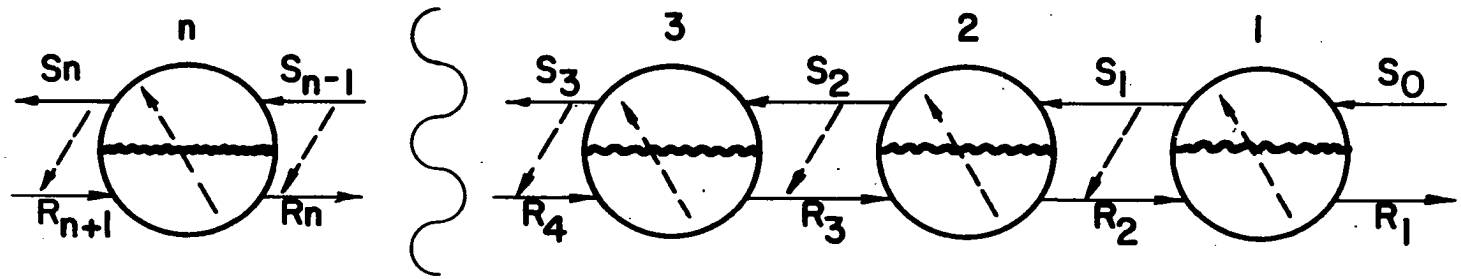


Figure 10. Cascade I

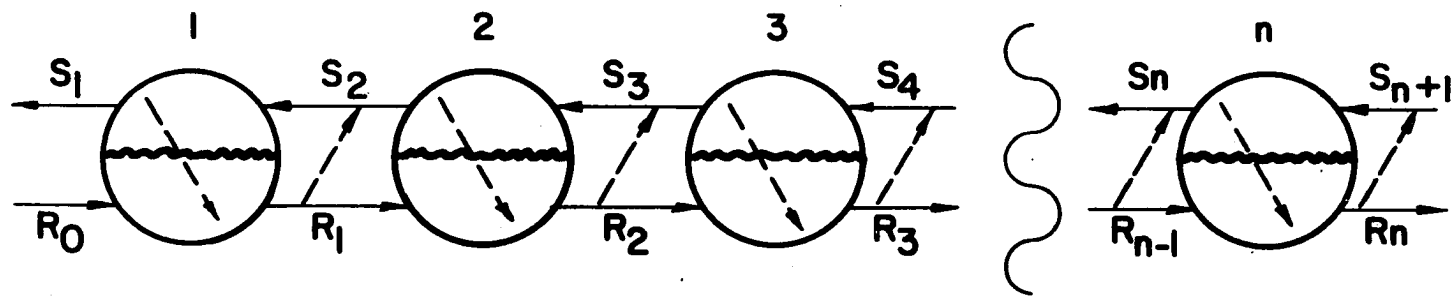


Figure 11. Cascade II

the operating line is known, that is, if two streams passing each other are completely defined, the conditions for any number of stages may be calculated "backwards" through the column if the operating line equation is known. The direction such a calculation would follow is shown by the dashed arrows in Figures 10 and 11. Obviously, but to ensure clarity, the calculation would be composed of alternating applications of the equilibrium model and the operating line.

In the present work, the assumption of mutual immiscibility of water and TBP was made. Writing a general operating line for the cascade pictured in Figure 10 gives

$$\left[(M_i)_{S_0} \times S_0\right] + \left[(M_i)_{R_n} \times R_n\right] = \left[(M_i)_{S_{n-1}} \times S_{n-1}\right] + \left[(M_i)_{R_1} \times R_1\right] \quad . \quad (12)$$

By the assumption of mutual immiscibility $S_0 = S_{n-1}$ and $R_n = R_1$ and so the subscripts may be deleted, and after rearrangement

$$(M_i)_{R_n} = \alpha(M_i)_{S_{n-1}} - \alpha(M_i)_{S_0} + (M_i)_{R_1} \quad . \quad (13)$$

The assumption of mutual immiscibility of water and TBP was felt to be justified. The solubility of TBP in water is very low, on the order of tenths of a gram per liter, and the solubility of water in TBP does not exceed approximately six percent by weight. Because the solvent is normally equi-

librated with water before use, the assumption of constant water content does not introduce a large error.

Using the proposed equilibrium model and operating lines of the form of Equation 13 several calculations of the stage-wise conditions in various cascades were carried out. The procedure was to arbitrarily choose the end conditions, either R_1 and S_0 for the cascade in Figure 10, or R_0 and S_1 for the cascade in Figure 11, and then to proceed as explained previously. The purposes of these calculations were to obtain a "feel" for the possible separations that could be made with the system and to select several predictions for experimental verification.

At this point an unexpected problem arose. In several of the calculations the total molality was "pinched" at a high value. This was done to impress high separation factors on the system, since, with the equilibrium model proposed the separation factors increase with increased total concentration. In each case in which this was done the individual concentrations also quickly "pinched". When the end conditions and flow ratio were chosen so that the total concentration changed from stage to stage no such "pinch" of the individual solutes was calculated.

The study of this "pinch" based on the limit of a sequence that can be written describing the molality of a general component in successive streams of a cascade is an inter-

esting problem the author has not been able to solve completely. A discussion of this approach is given in Appendix C.

As the stagewise calculation is quite tedious and time consuming, four digital computor programs were written for various cascades of interest. These programs were compiled and debugged on the IBM 7074. Although some calculations were made with each program they are intended primarily for future use in design and optimization studies, and as guides for further programming. A complete discussion of these programs is given in Appendix D.

VERIFICATION OF MODEL

A specification of the source and method of preparation of the materials used in the experimental phase of this project follows:

Tributyl phosphate Commercial grade TBP, obtained from Commercial Solvents Corporation, was pre-equilibrated with distilled water before use as the solvent. The TBP was stored in contact with a water phase to ensure equilibrium.

Nitric acid Reagent grade nitric acid was used in all laboratory work.

Rare earth nitrate solutions The oxides of La, Pr, Nd, and Sm, 99.9 percent pure, were obtained from the ion exchange group of the Ames Laboratory of the Atomic Energy Commission. Stock nitrate solutions of each rare earth were prepared by dissolving the oxides in boiling, concentrated nitric acid. After complete reaction, the excess nitric acid was boiled off and distilled water added. All feed solutions for the simulated column experiments were prepared by mixing these stock solutions, reagent grade concentrated nitric acid and distilled water.

As mentioned previously, the simulated column technique was used to obtain experimental stagewise conditions for comparison with the predicted values. Briefly, a simulated column experiment is a batchwise approximation to a continuous counter-

current cascade. The error in the approximation may be made arbitrarily small by increasing the number of cycles the experiment is run. The mechanics and mathematical demonstrations involved will not be gone into here as this technique has been discussed extensively by Scheibel (49,50,51,52).

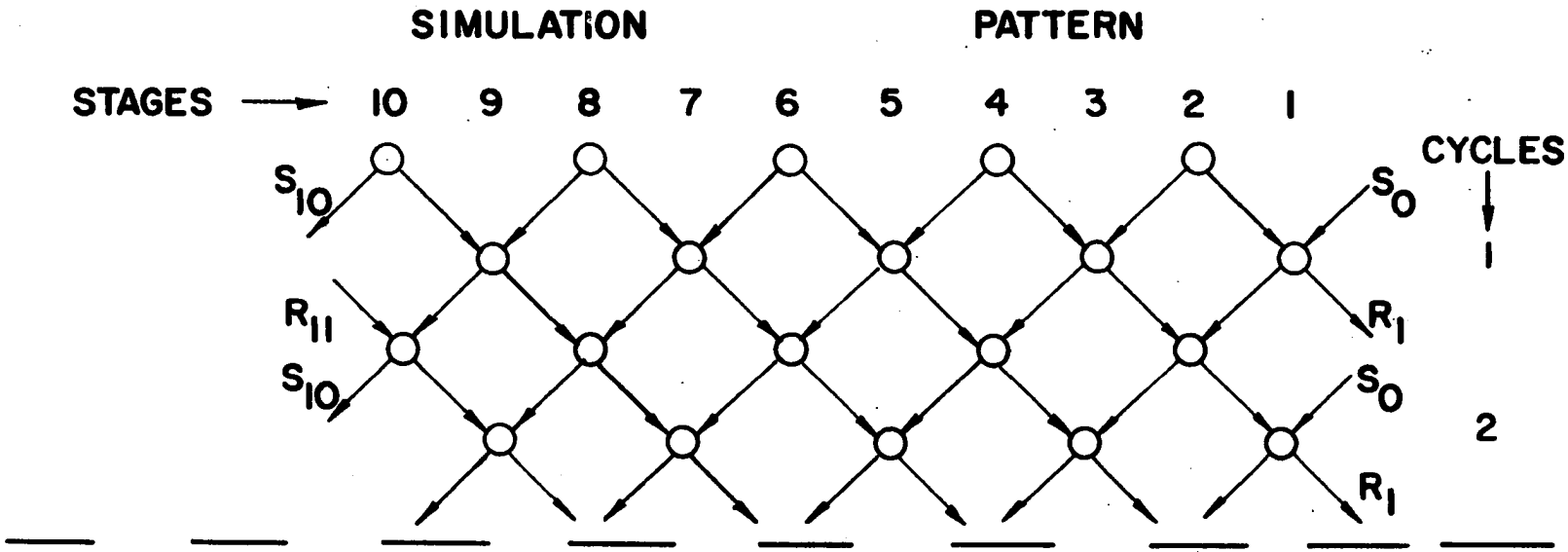
Four of the prediction calculations discussed in the Method of Calculation section were chosen for simulation. The experiments were carried out in laboratory glassware at room temperature, using 1/100 horsepower laboratory stirrers for the mixing steps. A minimum of two minutes mixing and three minutes settling time was maintained for each contact.

Along with the phases from the final cycle, the leaving aqueous phase from each cycle was retained and analyzed as a check on the approach to steady state. In all cases the number of cycles was felt to be sufficient.

All organic and aqueous phases from the final cycle were analyzed for total oxides, nitric acid content, and rare earth composition. The analytical methods used are discussed in Appendix A.

A complete compilation of the experimental conditions and the final experimental-predicted comparisons from these four simulations is given on pages 32 to 52. In each case, the first figure gives all pertinent experimental conditions, including the simulation pattern and the continuous cascade being simu-

lated, and is followed by both tabular and graphic experimental-predicted concentration and composition comparisons.



TOTAL NUMBER OF CYCLES - 11 , FLOW RATE RATIO = α = 0.5

VOLUME R_{11}/INJECTION = 74.6 ml. , CONCENTRATION R_{11}: M_{HNO_3} = 1.86, M_{RE} = 6.89

VOLUME S_o/INJECTION = 30.7 ml. , CONCENTRATION S_o: M_{HNO_3} = 0.00, M_{RE} = 0.00

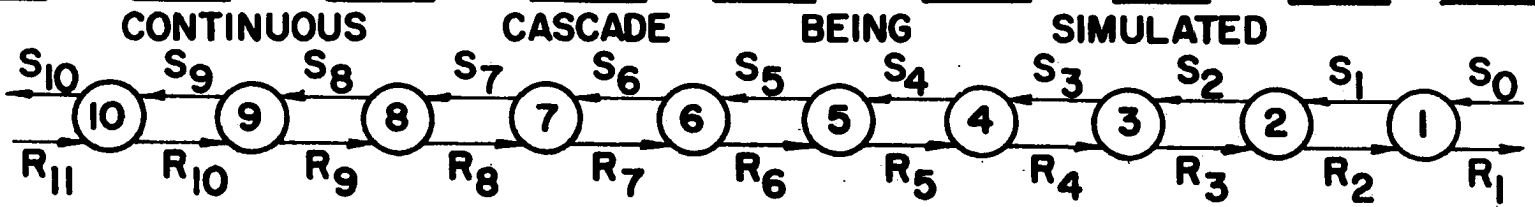


Figure 12. General information pertaining to Simulated Column Experiment I

Table 1. Comparison of experimental and predicted compositions and concentrations for Simulated Column Experiment I

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
R_1	32.3	32.3	25.2	25.3	25.6	25.0	17.0	17.3	0.191	0.195	0.039	0.037
R_2	30.0	29.5	26.8	24.8	25.0	25.6	18.2	20.1	0.208	0.211	0.055	0.053
R_3	28.0	29.2	25.4	24.5	25.9	25.4	20.7	21.0	0.206	0.208	0.060	0.060
R_4	28.8	29.3	24.7	24.4	25.7	25.3	20.8	21.1	0.204	0.207	0.062	0.062
R_5	28.4	29.3	26.4	24.4	25.4	25.2	19.8	21.0	0.204	0.207	0.062	0.062
R_6	29.9	29.3	25.2	24.4	25.0	25.2	19.9	21.0	0.203	0.207	0.062	0.063
R_7	29.7	29.3	24.8	24.4	25.4	25.2	20.2	21.0	0.202	0.207	0.062	0.063
R_8	29.1	29.3	24.4	24.4	28.8	25.2	17.8	21.0	0.202	0.207	0.062	0.063
R_9	29.2	29.3	24.8	24.4	26.5	25.2	19.5	21.0	0.202	0.207	0.062	0.063
R_{10}	30.1	29.3	24.9	24.4	26.0	25.2	18.9	21.0	0.205	0.207	0.062	0.063
R_{11}	29.0	29.3	24.9	24.4	26.5	25.2	19.6	21.0	0.204	0.207	0.062	0.063
S_1	12.1	13.1	22.4	21.6	28.4	28.8	37.1	36.6	0.088	0.088	0.054	0.054

Table 1 (Continued)

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
S_2	8.0	10.0	19.9	19.1	28.8	27.4	43.3	43.5	0.085	0.083	0.071	0.074
S_3	9.4	9.6	18.8	18.6	28.1	26.7	43.8	45.2	0.082	0.080	0.076	0.080
S_4	9.3	9.5	19.1	18.5	27.5	26.6	44.1	45.4	0.081	0.078	0.078	0.082
S_5	9.4	9.6	19.0	18.5	27.1	26.6	44.5	45.4	0.080	0.078	0.078	0.083
S_6	10.0	9.6	18.7	18.5	27.0	26.6	44.4	45.3	0.081	0.078	0.078	0.083
S_7	10.1	9.6	19.0	18.5	27.2	26.6	43.6	45.3	0.080	0.078	0.078	0.083
S_8	7.5	9.6	20.5	18.5	28.3	26.6	43.7	45.3	0.081	0.078	0.078	0.083
S_9	10.2	9.6	19.0	18.5	26.0	26.6	44.8	45.3	0.081	0.078	0.077	0.083
S_{10}	8.2	9.6	19.8	18.5	27.5	26.6	44.5	45.3	0.081	0.078	0.077	0.083

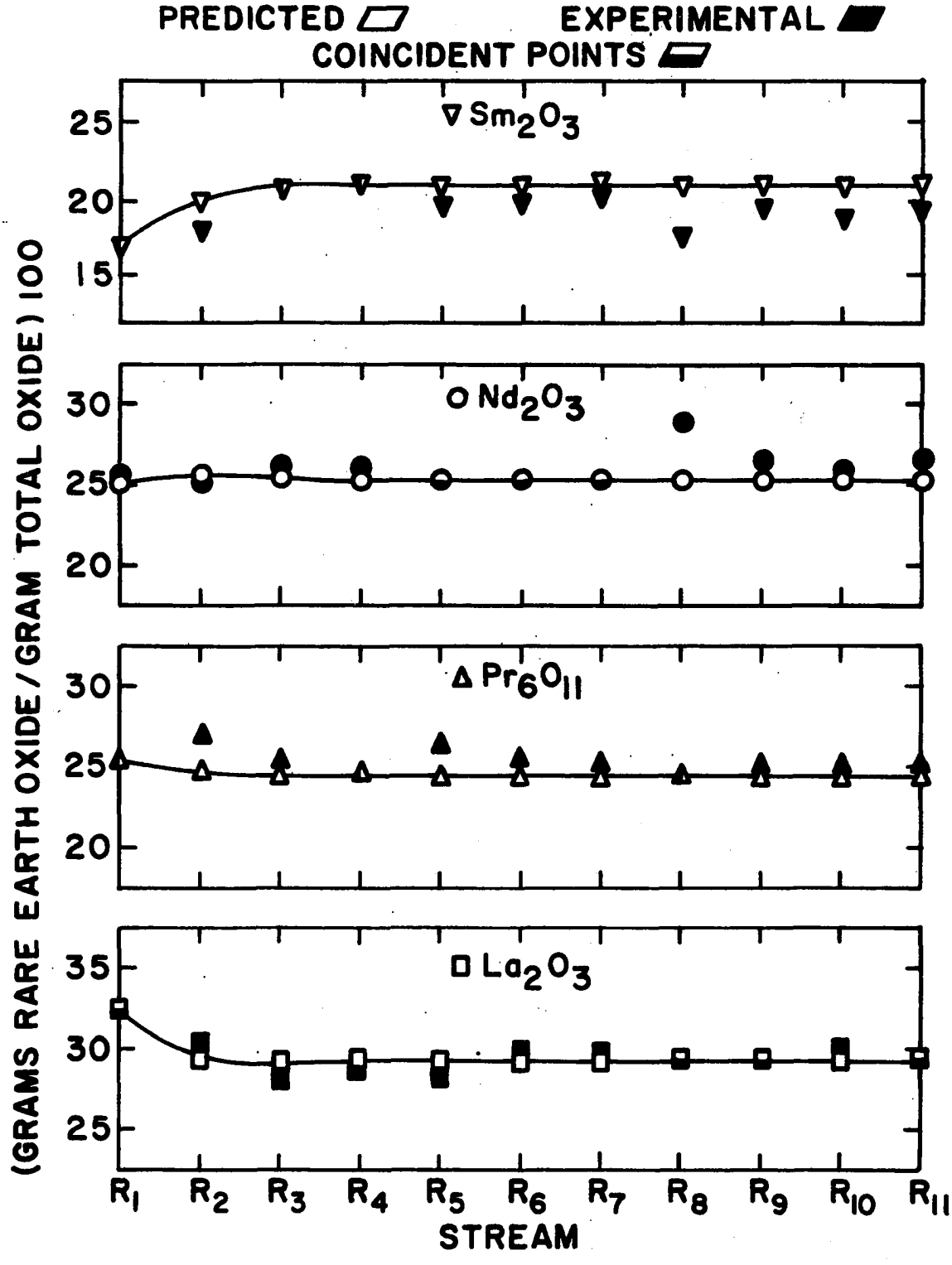


Figure 13. Stagewise aqueous rare earth oxide composition for Simulated Column Experiment I

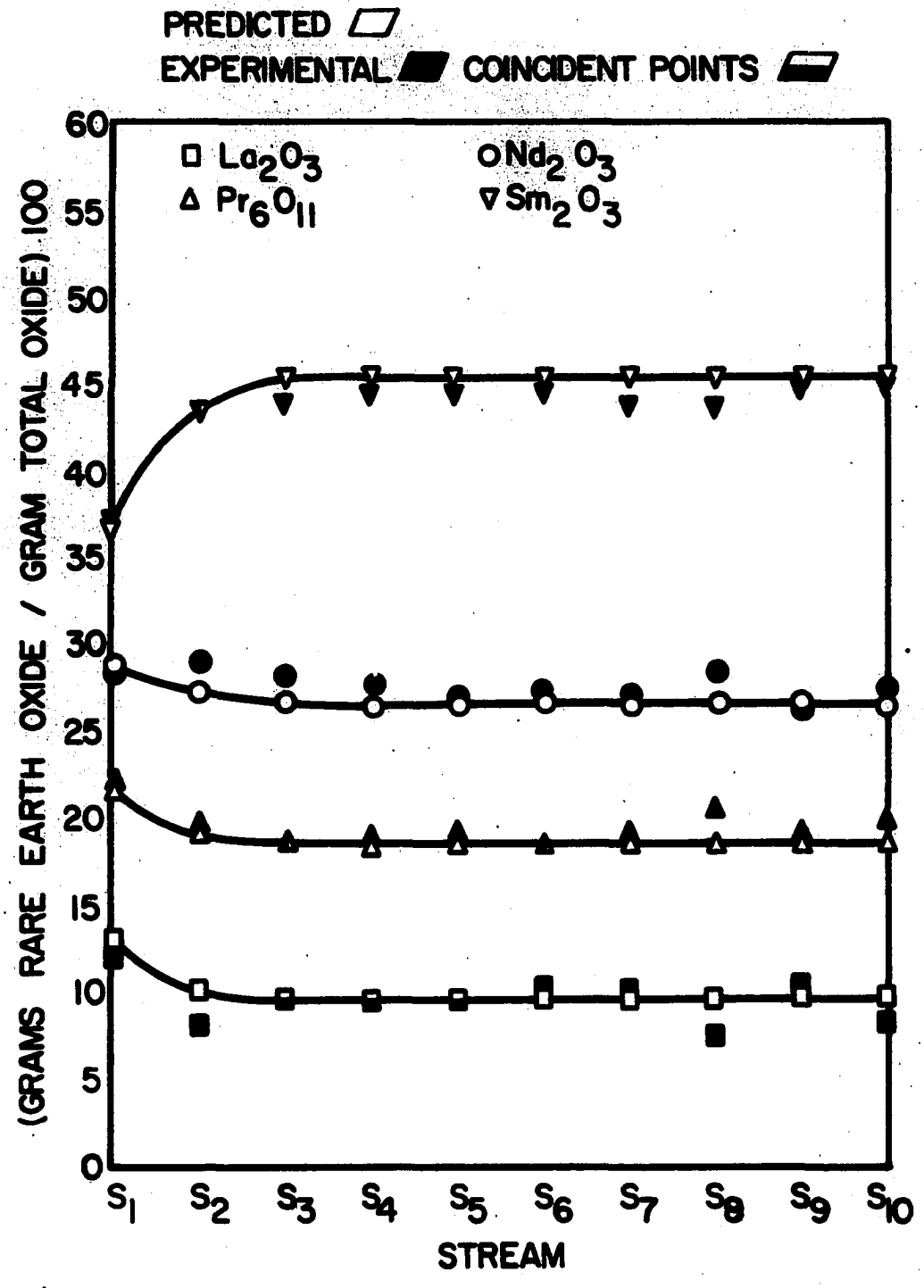


Figure 14. Stagewise organic rare earth oxide composition for Simulated Column Experiment I

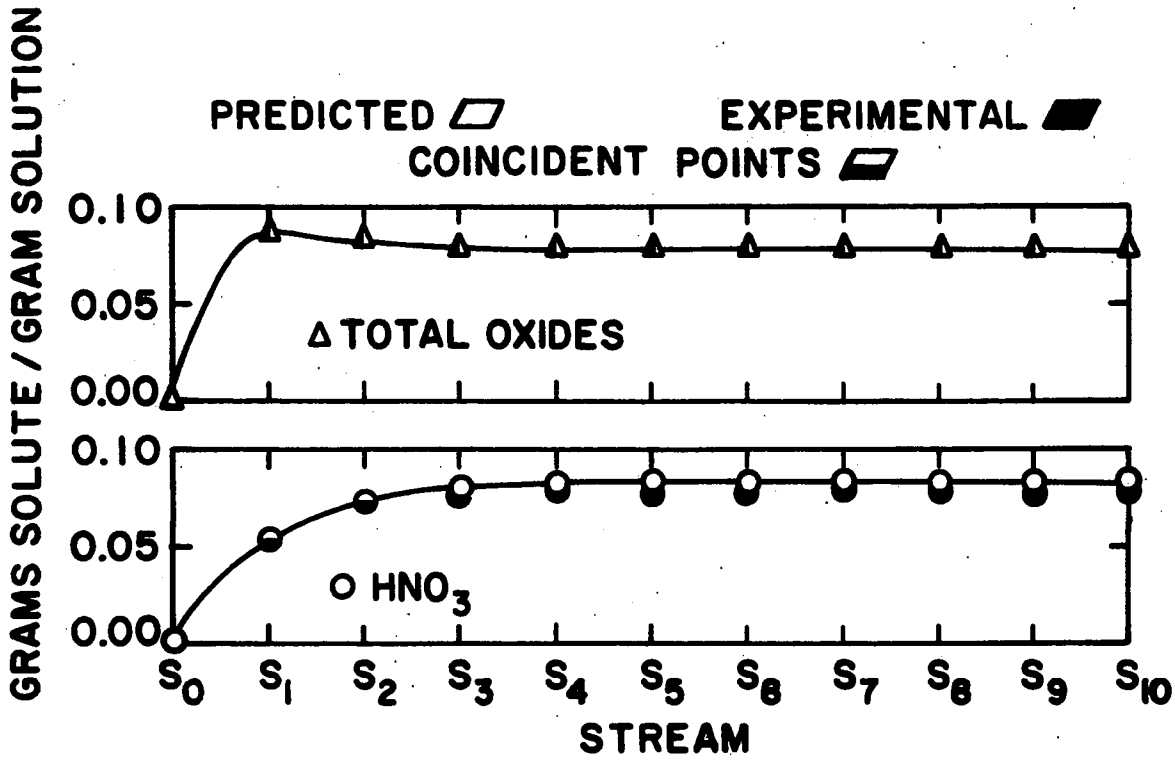


Figure 15. Stagewise organic rare earth oxide and nitric acid concentrations for Simulated Column Experiment I

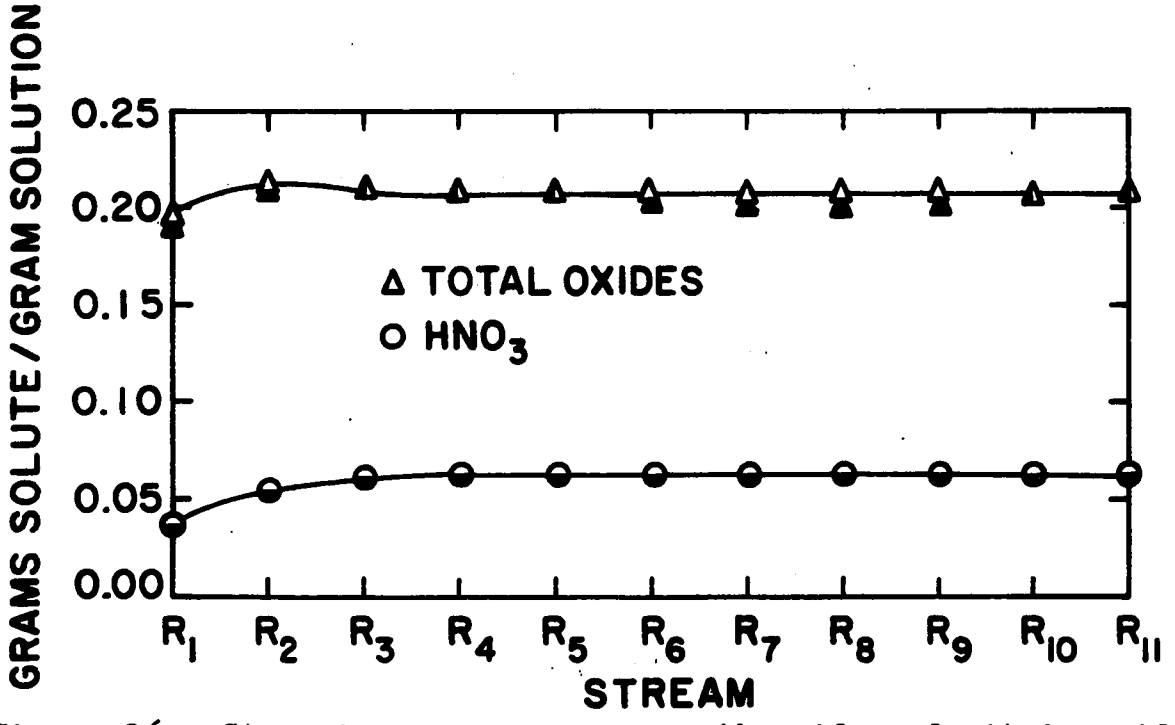
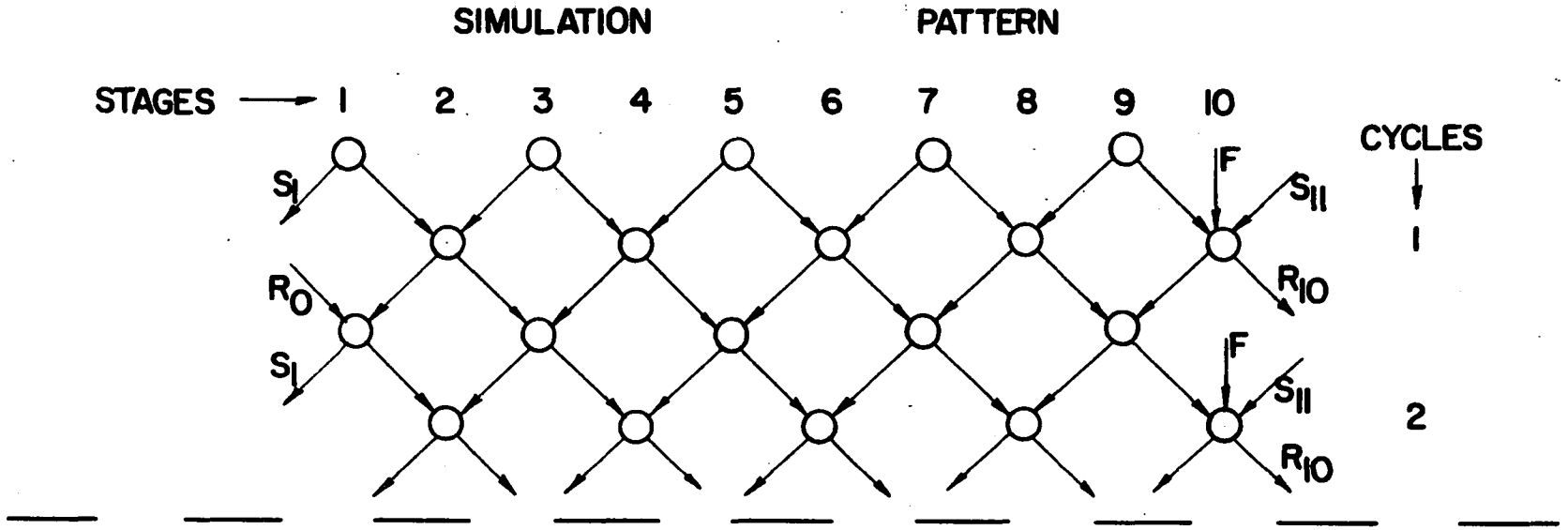


Figure 16. Stagewise aqueous rare earth oxide and nitric acid concentrations for Simulated Column Experiment I



TOTAL NUMBER OF CYCLES - 10 , FLOW RATE RATIO = α = 8.0

VOLUME R_o/INJECTION = 30.0 ml. , CONCENTRATION R_o:M_{HNO_3} = 0.00, M_{RE} = 0.00

VOLUME S_{11}/INJECTION = 245.2 ml. , CONCENTRATION S_{11}:M_{HNO_3} = 0.00, M_{RE} = 0.00

VOLUME F/INJECTION = 215.6 ml. , CONCENTRATION F:M_{HNO_3} = 6.66, M_{RE} = 11.69

CONTINUOUS CASCADE BEING SIMULATED

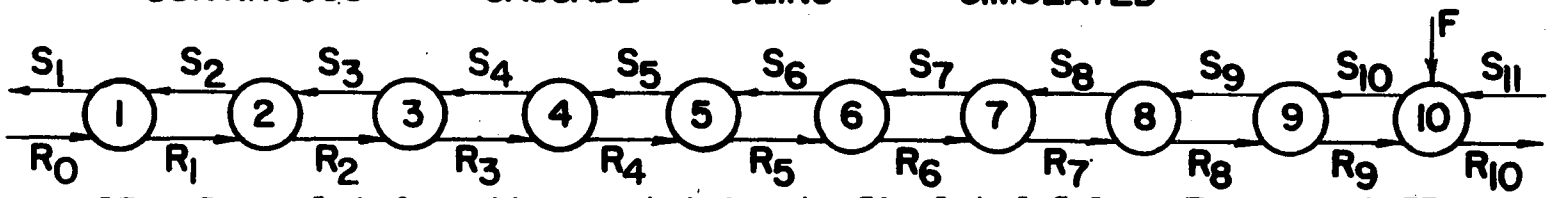


Figure 17. General information pertaining to Simulated Column Experiment II

Table 2. Comparison of experimental and predicted compositions and concentrations for Simulated Column Experiment II

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
R_1	7.3	11.2	10.4	9.5	11.4	12.1	70.9	67.3	0.052	0.058	0.139	0.136
R_2	14.6	19.9	12.9	11.7	11.9	13.2	60.6	55.2	0.072	0.076	0.168	0.167
R_3	26.4	31.0	15.0	12.3	10.5	12.6	48.2	44.1	0.087	0.092	0.172	0.171
R_4	37.4	43.4	14.7	11.5	8.6	10.9	39.3	34.2	0.103	0.108	0.165	0.164
R_5	50.6	55.4	12.0	9.8	7.0	8.7	30.4	26.0	0.122	0.126	0.152	0.151
R_6	62.8	65.8	9.8	7.9	4.2	6.7	23.2	19.6	0.140	0.145	0.136	0.136
R_7	72.9	74.0	7.5	6.1	2.6	5.1	17.0	14.9	0.163	0.166	0.117	0.119
R_8	82.3	80.0	3.4	4.6	1.2	3.9	13.2	11.4	0.184	0.186	0.102	0.104
R_9	81.3	84.4	6.1	3.6	2.5	3.1	10.1	8.9	0.204	0.207	0.088	0.090
R_{10}	86.4	87.8	5.8	2.8	1.9	2.4	5.8	7.0	0.220	0.228	0.076	0.077
F	83.0	81.2	2.9	3.0	0.8	3.0	13.2	12.8	0.235	0.238	0.153	0.156
S_1	0.0	3.8	5.7	5.9	10.8	9.7	83.5	80.6	0.023	0.024	0.108	0.107

Table 2 (Continued)

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
S_2	3.4	5.6	7.1	6.8	11.9	10.3	77.6	77.3	0.029	0.031	0.124	0.122
S_3	6.5	9.0	8.2	7.8	12.5	10.9	72.8	72.3	0.032	0.035	0.127	0.126
S_4	10.5	14.1	8.9	8.4	12.4	10.8	68.3	66.7	0.034	0.037	0.129	0.127
S_5	18.6	20.7	9.2	8.3	11.2	10.2	61.0	60.7	0.037	0.040	0.128	0.126
S_6	25.5	28.3	9.3	7.8	10.5	9.3	54.6	54.6	0.040	0.044	0.126	0.125
S_7	36.3	36.1	7.4	6.9	9.9	8.2	46.5	48.8	0.044	0.047	0.124	0.122
S_8	45.4	43.4	5.7	6.0	8.4	7.1	40.5	43.5	0.047	0.052	0.121	0.119
S_9	51.2	49.8	5.4	5.1	7.5	6.2	35.9	38.8	0.052	0.056	0.117	0.116
S_{10}	50.7	55.5	5.0	4.4	5.7	5.5	38.6	34.6	0.057	0.062	0.115	0.114

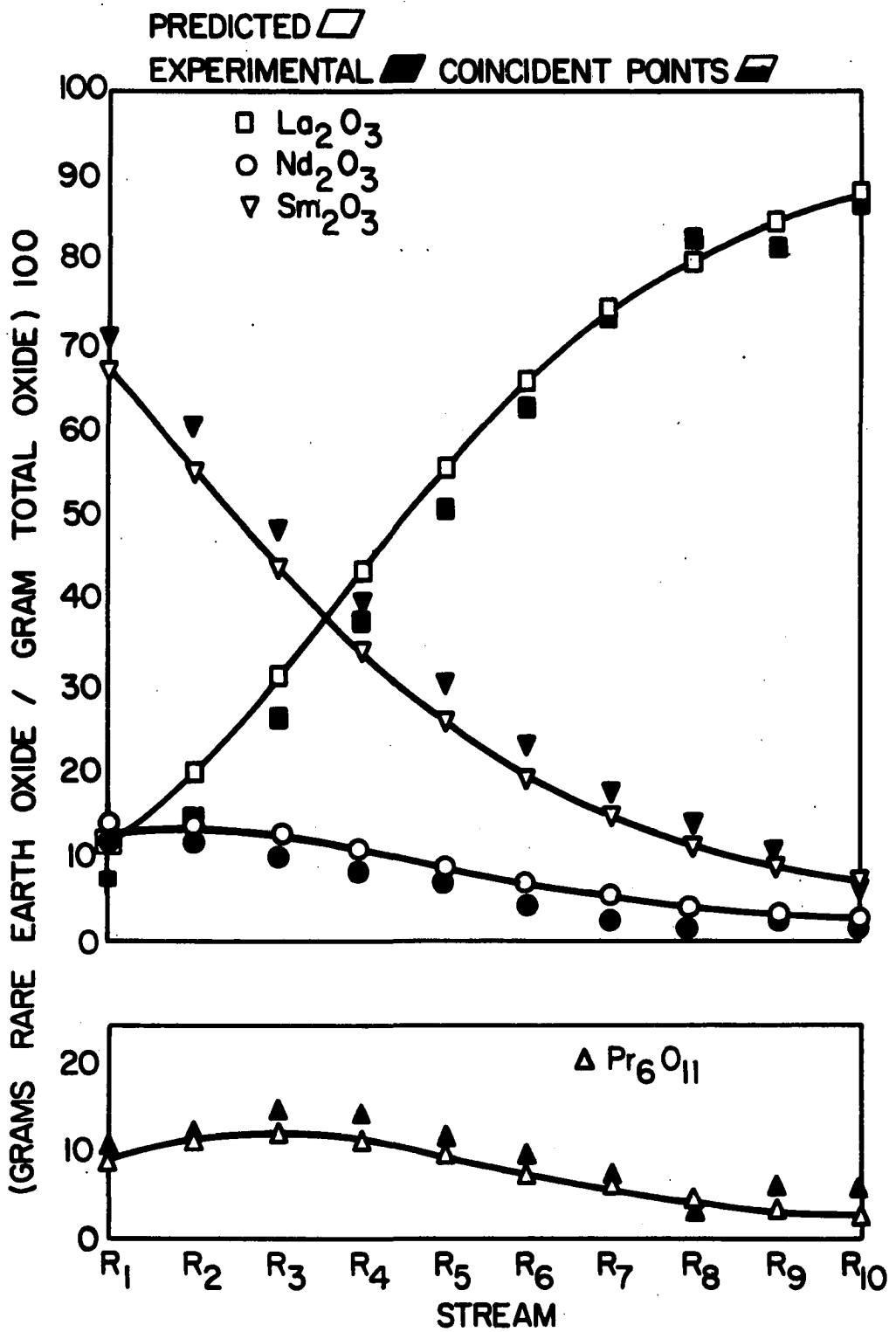


Figure 18. Stagewise aqueous rare earth oxide composition for Simulated Column Experiment II

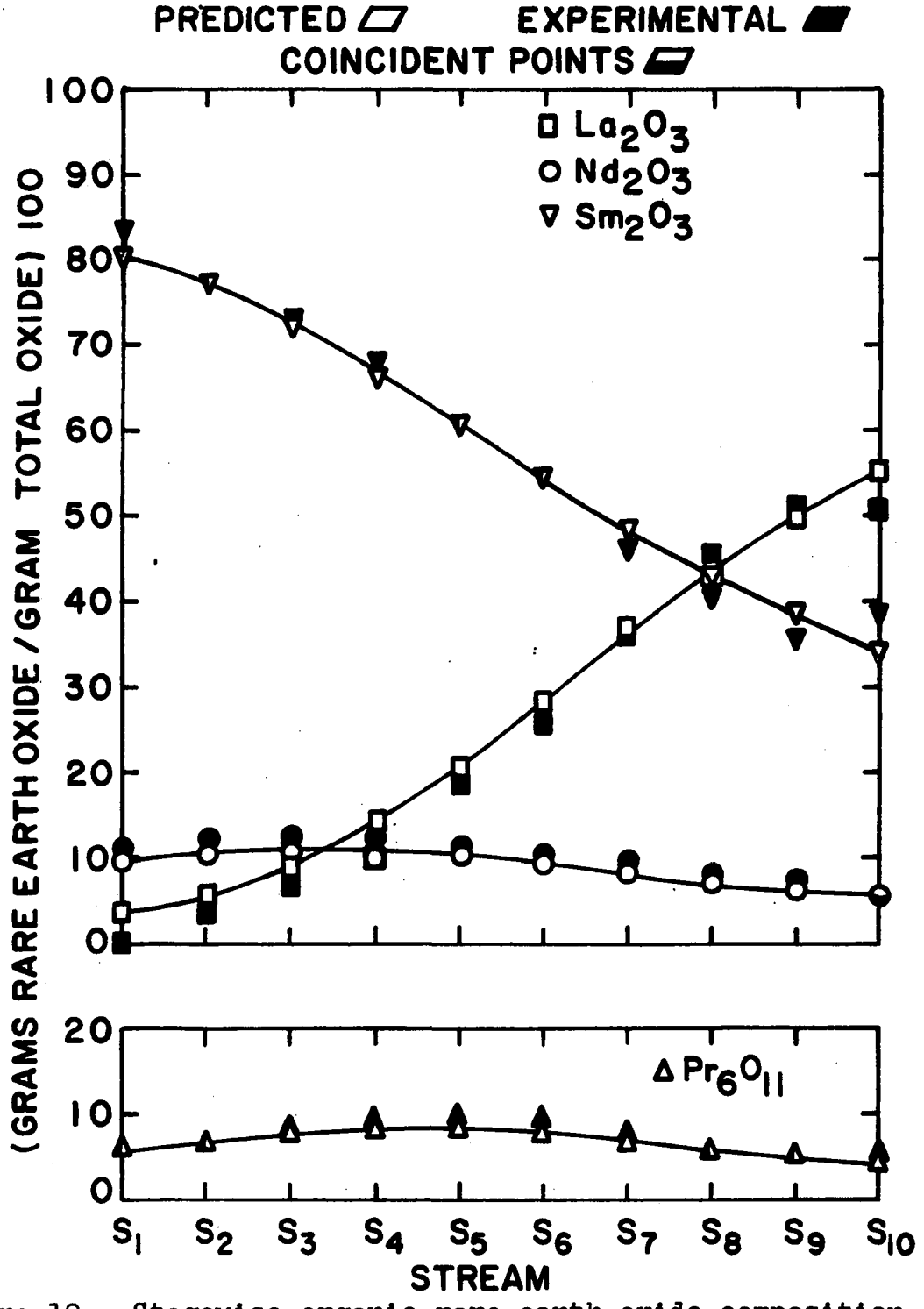


Figure 19. Stagewise organic rare earth oxide composition for Simulated Column Experiment II

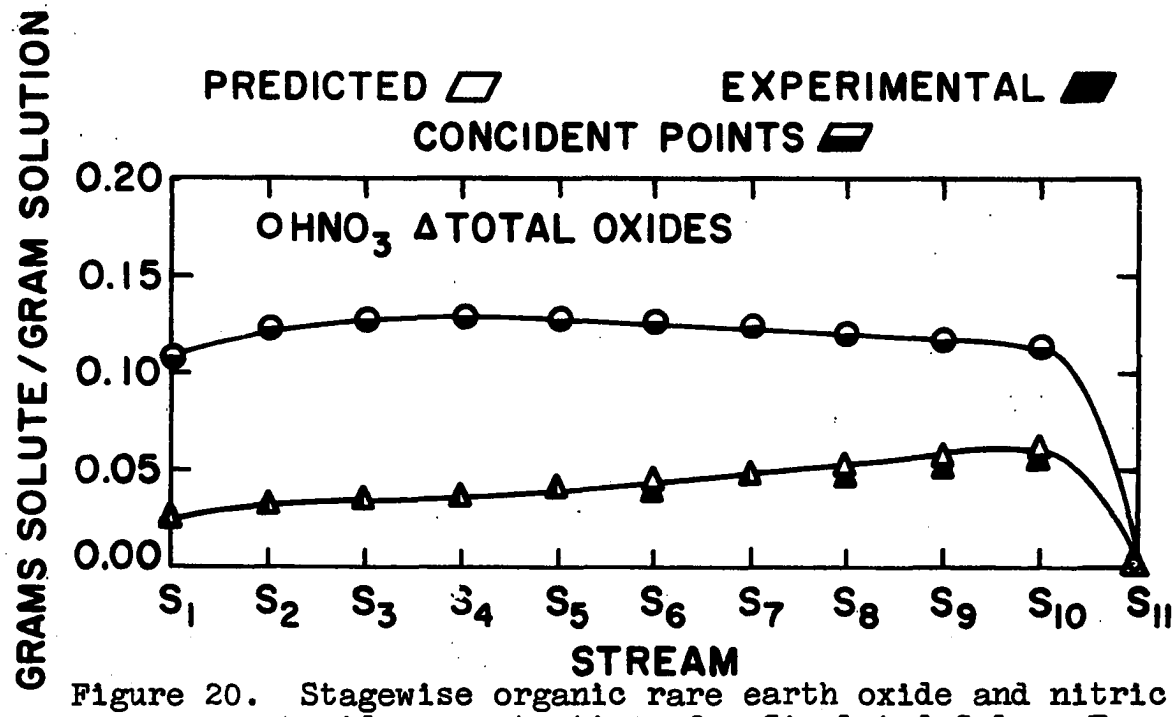


Figure 20. Stagewise organic rare earth oxide and nitric acid concentrations for Simulated Column Experiment II

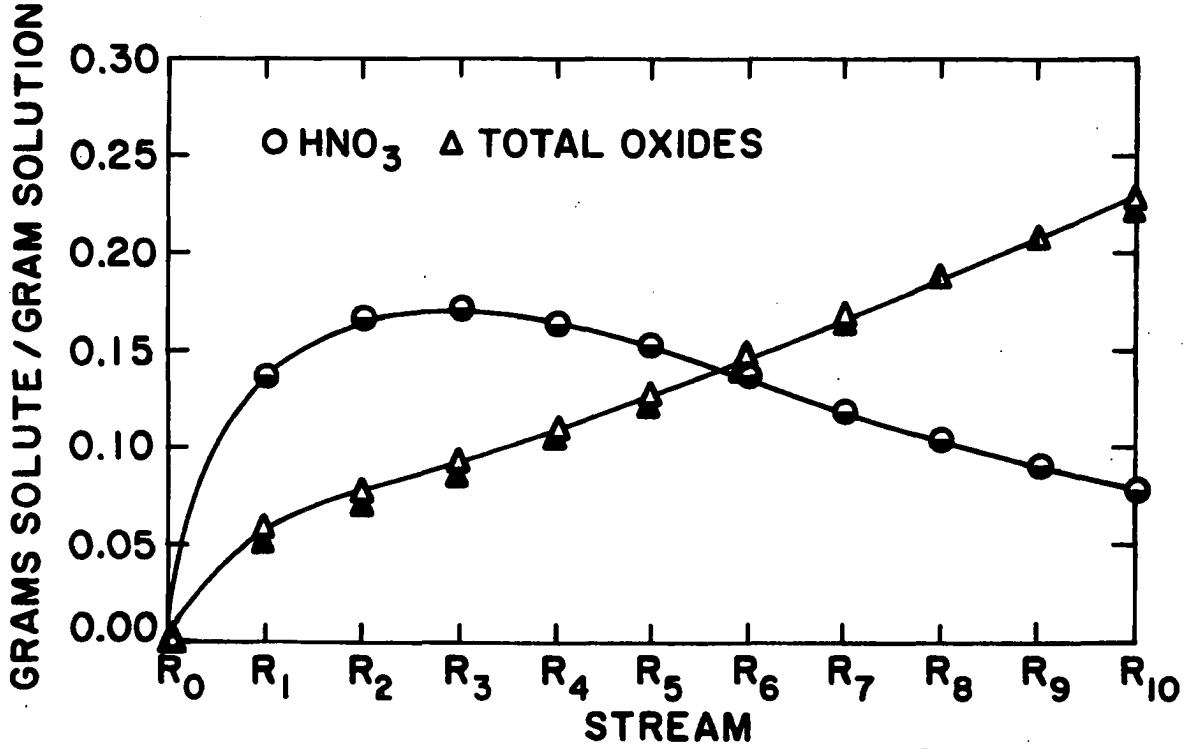
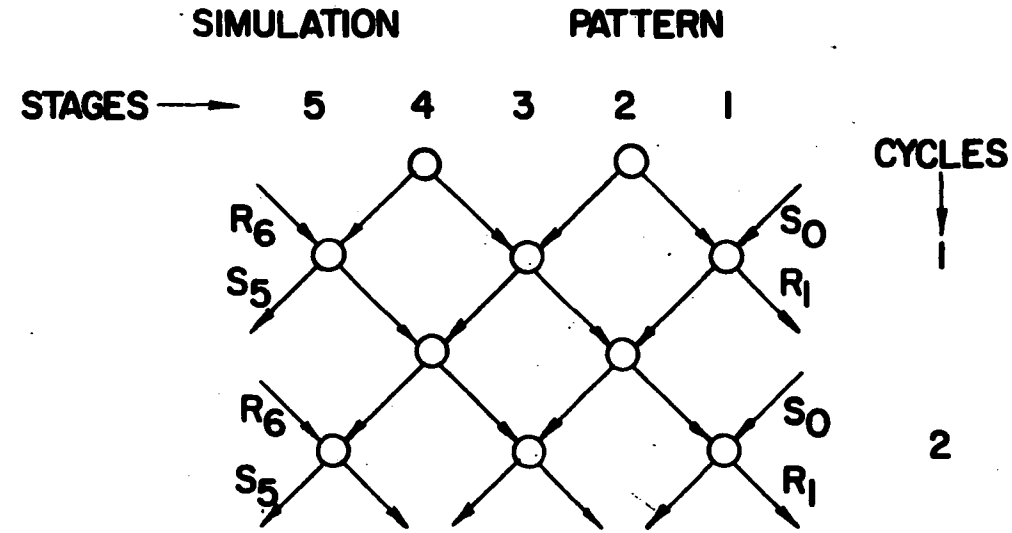


Figure 21. Stagewise aqueous rare earth oxide and nitric acid concentrations for Simulated Column Experiment II



TOTAL NUMBER OF CYCLES - 10 , FLOW RATE RATIO = α = 2.0

VOLUME R_6/INJECTION = 40.5 ml. , CONCENTRATION R_6:M_{HNO_3} = 7.14, M_{RE} = 4.49

VOLUME S_o/INJECTION = 61.3 ml. , CONCENTRATION S_o:M_{HNO_3} = 0.00, M_{RE} = 0.00

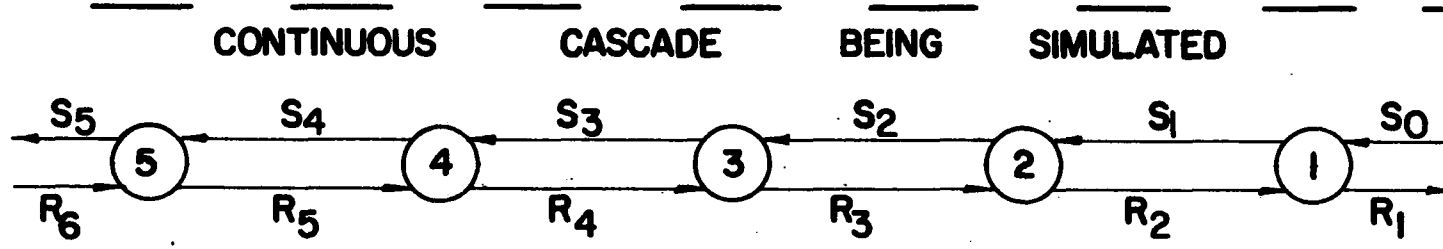


Figure 22. General information pertaining to Simulated Column Experiment III

Table 3. Comparison of experimental and predicted compositions and concentrations for Simulated Column Experiment III

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
S_1	65.8	66.8	10.5	11.4	11.5	12.1	12.3	9.7	0.049	0.060	0.044	0.031
S_2	43.7	47.4	12.8	12.8	16.7	16.7	26.8	23.1	0.050	0.061	0.098	0.083
S_3	29.1	28.5	10.7	11.1	17.0	17.4	43.3	43.1	0.039	0.046	0.137	0.128
S_4	26.9	19.6	7.1	8.2	13.5	14.1	52.5	58.1	0.032	0.035	0.156	0.154
S_5	17.0	17.8	6.7	6.7	10.2	11.3	66.0	64.3	0.030	0.030	0.163	0.166
R_1	79.6	79.3	8.2	8.3	7.4	7.2	4.9	5.3	0.118	0.127	0.025	0.016
R_2	77.8	73.7	9.3	9.7	5.2	9.4	7.7	7.3	0.163	0.183	0.081	0.055
R_3	64.5	64.3	10.2	10.4	11.3	11.6	13.9	13.6	0.158	0.174	0.148	0.122
R_4	61.8	58.7	8.7	9.4	9.9	11.3	19.5	20.6	0.139	0.151	0.199	0.182
R_5	62.4	58.8	7.8	8.3	8.6	9.5	21.2	23.4	0.130	0.136	0.223	0.216
R_6	63.9	60.4	7.1	7.8	7.5	8.4	21.4	23.4	0.126	0.128	0.232	0.232

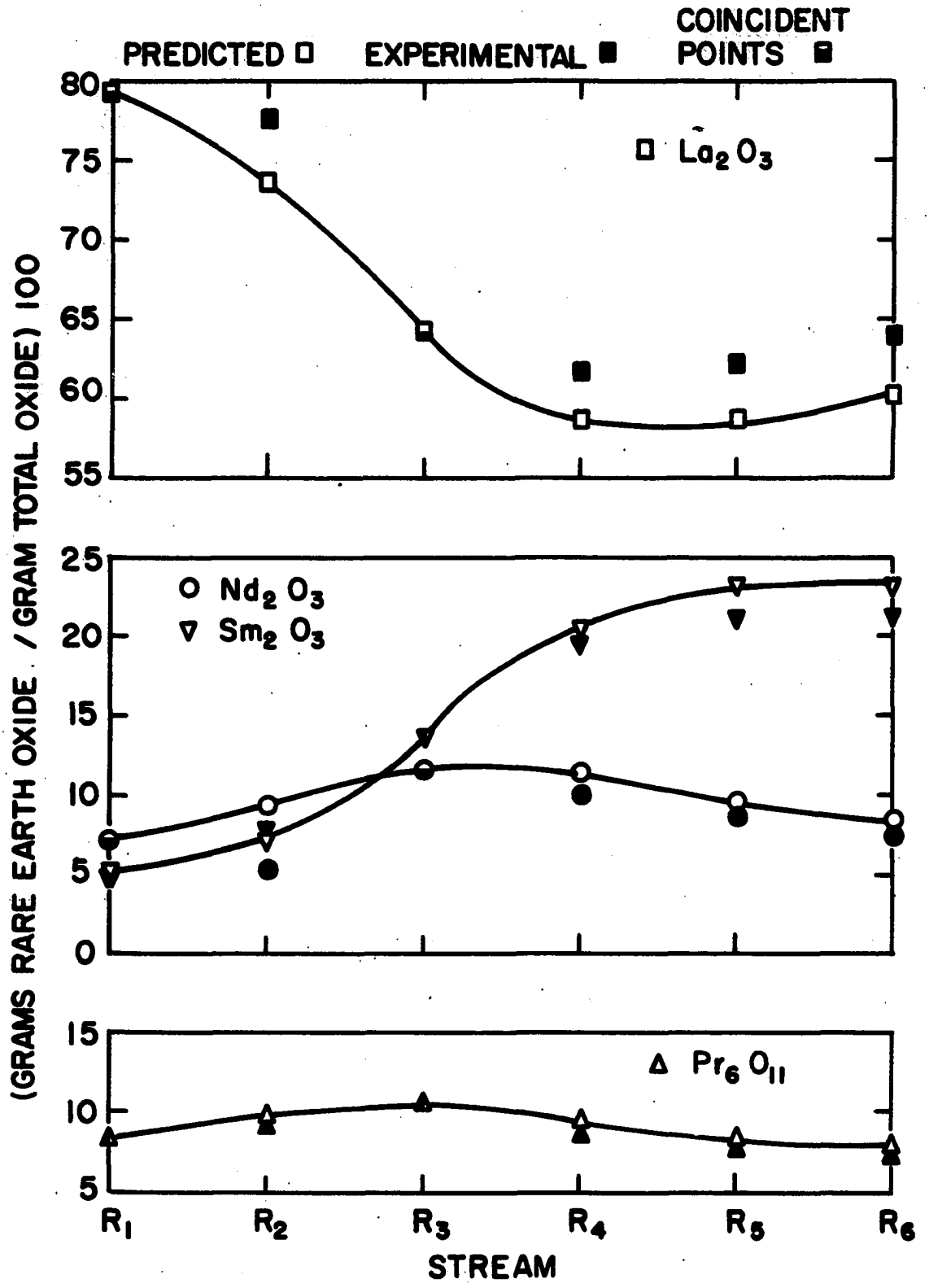


Figure 23. Stagewise aqueous rare earth oxide composition for Simulated Column Experiment III

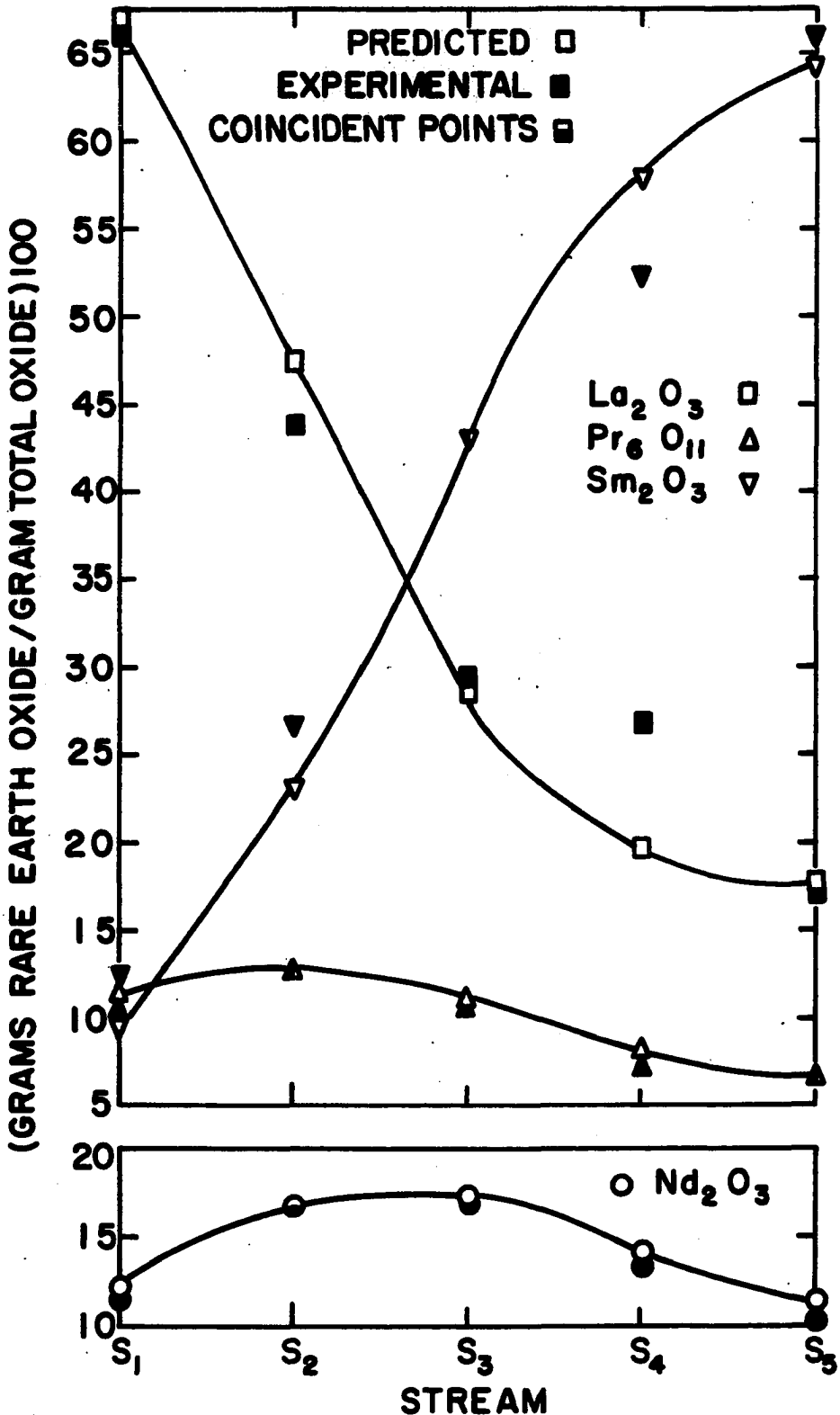


Figure 24. Stagewise organic rare earth oxide composition for Simulated Column Experiment III

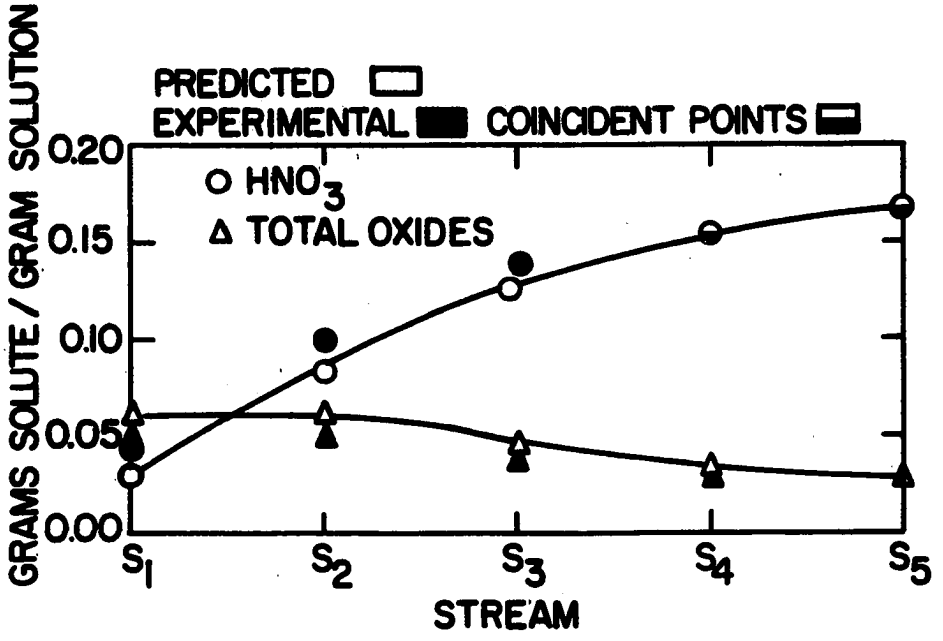


Figure 25. Stagewise organic rare earth oxide and nitric acid concentrations for Simulated Column Experiment III

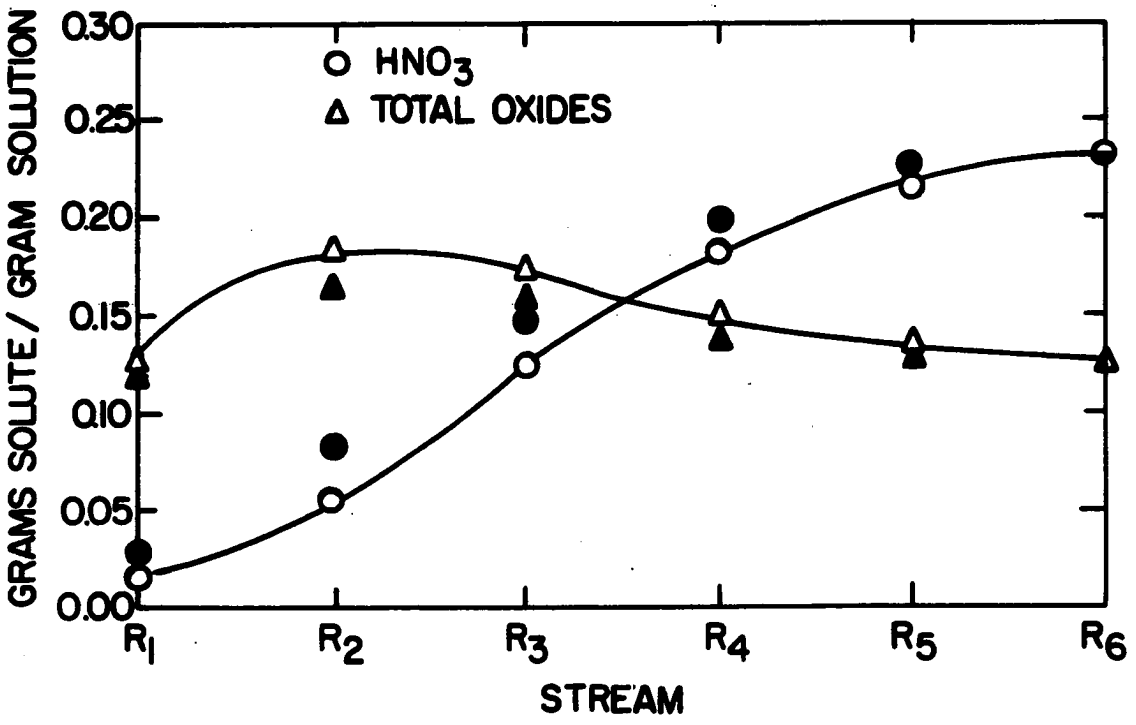
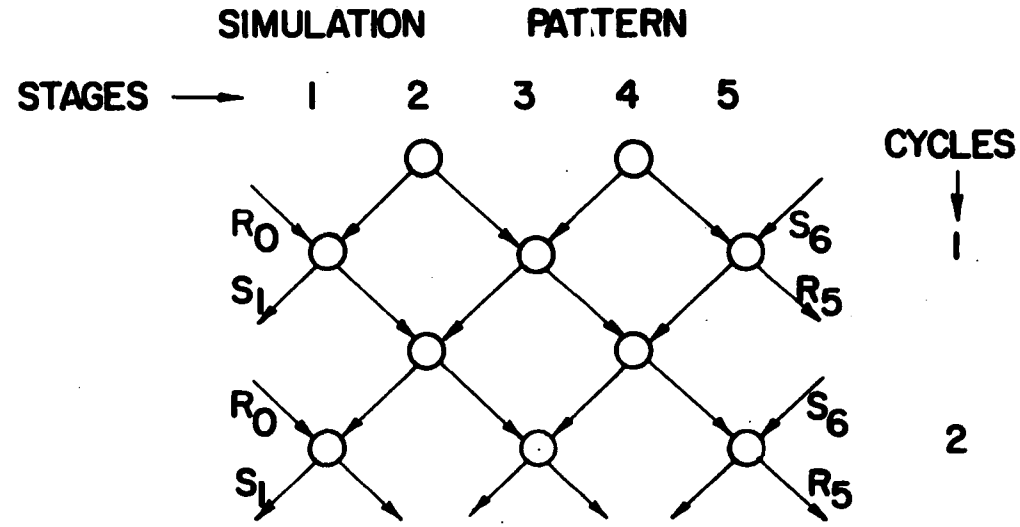


Figure 26. Stagewise aqueous rare earth oxide and nitric acid concentrations for Simulated Column Experiment III



TOTAL NUMBER OF CYCLES - 10 , FLOW RATE RATIO = α = 1.0

VOLUME R_o/INJECTION = 54.2 ml. , CONCENTRATION R_o:M_{HNO_3} = 4.97, M_{RE} = 7.15

VOLUME S_6/INJECTION = 40.9 ml. , CONCENTRATION S_6:M_{HNO_3} = 0.00, M_{RE} = 0.00

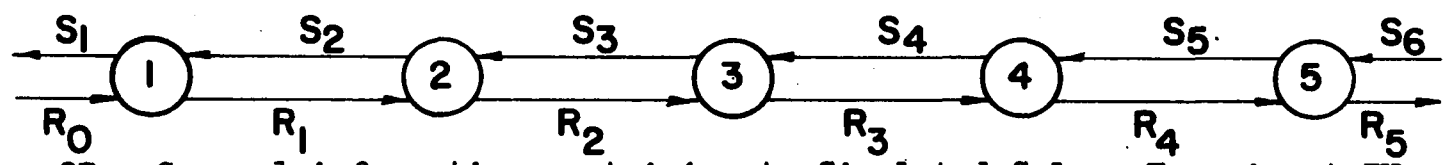


Figure 27. General information pertaining to Simulated Column Experiment IV

Table 4. Comparison of experimental and predicted compositions and concentrations for Simulated Column Experiment IV

	Weight % La_2O_3 in total oxides		Weight % Pr_6O_{11} in total oxides		Weight % Nd_2O_3 in total oxides		Weight % Sm_2O_3 in total oxides		Grams total oxides per gram of solution		Grams HNO_3 per gram of solution	
	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.	exp.	pred.
S_1	7.0	9.1	17.9	19.0	21.8	21.8	53.4	50.0	0.052	0.050	0.136	0.142
S_2	6.9	9.1	17.9	19.0	22.3	21.9	52.9	50.1	0.053	0.050	0.135	0.142
S_3	7.1	9.1	18.2	19.2	22.7	22.2	51.9	49.5	0.054	0.052	0.132	0.138
S_4	7.7	10.1	19.7	20.7	25.1	23.6	47.5	45.7	0.059	0.058	0.122	0.127
S_5	14.3	16.0	24.5	24.7	27.6	25.2	33.6	34.1	0.067	0.067	0.088	0.090
R_0		34.0		25.8		20.4		19.8		0.191		0.149
R_1	33.4	34.0	23.9	25.8	20.7	20.4	22.0	19.9	0.193	0.191	0.147	0.149
R_2	33.2	33.9	24.2	25.8	21.7	20.5	21.0	19.9	0.194	0.192	0.145	0.147
R_3	33.5	33.6	25.9	25.9	21.9	20.7	18.8	19.7	0.197	0.196	0.138	0.140
R_4	34.8	34.3	25.8	26.6	22.0	21.1	17.4	18.0	0.204	0.204	0.118	0.117
R_5	36.4	38.9	24.6	27.1	21.8	20.1	17.2	13.9	0.185	0.188	0.072	0.071

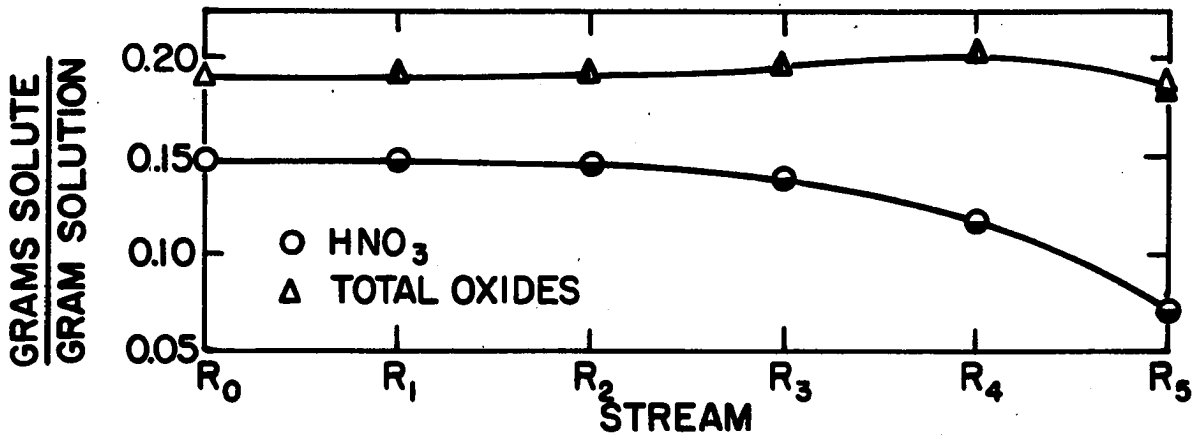


Figure 28. Stagewise aqueous rare earth oxide and nitric acid concentrations for Simulated Column Experiment IV

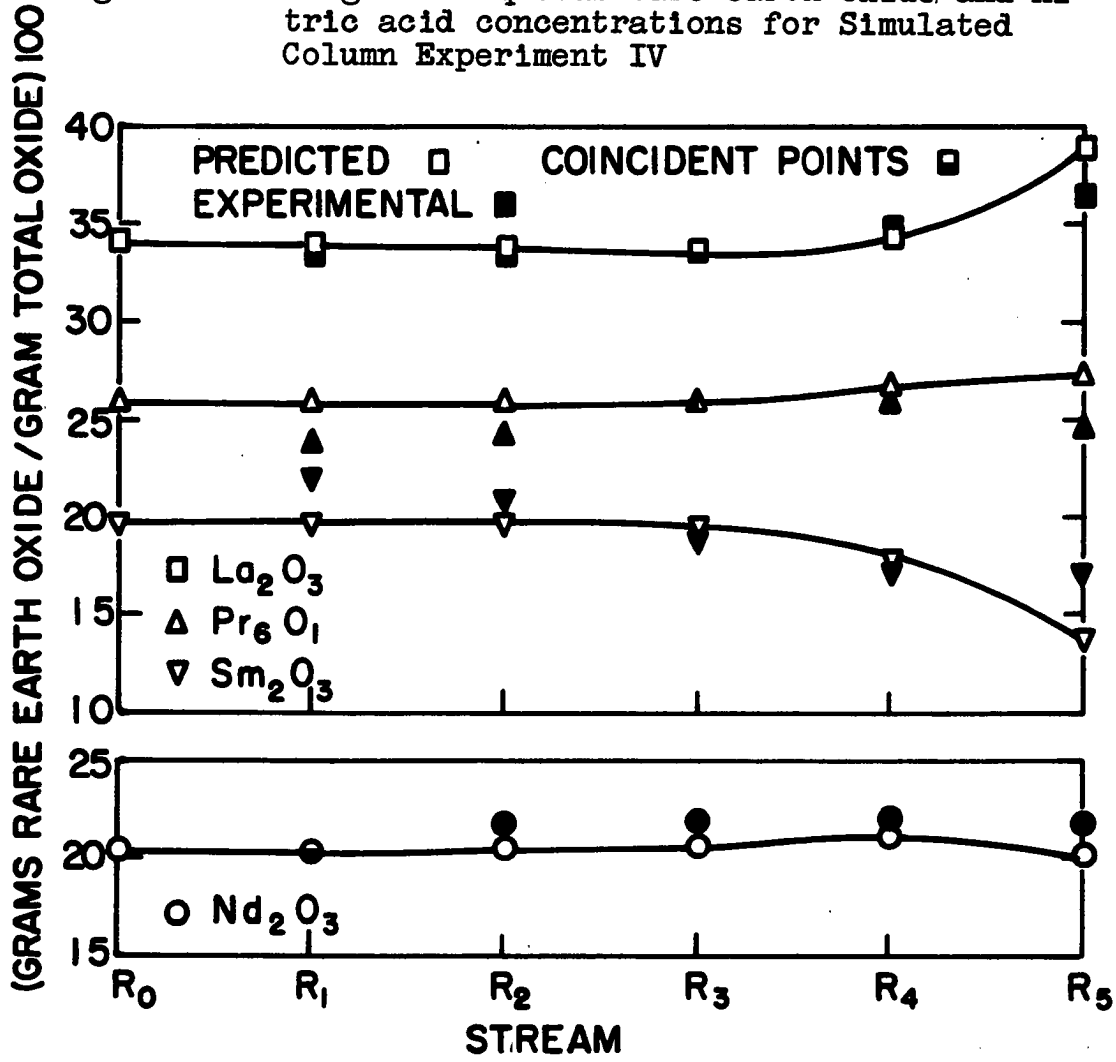


Figure 29. Stagewise aqueous rare earth oxide composition for Simulated Column Experiment IV

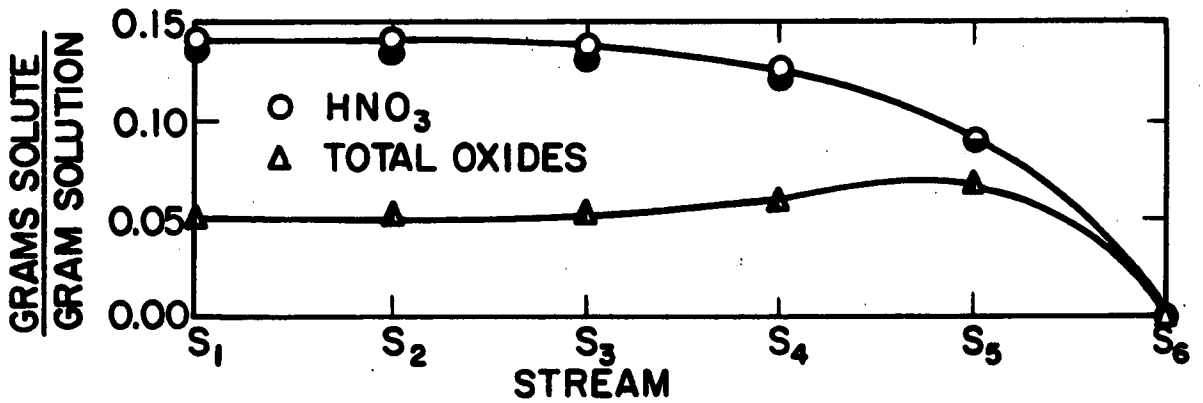


Figure 30. Stagewise organic rare earth oxide and nitric acid concentrations for Simulated Column Experiment IV

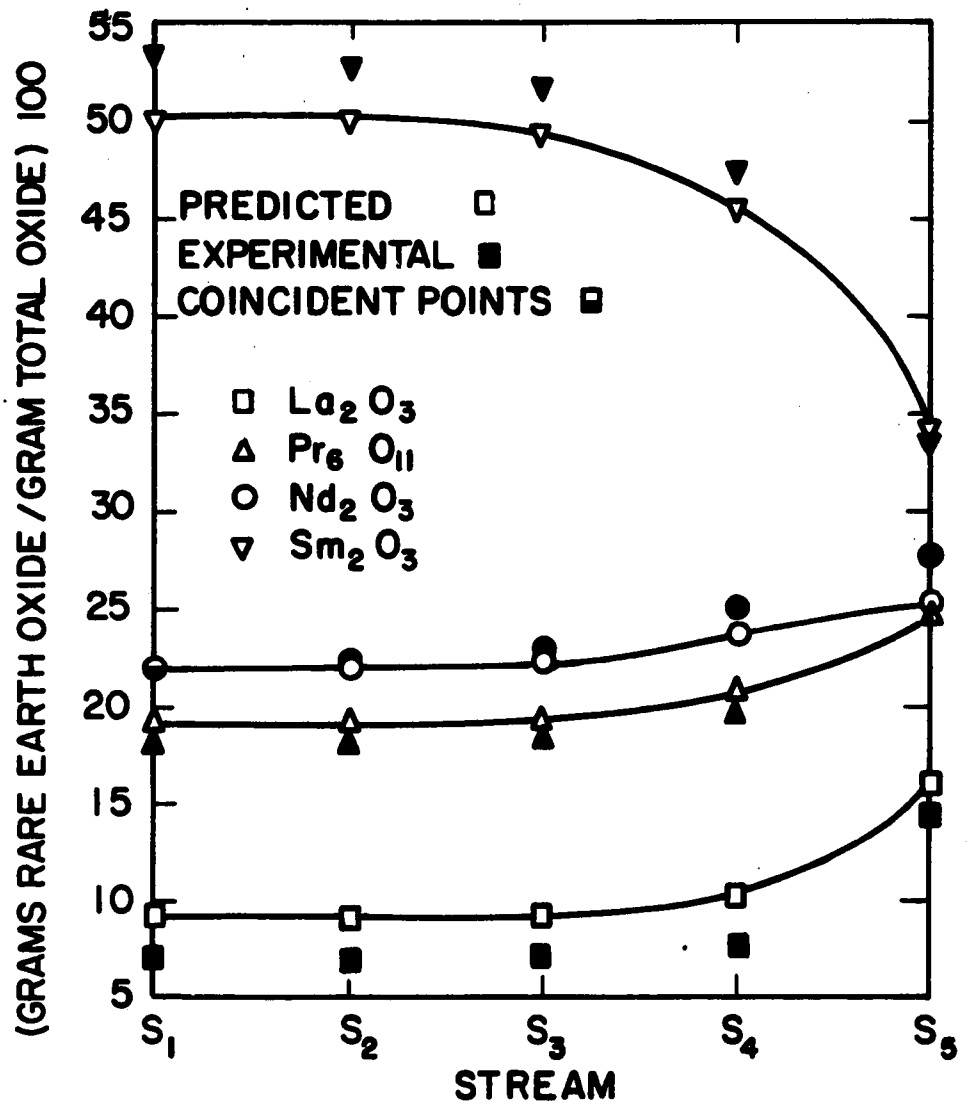


Figure 31. Stagewise organic rare earth oxide composition for Simulated Column Experiment IV

CONCLUSIONS

1. The calculation method developed for the multistage multisolute system gave good agreement with experimental data from four simulated column experiments. The conditions for each of the four simulated column experiments were quite different, and the agreement between predicted values and experimental data was believed to be a valid test of the method.

2. The assumption made that the separation factor between two rare earth nitrate solutes was a function only of the total molality of the organic phase, when $(M_t)_{org.}$ was greater than 1.75, was found to give surprisingly reliable results. The reason for the validity of this assumption is not known, but it appears to be a good approximation.

3. The digital computor technique for deriving distribution coefficients from a series of arrays was accurate and convenient. The technique makes it possible to use experimentally determined equilibrium data directly in the computor solution rather than introduce the data in terms of a mathematical correlation.

4. The digital computor programs for stage by stage calculations should make it possible to carry out various studies on the effects of process variables, such as the effect of acidity of an internal feed stage on recovery in an

end stream, etc. Such studies without the use of machine calculations would be prohibitively time consuming.

5. The flame spectroscopic analytical technique developed by the analytical chemistry group headed by Dr. V. A. Fassel of the Ames Laboratory of the Atomic Energy Commission has been found to give reliable results for each of the rare earths used in this study. The fact that lanthanum can now be determined directly, rather than by difference, is a significant scientific advance in studies of this type.

RECOMMENDATIONS FOR FUTURE WORK

There are several logical extensions of the present work, the most straightforward being an incorporation into the calculation method of systems with a greater number of rare earth nitrate solutes.

Assuming that it was desired to incorporate a rare earth nitrate solute denoted $RE(NO_3)_3$ into the method it would be necessary to acquire single stage equilibrium data for the systems $RE(NO_3)_3$ - HNO_3 - TBP - H_2O and $RE(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O by the methods described by Sharp (47). These data could then be processed in the manner described in the Method of Calculation section, and the calculation for the six solute system $La(NO_3)_3$ - $Pr(NO_3)_3$ - $Nd(NO_3)_3$ - $Sm(NO_3)_3$ - $RE(NO_3)_3$ - HNO_3 - TBP - H_2O would follow exactly the steps also given in that section. Also, the modification of the computor programs for the six solute system would be completely straightforward, as no changes would be made in the logic flow as described in Appendix D.

Such incorporation might be a worthwhile program if it was desired to apply this work to the design of ore processing equipment.

An interesting computor extension would be the writing of a program for a center fed cascade, the calculation to

start from both ends from an initial assumption of end conditions, and, continuously modifying the end concentrations, repeat the calculation a large number of times, endeavoring to match all concentrations at the feed stage.

There are also possibilities of using the existing computor programs, plus others that could be written, in various optimization studies. Because of the large number of variables such a project would probably have to have a statistical basis, and would probably be primarily of academic interest.

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APPENDIX A. ANALYTICAL PROCEDURES

Weighed samples of each equilibrium phase were analyzed. The solutes in the organic samples were transferred to aqueous solution prior to analysis. This was accomplished by contacting the organic samples a minimum of three times with distilled water. The aqueous phases were combined and analyzed in the same manner as the aqueous phase samples.

For the determination of total rare earths the aqueous sample was diluted to approximately 200 ml. with distilled water, brought to a boil on a hot plate, and the rare earths completely precipitated with a saturated solution of oxalic acid. The oxalates were filtered and converted to the oxides at approximately 870° C. in a muffle furnace. The weight of the oxides was determined on an analytical balance.

The composition of the final rare earth oxide sample was determined by a flame photometric method developed by members of the analytical chemistry group headed by Dr. V. A. Fassel of the Ames Laboratory of the Atomic Energy Commission.

To determine the nitric acid content, the samples were diluted to approximately 200 ml. and the rare earths present precipitated by addition of an excess of saturated potassium ferrocyanide. The nitric acid content was then determined by titration with standardized sodium hydroxide. An automatic titrater was used and the end point was taken at a pH of 8.7.

It was found that the nitric acid content of aqueous solutions of nitric acid and potassium ferrocyanide diminishes with time. This was thought to be due to oxidation by the acid. To obtain satisfactory analyses for the nitric acid it was necessary to titrate the aqueous solutions of nitric acid, potassium ferrocyanide, and precipitated rare earth ferrocyanides within about 15 minutes after addition of the potassium ferrocyanide solution.

APPENDIX B. EQUILIBRIUM DATA

Table 5. Equilibrium data for the system $La(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase			Organic phase		
	Grams of $La(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $La(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.127	0.065	0.808	0.026	0.075	0.899
2	0.170	0.087	0.743	0.035	0.095	0.871
3	0.204	0.112	0.684	0.037	0.113	0.849
4	0.258	0.147	0.595	0.037	0.143	0.820
5	0.309	0.173	0.519	0.035	0.161	0.804
6	0.169	0.036	0.796	0.051	0.054	0.896
7	0.214	0.050	0.736	0.061	0.070	0.869
8	0.278	0.064	0.658	0.074	0.087	0.839
9	0.351	0.082	0.567	0.078	0.112	0.810
10	0.419	0.093	0.488	0.078	0.134	0.788
11	0.070	0.099	0.831	0.011	0.090	0.899
12	0.089	0.131	0.781	0.014	0.115	0.871
13	0.111	0.173	0.716	0.015	0.140	0.845
14	0.142	0.229	0.629	0.013	0.170	0.817
15	0.162	0.283	0.555	0.012	0.191	0.798
16	0.032	0.126	0.842	0.004	0.097	0.898
17	0.046	0.166	0.789	0.006	0.121	0.873
18	0.055	0.232	0.713	0.005	0.154	0.841
19	0.072	0.288	0.640	0.006	0.177	0.817
20	0.089	0.343	0.568	0.005	0.194	0.801
21	0.211	0.013	0.776	0.094	0.027	0.880
22	0.272	0.020	0.709	0.114	0.037	0.849
23	0.342	0.025	0.633	0.131	0.049	0.819
24	0.432	0.031	0.537	0.145	0.066	0.789
25	0.226	0.006	0.768	0.116	0.014	0.869

Table 5 (Continued)

	Aqueous phase			Organic phase		
	Grams of $La(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $La(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
26	0.287	0.009	0.704	0.140	0.021	0.839
27	0.360	0.010	0.631	0.169	0.024	0.807
28	0.457	0.012	0.531	0.191	0.034	0.776
29	0.091	0.399	0.511	0.006	0.195	0.799
30	0.102	0.444	0.454	0.008	0.213	0.779
31	0.180	0.332	0.488	0.016	0.209	0.775
32	0.195	0.363	0.443	0.020	0.223	0.757
33	0.110	0.507	0.383	0.016	0.267	0.717
34	0.338	0.210	0.453	0.038	0.187	0.775
35	0.511	0.036	0.453	0.143	0.089	0.768
36	0.531	0.019	0.450	0.177	0.061	0.763
37	0.457	0.111	0.432	0.071	0.156	0.773
38	0.529	0.051	0.420	0.120	0.115	0.765
39	0.358	0.229	0.413	0.042	0.198	0.760
40	0.461	0.138	0.402	0.065	0.170	0.765
41	0.208	0.432	0.360	0.035	0.253	0.712

Table 6. Equilibrium data for the system $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase			Organic phase		
	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.079	0.134	0.787	0.022	0.108	0.870
2	0.099	0.179	0.721	0.027	0.133	0.841
3	0.130	0.237	0.634	0.028	0.160	0.812
4	0.158	0.287	0.554	0.030	0.179	0.792
5	0.173	0.332	0.495	0.034	0.195	0.771
6	0.146	0.087	0.766	0.050	0.087	0.864
7	0.187	0.113	0.700	0.061	0.103	0.836
8	0.245	0.150	0.605	0.067	0.130	0.803
9	0.294	0.184	0.522	0.065	0.153	0.782
10	0.328	0.211	0.461	0.069	0.168	0.763
11	0.230	0.041	0.729	0.102	0.055	0.842
12	0.268	0.065	0.667	0.108	0.075	0.817
13	0.336	0.085	0.579	0.116	0.095	0.789
14	0.409	0.101	0.489	0.116	0.117	0.768
15	0.455	0.115	0.430	0.116	0.133	0.752
16	0.467	0.143	0.390	0.113	0.151	0.763
17	0.258	0.022	0.720	0.137	0.036	0.828
18	0.328	0.027	0.646	0.167	0.040	0.793
19	0.416	0.032	0.552	0.185	0.050	0.765
20	0.491	0.040	0.470	0.183	0.067	0.750
21	0.536	0.051	0.412	0.170	0.088	0.742
22	0.269	0.011	0.720	0.164	0.020	0.816
23	0.343	0.012	0.645	0.198	0.021	0.781
24	0.437	0.019	0.544	0.211	0.032	0.757
25	0.522	0.018	0.459	0.219	0.038	0.743
26	0.184	0.372	0.444	0.043	0.209	0.749
27	0.349	0.241	0.410	0.081	0.180	0.739
28	0.195	0.401	0.404	0.055	0.220	0.725
29	0.352	0.270	0.378	0.091	0.192	0.717
30	0.064	0.103	0.834	0.017	0.094	0.889

Table 6 (Continued)

	Aqueous phase			Organic phase		
	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
31	0.124	0.066	0.809	0.040	0.072	0.888
32	0.172	0.039	0.789	0.069	0.054	0.877
33	0.208	0.014	0.778	0.113	0.026	0.860
34	0.224	0.007	0.770	0.139	0.014	0.847
35	0.201	0.424	0.375	0.068	0.226	0.706

Table 7. Equilibrium data for the system $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase			Organic phase		
	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.301	0.017	0.681	0.185	0.025	0.790
2	0.352	0.021	0.627	0.201	0.029	0.770
3	0.377	0.023	0.600	0.207	0.032	0.762
4	0.355	0.019	0.626	0.205	0.028	0.767
5	0.458	0.023	0.519	0.222	0.037	0.742
6	0.483	0.026	0.491	0.218	0.043	0.739
7	0.454	0.093	0.454	0.142	0.110	0.748
8	0.427	0.076	0.498	0.151	0.091	0.757
9	0.397	0.081	0.522	0.144	0.091	0.764
10	0.370	0.074	0.556	0.146	0.081	0.773

Table 7 (Continued)

	Aqueous phase			Organic phase		
	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
11	0.348	0.071	0.581	0.145	0.078	0.778
12	0.325	0.068	0.607	0.141	0.073	0.786
13	0.295	0.060	0.645	0.135	0.068	0.797
14	0.287	0.060	0.653	0.134	0.068	0.798
15	0.350	0.207	0.444	0.093	0.163	0.744
16	0.346	0.178	0.476	0.093	0.150	0.757
17	0.312	0.178	0.510	0.085	0.147	0.768
18	0.295	0.164	0.591	0.087	0.138	0.776
19	0.284	0.159	0.557	0.085	0.135	0.780
20	0.262	0.152	0.586	0.083	0.124	0.793
21	0.238	0.134	0.628	0.084	0.113	0.804
22	0.225	0.130	0.644	0.082	0.109	0.809
23	0.204	0.384	0.411	0.073	0.206	0.722
24	0.200	0.341	0.459	0.059	0.198	0.744
25	0.183	0.324	0.493	0.049	0.191	0.761
26	0.172	0.290	0.538	0.043	0.179	0.778
27	0.169	0.286	0.545	0.042	0.177	0.781
28	0.154	0.264	0.582	0.040	0.167	0.794
29	0.142	0.236	0.622	0.040	0.156	0.804
30	0.133	0.227	0.640	0.038	0.152	0.809
31	0.151	0.446	0.404	0.064	0.227	0.709
32	0.151	0.398	0.451	0.050	0.211	0.740
33	0.140	0.376	0.485	0.040	0.202	0.758
34	0.134	0.343	0.523	0.034	0.192	0.774
35	0.129	0.331	0.541	0.032	0.187	0.781
36	0.119	0.306	0.576	0.029	0.179	0.792
37	0.111	0.277	0.612	0.028	0.168	0.804
38	0.100	0.254	0.645	0.028	0.162	0.811
39	0.144	0.353	0.503	0.036	0.195	0.768
40	0.270	0.236	0.494	0.066	0.167	0.767

Table 7 (Continued)

	Aqueous phase			Organic phase		
	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
41	0.330	0.191	0.479	0.084	0.152	0.764
42	0.463	0.057	0.480	0.173	0.078	0.749
43	0.453	0.055	0.492	0.176	0.077	0.747
44	0.367	0.125	0.508	0.112	0.124	0.764
45	0.265	0.217	0.518	0.068	0.160	0.772
46	0.143	0.331	0.527	0.036	0.189	0.775
47	0.535	0.062	0.403	0.179	0.096	0.726
48	0.468	0.138	0.394	0.133	0.144	0.724
49	0.404	0.183	0.413	0.120	0.155	0.725
50	0.211	0.423	0.366	0.091	0.226	0.683
51	0.238	0.475	0.287	0.132	0.250	0.618
52	0.596	0.005	0.399	0.273	0.007	0.720
53	0.512	0.055	0.434	0.182	0.085	0.733
54	0.436	0.147	0.417	0.121	0.146	0.733
55	0.273	0.339	0.388	0.091	0.205	0.704
56	0.231	0.441	0.328	0.112	0.235	0.653
57	0.335	0.257	0.408	0.096	0.182	0.723
58	0.473	0.115	0.412	0.140	0.132	0.728
59	0.529	0.047	0.424	0.194	0.079	0.727
60	0.223	0.478	0.299	0.125	0.242	0.633
61	0.201	0.009	0.790	0.124	0.018	0.858
62	0.175	0.030	0.795	0.082	0.043	0.875
63	0.126	0.059	0.815	0.046	0.066	0.888
64	0.061	0.097	0.843	0.018	0.088	0.894
65	0.265	0.014	0.721	0.166	0.023	0.811
66	0.225	0.043	0.732	0.112	0.055	0.834
67	0.163	0.085	0.752	0.064	0.083	0.853
68	0.079	0.137	0.784	0.026	0.107	0.867
69	0.202	0.111	0.687	0.073	0.102	0.825
70	0.100	0.181	0.719	0.035	0.128	0.837

Table 8. Equilibrium data for the system $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase			Organic phase		
	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.487	0.029	0.484	0.226	0.047	0.727
2	0.447	0.030	0.523	0.228	0.037	0.735
3	0.386	0.027	0.587	0.225	0.031	0.744
4	0.341	0.023	0.637	0.217	0.027	0.756
5	0.307	0.020	0.672	0.207	0.026	0.767
6	0.313	0.022	0.665	0.208	0.026	0.766
7	0.277	0.018	0.705	0.194	0.023	0.783
8	0.248	0.016	0.737	0.177	0.018	0.805
9	0.400	0.108	0.492	0.160	0.098	0.742
10	0.376	0.096	0.528	0.163	0.086	0.751
11	0.324	0.087	0.589	0.159	0.076	0.765
12	0.282	0.072	0.646	0.154	0.066	0.781
13	0.261	0.063	0.676	0.148	0.063	0.789
14	0.259	0.071	0.670	0.146	0.063	0.791
15	0.234	0.059	0.707	0.136	0.057	0.808
16	0.178	0.043	0.779	0.102	0.049	0.850
17	0.269	0.283	0.448	0.113	0.161	0.726
18	0.261	0.260	0.480	0.104	0.156	0.740
19	0.230	0.228	0.542	0.092	0.142	0.766
20	0.205	0.196	0.599	0.088	0.129	0.783
21	0.188	0.179	0.633	0.088	0.123	0.790
22	0.176	0.174	0.650	0.083	0.120	0.798
23	0.162	0.159	0.680	0.081	0.113	0.807
24	0.142	0.140	0.718	0.072	0.102	0.826
25	0.129	0.432	0.439	0.090	0.197	0.657
26	0.123	0.402	0.475	0.074	0.189	0.684
27	0.119	0.344	0.537	0.056	0.176	0.768
28	0.103	0.294	0.604	0.047	0.164	0.789
29	0.099	0.283	0.618	0.046	0.160	0.794
30	0.094	0.271	0.636	0.044	0.153	0.803

Table 8 (Continued)

	Aqueous phase			Organic phase		
	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
31	0.085	0.243	0.672	0.041	0.148	0.811
32	0.055	0.142	0.804	0.026	0.108	0.869
33	0.222	0.291	0.487	0.097	0.165	0.739
34	0.217	0.280	0.503	0.093	0.160	0.747
35	0.213	0.269	0.518	0.089	0.156	0.754
36	0.202	0.245	0.553	0.085	0.147	0.769
37	0.222	0.292	0.486	0.095	0.166	0.739
38	0.219	0.285	0.497	0.092	0.162	0.746
39	0.214	0.270	0.516	0.088	0.158	0.754
40	0.204	0.244	0.553	0.082	0.151	0.767
41	0.129	0.526	0.345	0.126	0.222	0.653
42	0.200	0.383	0.418	0.114	0.188	0.698
43	0.278	0.268	0.454	0.116	0.161	0.723
44	0.422	0.130	0.448	0.156	0.116	0.728
45	0.484	0.064	0.452	0.202	0.073	0.725
46	0.541	0.043	0.416	0.222	0.065	0.713
47	0.579	0.007	0.416	0.277	0.009	0.714
48	0.101	0.597	0.302	0.138	0.248	0.614
49	0.075	0.088	0.837	0.032	0.080	0.888
50	0.113	0.066	0.821	0.052	0.067	0.882
51	0.163	0.034	0.803	0.092	0.047	0.862
52	0.194	0.014	0.792	0.132	0.022	0.847
53	0.144	0.093	0.763	0.075	0.081	0.844

Table 9. Equilibrium data for the system $La(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase				Organic phase			
	Grams of $La(NO_3)_3$ per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $La(NO_3)_3$ per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $HNO_3)_3$ per gram of solution	Grams of solvent per gram of solution
1	0.075	0.130	0.019	0.776	0.025	0.069	0.036	0.870
2	0.142	0.065	0.19	0.774	0.054	0.035	0.037	0.873
3	0.057	0.096	0.051	0.796	0.014	0.036	0.066	0.885
4	0.106	0.049	0.049	0.797	0.027	0.018	0.067	0.887
5	0.029	0.055	0.093	0.824	0.005	0.015	0.087	0.893
6	0.057	0.027	0.089	0.827	0.010	0.008	0.087	0.895
7	0.119	0.205	0.036	0.639	0.031	0.108	0.056	0.805
8	0.233	0.098	0.033	0.636	0.072	0.059	0.058	0.811
9	0.086	0.152	0.089	0.673	0.017	0.058	0.098	0.828
10	0.168	0.074	0.087	0.671	0.034	0.031	0.102	0.833
11	0.052	0.080	0.161	0.707	0.007	0.024	0.131	0.838
12	0.092	0.040	0.160	0.707	0.013	0.013	0.131	0.843
13	0.178	0.300	0.054	0.468	0.026	0.127	0.091	0.757

Table 9 (Continued)

	Aqueous phase				Organic phase			
	Grams of $La(NO_3)_3$ per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $La(NO_3)_3$ per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $HNO_3)_3$ per gram of solution	Grams of solvent per gram of solution
14	0.334	0.145	0.050	0.417	0.064	0.078	0.096	0.763
15	0.126	0.233	0.142	0.500	0.013	0.065	0.143	0.779
16	0.247	0.112	0.138	0.503	0.031	0.036	0.148	0.785
17	0.069	0.132	0.256	0.544	0.006	0.026	0.176	0.792
18	0.144	0.273	0.176	0.407	0.013	0.072	0.167	0.748
19	0.289	0.130	0.171	0.409	0.031	0.041	0.171	0.757
20	0.086	0.154	0.328	0.433	0.007	0.039	0.203	0.752
21	0.167	0.076	0.325	0.433	0.015	0.021	0.207	0.756

Table 10. Equilibrium data for the system $Nd(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase				Organic phase			
	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $Nd(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.074	0.126	0.021	0.780	0.032	0.071	0.035	0.861
2	0.064	0.033	0.087	0.816	0.018	0.012	0.083	0.888
3	0.211	0.105	0.039	0.645	0.092	0.060	0.053	0.795
4	0.048	0.102	0.151	0.699	0.014	0.036	0.119	0.830
5	0.146	0.328	0.059	0.467	0.042	0.130	0.083	0.745
6	0.148	0.079	0.236	0.538	0.028	0.022	0.167	0.783
7	0.266	0.137	0.195	0.402	0.055	0.045	0.166	0.734
8	0.088	0.182	0.301	0.429	0.017	0.056	0.190	0.737

Table 11. Equilibrium data for the system $Sm(NO_3)_3$ - $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O

	Aqueous phase				Organic phase			
	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution	Grams of $Pr(NO_3)_3$ per gram of solution	Grams of $Sm(NO_3)_3$ per gram of solution	Grams of HNO_3 per gram of solution	Grams of solvent per gram of solution
1	0.073	0.118	0.022	0.787	0.033	0.079	0.033	0.855
2	0.064	0.025	0.088	0.824	0.020	0.010	0.082	0.888
3	0.221	0.087	0.040	0.652	0.090	0.072	0.049	0.789
4	0.052	0.083	0.154	0.711	0.013	0.047	0.116	0.825
5	0.176	0.288	0.062	0.474	0.031	0.159	0.075	0.735
6	0.158	0.062	0.236	0.545	0.027	0.035	0.159	0.779
7	0.265	0.108	0.220	0.408	0.043	0.071	0.162	0.724
8	0.102	0.154	0.311	0.433	0.013	0.090	0.173	0.723

APPENDIX C. MATHEMATICAL ANALYSIS OF PINCH

In this section an attempt to determine mathematically the generality of the "pinch" properties of the multicomponent, multistage calculation discussed in the body of this report is presented. The treatment is quite incomplete, however, the results indicate that the "pinch" of solute concentrations may be general over a wide range of system parameters. The cascade portrayed in Figure 10 was considered.

The approach used was to combine the defining equation of separation factor with a material balance and write an equation for the molality of solute j in organic stream S_n. Remember that the calculation to be considered is applied to the end of the cascade, first defining the solvent (S_0), the raffinate (R_1), and the flow ratio (α), and then working back through the cascade toward the feed.

By definition

$$(\beta_{j\text{-}Pr})_n = \frac{(M_j)_{S_n}/(M_j)_{R_n}}{(K_{Pr})_n} \qquad (14)$$

or

$$(K_{Pr})_n(\beta_{j\text{-}Pr})_n(M_j)_{R_n} = (M_j)_{S_n} \quad . \qquad (15)$$

Summing each side of Equation 15 over the solutes in the system get

$$(K_{Pr})_n \sum_{i=1}^{T} (\beta_{i\text{-}Pr})_n (M_i)_{R_n} = \sum_{i=1}^{T} (M_i)_{S_n} = (M_t)_{S_n} \quad . \qquad (16)$$

Substituting Equation 16 into 15 get

$$(M_j)_{S_n} = \frac{(M_t)_{S_n}(\beta_{j\text{-}Pr})_n(M_j)_{R_n}}{\sum_{i=1}^{T}(\beta_{i\text{-}Pr})_n(M_i)_{R_n}} \quad . \qquad (17)$$

Writing a material balance over the right hand end of the cascade gives

$$\left[(M_j)_{R_1} \times R_1\right] + \left[(M_j)_{S_{n-1}} \times S_{n-1}\right] =$$

$$\left[(M_j)_{S_0} \times S_0\right] + \left[(M_j)_{R_n} \times R_n\right] \quad , \qquad (18)$$

and assuming immiscible solvents

$$(M_j)_{R_n} = \alpha(M_j)_{S_{n-1}} + (M_j)_{R_1} - \alpha(M_j)_{S_0} \quad . \qquad (19)$$

Substituting into Equation 17 get

$$(M_j)_{S_n} = \frac{(M_t)_{S_n}(\beta_{j\text{-}Pr})_n\left[\alpha(M_j)_{S_{n-1}} + (M_j)_{R_1} - \alpha(M_j)_{S_0}\right]}{\sum_{i=1}^{T}(\beta_{i\text{-}Pr})_n\left[\alpha(M_i)_{S_{n-1}} + (M_i)_{R_1} - \alpha(M_i)_{S_0}\right]} \quad . \qquad (20)$$

The assumptions of "pinched" total molality and constant separation factors were now applied. The general situation in which the total molality is "pinched" at a high value is shown on a McCabe Thiele diagram in Figure 32. The equations to be considered below apply to the circled section on the drawing, that is to the "pinched" stages. The fact that the following equations assume a "pinch" in stage 1 causes no loss in generality, as in a case in which the total molality of

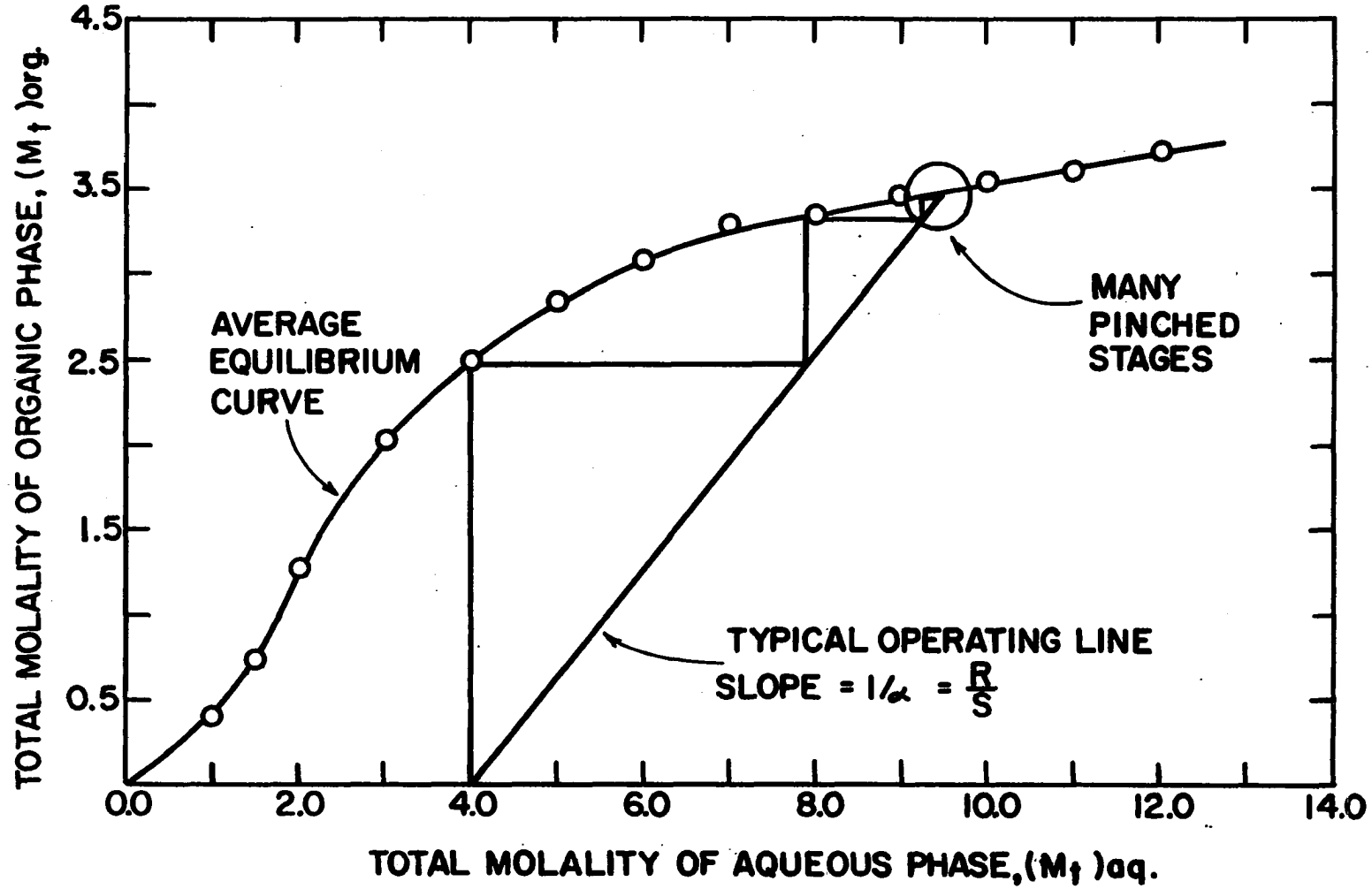


Figure 32. McCabe-Thiele representation of "pinched" total molality

several of the right hand stages is not constant stage 1 may be chosen as the first stage in which the organic molality attains its "pinch" value.

For this equilibrium model the stream and stage designations of the total molalities and separation factors may be deleted, and also, for convenience $(M_i)_n$ will be inserted for $(M_i)_{S_n}$ and so

$$(M_j)_n = \frac{\alpha M_t \beta_{j-Pr} (M_j)_{n-1} + M_t \beta_{j-Pr} \left[(M_j)_{R_1} - \alpha (M_j)_{S_0} \right]}{\alpha \sum_{i=1}^{T} \beta_{i-Pr} (M_i)_{n-1} + \sum_{i=1}^{T} \beta_{i-Pr} \left[(M_i)_{R_1} - \alpha (M_i)_{S_0} \right]} \quad . \quad (21)$$

Note that for specified end conditions and a specified "pinch" value of the total molality Equation 21 gives the molality of solute j in stream S_n as a function of the molalities of all solutes in stream S_{n-1}. By letting n = 1,2,3, ----, a sequence was generated which gives the molality of solute j in successive organic streams in terms of the system parameters. If the sequence could be shown to converge to a non-zero value the "pinch" would be proven general. The author has written a large number of terms of the sequence but has not been able to write the general term.

For the special case of T = 2, that is two solutes, an analytical treatment of the general equation was developed and the limit taken. This case is now discussed. For convenience it was assumed that stream S_0 is pure solvent. This is not

necessary but simplifies the following equations algebraically. For this case, denoting quantities that pertain to the two solutes by the subscripts 1 and 2

$$(M_1)_n = \frac{M_t\beta_{1\text{-}Pr}(M_1)_{n-1} + (M_t/\alpha)\beta_{1\text{-}Pr}(M_1)_{R_1}}{\left[\beta_{1\text{-}Pr}(M_1)_{n-1} + \beta_{2\text{-}Pr}(M_2)_{n-1}\right] + (1/\alpha)\sum_{i=1}^{2}\beta_{i\text{-}Pr}(M_i)_{R_1}} , \tag{22}$$

and

$$(M_2)_n = \frac{M_t\beta_{2\text{-}Pr}(M_2)_{n-1} + (M_t/\alpha)\beta_{2\text{-}Pr}(M_2)_{R_1}}{\left[\beta_{1\text{-}Pr}(M_1)_{n-1} + \beta_{2\text{-}Pr}(M_2)_{n-1}\right] + (1/\alpha)\sum_{i=1}^{2}\beta_{i\text{-}Pr}(M_i)_{R_1}} . \tag{23}$$

These equations are of exactly the same form. By use of finite difference techniques they were solved for the molalities of the solutes as a function of the system parameters and stage number, and the limit taken as n becomes large. This technique is now illustrated by solving Equation 22 and then a numerical example given.

For the two solute case with "pinched" total molality

$$(M_1)_{n-1} + (M_2)_{n-1} = M_t , \tag{24}$$

and so substituting into Equation 22 get

$$(M_1)_n = \frac{M_t\beta_{1\text{-}Pr}(M_1)_{n-1} + (M_t/\alpha)\beta_{1\text{-}Pr}(M_1)_{R_1}}{(\beta_{1\text{-}Pr} - \beta_{2\text{-}Pr})(M_1)_{n-1} + \beta_{2\text{-}Pr}M_t + (1/\alpha)\sum_{i=1}^{2}\beta_{i\text{-}Pr}(M_i)_{R_1}} . \tag{25}$$

Now let

$$a_1 = M_t \beta_{1\text{-}Pr} \quad ,$$

$$b_1 = (M_t/\alpha)\beta_{1\text{-}Pr}(M_1)_{R_1} \quad ,$$

$$c_1 = \beta_{1\text{-}Pr} - \beta_{2\text{-}Pr} \quad ,$$

$$d_1 = \beta_{2\text{-}Pr} M_t + (1/\alpha) \sum_{i=1}^{2} \beta_{i\text{-}Pr}(M_i)_{R_1} \quad .$$

Substitution into Equation 25 and simplification gives

$$(M_1)_n(M_1)_{n-1} + \alpha_1(M_1)_n + \theta_1(M_1)_{n-1} + \gamma_1 = 0 \quad , \qquad (26)$$

with

$$\alpha_1 = d_1/c_1 \quad ,$$

$$\theta_1 = -a_1/c_1 \quad ,$$

$$\gamma_1 = -b_1/c_1 \quad .$$

At this point it is to be noted that the limit of $(M_1)_n$ as n becomes large can be determined without solving Equation 26. This can be done by recognizing that if a "pinch" takes place $(M_1)_n = (M_1)_{n-1}$. If this substitution is made in Equation 26 and the resulting quadratic solved for $(M_1)_n$ two roots are obtained, one of which must be discarded on physical grounds.

Alternatively, Equation 26 is a Ricatti difference equation and may be reduced to a linear difference equation with constant coefficients by the substitution

$$(M_1)_{n-1} = (V_1)_n/(V_1)_{n-1} - \alpha_1 \quad . \qquad (27)$$

For the methods of solution the reader is referred to Boole (53) and Brand (54).

After substitution and simplification get

$$(V_1)_{n+1} + E_1(V_1)_n + F_1(V_1)_{n-1} = 0 \qquad (28)$$

with

$$E_1 = \theta_1 - \alpha_1 \quad ,$$

$$F_1 = \gamma_1 - \alpha_1\theta_1 \quad .$$

A trial solution of the form $(V_1)_n = Z^n$ gives the characteristic equation

$$Z^2 + E_1Z + F_1 = 0 \quad , \qquad (29)$$

and so

$$Z = \frac{-E_1 \pm (E_1^2 - 4F_1)^{0.5}}{2} \quad . \qquad (30)$$

To complete the solution it was necessary to know the nature of the roots of the characteristic quadratic. For all calculations considered the roots were real and distinct. The author has attempted to prove that the discriminant of the quadratic is positive by expanding it in terms of the original system parameters. A proof has not been possible and so it was assumed that this is the case and the roots are real and distinct.

Let

$$G_{1+} = \frac{-E_1 + (E_1^2 - 4F_1)^{0.5}}{2}$$

and

$$G_{1-} = \frac{-E_1 - (E_1^2 - 4F_1)^{0.5}}{2} \quad .$$

Then the solution of Equation 28 is

$$(V_1)_n = C_1 G_{1+}^n + C_2 G_{1-}^n \qquad (31)$$

with C_1 and C_2 constants, and the solution of Equation 26 is

$$(M_1)_n = \frac{C_1 G_{1+}^{n+1} + C_2 G_{1-}^{n+1}}{C_1 G_{1+}^n + C_2 G_{1-}^n} - \alpha_1 \quad . \qquad (32)$$

The limit of Equation 32 was taken by noting that the roots are real and distinct. Then necessarily either $|G_{1+}| > |G_{1-}|$ or $|G_{1+}| < |G_{1-}|$. Assuming that $|G_{1+}| > |G_{1-}|$ the numerator and denominator of the fraction on the right hand side of Equation 32 was divided by G_{1+}^n giving

$$(M_1)_n = \frac{C_1 G_{1+} + C_2 G_{1-} (G_{1-}/G_{1+})^n}{C_1 + C_2 (G_{1-}/G_{1+})^n} - \alpha_1 \quad , \qquad (33)$$

and so

$$\lim_{n \to \infty} (M_1)_n = G_{1+} - \alpha_1 \quad . \qquad (34)$$

It should be noted at this point that the algebraic combinations of system parameters a_1, b_1, c_1, d_1, α_1, θ_1, γ_1, E_1, F_1, G_{1+}, G_{1-} all refer to solute 1. Corresponding expressions for solute 2 may be obtained by interchanging the solute subscripts in the defining equations. Exactly the same treatment was applied to Equation 23. Alternatively, the limit of the differences of the molalities in successive

stages, that is $\left[(M_1)_{n+1} - (M_1)_n\right]$ and $\left[(M_2)_{n+1} - (M_2)_n\right]$ may be shown to approach zero as n becomes large.

As a numerical example the following values were chosen:

$$\alpha = 1.0 \quad ,$$

$$M_t = 3.50 \quad ,$$

$$\beta_{1\text{-}Pr} = 0.43 \quad ,$$

$$\beta_{2\text{-}Pr} = 1.00 \quad ,$$

$$(M_t)_{R_1} = 8.00 \quad ,$$

$$(M_1)_{R_1} = 4.00 \quad ,$$

$$(M_2)_{R_2} = 4.00 \quad .$$

Using these values

$$G_{1+} = -3.472 \quad ,$$

$$G_{1-} = -15.344 \quad ,$$

$$\alpha_1 = -16.175 \quad ,$$

$$G_{2+} = 15.344 \quad ,$$

$$G_{2-} = 3.472 \quad ,$$

$$\alpha_2 = 12.675 \quad ,$$

were calculated. The limits of $(M_1)_n$ and $(M_2)_n$ were then calculated to be

$$\lim_{n\to\infty} (M_1)_n = -15.344 + 16.175 = 0.831 \quad ,$$

$$\lim_{n\to\infty} (M_2)_n = 15.344 - 12.675 = 2.669 \quad .$$

Using alternate material balances and the chosen equilibrium model the stagewise values shown in Table 12 were calculated for this numerical example.

Table 12. Molalities of solutes 1 and 2 in organic streams of ideal cascade

	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7
M_1	0.0000	1.0520	0.8820	0.8429	0.8340	0.8320	0.8315	0.8314
M_2	0.0000	2.4480	2.6180	2.6571	2.6660	2.6680	2.6685	2.6686

The stagewise concentrations "pinch" rather rapidly to the limiting values. Note however that this is not an independent check of the validity of the process, as the equation which was used to solve for and take the limit of the molalities is simply a generalization of the stage by stage calculation used to determine the stagewise concentrations in the preceeding table. This result indicates only that the solution of Equations 22 and 23 by finite difference techniques and the limiting process were carried out correctly.

Two comments should be made concerning the preceeding treatment. First the form of the solution is dependent on the

assumption of real and distinct roots of the characteristic quadratic. As pointed out previously, this has been true in all specific cases studied but no proof has been given. Secondly, it may be that the derived result, that is "pinched" concentrations of the individual solutes under the assumptions made and the situations considered, is or should be intuitively obvious from simple material balance considerations. No definite conclusion has been reached concerning this second statement.

APPENDIX D. DIGITAL COMPUTOR PROGRAMS

The calculation which is discussed in the body of this thesis to give the stagewise conditions in a cascade of equilibrium stages was programmed in the Full Fortran Language for the IBM 7074 digital computor for four cascades of interest. These cascades are shown in Figures 33, 34, 35, and 36 with the direction of calculation denoted by dashed arrows.

In the computor operation the values of K_t and K_{HNO_3} were derived by straight line interpolation in two dimensional arrays prepared from the parametic plots of K_t and K_{HNO_3} versus equilibrium phase composition discussed in the Method of Calculation section. These two dimensional arrays are shown in Tables 13 through 28. All non-zero values in these arrays were taken from plots of the type depicted in Figures 1 through 8. The zero values have no physical meaning but were inserted for convenience in making "branches" in the programs.

The principal variable names used in the programs are given in Figure 37. A compilation of the four programs is given in Figures 38 through 45. In each case the logic flow is diagrammed and is followed by the Fortran program. The program designation corresponds to the cascade designation in Figures 33, 34, 35, and 36.

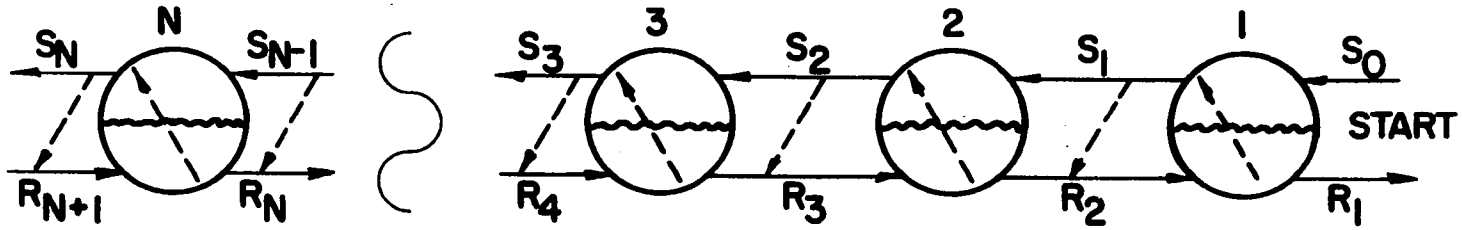


Figure 33. Cascade I

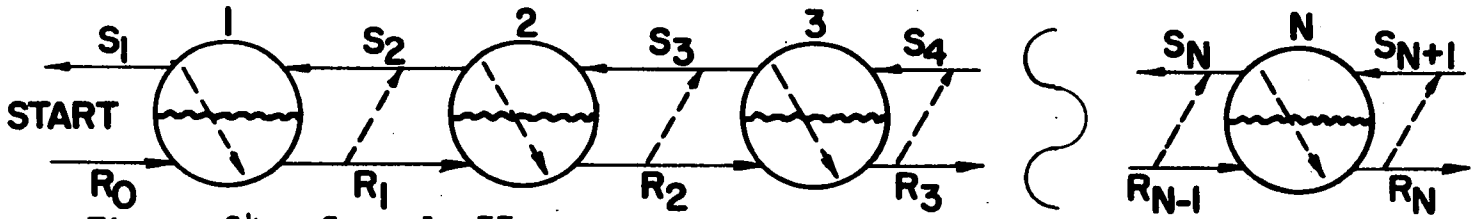


Figure 34. Cascade II

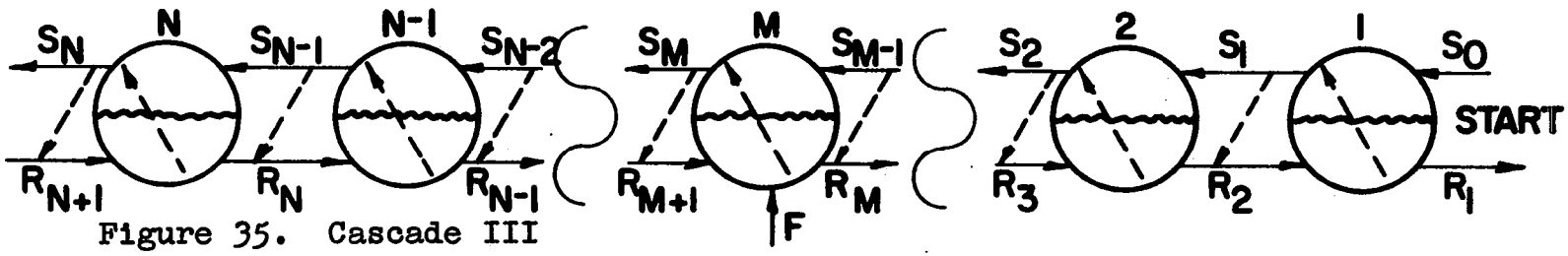


Figure 35. Cascade III

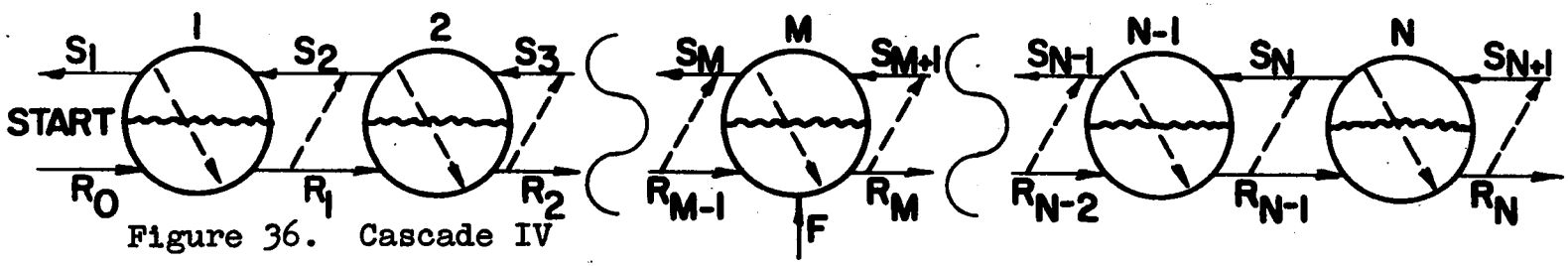


Figure 36. Cascade IV

Table 13. Array of values of K_t for the system $La(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{La}

X_{La}	$(M_t)_{aq.}$						
	3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.695	0.626	0.569	0.475	0.382	0.329	0.298
0.10	0.676	0.612	0.560	0.471	0.382	0.328	0.299
0.15	0.659	0.598	0.550	0.468	0.382	0.326	0.299
0.20	0.643	0.586	0.541	0.464	0.382	0.325	0.299
0.25	0.628	0.575	0.533	0.460	0.381	0.324	0.298
0.30	0.614	0.564	0.524	0.456	0.380	0.322	0.297
0.35	0.601	0.554	0.516	0.452	0.378	0.320	0.295
0.40	0.589	0.545	0.508	0.448	0.376	0.318	0.293
0.45	0.578	0.537	0.501	0.443	0.374	0.316	0.289
0.50	0.568	0.529	0.494	0.438	0.371	0.314	0.285
0.55	0.559	0.523	0.487	0.433	0.369	0.311	0.281
0.60	0.549	0.516	0.481	0.428	0.366	0.308	0.276
0.65	0.541	0.511	0.474	0.423	0.363	0.306	0.271
0.70	0.533	0.506	0.469	0.417	0.359	0.303	0.266
0.75	0.526	0.500	0.464	0.412	0.355	0.301	0.259
0.80	0.521	0.495	0.460	0.407	0.349	0.296	0.252
0.85	0.518	0.491	0.456	0.401	0.336	0.288	0.244
0.90	0.519	0.489	0.455	0.396	0.331	0.278	0.236
0.95	0.524	0.491	0.454	0.389	0.319	0.266	0.226
1.00	0.534	0.497	0.456	0.384	0.303	0.248	0.217

Table 14. Array of values of K_t for the system $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Pr}

X_{Pr}	$(M_t)_{aq.}$ 3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.702	0.628	0.571	0.476	0.388	0.331	0.298
0.10	0.690	0.617	0.564	0.474	0.383	0.332	0.299
0.15	0.679	0.608	0.556	0.470	0.383	0.332	0.299
0.20	0.668	0.601	0.550	0.468	0.385	0.331	0.299
0.25	0.659	0.595	0.545	0.465	0.384	0.330	0.298
0.30	0.650	0.588	0.540	0.462	0.383	0.330	0.297
0.35	0.642	0.583	0.535	0.460	0.382	0.328	0.296
0.40	0.634	0.578	0.532	0.458	0.381	0.327	0.295
0.45	0.627	0.574	0.529	0.455	0.380	0.325	0.294
0.50	0.622	0.570	0.526	0.453	0.378	0.324	0.292
0.55	0.616	0.566	0.525	0.451	0.376	0.322	0.290
0.60	0.612	0.565	0.523	0.450	0.374	0.320	0.288
0.65	0.608	0.563	0.523	0.450	0.373	0.317	0.285
0.70	0.605	0.562	0.523	0.449	0.370	0.315	0.282
0.75	0.600	0.562	0.523	0.449	0.368	0.312	0.000
0.80	0.601	0.564	0.524	0.448	0.365	0.309	0.000
0.85	0.605	0.570	0.527	0.449	0.361	0.306	0.000
0.90	0.615	0.582	0.535	0.450	0.358	0.302	0.000
0.95	0.631	0.599	0.547	0.451	0.354	0.298	0.000
1.00	0.657	0.619	0.567	0.454	0.350	0.294	0.000

Table 15. Array of values of K_t for the system $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Nd}

X_{Nd}	$(M_t)_{aq.}$ 3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.702	0.626	0.570	0.476	0.383	0.332	0.301
0.10	0.693	0.615	0.562	0.474	0.385	0.335	0.303
0.15	0.683	0.605	0.555	0.471	0.386	0.337	0.305
0.20	0.673	0.597	0.550	0.469	0.387	0.338	0.305
0.25	0.664	0.593	0.547	0.467	0.387	0.338	0.306
0.30	0.656	0.587	0.544	0.465	0.388	0.338	0.306
0.35	0.649	0.585	0.542	0.463	0.388	0.338	0.306
0.40	0.643	0.583	0.541	0.461	0.388	0.337	0.305
0.45	0.637	0.582	0.540	0.460	0.387	0.336	0.305
0.50	0.631	0.582	0.540	0.459	0.386	0.335	0.303
0.55	0.626	0.582	0.540	0.458	0.385	0.335	0.302
0.60	0.622	0.583	0.542	0.457	0.382	0.333	0.300
0.65	0.620	0.585	0.544	0.457	0.380	0.330	0.298
0.70	0.620	0.587	0.546	0.457	0.337	0.329	0.295
0.75	0.620	0.591	0.548	0.457	0.374	0.326	0.000
0.80	0.623	0.597	0.552	0.460	0.370	0.324	0.000
0.85	0.628	0.605	0.556	0.463	0.366	0.320	0.000
0.90	0.640	0.615	0.562	0.466	0.362	0.314	0.000
0.95	0.660	0.627	0.568	0.464	0.358	0.307	0.000
1.00	0.697	0.643	0.577	0.457	0.352	0.000	0.000

Table 16. Array of values of K_t for the system $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Sm}

X_{Sm}	$(M_t)_{aq.}$						
	3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.706	0.635	0.576	0.480	0.388	0.335	0.309
0.10	0.699	0.630	0.573	0.479	0.391	0.339	0.316
0.15	0.693	0.628	0.570	0.479	0.394	0.342	0.323
0.20	0.687	0.625	0.569	0.479	0.396	0.345	0.327
0.25	0.681	0.622	0.567	0.479	0.398	0.348	0.332
0.30	0.675	0.620	0.566	0.480	0.399	0.350	0.335
0.35	0.672	0.619	0.565	0.480	0.399	0.350	0.338
0.40	0.668	0.618	0.566	0.480	0.399	0.351	0.341
0.45	0.666	0.619	0.566	0.481	0.398	0.351	0.343
0.50	0.665	0.619	0.568	0.483	0.396	0.351	0.344
0.55	0.665	0.621	0.570	0.480	0.395	0.350	0.000
0.60	0.667	0.623	0.573	0.486	0.394	0.348	0.000
0.65	0.670	0.625	0.577	0.488	0.393	0.346	0.000
0.70	0.674	0.630	0.581	0.490	0.390	0.343	0.000
0.75	0.681	0.637	0.586	0.492	0.389	0.340	0.000
0.80	0.688	0.648	0.591	0.494	0.387	0.335	0.000
0.85	0.697	0.666	0.598	0.496	0.384	0.328	0.000
0.90	0.708	0.682	0.604	0.498	0.380	0.319	0.000
0.95	0.731	0.693	0.612	0.501	0.375	0.307	0.000
1.00	0.770	0.700	0.620	0.504	0.370	0.290	0.000

Table 17. Array of values of K_{HNO_3} for the system $La(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{La}

X_{La}	$(M_t)_{aq.}$ 3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.713	0.650	0.587	0.491	0.400	0.341	0.303
0.10	0.720	0.659	0.597	0.510	0.417	0.357	0.313
0.15	0.732	0.672	0.611	0.531	0.438	0.376	0.325
0.20	0.750	0.690	0.630	0.533	0.459	0.396	0.341
0.25	0.774	0.711	0.651	0.579	0.483	0.416	0.360
0.30	0.803	0.738	0.677	0.603	0.507	0.438	0.382
0.35	0.838	0.769	0.708	0.630	0.533	0.461	0.408
0.40	0.880	0.806	0.741	0.660	0.561	0.489	0.437
0.45	0.927	0.847	0.777	0.696	0.592	0.519	0.469
0.50	0.981	0.893	0.817	0.733	0.627	0.552	0.505
0.55	1.042	0.937	0.869	0.777	0.668	0.593	0.543
0.60	1.108	0.994	0.928	0.833	0.716	0.642	0.586
0.65	1.180	1.057	0.999	0.902	0.777	0.703	0.634
0.70	1.257	1.137	1.083	0.986	0.854	0.784	0.000
0.75	1.347	1.230	1.177	1.078	0.965	0.905	0.000
0.80	1.456	1.337	1.281	1.187	1.090	1.044	0.000
0.85	1.584	1.465	1.403	1.322	1.251	1.220	0.000
0.90	1.755	1.630	1.569	1.497	1.482	1.500	0.000
0.95	2.043	1.930	1.830	1.783	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 18. Array of values of K_{HNO_3} for the system $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Pr}

X_{Pr}	$(M_t)_{aq.}$ 3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.710	0.640	0.586	0.490	0.397	0.340	0.303
0.10	0.712	0.644	0.593	0.507	0.411	0.351	0.313
0.15	0.722	0.654	0.606	0.523	0.428	0.365	0.324
0.20	0.739	0.669	0.620	0.541	0.447	0.380	0.336
0.25	0.758	0.688	0.640	0.562	0.467	0.397	0.351
0.30	0.781	0.711	0.660	0.584	0.488	0.413	0.365
0.35	0.811	0.739	0.683	0.607	0.510	0.432	0.384
0.40	0.849	0.771	0.710	0.631	0.535	0.455	0.405
0.45	0.889	0.801	0.739	0.659	0.561	0.480	0.430
0.50	0.936	0.851	0.769	0.688	0.590	0.508	0.457
0.55	0.988	0.900	0.805	0.721	0.622	0.540	0.490
0.60	1.044	0.950	0.850	0.759	0.663	0.580	0.529
0.65	1.104	1.003	0.906	0.802	0.712	0.627	0.573
0.70	1.177	1.060	0.969	0.855	0.766	0.685	0.000
0.75	1.268	1.126	1.045	0.920	0.841	0.757	0.000
0.80	1.371	1.203	1.127	0.994	0.922	0.848	0.000
0.85	1.494	1.307	1.221	1.087	1.014	0.952	0.000
0.90	1.652	1.454	1.329	1.190	1.128	1.075	0.000
0.95	1.879	1.665	1.453	1.383	1.309	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 19. Array of values of K_{HNO_3} for the system $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Nd}

X_{Nd}	$(M_t)_{aq.}$						
	3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.724	0.646	0.586	0.487	0.390	0.340	0.303
0.10	0.738	0.650	0.592	0.500	0.403	0.350	0.313
0.15	0.751	0.660	0.600	0.511	0.420	0.364	0.324
0.20	0.769	0.670	0.612	0.529	0.438	0.380	0.336
0.25	0.789	0.687	0.627	0.546	0.457	0.397	0.350
0.30	0.810	0.709	0.646	0.562	0.477	0.414	0.365
0.35	0.833	0.732	0.667	0.581	0.499	0.432	0.380
0.40	0.861	0.760	0.692	0.603	0.521	0.454	0.398
0.45	0.895	0.791	0.723	0.627	0.547	0.480	0.416
0.50	0.930	0.826	0.758	0.650	0.571	0.507	0.440
0.55	0.978	0.866	0.797	0.678	0.601	0.537	0.467
0.60	1.030	0.907	0.836	0.710	0.636	0.577	0.502
0.65	1.088	0.957	0.881	0.747	0.674	0.618	0.555
0.70	1.150	1.014	0.932	0.790	0.720	0.668	0.000
0.75	1.227	1.080	0.989	0.842	0.777	0.733	0.000
0.80	1.310	1.154	1.054	0.910	0.848	0.813	0.000
0.85	1.415	1.243	1.130	0.983	0.939	0.917	0.000
0.90	1.570	1.360	1.229	1.090	1.049	1.038	0.000
0.95	1.795	1.525	1.353	1.240	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 20. Array of values of K_{HNO_3} for the system $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{Sm}

X_{Sm}	$(M_t)_{aq.}$						
	3.0	4.0	5.0	7.0	10.0	13.0	16.0
0.00	0.713	0.640	0.580	0.478	0.382	0.330	0.296
0.05	0.717	0.648	0.581	0.481	0.387	0.332	0.299
0.10	0.727	0.657	0.583	0.488	0.395	0.340	0.303
0.15	0.738	0.667	0.590	0.498	0.402	0.348	0.309
0.20	0.751	0.679	0.597	0.507	0.413	0.357	0.316
0.25	0.770	0.689	0.603	0.519	0.423	0.368	0.324
0.30	0.789	0.701	0.611	0.532	0.437	0.378	0.333
0.35	0.810	0.717	0.621	0.547	0.449	0.393	0.345
0.40	0.832	0.734	0.637	0.562	0.464	0.409	0.357
0.45	0.857	0.753	0.658	0.580	0.418	0.428	0.371
0.50	0.884	0.772	0.683	0.598	0.501	0.450	0.387
0.55	0.917	0.796	0.711	0.618	0.525	0.478	0.000
0.60	0.951	0.820	0.745	0.642	0.551	0.510	0.000
0.65	0.991	0.850	0.782	0.669	0.586	0.550	0.000
0.70	1.031	0.887	0.824	0.701	0.623	0.604	0.000
0.75	1.077	0.928	0.868	0.737	0.678	0.670	0.000
0.80	1.123	0.979	0.915	0.783	0.752	0.750	0.000
0.85	1.172	1.047	0.966	0.840	0.856	0.840	0.000
0.90	1.227	1.175	1.026	0.917	1.050	0.939	0.000
0.95	1.282	1.380	1.087	1.011	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 21. Array of values of K_t for the system $La(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{La}

Y_{La}	$(M_t)_{org.}$					
	2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.610	0.547	0.484	0.394	0.344	0.304
0.10	0.568	0.505	0.452	0.370	0.329	0.295
0.15	0.545	0.482	0.430	0.354	0.314	0.283
0.20	0.529	0.466	0.413	0.345	0.300	0.270
0.25	0.516	0.457	0.399	0.337	0.284	0.254
0.30	0.505	0.450	0.389	0.329	0.269	0.000
0.35	0.498	0.445	0.380	0.320	0.254	0.000
0.40	0.492	0.442	0.374	0.312	0.239	0.000
0.45	0.486	0.438	0.370	0.303	0.000	0.000
0.50	0.484	0.435	0.367	0.295	0.000	0.000
0.55	0.482	0.432	0.365	0.286	0.000	0.000
0.60	0.480	0.430	0.364	0.278	0.000	0.000
0.65	0.480	0.427	0.361	0.270	0.000	0.000
0.70	0.481	0.425	0.357	0.262	0.000	0.000
0.75	0.483	0.424	0.352	0.253	0.000	0.000
0.80	0.485	0.422	0.346	0.245	0.000	0.000
0.85	0.487	0.420	0.339	0.237	0.000	0.000
0.90	0.490	0.419	0.331	0.228	0.000	0.000
0.95	0.494	0.417	0.322	0.220	0.000	0.000
1.00	0.498	0.415	0.313	0.212	0.000	0.000

Table 22. Array of values of K_t for the system $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Pr}

Y_{Pr}	$(M_t)_{org.}$					
	2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.693	0.603	0.531	0.437	0.358	0.315
0.10	0.662	0.575	0.509	0.433	0.355	0.314
0.15	0.639	0.559	0.495	0.426	0.351	0.310
0.20	0.620	0.549	0.484	0.420	0.346	0.305
0.25	0.605	0.544	0.475	0.413	0.340	0.298
0.30	0.595	0.540	0.469	0.406	0.331	0.290
0.35	0.588	0.537	0.464	0.398	0.323	0.280
0.40	0.584	0.535	0.461	0.389	0.314	0.269
0.45	0.582	0.533	0.459	0.379	0.304	0.000
0.50	0.583	0.533	0.456	0.368	0.000	0.000
0.55	0.584	0.534	0.455	0.359	0.000	0.000
0.60	0.588	0.535	0.455	0.352	0.000	0.000
0.65	0.593	0.539	0.455	0.349	0.000	0.000
0.70	0.599	0.544	0.458	0.346	0.000	0.000
0.75	0.607	0.551	0.461	0.345	0.000	0.000
0.80	0.616	0.561	0.467	0.345	0.000	0.000
0.85	0.625	0.574	0.475	0.345	0.000	0.000
0.90	0.636	0.588	0.485	0.346	0.000	0.000
0.95	0.648	0.602	0.499	0.349	0.000	0.000
1.00	0.660	0.619	0.519	0.351	0.000	0.000

Table 23. Array of values of K_t for the system $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Nd}

Y_{Nd}	$(M_t)_{org.}$ 2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.700	0.611	0.540	0.445	0.368	0.321
0.10	0.665	0.584	0.522	0.445	0.374	0.326
0.15	0.643	0.569	0.508	0.442	0.378	0.329
0.20	0.627	0.564	0.499	0.435	0.377	0.329'
0.25	0.618	0.562	0.492	0.424	0.375	0.326
0.30	0.612	0.564	0.487	0.415	0.368	0.321
0.35	0.611	0.565	0.485	0.408	0.357	0.315
0.40	0.610	0.566	0.485	0.403	0.345	0.306
0.45	0.611	0.569	0.488	0.400	0.327	0.000
0.50	0.614	0.572	0.490	0.400	0.307	0.000
0.55	0.616	0.575	0.494	0.401	0.000	0.000
0.60	0.620	0.580	0.500	0.404	0.000	0.000
0.65	0.625	0.584	0.508	0.405	0.000	0.000
0.70	0.630	0.590	0.519	0.405	0.000	0.000
0.75	0.636	0.596	0.527	0.403	0.000	0.000
0.80	0.645	0.603	0.533	0.400	0.000	0.000
0.85	0.655	0.613	0.537	0.398	0.000	0.000
0.90	0.669	0.624	0.540	0.395	0.000	0.000
0.95	0.684	0.637	0.542	0.390	0.000	0.000
1.00	0.702	0.653	0.543	0.386	0.000	0.000

Table 24. Array of values of K_t for the system $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Sm}

Y_{Sm}	$(M_t)_{org.}$					
	2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.724	0.641	0.555	0.449	0.370	0.328
0.10	0.700	0.626	0.548	0.454	0.377	0.339
0.15	0.684	0.615	0.543	0.458	0.383	0.345
0.20	0.672	0.608	0.541	0.460	0.388	0.349
0.25	0.665	0.605	0.541	0.461	0.390	0.350
0.30	0.660	0.603	0.544	0.462	0.390	0.349
0.35	0.659	0.604	0.548	0.461	0.388	0.346
0.40	0.659	0.606	0.553	0.461	0.386	0.341
0.45	0.660	0.610	0.560	0.460	0.382	0.000
0.50	0.664	0.616	0.567	0.459	0.377	0.000
0.55	0.669	0.623	0.575	0.475	0.372	0.000
0.60	0.676	0.630	0.582	0.455	0.365	0.000
0.65	0.685	0.640	0.590	0.450	0.359	0.000
0.70	0.695	0.652	0.598	0.450	0.351	0.000
0.75	0.707	0.665	0.605	0.449	0.343	0.000
0.80	0.720	0.679	0.614	0.450	0.000	0.000
0.85	0.733	0.694	0.622	0.455	0.000	0.000
0.90	0.748	0.710	0.630	0.463	0.000	0.000
0.95	0.763	0.727	0.638	0.475	0.000	0.000
1.00	0.780	0.746	0.646	0.492	0.000	0.000

Table 25. Array of values of K_{HNO_3} for the system $La(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{La}

Y_{Sm}	$(M_t)_{org.}$ 2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.802	0.701	0.617	0.523	0.464	0.399
0.10	0.845	0.749	0.681	0.612	0.566	0.474
0.15	0.895	0.804	0.756	0.701	0.668	0.546
0.20	0.950	0.867	0.831	0.797	0.767	0.617
0.25	1.016	0.937	0.910	0.895	0.863	0.685
0.30	1.087	1.009	0.991	0.995	0.963	0.000
0.35	1.160	1.083	1.071	1.101	1.068	0.000
0.40	1.234	1.161	1.157	1.218	0.000	0.000
0.45	1.307	1.244	1.245	1.331	0.000	0.000
0.50	1.384	1.331	1.337	1.452	0.000	0.000
0.55	1.467	1.423	1.434	1.574	0.000	0.000
0.60	1.548	1.520	1.539	1.697	0.000	0.000
0.65	1.637	1.618	1.649	1.825	0.000	0.000
0.70	1.732	1.718	1.769	1.956	0.000	0.000
0.75	1.829	1.823	1.900	2.087	0.000	0.000
0.80	1.933	1.929	2.037	2.222	0.000	0.000
0.85	2.041	2.041	2.186	0.000	0.000	0.000
0.90	2.157	2.156	2.348	0.000	0.000	0.000
0.95	2.275	2.276	0.000	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000

Table 26. Array of values of K_{HNO_3} for the system $Pr(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Pr}

Y_{Pr}	$(M_t)_{org.}$					
	2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.785	0.678	0.581	0.479	0.399	0.346
0.10	0.809	0.697	0.601	0.521	0.442	0.380
0.15	0.839	0.723	0.628	0.563	0.487	0.418
0.20	0.872	0.760	0.661	0.607	0.534	0.458
0.25	0.912	0.802	0.700	0.653	0.584	0.507
0.30	0.959	0.848	0.748	0.701	0.638	0.571
0.35	1.011	0.894	0.795	0.750	0.697	0.640
0.40	1.067	0.940	0.844	0.799	0.756	0.722
0.45	1.133	0.991	0.892	0.854	0.819	0.000
0.50	1.207	1.044	0.945	0.911	0.886	0.000
0.55	1.280	1.099	0.999	0.971	0.000	0.000
0.60	1.358	1.157	1.055	1.035	0.000	0.000
0.65	1.437	1.221	1.112	1.099	0.000	0.000
0.70	1.523	1.291	1.173	1.167	0.000	0.000
0.75	1.613	1.370	1.237	1.234	0.000	0.000
0.80	1.709	1.454	1.301	1.303	0.000	0.000
0.85	1.810	1.547	1.371	1.376	0.000	0.000
0.90	1.913	1.643	1.442	1.449	0.000	0.000
0.95	2.021	1.752	0.000	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000

Table 27. Array of values of K_{HNO_3} for the system $Nd(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Nd}

Y_{Nd}	$(M_t)_{org.}$ 2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.772	0.678	0.566	0.461	0.385	0.336
0.10	0.780	0.696	0.573	0.488	0.423	0.366
0.15	0.802	0.716	0.589	0.520	0.469	0.399
0.20	0.836	0.740	0.612	0.557	0.516	0.439
0.25	0.876	0.773	0.641	0.597	0.561	0.490
0.30	0.924	0.816	0.680	0.637	0.608	0.542
0.35	0.977	0.857	0.721	0.680	0.655	0.600
0.40	1.033	0.900	0.764	0.725	0.701	0.663
0.45	1.090	0.946	0.808	0.770	0.748	0.000
0.50	1.151	0.993	0.855	0.819	0.795	0.000
0.55	1.220	1.042	0.901	0.869	0.843	0.000
0.60	1.291	1.093	0.956	0.920	0.891	0.000
0.65	1.371	1.148	0.013	0.975	0.000	0.000
0.70	1.455	1.207	1.075	1.030	0.000	0.000
0.75	1.545	1.268	1.136	1.089	0.000	0.000
0.80	1.642	1.329	1.207	1.150	0.000	0.000
0.85	1.746	1.396	1.279	1.211	0.000	0.000
0.90	1.857	1.466	1.353	1.273	0.000	0.000
0.95	1.977	1.537	0.000	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000

Table 28. Array of values of K_{HNO_3} for the system $Sm(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{Sm}

Y_{Sm}	$(M_t)_{org.}$					
	2.0	2.5	3.0	3.5	4.0	4.5
0.00	0.769	0.667	0.566	0.441	0.358	0.314
0.05	0.769	0.658	0.560	0.448	0.367	0.336
0.10	0.773	0.656	0.564	0.456	0.380	0.336
0.15	0.787	0.664	0.571	0.467	0.395	0.350
0.20	0.804	0.677	0.584	0.482	0.413	0.368
0.25	0.829	0.696	0.600	0.500	0.435	0.388
0.30	0.859	0.716	0.619	0.523	0.461	0.410
0.35	0.892	0.738	0.641	0.550	0.493	0.437
0.40	0.928	0.767	0.668	0.580	0.531	0.464
0.45	0.963	0.797	0.700	0.612	0.573	0.000
0.50	0.1003	0.831	0.735	0.648	0.623	0.000
0.55	1.047	0.869	0.776	0.684	0.690	0.000
0.60	1.092	0.907	0.817	0.722	0.772	0.000
0.65	1.139	0.947	0.863	0.762	0.878	0.000
0.70	1.191	0.988	0.911	0.805	1.018	0.000
0.75	1.245	1.032	0.961	0.850	0.000	0.000
0.80	1.301	1.079	1.015	0.897	0.000	0.000
0.85	1.360	1.129	1.072	0.947	0.000	0.000
0.90	1.421	1.179	1.131	0.998	0.000	0.000
0.95	1.488	1.231	0.000	0.000	0.000	0.000
1.00	0.000	0.000	0.000	0.000	0.000	0.000

N - total number of stages in an extraction cascade

M - feed stage in an extraction cascade with internal feed

S - flow rate of solvent in organic streams, kgm. TBP/ unit time

F - flow rate of solvent in a feed stream, kgm. H_2O/ unit time

SOVR - flow rate ratio, S/R

ROVS - flow rate ratio, R/S

REX - flow rate of solvent in aqueous streams on extract side of internally fed cascade, kgm. H_2O/unit time

RSC - flow rate of solvent in aqueous streams on scrub side of internally fed cascade

TMAQ - $(M_t)_{aq.}$

AMAQ - $(M_{HNO_3})_{aq.}$

XLAMAQ - $(M_{La})_{aq.}$

PRMAQ - $(M_{Pr})_{aq.}$

XNDMAQ - $(M_{Nd})_{aq.}$

SMMAQ - $(M_{Sm})_{aq.}$

REMAQ - $(M_{RE})_{aq.}$

XHNO3 - X_{HNO_3}

XLA - X_{La}

XPR - X_{Pr}

XND - X_{Nd}

XSM - X_{Sm}

Figure 37. Principal variable names

XRE - x_{RE}

XLASF - x_{La}

XPRSF - x_{Pr}

XNDSF - x_{Nd}

XSMSF - x_{Sm}

TMOR - $(M_t)_{org.}$

AMOR - $(M_{HNO_3})_{org.}$

XLAMOR - $(M_{La})_{org.}$

PRMOR - $(M_{Pr})_{org.}$

XNDMOR - $(M_{Nd})_{org.}$

SMMOR - $(M_{Sm})_{org.}$

REMOR - $(M_{RE})_{org.}$

YHNO3 - Y_{HNO_3}

YLA - Y_{La}

YPR - Y_{Pr}

YND - Y_{Nd}

YSM - Y_{Sm}

YRE - Y_{RE}

YLASF - y_{La}

YPRSF - y_{Pr}

YNDSF - y_{Nd}

YSMSF - y_{Sm}

Figure 37. (Continued)

XKTRE - K_t for the system $RE(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{RE}; RE = La, Pr, Nd, Sm

XKARE - K_{HNO_3} for the system $RE(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{aq.}$ and X_{RE}; RE = La, Pr, Nd, Sm

YKTRE - K_t for the system $RE(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{RE}; RE = La, Pr, Nd, Sm

YKARE - K_{HNO_3} for the system $RE(NO_3)_3$ - HNO_3 - TBP - H_2O as a function of $(M_t)_{org.}$ and Y_{RE}; RE = La, Pr, Nd, Sm

BLAPR - β_{La-Pr}

BPRPR - β_{Pr-Pr}

BNDPR - β_{Nd-Pr}

BSMPR - β_{Sm-Pr}

TOTK - K_t

HNO3K - K_{HNO_3}

FTM - $(M_t)_F$

FAM - $(M_{HNO_3})_F$

FLAM - $(M_{La})_F$

FPRM - $(M_{Pr})_F$

FNDM - $(M_{Nd})_F$

FSMM - $(M_{Sm})_F$

FREM - $(M_{RE})_F$

XAF - $(X_{HNO_3})_F$

Figure 37. (Continued)

XLAF - $(X_{La})_F$

XPRF - $(X_{Pr})_F$

XNDF - $(X_{Nd})_F$

XSMF - $(X_{Sm})_F$

XREF - $(X_{RE})_F$

XLASFF - $(x_{La})_F$

XPRSFF - $(x_{Pr})_F$

XNDSFF - $(x_{Nd})_F$

XSMSFF - $(x_{Sm})_F$

For Programs 1 and 3:

R1TM - $(M_t)_{R_1}$

R1AM - $(M_{HNO_3})_{R_1}$

R1LAM - $(M_{La})_{R_1}$

R1PRM - $(M_{Pr})_{R_1}$

R1NDM - $(M_{Nd})_{R_1}$

R1SMM - $(M_{Sm})_{R_1}$

SOTM - $(M_t)_{S_0}$

SOAM - $(M_{HNO_3})_{S_0}$

SOLAM - $(M_{La})_{S_0}$

SOPRM - $(M_{Pr})_{S_0}$

Figure 37. (Continued)

SONDM - $(M_{Nd})_{S_0}$

SOSMM - $(M_{Sm})_{S_0}$

For Programs 2 and 4:

ROTM - $(M_t)_{R_0}$

ROAM - $(M_{HNO_3})_{R_0}$

ROLAM - $(M_{La})_{R_0}$

ROPRM - $(M_{Pr})_{R_0}$

RONDM - $(M_{Nd})_{R_0}$

ROSMM - $(M_{Sm})_{R_0}$

S1TM - $(M_t)_{S_1}$

S1AM - $(M_{HNO_3})_{S_1}$

S1LAM - $(M_{La})_{S_1}$

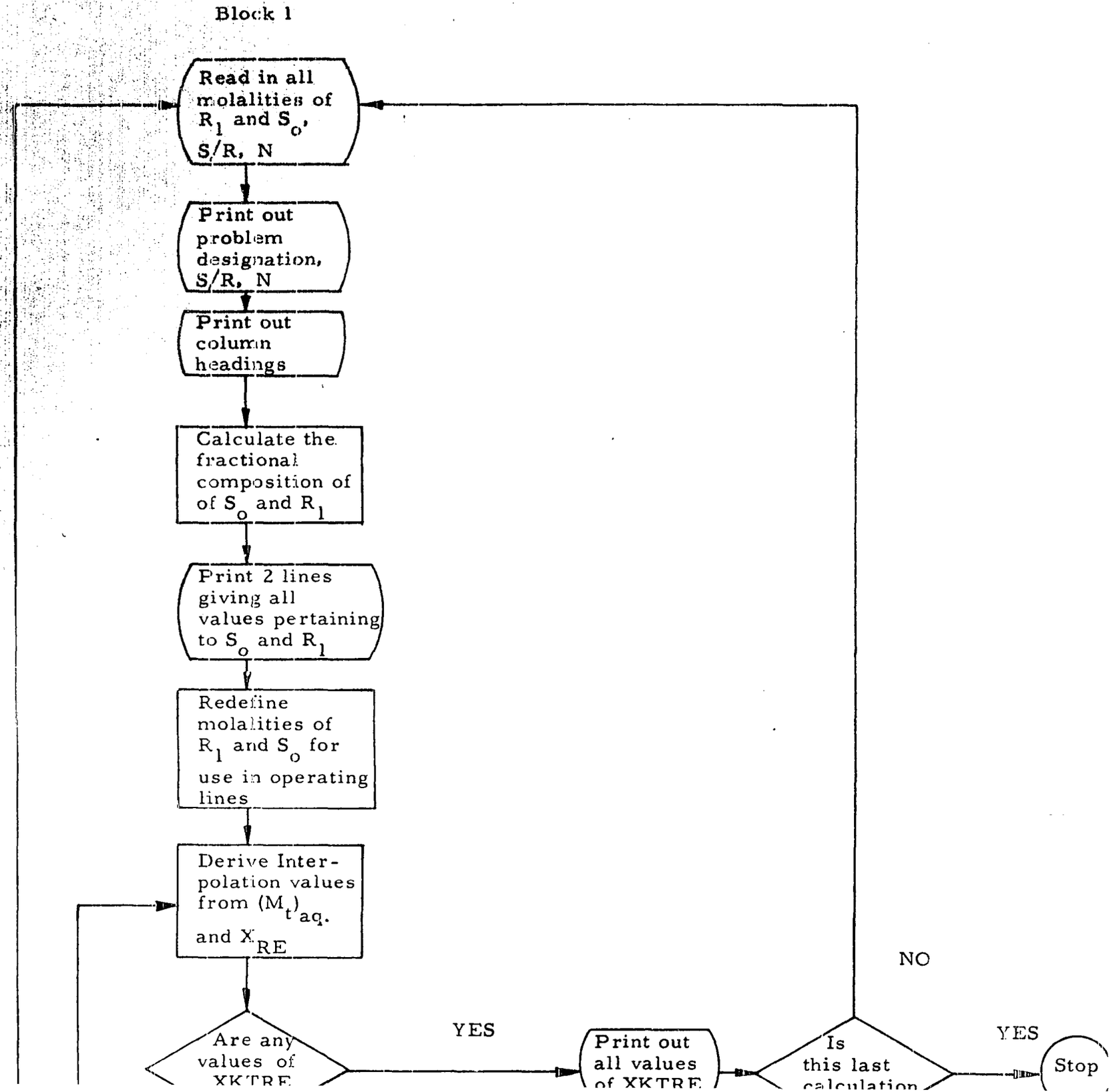
S1PRM - $(M_{Pr})_{S_1}$

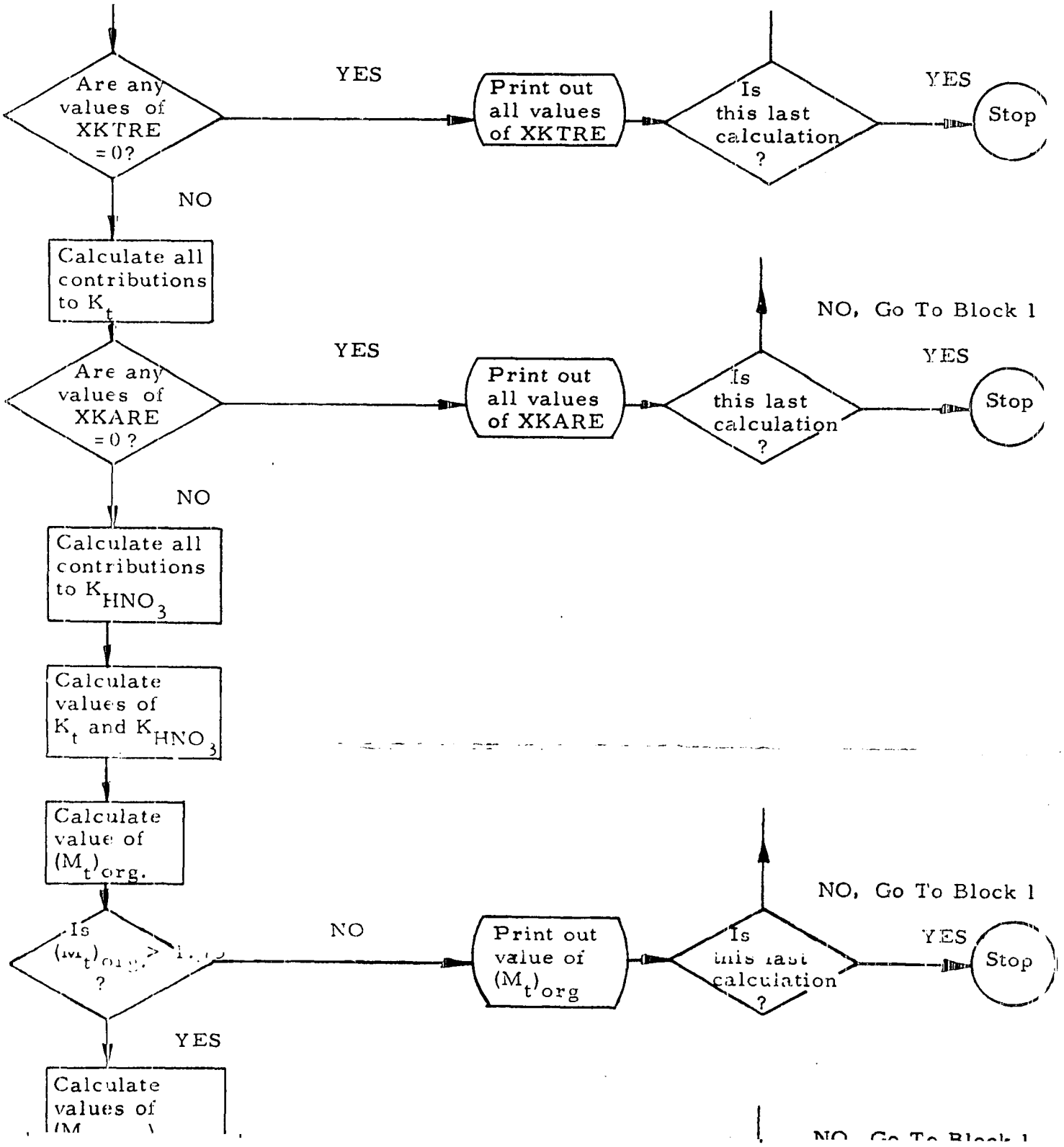
S1NDM - $(M_{Nd})_{S_1}$

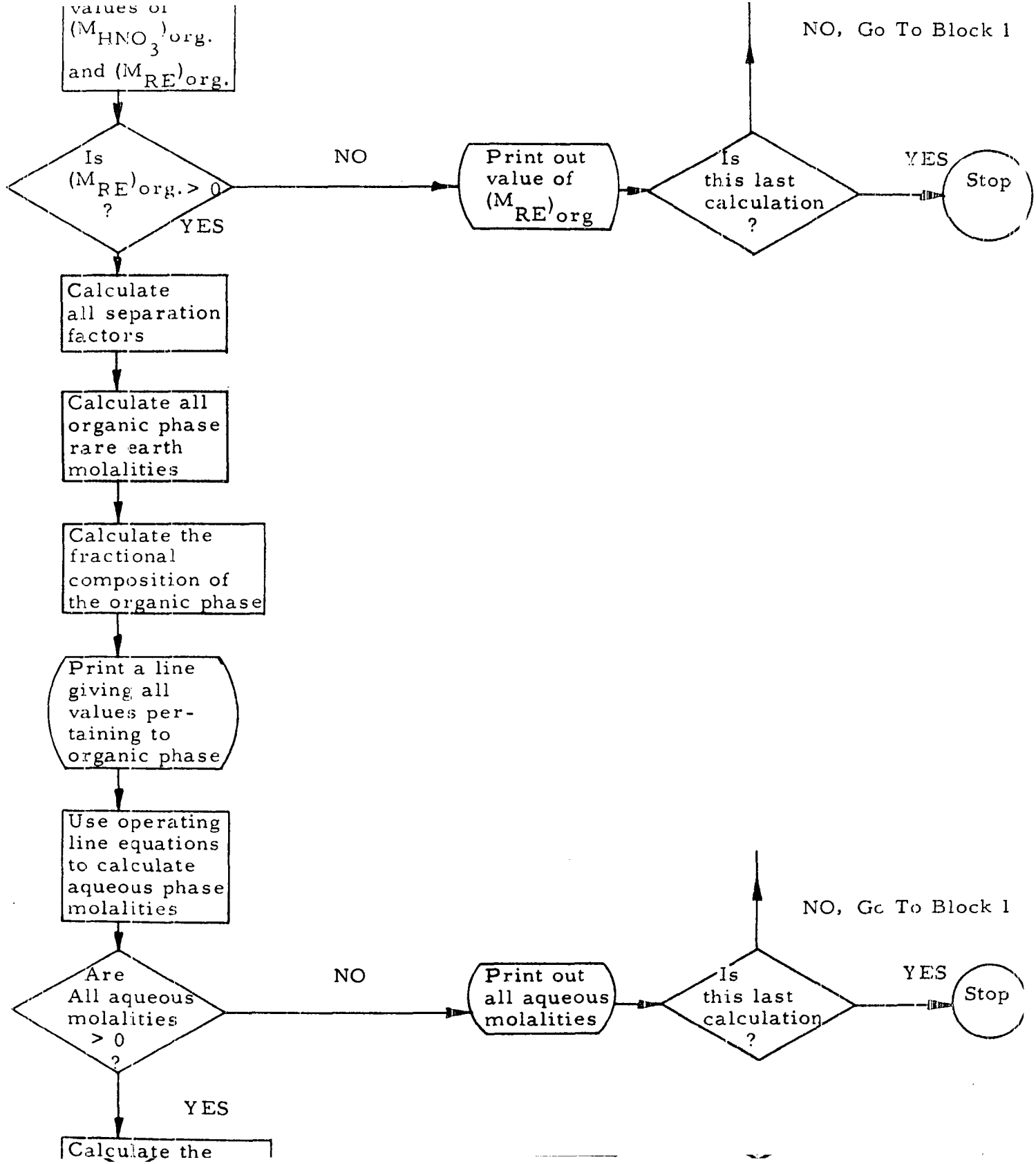
S1SMM - $(M_{Sm})_{S_1}$

Figure 37. (Continued)

Block 1


Read in all molalities of R_1 and S_o, S/R, N
Print out problem designation, S/R, N
Print out column headings
Calculate the fractional composition of of S_o and R_1
Print 2 lines giving all values pertaining to S_o and R_1
Redefine molalities of R_1 and S_o for use in operating lines
Derive Inter-polation values from $(M_t)_{aq.}$ and X_{RE}
Are any values of XKTRE
YES
Print out all values of XKTRE
Is this last calculation
YES
Stop
NO


Are any values of XKTRE = 0?
YES
Print out all values of XKTRE
Is this last calculation ?
YES
Stop
NO
Calculate all contributions to K_t
Are any values of XKARE = 0 ?
YES
Print out all values of XKARE
Is this last calculation ?
NO, Go To Block 1
YES
Stop
NO
Calculate all contributions to K_{HNO_3}
Calculate values of K_t and K_{HNO_3}
Calculate value of $(M_t)_{org.}$
Is $(M_t)_{org.}$?
NO
Print out value of $(M_t)_{org}$
Is this last calculation ?
NO, Go To Block 1
YES
Stop
YES
Calculate values of


values of $(M_{HNO_3})_{org.}$ and $(M_{RE})_{org.}$
Is $(M_{RE})_{org.} > 0$?
NO
Print out value of $(M_{RE})_{org}$
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Calculate all separation factors
Calculate all organic phase rare earth molalities
Calculate the fractional composition of the organic phase
Print a line giving all values pertaining to organic phase
Use operating line equations to calculate aqueous phase molalities
Are All aqueous molalities > 0 ?
NO
Print out all aqueous molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Calculate the

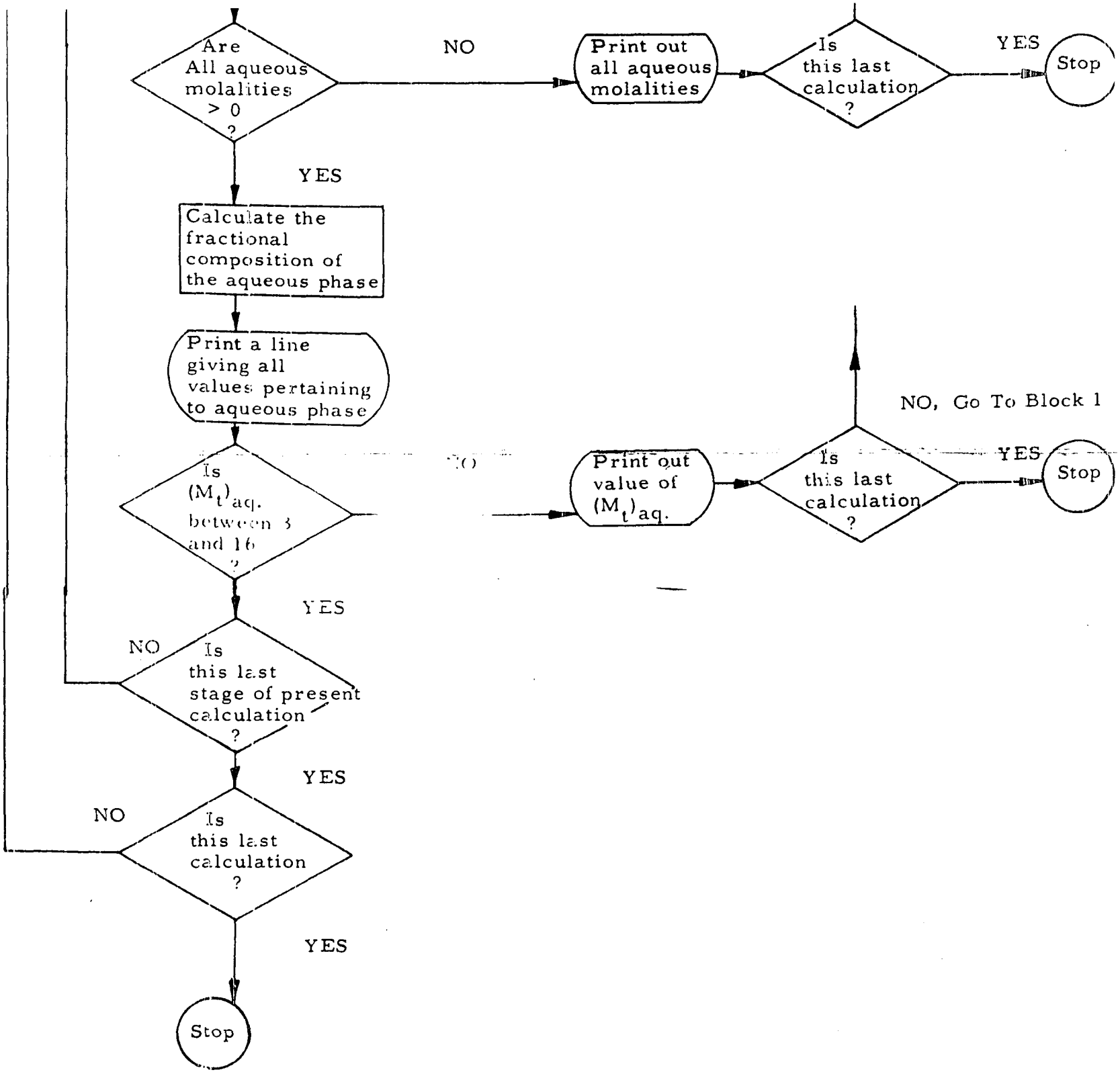


Figure 38. Flow diagram, Program I

```
      DIMENSION XKTLA(21,7),XKTPR(21,7),XKTND(21,7),XKTSM(21,7),XKALA(21BMS1 001
     1,7),XKAPR(21,7),XKAND(21,7),XKASM(21,7)                          BMS1 002
      DO 5 I = 1,21                                                    BMS1  C1
5     READ INPUT TAPE 5, 500, (XKTLA(I,J),J = 1,7)                     BMS1  C2
      DO 10 I = 1,21                                                   BMS1  C3
10    READ INPUT TAPE 5, 500, (XKTPR(I,J),J = 1,7)                     BMS1  C4
      DO 15 I = 1,21                                                   BMS1  C5
15    READ INPUT TAPE 5, 500, (XKTND(I,J),J = 1,7)                     BMS1  C6
      DO 20 I = 1,21                                                   BMS1  C7
20    READ INPUT TAPE 5, 500, (XKTSM(I,J),J = 1,7)                     BMS1  C8
      DO 25 I = 1,21                                                   BMS1  C9
25    READ INPUT TAPE 5, 500, (XKALA(I,J),J = 1,7)                     BMS1 C10
      DO 30 I =1,21                                                    BMS1 C11
30    READ INPUT TAPE 5, 500, (XKAPR(I,J),J = 1,7)                     BMS1 C12
      DO 35 I = 1,21                                                   BMS1 C13
35    READ INPUT TAPE 5, 500, (XKAND(I,J),J = 1,7)                     BMS1 C14
      DO 40 I = 1,21                                                   BMS1 C15
40    READ INPUT TAPE 5, 500, (XKASM(I,J),J = 1,7)                     BMS1 C16
45    READ INPUT TAPE 5, 501, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ BMS1 035
      READ INPUT TAPE 5, 502, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,BMS1 036
     1SOVR,N,K                                                         BMS1 037
      PRINT 503, SOVR,N                                                BMS1 038
      PRINT 504                                                        BMS1 039
      XHNO3 = AMAQ/TMAQ                                                BMS1 040
      XLA = XLAMAQ/TMAQ                                                BMS1 041
      XPR = PRMAQ/TMAQ                                                 BMS1 042
      XND = XNDMAQ/TMAQ                                                BMS1 043
      XSM = SMMAQ/TMAQ                                                 BMS1 044
      XRE = REMAQ/TMAQ                                                 BMS1 045
      SXA = XHNO3 + XLA + XPR + XND + XSM                              BMS1 046
      XLASF = XLAMAQ/REMAQ                                             BMS1 047
      XPRSF = PRMAQ/REMAQ                                              BMS1 048
      XNDSF = XNDMAQ/REMAQ                                             BMS1 049
      XSMSF = SMMAQ/REMAQ                                              BMS1 050
      SXREA = XLASF + XPRSF + XNDSF + XSMSF                            BMS1 051
      YHNO3 = AMOR/TMOR                                                BMS1 052
      YLA = XLAMOR/TMOR                                                BMS1 053
      YPR = PRMOR/TMOR                                                 BMS1 054
      YND = XNDMOR/TMOR                                                BMS1 055
      YSM = SMMOR/TMOR                                                 BMS1 056
      YRE = REMOR/TMOR                                                 BMS1 057
      SYO = YHNO3 + YLA + YPR + YND + YSM                              BMS1 058
      YLASF = XLAMOR/REMOR                                             BMS1 059
      YPRSF = PRMOR/REMOR                                              BMS1 060
      YNDSF = XNDMOR/REMOR                                             BMS1 061
      YSMSF = SMMOR/REMOR                                              BMS1 062
      SYREO = YLASF + YPRSF + YNDSF + YSMSF                            BMS1 063
      PRINT 505, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPRBMS1 064
     1,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF,SYO,SYREO                   BMS1 065
      PRINT 506, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS1 066
     1,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF,SXA,SXREA                   BMS1 067
      R1TH = TMAQ                                                      BMS1 068
      R1AM = AMAQ                                                      BMS1 069
      R1LAM = XLAMAQ                                                   BMS1 070
      R1PRM = PRMAQ                                                    BMS1 071
      R1NDM = XNDMAQ                                                   BMS1 072
      R1SMM = SMMAQ                                                    BMS1 073
      SOTH = TMOR                                                      BMS1 074
      SOAM = AMOR                                                      BMS1 075
      SOLAM = XLAMOR                                                   BMS1 076
      SOPRM = PRMOR                                                    BMS1 077
      SONDM = XNDMOR                                                   BMS1 078
```

Figure 39. Fortran statements, Program I

```
      SQSMM = SMMOR                                                          BMS1 079
50    DO 150 L = 1,N                                                         BMS1 080
      XREI = (XRE*100.0 + 5.0)/5.0                                           BMS1 081
      IX = XREI                                                              BMS1 082
      XI = IX                                                                BMS1 083
      FRX = XREI - XI                                                        BMS1 084
55    IF(5.0 - TMAQ) 60,70,65                                                BMS1 085
60    IF(7.0 - TMAQ) 75,75,70                                                BMS1 086
65    Z = TMAQ - 2.0                                                         BMS1 087
      GO TO 80                                                               BMS1 088
70    Z = (TMAQ + 1.0)/2.0                                                   BMS1 089
      GO TO 80                                                               BMS1 090
75    Z = (TMAQ + 5.0)/3.0                                                   BMS1 091
80    KZ = Z                                                                 BMS1 092
      ZK = KZ                                                                BMS1 093
      FRZ = Z - ZK                                                           BMS1 094
      SKT = MIN1F(XKTLA(IX,KZ),XKTLA(IX+1,KZ),XKTLA(IX,KZ+1),XKTLA(IX+1,BMS1 095
     1KZ+1),XKTPR(IX,KZ),XKTPR(IX+1,KZ),XKTPR(IX,KZ+1),XKTPR(IX+1,KZ+1),BMS1 096
     2XKTND(IX,KZ),XKTND(IX+1,KZ),XKTND(IX,KZ+1),XKTND(IX+1,KZ+1),XKTSM(BMS1 097
     3IX,KZ),XKTSM(IX+1,KZ),XKTSM(IX,KZ+1),XKTSM(IX+1,KZ+1))                BMS1 098
      IF(SKT) 85,85,90                                                       BMS1 099
85    PRINT 507, XKTLA(IX,KZ),XKTLA(IX+1,KZ),XKTLA(IX,KZ+1),XKTLA(IX+1,KBMS1 100
     1Z+1),XKTPR(IX,KZ),XKTPR(IX+1,KZ),XKTPR(IX,KZ+1),XKTPR(IX+1,KZ+1),XBMS1 101
     2KTND(IX,KZ),XKTND(IX+1,KZ),XKTND(IX,KZ+1),XKTND(IX+1,KZ+1),XKTSM(IBMS1 102
     3X,KZ),XKTSM(IX+1,KZ),XKTSM(IX,KZ+1),XKTSM(IX+1,KZ+1),TMAQ,XRE        BMS1 103
      IF(K) 495,495,45                                                       BMS1 104
90    XKTLA1 = XKTLA(IX,KZ)*(1.0 - FRX) + XKTLA(IX+1,KZ)*FRX                 BMS1 105
      XKTLA2 = XKTLA(IX,KZ+1)*(1.0 - FRX) + XKTLA(IX+1,KZ+1)*FRX             BMS1 106
      XKTLA3 = XKTLA1*(1.0 - FRZ) + XKTLA2*FRZ                               BMS1 107
      CKTLA = XKTLA3 * XLASF                                                 BMS1 108
      XKTPR1 = XKTPR(IX,KZ)*(1.0 - FRX) + XKTPR(IX+1,KZ)*FRX                 BMS1 109
      XKTPR2 = XKTPR(IX,KZ+1)*(1.0 - FRX) + XKTPR(IX+1,KZ+1)*FRX             BMS1 110
      XKTPR3 = XKTPR1*(1.0 - FRZ) + XKTPR2*FRZ                               BMS1 111
      CKTPR = XKTPR3 * XPRSF                                                 BMS1 112
      XKTND1 = XKTND(IX,KZ)*(1.0 - FRX) + XKTND(IX+1,KZ)*FRX                 BMS1 113
      XKTND2 = XKTND(IX,KZ+1)*(1.0 - FRX) + XKTND(IX+1,KZ+1)*FRX             BMS1 114
      XKTND3 = XKTND1*(1.0 - FRZ) + XKTND2*FRZ                               BMS1 115
      CKTND = XKTND3 * XNDSF                                                 BMS1 116
      XKTSM1 = XKTSM(IX,KZ)*(1.0 - FRX) + XKTSM(IX+1,KZ)*FRX                 BMS1 117
      XKTSM2 = XKTSM(IX,KZ+1)*(1.0 - FRX) + XKTSM(IX+1,KZ+1)*FRX             BMS1 118
      XKTSM3 = XKTSM1*(1.0 - FRZ) + XKTSM2*FRZ                               BMS1 119
      CKTSM = XKTSM3 * XSMSF                                                 BMS1 120
      SKA = MIN1F(XKALA(IX,KZ),XKALA(IX+1,KZ),XKALA(IX,KZ+1),XKALA(IX+1,BMS1 121
     1KZ+1),XKAPR(IX,KZ),XKAPR(IX+1,KZ),XKAPR(IX,KZ+1),XKAPR(IX+1,KZ+1),BMS1 122
     2XKAND(IX,KZ),XKAND(IX+1,KZ),XKAND(IX,KZ+1),XKAND(IX+1,KZ+1),XKASM(BMS1 123
     3IX,KZ),XKASM(IX+1,KZ),XKASM(IX,KZ+1),XKASM(IX+1,KZ+1))                BMS1 124
      IF(SKA) 95,95,100                                                      BMS1 125
95    PRINT 508, XKALA(IX,KZ),XKALA(IX+1,KZ),XKALA(IX,KZ+1),XKALA(IX+1,KBMS1 126
     1Z+1),XKAPR(IX,KZ),XKAPR(IX+1,KZ),XKAPR(IX,KZ+1),XKAPR(IX+1,KZ+1),XBMS1 127
     2KAND(IX,KZ),XKAND(IX+1,KZ),XKAND(IX,KZ+1),XKAND(IX+1,KZ+1),XKASM(IBMS1 128
     3X,KZ),XKASM(IX+1,KZ),XKASM(IX,KZ+1),XKASM(IX+1,KZ+1),TMAQ,XRE        BMS1 129
      IF(K) 495,495,45                                                       BMS1 130
100   XKALA1 = XKALA(IX,KZ)*(1.0 - FRX) + XKALA(IX+1,KZ)*FRX                 BMS1 131
      XKALA2 = XKALA(IX,KZ+1)*(1.0 - FRX) + XKALA(IX+1,KZ+1)*FRX             BMS1 132
      XKALA3 = XKALA1*(1.0 - FRZ) + XKALA2*FRZ                               BMS1 133
      CKALA = XKALA3 * XLASF                                                 BMS1 134
      XKAPR1 = XKAPR(IX,KZ)*(1.0 - FRX) + XKAPR(IX+1,KZ)*FRX                 BMS1 135
      XKAPR2 = XKAPR(IX,KZ+1)*(1.0 - FRX) + XKAPR(IX+1,KZ+1)*FRX             BMS1 136
      XKAPR3 = XKAPR1*(1.0 - FRZ) + XKAPR2*FRZ                               BMS1 137
      CKAPR = XKAPR3 * XPRSF                                                 BMS1 138
      XKAND1 = XKAND(IX,KZ)*(1.0 - FRX) + XKAND(IX+1,KZ)*FRX                 BMS1 139
      XKAND2 = XKAND(IX,KZ+1)*(1.0 - FRX) + XKAND(IX+1,KZ+1)*FRX             BMS1 140
```

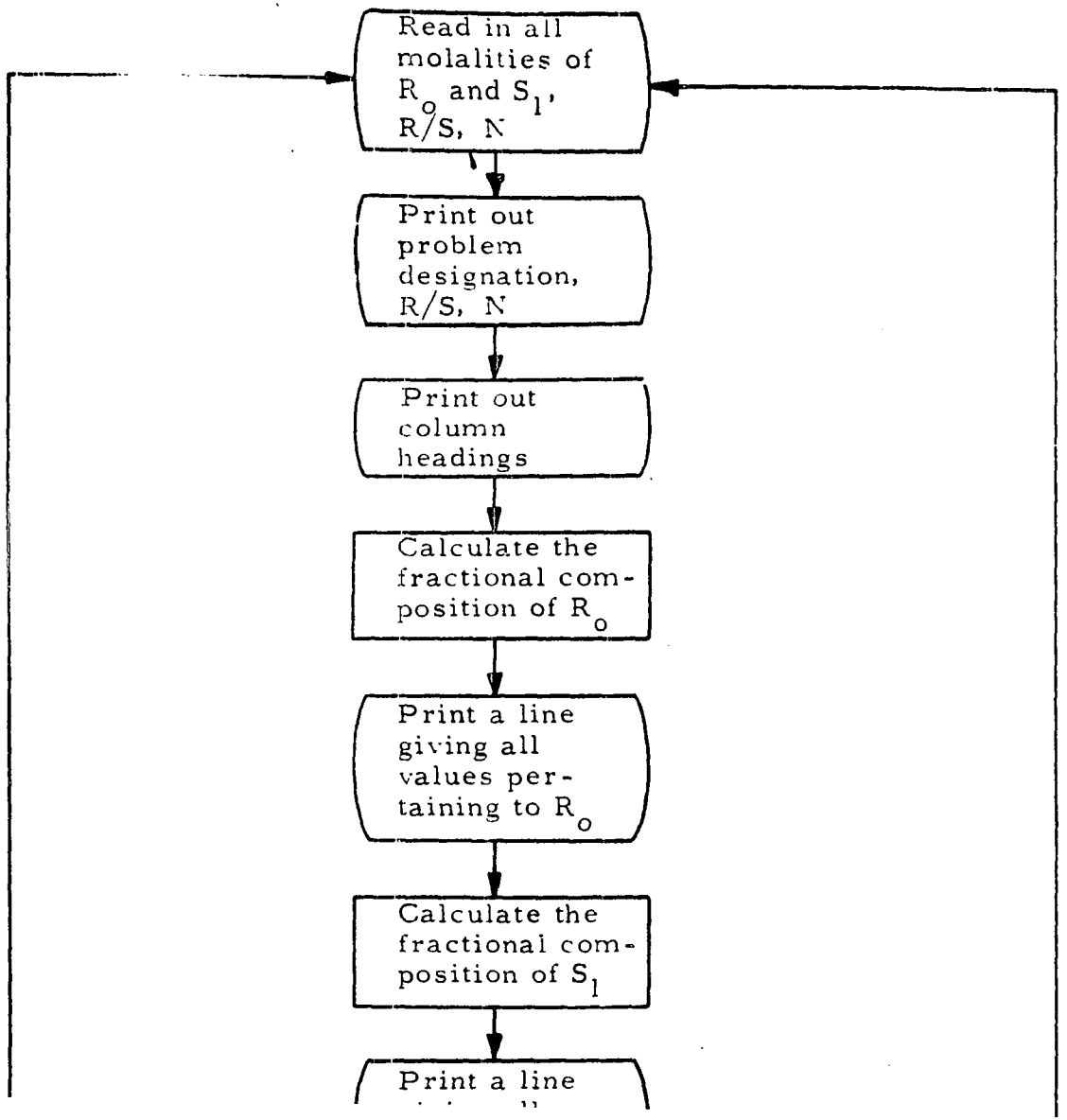
Figure 39. (Continued)

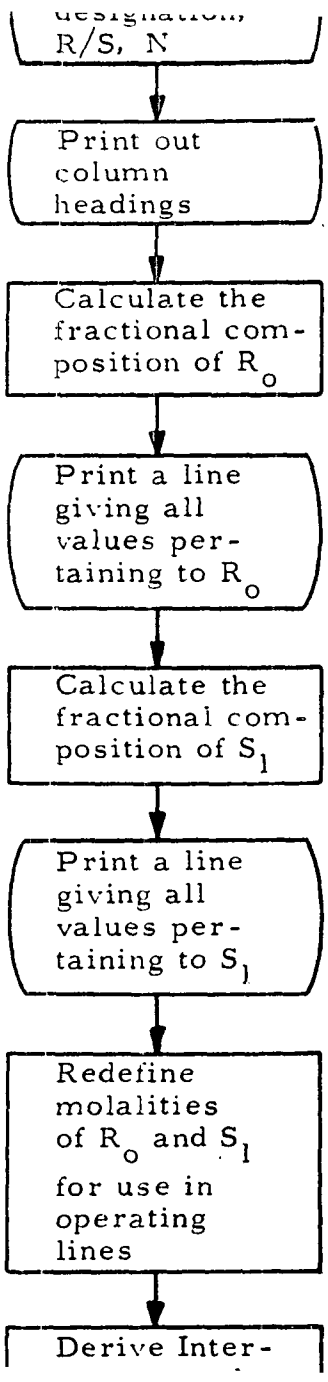
```
      XKAND3 = XKAND1*(1.0 - FRZ) + XKAND2*FRZ                                  BMS1 141
      CKAND = XKAND3 * XNDSF                                                    BMS1 142
      XKASM1 = XKASM(IX,KZ)*(1.0 - FRX) + XKASM(IX+1,KZ)*FRX                    BMS1 143
      XKASM2 = XKASM(IX,KZ+1)*(1.0 - FRX) + XKASM(IX+1,KZ+1)*FRX                BMS1 144
      XKASM3 = XKASM1*(1.0 - FRZ) + XKASM2*FRZ                                  BMS1 145
      CKASM = XKASM3 * XSMSF                                                    BMS1 146
      TOTK = CKTLA + CKTPR + CKTND + CKTSM                                      BMS1 147
      HNO3K = CKALA + CKAPR + CKAND + CKASM                                     BMS1 148
      TMOR = TMAQ*TOTK                                                          BMS1 149
      IF(TMOR - 1.75) 105,110,110                                               BMS1 150
105   PRINT 509, TMOR,TMAQ,TOTK                                                 BMS1 151
      IF(K) 495,495,45                                                          BMS1 152
110   AMOR = AMAQ*HNO3K                                                         BMS1 153
      REMOR = TMOR - AMOR                                                       BMS1 154
      IF(REMOR) 115,115,120                                                     BMS1 155
115   PRINT 510, TMOR,AMOR,REMOR,HNO3K                                          BMS1 156
      IF(K) 495,495,45                                                          BMS1 157
120   BLAPR = 0.8187 - 0.1106*TMOR                                              BMS1 158
      BPRPR = 1.0                                                               BMS1 159
      BNDPR = 1.0448 + 0.09874*TMOR                                             BMS1 160
      BSMPR = -0.3795 + 0.9214*TMOR                                             BMS1 161
      DEMS = XLAMAQ*BLAPR + PRMAQ*BPRPR + XNDMAQ*BNDPR + SMMAQ*BSMPR            BMS1 162
      XLAMOR = REMOR*BLAPR*XLAMAQ/DEMS                                          BMS1 163
      PRMOR = REMOR*BPRPR*PRMAQ/DEMS                                            BMS1 164
      XNDMOR = REMOR*BNDPR*XNDMAQ/DEMS                                          BMS1 165
      SMMOR = REMOR*BSMPR*SMMAQ/DEMS                                            BMS1 166
      YHNO3 = AMOR/TMOR                                                         BMS1 167
      YLA = XLAMOR/TMOR                                                         BMS1 168
      YPR = PRMOR/TMOR                                                          BMS1 169
      YND = XNDMOR/TMOR                                                         BMS1 170
      YSM = SMMOR/TMOR                                                          BMS1 171
      YRE = REMOR/TMOR                                                          BMS1 172
      SYO = YHNO3 + YLA + YPR + YND + YSM                                       BMS1 173
      YLASF = XLAMOR/REMOR                                                      BMS1 174
      YPRSF = PRMOR/REMOR                                                       BMS1 175
      YNDSF = XNDMOR/REMOR                                                      BMS1 176
      YSMSF = SMMOR/REMOR                                                       BMS1 177
      SYREO = YLASF + YPRSF + YNDSF + YSMSF                                     BMS1 178
      PRINT 511,L,TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPBMS1 179
     1R,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF,SYO,SYREO                           BMS1 180
      TMAQ = TMOR*SOVR - SOTM*SOVR + R1TM                                       BMS1 181
      AMAQ = AMOR*SOVR - SOAM*SOVR + R1AM                                       BMS1 182
      XLAMAQ = XLAMOR*SOVR - SOLAM*SOVR + R1LAM                                 BMS1 183
      PRMAQ = PRMOR*SOVR  - SOPRM*SOVR + R1PRM                                  BMS1 184
      XNDMAQ = XNDMOR*SOVR - SONDM*SOVR + R1NDM                                 BMS1 185
      SMMAQ = SMMOR*SOVR - SOSMM*SOVR + R1SMM                                   BMS1 186
      REMAQ = TMAQ - AMAQ                                                       BMS1 187
      SAM = MIN1F(TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ)                    BMS1 188
      IF(SAM) 125,125,130                                                       BMS1 189
125   PRINT 512,TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                       BMS1 190
      IF(K) 495,495,45                                                          BMS1 191
130   XHNO3 = AMAQ/TMAQ                                                         BMS1 192
      XLA = XLAMAQ/TMAQ                                                         BMS1 193
      XPR = PRMAQ/TMAQ                                                          BMS1 194
      XND = XNDMAQ/TMAQ                                                         BMS1 195
      XSM = SMMAQ/TMAQ                                                          BMS1 196
      XRE = REMAQ/TMAQ                                                          BMS1 197
      SXA = XHNO3 + XLA + XPR + XND + XSM                                       BMS1 198
      XLASF = XLAMAQ/REMAQ                                                      BMS1 199
      XPRSF = PRMAQ/REMAQ                                                       BMS1 200
      XNDSF = XNDMAQ/REMAQ                                                      BMS1 201
      XSMSF = SMMAQ/REMAQ                                                       BMS1 202
```

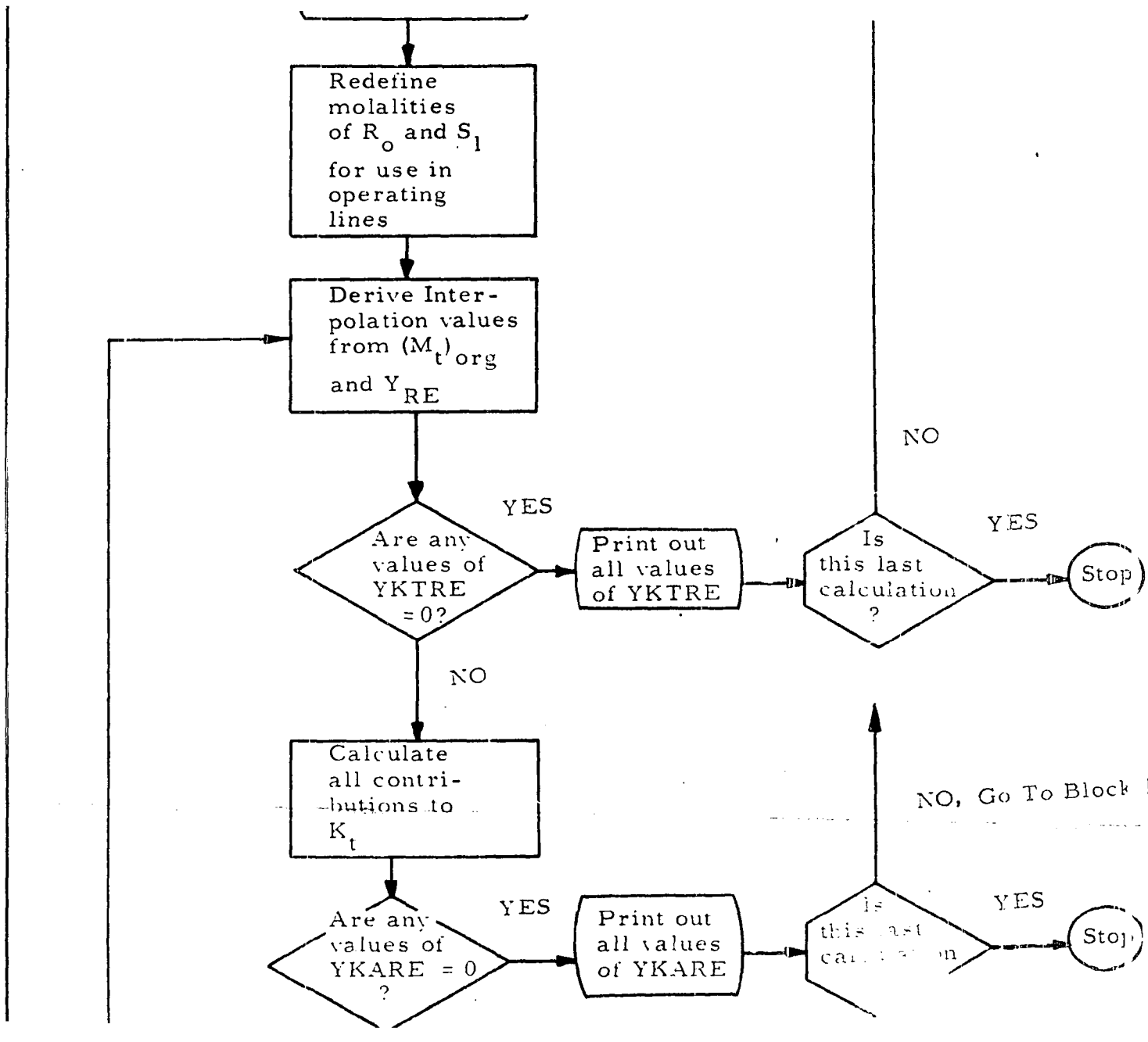
Figure 39. (Continued)

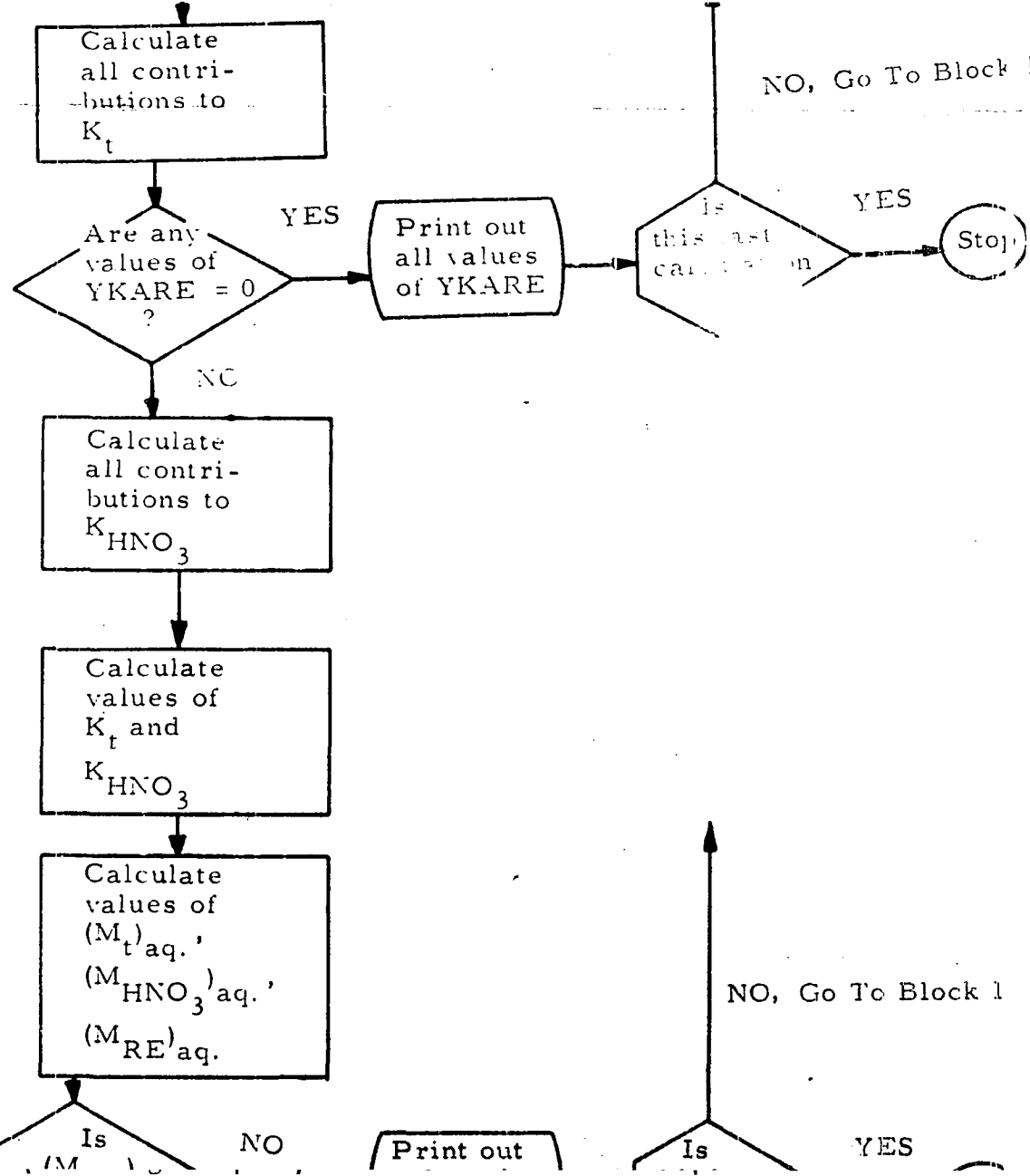
```
      SXREA = XLASF + XPRSF + XNDSF + XSMSF                                  BMS1 203
      LL = L+1                                                               BMS1 204
      PRINT 513,LL,TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XBMS1 205
     1PR,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF,SXA,SXREA                       BMS1 206
      IF(TMAQ - 3.0) 135,140,140                                             BMS1 207
135   PRINT 514, TMAQ                                                        BMS1 208
      IF(K) 495,495,45                                                       BMS1 209
140   IF(TMAQ - 16.0) 150,145,145                                            BMS1 210
145   PRINT 514,TMAQ                                                         BMS1 211
      IF(K) 495,495,45                                                       BMS1 212
150   CONTINUE                                                               BMS1 213
      IF(K)495,495,45                                                        BMS1 214
500   FORMAT (7F10.3)                                                        BMS1 217
501   FORMAT (7F9.4)                                                         BMS1 218
502   FORMAT (7F7.4,F8.4,I3,I3)                                              BMS1 219
503   FORMAT (31H1EXTRACT SIDE CALCULATION SOVR= F8.4,4H  N= I3)             BMS1 220
504   FORMAT (120HJ   TOTALMOLHNO3 MOL  LA MOL  PR MOL  ND MOL  SM MOL  BMS1 221
     1RE MOL ACFR LAFR PRFR NDFR SMFR REFRLA/REPR/REND/RESM/RE STFRSREFRBMS1 222
     2)                                                                     BMS1 223
505   FORMAT (4HJS 0 7F8.4,12F5.3)                                           BMS1 224
506   FORMAT (4H R 1 7F8.4,12F5.3)                                           BMS1 225
507   FORMAT (8HJXKTRE=0 16F6.3,F8.4,F6.3)                                   BMS1 226
508   FORMAT (8HJXKARE=0 16F6.3,F8.4,F6.3)                                   BMS1 227
509   FORMAT (6HJTMOR= F10.4,6H TMAQ= F8.4,6H TOTK= F8.4)                    BMS1 228
510   FORMAT (6HJTMOR= F10.4,6H AMOR= F10.8,7H REMOR= F10.8,7H HNO3K= F1BMS1 229
     10.8)                                                                  BMS1 230
511   FORMAT (2HJS I2,7F8.4,12F5.3)                                          BMS1 231
512   FORMAT (6HJTMAQ= F10.4,6H AMAQ= F10.4,8H XLAMAQ= F10.4,7H PRMAQ= FBMS1 232
     110.4,8H XNDMAQ= F10.4,7H SMMAQ= F10.4,7H REMAQ= F10.4)                BMS1 233
513   FORMAT (2H R I2,7F8.4,12F5.3)                                          BMS1 234
514   FORMAT (6HJTMAQ= F10.4)                                                BMS1 235
495   STOP 89                                                                BMS1 215
      END                                                                    BMS1 216
```

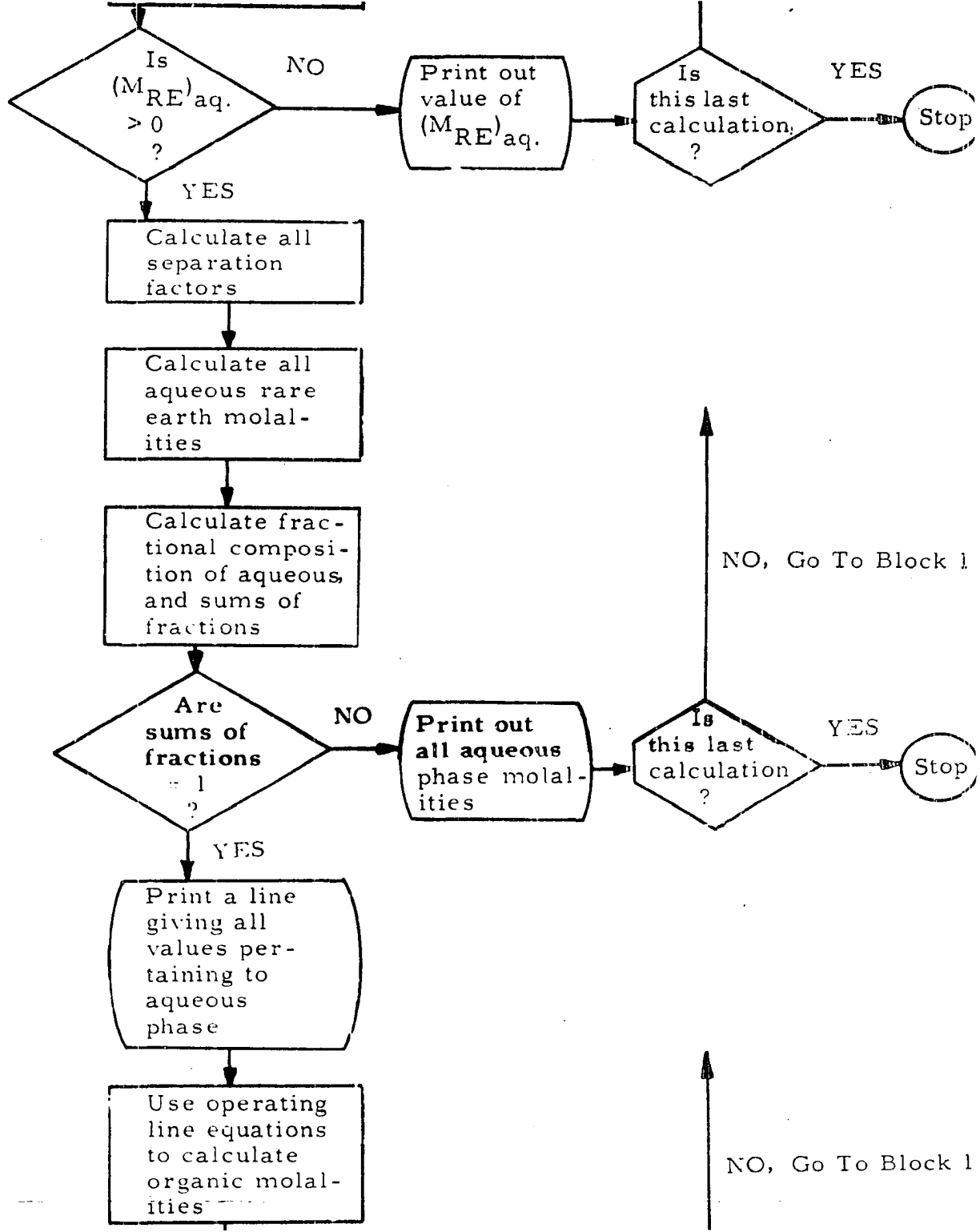
Figure 39. (Continued)

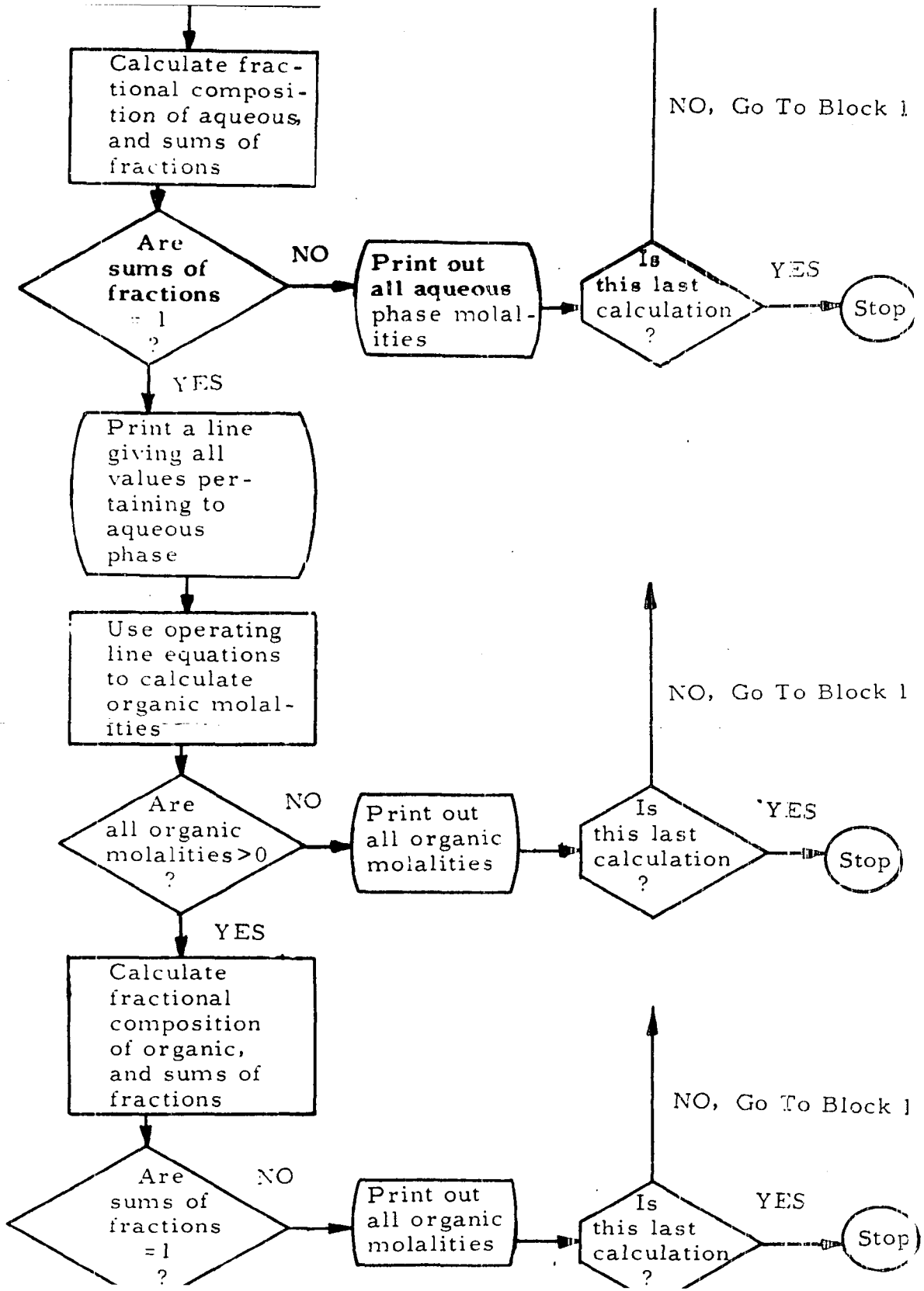

Read in all molalities of R_o and S_1, R/S, N
Print out problem designation, R/S, N
Print out column headings
Calculate the fractional composition of R_o
Print a line giving all values pertaining to R_o
Calculate the fractional composition of S_1
Print a line

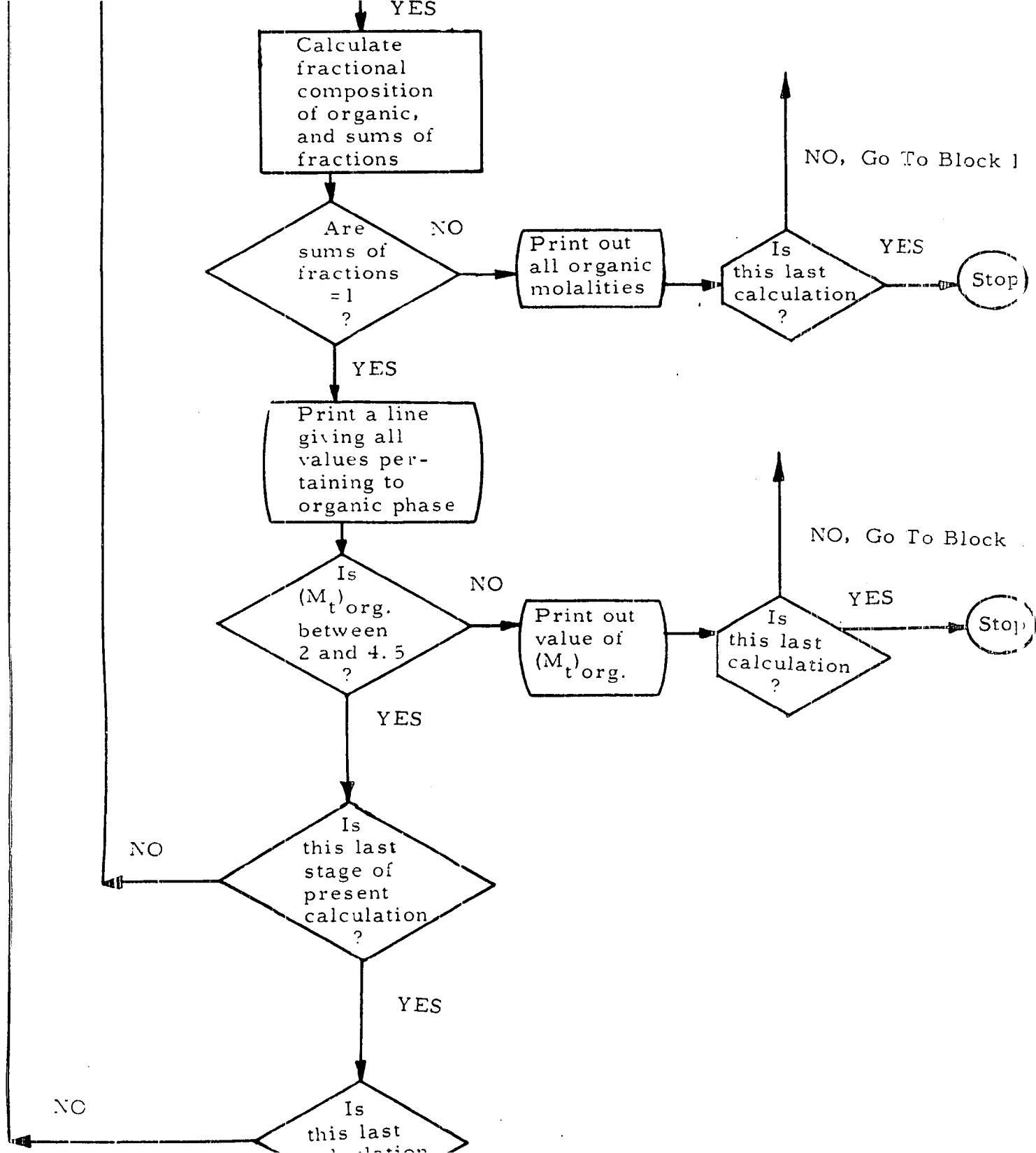

designation,
R/S, N
Print out column headings
Calculate the fractional composition of R_o
Print a line giving all values pertaining to R_o
Calculate the fractional composition of S_1
Print a line giving all values pertaining to S_1
Redefine molalities of R_o and S_1 for use in operating lines
Derive Inter-


Redefine molalities of R_o and S_1 for use in operating lines
Derive Interpolation values from $(M_t)_{org}$ and Y_{RE}
Are any values of YKTRE = 0?
YES
Print out all values of YKTRE
Is this last calculation ?
YES
Stop
NO
NO
Calculate all contributions to K_t
Are any values of YKARE = 0 ?
YES
Print out all values of YKARE
Is this last calculation ?
YES
Stop
NO, Go To Block 1


Calculate all contributions to K_t
Are any values of YKARE = 0 ?
YES
Print out all values of YKARE
Is this last case
YES
Stop
NO, Go To Block 1
NO
Calculate all contributions to K_{HNO_3}
Calculate values of K_t and K_{HNO_3}
Calculate values of $(M_t)_{aq.}$, $(M_{HNO_3})_{aq.}$, $(M_{RE})_{aq.}$
Is
NO
Print out
Is
YES
NO, Go To Block 1


Is $(M_{RE})_{aq.} > 0$?
NO
Print out value of $(M_{RE})_{aq.}$
Is this last calculation ?
YES
Stop
YES
Calculate all separation factors
Calculate all aqueous rare earth molalities
Calculate fractional composition of aqueous, and sums of fractions
NO, Go To Block 1
Are sums of fractions = 1 ?
NO
Print out all aqueous phase molalities
Is this last calculation ?
YES
Stop
YES
Print a line giving all values pertaining to aqueous phase
Use operating line equations to calculate organic molalities
NO, Go To Block 1


Calculate fractional composition of aqueous, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all aqueous phase molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Print a line giving all values pertaining to aqueous phase
Use operating line equations to calculate organic molalities
Are all organic molalities>0 ?
NO
Print out all organic molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Calculate fractional composition of organic, and sums of fractions
Are sums of fractions =1 ?
NO
Print out all organic molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1


YES
Calculate fractional composition of organic, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all organic molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Print a line giving all values pertaining to organic phase
Is $(M_t)_{org.}$ between 2 and 4.5 ?
NO
Print out value of $(M_t)_{org.}$
Is this last calculation ?
YES
Stop
NO, Go To Block
YES
Is this last stage of present calculation ?
NO
YES
Is this last
NO

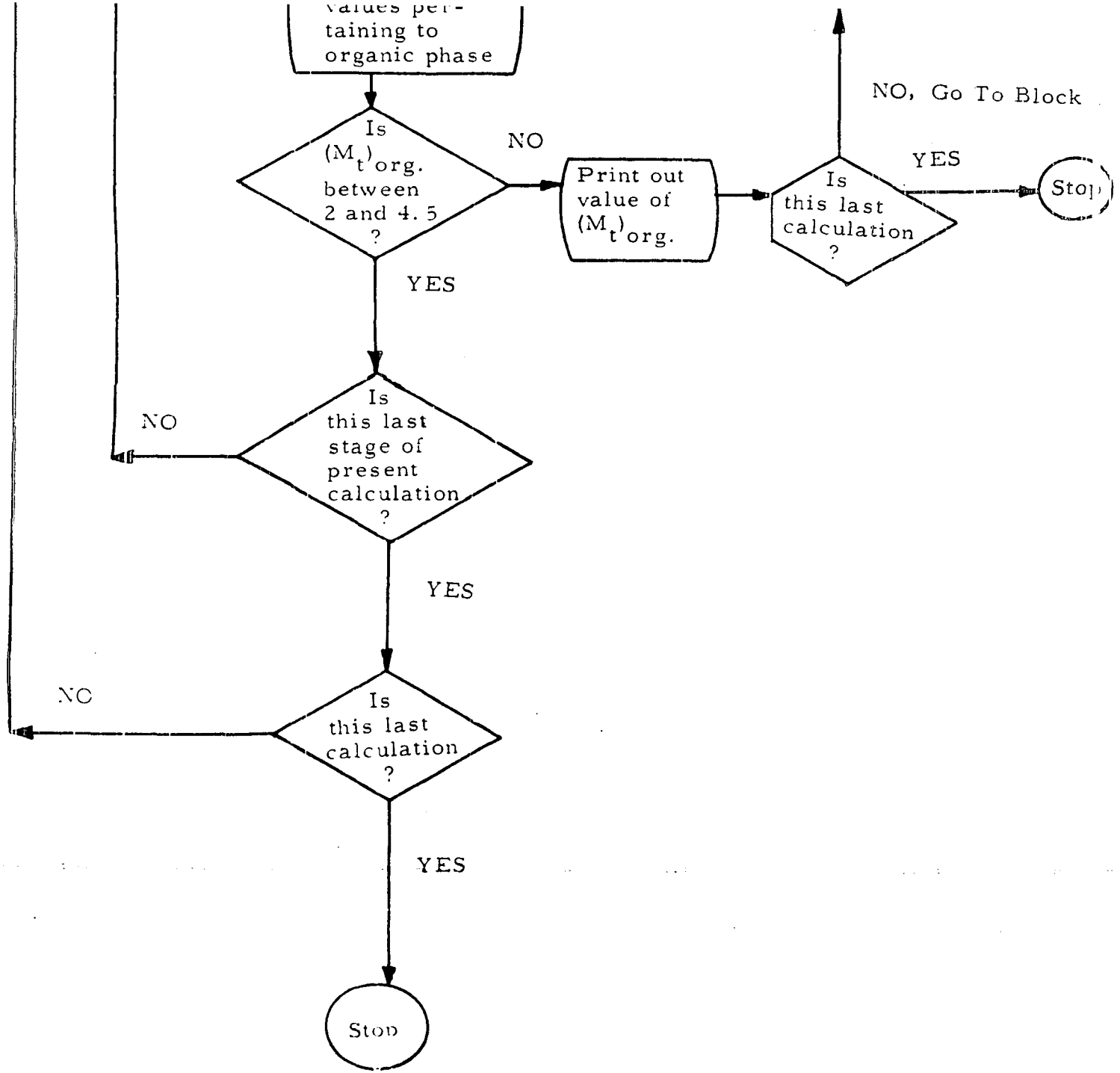


Figure 40. Flow diagram, Program II

```
      DIMENSION YKTLA(21,6),YKTPR(21,6),YKTND(21,6),YKTSM(21,6),YKALA(21BMS2 001
     1,6),YKAPR(21,6),YKAND(21,6),YKASM(21,6)                          BMS2 002
      DO 5 I = 1,21                                                    BMS2 003
5     READ INPUT TAPE 5, 500, (YKTLA(I,J),J = 1,6)                     BMS2 004
      DO 10 I = 1,21                                                   BMS2 005
10    READ INPUT TAPE 5, 500, (YKTPR(I,J),J = 1,6)                     BMS2 006
      DO 15 I = 1,21                                                   BMS2 007
15    READ INPUT TAPE 5, 500, (YKTND(I,J),J = 1,6)                     BMS2 008
      DO 20 I = 1,21                                                   BMS2 009
20    READ INPUT TAPE 5, 500, (YKTSM(I,J),J = 1,6)                     BMS2 010
      DO 25 I = 1,21                                                   BMS2 011
25    READ INPUT TAPE 5, 500, (YKALA(I,J),J = 1,6)                     BMS2 012
      DO 30 I = 1,21                                                   BMS2 013
30    READ INPUT TAPE 5, 500, (YKAPR(I,J),J = 1,6)                     BMS2 014
      DO 35 I = 1,21                                                   BMS2 015
35    READ INPUT TAPE 5, 500, (YKAND(I,J),J = 1,6)                     BMS2 016
      DO 40 I = 1,21                                                   BMS2 017
40    READ INPUT TAPE 5, 500, (YKASM(I,J),J = 1,6)                     BMS2 018
45    READ INPUT TAPE 5, 501, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ BMS2 019
      READ INPUT TAPE 5, 502, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,BMS2 020
     1ROVS,N,K                                                         BMS2 021
      PRINT 503, ROVS,N                                                BMS2 022
      PRINT 504                                                        BMS2 023
      IF(TMAQ) 600,65,50                                               BMS2 024
50    XHNO3 = AMAQ/TMAQ                                                BMS2 025
      XLA = XLAMAQ/TMAQ                                                BMS2 026
      XPR = PRMAQ/TMAQ                                                 BMS2 027
      XND = XNDMAQ/TMAQ                                                BMS2 028
      XSM = SMMAQ/TMAQ                                                 BMS2 029
      XRE = REMAQ/TMAQ                                                 BMS2 030
      IF(REMAQ) 600,60,55                                              BMS2 031
55    XLASF = XLAMAQ/REMAQ                                             BMS2 032
      XPRSF = PRMAQ/REMAQ                                              BMS2 033
      XNDSF = XNDMAQ/REMAQ                                             BMS2 034
      XSMSF = SMMAQ/REMAQ                                              BMS2 035
      PRINT 505, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS2 036
     1,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                             BMS2 037
      GO TO 70                                                         BMS2 038
60    PRINT 506, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS2 039
     1,XND,XSM,XRE                                                     BMS2 040
      GO TO 70                                                         BMS2 041
65    PRINT 507, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ            BMS2 042
70    YHNO3 = AMOR/TMOR                                                BMS2 043
      YLA = XLAMOR/TMOR                                                BMS2 044
      YPR = PRMOR/TMOR                                                 BMS2 045
      YND = XNDMOR/TMOR                                                BMS2 046
      YSM = SMMOR/TMOR                                                 BMS2 047
      YRE = REMOR/TMOR                                                 BMS2 048
      YLASF = XLAMOR/REMOR                                             BMS2 049
      YPRSF = PRMOR/REMOR                                              BMS2 050
      YNDSF = XNDMOR/REMOR                                             BMS2 051
      YSMSF = SMMOR/REMOR                                              BMS2 052
      PRINT 508, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPRBMS2 053
     1,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                             BMS2 054
      ROTM = TMAQ                                                      BMS2 055
      ROAM = AMAQ                                                      BMS2 056
      ROLAM = XLAMAQ                                                   BMS2 057
      ROPRM = PRMAQ                                                    BMS2 058
      RONDM = XNDMAQ                                                   BMS2 059
      ROSMM = SMMAQ                                                    BMS2 060
      S1TM = TMOR                                                      BMS2 061
      S1AM = AMOR                                                      BMS2 062
```

Figure 41. Fortran statements, Program II

```
      S1LAM = XLAMOR                                                    BMS2 063
      S1PRM = PRMOR                                                     BMS2 064
      S1NDM = XNDMOR                                                    BMS2 065
      S1SMM = SMMOR                                                     BMS2 066
      DO 185 L = 1,N                                                    BMS2 067
      YREI = (YRE*100.0 + 5.01/5.0                                      BMS2 068
      IY = YREI                                                         BMS2 069
      YI = IY                                                           BMS2 070
      FRY = YREI - YI                                                   BMS2 071
      Z = (TMOR*10.0 - 15.0)/5.0                                        BMS2 072
      KZ = Z                                                            BMS2 073
      ZK = KZ                                                           BMS2 074
      FRZ = Z - ZK                                                      BMS2 075
      SKT = MIN1F(YKTLA(IY,KZ),YKTLA(IY+1,KZ),YKTLA(IY,KZ+1),YKTLA(IY+1,BMS2 076
     1KZ+1),YKTPR(IY,KZ),YKTPR(IY+1,KZ),YKTPR(IY,KZ+1),YKTPR(IY+1,KZ+1),BMS2 077
     2YKTND(IY,KZ),YKTND(IY+1,KZ),YKTND(IY,KZ+1),YKTND(IY+1,KZ+1),YKTSM(BMS2 078
     3IY,KZ),YKTSM(IY+1,KZ),YKTSM(IY,KZ+1),YKTSM(IY+1,KZ+1))           BMS2 079
      IF (SKT) 75,75,80                                                 BMS2 080
75    PRINT 509, YKTLA(IY,KZ),YKTLA(IY+1,KZ),YKTLA(IY,KZ+1),YKTLA(IY+1,KBMS2 081
     1Z+1),YKTPR(IY,KZ),YKTPR(IY+1,KZ),YKTPR(IY,KZ+1),YKTPR(IY+1,KZ+1),YBMS2 082
     2KTND(IY,KZ),YKTND(IY+1,KZ),YKTND(IY,KZ+1),YKTND(IY+1,KZ+1),YKTSM(IBMS2 083
     3Y,KZ),YKTSM(IY+1,KZ),YKTSM(IY,KZ+1),YKTSM(IY+1,KZ+1),TMOR,YRE    BMS2 084
      IF (K) 600,600,45                                                 BMS2 085
80    YKTLA1 = YKTLA(IY,KZ)*(1.0 - FRY) + YKTLA(IY+1,KZ)*FRY            BMS2 086
      YKTLA2 = YKTLA(IY,KZ+1)*(1.0 - FRY) + YKTLA(IY+1,KZ+1)*FRY        BMS2 087
      YKTLA3 = YKTLA1*(1.0 - FRZ) + YKTLA2*FRZ                          BMS2 088
      CKTLA = YKTLA3 * YLASF                                            BMS2 089
      YKTPR1 = YKTPR(IY,KZ)*(1.0 - FRY) + YKTPR(IY+1,KZ)*FRY            BMS2 090
      YKTPR2 = YKTPR(IY,KZ+1)*(1.0 - FRY) + YKTPR(IY+1,KZ+1)*FRY        BMS2 091
      YKTPR3 = YKTPR1*(1.0 - FRZ) + YKTPR2*FRZ                          BMS2 092
      CKTPR = YKTPR3 * YPRSF                                            BMS2 093
      YKTND1 = YKTND(IY,KZ)*(1.0 - FRY) + YKTND(IY+1,KZ)*FRY            BMS2 094
      YKTND2 = YKTND(IY,KZ+1)*(1.0 - FRY) + YKTND(IY+1,KZ+1)*FRY        BMS2 095
      YKTND3 = YKTND1*(1.0 - FRZ) + YKTND2*FRZ                          BMS2 096
      CKTND = YKTND3 * YNDSF                                            BMS2 097
      YKTSM1 = YKTSM(IY,KZ)*(1.0 - FRY) + YKTSM(IY+1,KZ)*FRY            BMS2 098
      YKTSM2 = YKTSM(IY,KZ+1)*(1.0 - FRY) + YKTSM(IY+1,KZ+1)*FRY        BMS2 099
      YKTSM3 = YKTSM1*(1.0 - FRZ) + YKTSM2*FRZ                          BMS2 100
      CKTSM = YKTSM3 * YSMSF                                            BMS2 101
      SKA = MIN1F(YKALA(IY,KZ),YKALA(IY+1,KZ),YKALA(IY,KZ+1),YKALA(IY+1,BMS2 102
     1KZ+1),YKAPR(IY,KZ),YKAPR(IY+1,KZ),YKAPR(IY,KZ+1),YKAPR(IY+1,KZ+1),BMS2 103
     2YKAND(IY,KZ),YKAND(IY+1,KZ),YKAND(IY,KZ+1),YKAND(IY+1,KZ+1),YKASM(BMS2 104
     3IY,KZ),YKASM(IY+1,KZ),YKASM(IY,KZ+1),YKASM(IY+1,KZ+1))           BMS2 105
      IF (SKA) 85,85,90                                                 BMS2 106
85    PRINT 510, YKALA(IY,KZ),YKALA(IY+1,KZ),YKALA(IY,KZ+1),YKALA(IY+1,KBMS2 107
     1Z+1),YKAPR(IY,KZ),YKAPR(IY+1,KZ),YKAPR(IY,KZ+1),YKAPR(IY+1,KZ+1),YBMS2 108
     2KAND(IY,KZ),YKAND(IY+1,KZ),YKAND(IY,KZ+1),YKAND(IY+1,KZ+1),YKASM(IBMS2 109
     3Y,KZ),YKASM(IY+1,KZ),YKASM(IY,KZ+1),YKASM(IY+1,KZ+1),TMOR,YRE    BMS2 110
      IF (K) 600,600,45                                                 BMS2 111
90    YKALA1 = YKALA(IY,KZ)*(1.0 - FRY) + YKALA(IY+1,KZ)*FRY            BMS2 112
      YKALA2 = YKALA(IY,KZ+1)*(1.0 - FRY) + YKALA(IY+1,KZ+1)*FRY        BMS2 113
      YKALA3 = YKALA1*(1.0 - FRZ) + YKALA2*FRZ                          BMS2 114
      CKALA = YKALA3 * YLASF                                            BMS2 115
      YKAPR1 = YKAPR(IY,KZ)*(1.0 - FRY) + YKAPR(IY+1,KZ)*FRY            BMS2 116
      YKAPR2 = YKAPR(IY,KZ+1)*(1.0 - FRY) + YKAPR(IY+1,KZ+1)*FRY        BMS2 117
      YKAPR3 = YKAPR1*(1.0 - FRZ) + YKAPR2*FRZ                          BMS2 118
      CKAPR = YKAPR3 * YPRSF                                            BMS2 119
      YKAND1 = YKAND(IY,KZ)*(1.0 - FRY) + YKAND(IY+1,KZ)*FRY            BMS2 120
      YKAND2 = YKAND(IY,KZ+1)*(1.0 - FRY) + YKAND(IY+1,KZ+1)*FRY        BMS2 121
      YKAND3 = YKAND1*(1.0 - FRZ) + YKAND2*FRZ                          BMS2 122
      CKAND = YKAND3 * YNDSF                                            BMS2 123
      YKASM1 = YKASM(IY,KZ)*(1.0 - FRY) + YKASM(IY+1,KZ)*FRY            BMS2 124
```

Figure 41. (Continued)

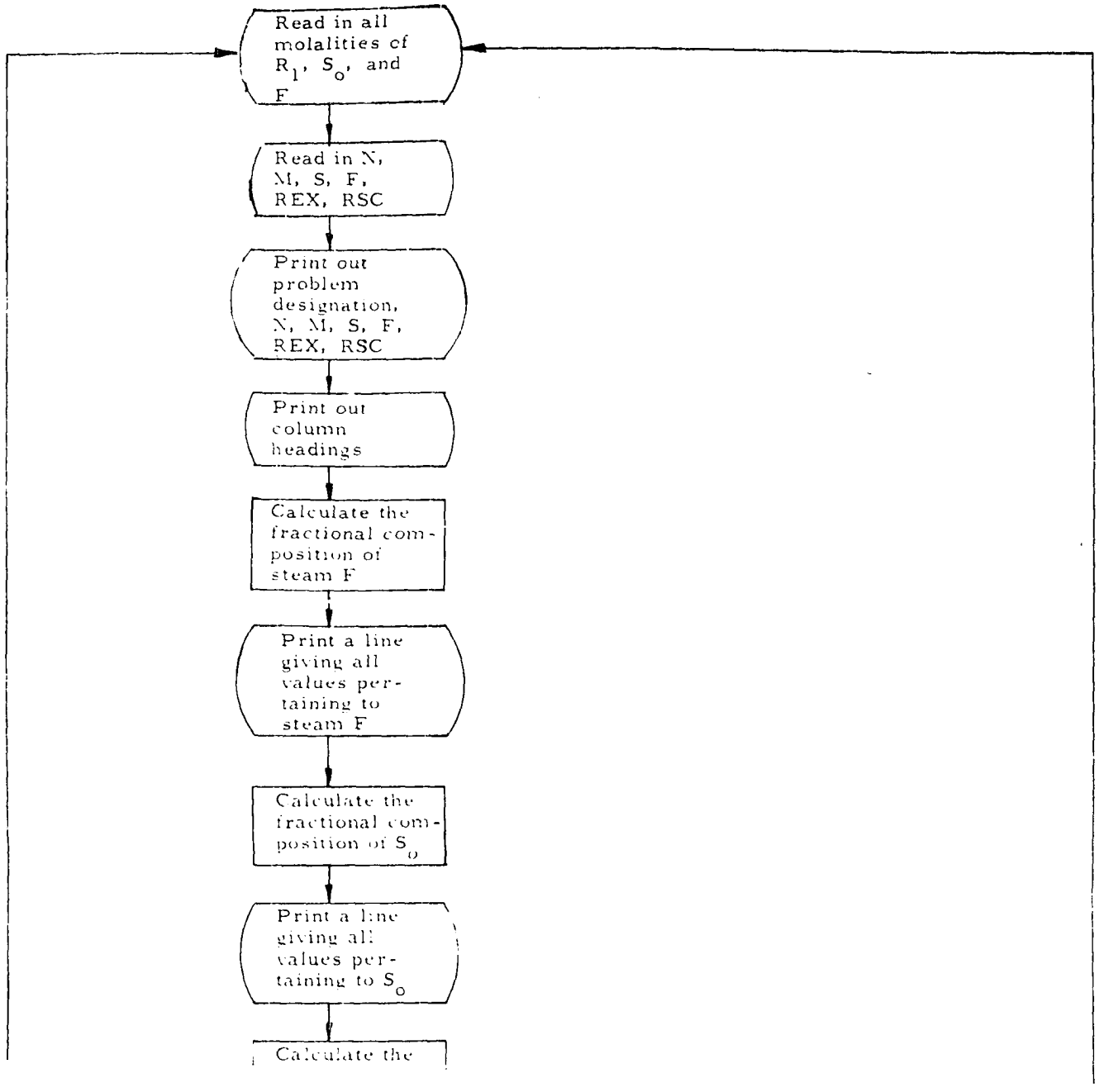
```
      YKASM2 = YKASM(IY,KZ+1)*(1.0 - FRY) + YKASM(IY+1,KZ+1)*FRY          BMS2 125
      YKASM3 = YKASM1*(1.0 - FRZ) + YKASM2*FRZ                            BMS2 126
      CKASM = YKASM3 * YSMSF                                              BMS2 127
      TOTK = CKTLA + CKTPR + CKTND + CKTSM                                BMS2 128
      HNO3K = CKALA + CKAPR + CKAND + CKASM                               BMS2 129
      TMAQ = TMOR/TOTK                                                    BMS2 130
      AMAQ = AMOR/HNO3K                                                   BMS2 131
      REMAQ = TMAQ - AMAQ                                                 BMS2 132
      IF(REMAQ) 95,95,100                                                 BMS2 133
 95   PRINT 511, TMAQ,AMAQ,REMAQ,HNO3K                                    BMS2 134
      IF (K) 600,600,45                                                   BMS2 135
100   BLAPR = 0.8187 - 0.1106*TMOR                                        BMS2 136
      BPRPR = 1.0                                                         BMS2 137
      BNDPR = 1.0448 + 0.09874*TMOR                                       BMS2 138
      BSMPR = -0.3795 + 0.9214*TMOR                                       BMS2 139
      DEMS = XLAMOR/BLAPR + PRMOR/BPRPR + XNDMOR/BNDPR + SMMOR/BSMPR      BMS2 140
      XLAMAQ = XLAMOR*REMAQ/(BLAPR*DEMS)                                  BMS2 141
      PRMAQ = PRMOR*REMAQ/(BPRPR*DEMS)                                    BMS2 142
      XNDMAQ = XNDMOR*REMAQ/(BNDPR*DEMS)                                  BMS2 143
      SMMAQ = SMMOR*REMAQ/(BSMPR*DEMS)                                    BMS2 144
      XHNO3 = AMAQ/TMAQ                                                   BMS2 145
      XLA = XLAMAQ/TMAQ                                                   BMS2 146
      XPR = PRMAQ/TMAQ                                                    BMS2 147
      XND = XNDMAQ/TMAQ                                                   BMS2 148
      XSM = SMMAQ/TMAQ                                                    BMS2 149
      XRE = REMAQ/TMAQ                                                    BMS2 150
      XLASF = XLAMAQ/REMAQ                                                BMS2 151
      XPRSF = PRMAQ/REMAQ                                                 BMS2 152
      XNDSF = XNDMAQ/REMAQ                                                BMS2 153
      XSMSF = SMMAQ/REMAQ                                                 BMS2 154
      SXA = XHNO3 + XLA + XPR + XND + XSM                                 BMS2 155
      IF (0.9999 - SXA) 105,115,110                                       BMS2 156
105   IF (1.0001 - SXA) 110,115,115                                       BMS2 157
110   PRINT 512, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ               BMS2 158
      IF (K) 600,600,45                                                   BMS2 159
115   SXREA = XLASF + XPRSF + XNDSF + XSMSF                               BMS2 160
      IF (0.9999 - SXREA)120,130,125                                      BMS2 161
120   IF (1.0001 - SXREA)125,130,130                                      BMS2 162
125   PRINT 513, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ               BMS2 163
      IF (K) 600,600,45                                                   BMS2 164
130   PRINT514,L,TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS2 165
     1,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                                BMS2 166
      TMOR =  TMAQ * ROVS + S1TM  - ROTM*ROVS                             BMS2 167
      AMOR =  AMAQ*ROVS + S1AM - ROAM*ROVS                                BMS2 168
      XLAMOR = XLAMAQ*ROVS + S1LAM  - ROLAM*ROVS                          BMS2 169
      PRMOR = PRMAQ*ROVS + S1PRM - ROPRM*ROVS                             BMS2 170
      XNDMOR = XNDMAQ*ROVS + S1NDM - RONDM*ROVS                           BMS2 171
      SMMOR = SMMAQ*ROVS + S1SMM - ROSMM*ROVS                             BMS2 172
      REMOR = TMOR - AMOR                                                 BMS2 173
      SOM = MIN1F(TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR)              BMS2 174
      IF (SOM) 135,135,140                                                BMS2 175
135   PRINT 515, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR               BMS2 176
      IF (K) 600,600,45                                                   BMS2 177
140   YHNO3 = AMOR/TMOR                                                   BMS2 178
      YLA = XLAMOR/TMOR                                                   BMS2 179
      YPR = PRMOR/TMOR                                                    BMS2 180
      YND = XNDMOR/TMOR                                                   BMS2 181
      YSM = SMMOR/TMOR                                                    BMS2 182
      YRE = REMOR/TMOR                                                    BMS2 183
      YLASF = XLAMOR/REMOR                                                BMS2 184
      YPRSF = PRMOR/REMOR                                                 BMS2 185
      YNDSF = XNDMOR/REMOR                                                BMS2 186
```

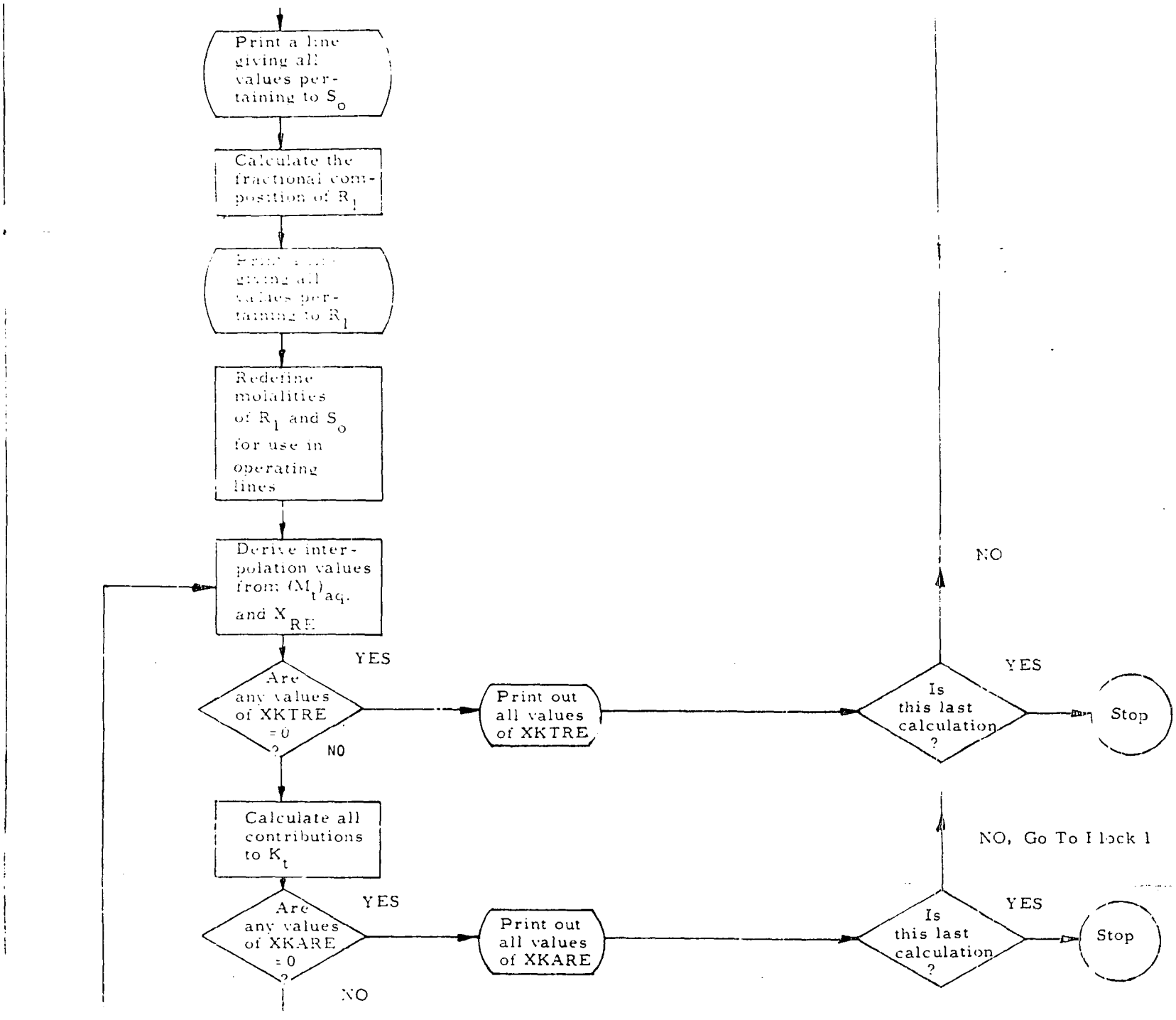
Figure 41. (Continued)

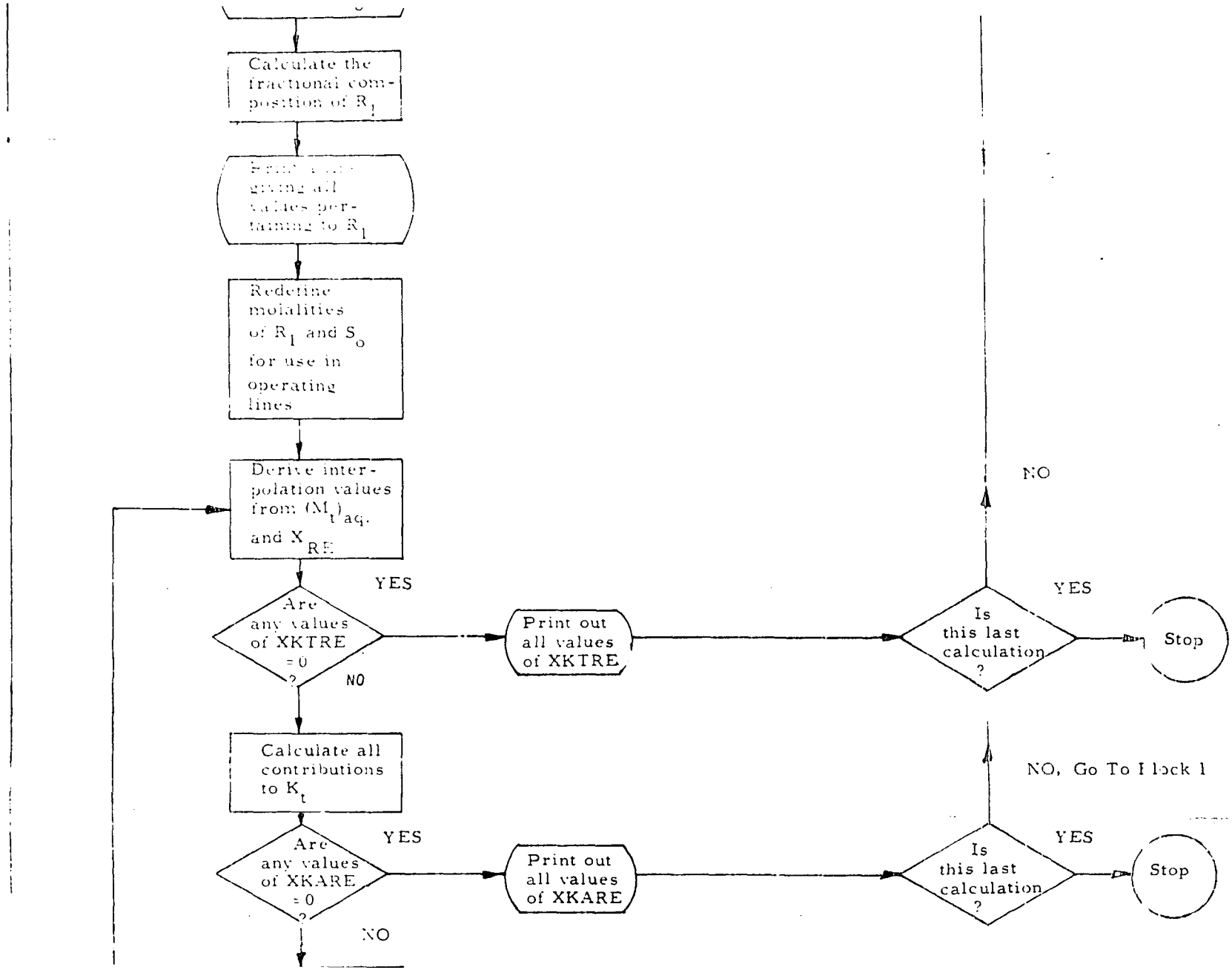
```
      YSMSF = SMMOR/REMOR                                                    BMS2 187
      SYO = YHNO3 + YLA + YPR + YND + YSM                                    BMS2 188
      IF (0.9999 - SYO) 145,155,150                                          BMS2 189
  145 IF (1.0001 - SYO) 150,155,155                                          BMS2 190
  150 PRINT 516, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR                   BMS2 191
      IF (K) 600,600,45                                                      BMS2 192
  155 SYREO = YLASF + YPRSF + YNDSF + YSMSF                                  BMS2 193
      IF (0.9999 - SYREO) 160,170,165                                        BMS2 194
  160 IF (1.0001 - SYREO) 165,170,170                                        BMS2 195
  165 PRINT 517, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR                   BMS2 196
      IF (K) 600,600,45                                                      BMS2 197
  170 LL = L + 1                                                             BMS2 198
      PRINT 518, LL,TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,BMS2 199
     1YPR,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                                BMS2 200
      IF (TMOR - 2.0) 175,180,180                                            BMS2 201
  175 PRINT 519, TMOR                                                        BMS2 202
      IF (K)  600,600,45                                                     BMS2 203
  180 IF (TMOR - 4.5)  185,175,175                                           BMS2 204
  185 CONTINUE                                                               BMS2 205
      IF (K) 600,600,45                                                      BMS2 206
  500 FORMAT (6F10.3)                                                        BMS2 207
  501 FORMAT (7F9.4)                                                         BMS2 208
  502 FORMAT (7F7.4,F8.4,I3,I3)                                              BMS2 209
  503 FORMAT (29H1SCRUB SIDE CALCULATION ROVS=F8.4,4H  N=I3)                 BMS2 210
  504 FORMAT (120HJ   TOTALMOLHNO3 MOL  LA MOL  PR MOL  ND MOL  SM MOL  BMS2 211
     1RE MOL  ACFR  LAFR  PRFR  NDFR  SMFR  REFR LA/RE PR/RE ND/RE SM/REBMS2 212
     2)                                                                      BMS2 213
  505 FORMAT (4HJR 07F8.4,10F6.3)                                            BMS2 214
  506 FORMAT (4HJR 07F8.4,6F6.3)                                             BMS2 215
  507 FORMAT (4HJR 07F8.4)                                                   BMS2 216
  508 FORMAT (4H S 17F8.4,10F6.3)                                            BMS2 217
  509 FORMAT (8HJYKTRE=016F6.3,F8.4,F6.3)                                    BMS2 218
  510 FORMAT (8HJYKARE=016F6.3,F8.4,F6.3)                                    BMS2 219
  511 FORMAT (18HJREMAQ LESS THAN 04F10.4)                                   BMS2 220
  512 FORMAT (16HJSXA NOT EQUAL 17F10.4)                                     BMS2 221
  513 FORMAT (18HJSXREA NOT EQUAL 17F10.4)                                   BMS2 222
  514 FORMAT (2HJR I2,7F8.4,10F6.3)                                          BMS2 223
  515 FORMAT (6HJTMOR=F10.4,6H AMOR=F10.4,8H XLAMOR=F10.4,7H PRMOR=F10.4BMS2 224
     1,8H XNDMOR=F10.4,7H SMMOR=F10.4,7H REMOR=F10.4)                        BMS2 225
  516 FORMAT (16HJSYO NOT EQUAL 17F10.4)                                     BMS2 226
  517 FORMAT (18HJSYREO NOT EQUAL 17F10.4)                                   BMS2 227
  518 FORMAT (2H SI2,7F8.4,10F6.3)                                           BMS2 228
  519 FORMAT (6HJTMOR=F10.4)                                                 BMS2 229
  600 STOP 89                                                                BMS2 230
      END                                                                    BMS2 231
```

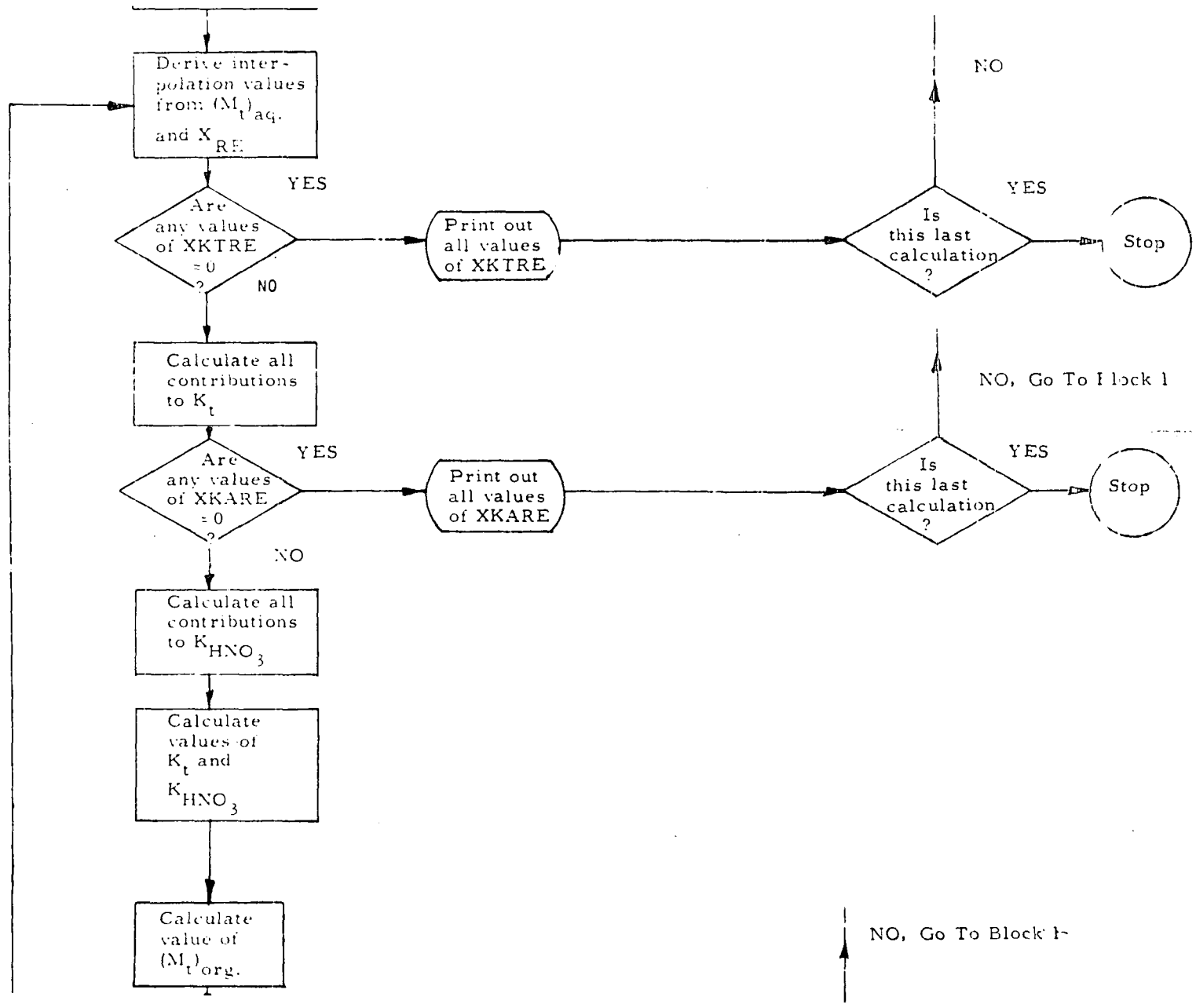
Figure 41. (Continued)

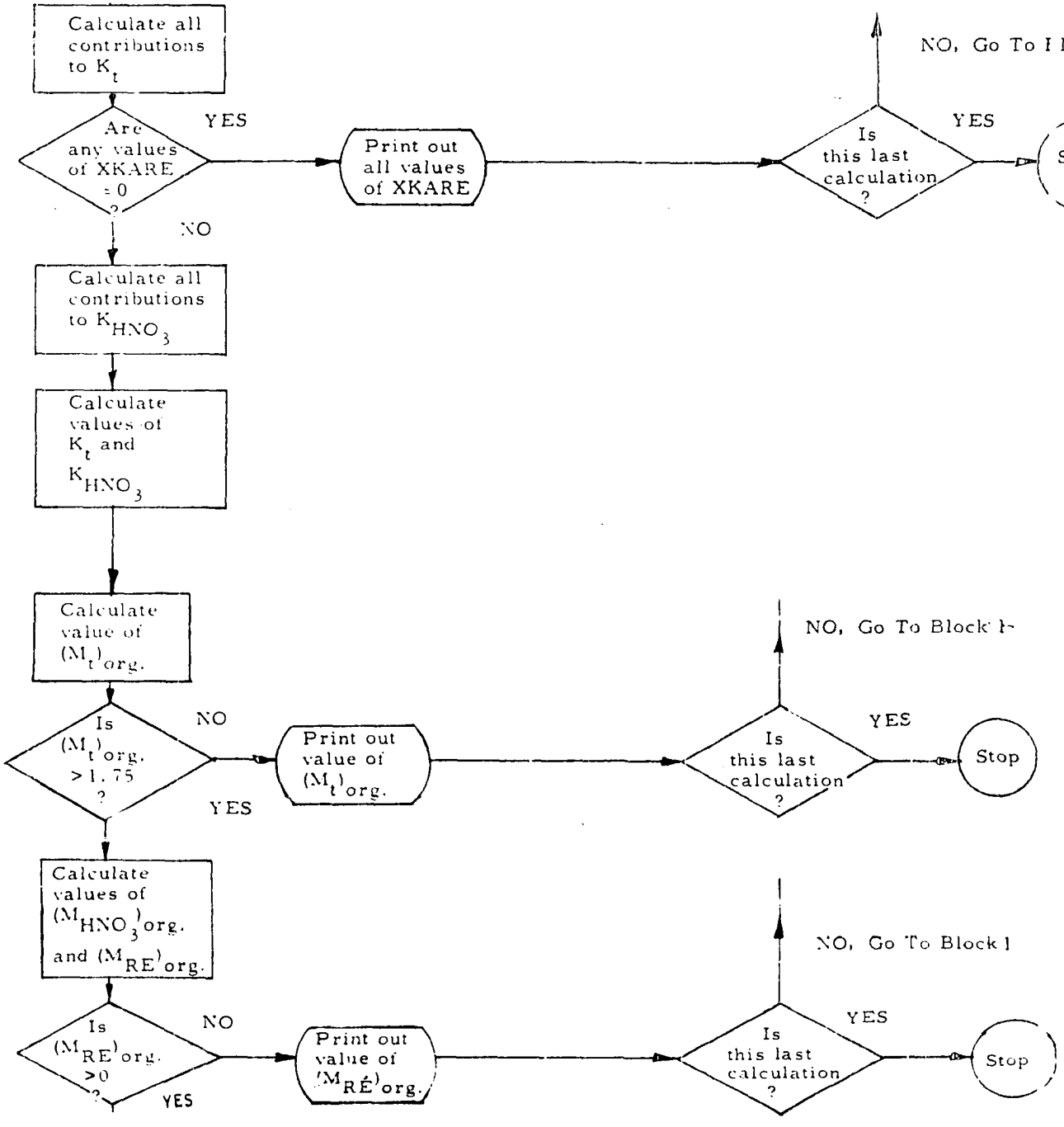
Block 1

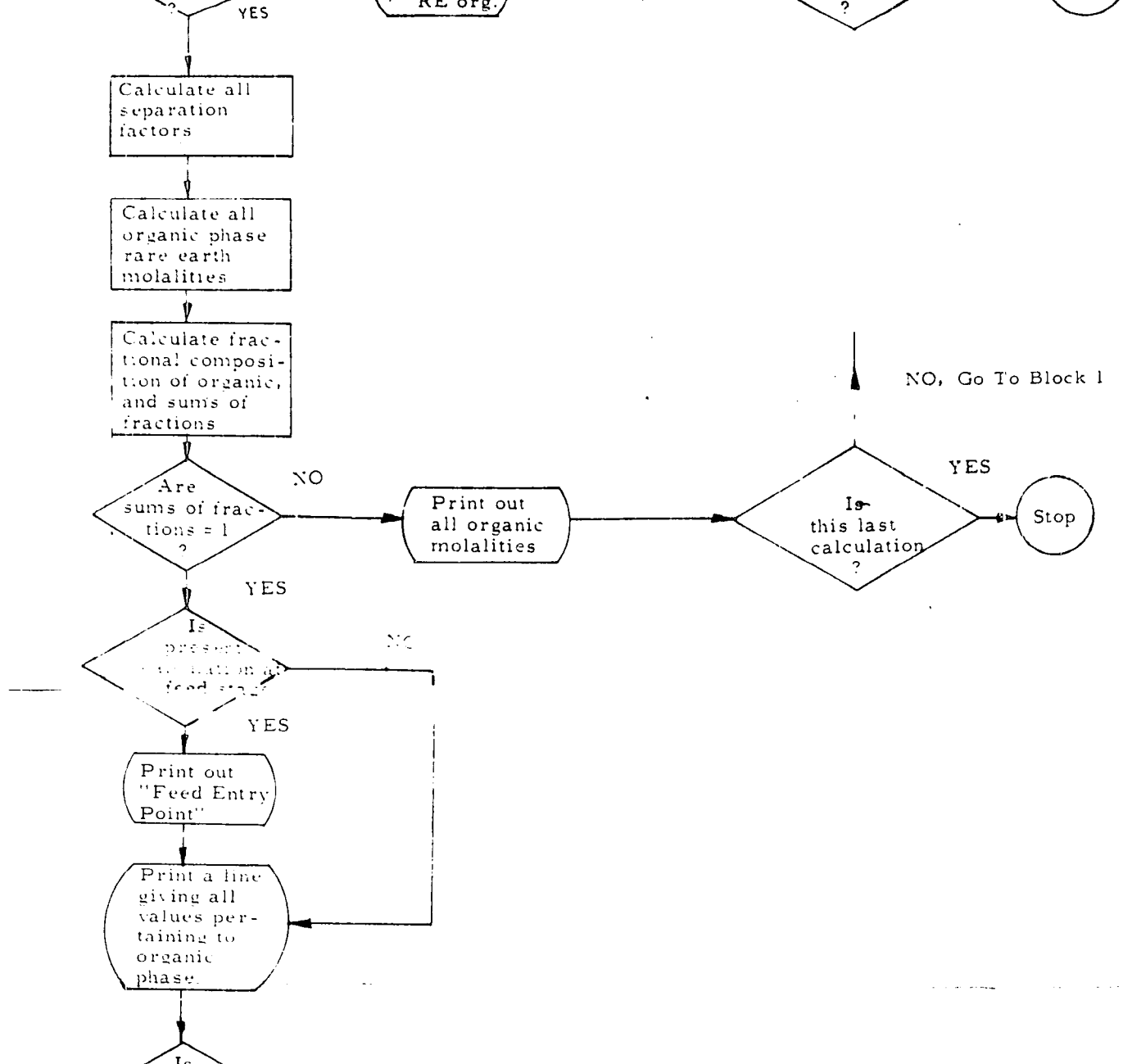

Read in all molalities of R_1, S_o, and F
Read in N, M, S, F, REX, RSC
Print out problem designation, N, M, S, F, REX, RSC
Print out column headings
Calculate the fractional composition of steam F
Print a line giving all values pertaining to steam F
Calculate the fractional composition of S_o
Print a line giving all values pertaining to S_o
Calculate the

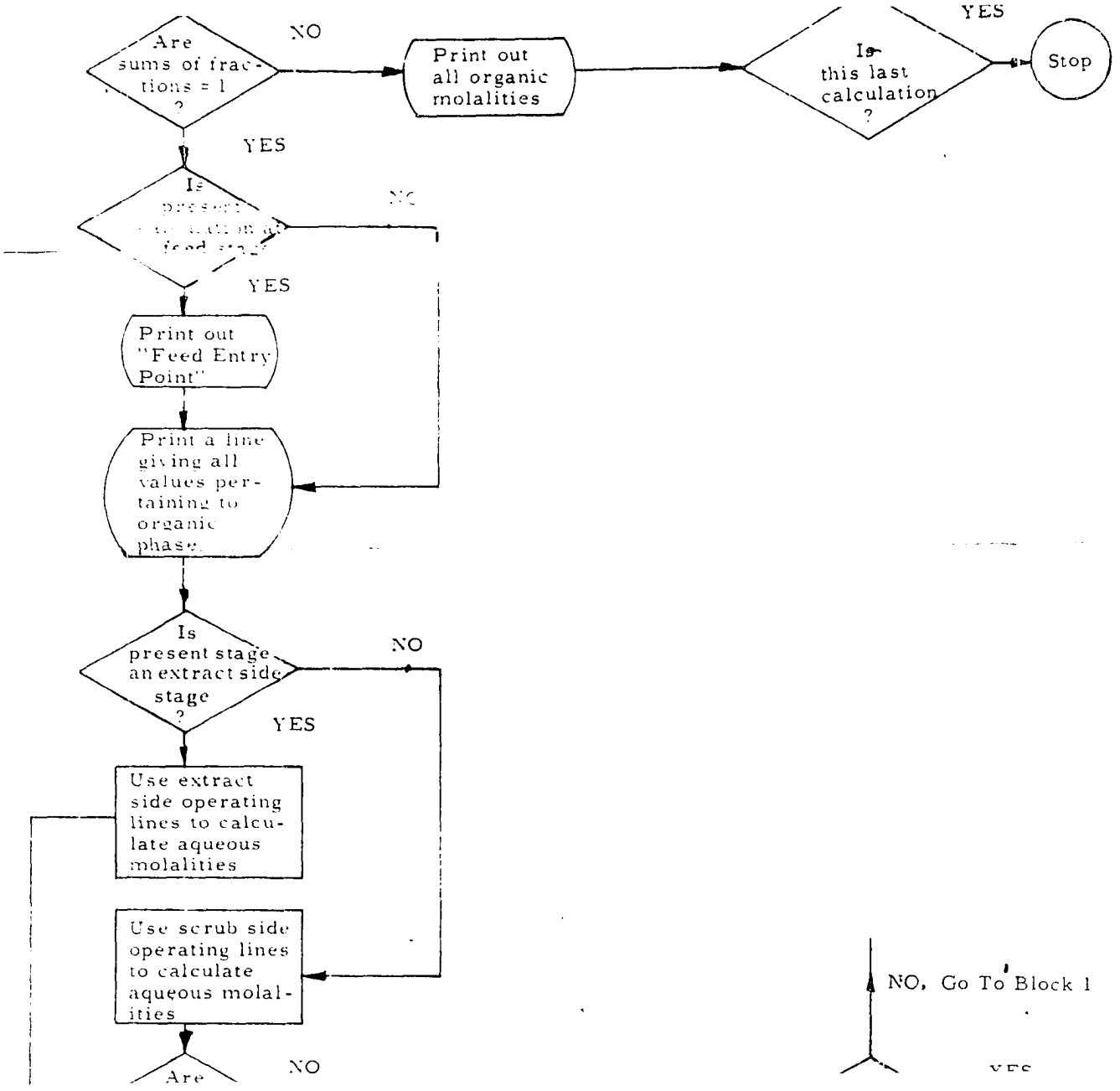

Print a line giving all values pertaining to S_o
Calculate the fractional composition of R_1
Print a line giving all values pertaining to R_1
Redefine molalities of R_1 and S_o for use in operating lines
Derive interpolation values from $(M_t)_{aq.}$ and X_{RE}
Are any values of XKTRE = 0 ?
YES
NO
Print out all values of XKTRE
Is this last calculation ?
YES
NO
Stop
Calculate all contributions to K_t
Are any values of XKARE = 0 ?
YES
NO
Print out all values of XKARE
Is this last calculation ?
YES
NO, Go To Block 1
Stop

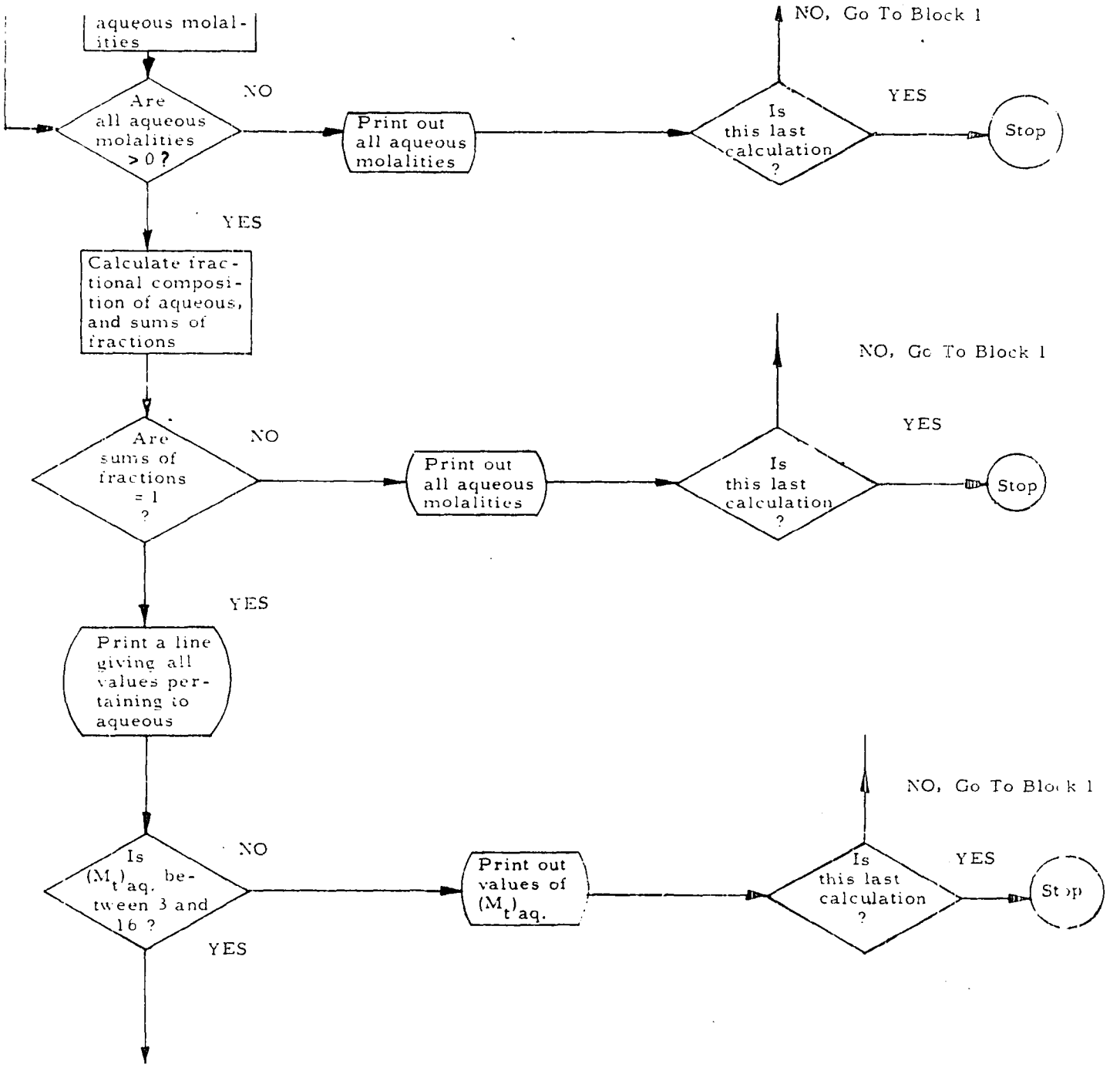

Calculate the fractional composition of R_1
Print out giving all values pertaining to R_1
Redefine molalities of R_1 and S_o for use in operating lines
Derive interpolation values from $(M_t)_{aq.}$ and X_{RE}
Are any values of XKTRE = 0 ?
YES
NO
Print out all values of XKTRE
Is this last calculation ?
YES
Stop
NO
Calculate all contributions to K_t
Are any values of XKARE = 0 ?
YES
NO
Print out all values of XKARE
Is this last calculation ?
YES
Stop
NO, Go To Block 1


Derive interpolation values from: $(M_t)_{aq.}$ and X_{RE}
Are any values of XKTRE = 0 ?
YES
NO
Print out all values of XKTRE
Is this last calculation ?
YES
NO
Stop
Calculate all contributions to K_t
Are any values of XKARE = 0 ?
YES
NO
Print out all values of XKARE
Is this last calculation ?
YES
NO, Go To Block 1
Stop
Calculate all contributions to K_{HNO_3}
Calculate values of K_t and K_{HNO_3}
Calculate value of $(M_t)_{org.}$
NO, Go To Block 1-


Calculate all contributions to K_t
Are any values of XKARE = 0 ?
YES
Print out all values of XKARE
Is this last calculation ?
YES
Stop
NO, Go To Block 1
NO
Calculate all contributions to K_{HNO_3}
Calculate values of K_t and K_{HNO_3}
Calculate value of $(M_t)_{org.}$
Is $(M_t)_{org.} > 1.75$?
NO
YES
Print out value of $(M_t)_{org.}$
Is this last calculation ?
YES
Stop
NO, Go To Block 1
Calculate values of $(M_{HNO_3})_{org.}$ and $(M_{RE})_{org.}$
Is $(M_{RE})_{org.} > 0$?
NO
YES
Print out value of $(M_{RE})_{org.}$
Is this last calculation ?
YES
Stop
NO, Go To Block 1


YES
Calculate all separation factors
Calculate all organic phase rare earth molalities
Calculate fractional composition of organic, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all organic molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
YES
Print out "Feed Entry Point"
Print a line giving all values pertaining to organic phase.


Are sums of fractions = 1 ?
NO
Print out all organic molalities
Is this last calculation ?
YES
Stop
YES
NO
YES
Print out "Feed Entry Point"
Print a line giving all values pertaining to organic phase
Is present stage an extract side stage ?
NO
YES
Use extract side operating lines to calculate aqueous molalities
Use scrub side operating lines to calculate aqueous molalities
NO
NO, Go To Block 1


aqueous molal-ities
Are all aqueous molalities > 0 ?
NO
Print out all aqueous molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Calculate fractional composition of aqueous, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all aqueous molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Print a line giving all values pertaining to aqueous
Is $(M_t)_{aq.}$ between 3 and 16 ?
NO
Print out values of $(M_t)_{aq.}$
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES

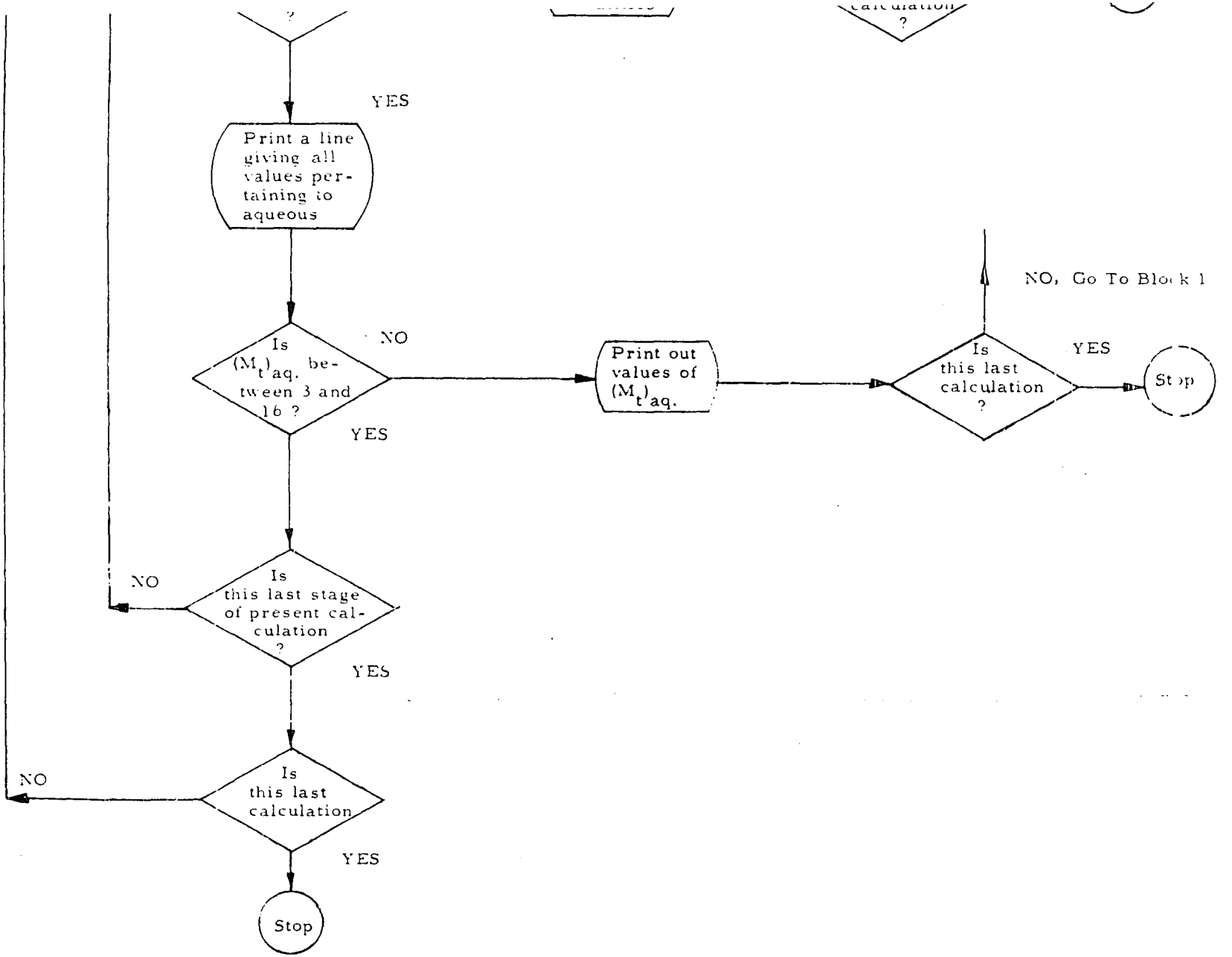


Figure 42. Flow diagram, Program III

```
      DIMENSION XKTLA(21,7),XKTPR(21,7),XKTND(21,7),XKTSM(21,7),XKALA(21BMS3 001
     1,7),XKAPR(21,7),XKAND(21,7),XKASM(21,7)                          BMS3 002
      DO 5 I = 1,21                                                    BMS3 003
5     READ INPUT TAPE 5, 500, (XKTLA(I,J),J = 1,7)                     BMS3 004
      DO 10 I = 1,21                                                   BMS3 005
10    READ INPUT TAPE 5, 500, (XKTPR(I,J),J = 1,7)                     BMS3 006
      DO 15 I = 1,21                                                   BMS3 007
15    READ INPUT TAPE 5, 500, (XKTND(I,J),J = 1,7)                     BMS3 008
      DO 20 I = 1,21                                                   BMS3 009
20    READ INPUT TAPE 5, 500, (XKTSM(I,J),J = 1,7)                     BMS3 010
      DO 25 I = 1,21                                                   BMS3 011
25    READ INPUT TAPE 5, 500, (XKALA(I,J),J = 1,7)                     BMS3 012
      DO 30 I = 1,21                                                   BMS3 013
30    READ INPUT TAPE 5, 500, (XKAPR(I,J),J = 1,7)                     BMS3 014
      DO 35 I = 1,21                                                   BMS3 015
35    READ INPUT TAPE 5, 500, (XKAND(I,J),J = 1,7)                     BMS3 016
      DO 40 I = 1,21                                                   BMS3 017
40    READ INPUT TAPE 5, 500, (XKASM(I,J),J = 1,7)                     BMS3 018
45    READ INPUT TAPE 5, 501, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ BMS3 019
      READ INPUT TAPE 5, 501, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR BMS3 020
      READ INPUT TAPE 5, 502, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,S,F,REX,RBMS3 021
     1SC,N,M,K                                                         BMS3 022
      PRINT 503, S,F,REX,RSC,N,M                                       BMS3 023
      PRINT 504                                                        BMS3 024
      IF (FTM) 600,65,50                                               BMS3 025
50    XAF = FAM/FTM                                                    BMS3 026
      XLAF = FLAM/FTM                                                  BMS3 027
      XPRF = FPRM/FTM                                                  BMS3 028
      XNDF = FNDM/FTM                                                  BMS3 029
      XSMF = FSMM/FTM                                                  BMS3 030
      XREF = FREM/FTM                                                  BMS3 031
      IF (FREM) 600,60,55                                              BMS3 032
55    XLASFF = FLAM/FREM                                               BMS3 033
      XPRSFF = FPRM/FREM                                               BMS3 034
      XNDSFF = FNDM/FREM                                               BMS3 035
      XSMSFF = FSMM/FREM                                               BMS3 036
      PRINT 505, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,XAF,XLAF,XPRF,XNDF,XSMBMS3 037
     1F,XREF,XLASFF,XPRSFF,XNDSFF,XSMSFF                               BMS3 038
      GO TO 70                                                         BMS3 039
60    PRINT 506, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,XAF,XLAF,XPRF,XNDF,XSMBMS3 040
     1F,XREF                                                           BMS3 041
      GO TO 70                                                         BMS3 042
65    PRINT 507, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM                      BMS3 043
70    IF(TMOR) 600,90,75                                               BMS3 044
75    YHNO3 = AMOR/TMOR                                                BMS3 045
      YLA = XLAMOR/TMOR                                                BMS3 046
      YPR = PRMOR/TMOR                                                 BMS3 047
      YND = XNDMOR/TMOR                                                BMS3 048
      YSM = SMMOR/TMOR                                                 BMS3 049
      YRE = REMOR/TMOR                                                 BMS3 050
      IF (REMOR) 600,85,80                                             BMS3 051
80    YLASF = XLAMOR/REMOR                                             BMS3 052
      YPRSF = PRMOR/REMOR                                              BMS3 053
      YNDSF = XNDMOR/REMOR                                             BMS3 054
      YSMSF = SMMOR/REMOR                                              BMS3 055
      PRINT 508, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPRBMS3 056
     1,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                             BMS3 057
      GO TO 95                                                         BMS3 058
85    PRINT 509, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPRBMS3 059
     1,YND,YSM,YRE                                                     BMS3 060
      GO TO 95                                                         BMS3 061
90    PRINT 510, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR            BMS3 062
```

Figure 43. Fortran statements, Program III

```
 95     XHNO3 =  AMAQ /TMAQ                                                    BMS3 063
        XLA =  XLAMAQ/TMAQ                                                     BMS3 064
        XPR =  PRMAQ/TMAQ                                                      BMS3 065
        XND =  XNDMAQ/TMAQ                                                     BMS3 066
        XSM =  SMMAQ/TMAQ                                                      BMS3 067
        XRE =  REMAQ/TMAQ                                                      BMS3 068
        XLASF = XLAMAQ/REMAQ                                                   BMS3 069
        XPRSF = PRMAQ/REMAQ                                                    BMS3 070
        XNDSF = XNDMAQ/REMAQ                                                   BMS3 071
        XSMSF = SMMAQ/REMAQ                                                    BMS3 072
        PRINT 511, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS3 073
       1,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                                   BMS3 074
        R1TM = TMAQ                                                            BMS3 075
        R1AM = AMAQ                                                            BMS3 076
        R1LAM= XLAMAQ                                                          BMS3 077
        R1PRM = PRMAQ                                                          BMS3 078
        R1NDM = XNDMAQ                                                         BMS3 079
        R1SMM = SMMAQ                                                          BMS3 080
        SOTM  = TMOR                                                           BMS3 081
        SOAM  = AMOR                                                           BMS3 082
        SOLAM = XLAMOR                                                         BMS3 083
        SOPRM = PRMOR                                                          BMS3 084
        SONDM = XNDMOR                                                         BMS3 085
        SOSMM = SMMOR                                                          BMS3 086
        DO 270 L = 1,N                                                         BMS3 087
        XREI = (XRE*100.0 + 5.0)/5.0                                           BMS3 088
        IX = XREI                                                              BMS3 089
        XI = IX                                                                BMS3 090
        FRX = XREI - XI                                                        BMS3 091
        IF (5.0 - TMAQ) 100,110,105                                            BMS3 092
100     IF (7.0 - TMAQ) 115,115,110                                            BMS3 093
105     Z =  TMAQ - 2.0                                                        BMS3 094
        GO TO 120                                                              BMS3 095
110     Z = (TMAQ + 1.0)/2.0                                                   BMS3 096
        GO TO 120                                                              BMS3 097
115     Z = (TMAQ + 5.0)/3.0                                                   BMS3 098
120     KZ = Z                                                                 BMS3 099
        ZK = KZ                                                                BMS3 100
        FRZ =  Z - ZK                                                          BMS3 101
        SKT = MIN1F(XKTLA(IX,KZ),XKTLA(IX+1,KZ),XKTLA(IX,KZ+1),XKTLA(IX+1,BMS3 102
       1KZ+1),XKTPR(IX,KZ),XKTPR(IX+1,KZ),XKTPR(IX,KZ+1),XKTPR(IX+1,KZ+1),BMS3 103
       2XKTND(IX,KZ),XKTND(IX+1,KZ),XKTND(IX,KZ+1),XKTND(IX+1,KZ+1),XKTSM(BMS3 104
       3IX,KZ),XKTSM(IX+1,KZ),XKTSM(IX,KZ+1),XKTSM(IX+1,KZ+1))                 BMS3 105
        IF (SKT) 125,125,130                                                   BMS3 106
125     PRINT 512, XKTLA(IX,KZ),XKTLA(IX+1,KZ),XKTLA(IX,KZ+1),XKTLA(IX+1,KBMS3 107
       1Z+1),XKTPR(IX,KZ),XKTPR(IX+1,KZ),XKTPR(IX,KZ+1),XKTPR(IX+1,KZ+1),XBMS3 108
       2KTND(IX,KZ),XKTND(IX+1,KZ),XKTND(IX,KZ+1),XKTND(IX+1,KZ+1),XKTSM(IBMS3 109
       3X,KZ),XKTSM(IX+1,KZ),XKTSM(IX,KZ+1),XKTSM(IX+1,KZ+1),TMAQ,XRE         BMS3 110
        IF (K) 600,600,45                                                      BMS3 111
130     XKTLA1 = XKTLA(IX,KZ)*(1.0 - FRX) + XKTLA(IX+1,KZ)*FRX                 BMS3 112
        XKTLA2 = XKTLA(IX,KZ+1)*(1.0 - FRX) + XKTLA(IX+1,KZ+1)*FRX             BMS3 113
        XKTLA3 = XKTLA1*(1.0-FRZ) + XKTLA2*FRZ                                 BMS3 114
        CKTLA = XKTLA3*XLASF                                                   BMS3 115
        XKTPR1 = XKTPR(IX,KZ)*(1.0-FRX) + XKTPR(IX+1,KZ)*FRX                   BMS3 116
        XKTPR2 = XKTPR(IX,KZ+1)*(1.0-FRX)+ XKTPR(IX+1,KZ+1)*FRX                BMS3 117
        XKTPR3 = XKTPR1*(1.0-FRZ) + XKTPR2 *FRZ                                BMS3 118
        CKTPR = XKTPR3* XPRSF                                                  BMS3 119
        XKTND1 = XKTND(IX,KZ)*(1.0-FRX) + XKTND(IX+1,KZ)*FRX                   BMS3 120
        XKTND2 = XKTND(IX,KZ+1)*(1.0 - FRX) + XKTND(IX+1,KZ+1)*FRX             BMS3 121
        XKTND3 = XKTND1* (1.0- FRZ)  + XKTND2 * FRZ                            BMS3 122
        CKTND = XKTND3 * XNDSF                                                 BMS3 123
        XKTSM1 = XKTSM(IX,KZ)*(1.0-FRX) + XKTSM(IX+1,KZ)*FRX                   BMS3 124
```

Figure 43. (Continued)

```
      XKTSM2 = XKTSM(IX,KZ+1)*(1.0 -FRX)+ XKTSM(IX+1,KZ+1)*FRX                BMS3 125
      XKTSM3 = XKTSM1*(1.0 -FRZ) + XKTSM2 * FRZ                               BMS3 126
      CKTSM = XKTSM3 * XSMSF                                                  BMS3 127
      SKA = MIN1F(XKALA(IX,KZ),XKALA(IX+1,KZ),XKALA(IX,KZ+1),XKALA(IX+1,BMS3 128
     1KZ+1),XKAPR(IX,KZ),XKAPR(IX+1,KZ),XKAPR(IX,KZ+1),XKAPR(IX+1,KZ+1),BMS3 129
     2XKAND(IX,KZ),XKAND(IX+1,KZ),XKAND(IX,KZ+1),XKAND(IX+1,KZ+1),XKASM(BMS3 130
     3IX,KZ),XKASM(IX+1,KZ),XKASM(IX,KZ+1),XKASM(IX+1,KZ+1))                 BMS3 131
      IF (SKA) 135,135,140                                                    BMS3 132
135   PRINT 513, XKALA(IX,KZ),XKALA(IX+1,KZ),XKALA(IX,KZ+1),XKALA(IX+1,KBMS3 133
     1Z+1),XKAPR(IX,KZ),XKAPR(IX+1,KZ),XKAPR(IX,KZ+1),XKAPR(IX+1,KZ+1),XBMS3 134
     2KAND(IX,KZ),XKAND(IX+1,KZ),XKAND(IX,KZ+1),XKAND(IX+1,KZ+1),XKASM(IBMS3 135
     3X,KZ),XKASM(IX+1,KZ),XKASM(IX,KZ+1),XKASM(IX+1,KZ+1),TMAQ,XRE      BMS3 136
      IF (K) 600,600,45                                                       BMS3 137
140   XKALA1 = XKALA(IX,KZ)*(1.0 - FRX) + XKALA(IX+1,KZ)*FRX                  BMS3 138
      XKALA2 = XKALA(IX,KZ+1)*(1.0-FRX) + XKALA(IX+1,KZ+1)*FRX                BMS3 139
      XKALA3 = XKALA1*(1.0-FRZ) + XKALA2*FRZ                                  BMS3 140
      CKALA = XKALA3 * XLASF                                                  BMS3 141
      XKAPR1 = XKAPR(IX,KZ)*(1.0 -FRX) + XKAPR(IX+1,KZ)* FRX                  BMS3 142
      XKAPR2 = XKAPR(IX,KZ+1)*(1.0 -FRX) + XKAPR(IX+1,KZ+1)*FRX               BMS3 143
      XKAPR3 = XKAPR1*(1.0 -FRZ) + XKAPR2 * FRZ                               BMS3 144
      CKAPR  = XKAPR3 * XPRSF                                                 BMS3 145
      XKAND1 = XKAND(IX,KZ)*(1.0 -FRX)+ XKAND(IX+1,KZ)*FRX                    BMS3 146
      XKAND2 = XKAND(IX,KZ+1)* (1.0 -FRX) +XKAND(IX+1,KZ+1)*FRX               BMS3 147
      XKAND3 = XKAND1*(1.0 -FRZ) + XKAND2 * FRZ                               BMS3 148
      CKAND  = XKAND3 * XNDSF                                                 BMS3 149
      XKASM1 = XKASM(IX,KZ)*(1.0 - FRX)+ XKASM(IX+1,KZ)*FRX                   BMS3 150
      XKASM2 = XKASM(IX,KZ+1)*(1.0 -FRX) + XKASM(IX+1,KZ+1)*FRX               BMS3 151
      XKASM3 = XKASM1*(1.0 -FRZ) + XKASM2 *FRZ                                BMS3 152
      CKASM = XKASM3 * XSMSF                                                  BMS3 153
      TOTK = CKTLA + CKTPR + CKTND + CKTSM                                    BMS3 154
      HNO3K = CKALA + CKAPR + CKAND + CKASM                                   BMS3 155
      TMOR = TMAQ * TOTK                                                      BMS3 156
      IF(TMOR - 1.75) 145,150,150                                             BMS3 157
145   PRINT 514, TMOR,TMAQ,TOTK                                               BMS3 158
      IF (K)  600,600,45                                                      BMS3 159
150   AMOR = AMAQ * HNO3K                                                     BMS3 160
      REMOR = TMOR - AMOR                                                     BMS3 161
      IF(REMOR) 155,155,160                                                   BMS3 162
155   PRINT 515, TMOR,AMOR,REMOR,HNO3K                                        BMS3 163
      IF (K) 600,600,45                                                       BMS3 164
160   BLAPR = 0.8187 - 0.1106*TMOR                                            BMS3 165
      BPRPR = 1.0                                                             BMS3 166
      BNDPR = 1.0448 + 0.09874*TMOR                                           BMS3 167
      BSMPR = -0.3795 + 0.9214*TMOR                                           BMS3 168
      DEMS = XLAMAQ*BLAPR + PRMAQ* BPRPR +  XNDMAQ*BNDPR + SMMAQ*BSMPR        BMS3 169
      XLAMOR = REMOR*BLAPR*XLAMAQ/DEMS                                        BMS3 170
      PRMOR =  REMOR*BPRPR*PRMAQ/DEMS                                         BMS3 171
      XNDMOR=  REMOR*BNDPR*XNDMAQ/DEMS                                        BMS3 172
      SMMOR =  REMOR*BSMPR*SMMAQ/DEMS                                         BMS3 173
      YHNO3 = AMOR/TMOR                                                       BMS3 174
      YLA   =  XLAMOR/TMOR                                                    BMS3 175
      YPR   =  PRMOR/TMOR                                                     BMS3 176
      YND   =  XNDMOR/TMOR                                                    BMS3 177
      YSM   =  SMMOR/TMOR                                                     BMS3 178
      YRE   =  REMOR/TMOR                                                     BMS3 179
      SYO = YHNO3 + YLA + YPR + YND + YSM                                     BMS3 180
      IF (0.9999 - SYO) 165,175,170                                           BMS3 181
165   IF (1.0001 - SYO) 170,175,175                                           BMS3 182
170   PRINT 516, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR                   BMS3 183
      IF (K)  600,600,45                                                      BMS3 184
175   YLASF = XLAMOR/REMOR                                                    BMS3 185
      YPRSF = PRMOR/REMOR                                                     BMS3 186
```

Figure 43. (Continued)

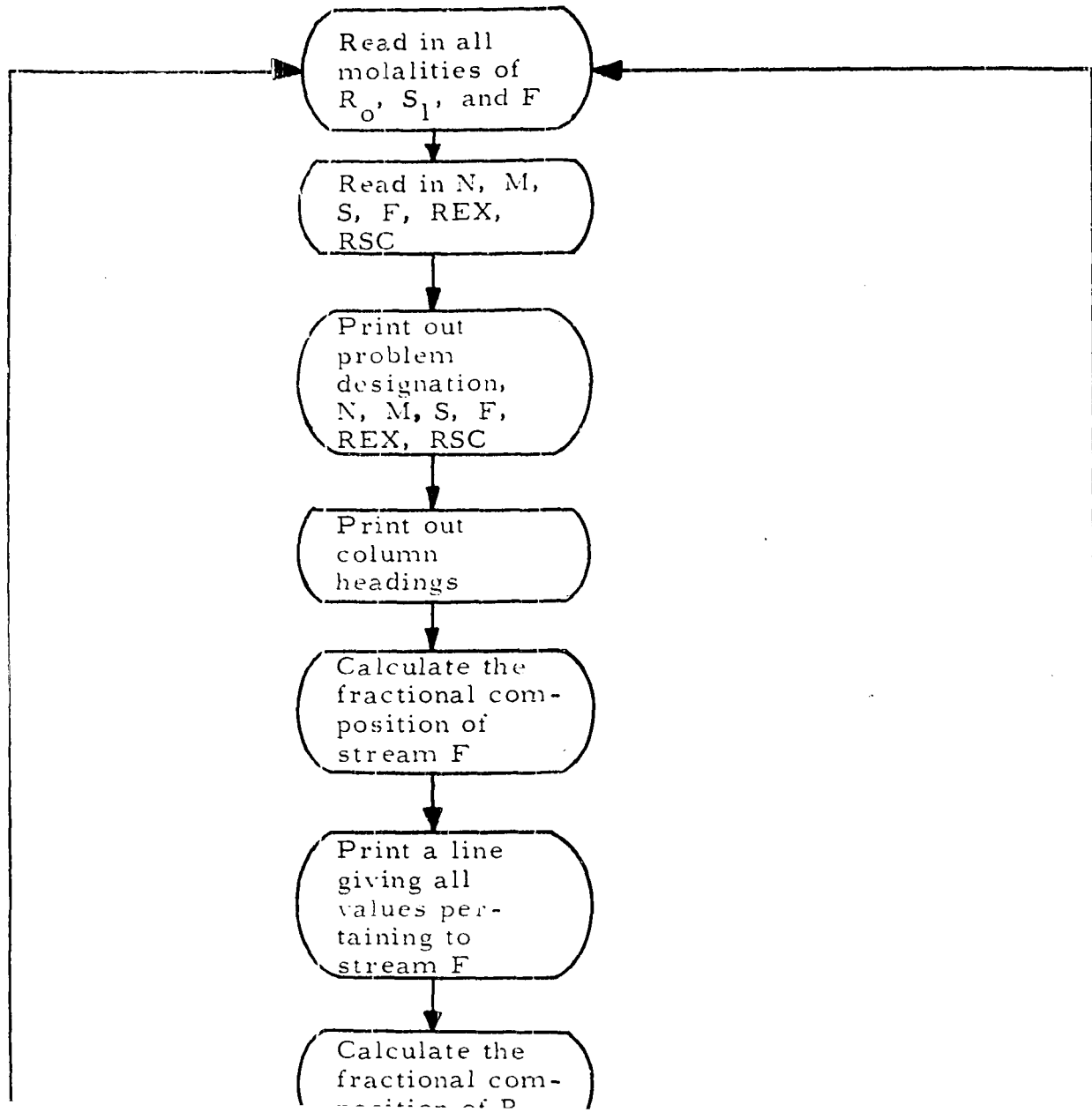
```
      YNDSF = XNDMOR/REMOR                                                  BMS3 187
      YSMSF = SMMOR/REMOR                                                   BMS3 188
      SYREO = YLASF + YPRSF + YNDSF + YSMSF                                 BMS3 189
      IF (0.9999 - SYREO)180,190,185                                        BMS3 190
180   IF (1.0001 - SYREO)185,190,190                                        BMS3 191
185   PRINT 517, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR                 BMS3 192
      IF (K)  600,600,45                                                    BMS3 193
190   IF (L - M) 200,195,200                                                BMS3 194
195   PRINT 518                                                             BMS3 195
200   PRINT 519,L,TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPBMS3 196
     1R,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                                 BMS3 197
      IF (L-M) 205,210,210                                                  BMS3 198
205   TMAQ = TMOR*S/REX    - SOTM*S/REX    + R1TM                           BMS3 199
      AMAQ = AMOR*S/REX    - SOAM*S/REX    + R1AM                           BMS3 200
      XLAMAQ = XLAMOR*S/REX    - SOLAM*S/REX  + R1LAM                       BMS3 201
      PRMAQ = PRMOR*S/REX  - SOPRM*S/REX   + R1PRM                          BMS3 202
      XNDMAQ = XNDMOR*S/REX    - SONDM*S/REX  + R1NDM                       BMS3 203
      SMMAQ = SMMOR*S/REX  - SOSMM*S/REX  + R1SMM                           BMS3 204
      GO TO 215                                                             BMS3 205
210   TMAQ = TMOR*S/RSC - SOTM*S/RSC - FTM*F/RSC + R1TM*REX/RSC             BMS3 206
      AMAQ = AMOR*S/RSC - SOAM*S/RSC - FAM*F/RSC + R1AM*REX/RSC             BMS3 207
      XLAMAQ = XLAMOR*S/RSC - SOLAM*S/RSC - FLAM*F/RSC + R1LAM*REX/RSC      BMS3 208
      PRMAQ = PRMOR*S/RSC - SOPRM*S/RSC - FPRM*F/RSC + R1PRM*REX/RSC        BMS3 209
      XNDMAQ = XNDMOR*S/RSC - SONDM*S/RSC - FNDM* F/RSC + R1NDM*REX/RSC     BMS3 210
      SMMAQ = SMMOR*S/RSC - SOSMM*S/RSC - FSMM*F/RSC + R1SMM*REX/RSC        BMS3 211
215   REMAQ = TMAQ - AMAQ                                                   BMS3 212
      SAM = MIN1F(TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ)                BMS3 213
      IF(SAM) 220,220,225                                                   BMS3 214
220   PRINT 520, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                 BMS3 215
      IF(K) 600,600,45                                                      BMS3 216
225   XHNO3 = AMAQ/TMAQ                                                     BMS3 217
      XLA = XLAMAQ/TMAQ                                                     BMS3 218
      XPR = PRMAQ/TMAQ                                                      BMS3 219
      XND = XNDMAQ/TMAQ                                                     BMS3 220
      XSM = SMMAQ/TMAQ                                                      BMS3 221
      XRE = REMAQ/TMAQ                                                      BMS3 222
      SXA = XHNO3 + XLA + XPR + XND + XSM                                   BMS3 223
      IF (0.9999 - SXA) 230,240,235                                         BMS3 224
230   IF (1.0001 - SXA) 235,240,240                                         BMS3 225
235   PRINT 521, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                 BMS3 226
      IF (K) 600,600,45                                                     BMS3 227
240   XLASF = XLAMAQ/REMAQ                                                  BMS3 228
      XPRSF = PRMAQ/REMAQ                                                   BMS3 229
      XNDSF = XNDMAQ/REMAQ                                                  BMS3 230
      XSMSF = SMMAQ/REMAQ                                                   BMS3 231
      SXREA =  XLASF + XPRSF + XNDSF + XSMSF                                BMS3 232
      IF(0.9999 - SXREA) 245,255,250                                        BMS3 233
245   IF(1.0001 - SXREA) 250,255,255                                        BMS3 234
250   PRINT 522, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                 BMS3 235
      IF(K) 600,600,45                                                      BMS3 236
255   LL = L+1                                                              BMS3 237
      PRINT 523,LL,TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPBMS3 238
     1PR,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                                BMS3 239
      IF (TMAQ - 3.0) 260,265,265                                           BMS3 240
260   PRINT 524, TMAQ                                                       BMS3 241
      IF (K) 600,600,45                                                     BMS3 242
265   IF (TMAQ - 16.0) 270,260,260                                          BMS3 243
270   CONTINUE                                                              BMS3 244
      IF (K) 600,600,45                                                     BMS3 245
500   FORMAT (7F10.3)                                                       BMS3 246
501   FORMAT (7F10.4)                                                       BMS3 247
502   FORMAT (7F7.4,4F5.2,3I3)                                              BMS3 248
```

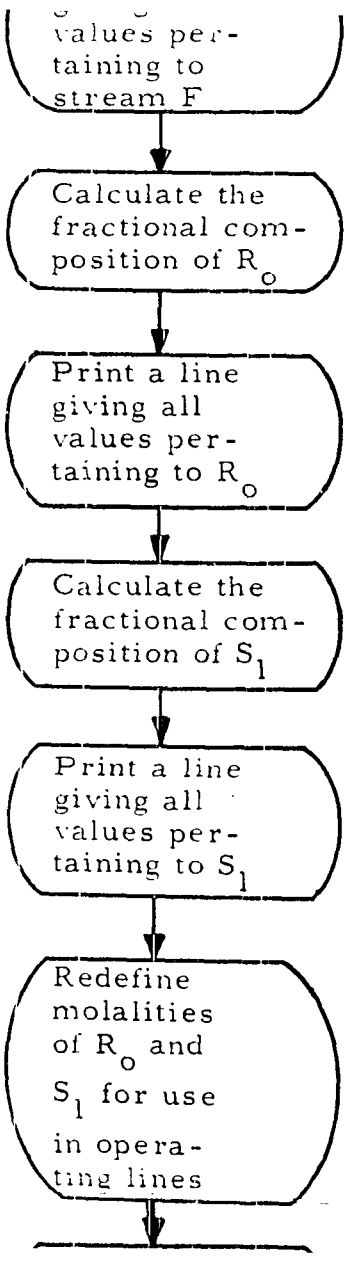
Figure 43. (Continued)

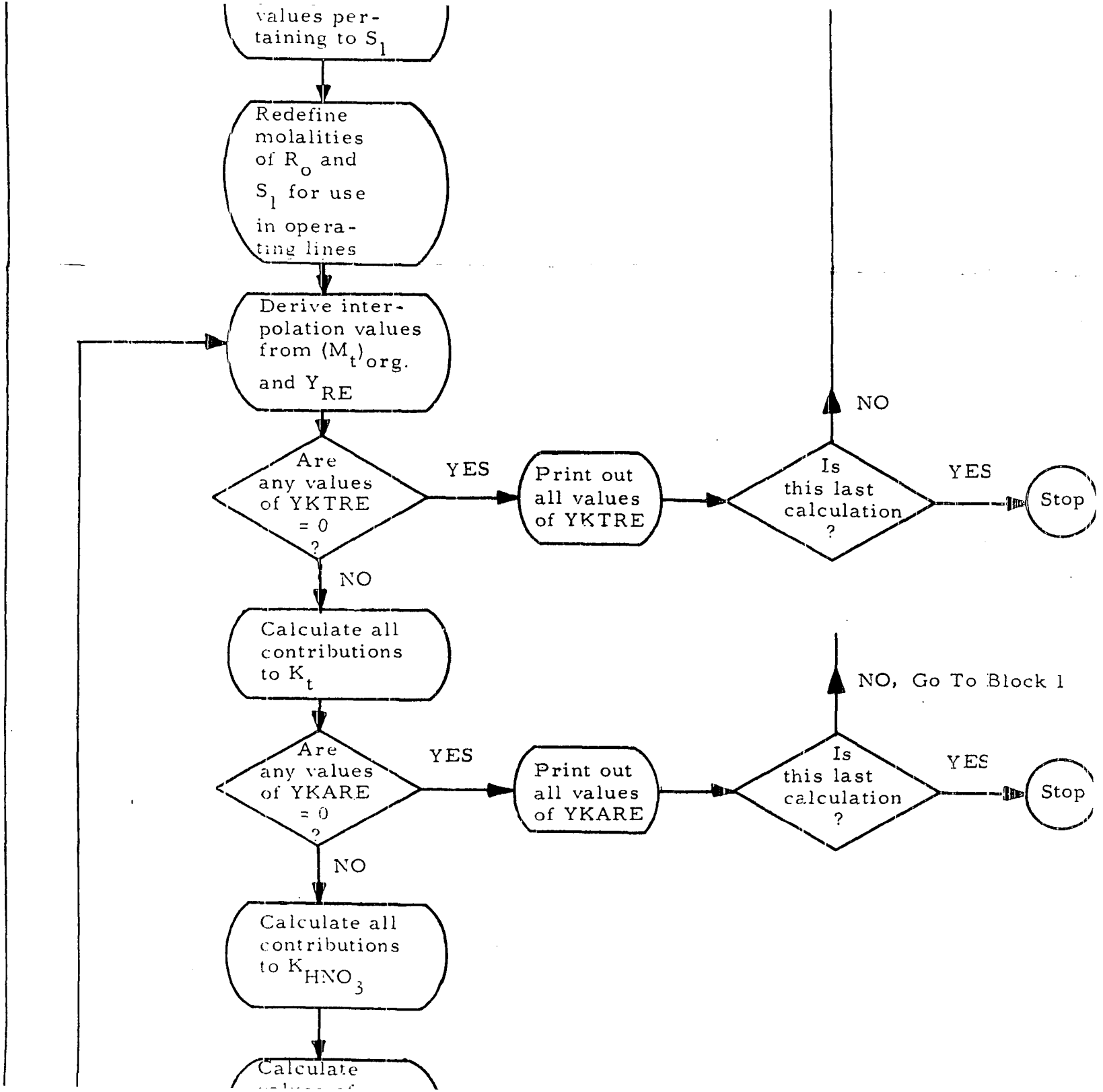
```
503   FORMAT (36HIINTERNAL FEED,EXTRACT SIDE START S=F5.2,3H F=F5.2,5H RBMS3 249
     1EX=F5.2,5H RSC=F5.2,3H N=I3,3H M=I3)                              BMS3 250
504   FORMAT (120HJ   TOTALMOLHNO3 MOL  LA MOL  PR MOL  ND MOL  SM MOL  BMS3 251
     1RE MOL  ACFR  LAFR  PRFR  NDFR  SMFR  REFR LA/RE PR/RE ND/RE SM/REBMS3 252
     2)                                                                 BMS3 253
505   FORMAT (4HJ  F7F8.4,10F6.3)                                        BMS3 254
506   FORMAT (4HJ  F7F8.4,6F6.3)                                         BMS3 255
507   FORMAT (4HJ  F7F8.4)                                               BMS3 256
508   FORMAT (4HJS O7F8.4,10F6.3)                                        BMS3 257
509   FORMAT (4HJS O7F8.4,6F6.3)                                         BMS3 258
510   FORMAT (4HJS O7F8.4)                                               BMS3 259
511   FORMAT (4H R 17F8.4,10F6.3)                                        BMS3 260
512   FORMAT (8HJXKTRE=016F6.3,F8.4,F6.3)                                BMS3 261
513   FORMAT (8HJXKARE=016F6.3,F8.4,F6.3)                                BMS3 262
514   FORMAT (6HJTMOR=F8.4,6H TMAQ=F8.4,6H TOTK=F8.4)                    BMS3 263
515   FORMAT (18HJREMOR LESS THAN 04F10.4)                               BMS3 264
516   FORMAT (16HJSYO NOT EQUAL 17F10.4)                                 BMS3 265
517   FORMAT (18HJSYREO NOT EQUAL 17F10.4)                               BMS3 266
518   FORMAT (17HJFEED ENTRY POINT)                                      BMS3 267
519   FORMAT (2HJSI2,7F8.4,10F6.3)                                       BMS3 268
520   FORMAT (6HJTMAQ=F10.4,6H AMAQ=F10.4,8H XLAMAQ=F10.4,7H PRMAQ=F10.4BMS3 269
     1,8H XNDMAQ=F10.4,7H SMMAQ=F10.4,7H REMAQ=F10.4)                   BMS3 270
521   FORMAT (16HJSXA NOT EQUAL 17F10.4)                                 BMS3 271
522   FORMAT (18HJSXREA NOT EQUAL 17F10.4)                               BMS3 272
523   FORMAT (2H RI2,7F8.4,10F6.3)                                       BMS3 273
524   FORMAT (6HJTMAQ=F10.4)                                             BMS3 274
600   STOP 89                                                            BMS3 275
      END                                                                BMS3 276
```

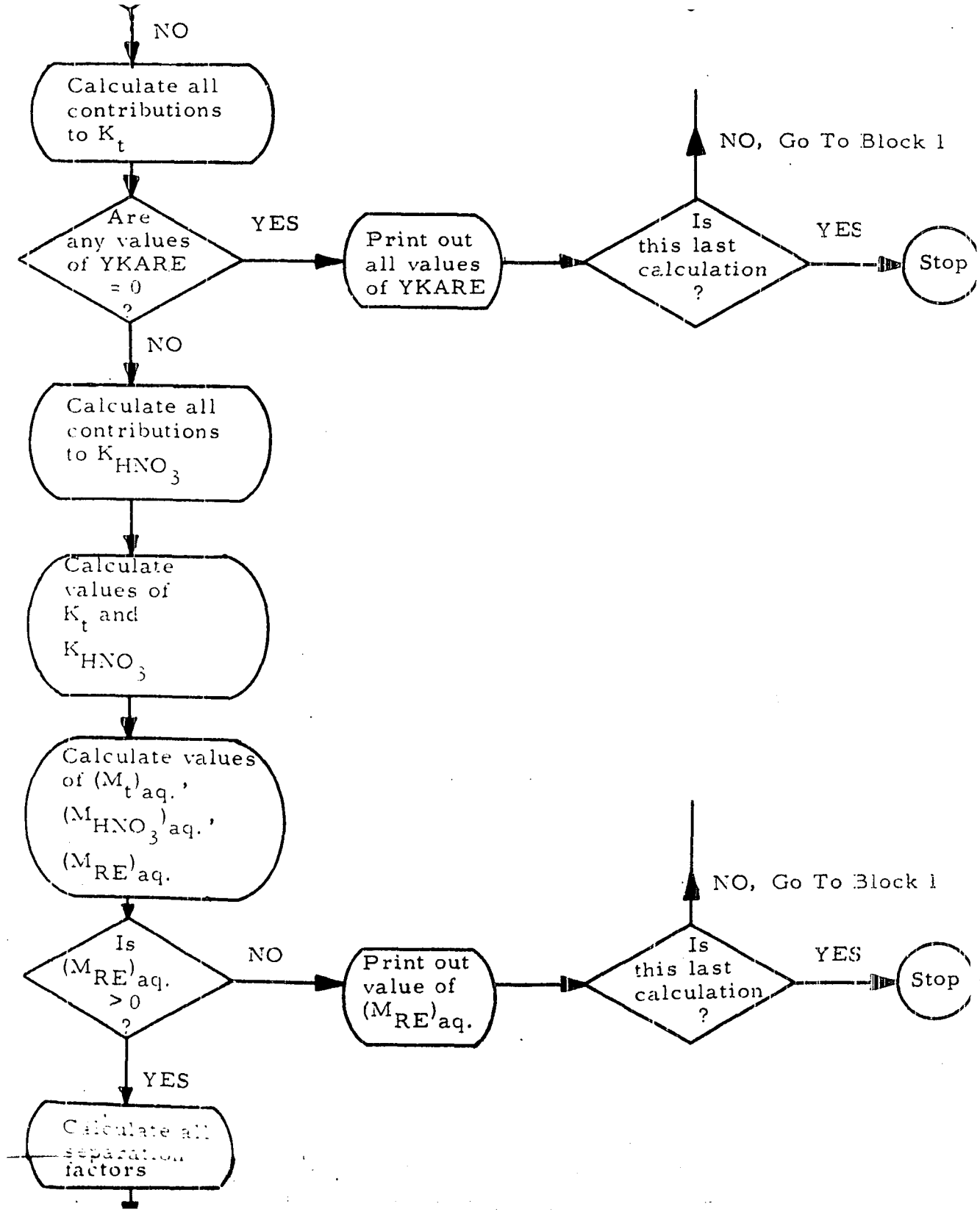
Figure 43. (Continued)

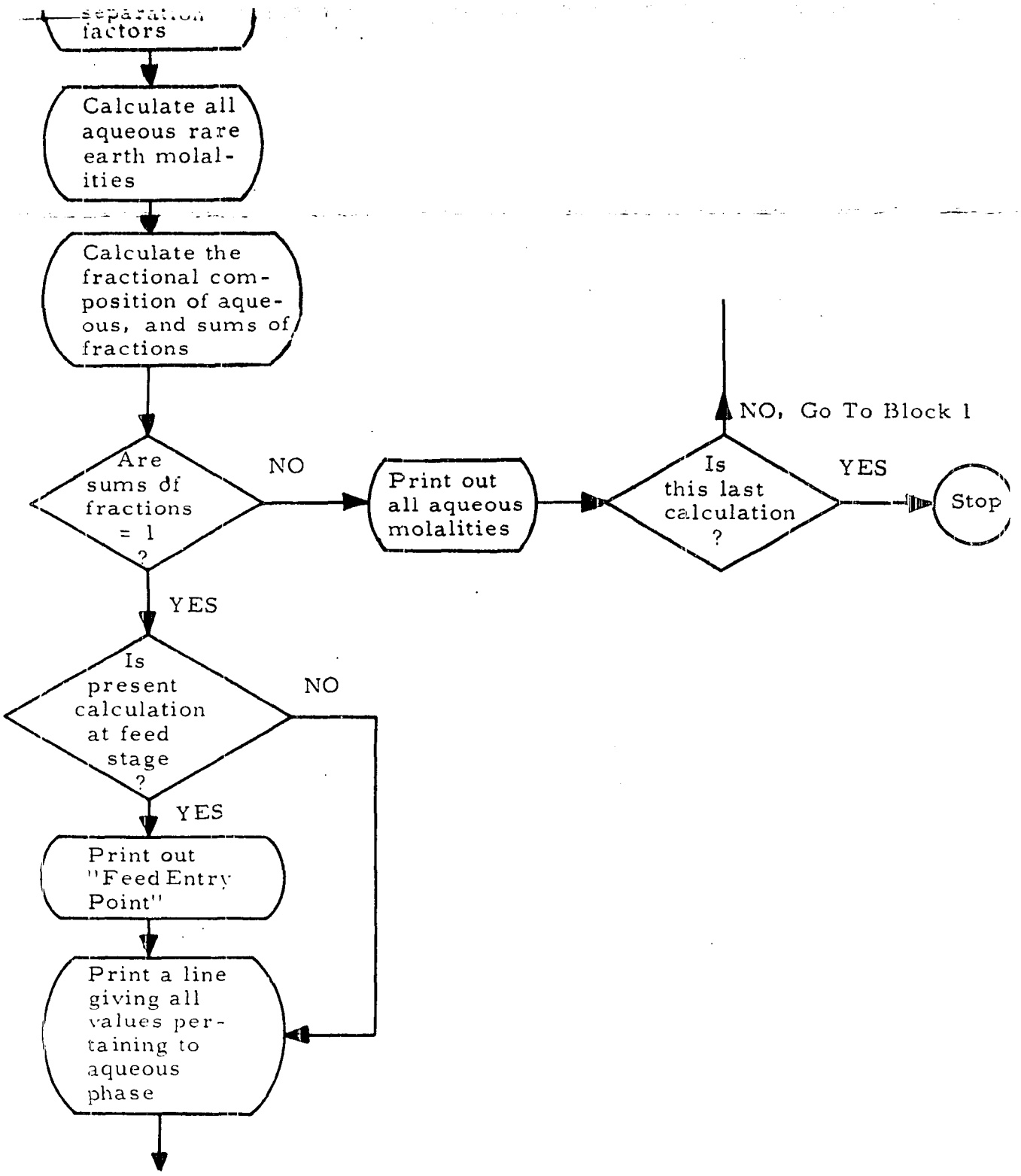
Block 1

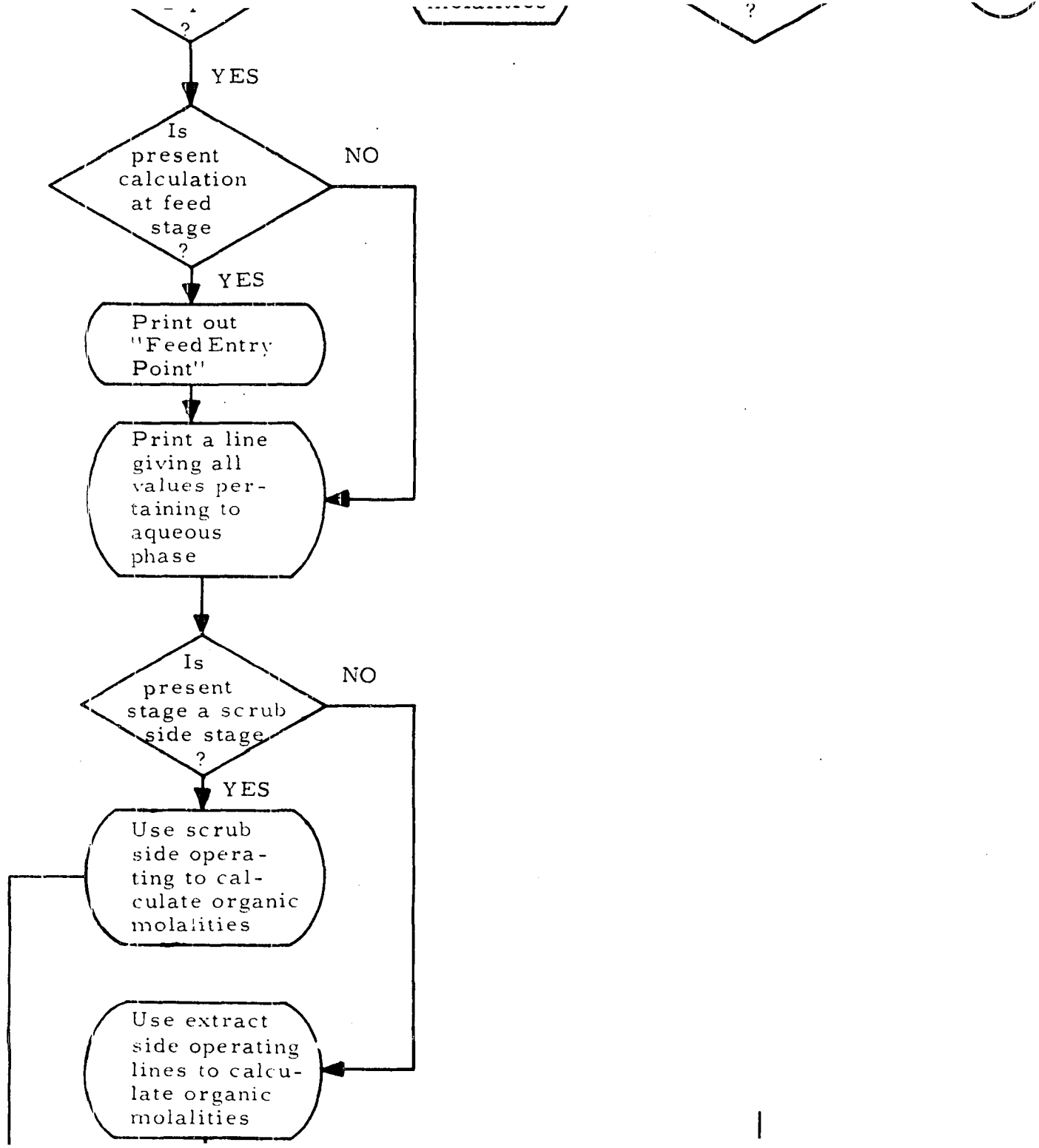

Read in all molalities of R_o, S_1, and F
Read in N, M, S, F, REX, RSC
Print out problem designation, N, M, S, F, REX, RSC
Print out column headings
Calculate the fractional composition of stream F
Print a line giving all values pertaining to stream F
Calculate the fractional com-

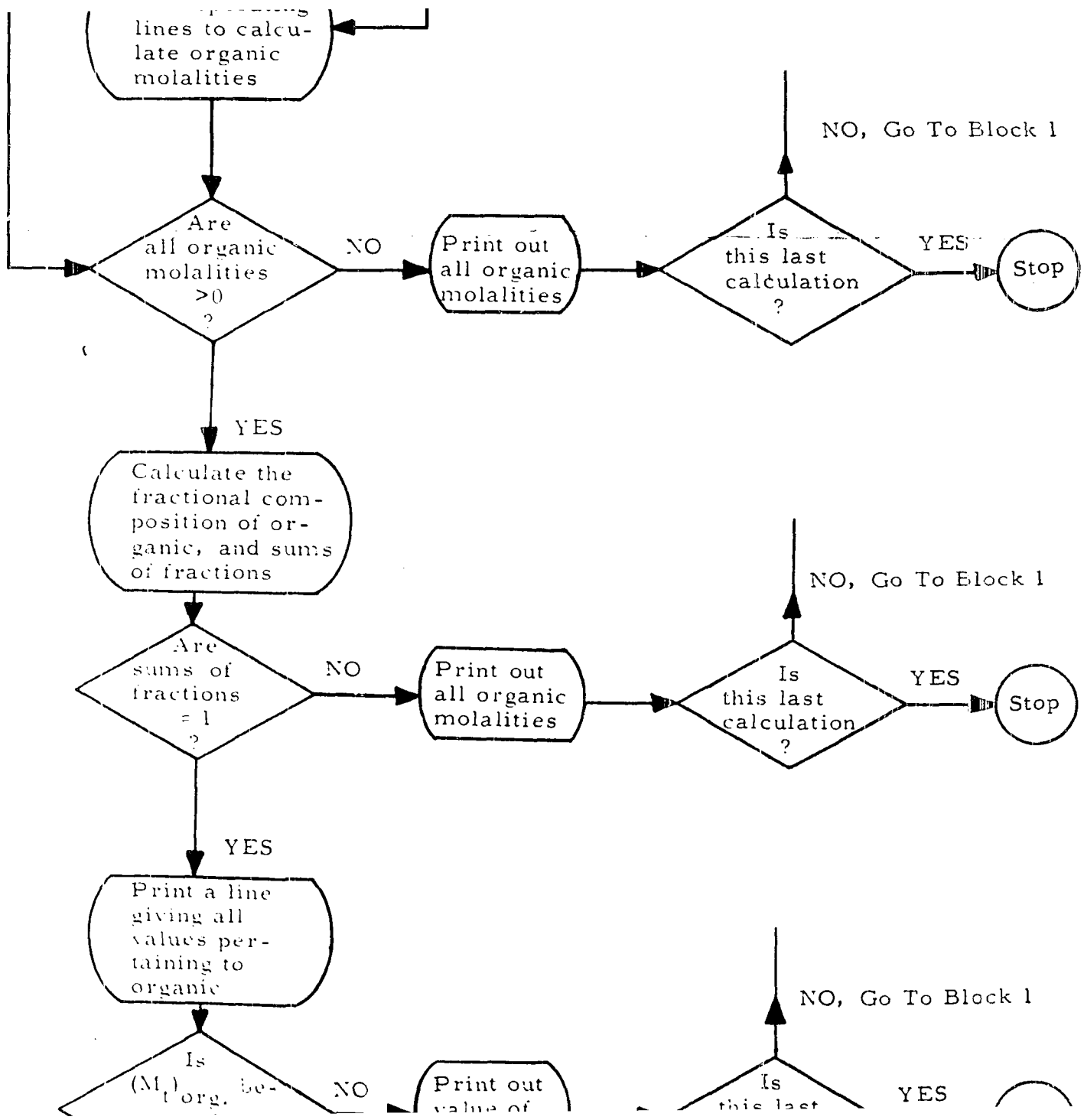

values pertaining to stream F
Calculate the fractional composition of R_o
Print a line giving all values pertaining to R_o
Calculate the fractional composition of S_1
Print a line giving all values pertaining to S_1
Redefine molalities of R_o and S_1 for use in operating lines


values pertaining to S_1
Redefine molalities of R_o and S_1 for use in operating lines
Derive interpolation values from $(M_t)_{org.}$ and Y_{RE}
Are any values of YKTRE = 0 ?
YES
Print out all values of YKTRE
Is this last calculation ?
YES
Stop
NO
NO
Calculate all contributions to K_t
Are any values of YKARE = 0 ?
YES
Print out all values of YKARE
Is this last calculation ?
YES
Stop
NO, Go To Block 1
NO
Calculate all contributions to K_{HNO_3}
Calculate


NO
Calculate all contributions to K_t
Are any values of YKARE = 0 ?
YES
Print out all values of YKARE
Is this last calculation ?
NO, Go To Block 1
YES
Stop
NO
Calculate all contributions to K_{HNO_3}
Calculate values of K_t and K_{HNO_3}
Calculate values of $(M_t)_{aq.}$, $(M_{HNO_3})_{aq.}$, $(M_{RE})_{aq.}$
Is $(M_{RE})_{aq.} > 0$?
NO
Print out value of $(M_{RE})_{aq.}$
Is this last calculation ?
NO, Go To Block 1
YES
Stop
YES
Calculate all separation factors


separation factors
Calculate all aqueous rare earth molalities
Calculate the fractional composition of aqueous, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all aqueous molalities
Is this last calculation ?
YES
Stop
NO, Go To Block 1
YES
Is present calculation at feed stage ?
NO
YES
Print out "Feed Entry Point"
Print a line giving all values pertaining to aqueous phase


?
YES
Is present calculation at feed stage ?
NO
YES
Print out "Feed Entry Point"
Print a line giving all values pertaining to aqueous phase
Is present stage a scrub side stage ?
NO
YES
Use scrub side operating to calculate organic molalities
Use extract side operating lines to calculate organic molalities


lines to calculate organic molalities
Are all organic molalities >0 ?
NO
Print out all organic molalities
Is this last calculation ?
NO, Go To Block 1
YES
Stop
YES
Calculate the fractional composition of organic, and sums of fractions
Are sums of fractions = 1 ?
NO
Print out all organic molalities
Is this last calculation ?
NO, Go To Block 1
YES
Stop
YES
Print a line giving all values pertaining to organic
Is
NO
Print out
Is
NO, Go To Block 1
YES

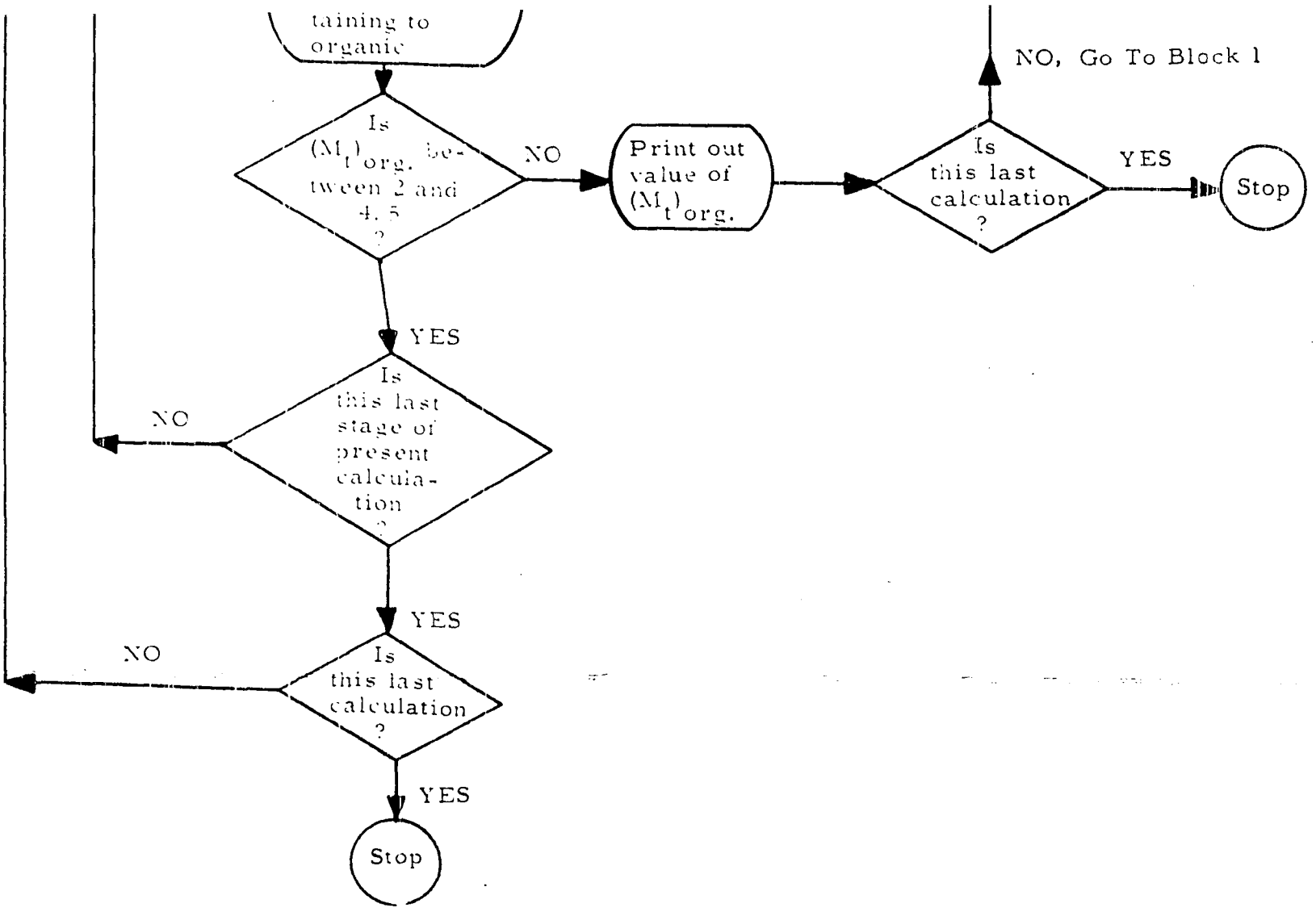


Figure 44. Flow diagram, Program IV

```
      DIMENSION YKTLA(21,6),YKTPR(21,6),YKTND(21,6),YKTSM(21,6),YKALA(21BMS4 001
     1,6),YKAPR(21,6),YKAND(21,6),YKASM(21,6)                          BMS4 002
      DO 5 I = 1,21                                                    BMS4 003
5     READ INPUT TAPE 5, 500, (YKTLA(I,J),J = 1,6)                     BMS4 004
      DO 10 I = 1,21                                                   BMS4 005
10    READ INPUT TAPE 5, 500, (YKTPR(I,J),J = 1,6)                     BMS4 006
      DO 15 I = 1,21                                                   BMS4 007
15    READ INPUT TAPE 5, 500, (YKTND(I,J),J = 1,6)                     BMS4 008
      DO 20 I = 1,21                                                   BMS4 009
20    READ INPUT TAPE 5, 500, (YKTSM(I,J),J = 1,6)                     BMS4 010
      DO 25 I = 1,21                                                   BMS4 011
25    READ INPUT TAPE 5, 500, (YKALA(I,J),J = 1,6)                     BMS4 012
      DO 30 I = 1,21                                                   BMS4 013
30    READ INPUT TAPE 5, 500, (YKAPR(I,J),J = 1,6)                     BMS4 014
      DO 35 I = 1,21                                                   BMS4 015
35    READ INPUT TAPE 5, 500, (YKAND(I,J),J = 1,6)                     BMS4 016
      DO 40 I = 1,21                                                   BMS4 017
40    READ INPUT TAPE 5, 500, (YKASM(I,J),J = 1,6)                     BMS4 018
45    READ INPUT TAPE 5, 501, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ BMS4 019
      READ INPUT TAPE 5, 501, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR BMS4 020
      READ INPUT TAPE 5, 502, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,S,F,REX,RBMS4 021
     1SC,N,M,K                                                         BMS4 022
      PRINT 503, S,F,REX,RSC,N,M                                       BMS4 023
      PRINT 504                                                        BMS4 024
      IF (FTM) 600,65,50                                               BMS4 025
50    XAF = FAM/FTM                                                    BMS4 026
      XLAF = FLAM/FTM                                                  BMS4 027
      XPRF = FPRM/FTM                                                  BMS4 028
      XNDF = FNDM/FTM                                                  BMS4 029
      XSMF = FSMM/FTM                                                  BMS4 030
      XREF = FREM/FTM                                                  BMS4 031
      IF (FREM) 600,60,55                                              BMS4 032
55    XLASFF = FLAM/FREM                                               BMS4 033
      XPRSFF = FPRM/FREM                                               BMS4 034
      XNDSFF = FNDM/FREM                                               BMS4 035
      XSMSFF = FSMM/FREM                                               BMS4 036
      PRINT 505, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,XAF,XLAF,XPRF,XNDF,XSMBMS4 037
     1F,XREF,XLASFF,XPRSFF,XNDSFF,XSMSFF                               BMS4 038
      GO TO 70                                                         BMS4 039
60    PRINT 506, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM,XAF,XLAF,XPRF,XNDF,XSMBMS4 040
     1F,XREF                                                           BMS4 041
      GO TO 70                                                         BMS4 042
65    PRINT 507, FTM,FAM,FLAM,FPRM,FNDM,FSMM,FREM                      BMS4 043
70    IF (TMAQ) 600,90,75                                              BMS4 044
75    XHNO3 = AMAQ/TMAQ                                                BMS4 045
      XLA = XLAMAQ/TMAQ                                                BMS4 046
      XPR = PRMAQ/TMAQ                                                 BMS4 047
      XND = XNDMAQ/TMAQ                                                BMS4 048
      XSM = SMMAQ/TMAQ                                                 BMS4 049
      XRE = REMAQ/TMAQ                                                 BMS4 050
      IF (REMAQ) 600,95,80                                             BMS4 051
80    XLASF = XLAMAQ/REMAQ                                             BMS4 052
      XPRSF = PRMAQ/REMAQ                                              BMS4 053
      XNDSF = XNDMAQ/REMAQ                                             BMS4 054
      XSMSF = SMMAQ/REMAQ                                              BMS4 055
      PRINT 508, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS4 056
     1,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                             BMS4 057
      GO TO 95                                                         BMS4 058
85    PRINT 509, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPRBMS4 059
     1,XND,XSM,XRE                                                     BMS4 060
      GO TO 95                                                         BMS4 061
90    PRINT 510, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ            BMS4 062
```

Figure 45. Fortran statements, Program IV

```
 95     YHNO3 = AMOR/TMOR                                                    BMS4 063
        YLA = XLAMOR/TMOR                                                    BMS4 064
        YPR = PRMOR/TMOR                                                     BMS4 065
        YND = XNDMOR/TMOR                                                    BMS4 066
        YSM = SMMOR/TMOR                                                     BMS4 067
        YRE = REMOR/TMOR                                                     BMS4 068
        YLASF = XLAMOR/REMOR                                                 BMS4 069
        YPRSF = PRMOR/REMOR                                                  BMS4 070
        YNDSF = XNDMOR/REMOR                                                 BMS4 071
        YSMSF = SMMOR/REMOR                                                  BMS4 072
        PRINT 511, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,YPRBMS4 073
       1,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                                 BMS4 074
        ROTM = TMAQ                                                          BMS4 075
        ROAM = AMAQ                                                          BMS4 076
        ROLAM = XLAMAQ                                                       BMS4 077
        ROPRM = PRMAQ                                                        BMS4 078
        RONDM = XNDMAQ                                                       BMS4 079
        ROSMM = SMMAQ                                                        BMS4 080
        SITM = TMOR                                                          BMS4 081
        SIAM = AMOR                                                          BMS4 082
        SILAM = XLAMOR                                                       BMS4 083
        SIPRM = PRMOR                                                        BMS4 084
        SINDM = XNDMOR                                                       BMS4 085
        SISMM = SMMOR                                                        BMS4 086
        DO 235 L = 1,N                                                       BMS4 087
        YREI = (YRE*100.0 + 5.0)/5.0                                         BMS4 088
        IY = YREI                                                            BMS4 089
        YI = IY                                                              BMS4 090
        FRY = YREI - YI                                                      BMS4 091
        Z = (TMOR*10.0 - 15.0)/5.0                                           BMS4 092
        KZ = Z                                                               BMS4 093
        ZK = KZ                                                              BMS4 094
        FRZ = Z - ZK                                                         BMS4 095
        SKT = MIN1F(YKTLA(IY,KZ),YKTLA(IY+1,KZ),YKTLA(IY,KZ+1),YKTLA(IY+1,BMS4 096
       1KZ+1),YKTPR(IY,KZ),YKTPR(IY+1,KZ),YKTPR(IY,KZ+1),YKTPR(IY+1,KZ+1),BMS4 097
       2YKTND(IY,KZ),YKTND(IY+1,KZ),YKTND(IY,KZ+1),YKTND(IY+1,KZ+1),YKTSM(BMS4 098
       3IY,KZ),YKTSM(IY+1,KZ),YKTSM(IY,KZ+1),YKTSM(IY+1,KZ+1))              BMS4 099
        IF (SKT) 100,100,105                                                 BMS4 100
 100    PRINT 512, YKTLA(IY,KZ),YKTLA(IY+1,KZ),YKTLA(IY,KZ+1),YKTLA(IY+1,KBMS4 101
       1Z+1),YKTPR(IY,KZ),YKTPR(IY+1,KZ),YKTPR(IY+1,KZ),YKTPR(IY+1,KZ+1),YBMS4 102
       2KTND(IY,KZ),YKTND(IY+1,KZ),YKTND(IY,KZ+1),YKTND(IY+1,KZ+1),YKTSM(IBMS4 103
       3Y,KZ),YKTSM(IY+1,KZ),YKTSM(IY,KZ+1),YKTSM(IY+1,KZ+1),TMOR,YRE       BMS4 104
        IF (K) 600,600,45                                                    BMS4 105
 105    YKTLA1 = YKTLA(IY,KZ)*(1.0 - FRY) + YKTLA(IY+1,KZ)*FRY               BMS4 106
        YKTLA2 = YKTLA(IY,KZ+1)*(1.0 - FRY) + YKTLA(IY+1,KZ+1)*FRY           BMS4 107
        YKTLA3 = YKTLA1*(1.0 - FRZ) + YKTLA2*FRZ                             BMS4 108
        CKTLA = YKTLA3 * YLASF                                               BMS4 109
        YKTPR1 = YKTPR(IY,KZ)*(1.0 - FRY) + YKTPR(IY+1,KZ)*FRY               BMS4 110
        YKTPR2 = YKTPR(IY,KZ+1)*(1.0 - FRY) + YKTPR(IY+1,KZ+1)*FRY           BMS4 111
        YKTPR3 = YKTPR1*(1.0 - FRZ) + YKTPR2*FRZ                             BMS4 112
        CKTPR = YKTPR3 * YPRSF                                               BMS4 113
        YKTND1 = YKTND(IY,KZ)*(1.0 - FRY) + YKTND(IY+1,KZ)*FRY               BMS4 114
        YKTND2 = YKTND(IY,KZ+1)*(1.0 - FRY) + YKTND(IY+1,KZ+1)*FRY           BMS4 115
        YKTND3 = YKTND1*(1.0 - FRZ) + YKTND2*FRZ                             BMS4 116
        CKTND = YKTND3 * YNDSF                                               BMS4 117
        YKTSM1 = YKTSM(IY,KZ)*(1.0 - FRY) + YKTSM(IY+1,KZ)*FRY               BMS4 118
        YKTSM2 = YKTSM(IY,KZ+1)*(1.0 - FRY) + YKTSM(IY+1,KZ+1)*FRY           BMS4 119
        YKTSM3 = YKTSM1*(1.0 - FRZ) + YKTSM2*FRZ                             BMS4 120
        CKTSM = YKTSM3 * YSMSF                                               BMS4 121
        SKA = MIN1F(YKALA(IY,KZ),YKALA(IY+1,KZ),YKALA(IY,KZ+1),YKALA(IY+1,BMS4 122
       1KZ+1),YKAPR(IY,KZ),YKAPR(IY+1,KZ),YKAPR(IY,KZ+1),YKAPR(IY+1,KZ+1),BMS4 123
       2YKAND(IY,KZ),YKAND(IY+1,KZ),YKAND(IY,KZ+1),YKAND(IY+1,KZ+1),YKASM(BMS4 124
```

Figure 45. (Continued)

```
     3IY,KZ),YKASM(IY+1,KZ),YKASM(IY,KZ+1),YKASM(IY+1,KZ+1))                    BMS4 125
      IF (SKA) 110,110,115                                                      BMS4 126
110   PRINT 513, YKALA(IY,KZ),YKALA(IY+1,KZ),YKALA(IY,KZ+1),YKALA(IY+1,KBMS4 127
     1Z+1),YKAPR(IY,KZ),YKAPR(IY+1,KZ),YKAPR(IY,KZ+1),YKAPR(IY+1,KZ+1),YBMS4 128
     2KAND(IY,KZ),YKAND(IY+1,KZ),YKAND(IY,KZ+1),YKAND(IY+1,KZ+1),YKASM(IBMS4 129
     3Y,KZ),YKASM(IY+1,KZ),YKASM(IY,KZ+1),YKASM(IY+1,KZ+1),TMOR,YRE      BMS4 130
      IF (K) 600,600,45                                                         BMS4 131
115   YKALA1 = YKALA(IY,KZ)*(1.0 - FRY) + YKALA(IY+1,KZ)*FRY                    BMS4 132
      YKALA2 = YKALA(IY,KZ+1)*(1.0 - FRY) + YKALA(IY+1,KZ+1)*FRY                BMS4 133
      YKALA3 = YKALA1*(1.0 - FRZ) + YKALA2*FRZ                                  BMS4 134
      CKALA = YKALA3 * YLASF                                                    BMS4 135
      YKAPR1 = YKAPR(IY,KZ)*(1.0 - FRY) + YKAPR(IY+1,KZ)*FRY                    BMS4 136
      YKAPR2 = YKAPR(IY,KZ+1)*(1.0 - FRY) + YKAPR(IY+1,KZ+1)*FRY                BMS4 137
      YKAPR3 = YKAPR1*(1.0 - FRZ) + YKAPR2*FRZ                                  BMS4 138
      CKAPR = YKAPR3 * YPRSF                                                    BMS4 139
      YKAND1 = YKAND(IY,KZ)*(1.0 - FRY) + YKAND(IY+1,KZ)*FRY                    BMS4 140
      YKAND2 = YKAND(IY,KZ+1)*(1.0 - FRY) + YKAND(IY+1,KZ+1)*FRY                BMS4 141
      YKAND3 = YKAND1*(1.0 - FRZ) + YKAND2*FRZ                                  BMS4 142
      CKAND = YKAND3 * YNDSF                                                    BMS4 143
      YKASM1 = YKASM(IY,KZ)*(1.0 - FRY) + YKASM(IY+1,KZ)*FRY                    BMS4 144
      YKASM2 = YKASM(IY,KZ+1)*(1.0 - FRY) + YKASM(IY+1,KZ+1)*FRY                BMS4 145
      YKASM3 = YKASM1*(1.0 - FRZ) + YKASM2*FRZ                                  BMS4 146
      CKASM = YKASM3 * YSMSF                                                    BMS4 147
      TOTK = CKTLA + CKTPR + CKTND + CKTSM                                      BMS4 148
      HNO3K = CKALA + CKAPR + CKAND + CKASM                                     BMS4 149
      TMAQ = TMOR/TOTK                                                          BMS4 150
      AMAQ = AMOR/HNO3K                                                         BMS4 151
      REMAQ = TMAQ - AMAQ                                                       BMS4 152
      IF (REMAQ) 120,120,125                                                    BMS4 153
120   PRINT 514, TMAQ,AMAQ,REMAQ,HNO3K                                          BMS4 154
      IF (K) 600,600,45                                                         BMS4 155
125   BLAPR = 0.8187 - 0.1106*TMOR                                              BMS4 156
      BPRPR = 1.0                                                               BMS4 157
      BNDPR = 1.0448 + 0.09874*TMOR                                             BMS4 158
      BSMPR = -0.3795 + 0.9214*TMOR                                             BMS4 159
      DEMS = XLAMOR/BLAPR + PRMOR/BPRPR + XNDMOR/BNDPR + SMMOR/BSMPR            BMS4 160
      XLAMAQ = XLAMOR*REMAQ/(BLAPR*DEMS)                                        BMS4 161
      PRMAQ = PRMOR*REMAQ/(BPRPR*DEMS)                                          BMS4 162
      XNDMAQ = XNDMOR*REMAQ/(BNDPR*DEMS)                                        BMS4 163
      SMMAQ = SMMOR*REMAQ/(BSMPR*DEMS)                                          BMS4 164
      XHNO3 = AMAQ/TMAQ                                                         BMS4 165
      XLA = XLAMAQ/TMAQ                                                         BMS4 166
      XPR = PRMAQ/TMAQ                                                          BMS4 167
      XND = XNDMAQ/TMAQ                                                         BMS4 168
      XSM = SMMAQ/TMAQ                                                          BMS4 169
      XRE = REMAQ/TMAQ                                                          BMS4 170
      XLASF = XLAMAQ/REMAQ                                                      BMS4 171
      XPRSF = PRMAQ/REMAQ                                                       BMS4 172
      XNDSF = XNDMAQ/REMAQ                                                      BMS4 173
      XSMSF = SMMAQ/REMAQ                                                       BMS4 174
      SXA = XHNO3 + XLA + XPR + XND + XSM                                       BMS4 175
      IF (0.9999 - SXA) 130,140,135                                             BMS4 176
130   IF (1.0001 - SXA) 135,140,140                                             BMS4 177
135   PRINT 515, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                      BMS4 178
      IF (K) 600,600,45                                                         BMS4 179
140   SXREA = XLASF + XPRSF + XNDSF + XSMSF                                     BMS4 180
      IF (0.9999 - SXREA) 145,155,150                                           BMS4 181
145   IF (1.0001 - SXREA) 150,155,155                                           BMS4 182
150   PRINT 516, TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ                      BMS4 183
      IF (K) 600,600,45                                                         BMS4 184
155   IF (L - M) 165,160,165                                                    BMS4 185
160   PRINT 517                                                                 BMS4 186
```

Figure 45. (Continued)

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165   PRINT 518,L,TMAQ,AMAQ,XLAMAQ,PRMAQ,XNDMAQ,SMMAQ,REMAQ,XHNO3,XLA,XPBMS4 187
     1R,XND,XSM,XRE,XLASF,XPRSF,XNDSF,XSMSF                              BMS4 188
      IF (L - M) 170,175,175                                             BMS4 189
170   TMOR =((TMAQ - ROTM)*RSC/S)+ S1TM                                  BMS4 190
      AMOR =((AMAQ - ROAM)*RSC/S)+ S1AM                                  BMS4 191
      XLAMOR =((XLAMAQ - ROLAM)*RSC/S)+ S1LAM                            BMS4 192
      PRMOR = ((PRMAQ - ROPRM)*RSC/S)+ S1PRM                             BMS4 193
      XNDMOR =((XNDMAQ - RONDM)*RSC/S)+ S1NDM                            BMS4 194
      SMMOR = ((SMMAQ - ROSMM)*RSC/S)+ S1SMM                             BMS4 195
      GO TO 180                                                          BMS4 196
175   TMOR = TMAQ*REX/S - FTM*F/S - ROTM*RSC/S + S1TM                    BMS4 197
      AMOR = AMAQ*REX/S   FAM*F/S - ROAM*RSC/S + S1AM                    BMS4 198
      XLAMOR = XLAMAQ*REX/S - FLAM*F/S -ROLAM*RSC/S + S1LAM              BMS4 199
      PRMOR = PRMAQ*REX/S - FPRM*F/S - ROPRM*RSC/S + S1PRM               BMS4 200
      XNDMOR = XNDMAQ*REX/S - FNDM*F/S - RONDM*RSC/S + S1NDM             BMS4 201
      SMMOR = SMMAQ*REX/S - FSMM*F/S - ROSMM*RSC/S + S1SMM               BMS4 202
180   REMOR = TMOR - AMOR                                                BMS4 203
      SOM = MIN1F(TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR)             BMS4 204
      IF (SOM) 185,185,190                                               BMS4 205
185   PRINT 519, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR              BMS4 206
      IF (K) 600,600,45                                                  BMS4 207
190   YHNO3 = AMOR/TMOR                                                  BMS4 208
      YLA = XLAMOR/TMOR                                                  BMS4 209
      YPR = PRMOR/TMOR                                                   BMS4 210
      YND = XNDMOR/TMOR                                                  BMS4 211
      YSM = SMMOR/TMOR                                                   BMS4 212
      YRE = REMOR/TMOR                                                   BMS4 213
      YLASF = XLAMOR/REMOR                                               BMS4 214
      YPRSF = PRMOR/REMOR                                                BMS4 215
      YNDSF = XNDMOR/REMOR                                               BMS4 216
      YSMSF = SMMOR/REMOR                                                BMS4 217
      SYO = YHNO3 + YLA + YPR + YND + YSM                                BMS4 218
      IF (0.9999 - SYO) 195,205,200                                      BMS4 219
195   IF (1.0001 - SYO) 200,205,205                                      BMS4 220
200   PRINT 520, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR              BMS4 221
      IF (K) 600,600,45                                                  BMS4 222
205   SYREO = YLASF + YPRSF + YNDSF + YSMSF                              BMS4 223
      IF (0.9999 - SYREO) 210,220,215                                    BMS4 224
210   IF (1.0001 - SYREO) 215,220,220                                    BMS4 225
215   PRINT 521, TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR              BMS4 226
      IF (K) 600,600,45                                                  BMS4 227
220   LL = L + 1                                                         BMS4 228
      PRINT 522, LL,TMOR,AMOR,XLAMOR,PRMOR,XNDMOR,SMMOR,REMOR,YHNO3,YLA,BMS4 229
     1YPR,YND,YSM,YRE,YLASF,YPRSF,YNDSF,YSMSF                            BMS4 230
      IF (TMOR - 2.0) 225,230,230                                        BMS4 231
225   PRINT 523, TMOR                                                    BMS4 232
      IF (K) 600,600,45                                                  BMS4 233
230   IF (TMOR - 4.5) 235,225,225                                        BMS4 234
235   CONTINUE                                                           BMS4 235
      IF (K) 600,600,45                                                  BMS4 236
500   FORMAT (6F10.3)                                                    BMS4 237
501   FORMAT (7F10.4)                                                    BMS4 238
502   FORMAT (7F7.4,4F5.2,3I3)                                           BMS4 239
503   FORMAT (34H1INTERNAL FEED,SCRUB SIDE START S=F5.2,3H F=F5.2,5H REXBMS4 240
     1=F5.2,5H RSC=F5.2,3H N=I3,3H M=I3)                                 BMS4 241
504   FORMAT (120HJ  TOTALMOLHNO3 MOL  LA MOL  PR MOL  ND MOL  SM MOL  BMS4 242
     1RE MOL  ACFR  LAFR  PRFR  NDFR  SMFR  REFR LA/RE PR/RE ND/RE SM/REBMS4 243
     2)                                                                  BMS4 244
505   FORMAT (4HJ  F7F8.4,10F6.3)                                        BMS4 245
506   FORMAT (4HJ  F7F8.4,6F6.3)                                         BMS4 246
507   FORMAT (4HJ  F7F8.4)                                               BMS4 247
508   FORMAT (4HJR 07F8.4,10F6.3)                                        BMS4 248
```

Figure 45. (Continued)

```
509   FORMAT (4HJR 07F8.4,6F6.3)                                          BMS4 249
510   FORMAT (4HJR 07F8.4)                                                BMS4 250
511   FORMAT (4H S 17F8.4,10F6.3)                                         BMS4 251
512   FORMAT (8HJYKTRE=016F6.3,F8.4,F6.3)                                 BMS4 252
513   FORMAT (8HJYKARE=016F6.3,F8.4,F6.3)                                 BMS4 253
514   FORMAT (18HJREMAQ LESS THAN 04F10.4)                                BMS4 254
515   FORMAT (16HJSXA NOT EQUAL 17F10.4)                                  BMS4 255
516   FORMAT (18HJSXREA NOT EQUAL 17F10.4)                                BMS4 256
517   FORMAT (17HJFEED ENTRY POINT)                                       BMS4 257
518   FORMAT (2HJRI2,7F8.4,10F6.3)                                        BMS4 258
519   FORMAT (6HJTMOR=F10.4,6H AMOR=F10.4,8H XLAMOR=F10.4,7H PRMOR=F10.4BMS4 259
     1,8H XNDMOR=F10.4,7H SMMOR=F10.4,7H REMOR=F10.4)                     BMS4 260
520   FORMAT (16HJSYO NOT EQUAL 17F10.4)                                  BMS4 261
521   FORMAT (18HJSYREO NOT EQUAL 17F10.4)                                BMS4 262
522   FORMAT (2H SI2,7F8.4,10F6.3)                                        BMS4 263
523   FORMAT (6HJTMOR=F10.4)                                              BMS4 264
600   STOP 89                                                             BMS4 265
      END                                                                 BMS4 266
```

Figure 45. (Continued)