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DEVELOPMENT OF A SAFEGUARDS EVALUATION METHOD THAT HAS FALSE ALARM ANALYSIS AS A KEY ELEMENT AND ITS APPLICATION TO A CENTRIFUGE ENRICHMENT PLANT

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Development of a Safeguards Evaluation Method That Has False Alarm Analysis as a Key Element and its Application to a Centrifuge Enrichment Plant

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Safeguards needs to have a methodology to assess and evaluate its effectiveness in order that it is implemented not only effectively but also efficiently. Therefore it is very important to develop a safeguards evaluation method which could be applied to the design, planning and implementation of safeguards. In this context, a method has been developed focussing on the importance of false alarm analysis besides the diversion analysis, and the method was applied to a centrifuge enrichment plant paying special attention to its sensitive information.

In accordance with the method, firstly a mathematical model for the enriching process of a centrifuge cascade was established and computerized on the basis of published documents. Secondly applying this simulation model to the plant, operations not related to the HEU production were analyzed to avoid false alarms, and theoretically possible scenarios for producing uranium with a higher enrichment were also analyzed to detect a diversion. Then the major anomalies were indicated for both cases and it was examined if the LFUA approach could differentiate these two types of anomalies in the plant.

This work has been carried out within the framework of the Japan Support Programme for Agency Safeguards as a project, JA-4, and this report describes the final result of the project.

Keywords: Safeguards, Effectiveness, Assessment, Evaluation, Methodology, False Alarm, Centrifuge, Enrichment, Mathematical Model, Computer Code, Diversion, Anomaly, LFUA Approach

誤警報の可能性の分析を主要な一要素とする保障措置評価法の開発とその遠心法ウラン濃縮施設への適用

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有効で効率的な保障措置を実施するためには，保障措置の設計，計画及び実施の各段階でその有効性を評価する尺度が必要である。したがって，このための保障措置評価法の開発は極めて重要である。本研究では，転用探知確率を有効性評価の尺度とする従来の考え方に対し，誤警報の可能性を系統的に分析することの重要性に着目した評価法を開発し，これを遠心法ウラン濃縮施設へ適用した。またこの際，機微情報の扱いに特に配慮した。

開発した評価法の手続きに従い，まず，遠心機カスケードにおける濃縮過程を記述する数学モデルを公開資料を基に確立し，コンピュータ化した。次に，これを遠心法ウラン濃縮施設へ適用し，誤警報を避ける観点から高濃縮ウランの生産に関係しない運転を分析し，また，転用探知の観点から理論上より高い濃縮度のウランを生産することが可能なシナリオについて分析した。さらに，主要なアノーマリを摘出し，これを誤りなく判定できるかどうかという観点から遠心法ウラン濃縮施設におけるLFUA法の有効性を検討した。

なお，本研究は，日本国のIAEA保障措置支援計画の一環としてプロジェクトJA-4として実施したものであり，本報告書は，その最終結果を記述している。

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1. Introduction

The International Atomic Energy Agency (IAEA) started to develop a safeguards effectiveness assessment methodology (SEAM) in 1979 with the help of experts from many countries, aiming at a common methodology which can be applied to the design, implementation planning and performance evaluation of IAEA safeguards, and the methodology was finalized at an IAEA advisory group meeting on safeguards effectiveness assessment methodology held in Vienna in 1981. [1] The basis of this methodology is to evaluate, as a measure of effectiveness, the probability of detection of at least one anomaly in the event that a diversion had occurred. This probability is evaluated usually in a model facility by analyzing the diversion paths, anomalies which would be created if a diversion were to occur, and the safeguards approach applied to the facility.

Although the methodology has never been in a routine use due to difficulties in, for example, obtaining a complete set of diversion scenarios including concealment measures, deciding to what extent the safeguards should cover the diversion paths, quantitatively evaluating the detection capability of a diversion path, and clearly understanding the physical meaning of the proposed aggregate measures, it has given us a good start in developing a more rational and complete method for assessment and evaluation of safeguards.

In order to improve some areas of SEAM, we started a project titled "Development of Safeguards Effectiveness Assessment Methodology (SEAM) and its Application to Existing and Planned Nuclear Facilities" within the framework of the Japan Support Programme for Agency Safeguards (JASPAS), i.e. a JASPAS project JA-4, in 1985. [2,3]

In SEAM, if an anomaly is detected, follow-up activities are to be carried out to decide whether the anomaly is an indication of a diversion or simply a false signal. In the course of analyzing such follow-up activities, we strongly felt the necessity of analyzing false alarm possibilities more systematically. In line with this thinking, we have developed an evaluation method which includes the false alarm analysis as a key element of the methodology and, using it, studied the effectiveness of safeguards in a centrifuge enrichment plant. This report gives a result of the study.

2. Safeguards Evaluation Method

In the paragraph 28 of INFCIRC/153 (Corrected) [4], the objective of safeguards is defined as follows: "The objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection." In accordance with this definition, the Safeguards Effectiveness Assessment Methodology (SEAM) [1] has been developed assuming that the safeguards effectiveness is measured by the extent to which the objectives of IAEA safeguards are satisfied in a given application. It is described in the report on SEAM that: "The principal parameter characterizing the effectiveness of Agency safeguards relates to its detection capability, that is, the probability of detection of diversion, should a diversion occur as a function of the quantity of material diverted and elapsed time, given that certain inspection activities are performed."

On the other hand, the first paragraph of INFCIRC/153 describes that the State accepts safeguards on all source or special fissionable material in all peaceful nuclear activities within its territory, under its jurisdiction or carried out under its control anywhere, for exclusive purpose of verifying that such material is not diverted to nuclear weapons or other nuclear explosive devices. From the viewpoint of the State, the Agency safeguards should clearly conclude that the nuclear material under the Agency safeguards is not diverted to nuclear weapons or other nuclear explosive devices because the State uses all nuclear material in all peaceful nuclear activities only for such purposes.

Therefore, the Agency safeguards should detect any diversion if a diversion were attempted and at the same time it should assure no diversion and avoid any false judgments if any diversions were not attempted. In this connection, much effort has been devoted to reduce a non-detection probability. Namely, diversion paths have been analyzed in detail, anomalies identified, and inspection strategy has been designed, planned and implemented so as to be able to detect such anomalies. Corresponding to such effort, however, the similar effort should be made to reduce a false alarm probability, that is, a probability of making a false decision that a diversion has occurred though it has not occurred. Normally a follow-up action is designed and taken if some anomalies are detected during the course of inspections in order to avoid false decisions. However, more systematic approach should be taken in the false alarm analysis by defining it as a key element of the methodology. The safeguards effectiveness should be measured not only by the detection capability but also by a non-false-decision probability.

False alarms are generated by some causes/reasons such as:

(1) Insufficient information provided to the Agency;
(2) Problems raised in a plant in operation; and
(3) The fundamental nature of the statistics used in the accountancy of nuclear material for safeguards.

On the information, the Agency is provided with design information for a facility to be safeguarded in a degree of sufficiency to design a safeguards approach and procedure and to implement them at the facility and at the Headquarters. Insufficiency of such information will occur if:

(1.a) The Agency does not require it or does not understand it sufficiently or simply the operator does not have it or does not correctly understand the requirement of the Agency; or
(1.b) The information is not provided to the Agency because it is a kind of sensitive information.

The Agency could avoid the former case if every divisions concerned in the Agency cooperate one another and if the Agency consult with advisors, consultants and experts from the Member States. As for the latter case, a cautious approach should be devised. One of such approaches was discussed in a report [5]. It is suggested that:

a. A mathematical process model should be developed on the basis of published theories and data, without including classified information. Such a model would contribute not only to provide the inspectorates with a tool to analyze the process but also to provide the public with transparency on a plant in which an advanced technology is used;
b. If there are technical parameters that can be easily modified depending on the progress of development of technologies, a sensitivity analysis should be carried out to evaluate the effect of such progress on the

safeguards approach/procedure to be adopted and, if appropriate, to modify them;

c. If appropriate, experts from the countries of technology holders could guarantee the degree of accuracy of the model; and

d. Reliable, effective and efficient safeguards could be designed using such model.

Since a centrifuge enrichment process, which is investigated in this report, has sensitive information, we have adopted the approach mentioned above.

On the problems raised in the plant in operation, there are some possibilities of making a false decision due to problems such as:

(2.a) Deviations from the normal operation;
(2.b) Malfunctions of equipment, instruments, devices or systems of an operator or inspector including clerical errors;
(2.c) Mis-operations due to human errors; and
(2.d) Quality of work done by a person who is responsible for, e.g., a measurement.

In a current practice of safeguards, these possibilities might be investigated in a follow-up activity if an anomaly is detected. The anomaly, however, could not be avoided or easily solved. A systematic analysis of such possibilities could beforehand provide us with not only a complete set of false alarms but also a measures to avoid the false alarms or to solve them easily, in the design, planning and implementing phases. In this report, such a systematic analysis is attempted in a centrifuge enrichment plant.

On the problem of statistics, it is said that it is inevitable to have a false alarm with regard to the fundamental safeguards statistics such as MUF statistic, D statistic and MUF-D statistic because the verification system allows to have a non-zero false alarm probability (the first kind of error). Solving anomalies raised by the statistics would be quite difficult because a part of nuclear material would have already been shipped to another facility, making it impossible to reverify such material. A new approach based on a fuel cycle might be a solution. This problem, however, is not investigated further in this report.

A method for safeguards design and evaluation, which we have developed and applied to a commercial centrifuge enrichment plant in order to investigate a safeguards approach for the plant, is as follows:

The first step to be carried out in this method is to establish a mathematical model, which can accurately simulate a dynamic behavior of the enriching process in a centrifuge cascade, without disclosing sensitive information. The second step in the method is to devise measures for avoiding false alarms beforehand in designing a safeguards approach. In this context, the method proposes to analyze normal operations including a transient one, as well as accidental operations such as a mis-operation of a valve and a malfunction of a centrifuge, other than the intentional operations for production of highly enriched uranium (HEU), in details enough to differentiate false indications from true anomalies. Then, the final step is to design a reliable, effective and efficient safeguards approach which could detect the true anomalies without false decisions.

Preliminary studies are as follows: On the mathematical model, we have developed a dynamical model and the corresponding computer codes, CCS-I [6] and CCS-II [7], on the basis of published documents [8,9,10] and, using this centrifuge cascade simulation codes, we have carried out some demonstration analyses, with regard to normal operations of the plant [11] and for the evaluation method which includes analyses of the normal operations and the operations for HEU production [7].

3. Model Centrifuge Enrichment Plant and its Safeguards

As a model centrifuge enrichment plant, a commercial type plant with the capacity of 800 tonSWU/y was designed in accordance with a procedure presented in the report [6]. Characteristics of the plant are as follows:

- Design characteristics of a UF_6 gas centrifuge
  - Separative power : 7 kgSWU/y
  - Separation factor : 1.27
  - Holding time : 73 sec
  - Throughput : 0.98 tonU/y
- Characteristics of a unit cascade
  - Separative work : 20 tonSWU/y
  - Enrichment for feed : 0.711 %
    - for product : 3.351 %
    - for tail : 0.218 %
  - Flow rate for feed : 26.19 tonU/y
    - for product : 4.12 tonU/y
    - for tail : 22.06 tonU/y
  - The number of stages for enriching section : 13
    - for stripping section : 9
- Operation unit and total separative work
  - One operation unit : five unit cascades = 100 tonSWU/y
  - The plant (40 unit cascades) : eight operation units = 800 tonSWU/y

The total number of centrifuges in a unit cascade is 2865 and the number of centrifuges for each stage is from the top to the bottom as follows: 10, 20, 31, 44, 59, 75, 93, 114, 137, 163, 193, 226, 263, 249, 232, 214, 193, 169, 143, 114, 80 and 43. The optimum feed flow rate for each stage, L_{opt}, is the product of the throughput of a centrifuge and the number of centrifuges for the stage. Dependency of the separation factor, γ, on a feed flow rate is given in the report [6].

This centrifuge enrichment plant consists of a UF_6 handling area and a cascade area. The former area includes a UF_6 gas feed station and the recovery equipment for product and tail UF_6 gases. $^{235}UF_6$ is enriched in a cascade of centrifuges in the latter area. Such centrifuge technology is one of the major technologies used to produce enriched uranium. If so intended, it could even produce HEU. It is also an advanced technology which should be protected against any misuse or proliferation because it includes sensitive information and commercial know-how. It is considered, therefore, that the cascade area is an especially important area from the viewpoint of safeguards.

It is not easy to establish an effective and efficient safeguards system for an enrichment plant that uses such advanced technology. The HEXAPARTITE project [12] tackled this problem and concluded that a limited frequency unannounced access (LFUA) inspection should be carried out as a basic safeguards approach in a centrifuge type enrichment plant already in existence, under construction, or firmly planned at that time. This LFUA approach might be used for a large scale, future commercial enrichment plant. Application of the LFUA approach to such a plant, however, should be fully investigated because the plant will have a larger capability of enriching uranium 235 and have more sensitive information from the commercial and non-proliferation viewpoints.

In this paper, the method for safeguards design and evaluation, which has been outlined in the chapter 2, is applied to the model centrifuge enrichment plant described above. Only HEU production scenarios and the relating normal and accidental operations are taken up. Therefore the cascade area is a main concern. Firstly, analyses are carried out on the operations not related to the HEU production and, secondly, theoretically possible scenarios for producing uranium with an enrichment higher than the declared one are analyzed and the major anomalies are indicated for both cases. Then it is examined if the LFUA approach can differentiate these two types of anomalies in the plant.

4. Cascade Simulation

A mathematical model and the corresponding computer simulation code have been developed as a tool to analyze not only a plant operation having no relation to HEU production but also an HEU production scenario in a model centrifuge enrichment plant. This simulation method makes it possible to simulate a transient operation of a cascade by solving time-dependent equations with regard to flow rate and concentration. A change of product enrichment is precisely calculated taking into account a change of inlet flow rate at each enriching and stripping stage of the cascade. The equations, however, are based on a theory which can be applied to the isotope separation of binary gas mixtures. Therefore, there is a limitation because of the existence of uranium 234 if it is intended to accurately simulate the cascade that produces HEU with a very high enrichment.

The simulation code can treat with two sets of cascades with the same structure. By connecting the product flow line of one set of cascades with the feed flow line of another set of cascades, the code simulates operations of a hierarchical cascade with a two-step structure. The code can also introduce side-streams both at enriched and depleted flow paths, making it possible to simulate a restructured cascade with a recycle flow between stages including those of upper and lower cascades. Because of these capabilities, it becomes possible to analyze various scenarios for HEU production.

4.1 Fundamental Equations for Dynamic Cascade Simulation

Yamashita defined equations for a dynamic cascade simulation in a case where an inlet flow distribution over the stages of the cascade is not changed but the concentration of fissile uranium is altered depending on time, taking account of the conservation of material at the mixing points as well as among these points and assuming that the higher derivatives than the first order can be neglected and that the holding times and the cuts are independent of the inlet flow rate. [13] Okamoto, et al., tried to extend Yamashita's approach to a case where an inlet flow distribution over the stages of the cascade is changed as well as the concentration of fissile material, and they developed two computer codes, CCS-I: Centrifuge Cascade Simulation - I [6] and CCS-II [7]. It was found, however, that they failed to correctly handle the equations for the concentration of uranium 235. Therefore, all relevant equations have been redefined and accordingly the CCS-I and CCS-II codes have been corrected and combined in a revised CCS-II code which includes both procedures for a hierarchical cascade as a function of the CCS-II code and for a normal one as a function of the CCS-I code. These are described here including other improvements.

Using the same notation as the reference [6], the basic equations for the flow rates at the j-th stage are given as follows:

$$L_j(t) = L'_j(t+h_j+h'_j)+L''_j(t+h_j+h''_j) \tag{1}$$

$$\theta_j = L'_j(t+h_j+h'_j)/L_j(t) \tag{2}$$

$$L_j(t) = L'_{j-1}(t)+L''_{j+1}(t)+\delta_{j0}F_0+f'_{j-1}-p'_{j-1}+f''_{j+1}-p''_{j+1} \tag{3}$$

where F_0 may be a time-dependent variable and a sum of several feed flow rates, δ_{j0} is one if j=0 and is zero if j is not equal to zero, $L_j(t)$ is the inlet flow rate at a mixing point between the (j-1)-th stage and the j-th stage at time t, $L'_j(t)$ is the product flow rate at a mixing point between the j-th stage and the (j+1)-th stage at time t, and $L''_j(t)$ is the tail flow rate at a mixing point between the (j-2)-th stage and the (j-1)-th stage at time t.

Similarly the basic equations for the concentration at the j-th stage are given as follows:

$$\begin{aligned} L_j(t)N_j(t) = {} & L'_j(t+h_j+h'_j)N'_j(t+h_j+h'_j) \\ & +L''_j(t+h_j+h''_j)N''_j(t+h_j+h''_j) \end{aligned} \tag{4}$$

$$\begin{aligned} \gamma_j \equiv \alpha_j\beta_j = {} & \left[N'_j(t+h_j+h'_j)\Big/\left\{1-N'_j(t+h_j+h'_j)\right\}\right]\Big/ \\ & \left[N''_j(t+h_j+h''_j)\Big/\left\{1-N''_j(t+h_j+h''_j)\right\}\right] \end{aligned} \tag{5}$$

$$\begin{aligned} L_j(t)N_j(t) = {} & L'_{j-1}(t)N'_{j-1}(t)+L''_{j+1}(t)N''_{j+1}(t)+\delta_{j0}F_0N_F \\ & +f'_{j-1}n'_{j-1}-p'_{j-1}N'_{j-1}(t)+f''_{j+1}n''_{j+1}-p''_{j+1}N''_{j+1}(t) \end{aligned} \tag{6}$$

where F_0N_F may be a time-dependent variable and a sum of several feed flow rates of fissile material, and γ_j is assumed to be independent from the concentration but may be dependent on the inlet flow rate.

It is assumed that the higher order derivatives may be neglected in a Taylor expansion or in a differentiated equation, and this effect may be evaluated since the second order derivatives are calculated and printed in the revised CCS-II code. Then Eq. 1 is approximately expressed in the following:

$$L_j(t) = L'_j(t)+(h_j+h'_j)\ dL'_j(t)/dt + L''_j(t)+(h_j+h''_j)\ dL''_j(t)/dt \qquad (7)$$

By differentiating Eq. 7, we have

$$dL_j(t)/dt = dL'_j(t)/dt + dL''_j(t)/dt \qquad (8)$$

Changing the time parameter in Eq. 2 and expanding in Taylor series, we have

$$L_j(t)-(h_j+h'_j)\ dL_j(t)/dt = L'_j(t)/\theta_j \qquad (9)$$

By differentiating Eq. 9, we have

$$dL_j(t)/dt = (1/\theta_j)\ dL'_j(t)/dt \qquad (10)$$

Eq. 9 becomes

$$L_j(t) = L'_j(t)/\theta_j+(h_j+h'_j)/\theta_j\cdot dL'_j(t)/dt \qquad (11)$$

Changing the time parameter in Eq. 1 and using Eq. 10 and Eq. 11, we have

$$L''_j(t) = L_j(t-h_j-h''_j)-L'_j(t+h'_j-h''_j) = (1/\theta_j-1)\left\{L'_j(t)+(h'_j-h''_j)\ dL'_j(t)/dt\right\} \qquad (12)$$

Using Eqs. 3, 7, 8 and 10, the following equation is obtained:

$$L'_{j-1}(t)-L'_j(t)+L''_{j+1}(t)-L''_j(t)+\delta_{j0}F_0+f'_{j-1}-p'_{j-1}+f''_{j+1}-p''_{j+1} = \left\{h'_j-h''_j+(h_j+h''_j)/\theta_j\right\} dL'_j(t)/dt \equiv Q_{Lj}\ dL'_j(t)/dt \qquad (13)$$

By summing Eq. 13 from j=j up to j=S and setting L''_{S+1} to zero, we have

$$L'_{j-1}(t)-L'_S(t)-L''_j(t)+A_{j0}F_0+\sum_{i=j}^{S}(f'_{i-1}-p'_{i-1}+f''_{i+1}-p''_{i+1}) = \sum_{i=j}^{S}Q_{Li}\ dL'_i(t)/dt \qquad (14)$$

where A_{j0} is zero if j is greater than zero and is one if j is zero or a negative value. It should be noted that L'_{j-1} is zero at j=-B and also f''_{S+1},

p''_{S+1}, f'_{-B-1} and p'_{-B-1} are zero in Eq. 14.

Similarly by expanding Eq. 4 in Taylor series, we have

$$L_j(t)N_j(t) = L'_j(t)N'_j(t)+(h_j+h'_j)\left\{N'_j(t)\ dL'_j(t)/dt + L'_j(t)\ dN'_j(t)/dt\right\}+L''_j(t)N''_j(t)+(h_j+h''_j)\left\{N''_j(t)\ dL''_j(t)/dt+L''_j(t)\ dN''_j(t)/dt\right\} \quad (15)$$

where we have neglected the product of two derivatives, dL'/dt*dN'/dt, because the product is a part of the second order derivative, $d^2L'N'/dt^2$. This effect may be evaluated because the derivative is calculated and printed in the revised CCS-II code. It is assumed for a while that the derivative of γ may be neglected (see the section 4.2). By solving Eq. 5 with regard to N", changing the time parameter and expanding in Taylor series, we have

$$N''_j(t)-(h'_j-h''_j)\ dN''_j(t)/dt = N'_j(t)\Big/\left[\gamma_j\left\{1-N'_j(t)\right\}+N'_j(t)\right] \equiv G_j(t) \quad (16)$$

By differentiating Eq. 16, we have

$$dN''_j(t)/dt = \gamma_j\Big/\left[\gamma_j\left\{1-N'_j(t)\right\}+N'_j(t)\right]^2 dN'_j(t)/dt \equiv K_j(t)\ dN'_j(t)/dt \quad (17)$$

By the substitution of Eq. 17 in Eq. 16, we have

$$N''_j(t) = G_j(t)+(h'_j-h''_j)K_j(t)\ dN'_j(t)/dt \quad (18)$$

Using Eqs. 6, 8, 10, 12, 15, 17 and 18, the following equation is obtained:

$$\begin{aligned} &L'_{j-1}(t)N'_{j-1}(t)-L'_j(t)N'_j(t)+L''_{j+1}(t)N''_{j+1}(t)-L''_j(t)N''_j(t) \\ &\quad +\delta_{j0}F_0N_F+f'_{j-1}n'_{j-1}-p'_{j-1}N'_{j-1}(t)+f''_{j+1}n''_{j+1}-p''_{j+1}N''_{j+1}(t) \\ &= \left\{(h_j+h'_j)N'_j(t)+(h_j+h''_j)G_j(t)(1/\theta_j-1)\right\}dL'_j(t)/dt \\ &\quad +\left\{h_j+h'_j+(h_j+h''_j)K_j(t)(1/\theta_j-1)\right\}L'_j(t)\ dN'_j(t)/dt \\ &\equiv T_j(t)\ dL'_j(t)/dt+Q_{Nj}(t)\ dN'_j(t)/dt \end{aligned} \quad (19)$$

where the product of two derivatives, dL'/dt*dN'/dt, has been neglected due to the same reason mentioned above. By summing Eq. 19 from j=j up to j=S and setting $L''_{j+1}N''_{j+1}$ to zero at j=S, we have

$$L'_{j-1}(t)N'_{j-1}(t)-L'_{S}(t)N'_{S}(t)-L''_{j}(t)N''_{j}(t)+A_{j0}F_{0}N_{F}$$
$$+\sum_{i=j}^{S}\left\{f'_{i-1}n'_{i-1}-p'_{i-1}N'_{i-1}(t)+f''_{i+1}n''_{i+1}-p''_{i+1}N''_{i+1}(t)\right\}$$
$$=\sum_{i=j}^{S}\left\{T_{i}(t)\ dL'_{i}(t)/dt+Q_{Ni}(t)\ dN'_{i}(t)/dt\right\} \tag{20}$$

It should be noted that $L'_{j-1}N'_{j-1}$ is zero at j=-B in Eq. 20.

In the revised CCS-II code, the approximation of a derivative, dX(t)/dt, is {X(t+Δt)-X(t)}/Δt and the calculation is carried out as follows:

a. Initial values are given to L'(t) and N'(t) at t=0 and the following steps are repeated increasing the time by an increment Δt.
b. On the basis of input data, F_0, f', f", p', p", N_F, n', and n" are prepared. On N", Eq. 18 is used, where γ which is γ(L(t)) in a precise expression is evaluated using Eq. 11 and dX'/dt, X is L or N, is calculated as {X'(t)-X'(t-Δt)}/Δt because X'(t+Δt) is not available at this point of time.
c. Eq. 14 is solved with regard to L'(t+Δt) after the substitution of Eq. 12 in Eq. 14.
d. L"(t) is calculated using Eq. 12.
e. L(t) is calculated using Eq. 3.
f. Eq. 20 is solved with regard to N'(t+Δt) after the substitution of Eq. 18 in Eq. 20.
g. N"(t) is calculated using Eq. 18.
h. N(t) is calculated using Eq. 6.
i. For evaluating and printing the higher derivatives, the following formulas are used:

$$X(t+a) = X(t) + a*dX(t)/dt + 1/2*a^2*d^2X(t)/dt^2$$
$$dX(t)/dt = \{X(t+\Delta t) - X(t-\Delta t)\}/2\Delta t$$
$$d^2X(t)/dt^2 = \{X(t+\Delta t) - 2X(t) + X(t-\Delta t)\}/\Delta t^2$$

In a printout, relative values are given, namely, a*dX(t)/dt/X(t) and

$1/2*a^2*d^2X(t)/dt^2/X(t)$.

4.2 Modification of Fundamental Equations

In a start-up operation of the cascade, an inlet flow rate is small compared with that of the optimum feed and its changes are relatively large in comparison with the inventory of UF_6 gas in the centrifuge. This means that the formation of countercurrent of gas in the centrifuge may be hindered, resulting in no or little enriching of fissile material. In the revised CCS-II code, two models have been provided to treat with such a case. In the first model it is assumed that there is no enriching if the ratio of the inlet flow rate, L, to the optimum one, L_{opt}, is less than a given ratio, R_L. In this case γ is equal to one. Therefore Eq.18 and Eq.20, respectively, become

$$N''_j(t) = N'_j(t)+(h'_j-h''_j)\, dN'_j(t)/dt \tag{21}$$

$$L'_{j-1}(t)N'_{j-1}(t)-L'_S(t)N'_S(t)-L''_j(t)N''_j(t)+A_{jo}F_oN_F$$
$$+\sum_{i=j}^{S}\left\{f'_{i-1}n'_{i-1}-p'_{i-1}N'_{i-1}(t)+f''_{i+1}n''_{i+1}-p''_{i+1}N''_{i+1}(t)\right\}$$
$$=\sum_{i=j}^{S}Q_{Li}(t)\, dL'_i(t)N'_i(t)/dt \tag{22}$$

In the calculation, these two equations are used instead of Eqs. 18 and 20. In the second model, the assumption is that the enriching capability increases in proportion to the inlet flow rate, L, until it reaches to a value, $L_{opt}*R_L$. Therefore γ is replaced by

$$\left\{\gamma_j(L_j)-1\right\}\cdot L_j/\,(L_{opt,j}R_L)+1 \tag{23}$$

The derivative of $\gamma(L(t))$ has been assumed to be zero in the section 4.1 as a standard calculation model. The revised CCS-II code, however, can handle it more precisely as an alternative model by assuming that it is relatively small. For this, the modification is as follows:

In Eq. 16 γ_j becomes

$$\gamma_j(L_j(t))-(h_j+h'_j)\, d\gamma_j(L_j(t))/dt \tag{24}$$

Instead of $G_j(t)$ we use the notation $G_{1j}(t)$. If we may assume that the product of two derivatives is negligible, then as an addition to the right hand side of Eq. 17, we have

$$-N'_j(t)\left\{1-N'_j(t)\right\}\Big/\left[\gamma_j(L_j(t))\left\{1-N'_j(t)\right\}+N'_j(t)\right]^2$$
$$\cdot\, d\gamma_j(L_j(t))/dt \equiv -C_j(t) \tag{25}$$

In Eq. 18 $G_{1j}(t)$ replaces $G_j(t)$ and an addition to the right hand side of the equation is

$$-(h'_j-h''_j)C_j(t) \tag{26}$$

In case of Eq. 19, if we assume that the product of two derivatives may be neglected, the following term should be added to the right hand side of Eqs. 19 and 20 together with Σ placed in front of it in the case of Eq. 20.

$$-(h_j+h''_j)(1/\theta_j-1)L'_j(t)C_j(t) \tag{27}$$

In case of the first model for γ, γ is changed by a step when L reaches to a given value. This change is not taken into account. In case of the second model, however, the derivative of γ is derived from Eq. 23. It is noted that the derivative of γ is also taken into consideration when N" is evaluated for a withdrawal flow or a recycle flow.

4.3 Reference Calculation Model

In order to evaluate the centrifuge cascade simulation model described in the sections 4.1 and 4.2, a reference calculation model has been developed and materialized as another function of the revised CCS-II code. This alternate model is based on the material balance at a stage of the cascade. If the increased amount of material at a stage is equally distributed over the stage, we have the following equations with regard to the flow rate and the concentration:

$$(L'_{j-1}-L'_j+L''_{j+1}-L''_j+\delta_{j0}F_0)\,\Delta t = h_j\Delta L_j+h'_j\Delta L'_j+h''_j\Delta L''_j \tag{28}$$

$$(L'_{j-1}N'_{j-1}-L'_jN'_j+L''_{j+1}N''_{j+1}-L''_jN''_j+\delta_{j0}F_0N_F)\,\Delta t$$
$$= h_j\Delta L_jN_j+h'_j\Delta L'_jN'_j+h''_j\Delta L''_jN''_j \tag{29}$$

where δ_{j0} is one if j=0 and is zero if j is not equal to zero, $L''_{j+1}=0$ at j=S, and $L'_{j-1}=0$ when j=-B, and the side streams are omitted for simplicity. We also have the following relationships among parameters at an arbitrary stage:

$$L_j = L'_j/\theta_j \tag{30}$$

$$L''_j = L'_j(1-\theta_j)/\theta_j \tag{31}$$

$$N_j = N'_j\theta_j + N''_j(1-\theta_j) \tag{32}$$

$$N''_j = N'_j/\left[N'_j+\gamma_j(1-N'_j)\right] \equiv G_j \tag{33}$$

The right hand side of Eq. 29 is approximately expressed in

$$\begin{aligned}&\mathrm{h}_j N_j \Delta L_j + \mathrm{h}'_j N'_j \Delta L'_j + \mathrm{h}''_j N''_j \Delta L''_j + \\ &\mathrm{h}_j L_j \Delta N_j + \mathrm{h}'_j L'_j \Delta N'_j + \mathrm{h}''_j L''_j \Delta N''_j\end{aligned} \tag{34}$$

Using this approximation and Eqs. 30, 31, 32 and 33, Eqs. 28 and 29 are rewritten as follows:

$$\begin{aligned}&\left[L'_{j-1} - L'_j/\theta_j + L'_{j+1}(1/\theta_{j+1}-1) + \delta_{j0}F_0\right]\Delta t \\ &= \left[\mathrm{h}'_j - \mathrm{h}''_j + (\mathrm{h}_j+\mathrm{h}''_j)/\theta_j\right]\Delta L'_j \equiv Q_{Lj}\Delta L'_j\end{aligned} \tag{35}$$

$$\begin{aligned}&\left[L'_{j-1}N'_{j-1} - L'_jN'_j + L''_{j+1}G_{j+1} - L''_jG_j + \delta_{j0}F_0N_F\right]\Delta t \\ &= \left[(\mathrm{h}_j+\mathrm{h}'_j)N'_j + (\mathrm{h}_j+\mathrm{h}''_j)G_j(1/\theta_j-1)\right]\Delta L'_j \\ &+\left[\mathrm{h}_j+\mathrm{h}'_j+(\mathrm{h}_j+\mathrm{h}''_j)K_j(1/\theta_j-1)\right]L'_j\Delta N'_j \\ &\equiv T_j\Delta L'_j + Q_{Nj}\Delta N'_j\end{aligned} \tag{36}$$

where

$$K_j = \gamma_j/\left\{\gamma_j(1-N'_j)+N'_j\right\}^2 \tag{37}$$

In this model, we can solve Eqs. 35 and 36 for ΔL' and ΔN' or the following equations which are obtained by summing Eqs. 35 and 36, respectively, from j=j up to j=S as in the previous model:

$$\left[L'_{j-1} - L'_{S} - L'_{j}\,(1/\theta_{j}-1) + A_{j0}F_{0} \right] \Delta t = \sum_{i=j}^{S} Q_{Li}\,\Delta L'_{i} \tag{38}$$

$$\left[L'_{j-1}N'_{j-1} - L'_{S}N'_{S} - L''_{j}G_{j} + A_{j0}F_{0}N_{F} \right] \Delta t$$

$$= \sum_{i=j}^{S} \left(T_{i}\,\Delta L'_{i} + Q_{Ni}\,\Delta N'_{i} \right) \tag{39}$$

where A_{j0} is zero if j is greater than zero and is one if j is less than or equal to zero. L, L", N and N" are calculated using Eqs. 30, 31, 32 and 33.

In comparison with the previous model, it is shown that if h'=h" Eqs. 38 and 39 are completely identical with Eqs. 14 and 20 and only difference is in L and N. In case of L, Eq. 30 corresponds to Eq. 11. This means that L of the reference model is smaller than that of the standard model if L' increases depending on time, resulting in the difference of γ.

4.4 Hierarchical Cascade

The revised CCS-II code provides a user with the capability of handling a two-step hierarchical cascade in which the first step cascade may consist of several unit cascades and the product from it is the feed to the second step cascade. The tail from the second step cascade may be recycled to the first step cascade as a part of the feed. The fundamental equations used for both cascades are identical but the input data for the optimal flow rates should be different and be proportional to the size of the cascades. The order of calculations is as follows: L', L" and L of the first step, L', L" and L of the second step, N' N" and N of the first step, and N', N" and N of the second step. In the case of recycling of the tail from the second step cascade to the first one, L" and N" which are used to calculate the recycle flow rate are evaluated using the approximation, $dX'/dt=\{X'(t)-X'(t-\Delta t)\}/\Delta t$, where X is L or N, because $X'(t+\Delta t)$ is not available at the time of calculation. In this case, due consideration may be given to the derivative of γ.

4.5 Centrifuge Cascade Characteristics

Various cascade parameters are calculated and printed in the revised

CCS-II code. If appropriate, the unit of L and F_0 is changed from tonU/y to grU/sec. These parameters are given below:

[A] Total amounts of uranium and uranium 235 in the product, which are accumulated during a period from the beginning up to a time, nΔt, and the corresponding average concentration. These are calculated by using L' and N' of the top stage of the second step cascade and by summing them over the time steps, i, as follows:

$$P \equiv P(n\Delta t) = \left[\sum_{i=1}^{n} (L'_{S,2})_i \right] \cdot \Delta t \qquad [\text{gr-U}] \qquad (40)$$

$$P_{235}(n\Delta t) = \left[\sum_{i=1}^{n} (L'_{S,2})_i \cdot (N'_{S,2})_i \right] \cdot \Delta t \qquad [\text{gr-}^{235}\text{U}] \qquad (41)$$

$$\overline{N_p}(n\Delta t) = P_{235}(n\Delta t) / P(n\Delta t) \qquad [-] \qquad (42)$$

[B] Total amounts of uranium and uranium 235 in the tail, which are accumulated during a period from the beginning up to a time, nΔt, and the corresponding average concentration. These are calculated by using L" and N" of the bottom stages of the first step cascade and the second step cascade if the recycle of tail flow does not exist, and by summing them over the time steps, i, as follows:

$$W \equiv W(n\Delta t) = \left[\sum_{i=1}^{n} (L''_{-B,1})_i \right] \cdot \Delta t + \left[\sum_{i=1}^{n} (L''_{-B,2})_i \right] \cdot \Delta t \qquad [\text{gr-U}] \qquad (43)$$

$$W_{235}(n\Delta t) = \left[\sum_{i=1}^{n} (L''_{-B,1})_i \cdot (N''_{-B,1})_i \right] \cdot \Delta t + \left[\sum_{i=1}^{n} (L''_{-B,2})_i \cdot (N''_{-B,2})_i \right] \cdot \Delta t \qquad [\text{gr-}^{235}\text{U}] \qquad (44)$$

$$\overline{N_w}(n\Delta t) = W_{235}(n\Delta t) / W(n\Delta t) \qquad [-] \qquad (45)$$

where, if the tail recycle exists, the second terms in the right hand side of Eqs. 43 and 44 are omitted.

[C] Total amounts of uranium and uranium 235 in the feed, which are accumulated during a period from the beginning up to a time, nΔt, and the corresponding average concentration. These are calculated by summing F_1, F_2, ..., F_k over the time steps, i, if F_0 consists of them, as follows:

$$F \equiv F(n\Delta t) = \left[\sum_{l=1}^{n}(F_1)_l\right]\cdot\Delta t+\left[\sum_{l=1}^{n}(F_2)_l\right]\cdot\Delta t+\cdots$$

$$+\left[\sum_{l=1}^{n}(F_k)_l\right]\cdot\Delta t \qquad [\text{gr-U}] \qquad (46)$$

$$F_{235}(n\Delta t) = \left[\sum_{l=1}^{n}(F_1)_l\cdot(N_{F,1})_l\right]\cdot\Delta t+\left[\sum_{l=1}^{n}(F_2)_l\cdot(N_{F,2})_l\right]\cdot\Delta t$$

$$+\cdots+\left[\sum_{l=1}^{n}(F_k)_l\cdot(N_{F,k})_l\right]\cdot\Delta t \qquad [\text{gr-}^{235}\text{U}] \qquad (47)$$

$$\overline{N_f}(n\Delta t) = F_{235}(n\Delta t)/F(n\Delta t) \qquad [-] \qquad (48)$$

[D] Inventories of uranium and uranium 235 in the cascade at a time, nΔt, and the corresponding average concentration. These are calculated on the basis of the following equations:

$$I(n\Delta t) = \sum_{m=1}^{2}\sum_{j=-B}^{S}\left[\int_0^{h_j} L_{j,m}(n\Delta t-t)\,dt+\int_0^{h'_j} L'_{j,m}(n\Delta t+t)\,dt\right.$$

$$\left.+\int_0^{h''_j} L''_{j,m}(n\Delta t+t)\,dt\right] \qquad [\text{gr-U}] \qquad (49)$$

$$I_{235}(n\Delta t) = \sum_{m=1}^{2}\sum_{j=-B}^{S}\left[\int_0^{h_j} LN_{j,m}(n\Delta t-t)\,dt+\int_0^{h'_j} L'N'_{j,m}(n\Delta t+t)\,dt\right.$$

$$\left.+\int_0^{h''_j} L''N''_{j,m}(n\Delta t+t)\,dt\right] \qquad [\text{gr-}^{235}\text{U}] \qquad (50)$$

$$N_I(n\Delta t) = I_{235}(n\Delta t)/I(n\Delta t) \qquad [-] \qquad (51)$$

where m=1 corresponds to the lower cascade and m=2 to the upper cascade and in Eq. 50 L, L' and L" have the same attribute as the coupled N, N' and N". The calculation is carried out after the flows and concentrations are expanded in a Taylor series, higher derivatives than the first order ones are neglected, and L, L", N, N" and their derivatives are converted to the corresponding terms with L' and N', if appropriate, using the proper equations derived in the previous sections. It is noted that the inventory calculation is also consistent with various modifications described in the sections 4.2 and 4.3.

[E] Material balances for uranium and uranium 235 over a period from the beginning up to a time, nΔt. These are calculated as follows:

$$MB(n\Delta t) = I(0)+F(n\Delta t)-P(n\Delta t)-W(n\Delta t)-I(n\Delta t)$$
$$+\sum_{l=1}^{n}\sum_{m=1}^{2}\sum_{j=-B}^{S}(f'_{j,m}-p'_{j,m}+f''_{j,m}-p''_{j,m})_l\cdot\Delta t \qquad [\text{gr-U}] \qquad (52)$$

$$MB_{235}(n\Delta t) = I_{235}(0)+F_{235}(n\Delta t)-P_{235}(n\Delta t)-W_{235}(n\Delta t)-I_{235}(n\Delta t)$$
$$+\sum_{l=1}^{n}\sum_{m=1}^{2}\sum_{j=-B}^{S}(f'n'_{j,m}-p'N'_{j,m}+f''n''_{j,m}-p''N''_{j,m})_l\cdot\Delta t \qquad [\text{gr-}^{235}\text{U}] \qquad (53)$$

where the summation is carried out over stages, lower and upper cascades and time steps and in Eq. 53 f', p', f" and p" have the same attribute as the corresponding n', N', n" and N".

[F] Sum of flow rates, L, L' and L", over both stages of the lower and upper cascades:

$$TL(n\Delta t) = \sum_{m=1}^{2}\sum_{j=-B}^{S}L_{j,m}(n\Delta t) \qquad [\text{ton-U/y}] \qquad (54)$$

$$TL'(n\Delta t) = \sum_{m=1}^{2}\sum_{j=-B}^{S}L'_{j,m}(n\Delta t) \qquad [\text{ton-U/y}] \qquad (55)$$

$$TL''(n\Delta t) = \sum_{m=1}^{2}\sum_{j=-B}^{S}L''_{j,m}(n\Delta t) \qquad [\text{ton-U/y}] \qquad (56)$$

[G] Separative work at a time, nΔt, which is calculated, when F_0 consists of F_1, F_2, ..., F_k, using L' and N' of the top stage of the second step cascade and L" and N" of the bottom stages of the first step cascade (m=1) and the second step cascade (m=2) if the recycle of tail flow does not exist, as follows:

$$\Delta U(n\Delta t) = L'_{S,2}(n\Delta t)\cdot\left[2N'_{S,2}(n\Delta t)-1\right]\cdot\log_e\frac{N'_{S,2}(n\Delta t)}{1-N'_{S,2}(n\Delta t)}$$
$$+\left[\sum_{m=1}^{2}L''_{-B,m}(n\Delta t)\right]\cdot\left[2\overline{N''}_{-B}(n\Delta t)-1\right]\cdot\log_e\frac{\overline{N''}_{-B}(n\Delta t)}{1-\overline{N''}_{-B}(n\Delta t)}$$
$$-\sum_{l=1}^{k}F_l(n\Delta t)\cdot\left[2\overline{N_F}(n\Delta t)-1\right]\cdot\log_e\frac{\overline{N_F}(n\Delta t)}{1-\overline{N_F}(n\Delta t)} \qquad (57)$$

where,

$$\overline{N''_{-B}}(n\Delta t) = \sum_{m=1}^{2} L''_{-B,m}(n\Delta t)\cdot N''_{-B,m}(n\Delta t) \Big/ \sum_{m=1}^{2} L''_{-B,m}(n\Delta t) \tag{58}$$

$$\overline{N_F}(n\Delta t) = \sum_{l=1}^{k} F_l(n\Delta t)\cdot N_{F,l}(n\Delta t) \Big/ \sum_{l=1}^{k} F_l(n\Delta t) \tag{59}$$

If the tail recycle exists, the term related to L" and N" of the second step cascade is omitted in Eqs. 57 and 58.

4.6 Preliminary Calculations

Among dynamical behaviors of a centrifuge cascade, those of the start-up operation might be the most difficult to predict because of the drastic changes of feed flow rate. Therefore a start-up operation is picked up and discussed here for some preliminary analyses. The feed flow rate was linearly increased from zero until reaching to the designed flow rate at 100 minutes after the start-up of feeding UF_6 gas and then it was assumed that it maintains this value.

(1) Difficulty in accurately computing dynamics at early time steps

At an early time step of the start-up operation calculation, it is considered that higher derivatives of L' and N' would considerably contribute to the dynamics. Eqs. 14 and 20, however, neglect such higher derivatives. As a matter of fact, Eq. 20 gave us very poor results. This deficiency sometimes spoiled whole results. In order to avoid this difficulty, we have modified the computer program so as to use Eq. 22 instead of Eq. 20 for a given number of time steps by assigning KCALX(3) in the revised CCS-II code (see Appendix A). As a result of parametric calculations, the reasonable number of KCALX(3) was around 10. Therefore this number was adopted in the standard calculation model.

(2) Time Increment

A time increment Δt (NDELT in the revised CCS-II code, see Appendix A) is an important parameter because it decides the accuracy of results and the economy of calculations in general. In case of the model cascade, 60 seconds were the reasonable choice and the convenient one to use except for investigating in details the dynamics during a time period just after the start-up of the cascade. Therefore 60 seconds were adopted for normal cases and 6 seconds were used for other special cases in the standard calculation model. It is noted that the choice of the time increment could not overcome the shortcoming in the calculation formulas for a non-linear change.

(3) Enriching in an early phase of the start-up operation

As mentioned before, it is quite difficult to accurately predict the separation factor γ at an early time of start-up operation. If γ was assumed to linearly increase in proportion to the inlet flow rate which covered the range from zero up to R_L*L_{opt}, the product enrichment from the normal cascade was given in a solid line in Fig. 1 in case of R_L being 0.1 (RATIO=0.1 and KCALX(2)=1 in the revised CCS-II code, see Appendix A). On the other hand, if γ was assumed to be one, i.e. no enriching, until the inlet flow rate reached to R_L*L_{opt}, then the dotted line in the same figure gave the product enrichment (RATIO=0.1 and KCALX(2)=0 in the revised CCS-II code, see Appendix A). If R_L was changed in the linear model for γ, the peak product enrichment was shifted as shown in Fig. 2. These figures show that we will have a more precise model for γ if we are able to experimentally determine a profile of the product enrichment. In the standard calculation model, we used the linear γ model with R_L being 0.1.

(4) Derivative of γ

Effect of the derivative of γ on the dynamics of the model centrifuge cascade was investigated using the normal cascade. When the derivative was taken into consideration, the product enrichment became lower before it reached to the peak value, but its difference between the two cases, i.e. with the derivative and without it, was less than 5%. On the other hand, it became higher after the peak value was attained but the difference was less than 1%. We did not take into account the derivative of γ in the standard calculation model.

(5) Reference model

The reference model was compared with the standard model using the normal cascade where the linear increase of γ in proportion to the inlet flow rate was assumed and the derivative of γ was neglected. The product enrichment was lower until it reached to the peak value and became higher after that point of time. The maximum difference was around 7% in the former situation and 0.6% in the latter one.

(6) Feed pattern

We changed the time at which the main feed flow rate reached to its design value, while keeping the pattern of a linear increase in the feed flow rate. As shown in Fig. 3, a shift of product enrichment curve was observed but the shift of the peak enrichment was relatively small. In the standard calculation model, 100 minutes were adopted as the time at which the feed flow rate reached to its designed value.

(7) Two-step cascade

We investigated the dynamics of a two-step cascade which consists of seven unit cascades in the lower part and one unit cascade in the upper part. The product enrichments from the lower and upper cascades, respectively, were given as shown in Fig. 4, in which the tail from the upper cascade was not recycled into the lower cascade. It is recognized from the figure that due to the time delay in the UF_6 gas transportation the product enrichment from the lower cascade is higher than that from the upper cascade at an early stage of the start-up operation. By looking at the peak values, this delayed time seems to be about 100 minutes. Although the tail recycle showed that it would reduce the product enrichment compared with the case of no recycle, this effect was very small in the beginning and then became larger but not larger than 7%. The tail was not recycled in the standard calculation model.

(8) Equilibrium

Within 1% difference, the product flow rate of the lower cascade reached to its equilibrium at 700 minutes after the start-up, while the product enrichment of the lower cascade reached to its equilibrium at 500 minutes after the start-up. In case of the upper cascade, these two parameters were, respectively, 1,000 and 800 minutes. After 1,000 minutes from the start-up in case of the lower cascade and 1,500 minutes as for the upper cascade, no meaningful changes were observed in these two parameters. Therefore the normal, stationary operation was assumed to be obtained at these times after the start-up in the standard calculation model.

5. Analysis of False Alarm Possibilities

5.1 False Alarm Possibilities

In the LFUA approach, a product enrichment is measured at a header pipe to detect an anomaly which would indicate an HEU production. The problem is whether or not the enrichment becomes higher than the declared one due to some innocent causes and as the result it is recognized as the anomaly. The following situations should be investigated:

a. Deviations from the normal operation which include transient operations such as a start-up, a shut-down and a change of material with one enrichment to another and operations in which the product flow is recycled due to some safety reasons;
b. Mis-operations due to human errors which include an operation with a reduced or increased feed flow rate; and
c. Malfunctions of equipment, instruments, devices or systems including a mechanical failure of centrifuges and a power supply failure.

These operations are discussed below.

5.2 Start-up Operation

Using the standard calculation model and the revised CCS-II code, we simulated a start-up operation where the feed flow rate was linearly increased until it reached to the designed flow rate at 100 minutes after the feed started. Figs. 5, 6 and 7 are the results obtained. Fig. 5 shows the ^{235}U enrichment and the uranium flow rate at a product header pipe. The product enrichment reaches to its maximum value at 100 minutes after the start-up and gradually decreases to the designed one, while the product flow rate steadily increases up to an equilibrium which is the designed flow rate. The product flow rate is only one tenth of the designed one when the maximum enrichment is attained. Fig. 6 shows the average enrichment, which is the enrichment of the product accumulated at the cold trap, and the accumulated amount of product together with the product enrichment at the header. Although the enrichment higher than the designed one is obtained as a product, it is homogenized with the lower one at the product cold trap and the accumulated amount of such product is very small. Fig. 7 gives the product enrichment when the feed is low enriched uranium with 1.0, 1.5 or 2.0% enrichment. Such a case is anticipated if the uranium recovered from spent fuel is used as a feed. In this case the product enrichment becomes much higher even at an equilibrium stage.

From these facts it is said that if an enrichment monitor for safeguards purposes is designed only to detect an enrichment higher than the declared one at a header pipe, it may produce a false alarm. If the recovered uranium is used as a feed, the alarm level for anomaly detection should be carefully set up. On the contrary the material accountancy based on inventory measurements may not generate any anomaly because the measurement is usually carried out after a considerable amount of product has been accumulated at a cold trap and transferred to a cylinder.

5.3 Shut-down Operation

A shut-down operation was simulated by linearly reducing the feed flow rate from that of an approximately stationary operation, which was obtained at 1000 minutes after the normal start-up, to zero which was reached to at 100 minutes after the start of shut-down operation. A result is given in Fig. 8. The figure shows that the product enrichment increases and reaches to 4.2% at its peak at around 200 minutes after the start of shut-down operation, while the product flow rate gradually diminishes. Further calculations showed that the peak of the product enrichment shifted without changing its value depending on the time period during which the feed flow rate was decreased to zero.

These facts lead to a conclusion that there would be no serious problem with regard to this operation and that, however, it might generate an anomaly if the enrichment monitor set at a header pipe is so much sensitive to the change of enrichment.

5.4 Change of Feed Enrichment

Feed material may be changed from natural uranium to a recovered one with low enrichment. Fig. 9 is a result of simulation of such transient operations, where the enrichment was linearly changed from that of natural uranium to 1.0, 1.5 or 2.0% enrichment in 100 minutes. Only a gradual increase in the product enrichment is recognized. Therefore no anomaly might be observed in case of the change of feed enrichment.

5.5 Recycled Flow

Due to a failure of centrifuges in a unit cascade or other safety reasons, the product flow might be recycled to the feed stage depending on the design. Fig. 10 gives the result of a simulation where the product flow was recycled in such a way that the recycled flow rate was linearly increased from 0 to 100% of the designed product flow rate during a time span of 100 minutes. The figure shows an increase in the enrichment at the product header pipe with the ultimate enrichment being 2.46 times as much as that of the normal operation. During this period of time, the corresponding flow rate was 1.19 times as much as that of the normal operation. One major characteristic in this case is that no enriched uranium is produced from the process except when the cascade is returned to the normal operation. This case, however, would be very rare even if it could happen.

5.6 Change of Feed Flow Rate

Due to mis-operations or some other reasons, the feed flow rate might be changed, i.e. increased or decreased or fluctuated. If the feed flow rate is increased, then the product enrichment is reduced and the amount of product is enlarged. On the contrary, if the feed flow rate is decreased, the enrichment is enhanced and the amount is lessened. Fig. 11 gives the product enrichment in a transient operation where the feed flow rate was linearly changed from the designed one to a half or 1.5 times of it in 100 minutes. The maximum enrichment to which the product reaches was about 4%. Even if the feed flow rate was reduced to a quarter of the designed rate, the maximum product enrichment was 4.1%. A case of feed flow fluctuation was also examined, where the feed flow rate was linearly fluctuated between the designed flow rate and a half of it in 100 minutes each for an increase or a decrease. The resulting product enrichment was fluctuated between 3.6% and 3.8%. These results suggest that there is no serious problem in this type of operations from the viewpoint of safeguards. Another characteristic of the operations is that the situation would be returned to the normal one sooner or later because the process indicator installed may show an abnormal flow rate which results in an action of the operator for remedies of the process.

5.7 Mechanical and Power Supply Failures

Centrifuge machines might stop to work due to a mechanical failure. If such a failure occurs at a stage, the optimum feed flow rate at the stage becomes smaller in proportion to the number of centrifuges working. Simulation calculations showed that the product enrichment was slightly reduced and even if 10% of centrifuges of the zero-th stage failed, the reduction of the product enrichment was only 0.4%.

In case of a power supply failure it is considered that γ decreases until it reaches to 1. Fig. 12 gives the result of such a simulation where γ was linearly reduced to 1 in 100 minutes. It shows that the product enrichment is simply decreased.

It is clear that these two operations do not cause us any problem in safeguards.

6. Analysis of Diversion Scenarios

6.1 Technical Means for HEU Production

The followings are the well-recognized technical means for the production of enriched uranium with an enrichment higher than the declared one if the facility equipment which has been declared as only for peaceful purposes is used:

(1) To change the piping arrangement within/between cascades, including the construction of a hierarchical cascade or a cascade with more stages and the setting up of a reflux path to recycle the gas flow,

(2) To refeed the product to the cascade,

(3) To manipulate the feed flow rate, i.e. decrease it or make it pulsate, and

(4) To change the parameters affecting the separative work, such as the cut and the rotating speed of a centrifuge, including the replacement of the centrifuge by an advanced one.

These technical means are discussed in the following sections.

6.2 Changes of Piping Arrangement

A typical means to produce HEU by changing the piping arrangement is to construct a hierarchical cascade by connecting a product header line of a group of unit cascades with a feeding line of another group of unit cascades. By doing so, the product from the lower group of cascades is further enriched in the upper group of cascades. An example is a hierarchical cascade which consists of seven unit cascades for the lower group of cascades and one unit cascade for the upper group of cascades. Simulation of a start-up operation of this cascade was carried out. A result is given in Fig. 13. It shows that the product enrichment reaches to a value far larger than 20% at its peak but that the accumulated product is very small, only 1.6 kg at its 20% average enrichment. Because the average enrichment comes down to 14.7%, it is necessary to further enrich the product in order to obtain the significant amount of HEU, i.e. 25 kg-U235 contained in HEU with more than 20% enrichment.

It is technically possible to construct a new cascade that can produce

HEU as a product by completely changing the piping arrangement or by making a three-step hierarchical cascade. Technical difficulties accompanied with this technical means, however, would be much greater than those of the two-step hierarchical cascade.

If a part of a product flow from a stage is recycled to a lower stage through a side line, the product enrichment at the top stage becomes higher. A special case in which all of the product flow from the top stage is led to the feed stage has been discussed in the section 5.5 and the result is that the product enrichment may reach 2.46 times as large as the designed enrichment at its maximum. If the recycle line is closed and the product line is opened to a recovery process, a product with higher enrichment is obtained. The product enrichment, however, will soon decrease because the process returns to the normal operation. Therefore the procedure must be repeated again if a product with the same level of enrichment is to be produced. In any case it is impossible to produce HEU using only this technical means.

Major characteristic of the technical means mentioned above is that the changes of piping arrangement would need tremendous efforts in completely removing UF_6 gas from the process, shutting down the centrifuges, reversing the pressure to normal, dismantling the piping system and replacing it by a new one, vacuuming the process, starting up the centrifuges and feeding the gas to the system. If the piping arrangement is returned back to the normal arrangement in order to avoid the detection of such changes, the same procedure should be repeated again. All of these events are recognized as anomalies. Another characteristic is that if the extent to which the piping arrangement is changed is limited to a small area, it needs much time to produce the significant amount of HEU although the efforts needed are reduced.

6.3 Operation to Refeed Product

It would be the easiest scenario to use the product as a feed to obtain much higher enrichment. We simulated a start-up operation, in which the product of the first cycle was used as a feed to the cascade, assuming the standard start-up operation. The enrichment of the second cycle product at the header pipe and the corresponding accumulated product and its enrichment were given in Fig. 14. This figure shows the second cycle product enrichment temporarily exceeds the 20% line but it fails to accumulate the significant amount of HEU. On the other hand, if the feed flow rate was fixed to the designed one during the course of changing the feed enrichment, it was shown that the enrichment obtained as a product gradually increased after the first cycle product started to be fed, and reached to 15% at this cycle as shown in Fig. 15, where the feed enrichment was linearly changed from one enrichment to another in 100 minutes. If the second cycle product was recycled again, as the same figure shows, the cascade produced a product with the enrichment far greater than 20% in the third cycle. Further calculation showed that 28 days were needed to accumulate the significant amount of HEU, i.e. 24 days for the second cycle and 4 days for the third cycle, if only one unit cascade was used and if the accumulation was started just after the change of feed enrichment began. On the other hand, if the plant was used as a whole and if the accumulation started in the same condition, the time needed to accumulate the significant amount of HEU was 35 hours, i.e. 30 hours for the second cycle and 5 hours for the third cycle. Characteristic of these accumulations is that the final product has a higher enrichment, i.e. 58% in case of the unit cascade and 28% for the plant as a whole. If 20% is the target, there is such an alternative method that the second cycle product is mixed with the first cycle product reducing the enrichment of the product and that this mixed product is used as a feed in the third cycle producing a product with about 20% enrichment. In case of the unit cascade, 17 days were needed to accumulate the significant quantity, i.e. 6 days for the second cycle and 11 days for the third cycle, using the mixed product with 4.4% enrichment. On the other hand, in case of the plant as a whole, 19 hours were needed, i.e. 12 hours for the first cycle and 7 hours for the third cycle, using the mixed product with 5.7% enrichment. Major anomaly in this scenario is the uranium with a higher enrichment at the header pipes for feed and product.

6.4 Reduced or Fluctuated Feed Flow Rate

As discussed in the section 5.6, reduced feed flow produces a higher enrichment but it is slightly higher than the designed enrichment. Even if the feed is reduced to one tenth of the designed one, the product enrichment is mere 4.24% in a stationary state.

As discussed in the section 5.2, the start-up operation produces the uranium with an enrichment higher than the declared one as a transient phenomenon. One of the potential technical means to produce HEU is to use this fact more systematically, i.e. to change the feed flow rate periodically.

An example is that the feed flow rate is linearly increased from zero to the designed flow rate, then linearly decreased to zero and is kept to zero for some time and the whole scheme is repeated. It was shown that the average enrichment became the highest in the first sequence, gradually decreased in the following sequences and approached to an enrichment which corresponded to that of the reduced feed flow rate that results in the same amount of accumulated feed. It means that this scenario does not considerably contribute to the HEU production in the long run.

Although a start-up operation generates a peak in the product enrichment, the peak value was almost constant over various reduced feed flow rates, i.e. around 6%. Therefore the scenarios mentioned here are meaningful for the HEU production only if they are combined with other scenarios. Such a case is discussed in the section 6.6.

6.5 Changes of Cut and Rotating Speed of a Centrifuge

One of the methods to change the separative power is to change the cut of the centrifuges from the designed one to another at all stages or at a part of them. Fig. 16 gives a result of the analysis with regard to the effect of a change of the cut on the product enrichment and the product flow rate in a stationary state. In general, the product enrichment became higher if a value of the cut decreased. This tendency was specifically intensified if the cut was changed all over the stages. If the cut of all stages was reduced to 89% or less than that, the product enrichment exceeded 20%. In case of 89%, about 126 days were needed to accumulate 25 kg-U235 by a unit cascade, where the cut was reduced from the normal value to 89% in 100 minutes and the accumulation of product was started just after the change began, and more days were required in case of 88% or less. If the whole plant was used under the same conditions, 86 hours were needed at a reduction of the cut to 88%, while 89% was not an optimal cut because it needed more time to attain the 20% enrichment in the accumulated product. In this scenario, however, there is a technical difficulty in setting up the cut at a proper value. A specific anomaly is a big change in the product flow and its enrichment even if the feed flow rate to the cascade is not altered.

If the rotating speed of a centrifuge is increased, the product enrichment is enhanced, but the safety would be greatly deteriorated. A specific anomaly is an increase in the electric power consumption. On the other hand, if the current centrifuge is replaced by an advanced one, higher enrichment is also obtained as a product. Efforts needed for the replacement, however, might be at the same level as that of the changes of piping arrangement. In order to investigate these cases, we have to analyze the characteristics of the cascade under the different conditions, which are not treated in this report.

6.6 A Combined Scenario

As seen in the previous sections, some technical means fail to produce HEU although they can enhance the product enrichment. These technical means, however, can be used in combination with other technical means. One possibility is to refeed the first cycle product with a reduced feed flow rate. In case of one tenth of the normal feed flow rate, the second cycle product had 19.9% enrichment in a stationary state. If this operation was carried out under the standard start-up operation, it was possible to produce the significant amount of HEU and 70 hours were needed to accumulate this amount using the whole plant. If only a unit cascade was used, 111 days were needed to accumulate 25 kg-U235 but the accumulated product enrichment was slightly less than 20%.

7. A Safeguards Approach

If activities aimed at producing HEU would take place, they create anomalies depending on the scenario adopted, for example: the feed flow rate is changed; the total inlet flow rate which is the sum of inlet flow rates at all stages is changed; the enrichment of product or both of product and feed are changed; the size and weight of a feed cylinder is not the same as a usual one; radiation background in the cascade area is increased; radiation background outside the cascade area is intensified; additional equipment is installed for a feed of low enriched uranium (LEU) and recoveries of the HEU product and the tail with rather a high enrichment; there exist abnormal arrangements of piping between centrifuges/headers of cascades and abnormal sounds in the cascade hall; separative work is increased; the electric power consumption is increased; and the total working hours are substantially increased.

Places of anomalies and for their detection are as follows: headers of feed, product and/or tail; piping between cascades; the cascade hall; an inlet flow path at an arbitrary stage of a cascade; the autoclave station at the feed line; sampling lines at the process; UF_6 handling facility; feed/product storage area; control room; and operational record and accounting record and report.

Taking into account the detection measures against each anomaly generated by each of the HEU production scenarios, a potential safeguards approach can be established. The LFUA approach is one of such approaches and it was agreed as an effective and efficient safeguards approach in the HEXAPARTITE project. This approach could be a favorable one for a future commercial enrichment plant. As seen in the chapter 6, the easiest scenario to produce the significant amount of HEU is to refeed the product without changing any equipment and piping arrangement. The LFUA approach can detect such an HEU production by a non-destructive assay (NDA) device set up at the product header pipe if the HEU production is attempted. This measure is also effective against the change of cut or the increase of rotating speed of centrifuges. The measure, however, might not be effective if the NDA device would be bypassed by setting up a special route. Although any changes of the piping arrangement are technically quite difficult, the LFUA approach can still detect such changes by visiting the cascade hall if the changes are attempted. Additional points to be given are as follows:

As discussed in the section 6.3, the time needed to accumulate the significant amount of HEU is very short in case of the model plant. Therefore it would be necessary to continuously monitor the product enrichment using an NDA device at the product header pipe. In setting an alarm level to the NDA device, however, a cautious approach should be taken. As discussed in the chapter 5, some anomalies may be generated by a normal, transient operation or a mis-operation. Uranium with an enrichment higher than the designed one may be produced as a result of such operations. This fact should be taken into account and the anomaly should be carefully analyzed so as to distinguish a false anomaly from a true one caused by an intentional activity for HEU production. If the agreed safeguards approach only permits the enrichment measurements at a time when an inspector visits the plant, the inspector could avoid a period of transient operation for his NDA measurements. In this case, however, the timing of the plant visits by inspectors would be a crucial parameter.

The number of NDA devices and where the devices should be installed would depend on the numbers of independent feeding and recovering systems and of operational units. It would not be necessary to cover all unit cascades by this monitoring system. The reason is that a longer time is required for the accumulation of the significant amount of HEU with a limited number of uncovered unit cascades and that in order to detect an attempt to produce HEU with such cascades it is sufficient to measure the product enrichment at a header pipe of the cascades when an inspector visits the plant. Frequencies and timing of the visits by inspectors for this purpose could be determined from the viewpoint of cost effectiveness.

For the purpose of detecting an attempt to produce HEU by changing the piping arrangement, frequencies and timing of the inspectors' visits depend on the time required for the accumulation of the significant amount of HEU and for the preparation for and concealment of this accumulation. The theoretical approach discussed in this report can predict the time for the accumulation, but it is difficult to estimate the time for preparation and concealment. Applying some C/S devices or radiation monitors would be a possible solution to avoid frequent visits from inspectors.

8. Discussion

In a future commercial enrichment plant a centrifuge will have a greater separative power, which brings in the following effects: since the numbers of stages and centrifuges in a unit cascade are reduced, the total length of pipes is shortened resulting in a reduced effort for the changes of piping arrangement; in-process inventory of UF_6 gas in a centrifuge reduces and electric power consumption also decreases; and since the cascade would need maintenance, workers will enter into the cascade hall and work there. Another effect is that for economical reasons the plant designer is expected to apply a cell type arrangement to the cascade to be constructed, in which one cell contains a number of centrifuges. In this case a cell seems to be a black box into which an inspector cannot make access. A built-in arrangement might be technically possible, by which the piping could be switched from the normal arrangement to the other without being detected.

There are other parameters that affect the safeguards for the future commercial enrichment plant. These are the enrichment of product uranium and the sizes of a unit cascade and the plant. A variety of enrichments would be required, which would necessitate a more careful analysis for the safeguards design. On the other hand, the size of a unit cascade would be decided on the basis of operational and economical requirements and the size of the plant, which could be expanded with relative easiness if needs arise, would depend on a predicted balance between supply and demand in the future.

9. Concluding Remarks

In designing a safeguards approach for a nuclear plant in which an advanced technology is used, there are difficulties because sensitive information might not be disclosed. Lack of key information could lead to low transparency on the plant on one hand and to low reliability in the safeguards on the other hand including possible misjudgements in conducting safeguards activities. In order to solve this problem we have developed a method, in which firstly a mathematical model to describe the key process should be developed on the basis of published documents, secondly unintentional and intentional operations of the process are to be analyzed using this model, and finally a reliable, effective and efficient safeguards approach should be established taking into consideration both anomalies generated by unintentional and intentional operations.

This method has been applied to a model centrifuge enrichment plant with a commercial size. A mathematical model that can simulate a dynamical behavior of cascades has been developed. Transient operations and potential mis-operations as well as technical means to produce uranium with a higher enrichment than the declared one have been analyzed. Then the LFUA approach has been examined. The mathematical model, which has been developed, is a relatively simple one but it has a capability of analyzing a variety of cascades aimed at HEU production. In order to enhance this capability, however, the following points should be investigated:

(1) To incorporate the mathematical model into a whole system that has the capability of simulating flows and inventories of feed, product and tail along with their corresponding enrichments all over the plant.

(2) To develop a calculation method that can predict as precisely as possible a relationship between the inlet flow to a centrifuge and the separative power especially in case of a small flow rate, although it would be difficult to theoretically predict such relationship because of a complex gas dynamics.

Although the analyses of unintentional and intentional operations, which have been carried out in this report, are not necessarily thorough, our results indicate that the transient phenomenon accompanied with normal process operations or mis-operations should be taken into account when an alarm level is set up to detect an anomaly in an enrichment measurement at a cascade header. It is noted, however, that the alarm level could be set to be low if the anomalies, which may be generated as a result, are easily resolved.

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is set up to detect an anomaly in an enrichment measurement at a cascade header. It is noted, however, that the alarm level could be set to be low if the anomalies, which may be generated as a result, are easily resolved.

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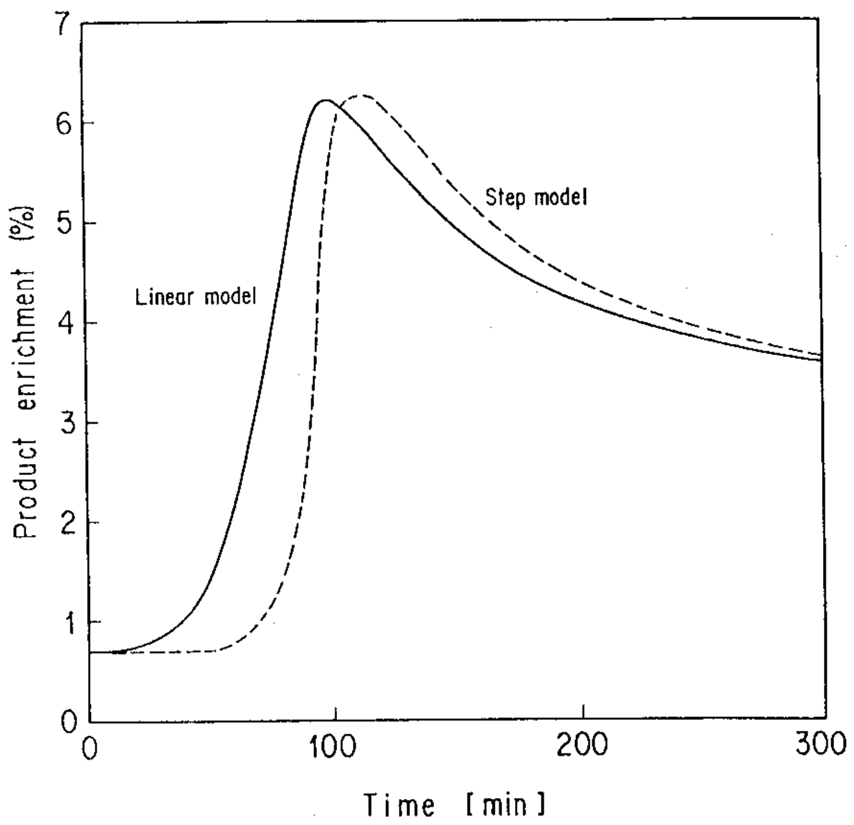

Fig. 1 Relationship between the product enrichment and the γ model, linear and step, in a start-up operation

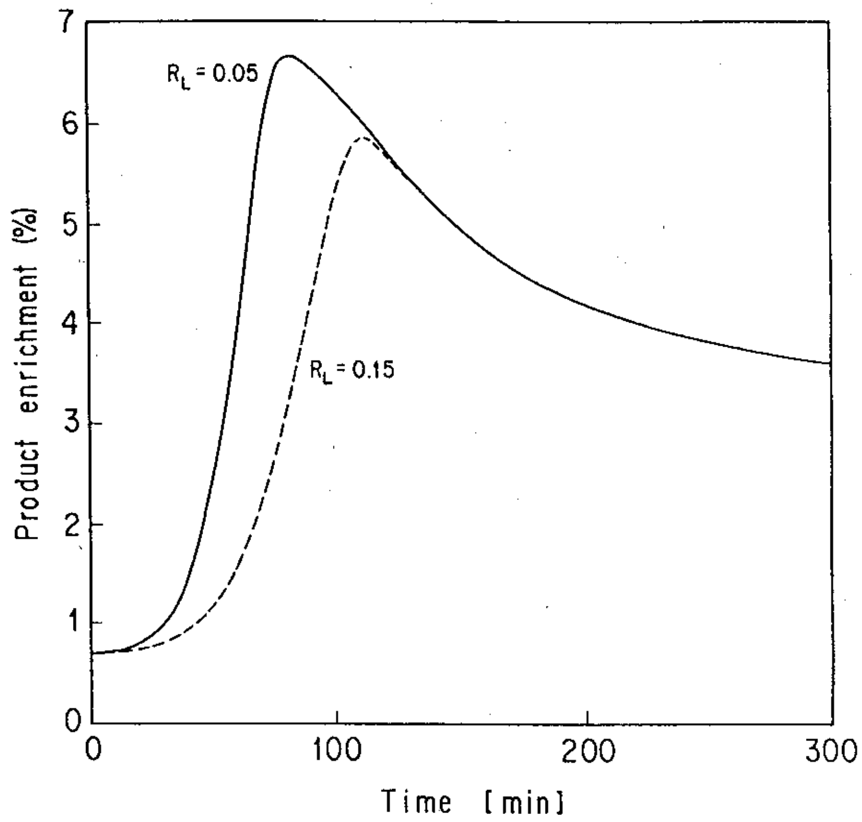

Fig. 2 Effect of R_L on the product enrichment in a start-up operation

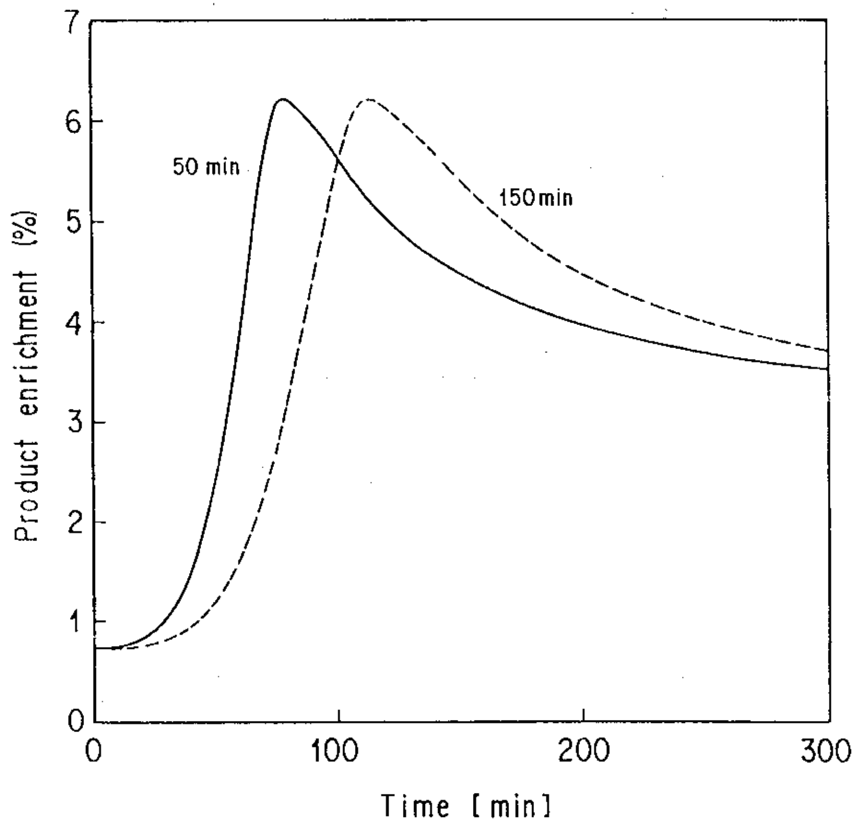

Fig. 3 Dependency of the product enrichment on the feed pattern in which the feed flow rate reaches to the designed value at 50 and 150 minutes after the start-up with a linear increase

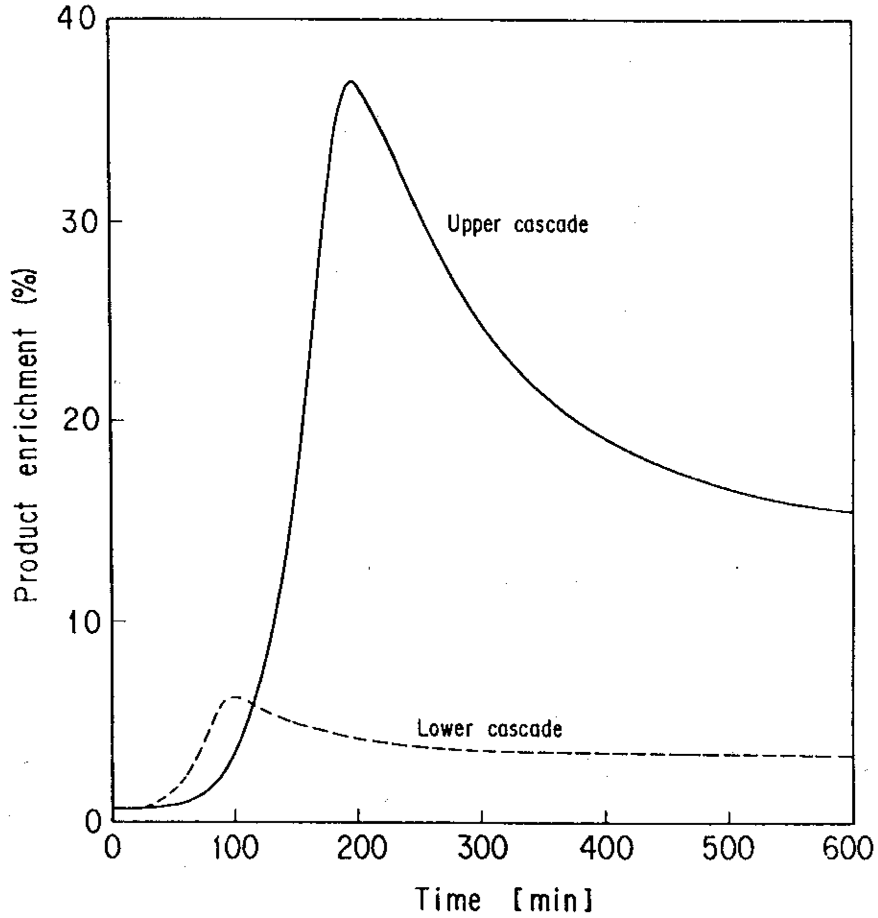

Fig. 4 Product enrichment from a two-step cascade in a start-up operation

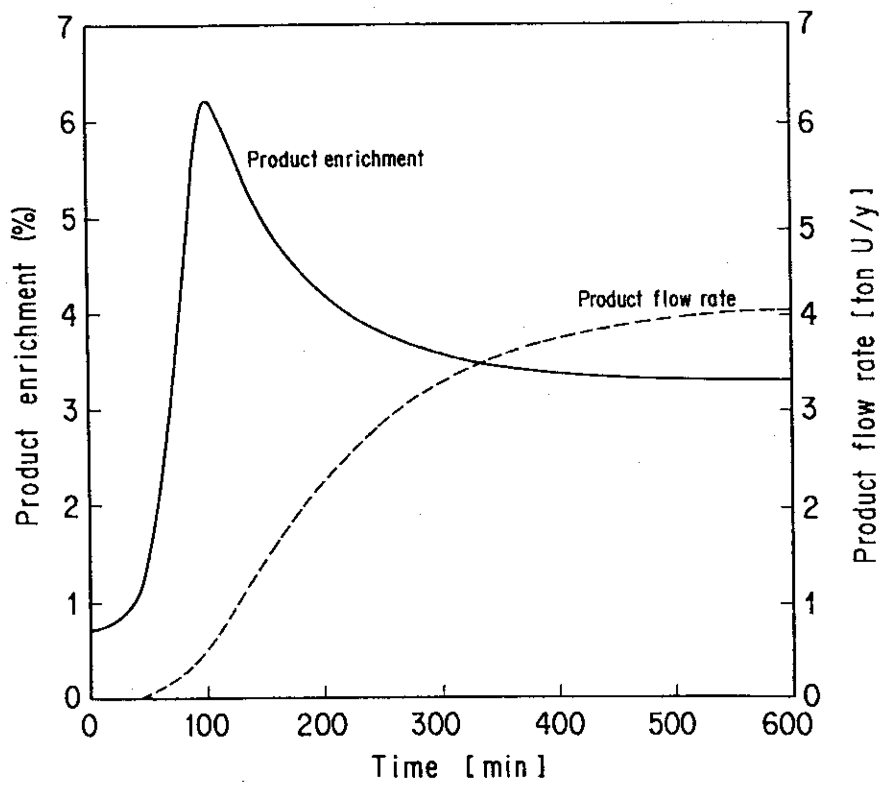

Fig. 5 Product flow rate and enrichment in a start-up operation

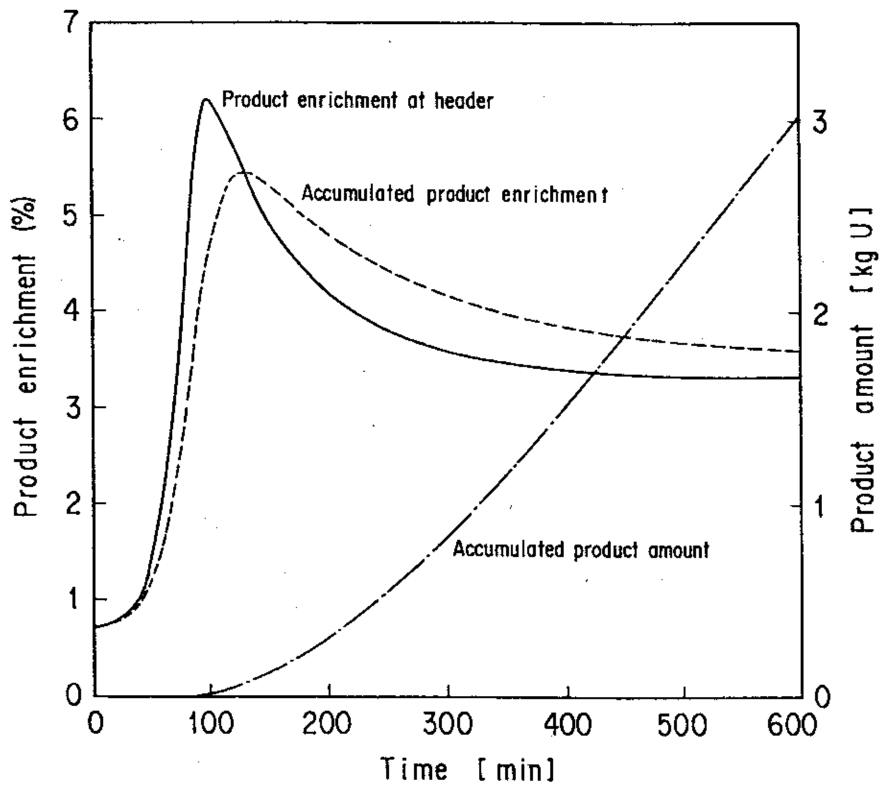

Fig. 6 Amount of the accumulated product uranium, its enrichment and product enrichment at a header pipe

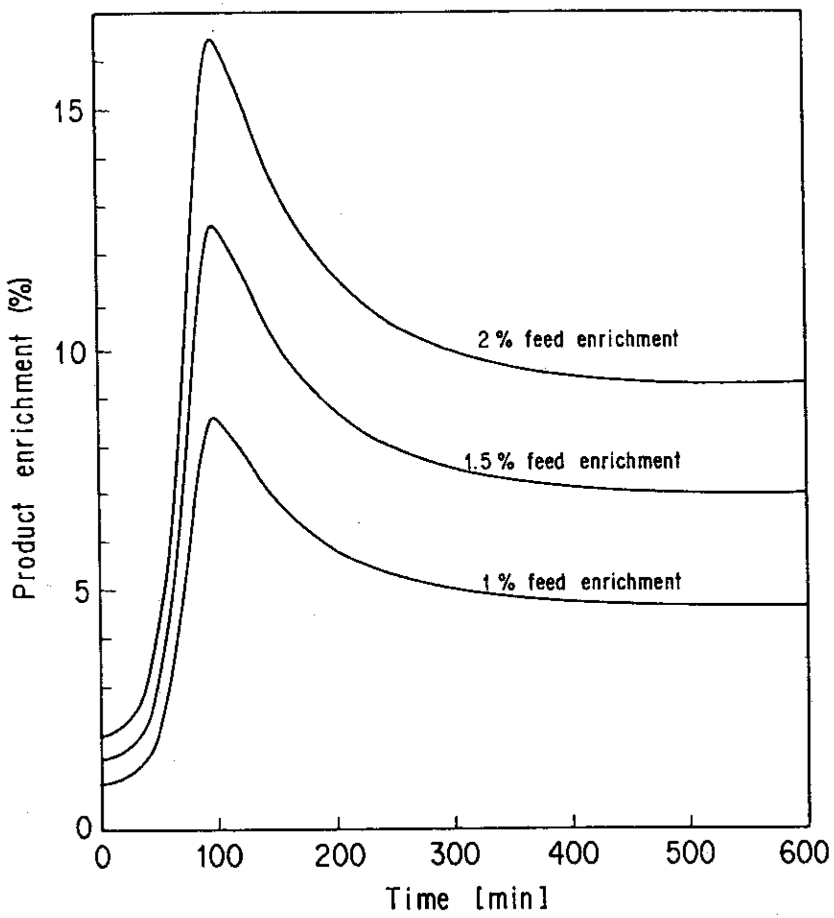

Fig. 7 Product enrichment in case of the low enriched uranium feed with 1, 1.5 and 2% enrichment in a start-up operation

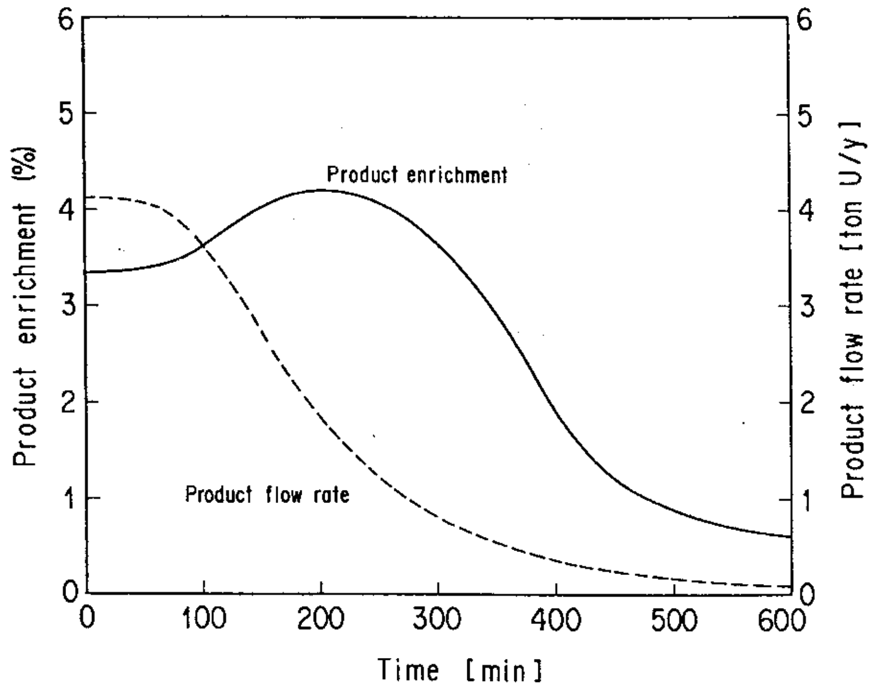

Fig. 8 Product flow rate and enrichment in a shut-down operation

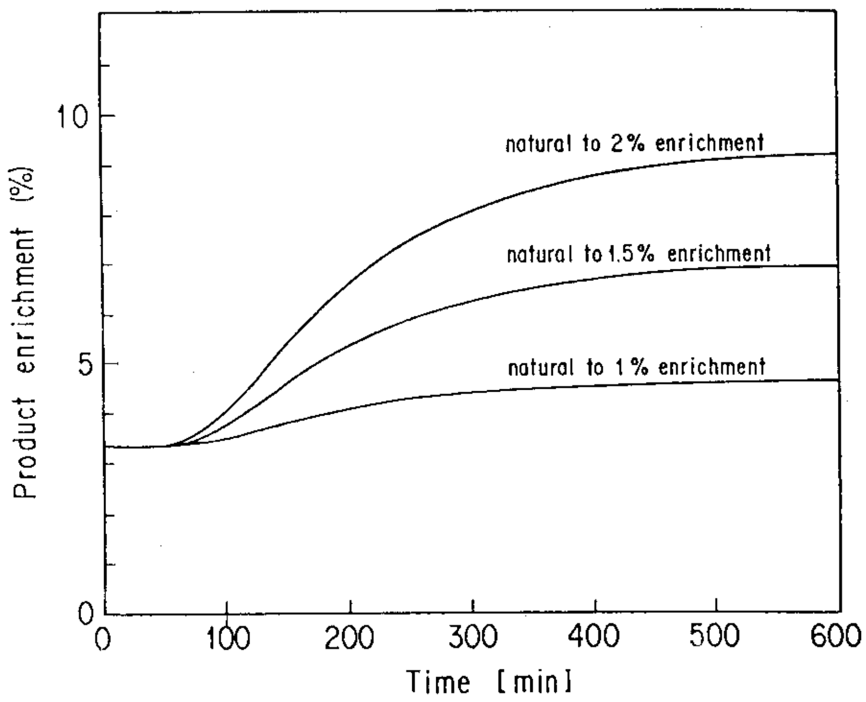

Fig. 9 Changes of the product enrichment when the feed is changed from natural uranium to low enriched uranium with 1, 1.5 and 2% enrichment

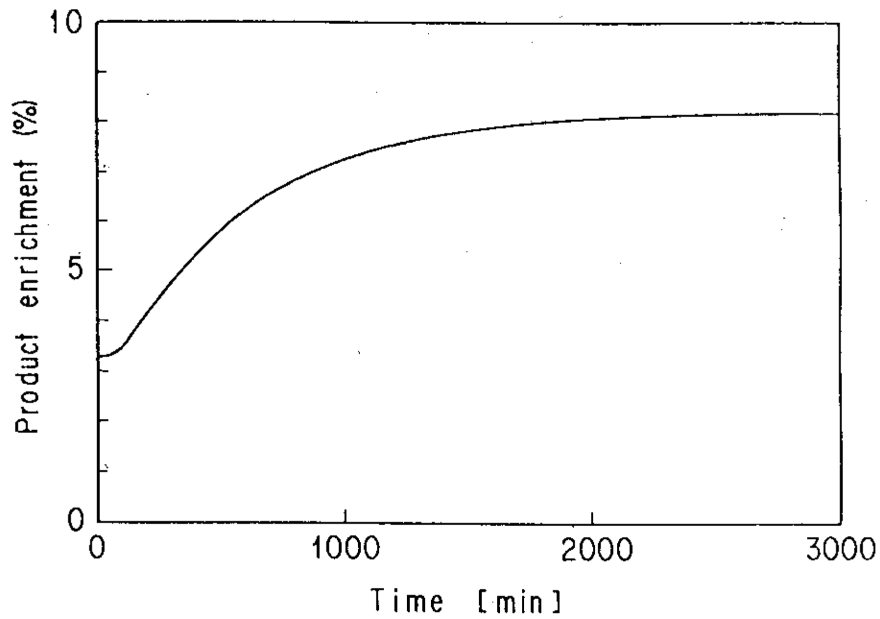

Fig. 10 Product enrichment in a transient operation where the product flow starts to be recycled to the feed stage

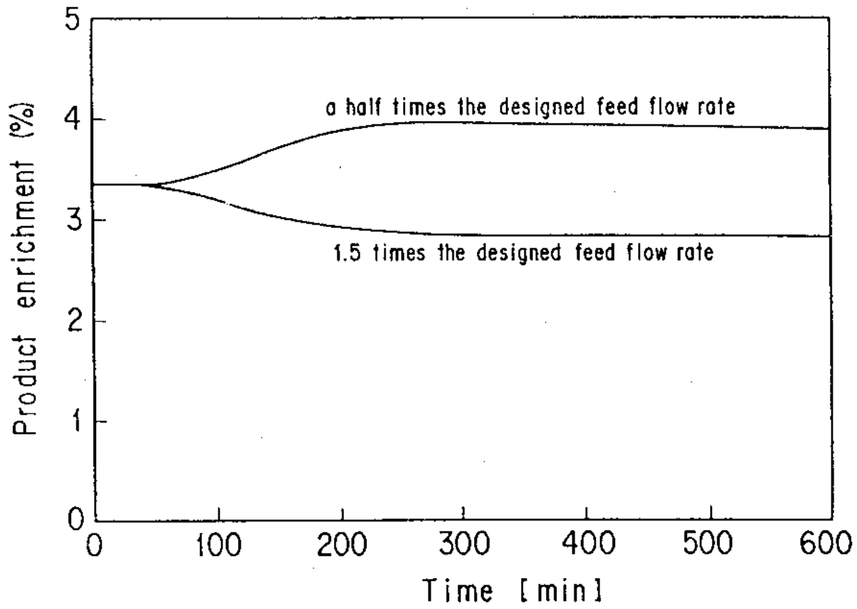

Fig. 11 Product enrichment in a transient operation where the feed flow rate is changed from the designed one to a half or 1.5 times of it

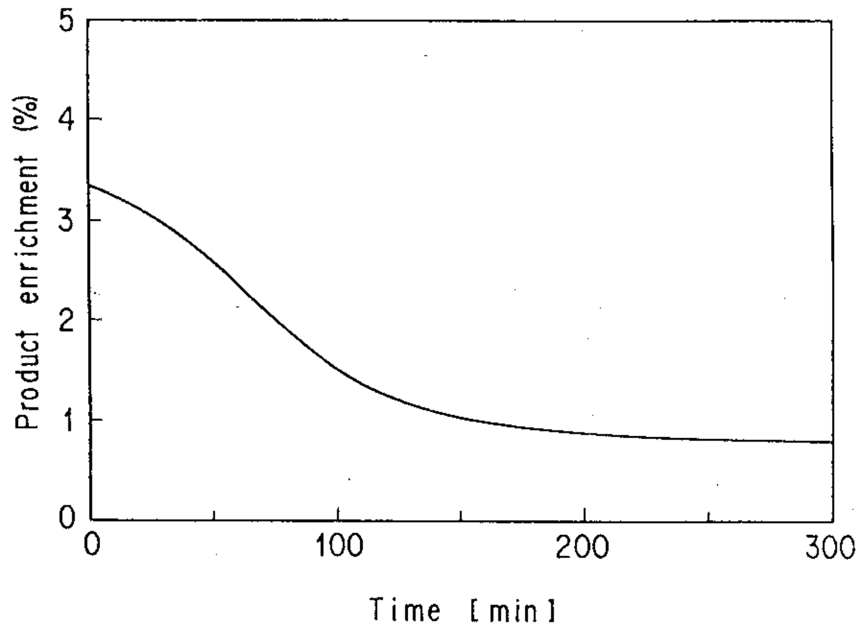

Fig. 12 Product enrichment in a power supply failure

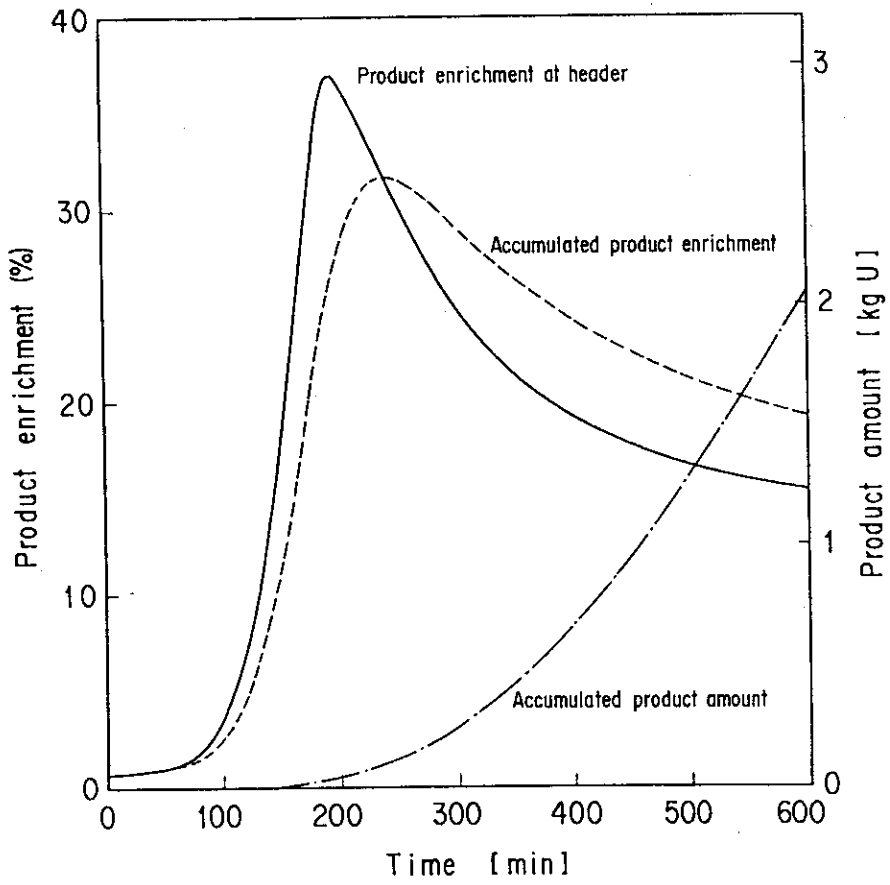

Fig. 13 Product enrichment at a header pipe, amount of the accumulated product uranium and its enrichment in a start-up operation of a two-step cascade

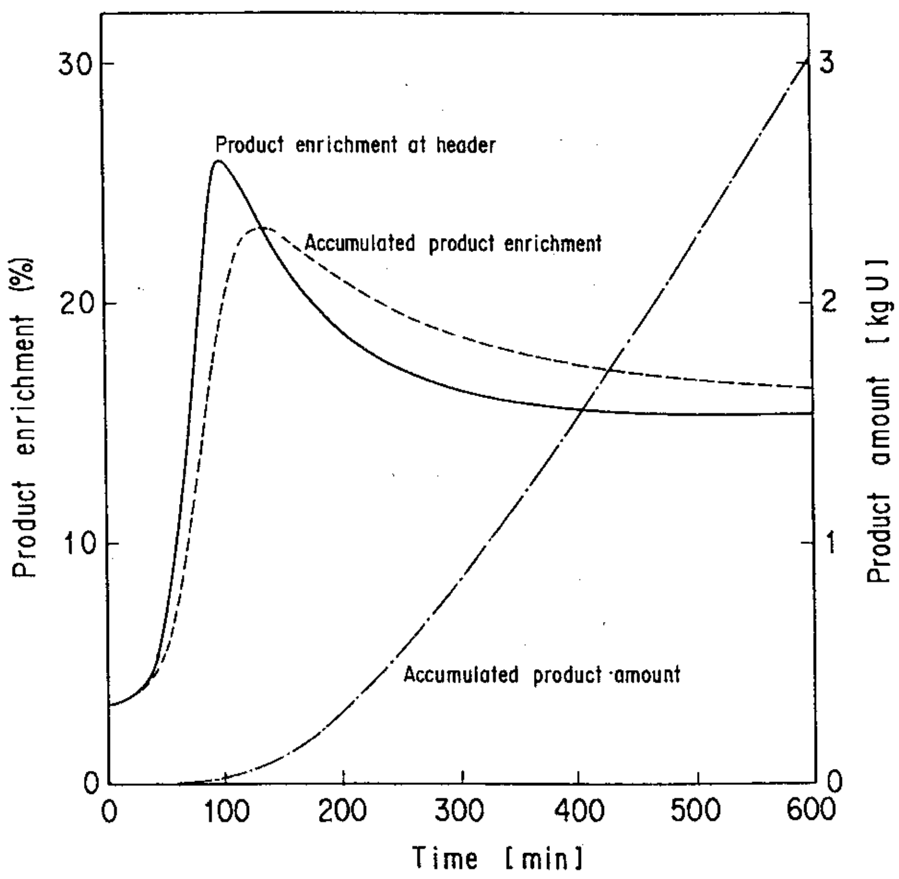

Fig. 14 Product enrichment at a header pipe, amount of the accumulated product uranium and its enrichment in a start-up operation where the first cycle product is used as the feed to the cascade

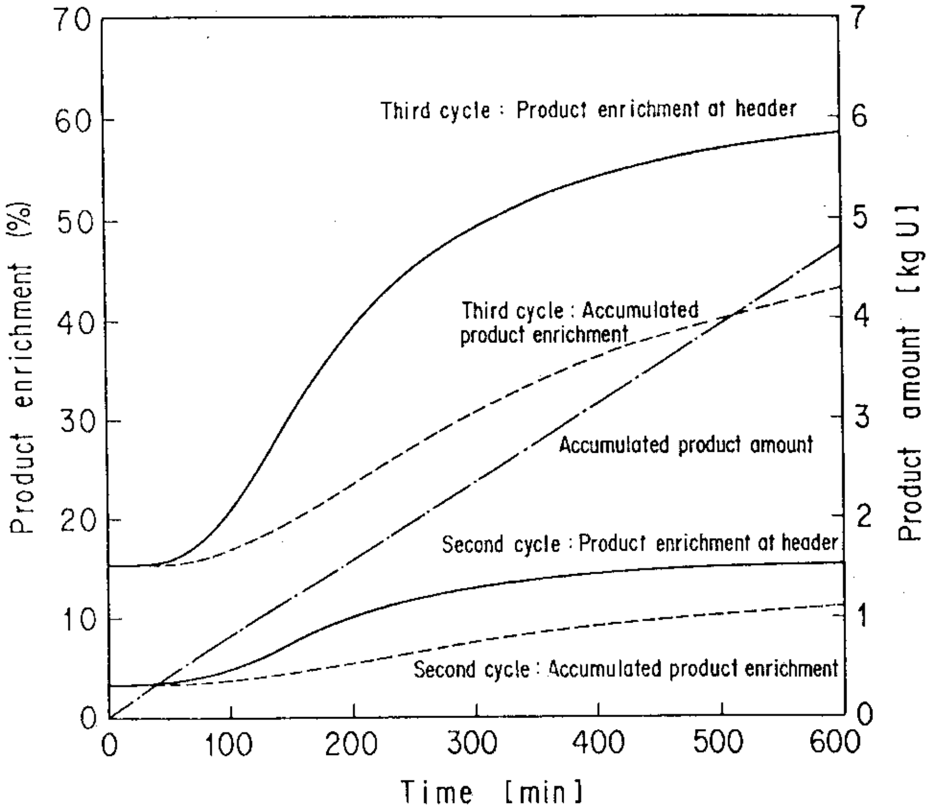

Fig. 15 Product enrichments at a header pipe or accumulated in the second and the third cycles, and amount of the accumulated product uranium in a transient operation where the feed enrichment is changed from one to another without changing the feed flow rate

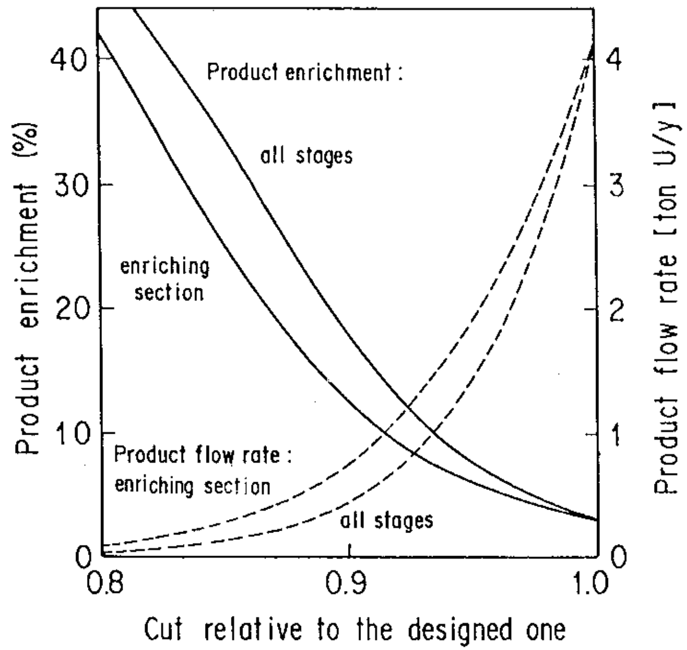

Fig. 16 Product flow rate and enrichment in case that the cut is changed in all stages or in enriching section

Appendix A Input and Output Data of Revised CCS-II Code

The input and output data of the revised CCS-II code are slightly different from those of the CCS-I code because the former code has the capability of handling a two-step hierarchical cascade as well as new functions added to it. For a user's convenience, however, explanations of all input data are given in Table A.1 with mathematical symbols used in this report, variable names used in the code, data types, explanation of suffixes of a variable, units and meanings. The following points should be taken into account when the input data are provided:

a. Only non-zero values are requested to be given as an input.
b. There is a limitation on the size of a variable, as shown in the column "Meaning" of Table A.1, and this should be strictly observed.
c. The input data that relate to stages are to be given firstly for the lower cascade and then for the upper cascade: in case of the enriching section, X(1) to X(S+1) are for the lower cascade and X(S+2) to X(2*(S+1)) are for the upper cascade and in case of the stripping section, X(1) to X(B) are for the lower cascade and X(B+1) to X(2*B) are for the upper cascade, where X is an arbitrary variable.
d. When a recycle flow is specified in the input, a side flow p' should be recycled as a feed f' and in case of p" as f". This is not a serious limitation because a feed as f''_j and a feed as f'_{j-2} are both mixed with the feed to the (j-1)-th stage and the former two feeds may be interchangeable.
e. Derivatives of L' are given as an output when KPRINT(2)=2, while L'N' and the derivatives of N' and L'N' are given if KPRINT(5)=2.
f. In case of a start-up operation of a cascade, the corresponding numerical calculation does not necessarily give a precise result. The use of KCALX(3) option is recommended.
g. The input data for a cut, main feed flow, recycle flow and a side stream should be given at a specific time defined by a multiple of the time step. If these data are not given at a time, a linear interpolation or a constant extension is carried out on the basis of the adjacent data given. One point data are permissible if these parameters do not change depending on time.

An example of actual input data is illustrated in Fig. A.1. As an additional output, lists of product flow rates and their corresponding enrichments, accumulated products and their corresponding enrichments are provided in the revised CCS-II code with each being aggregated over all output points. Dimensions for these parameters are 2,000. If the number of output points is over this number, only the first 2,000 are given in the list. An output example is shown in Fig. A.2.

Table A.1 Explanation of input data

Sym-bol	Variables	Type	Suffix	Unit	Meaning
S	IS	I	-	-	Top stage No. in the enriching section (up to 200)
B	IB	I	-	-	Bottom stage No. in the stripping section (up to 200)
	MAXCUT	I	-	-	Number of ICUT,CUTI(i) data (up to 50)
	ICUT(i)	I	i:1,2,3,···	Δt	Series of times when the cut is changed
θ_j	CUTI(m,i,1)	R	m:(m-1)-th stage (*) i:1,2,3,···	-	Cut in the enriching section
	CUTI(m,i,2)	R	m:(-m)-th stage (*) i:1,2,3,···	-	Cut in the stripping section
h_j	JH(m,1)	I	m:(m-1)-th stage (*)	sec	Holding time regarding L_j in the enriching section
	JH(m,2)	I	m:(-m)-th stage (*)	sec	Holding time regarding L_j in the stripping section
h'_j	JHD(m,1)	I	m:(m-1)-th stage (*)	sec	Holding time regarding L'_j in the enriching section
	JHD(m,2)	I	m:(-m)-th stage (*)	sec	Holding time regarding L'_j in the stripping section
h''_j	JHDD(m,1)	I	m:(m-1)-th stage (*)	sec	Holding time regarding L''_j in the enriching section
	JHDD(m,2)	I	m:(-m)-th stage (*)	sec	Holding time regarding L''_j in the stripping section
L_{opt}	XLOPT(m,1)	R	m:(m-1)-th stage (*)	tonU/y	Optimum inlet flow rate in the enriching section
	XLOPT(m,2)	R	m:(-m)-th stage (*)	tonU/y	Optimum inlet flow rate in the stripping section
L'_j	XLDI(m,1)	R	m:(m-1)-th stage (*)	tonU/y	Initial value for enriched flow rate in the enriching section
	XLDI(m,2)	R	m:(-m)-th stage (*)	tonU/y	Initial value for enriched flow rate in the stripping section

Table A.1 (Continued)

Symbol	Variables	Type	Suffix	Unit	Meaning
N'_j	XNDI(m,1)	R	m:(m-1)-th stage (*)	-	Initial value for enrichment in enriched flow in the enriching section
	XNDI(m,2)	R	m:(-m)-th stage (*)	-	Initial value for enrichment in enriched flow in the stripping section
k	NFEED	I	-	-	Number of main feed flows (n, up to 50)
	MAXF(n)	I	n:n-th main feed flow	-	Number of IFEED,FEEDI, XNFI data (i,up to 50)
	IFEED(i,n)	I	i:1,2,3,··· n:n-th main feed flow	Δt	A time when the main feed flow is changed
F_0	FEEDI(i,n)	R	i:1,2,3,··· n:n-th main feed flow	tonU/y	Flow rate of the main feed flow changed
N_F	XNFI(i,n)	R	i:1,2,3,··· n:n-th main feed flow	-	Enrichment in the main feed flow changed
(Recycle flow)	MAXFXD	I	-	-	Number of recycle flows (n, up to 200)
	NBR(k,n,1)	I	k=1:p',=2:p" n:n-th recycle flow	-	Outlet stage No. for a recycle flow
	NBR(k,n,2)	I	k=1:f',=2:f" n:n-th recycle flow	-	Inlet stage No. for a recycle flow (k should be the same as above)
	MAXSPR(1,n)	I	n:n-th recycle flow	-	Number of ISPR,SPRI data for k=1 (i, up to 50)
	MAXSPR(2,n)	I	n:n-th recycle flow	-	Number of ISPR,SPRI data for k=2 (i, up to 50)
	ISPR(i,1,n)	I	i:1,2,3,··· n:n-th recycle flow	Δt	A time when the recycle flow corresponding to k=1 is changed
	ISPR(i,2,n)	I	i:1,2,3,··· n:n-th recycle flow	Δt	A time when the recycle flow corresponding to k=2 is changed
	SPRI(i,1,n)	R	i:1,2,3,··· n:n-th recycle flow	tonU/y	Recycle flow rate changed at ISPR(i,1,n)
	SPRI(i,2,n)	R	i:1,2,3,··· n:n-th recycle flow	tonU/y	Recycle flow rate changed at ISPR(i,2,n)

Table A.1 (Continued)

Symbol	Variables	Type	Suffix	Unit	Meaning
	MAXSFD(m,1)	I	m:(m-1)-th stage (*)	-	Number of ISFD,SFDI, SNDI data(i) for (m,1) (up to 50)
	MAXSFD(m,2)	I	m:(-m)-th stage (*)	-	Number of ISFD,SFDI, SNDI data(i) for (m,2) (up to 50)
	ISFD(i,m,1)	I	i:1,2,3,··· m:(m-1)-th stage (*)	Δt	A time when side feed f'_j is changed in the enriching section
	ISFD(i,m,2)	I	i:1,2,3,··· m:(-m)-th stage (*)	Δt	A time when side feed f'_j is changed in the stripping section
f'_j	SFDI(i,m,1)	R	i:1,2,3,··· m:(m-1)-th stage (*)	tonU/y	Flow rate of the side feed f'_j in the enriching section
	SFDI(i,m,2)	R	i:1,2,3,··· m:(-m)-th stage (*)	tonU/y	Flow rate of the side feed f'_j in the stripping section
n'_j	SNDI(i,m,1)	R	i:1,2,3,··· m:(m-1)-th stage (*)	-	Enrichment in the side feed f'_j in the enriching section
	SNDI(i,m,2)	R	i:1,2,3,··· m:(-m)-th stage (*)	-	Enrichment in the side feed f'_j in the stripping section
	MXSFDD(m,1)	I	m:(m-1)-th stage (*)	-	Number of ISFDD,SFDDI, SNDDI data (i) for (m,1), (up to 50)
	MXSFDD(m,2)	I	m:(-m)-th stage (*)	-	Number of ISFDD,SFDDI, SNDDI data (i) for (m,2), (up to 50)
	ISFDD(i,m,1)	I	i:1,2,3,··· m:(m-1)-th stage (*)	Δt	A time when side feed f''_j is changed in the enriching section
	ISFDD(i,m,2)	I	i:1,2,3,··· m:(-m)-th stage (*)	Δt	A time when side feed f''_j is changed in the stripping section
f''_j	SFDDI(i,m,1)	R	i:1,2,3,··· m:(m-1)-th stage (*)	tonU/y	Flow rate of the side feed f''_j in the enriching section
	SFDDI(i,m,2)	R	i:1,2,3,··· m:(-m)-th stage (*)	tonU/y	Flow rate of the side feed f''_j in the stripping section
n''_j	SNDDI(i,m,1)	R	i:1,2,3,··· m:(m-1)-th stage (*)	-	Enrichment in the side feed f''_j in the enriching section
	SNDDI(i,m,2)	R	i:1,2,3,··· m:(-m)-th stage (*)	-	Enrichment in the side feed f''_j in the stripping section

Table A.1 (Continued)

Sym-bol	Variables	Type	Suffix	Unit	Meaning
	MAXSPD(m,1)	I	m:(m-1)-th stage (*)	-	Number of ISPD,SPDI data (i) for (m,1) (up to 50)
	MAXSPD(m,2)	I	m:(-m)-th stage (*)	-	Number of ISPD,SPDI data (i) for (m,2) (up to 50)
	ISPD(i,m,1)	I	i:1,2,3,··· m:(m-1)-th stage (*)	Δt	A time when removal p'_j is changed in the enriching section
	ISPD(i,m,2)	I	i:1,2,3,··· m:(-m)-th stage (*)	Δt	A time when removal p'_j is changed in the stripping section
p'_j	SPDI(i,m,1)	R	i:1,2,3,··· m:(m-1)-th stage (*)	tonU/y	Flow rate of the removal p'_j in the enriching section
	SPDI(i,m,2)	R	i:1,2,3,··· m:(-m)-th stage (*)	tonU/y	Flow rate of the removal p'_j in the stripping section
	MXSPDD(m,1)	I	m:(m-1)-th stage (*)	-	Number of ISPDD,SPDDI data (i) for (m,1) (up to 50)
	MXSPDD(m,2)	I	m:(-m)-th stage (*)	-	Number of ISPDD,SPDDI data (i) for (m,2) (up to 50)
	ISPDD(i,m,1)	I	i:1,2,3,··· m:(m-1)-th stage (*)	Δt	A time when removal p''_j is changed in the enriching section
	ISPDD(i,m,2)	I	i:1,2,3,··· m:(-m)-th stage (*)	Δt	A time when removal p''_j is changed in the stripping section
p''_j	SPDDI(i,m,1)	R	i:1,2,3,... m:(m-1)-th stage (*)	tonU/y	Flow rate of the removal p''_j in the enriching section
	SPDDI(i,m,2)	R	i:1,2,3,... m:(-m)-th stage (*)	tonU/y	Flow rate of the removal p''_j in the stripping section
	MAXG	I	-	-	Number of data points (i, up to 200)
	RLOPTI(i)	R	i:1,2,3,...	-	Flow rate ratio parameter (L/L_{opt}) for γ
γ	GAMI(i)	R	i:1,2,3,...	-	Separation factor
R_L	RATIO	R	-	-	Threshold ratio for full enrichment calculation, compared with L/L_{opt}
Δt	NDELT	I	-	sec	Time step for comput.

Table A.1 (Continued)

Sym-bol	Variables	Type	Suffix	Unit	Meaning
(For cal. and out-put)	INTVLP	I	-	Δt	Interval for output
	KPRINT(i)	I	i:1,2,...,7	-	Output option for L, L', L'', N, N', N'' in this order for (i=1,6) =0: no output =1: output is given =2: with derivatives for L'(i=2), N' and $L'N'$(i=5) =-1,-2: at last point (i=7)=0: no output for each time step =1: output is given for each time step =-n: output is given from the n-th step
	NSTOP	I	-	Δt	Number of time steps for calculation
	MODEL	I	-	-	Calculation model =0: standard model =1: model which takes account of the derivative of γ =-1: reference model
	KCALX(i)	I	i:1,2,...,7	-	Calculation option (1)=0: normal cascade =1: two-step hierarchical cascade =2: two-step with tail recycle =-n: 2nd step feed = F_0/n (2)=0: step $\gamma(L)$ =1: linear γ (3)=n: γ=1 till the n-th time step (4)=0: flow rate for p',p",recycle flow =1: flow rate ratio for p',p",recycle flow (5)=0: normal =T_0(Δt): γ starts to linearly decrease due to power failure (6)=T_1(Δt): γ reaches to 1 by power failure

Table A.1 (Continued)

Sym-bol	Variables	Type	Suffix	Unit	Meaning
	EMPTY	R	-	-	(7)=0: no change of XLDI,XNDI in the next run =1: last L',N' for XLDI,XNDI (**) If L' < EMPTY, it is regarded that the cascade is emptied and the run is stopped; default: 1.0E-5

Note: Type I means integer-type data and type R means real-type data.

(*) In case of enriching section, m:1∼S+1 is for the lower cascade and m:S+2∼2*(S+1) is for the upper cascade. In case of stripping section, m:1∼B is for the lower cascade and m:B+1∼2*B is for the upper cascade.

(**) If the run is continued with L' and N' transferred from the previous case, KCALX(3) should be 0. Since N"(-Δt) is not transferred, p" is slightly changed. It is also noted that P, F and W are reset to zeros.

```
                        INPUT DATA IMAGE
                       ********************
1       10        20        30        40        50        60        70        80
........+.........+.........+.........+.........+.........+.........+.........+
 &DATA
     IS=12,IB=9,
     MAXCUT=1,ICUT(1)=0,
     CUTI(1,1,1)=26*0.47014,CUTI(1,1,2)=18*0.47014,
     JH(1,1)=26*75,JH(1,2)=18*75,JHD(1,1)=26*5,JHD(1,2)=18*5,
     JHDD(1,1)=26*5,JHDD(1,2)=18*5,
     XLOPT(1,1)=1.804180E+3,1.550360E+3,1.323980E+3,1.118180E+3,
                0.939820E+3,0.782040E+3,6.379800E+2,5.145000E+2,
                4.047400E+2,3.018400E+2,2.126600E+2,1.372000E+2,
                6.860000E+1,
                0.257740E+3,0.221480E+3,0.189140E+3,0.159740E+3,
                0.134260E+3,0.111720E+3,0.911400E+2,0.735000E+2,
                0.578200E+2,0.431200E+2,0.303800E+2,0.196000E+2,
                0.980000E+1,
     XLOPT(1,2)=1.708140E+3,1.591520E+3,1.468040E+3,1.323980E+3,
                1.159340E+3,0.980980E+3,0.782040E+3,5.488000E+2,
                2.949800E+2,
                0.244020E+3,0.227360E+3,0.209720E+3,0.189140E+3,
                0.165620E+3,0.140140E+3,0.111720E+3,0.784000E+2,
                0.421400E+2,
     XLDI(1,1)=26*0.0,XLDI(1,2)=18*0.0,
     XNDI(1,1)=26*0.0,XNDI(1,2)=18*0.0,
     NFEED=1,MAXF(1)=3,IFEED(1,1)=0,1000,10000,
     FEEDI(1,1)=0.0,2*183.2992,XNFI(1,1)=3*7.11E-3,
     MAXFXD=0,NBR(2,1,1)=-18,NBR(2,1,2)=1,
     MAXSPR(2,1)=2,ISPR(1,2,1)=0,1000,SPRI(1,2,1)=2*1.0,
     MAXG=31,
     RLOPTI=0.00,0.10,0.20,0.30,0.40,0.50,0.60,0.70,0.80,0.90,1.00,
                 1.10,1.20,1.30,1.40,1.50,1.60,1.70,1.80,1.90,2.00,
                 2.10,2.20,2.30,2.40,2.50,2.60,2.70,2.80,2.90,3.00,
     GAMI=  1.51,1.49,1.46,1.42,1.39,1.37,1.35,1.33,1.31,1.29,1.27,
            1.25,1.24,1.23,1.22,1.21,1.20,1.19,1.18,1.18,1.17,1.16,
            2*1.15,2*1.14,2*1.13,3*1.12,
     RATIO=0.1,NDELT=6,INTVLP=100,KPRINT=-1,-1,-1,-1,-1,-1,
     NSTOP=6000,MODEL=0,KCALX=1,1,10,1,EMPTY=1.0E-5,
 &END
```

Fig. A.1 An example of standard input data for the revised CCS-II code

```
****************************************************************
*                                                              *
*   ANALYSIS  OF  DYNAMICS  IN UF6 GAS CENTRIFUGE  CASCADE     *
*                                                              *
*                    WITH  SIDE  FLOWS                         *
*                                                              *
****************************************************************
```

CHARACTERISTICS OF CENTRIFUGE CASCADE

STAGE NO. J (-)	CUT (-)	HOLDING TIME H (SEC)	H* (SEC)	H** (SEC)	ENRICHED FLOW RATE L* (TON-U/YR)	OPTIMAL FLOW RATE LOPT (TON-U/YR)	ENRICHED ASSAY N* (-)	ENRICHING RESTRICTED L (TON-U/YR)
25	4.70140E-01	75	5	5	0.0	9.80000E+00	0.0	9.80000E-01
24	4.70140E-01	75	5	5	0.0	1.96000E+01	0.0	1.96000E+00
23	4.70140E-01	75	5	5	0.0	3.03800E+01	0.0	3.03800E+00
22	4.70140E-01	75	5	5	0.0	4.31200E+01	0.0	4.31200E+00
21	4.70140E-01	75	5	5	0.0	5.78200E+01	0.0	5.78200E+00
20	4.70140E-01	75	5	5	0.0	7.35000E+01	0.0	7.35000E+00
19	4.70140E-01	75	5	5	0.0	9.11400E+01	0.0	9.11400E+00
18	4.70140E-01	75	5	5	0.0	1.11720E+02	0.0	1.11720E+01
17	4.70140E-01	75	5	5	0.0	1.34260E+02	0.0	1.34260E+01
16	4.70140E-01	75	5	5	0.0	1.59740E+02	0.0	1.59740E+01
15	4.70140E-01	75	5	5	0.0	1.89140E+02	0.0	1.89140E+01
14	4.70140E-01	75	5	5	0.0	2.21480E+02	0.0	2.21480E+01
13	4.70140E-01	75	5	5	0.0	2.57740E+02	0.0	2.57740E+01
12	4.70140E-01	75	5	5	0.0	6.86000E+01	0.0	6.86000E+00
11	4.70140E-01	75	5	5	0.0	1.37200E+02	0.0	1.37200E+01
10	4.70140E-01	75	5	5	0.0	2.12660E+02	0.0	2.12660E+01
9	4.70140E-01	75	5	5	0.0	3.01840E+02	0.0	3.01840E+01
8	4.70140E-01	75	5	5	0.0	4.04740E+02	0.0	4.04740E+01
7	4.70140E-01	75	5	5	0.0	5.14500E+02	0.0	5.14500E+01
6	4.70140E-01	75	5	5	0.0	6.37980E+02	0.0	6.37980E+01
5	4.70140E-01	75	5	5	0.0	7.82040E+02	0.0	7.82040E+01
4	4.70140E-01	75	5	5	0.0	9.39820E+02	0.0	9.39820E+01
3	4.70140E-01	75	5	5	0.0	1.11818E+03	0.0	1.11818E+02
2	4.70140E-01	75	5	5	0.0	1.32398E+03	0.0	1.32398E+02
1	4.70140E-01	75	5	5	0.0	1.55036E+03	0.0	1.55036E+02
0	4.70140E-01	75	5	5	0.0	1.80418E+03	0.0	1.80418E+02
-1	4.70140E-01	75	5	5	0.0	1.70814E+03	0.0	1.70814E+02
-2	4.70140E-01	75	5	5	0.0	1.59152E+03	0.0	1.59152E+02
-3	4.70140E-01	75	5	5	0.0	1.46804E+03	0.0	1.46804E+02
-4	4.70140E-01	75	5	5	0.0	1.32398E+03	0.0	1.32398E+02
-5	4.70140E-01	75	5	5	0.0	1.15934E+03	0.0	1.15934E+02
-6	4.70140E-01	75	5	5	0.0	9.80980E+02	0.0	9.80980E+01
-7	4.70140E-01	75	5	5	0.0	7.82040E+02	0.0	7.82040E+01
-8	4.70140E-01	75	5	5	0.0	5.48800E+02	0.0	5.48800E+01
-9	4.70140E-01	75	5	5	0.0	2.94980E+02	0.0	2.94980E+01
-10	4.70140E-01	75	5	5	0.0	2.44020E+02	0.0	2.44020E+01
-11	4.70140E-01	75	5	5	0.0	2.27360E+02	0.0	2.27360E+01
-12	4.70140E-01	75	5	5	0.0	2.09720E+02	0.0	2.09720E+01
-13	4.70140E-01	75	5	5	0.0	1.89140E+02	0.0	1.89140E+01
-14	4.70140E-01	75	5	5	0.0	1.65620E+02	0.0	1.65620E+01
-15	4.70140E-01	75	5	5	0.0	1.40140E+02	0.0	1.40140E+01
-16	4.70140E-01	75	5	5	0.0	1.11720E+02	0.0	1.11720E+01
-17	4.70140E-01	75	5	5	0.0	7.84000E+01	0.0	7.84000E+00
-18	4.70140E-01	75	5	5	0.0	4.21400E+01	0.0	4.21400E+00

Fig. A.2 An example of standard computer output for the revised CCS-II code

FLOW RATE RATIO L / LOPT (-)	STAGE SEPARATION FACTOR GAMMA (-)
0.0	1.51000E+00
0.10	1.49000E+00
0.20	1.46000E+00
0.30	1.42000E+00
0.40	1.39000E+00
0.50	1.37000E+00
0.60	1.35000E+00
0.70	1.33000E+00
0.80	1.31000E+00
0.90	1.29000E+00
1.00	1.27000E+00
1.10	1.25000E+00
1.20	1.24000E+00
1.30	1.23000E+00
1.40	1.22000E+00
1.50	1.21000E+00
1.60	1.20000E+00
1.70	1.19000E+00
1.80	1.18000E+00
1.90	1.18000E+00
2.00	1.17000E+00
2.10	1.16000E+00
2.20	1.15000E+00
2.30	1.15000E+00
2.40	1.14000E+00
2.50	1.14000E+00
2.60	1.13000E+00
2.70	1.13000E+00
2.80	1.12000E+00
2.90	1.12000E+00
3.00	1.12000E+00

```
NUMBER OF FEED FLOWS
       K    =      1 (-)

NUMBER OF SIDE FLOWS
       SF*  =      0 (-)
       SF** =      0 (-)
       SP*  =      0 (-)
       SP** =      0 (-)

REFLUX FLOW BETWEEN SIDE FLOWS
          --- NO DATA ---
...........................................

 RATIO OF L/LOPT =     0.100 (-)

...........................................

SPECIFICATION OF FEED FLOWS
       ( )X DELTA-T (SEC)
        0         1000         10000

       F(  1) (TON-U/YR)
0.0          1.83299E+02  1.83299E+02

       NF(  1) (-)
7.11000E-03  7.11000E-03  7.11000E-03

...........................................

SPECIFICATION OF FEED SIDE FLOWS
          --- NO DATA ---
...........................................

SPECIFICATION OF PRODUCT SIDE FLOWS
          --- NO DATA ---
...........................................

SPECIFICATION OF REFLUX FLOWS
          --- NO DATA ---
...........................................

SPECIFICATION OF CUT
          --- NO DATA ---
...........................................
```

Fig. A.2 (Continued)

```
CONDITIONS IN NUMERICAL CALCULATION AND PRINT

          TIME INTERVAL DELTA-T =        6 (SEC)

          NUMBER OF TIME STEPS  =     6000 (-)

          PRINT OPTION          =     L ,  L* ,  L**        N ,  N* ,  N**      OTHERS
                                     -1   -1    -1         -1   -1    -1            0    0

          PRINT INTERVAL        =      100 (-)

          CALCULATION MODEL     =     MODEL  KCALX
                                        0      1      1     10      1      0      0      0      0

          CONDITION OF EMPTY    =      1.00000E-05

*     6000X DELTA-T (SEC)
                        PRODUCT        WASTE          FEED       INVENTORY   MAT.BALANCE   TOTAL FLOW RATE SUMMED UP OVER STAGES
U AMOUNT      (GR)  2.01495E+03  1.33426E+05  1.91597E+05  5.63158E+04 -1.60199E+02           SIGMA L    = 2.22027E+04 (TON-U/YR)
U235 AMOUNT   (GR)  3.87193E+02  3.33415E+02  1.36319E+03  6.60733E+02 -1.81494E+01           SIGMA L*   = 1.04362E+04 (TON-U/YR)
AVERAGE ASSAY (-)   1.92160E-01  2.49887E-03  7.11490E-03  1.17326E-02  -----------           SIGMA L**  = 1.17619E+04 (TON-U/YR)
                                                                                     SEPARATIVE WORK  = 1.08395E+02 (TON-SWU/YR)

L       6.03963E+01 1.28488E+02 2.05277E+02 2.91898E+02 3.89627E+02 4.99907E+02 6.24365E+02 7.64834E+02 9.23379E+02 1.10232E+03
        1.30428E+03 1.53220E+03 1.78940E+03
        1.68973E+03 1.57775E+03 1.45190E+03 1.31040E+03 1.15124E+03 9.72172E+02 7.70613E+02 5.43657E+02 2.88026E+02
2-ND 8.57840E+00 1.82665E+01 2.92274E+01 4.16475E+01 5.57380E+01 7.17393E+01 8.99236E+01 1.10599E+02 1.34112E+02 1.60857E+02
        1.91274E+02 2.25861E+02 2.65176E+02
        2.49451E+02 2.32090E+02 2.12879E+02 1.91570E+02 1.67874E+02 1.41459E+02 1.11940E+02 7.88756E+01 4.17564E+01
N       2.94397E-02 2.60816E-02 2.31792E-02 2.06019E-02 1.82869E-02 1.62285E-02 1.44110E-02 1.27963E-02 1.13614E-02 1.00899E-02
        8.95975E-03 7.95579E-03 7.06639E-03
        6.26789E-03 5.55850E-03 4.92904E-03 4.36994E-03 3.87535E-03 3.43752E-03 3.04793E-03 2.70243E-03 2.39648E-03
2-ND 1.37316E-01 1.22938E-01 1.10112E-01 9.84384E-02 8.77522E-02 7.81081E-02 6.94978E-02 6.17911E-02 5.49104E-02 4.87985E-02
        4.33621E-02 3.85362E-02 3.42676E-02
        3.06323E-02 2.73427E-02 2.43772E-02 2.17077E-02 1.93206E-02 1.71892E-02 1.52796E-02 1.35780E-02 1.20665E-02

L*      2.83895E+01 6.03963E+01 9.64921E+01 1.37209E+02 1.83149E+02 2.34989E+02 2.93494E+02 3.59527E+02 4.34060E+02 5.18183E+02
        6.13126E+02 7.20277E+02 8.41194E+02
        7.94334E+02 7.41687E+02 6.82520E+02 6.15998E+02 5.41180E+02 4.56999E+02 3.62249E+02 2.55563E+02 1.35394E+02
2-ND 4.02859E+00 8.57840E+00 1.37262E+01 1.95594E+01 2.61777E+01 3.36941E+01 4.22364E+01 5.19495E+01 6.29972E+01 7.55638E+01
        8.98574E+01 1.06112E+02 1.24589E+02
        1.17196E+02 1.09036E+02 1.00007E+02 8.99933E+01 7.88597E+01 6.64495E+01 5.25823E+01 3.70501E+01 1.96140E+01
N*      3.33495E-02 2.94398E-02 2.61183E-02 2.32179E-02 2.06207E-02 1.82919E-02 1.62383E-02 1.44221E-02 1.28027E-02 1.13688E-02
        1.00971E-02 8.96469E-03 7.96126E-03
        7.06351E-03 6.26352E-03 5.55549E-03 4.92530E-03 4.36698E-03 3.87433E-03 3.43674E-03 3.04604E-03 2.70410E-03
2-ND 1.53674E-01 1.37316E-01 1.22925E-01 1.10007E-01 9.81913E-02 8.74190E-02 7.77967E-02 6.92095E-02 6.15086E-02 5.46651E-02
        4.85874E-02 4.31749E-02 3.83842E-02
        3.43402E-02 3.06647E-02 2.73573E-02 2.43708E-02 2.16936E-02 1.93094E-02 1.71760E-02 1.52603E-02 1.35778E-02

L**     3.19956E+01 6.80682E+01 1.08749E+02 1.54638E+02 2.06413E+02 2.64838E+02 3.30775E+02 4.05196E+02 4.89196E+02 5.84005E+02
        6.91009E+02 8.11770E+02 9.48047E+02
        8.95235E+02 8.35901E+02 7.69217E+02 6.94245E+02 6.09923E+02 5.15050E+02 4.08263E+02 2.88026E+02 1.52593E+02
2-ND 4.54032E+00 9.66808E+00 1.54697E+01 2.20439E+01 2.95030E+01 3.79741E+01 4.76015E+01 5.85484E+01 7.09994E+01 8.51624E+01
        1.01272E+02 1.19591E+02 1.40415E+02
        1.32083E+02 1.22886E+02 1.12710E+02 1.01425E+02 8.88769E+01 7.48903E+01 5.92616E+01 4.17564E+01 2.21055E+01
N**     2.59708E-02 2.31013E-02 2.05703E-02 1.82794E-02 1.62145E-02 1.43959E-02 1.27880E-02 1.13521E-02 1.00809E-02 8.95367E-03
        7.94913E-03 7.05937E-03 6.27130E-03
        5.56080E-03 4.93180E-03 4.37204E-03 3.87602E-03 3.43799E-03 3.04887E-03 2.70188E-03 2.39649E-03 2.12258E-03
2-ND 1.22978E-01 1.10324E-01 9.88566E-02 8.82615E-02 7.85540E-02 6.98923E-02 6.21650E-02 5.52270E-02 4.90657E-02 4.35954E-02
        3.87232E-02 3.44145E-02 3.06073E-02
        2.73316E-02 2.43818E-02 2.17176E-02 1.93279E-02 1.71970E-02 1.52892E-02 1.35781E-02 1.20665E-02 1.07069E-02
```

Fig. A.2 (Continued)

PRODUCT FLOW AND CONCENTRATION FOR EVERY 100 * DELTA-T

FLOW (TON-U/YR)

0.0	4.15868E-17	1.19237E-10	8.77564E-08	3.96644E-06
4.84592E-05	2.87700E-04	1.09862E-03	3.13848E-03	7.32957E-03
1.47928E-02	2.67627E-02	4.45070E-02	6.92609E-02	1.02177E-01
1.44265E-01	1.96287E-01	2.58649E-01	3.31339E-01	4.13949E-01
5.05745E-01	6.05769E-01	7.12921E-01	8.26040E-01	9.43961E-01
1.06555E+00	1.18976E+00	1.31560E+00	1.44217E+00	1.56870E+00
1.69446E+00	1.81886E+00	1.94135E+00	2.06151E+00	2.17894E+00
2.29336E+00	2.40450E+00	2.51218E+00	2.61625E+00	2.71663E+00
2.81323E+00	2.90602E+00	2.99501E+00	3.08021E+00	3.16166E+00
3.23943E+00	3.31356E+00	3.38416E+00	3.45133E+00	3.51515E+00
3.57574E+00	3.63320E+00	3.68765E+00	3.73920E+00	3.78797E+00
3.83408E+00	3.87763E+00	3.91875E+00	3.95754E+00	3.99412E+00
4.02859E+00				

DITTO BUT FROM LOWER CASCADE

0.0	6.85158E-06	2.34058E-03	2.91023E-02	1.25336E-01
3.32945E-01	6.78775E-01	1.17610E+00	1.82890E+00	2.63543E+00
3.59057E+00	4.68736E+00	5.91560E+00	7.24494E+00	8.62201E+00
9.99687E+00	1.13349E+01	1.26153E+01	1.38272E+01	1.49658E+01
1.60300E+01	1.70210E+01	1.79415E+01	1.87948E+01	1.95845E+01
2.03146E+01	2.09889E+01	2.16113E+01	2.21854E+01	2.27147E+01
2.32026E+01	2.36521E+01	2.40661E+01	2.44474E+01	2.47985E+01
2.51218E+01	2.54194E+01	2.56934E+01	2.59456E+01	2.61777E+01
2.63914E+01	2.65880E+01	2.67690E+01	2.69355E+01	2.70888E+01
2.72298E+01	2.73596E+01	2.74791E+01	2.75890E+01	2.76902E+01
2.77833E+01	2.78689E+01	2.79478E+01	2.80203E+01	2.80870E+01
2.81485E+01	2.82050E+01	2.82570E+01	2.83048E+01	2.83489E+01
2.83895E+01				

CONCENTRATION (-)

0.0	7.14356E-03	7.23220E-03	7.42996E-03	7.83654E-03
8.60474E-03	9.98036E-03	1.23705E-02	1.64181E-02	2.30486E-02
3.34599E-02	4.88886E-02	6.98858E-02	9.66529E-02	1.30350E-01
1.72544E-01	2.22907E-01	2.77372E-01	3.28454E-01	3.64465E-01
3.67772E-01	3.58379E-01	3.46147E-01	3.32608E-01	3.18260E-01
3.03999E-01	2.90503E-01	2.78248E-01	2.67334E-01	2.57400E-01
2.48492E-01	2.40722E-01	2.33719E-01	2.27205E-01	2.21125E-01
2.15456E-01	2.10171E-01	2.05251E-01	2.00673E-01	1.96416E-01
1.92460E-01	1.88787E-01	1.85379E-01	1.82218E-01	1.79288E-01
1.76574E-01	1.74060E-01	1.71735E-01	1.69583E-01	1.67593E-01
1.65754E-01	1.64056E-01	1.62488E-01	1.61043E-01	1.59710E-01
1.58482E-01	1.57352E-01	1.56312E-01	1.55357E-01	1.54479E-01
1.53674E-01				

DITTO BUT FROM LOWER CASCADE

0.0	7.19676E-03	7.54528E-03	8.50139E-03	1.05983E-02
1.46719E-02	2.18098E-02	3.26341E-02	4.61776E-02	5.86902E-02
6.19196E-02	5.98842E-02	5.71254E-02	5.41045E-02	5.13051E-02
4.89830E-02	4.70423E-02	4.54675E-02	4.41627E-02	4.29974E-02
4.19496E-02	4.10084E-02	4.01637E-02	3.94065E-02	3.87281E-02
3.81206E-02	3.75768E-02	3.70903E-02	3.66551E-02	3.62662E-02
3.59188E-02	3.56087E-02	3.53320E-02	3.50855E-02	3.48661E-02
3.46709E-02	3.44976E-02	3.43438E-02	3.42076E-02	3.40873E-02
3.39811E-02	3.38876E-02	3.38056E-02	3.37338E-02	3.36711E-02
3.36166E-02	3.35695E-02	3.35289E-02	3.34940E-02	3.34644E-02
3.34393E-02	3.34183E-02	3.34010E-02	3.33868E-02	3.33755E-02
3.33665E-02	3.33598E-02	3.33550E-02	3.33518E-02	3.33500E-02
3.33495E-02				

Fig. A.2 (Continued)

```
ACCUMULATED PRODUCT (GR-U)
 0.0         3.42062E-17 2.42960E-10 3.21482E-07 2.25087E-05
 3.89354E-04 3.08003E-03 1.50011E-02 5.28922E-02 1.48617E-01
 3.53627E-01 7.41927E-01 1.41142E+00 2.48393E+00 4.10411E+00
 6.43721E+00 9.66558E+00 1.39827E+01 1.95856E+01 2.66673E+01
 3.54105E+01 4.59808E+01 5.85246E+01 7.31661E+01 9.00078E+01
 1.09130E+02 1.30592E+02 1.54435E+02 1.80680E+02 2.09335E+02
 2.40390E+02 2.73819E+02 3.09593E+02 3.47675E+02 3.88018E+02
 4.30566E+02 4.75260E+02 5.22036E+02 5.70826E+02 6.21561E+02
 6.74169E+02 7.28579E+02 7.84717E+02 8.42512E+02 9.01892E+02
 9.62786E+02 1.02512E+03 1.08884E+03 1.15387E+03 1.22014E+03
 1.28759E+03 1.35617E+03 1.42581E+03 1.49645E+03 1.56806E+03
 1.64056E+03 1.71392E+03 1.78808E+03 1.86300E+03 1.93864E+03
 2.01495E+03

DITTO BUT FROM LOWER CASCADE
 0.0         1.21708E-05 1.07967E-02 2.40805E-01 1.57184E+00
 5.74876E+00 1.51731E+01 3.26196E+01 6.10209E+01 1.03325E+02
 1.62412E+02 2.41045E+02 3.41824E+02 4.67013E+02 6.18041E+02
 7.95315E+02 9.98436E+02 1.22648E+03 1.47825E+03 1.75237E+03
 2.04744E+03 2.36204E+03 2.69483E+03 3.04447E+03 3.40973E+03
 3.78943E+03 4.18245E+03 4.58764E+03 5.00421E+03 5.43127E+03
 5.86799E+03 6.31362E+03 6.76746E+03 7.22886E+03 7.69723E+03
 8.17200E+03 8.65266E+03 9.13876E+03 9.62986E+03 1.01256E+04
 1.06255E+04 1.11293E+04 1.16368E+04 1.21475E+04 1.26613E+04
 1.31778E+04 1.36970E+04 1.42185E+04 1.47422E+04 1.52679E+04
 1.57954E+04 1.63247E+04 1.68555E+04 1.73877E+04 1.79212E+04
 1.84560E+04 1.89919E+04 1.95289E+04 2.00668E+04 2.06055E+04
 2.11451E+04

AVERAGE CONCENTRATION (-)
 0.0         7.14172E-03 7.22126E-03 7.38781E-03 7.71203E-03
 8.29412E-03 9.28404E-03 1.09161E-02 1.35468E-02 1.76821E-02
 2.39763E-02 3.31742E-02 4.58589E-02 6.22729E-02 8.27361E-02
 1.07886E-01 1.38215E-01 1.73216E-01 2.10890E-01 2.47670E-01
 2.77532E-01 2.97240E-01 3.09014E-01 3.15051E-01 3.16953E-01
 3.15882E-01 3.12772E-01 3.08340E-01 3.03139E-01 2.97528E-01
 2.91740E-01 2.85970E-01 2.80329E-01 2.74862E-01 2.69586E-01
 2.64513E-01 2.59648E-01 2.54991E-01 2.50541E-01 2.46295E-01
 2.42246E-01 2.38390E-01 2.34718E-01 2.31224E-01 2.27900E-01
 2.24738E-01 2.21732E-01 2.18874E-01 2.16156E-01 2.13569E-01
 2.11103E-01 2.08759E-01 2.06528E-01 2.04408E-01 2.02390E-01
 2.00470E-01 1.98642E-01 1.96902E-01 1.95244E-01 1.93664E-01
 1.92160E-01

DITTO BUT FROM LOWER CASCADE
 0.0         7.18482E-03 7.44830E-03 8.10397E-03 9.43690E-03
 1.18578E-02 1.59197E-02 2.20968E-02 3.03589E-02 3.97206E-02
 4.76114E-02 5.19612E-02 5.38819E-02 5.43287E-02 5.39104E-02
 5.30527E-02 5.20156E-02 5.09346E-02 4.98868E-02 4.88964E-02
 4.79677E-02 4.71010E-02 4.62944E-02 4.55452E-02 4.48499E-02
 4.42050E-02 4.36071E-02 4.30537E-02 4.25399E-02 4.20625E-02
 4.16189E-02 4.12058E-02 4.08200E-02 4.04609E-02 4.01262E-02
 3.98141E-02 3.95228E-02 3.92506E-02 3.89962E-02 3.87582E-02
 3.85353E-02 3.83264E-02 3.81305E-02 3.79466E-02 3.77739E-02
 3.76116E-02 3.74588E-02 3.73149E-02 3.71795E-02 3.70517E-02
 3.69310E-02 3.68172E-02 3.67096E-02 3.66076E-02 3.65114E-02
 3.64200E-02 3.63335E-02 3.62514E-02 3.61734E-02 3.60993E-02
 3.60289E-02
```

Fig. A.2 (Continued)

Appendix B Source List of Revised CCS-II Code

The revised CCS-II code has been programmed in FORTRAN 77. It consists of the main routine, block data and 18 subroutines and the source list of these subroutines is given in an alphabetical order of their names at the following pages. Outline of these is as follows:

Main routine: calls five subroutines, CLEAR, PCARD, CLEAR1, INPUTX and CALX, and repeats calculations until the end is detected in an array of input data.

BLOCK DATA: sets up characters for output.

ALIST: prints L' and N' of the top stage and P and N_P for every print-out point.

AVERAG: calculates cascade characteristics such as the average concentration and the separative work.

CALLD: calculates L' and then L" and L.

CALND: calls one subroutine, INTERG, and calculates N' and then N" and N.

CALPRE: calls two subroutines, ZEROO and INTERG, and calculates N" for a side stream or for a tail recycle.

CALX: calls eleven subroutines, INITL, ALIST, INTCUT, CALPRE, INTERZ, CALLD, CALND, SUM, OUTPUT, MOVE and AVERAG, and controls time steps.

CLEAR: has one entry, CLEAR1, calls two subroutines, NINE1 and ZEROO, and carries out the zero clear or the initial setting.

INITL: gives the initial values to L' and N'.

INPUTX: reads input data from the unit one, prints them and defines basic parameters.

INTCUT: interpolates a cut on the basis of given data.

INTERG: interpolates a variable on the basis of given data and is exclusively used for the separation factor.

INTERY: interpolates two variables on the basis of given data.

INTERZ: calls two subroutines, ZEROO and INTERY, and interpolates F_0, N_F, f', n', f", n", p' and p" and/or determines the path and the rate of a recycle flow on the basis of given data.

MOVE: preserves the latest L' and N' for the next time step calculation as the previous data.

OUTPUT: prints accumulated amounts of the product, tail and the feed and N, L, N', L', N", L", dN'/dt, dL'/dt, d^2N'/dt^2 and d^2L'/dt^2 over all stages for every print-out point.

PCARD: reads input data from the unit five and writes them on the unit one and also prints them.

SUM: sums up L, L' and L" over stages.

ZEROO: has one entry, NINE1, and gives zero or 999 to a variable.

Source list of the revised CCS-II code is given for each routine as follows:

```
 ----------------------------
| File Name : ccslc.f        |
|      Size :    59951 bytes |
|      Date : 91-11-19 12:19 |
 ----------------------------
```

Source Listing - V. 4.0 < MAIN : ccslc.f > Tue Nov 19 12:56:27 1991 Page 0001

```
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
C     PROGRAM CCS-II, REV.1 (1991-06-18)
C     CENTRIFUGE CASCADE SIMULATION CODE II
C     WHICH CAN HANDLE HIERARCHICAL CASCADES AS WELL AS NORMAL ONES
C
      CALL CLEAR
      CALL PCARD
  100 CALL CLEAR1
      CALL INPUTX(KEND)
      IF(KEND.NE.0) GO TO 200
      CALL CALX
      GO TO 100
  200 STOP
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

Source Listing - V. 4.0 < BLOCK DATA : ccslc.f > Tue Nov 19 12:56:27 1991 Page 0002

```
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      BLOCK DATA
C
      COMMON/COM7/ KPRNL(3),KPRNF(3),KPRNP(3),KPRNN(3)
      CHARACTER*4 KPRNL,KPRNF,KPRNP,KPRNN
C
      DATA KPRNN/'N','N*','N**'/,KPRNL/'L','L*','L**'/
      DATA KPRNF/'F','F*','F**'/,KPRNP/'P','P*','P**'/
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

Source Listing - V. 4.0 < ALIST : ccslc.f > Tue Nov 19 12:56:27 1991 Page 0003

```
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE ALIST(N)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X              ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X              ,XLIMIT(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X             ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      DIMENSION PL(2000,2),PN(2000,2),APL(2000,2),APN(2000,2)
C
      ID=2000
      IF(N.NE.0) GO TO 100
      NPN=0
      RETURN
  100 IF(N.NE.1) GO TO 300
      IF(KCALX(7).EQ.0) GO TO 250
      IF(NTIME.NE.NSTOP+1) GO TO 250
      DO 200 M=1,2
      IF(M.EQ.1) ISB=IS3
      IF(M.EQ.2) ISB=IB3
      DO 150 J=1,ISB
      XLDI(J,M)=XLD(J,M)
      XNDI(J,M)=XND(J,M)
  150 CONTINUE
  200 CONTINUE
  250 NPN=NPN+1
      IF(NPN.GT.ID) RETURN
      PL(NPN,1)=XLD(IS3,1)
      PL(NPN,2)=XLD(IS1,1)
      PN(NPN,1)=XND(IS3,1)
      PN(NPN,2)=XND(IS1,1)
      APL(NPN,1)=TPL(1)
      APL(NPN,2)=TPL(2)
      APN(NPN,1)=0.0
      APN(NPN,2)=0.0
      IF(TPL(1).NE.0.0) APN(NPN,1)=TPLN(1)/TPL(1)
      IF(TPL(2).NE.0.0) APN(NPN,2)=TPLN(2)/TPL(2)
      RETURN
  300 IF(NPN.GT.ID) NPN=ID
      WRITE(6,6000) INTVLP
      WRITE(6,6010) (PL(I,1),I=1,NPN)
      IF(KCALX(1).NE.0)
     *WRITE(6,6030) (PL(I,2),I=1,NPN)
      WRITE(6,6020) (PN(I,1),I=1,NPN)
      IF(KCALX(1).NE.0)
     *WRITE(6,6030) (PN(I,2),I=1,NPN)
      WRITE(6,6040) (APL(I,1),I=1,NPN)
      IF(KCALX(1).NE.0)
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
     *WRITE(6,6030) (APL(I,2),I=1,NPN)
      WRITE(6,6050) (APN(I,1),I=1,NPN)
      IF(KCALX(1).NE.0)
     *WRITE(6,6030) (APN(I,2),I=1,NPN)
      RETURN
 6000 FORMAT(1H1,'PRODUCT FLOW AND CONCENTRATION FOR EVERY',I8,
     *         ' * DELTA-T')
 6010 FORMAT(/1X,'FLOW (TON-U/YR)'/(1X,1P5E12.5))
 6020 FORMAT(/1X,'CONCENTRATION (-)'/(1X,1P5E12.5))
 6030 FORMAT(/1X,'DITTO BUT FROM LOWER CASCADE'/(1X,1P5E12.5))
 6040 FORMAT(/1X,'ACCUMULATED PRODUCT (GR-U)'/(1X,1P5E12.5))
 6050 FORMAT(/1X,'AVERAGE CONCENTRATION (-)'/(1X,1P5E12.5))
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE AVERAG
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X            ,FEED(50),CUT(200,2),XNF(50)
     X            ,SND(200,2),SNDD(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X            ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X            ,SPNDD(200,2),SUMFN
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
C
      STFCT(ZL,ZN)=ZL*(2.*ZN-1.)*ALOG(ZN/(1.-ZN))
C
      XLDD1=XLDD(IB,2)-SPDD(IB,2)+SFDD(IB,2)
      IF(KCALX(1).EQ.1.OR.KCALX(1).LT.0)
     *XLDD1=XLDD1+XLDD(IB3,2)-SPDD(IB3,2)+SFDD(IB3,2)
      XLNDD1=XLDD(IB,2)*XNDD(IB,2)-SPNDD(IB,2)+SFNDD(IB,2)
      IF(KCALX(1).EQ.1.OR.KCALX(1).LT.0)
     *XLNDD1=XLNDD1+XLDD(IB3,2)*XNDD(IB3,2)-SPNDD(IB3,2)+SFNDD(IB3,2)
C
      IF(NTIME.EQ.1) GO TO 100
      TEMP1=XLD(IS3,1)-SPD(IS3,1)+SFD(IS3,1)
      TEMP2=XLD(IS1,1)-SPD(IS1,1)+SFD(IS1,1)
      TPL(1)=TPL(1)+TEMP1*NDELT*UNIT
      TPL(2)=TPL(2)+TEMP2*NDELT*UNIT
      TWL=TWL+XLDD1*NDELT*UNIT
      TFL=TFL+SUMF*UNIT*NDELT
      TEMP1=XLD(IS3,1)*XND(IS3,1)-SPND(IS3,1)+SFND(IS3,1)
      TEMP2=XLD(IS1,1)*XND(IS1,1)-SPND(IS1,1)+SFND(IS1,1)
      TPLN(1)=TPLN(1)+TEMP1*NDELT*UNIT
      TPLN(2)=TPLN(2)+TEMP2*NDELT*UNIT
      TWLN=TWLN+XLNDD1*NDELT*UNIT
      TFLN=TFLN+SUMFN*NDELT*UNIT
      IF(TFL.NE.0.0) ANF=TFLN/TFL
      IF(TPL(1).NE.0.0) ANP=TPLN(1)/TPL(1)
      IF(TWL.NE.0.0) ANW=TWLN/TWL
C
  100 DUT=99999.
      XNDD1=0.0
      IF(XLDD1.NE.0.0) XNDD1=XLNDD1/XLDD1
      ANF1=0.0
      IF(SUMF.NE.0.0) ANF1=SUMFN/SUMF
      IF(XND(IS3,1).LE.0.) RETURN
      IF(XND(IS3,1).GE.1.) RETURN
      IF(XNDD1.LE.0.) RETURN
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
000155        IF(XNDD1.GE.1.) RETURN
000156        IF(ANF1.LE.0.) RETURN
000157        IF(ANF1.GE.1.) RETURN
000158        DUT1=STFCT(XLD(IS3,1),XND(IS3,1))
000159        DUT2=STFCT(XLDD1,XNDD1)
000160        DUT3=STFCT(SUMF,ANF1)
000161        DUT=DUT1+DUT2-DUT3
000162        RETURN
000163        END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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```
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE CALLD(II1,II2,IJ1,IJ2,SUMX,UINV)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X              ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X              ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X             ,FEED(50),CUT(200,2),XNF(50)
     X             ,SND(200,2),SNDD(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X             ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
C
      SUMQ=0.0
      SUMDD=0.0
      SUMD=0.0
C
      DO 200 M=1,2
      IF(M.NE.1) GO TO 100
C  J=0,1,2,3,...,S
      ISB=IS1
      GO TO 110
C  J=-1,-2,-3,...,-B
  100 ISB=IB
  110 DO 190 JJ=1,ISB
      ZZ=0.0
      IF(M.NE.1) GO TO 140
      J=II2-JJ+1
      IF(JJ.EQ.ISB) GO TO 120
      J1=J-1
      GO TO 150
  120 ZZ=ZZ+SUMX*NDELT
      ZZ=ZZ+XLD(IJ1,2)*NDELT
      SUMD=SUMD+(SFD(IJ1,2)-SPD(IJ1,2))
      GO TO 170
  140 ZZ=ZZ+SUMX*NDELT
      J=JJ+IJ1-1
      IF(JJ.EQ.ISB) GO TO 170
      J1=J+1
  150 ZZ=ZZ+XLD(J1,M)*NDELT
      SUMD=SUMD+(SFD(J1,M)-SPD(J1,M))
  170 ZZ=ZZ+(-XLD(II2,1)-XLD(J,M)*(1./CUT(J,M)-1.)+SUMD
     X     +SUMDD)*NDELT
      QCONT0=JHD(J,M)-JHDD(J,M)+(JH(J,M)+JHDD(J,M))/CUT(J,M)
      QCONT1=QCONT0
      IF(MODEL.GE.0)
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
     *QCONT1=QCONT1+(JHD(J,M)-JHDD(J,M))*(1.0/CUT(J,M)-1.0)
      YLD(J,M)=XLD(J,M)+(ZZ-SUMQ)/QCONT1
      IF(YLD(J,M).LT.0.0) YLD(J,M)=0.0
      IF(M.EQ.2.AND.JJ.EQ.IB) GO TO 190
      SUMDD=SUMDD+(SFDD(J,M)-SPDD(J,M))
      SUMQ=SUMQ+QCONT0*(YLD(J,M)-XLD(J,M))
  190 CONTINUE
  200 CONTINUE
C
C  L, LDD, DERIVATIVES
C
      DO 300 M=1,2
      IF(M.NE.1) GO TO 210
      ISB0=II1
      ISB1=II2
      GO TO 220
  210 ISB0=IJ1
      ISB1=IJ2
  220 DO 250 J=ISB0,ISB1
      XL(J,M)=XLD(J,M)/CUT(J,M)
      XLDD(J,M)=(1./CUT(J,M)-1.)*XLD(J,M)
      IF(MODEL.GE.0) XLDD(J,M)=XLDD(J,M)+
     *(JHD(J,M)-JHDD(J,M))*(1./CUT(J,M)-1.)*(YLD(J,M)-XLD(J,M))/NDELT
      IF(XLD(J,M).EQ.0.0) GO TO 250
      TEMP1=JH(J,M)+JHD(J,M)
      TEMP2=TEMP1*TEMP1/2.0
      DLD(J,M)=TEMP1*(YLD(J,M)-WLD(J,M))/2.0/NDELT/XLD(J,M)
      DDLD(J,M)=(YLD(J,M)-2.0*XLD(J,M)+WLD(J,M))/NDELT**2/XLD(J,M)
     **TEMP2
  250 CONTINUE
  300 CONTINUE
      IF(MODEL.LT.0) GO TO 500
      J=II2
      J1=J-1
      TEMP1=SFD(J1,1)-SPD(J1,1)
      XL(J,1)=XLD(J1,1)+TEMP1
      DO 420 JJ=2,IS
      J=JJ+II1-1
      J1=J-1
      J2=J+1
      TEMP1=SFD(J1,1)-SPD(J1,1)+SFDD(J2,1)-SPDD(J2,1)
      XL(J,1)=XLD(J1,1)+XLDD(J2,1)+TEMP1
  420 CONTINUE
      J=II1
      J1=IJ1
      J2=J+1
      TEMP1=SFD(J1,2)-SPD(J1,2)+SFDD(J2,1)-SPDD(J2,1)
      XL(J,1)=XLD(J1,2)+XLDD(J2,1)+TEMP1+SUMX
      J=IJ1
      J1=II1
      J2=J+1
      TEMP2=SFD(J2,2)-SPD(J2,2)+SFDD(J1,1)-SPDD(J1,1)
      XL(J,2)=XLD(J2,2)+XLDD(J1,1)+TEMP2
      DO 430 JJ=2,IB-1
      J=JJ+IJ1-1
      J1=J-1
      J2=J+1
      TEMP1=SFD(J2,2)-SPD(J2,2)+SFDD(J1,2)-SPDD(J1,2)
      XL(J,2)=XLD(J2,2)+XLDD(J1,2)+TEMP1
  430 CONTINUE
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

```
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
            J=IJ2
            J1=J-1
            TEMP1=SFDD(J1,2)-SPDD(J1,2)
            XL(J,2)=XLDD(J1,2)+TEMP1
      C
      C  FOR INVENTORY AND MATERIAL BALANCE
      C
        500 DO 540 M=1,2
            IF(M.NE.1) GO TO 510
            ISB0=II1
            ISB1=II2
            GO TO 520
        510 ISB0=IJ1
            ISB1=IJ2
        520 DO 530 J=ISB0,ISB1
            UINV=UINV+XL(J,M)*JH(J,M)+XLD(J,M)*JHD(J,M)+XLDD(J,M)*JHDD(J,M)
            IF(MODEL.LT.0) GO TO 530
            UINV=UINV+(JHD(J,M)**2-JHDD(J,M)**2-(JH(J,M)**2-JHDD(J,M)**2)
           */CUT(J,M))*(YLD(J,M)-XLD(J,M))/NDELT/2.0
            SFBAL=SFBAL+(SFD(J,M)-SPD(J,M)+SFDD(J,M)-SPDD(J,M))*NDELT
        530 CONTINUE
        540 CONTINUE
            RETURN
            END
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE CALND(II1,II2,IJ1,IJ2,SUMXN,U5INV)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X              ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X              ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X             ,FEED(50),CUT(200,2),XNF(50)
     X             ,SND(200,2),SNDD(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X             ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X             ,SPNDD(200,2),SUMFN
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X              WLD(200,2),WND(200,2),WLDND(200,2),
     X              DLD(200,2),DND(200,2),DLDND(200,2),
     X              DDLD(200,2),DDND(200,2),DDLDND(200,2)
C
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      SUM5=0.0
      ANUM1=XLDND(II2,1)
C
      DO 200 M=1,2
      IF(M.NE.1) GO TO 100
C  J=0,1,2,3,...,S
      ISB=IS1
      GO TO 101
C  J=-1,-2,-3,...,-B
  100 ISB=IB
  101 DO 190 JJ=1,ISB
      ANUM2=0.0
      IF(M.NE.1) GO TO 115
      J=II2-JJ+1
      IF(JJ.EQ.ISB) GO TO 110
      J1=J-1
      GO TO 116
  110 ANUM2=XLDND(IJ1,2)
      SUM2=SUM2+SFND(IJ1,2)-SPND(IJ1,2)
      GO TO 120
  115 J=JJ+IJ1-1
      IF(JJ.EQ.ISB) GO TO 120
      J1=J+1
  116 ANUM2=XLDND(J1,M)
      SUM2=SUM2+(SFND(J1,M)-SPND(J1,M))
  120 DS2=SUM2*NDELT
      DS3=SUM3*NDELT
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      IF(XLD(J,M).NE.0.0) GO TO 130
      NCOUNT(J,M)=0
      GO TO 170
  130 NCOUNT(J,M)=NCOUNT(J,M)+1
      IF(NCOUNT(J,M).LT.KCALX(3)) GO TO 170
      IF(XL(J,M).GT.XLIMIT(J,M)) GO TO 140
      IF(KCALX(2).EQ.0) GO TO 170
C  ND
  140 RL=XL(J,M)/XLOPT(J,M)
      CALL INTERG(RLOPTI,GAMI,RL,MAXG,GAM0,DGMDRL)
      IF(KCALX(5).EQ.0) GO TO 145
      NTIME0=NTIME-1
      IF(NTIME0.LE.KCALX(5)) GO TO 145
      IF(NTIME0.GE.KCALX(6)) GO TO 144
      GAM0=(GAM0-1.0)*(KCALX(6)-NTIME0)/(KCALX(6)-KCALX(5))+1.0
      DGMDRL=DGMDRL*(KCALX(6)-NTIME0)/(KCALX(6)-KCALX(5))
      GO TO 145
  144 GAM0=1.0
      DGMDRL=0.0
  145 IF(XL(J,M).GT.XLIMIT(J,M)) GO TO 150
      IF(XLIMIT(J,M).EQ.0.0) GO TO 150
      GAM0=(GAM0-1.0)*XL(J,M)/XLIMIT(J,M)+1.0
  150 DENO=GAM0*(1.0-XND(J,M))+XND(J,M)
      G0=XND(J,M)/DENO
      ZK0=GAM0/(DENO*DENO)
      TEMP1=(JH(J,M)+JHDD(J,M))*(1.0/CUT(J,M)-1.0)*ZK0
      TEMP2=JH(J,M)+JHD(J,M)
      Q0=(TEMP1+TEMP2)*XLD(J,M)
      TEMP1=(JH(J,M)+JHD(J,M))*XND(J,M)
      TEMP2=(JH(J,M)+JHDD(J,M))*(1.0/CUT(J,M)-1.0)*G0
      TCONT0=TEMP1+TEMP2
      IF(MODEL.NE.1) GO TO 160
      TEMP1=DGMDRL/CUT(J,M)/XLOPT(J,M)*(YLD(J,M)-XLD(J,M))/NDELT
      IF(XL(J,M).LE.XLIMIT(J,M).AND.XL(J,M).NE.0.)
     *TEMP1=TEMP1*XL(J,M)/XLIMIT(J,M)+(GAM0-1.0)/XL(J,M)/CUT(J,M)
     **(YLD(J,M)-XLD(J,M))/NDELT
      DENO1=(GAM0-(JH(J,M)+JHD(J,M))*TEMP1)
     **(1.0-XND(J,M))+XND(J,M)
      G10=XND(J,M)/DENO1
      C0=XND(J,M)*(1.0-XND(J,M))/(DENO*DENO)*TEMP1
C
  160 IF(MODEL.NE.1) ANUM3=XLDD(J,M)*G0
      IF(MODEL.EQ.1)
     *ANUM3=XLDD(J,M)*(G10-(JHD(J,M)-JHDD(J,M))*C0)
      ANUM=(-ANUM1+ANUM2-ANUM3)*NDELT
      IF(M.EQ.1.AND.JJ.EQ.ISB) ANUM=ANUM+SUMXN*NDELT
      IF(M.EQ.2) ANUM=ANUM+SUMXN*NDELT
      DENO=Q0
      IF(MODEL.GE.0) DENO=DENO+
     *(JHD(J,M)-JHDD(J,M))*(1./CUT(J,M)-1.)*ZK0*XLD(J,M)
      SUM4=SUM4+TCONT0*(YLD(J,M)-XLD(J,M))
      IF(MODEL.EQ.1)
     *SUM5=SUM5+(JH(J,M)+JHDD(J,M))*(1./CUT(J,M)-1.)*XLD(J,M)*C0
      YND(J,M)=0.0
      IF(DENO.NE.0.)
     *YND(J,M)=XND(J,M)+(ANUM-SUM1-SUM4+SUM5+DS2+DS3)/DENO
      IF(YND(J,M).LT.0.0) YND(J,M)=0.
      IF(YND(J,M).GT.1.0) YND(J,M)=1.
      YLDND(J,M)=YLD(J,M)*YND(J,M)
      SUM1=SUM1+Q0*(YND(J,M)-XND(J,M))
....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
C  INVENTORY
      IF(MODEL.LT.0) GO TO 165
      TEMP1=(JH(J,M)**2-JHD(J,M)**2)/2.0
      TEMP2=(JH(J,M)**2-JHDD(J,M)**2)*(1.0/CUT(J,M)-1.0)/2.0
      U5INV=U5INV
     *-(TEMP1*XND(J,M)+TEMP2*G0)*(YLD(J,M)-XLD(J,M))/NDELT
     *-(TEMP1+TEMP2*ZK0)*XLD(J,M)*(YND(J,M)-XND(J,M))/NDELT
      IF(MODEL.EQ.1) U5INV=U5INV+TEMP2*XLD(J,M)*C0
C  NDD
  165 XNDD(J,M)=G0
      IF(MODEL.EQ.0) XNDD(J,M)=XNDD(J,M)+
     *(JHD(J,M)-JHDD(J,M))*ZK0*(YND(J,M)-XND(J,M))/NDELT
      IF(MODEL.EQ.1) XNDD(J,M)=G10+
     *(JHD(J,M)-JHDD(J,M))*(ZK0*(YND(J,M)-XND(J,M))/NDELT-C0)
      IF(XNDD(J,M).LT.0.) XNDD(J,M)=0.
      IF(XNDD(J,M).GT.1.) XNDD(J,M)=1.
C  N
      TEMP1=CUT(J,M)*XND(J,M)
      TEMP2=(1.0-CUT(J,M))*G0
      XN(J,M)=TEMP1+TEMP2
      IF(XN(J,M).LT.0.) XN(J,M)=0.
      IF(XN(J,M).GT.1.) XN(J,M)=1.
      GO TO 180
C  ND
  170 QCONT0=JHD(J,M)-JHDD(J,M)+(JH(J,M)+JHDD(J,M))/CUT(J,M)
      DENO=QCONT0
      IF(MODEL.GE.0) DENO=DENO+(JHD(J,M)-JHDD(J,M))*(1./CUT(J,M)-1.)
      ANUM3=XLDND(J,M)*(1./CUT(J,M)-1.)
      ANUM=(-ANUM1+ANUM2-ANUM3)*NDELT
      IF(M.EQ.1.AND.JJ.EQ.ISB) ANUM=ANUM+SUMXN*NDELT
      IF(M.EQ.2) ANUM=ANUM+SUMXN*NDELT
      YND(J,M)=0.0
      IF(YLD(J,M).NE.0.0)
     *YND(J,M)=(XLDND(J,M)+(ANUM-SUM1+DS2+DS3)/DENO)/YLD(J,M)
      IF(YND(J,M).LT.0.) YND(J,M)=0.
      IF(YND(J,M).GT.1.) YND(J,M)=1.
      YLDND(J,M)=YLD(J,M)*YND(J,M)
      SUM1=SUM1+QCONT0*(YLDND(J,M)-XLDND(J,M))
C  INVENTORY
      IF(MODEL.LT.0) GO TO 175
      TEMP1=(JH(J,M)**2-JHD(J,M)**2)/2.0
      TEMP2=(JH(J,M)**2-JHDD(J,M)**2)*(1.0/CUT(J,M)-1.0)/2.0
      U5INV=U5INV-(TEMP1+TEMP2)*(YLDND(J,M)-XLDND(J,M))/NDELT
C  NDD
  175 XNDD(J,M)=XND(J,M)
      IF(MODEL.GE.0) XNDD(J,M)=XNDD(J,M)+
     *(JHD(J,M)-JHDD(J,M))*(YND(J,M)-XND(J,M))/NDELT
      IF(XNDD(J,M).LT.0.) XNDD(J,M)=0.
      IF(XNDD(J,M).GT.1.) XNDD(J,M)=1.
C  N
      XN(J,M)=XND(J,M)
C
  180 SUM3=SUM3+(SFNDD(J,M)-SPNDD(J,M))
  190 CONTINUE
  200 CONTINUE
C
C  DERIVATIVES
C
      DO 300 M=1,2
      IF(M.NE.1) GO TO 210
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      ISB0=II1
      ISB1=II2
      GO TO 220
  210 ISB0=IJ1
      ISB1=IJ2
  220 DO 250 J=ISB0,ISB1
      TEMP1=JH(J,M)+JHD(J,M)
      TEMP2=TEMP1*TEMP1/2.0
      IF(XND(J,M).EQ.0.0) GO TO 230
      DND(J,M)=TEMP1*(YND(J,M)-WND(J,M))/2.0/NDELT/XND(J,M)
      DDND(J,M)=(YND(J,M)-2.0*XND(J,M)+WND(J,M))/NDELT**2/XND(J,M)
     **TEMP2
  230 IF(XLDND(J,M).EQ.0.0) GO TO 250
      DLDND(J,M)=TEMP1*(YLDND(J,M)-WLDND(J,M))/2.0/NDELT/XLDND(J,M)
      DDLDND(J,M)=(YLDND(J,M)-2.0*XLDND(J,M)+WLDND(J,M))/NDELT**2
     */XLDND(J,M)*TEMP2
  250 CONTINUE
  300 CONTINUE
C
      IF(MODEL.LT.0) GO TO 500
C  N
      J=II2
      J1=J-1
      TEMP1=SFND(J1,1)-SPND(J1,1)
      IF(XL(J,1).NE.0.)
     *XN(J,1)=(XLDND(J1,1)+TEMP1)/XL(J,1)
      DO 420 JJ=2,IS
      J=JJ+II1-1
      J1=J-1
      J2=J+1
      TEMP1=SFND(J1,1)-SPND(J1,1)+SFNDD(J2,1)-SPNDD(J2,1)
      IF(XL(J,1).NE.0.)
     *XN(J,1)=(XLDND(J1,1)+XLDD(J2,1)*XNDD(J2,1)+TEMP1)/XL(J,1)
  420 CONTINUE
      J=II1
      J1=IJ1
      J2=J+1
      TEMP1=SFND(J1,2)-SPND(J1,2)+SFNDD(J2,1)-SPNDD(J2,1)
      IF(XL(J,1).NE.0.)
     *XN(J,1)=(XLDND(J1,2)+XLDD(J2,1)*XNDD(J2,1)+TEMP1+SUMXN)/XL(J,1)
      J=IJ1
      J1=II1
      J2=J+1
      TEMP2=SFND(J2,2)-SPND(J2,2)+SFNDD(J1,1)-SPNDD(J1,1)
      IF(XL(J,2).NE.0.)
     *XN(J,2)=(XLDND(J2,2)+XLDD(J1,1)*XNDD(J1,1)+TEMP2)/XL(J,2)
      DO 430 JJ=2,IB-1
      J=JJ+IJ1-1
      J1=J-1
      J2=J+1
      TEMP1=SFND(J2,2)-SPND(J2,2)+SFNDD(J1,2)-SPNDD(J1,2)
      IF(XL(J,2).NE.0.)
     *XN(J,2)=(XLDND(J2,2)+XLDD(J1,2)*XNDD(J1,2)+TEMP1)/XL(J,2)
  430 CONTINUE
      J=IJ2
      J1=J-1
      TEMP1=SFNDD(J1,2)-SPNDD(J1,2)
      IF(XL(J,2).NE.0.)
     *XN(J,2)=(XLDD(J1,2)*XNDD(J1,2)+TEMP1)/XL(J,2)
C
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
C  FOR INVENTORY AND MATERIAL BALANCE
C
   500 DO 540 M=1,2
       IF(M.NE.1) GO TO 510
       ISB0=II1
       ISB1=II2
       GO TO 520
   510 ISB0=IJ1
       ISB1=IJ2
   520 DO 530 J=ISB0,ISB1
       U5INV=U5INV+XL(J,M)*XN(J,M)*JH(J,M)+XLD(J,M)*XND(J,M)*JHD(J,M)
      *           +XLDD(J,M)*XNDD(J,M)*JHDD(J,M)
       SFNBAL=SFNBAL+(SFND(J,M)-SPND(J,M)+SFNDD(J,M)-SPNDD(J,M))*NDELT
   530 CONTINUE
   540 CONTINUE
       RETURN
       END
....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE CALPRE
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X            ,FEED(50),CUT(200,2),XNF(50)
     X            ,SND(200,2),SNDD(200,2)
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM9/ XLDD0(200,2),XNDD0(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
C
      CALL ZERO0(XLDD0,800)
      IF (NSPDD.NE.0) GO TO 100
      IF (MAXFXD.NE.0) GO TO 100
      IF (KCALX(1).GE.2) GO TO 100
      IF (KCALX(4).EQ.1) GO TO 100
      RETURN
C  PRELIMINARY CALCULATION OF L** AND N** FOR REMOVAL FLOW
  100 DO 200 M=1,2
      IF(M.NE.1) GO TO 110
      ISB=IS3
      GO TO 115
  110 ISB=IB3
  115 DO 150 J=1,ISB
C  L**
      XLDD0(J,M)=(1./CUT(J,M)-1.)*XLD(J,M)
      IF(MODEL.GE.0) XLDD0(J,M)=XLDD0(J,M)+
     *(JHD(J,M)-JHDD(J,M))*(1./CUT(J,M)-1.)*(XLD(J,M)-WLD(J,M))/NDELT
C  N**
      TEMP1=(JH(J,M)+JHD(J,M))/CUT(J,M)
      XL0=XLD(J,M)/CUT(J,M)
      IF(MODEL.GE.0)
     *XL0=XL0+TEMP1*(XLD(J,M)-WLD(J,M))/NDELT
      RL=XL0/XLOPT(J,M)
      CALL INTERG(RLOPTI,GAMI,RL,MAXG,GAM0,DGMDRL)
      IF(KCALX(5).EQ.0) GO TO 119
      NTIME0=NTIME-1
      IF(NTIME0.LE.KCALX(5)) GO TO 119
      IF(NTIME0.GE.KCALX(6)) GO TO 118
      GAM0=(GAM0-1.0)*(KCALX(6)-NTIME0)/(KCALX(6)-KCALX(5))+1.0
      DGMDRL=DGMDRL*(KCALX(6)-NTIME0)/(KCALX(6)-KCALX(5))
      GO TO 119
  118 GAM0=1.0
      DGMDRL=0.0
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
  119 IF(XLO.GT.XLIMIT(J,M)) GO TO 120
      IF(XLIMIT(J,M).EQ.0.0) GO TO 120
      GAM0=(GAM0-1.0)*XLO/XLIMIT(J,M)+1.0
  120 DENO=GAM0*(1.0-XND(J,M))+XND(J,M)
      G0=XND(J,M)/DENO
      ZK0=GAM0/(DENO*DENO)
      IF(XLO.GT.XLIMIT(J,M)) GO TO 130
      IF(KCALX(2).EQ.0) GO TO 140
  130 IF(MODEL.NE.1) GO TO 135
      TEMP1=DGMDRL/CUT(J,M)/XLOPT(J,M)*(XLD(J,M)-WLD(J,M))/NDELT
      IF(XLO.LE.XLIMIT(J,M).AND.XLO.NE.0.)
     *TEMP1=TEMP1*XLO/XLIMIT(J,M)+(GAM0-1.0)/XLO/CUT(J,M)
     **(XLD(J,M)-WLD(J,M))/NDELT
      DENO1=(GAM0-(JH(J,M)+JHD(J,M))*TEMP1)
     **(1.0-XND(J,M))+XND(J,M)
      G10=XND(J,M)/DENO1
      C0=XND(J,M)*(1.0-XND(J,M))/(DENO*DENO)*TEMP1
  135 XNDD0(J,M)=G0
      IF(MODEL.EQ.1) XNDD0(J,M)=G10
      IF(MODEL.GE.0) XNDD0(J,M)=XNDD0(J,M)
     *+(JHD(J,M)-JHDD(J,M))*ZK0*(XND(J,M)-WND(J,M))/NDELT
      IF(MODEL.EQ.1) XNDD0(J,M)=XNDD0(J,M)
     *-(JHD(J,M)-JHDD(J,M))*C0
      GO TO 150
  140 XNDD0(J,M)=XND(J,M)
      IF(MODEL.GE.0) XNDD0(J,M)=XNDD0(J,M)+
     *(JHD(J,M)-JHDD(J,M))*(XND(J,M)-WND(J,M))/NDELT
  150 CONTINUE
  200 CONTINUE
      RETURN
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE CALX
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X              ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X              ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X             ,FEED(50),CUT(200,2),XNF(50)
     X             ,SND(200,2),SNDD(200,2)
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X             ,SPNDD(200,2),SUMFN
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM9/ XLDD0(200,2),XNDD0(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      DIMENSION KPRNT0(7)
C
      NTIME=0
      DO 100 I=1,7
      KPRNT0(I)=KPRINT(I)
  100 CONTINUE
      CALL INITL
      CALL ALIST(0)
C
      DO 200 NTIME=1,NSTOP+1
C
      UINV=0.0
      U5INV=0.0
      CALL INTCUT(NTIME)
      CALL CALPRE
      CALL INTERZ
C  LD FOR LOWER CASCADE
      ICAS=1
      SUMX=SUMF
      IF(KCALX(1).LE.1) GO TO 110
      SUMX=SUMX+XLDD0(IB3,2)
  110 CALL CALLD(1,IS1,1,IB,SUMX,UINV)
      IF(NTIME.EQ.1) UINV0=UINV
      IF(KCALX(1).EQ.0) GO TO 130
C  LD FOR HIGHER CASCADE
      ICAS=2
      SUMX=XLD(IS1,1)
      IF(KCALX(1).GE.0) GO TO 120
      SUMX=-KCALX(1)
      SUMX=SUMF/SUMX
  120 CALL CALLD(IS2,IS3,IB2,IB3,SUMX,UINV)
      IF(NTIME.EQ.1) UINV0=UINV0+UINV
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
C  ND FOR LOWER CASCADE
  130 ICAS=1
      SUMXN=SUMFN
      IF(KCALX(1).GE.2)
     *SUMXN=SUMXN+XLDD(IB3,2)*XNDD0(IB3,2)
      CALL CALND(1,IS1,1,IB,SUMXN,U5INV)
      IF(NTIME.EQ.1) U5INV0=U5INV
      IF(KCALX(1).EQ.0) GO TO 150
C  ND FOR HIGHER CASCADE
      ICAS=2
      SUMXN=XLDND(IS1,1)
      IF(KCALX(1).GE.0) GO TO 140
      SUMXN=-KCALX(1)
      SUMXN=SUMFN/SUMXN
  140 CALL CALND(IS2,IS3,IB2,IB3,SUMXN,U5INV)
      IF(NTIME.EQ.1) U5INV0=U5INV0+U5INV
  150 CALL AVERAG
      CALL SUM(JUMP)
      IF(NTIME.GT.200.AND.JUMP.EQ.1) GO TO 300
      IF(MOD(NTIME-1,INTVLP).NE.0) GO TO 180
      NTIME0=NTIME-1
      KPRNT1=-KPRINT(7)
      IF(KPRINT(7).LT.0.AND.NTIME0.GE.KPRNT1) KPRNT0(7)=1
      NTIME0=NSTOP+1-INTVLP
      IF(NTIME.LE.NTIME0) GO TO 170
      DO 160 I=1,6
      IF(KPRINT(I).LT.0) KPRNT0(I)=-KPRINT(I)
  160 CONTINUE
  170 CALL OUTPUT(KPRNT0,UINV0,UINV,U5INV0,U5INV)
      CALL ALIST(1)
  180 CALL MOVE
  200 CONTINUE
C
      CALL ALIST(2)
      RETURN
C
  300 NTIME0=NTIME-1
      KPRNT1=-KPRINT(7)
      IF(KPRINT(7).LT.0.AND.NTIME0.GE.KPRNT1) KPRNT0(7)=1
      DO 310 I=1,6
      IF(KPRINT(I).LT.0) KPRNT0(I)=-KPRINT(I)
  310 CONTINUE
      CALL OUTPUT(KPRNT0,UINV0,UINV,U5INV0,U5INV)
      WRITE(6,6000)
      CALL ALIST(2)
      RETURN
 6000 FORMAT(/15X,'***** THE UF6 GAS IN CENTRIFUGE CASCADE EMPTIED AT',
     *' THIS TIME *****')
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

Source Listing - V. 4.0   < CLEAR : ccslc.f >   Tue Nov 19 12:56:27 1991   Page 0019

```
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE CLEAR
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X            ,FEED(50),CUT(200,2),XNF(50)
     X            ,SND(200,2),SNDD(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X            ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X            ,SPNDD(200,2),SUMFN
      COMMON/COM7/ KPRNL(3),KPRNF(3),KPRNP(3),KPRNN(3)
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM9/ XLDD0(200,2),XNDD0(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      COMMON/COMA/ EMPTY
      DIMENSION EQ1(1),EQ2(1),EQ3(1),EQ4(1),EQ5(1),EQ6(1),
     X          EQ8(1),EQ9(1),EQ0(1)
      EQUIVALENCE (EQ1,IS),(EQ2,FEEDI),(EQ3,XL),(EQ4,SFD),(EQ5,SUML),
     X            (EQ6,UNIT),(EQ8,XLDND),(EQ9,XLDD0),(EQ0,ICAS)
      CHARACTER*4 KPRNL,KPRNF,KPRNP,KPRNN
C
C   CONDITION OF EMPTY
      EMPTY=1.0E-5
C
      CALL ZERO0(EQ1,106633)
      CALL ZERO0(EQ2,166600)
      CALL ZERO0(EQ3,  3600)
      CALL ZERO0(EQ4,  2900)
      CALL ZERO0(EQ5,    17)
      CALL ZERO0(EQ6,  1602)
      CALL ZERO0(EQ8,  4800)
      CALL ZERO0(EQ9,   800)
      CALL ZERO0(EQ0,     6)
C
C   MODEL= 0: MATERIAL BALANCE AT A MIXING POINT
C        = 1: SAME AS ABOVE, BUT D.GAMMA/D.T .NE. 0
C        =-1: MATERIAL BALANCE AT A STAGE
      MODEL=0
C   KCALX(1)=0: 1-ST STEP CASCADE
C           =1: 1-ST AND 2-ND STEP CASCADES WITHOUT TAIL RECYCLE
C           =2: 1-ST AND 2-ND STEP CASCADES WITH TAIL RECYCLE
      KCALX(1)=0
C   KCALX(2)=0: GAMMA=1 IF L IS LESS THAN L0
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
C             =1: GAMMA INCREASES IN PROPORTION TO L/L0
      KCALX(2)=0
C KCALX(3)=N: GAMMA=1 IF TIME STEP NO. IS LESS THAN N
C                 (IF LD=0 THEN TIME STEP NO. DOES NOT INCREASE)
      KCALX(3)=0
C PRINT INTERVAL BY TIME STEPS
      INTVLP=1
C PRINT OPTION: (1)L, (2)LD, (3)LDD, (4)N, (5)ND, (6)NDD
C                 =0:NO PRINT, =1:PRINT, =-1:PRINT BUT LAST ONE
C                 =2 AT (5):PRINT INCLUDING DERIVATIVES
      DO 100 I=1,6
      KPRINT(I)=1
  100 CONTINUE
      CALL NINE1(NBR,800)
      RETURN
C
      ENTRY CLEAR1
C
      CALL ZERO0(EQ3,  3600)
      CALL ZERO0(EQ4,  2900)
      CALL ZERO0(EQ5,    17)
      CALL ZERO0(EQ6,  1602)
      CALL ZERO0(EQ8,  4800)
      CALL ZERO0(EQ9,   800)
      CALL ZERO0(EQ0,     6)
      RETURN
      END
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE INITL
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X            ,SPNDD(200,2),SUMFN
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
C
      UNIT=1000.*1000./(365.*24.*60.*60.)
      DO 200 M=1,2
      IF(M.NE.1) GO TO 110
      ISB=IS3
      GO TO 120
  110 ISB=IB3
  120 DO 150 J=1,ISB
      XLD(J,M)=XLDI(J,M)
      YLD(J,M)=XLD(J,M)
      WLD(J,M)=XLD(J,M)
      XND(J,M)=XNDI(J,M)
      YND(J,M)=XND(J,M)
      WND(J,M)=XND(J,M)
      XLDND(J,M)=XLD(J,M)*XND(J,M)
      YLDND(J,M)=XLDND(J,M)
      WLDND(J,M)=XLDND(J,M)
  150 CONTINUE
  200 CONTINUE
      RETURN
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE INPUTX(KEND)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM7/ KPRNL(3),KPRNF(3),KPRNP(3),KPRNN(3)
      COMMON/COMO/ ICAS,IS2,IS3,IB2,IB3,SUMF
      COMMON/COMA/ EMPTY
      DIMENSION NAMEU(3),NAMEU1(3),NAMEU2(3)
C
      CHARACTER*4 KPRNL,KPRNF,KPRNP,KPRNN,NAMEU,NAMEU1,NAMEU2
      DATA NAMEU1/'(TON','-U/Y','R)'/,NAMEU2/'(RAT','IO)',' '/
C
      NAMELIST/DATA/ IS,IB,NSTOP,NDELT,INTVLP,KPRINT,MODEL,KCALX
     X    ,NFEED,IFEED,MAXF,ISFD,MAXSFD,ISFDD,MXSFDD,ISPD
     X    ,MAXSPD,ISPDD,MXSPDD,ICUT,MAXCUT,MAXFXD,MAXSPR,MAXG
     X    ,JH,JHD,JHDD,XLDI,FEEDI,SFDI,SFDDI,SPDI,SPDDI,XNFI,NBR
     X    ,SNDI,SNDDI,XLOPT,XNDI,RLOPTI,GAMI,ISPR,SPRI,CUTI,RATIO
     X    ,EMPTY
C
      KEND=0
      READ(1,DATA,END=11111)
C
C  BASIC PARAMETERS
      DO 1 I=1,3
      NAMEU(I)=NAMEU1(I)
    1 CONTINUE
      IF(KCALX(4).EQ.0) GO TO 3
      DO 2 I=1,3
      NAMEU(I)=NAMEU2(I)
    2 CONTINUE
    3 IS1=IS+1
      IS2=1
      IS3=IS1
      IB2=1
      IB3=IB
      IF(KCALX(1).EQ.0) GO TO 5
      IS2=IS1+1
      IS3=2*IS1
      IB2=IB+1
      IB3=2*IB
    5 NSFD=0
      NSFDD=0
      NSPD=0
      NSPDD=0
      DO 7 M=1,2
      IF(M.EQ.1) ISB=IS3
      IF(M.EQ.2) ISB=IB3
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

```
....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      DO 6 J=1,ISB
      XLIMIT(J,M)=XLOPT(J,M)*RATIO
      IF(MAXSFD(J,M).NE.0) NSFD=NSFD+1
      IF(MXSFDD(J,M).NE.0) NSFDD=NSFDD+1
      IF(MAXSPD(J,M).NE.0) NSPD=NSPD+1
      IF(MXSPDD(J,M).NE.0) NSPDD=NSPDD+1
    6 CONTINUE
    7 CONTINUE
C
C  TITLE PRINT
      WRITE(6,6000)
      WRITE(6,6010)
C  PRINT FOR ENRICHING SECTION
      WRITE(6,6020)
      WRITE(6,6030)
      WRITE(6,6040)
      WRITE(6,6020)
      DO 10 I1=1,IS3
      J1=IS3-I1+1
      J=J1-1
      WRITE(6,6050) J,CUTI(J1,1,1),JH(J1,1),JHD(J1,1),JHDD(J1,1)
     X             ,XLDI(J1,1),XLOPT(J1,1),XNDI(J1,1),XLIMIT(J1,1)
      IF(J.EQ.IS1) WRITE(6,6001)
   10 CONTINUE
      WRITE(6,6020)
C  PRINT FOR STRIPPING SECTION
      DO 20 J=1,IB3
      JMINUS=-J
      IF(J.EQ.IB+1) WRITE(6,6001)
      WRITE(6,6050) JMINUS,CUTI(J,1,2),JH(J,2),JHD(J,2),JHDD(J,2)
     X             ,XLDI(J,2),XLOPT(J,2),XNDI(J,2),XLIMIT(J,2)
   20 CONTINUE
      WRITE(6,6020)
C  L / LOPT...GAMMER
      WRITE(6,6500)
      DO 150 J=1,MAXG
      WRITE(6,6510) RLOPTI(J),GAMI(J)
  150 CONTINUE
      WRITE(6,6520)
C  NUMBER OF FEED FLOWS PRINT
      WRITE(6,6060)
      WRITE(6,6070) NFEED
C  NUMBER OF SIDE FLOWS
      WRITE(6,6080)
      WRITE(6,6090) NSFD,NSFDD,NSPD,NSPDD
C  REFLUX FLOW BETWEEN SIDE FLOWS
      WRITE(6,6400)
      IF(MAXFXD.EQ.0) GO TO 310
      DO 300 J=1,MAXFXD
      DO 300 I=1,2
      IF(NBR(I,J,1).EQ.999) GO TO 300
      IF(NBR(1,J,2).NE.999) WRITE(6,6410) KPRNP(I+1),NBR(I,J,1)
     X                      ,KPRNF(2),NBR(1,J,2)
      IF(NBR(2,J,2).NE.999) WRITE(6,6410) KPRNP(I+1),NBR(I,J,1)
     X                      ,KPRNF(3),NBR(2,J,2)
  300 CONTINUE
  310 IF(MAXFXD.EQ.0) WRITE(6,6300)
      WRITE(6,6330)
      WRITE(6,6095) RATIO
C  CONDITIONS OF FEED FLOWS
....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      WRITE(6,6330)
      WRITE(6,6100)
      DO 30 K=1,NFEED
      WRITE(6,6110)
      WRITE(6,6120) (IFEED(I,K),I=1,MAXF(K))
      WRITE(6,6130) K
      WRITE(6,6140) (FEEDI(I,K),I=1,MAXF(K))
      WRITE(6,6420) K
      WRITE(6,6140) (XNFI(I,K),I=1,MAXF(K))
      WRITE(6,6335)
   30 CONTINUE
      IF(NFEED.EQ.0) WRITE(6,6300)
      WRITE(6,6330)
C  CONDITIONS OF FEED SIDE FLOWS
      WRITE(6,6150)
      KZERO=0
      DO 40 I1=1,IS3
      J1=IS3-I1+1
      J=J1-1
      IF(MAXSFD(J1,1).EQ.0) GO TO 40
      KZERO=1
      WRITE(6,6110)
      WRITE(6,6120) (ISFD(I,J1,1),I=1,MAXSFD(J1,1))
      WRITE(6,6160) J
      WRITE(6,6140) (SFDI(I,J1,1),I=1,MAXSFD(J1,1))
      WRITE(6,6420) J
      WRITE(6,6140) (SNDI(I,J1,1),I=1,MAXSFD(J1,1))
      WRITE(6,6335)
   40 CONTINUE
      DO 50 J=1,IB3
      IF(MAXSFD(J,2).EQ.0) GO TO 50
      KZERO=1
      JMINUS=-J
      WRITE(6,6110)
      WRITE(6,6120) (ISFD(I,J,2),I=1,MAXSFD(J,2))
      WRITE(6,6160) JMINUS
      WRITE(6,6140) (SFDI(I,J,2),I=1,MAXSFD(J,2))
      WRITE(6,6420) JMINUS
      WRITE(6,6140) (SNDI(I,J,2),I=1,MAXSFD(J,2))
      WRITE(6,6335)
   50 CONTINUE
      DO 60 I1=1,IS3
      J1=IS3-I1+1
      J=J1-1
      IF(MXSFDD(J1,1).EQ.0) GO TO 60
      KZERO=1
      WRITE(6,6110)
      WRITE(6,6120) (ISFDD(I,J1,1),I=1,MXSFDD(J1,1))
      WRITE(6,6280) J
      WRITE(6,6140) (SFDDI(I,J1,1),I=1,MXSFDD(J1,1))
      WRITE(6,6420) J
      WRITE(6,6140) (SNDDI(I,J1,1),I=1,MXSFDD(J1,1))
      WRITE(6,6335)
   60 CONTINUE
      DO 70 J=1,IB3
      IF(MXSFDD(J,2).EQ.0) GO TO 70
      KZERO=1
      JMINUS=-J
      WRITE(6,6110)
      WRITE(6,6120) (ISFDD(I,J,2),I=1,MXSFDD(J,2))
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      WRITE(6,6280) JMINUS
      WRITE(6,6140) (SFDDI(I,J,2),I=1,MXSFDD(J,2))
      WRITE(6,6420) JMINUS
      WRITE(6,6140) (SNDDI(I,J,2),I=1,MXSFDD(J,2))
      WRITE(6,6335)
   70 CONTINUE
      IF(KZERO.EQ.0) WRITE(6,6300)
      KZERO=0
C  CONDITIONS OF PRODUCT SIDE FLOWS
      WRITE(6,6330)
      WRITE(6,6170)
      DO 80 I1=1,IS3
      J1=IS3-I1+1
      J=J1-1
      IF(MAXSPD(J1,1).EQ.0) GO TO 80
      KZERO=1
      WRITE(6,6110)
      WRITE(6,6120) (ISPD(I,J1,1),I=1,MAXSPD(J1,1))
      WRITE(6,6180) J,(NAMEU(I),I=1,3)
      WRITE(6,6140) (SPDI(I,J1,1),I=1,MAXSPD(J1,1))
      WRITE(6,6335)
   80 CONTINUE
      DO 90 J=1,IB3
      IF(MAXSPD(J,2).EQ.0) GO TO 90
      KZERO=1
      JMINUS=-J
      WRITE(6,6110)
      WRITE(6,6120) (ISPD(I,J,2),I=1,MAXSPD(J,2))
      WRITE(6,6180) JMINUS,(NAMEU(I),I=1,3)
      WRITE(6,6140) (SPDI(I,J,2),I=1,MAXSPD(J,2))
      WRITE(6,6335)
   90 CONTINUE
      DO 100  I1=1,IS3
      J1=IS3-I1+1
      J=J1-1
      IF(MXSPDD(J1,1).EQ.0) GO TO 100
      KZERO=1
      WRITE(6,6110)
      WRITE(6,6120) (ISPDD(I,J1,1),I=1,MXSPDD(J1,1))
      WRITE(6,6190) J,(NAMEU(I),I=1,3)
      WRITE(6,6140) (SPDDI(I,J1,1),I=1,MXSPDD(J1,1))
      WRITE(6,6335)
  100 CONTINUE
      DO 110 J=1,IB3
      IF(MXSPDD(J,2).EQ.0) GO TO 110
      KZERO=1
      JMINUS=-J
      WRITE(6,6110)
      WRITE(6,6120) (ISPDD(I,J,2),I=1,MXSPDD(J,2))
      WRITE(6,6190) JMINUS,(NAMEU(I),I=1,3)
      WRITE(6,6140) (SPDDI(I,J,2),I=1,MXSPDD(J,2))
      WRITE(6,6335)
  110 CONTINUE
      IF(KZERO.EQ.0) WRITE(6,6300)
C CONDITIONS OF REFLUX FLOWS
      WRITE(6,6330)
      WRITE(6,6440)
      IF(MAXFXD.GT.0) GO TO 170
      WRITE(6,6300)
      GO TO 185
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
   170 DO 180 J=1,MAXFXD
       DO 180 I=1,2
       IF(NBR(I,J,1).EQ.999) GO TO 180
       WRITE(6,6110)
       WRITE(6,6120) (ISPR(N,I,J),N=1,MAXSPR(I,J))
       IF(I.EQ.1) WRITE(6,6450) KPRNP(2),NBR(I,J,1),(NAMEU(N),N=1,3)
       IF(I.EQ.2) WRITE(6,6450) KPRNP(3),NBR(I,J,1),(NAMEU(N),N=1,3)
       WRITE(6,6140) (SPRI(N,I,J),N=1,MAXSPR(I,J))
       WRITE(6,6335)
   180 CONTINUE
   185 WRITE(6,6330)
C  CONDITIONS OF CUT
       KCUT=0
       WRITE(6,6310)
       IF(MAXCUT.EQ.1) GO TO 200
       KCUT=1
       WRITE(6,6110)
       WRITE(6,6120) (ICUT(I),I=1,MAXCUT)
       DO 120 I1=1,IS3
       J1=IS3-I1+1
       J=J1-1
       WRITE(6,6320) J
       WRITE(6,6140) (CUTI(J1,I,1),I=1,MAXCUT)
   120 CONTINUE
       DO 130 J=1,IB3
       JMINUS=-J
       WRITE(6,6320) JMINUS
       WRITE(6,6140) (CUTI(J,I,2),I=1,MAXCUT)
   130 CONTINUE
   200 IF(KCUT.EQ.0) WRITE(6,6300)
       WRITE(6,6330)
C  CONDITIONS OF NUMERICAL AND PRINT
       WRITE(6,6230)
       WRITE(6,6240) NDELT
       WRITE(6,6250) NSTOP
       WRITE(6,6260)
       WRITE(6,6290) (KPRINT(I),I=1,8)
       WRITE(6,6270) INTVLP
       WRITE(6,6271) MODEL,(KCALX(I),I=1,8)
       WRITE(6,6272) EMPTY
       RETURN
 11111 KEND=1
       RETURN
  6000 FORMAT(1H1,24X,66(1H*)/25X,1H*,64X,1H*/25X,1H*,5X,'ANALYSIS'
     1      ,'  OF  DYNAMICS  IN UF6 GAS CENTRIFUGE  '
     2      ,'CASCADE',5X,1H*/25X,1H*,64X,1H*/25X,1H*,19X,'WITH  SIDE'
     3      ,'  FLOWS',28X,1H*/25X,1H*,64X,1H*/25X,66(1H*))
  6001 FORMAT(1X)
  6010 FORMAT(//5X,'CHARACTERISTICS OF CENTRIFUGE CASCADE')
  6020 FORMAT(1H0,1X,130(1H.))
  6030 FORMAT(1H0,2X,'STAGE NO.',5X,'CUT',14X,'HOLDING    TIME',9X
     1,'ENRICHED FLOW RATE',2X,'OPTIMAL FLOW RATE',2X,'ENRICHED '
     2,'ASSAY',1X,'ENRICHING RESTRICTED')
  6040 FORMAT(4X,'J (-)',8X,'(-)',8X,'H (SEC)  H* (SEC)  H** (SEC)'
     1,4X,'L* (TON-U/YR)',6X,'LOPT (TON-U/YR)',5X,'N* (-)'
     2,10X,'L (TON-U/YR)')
  6050 FORMAT(5X,I4,4X,1PE12.5,3(5X,I5),6X,1PE12.5,6X,1PE12.5
     1,6X,1PE12.5,6X,1PE12.5)
  6060 FORMAT(//5X,'NUMBER OF FEED FLOWS')
  6070 FORMAT(12X,'K    = ',I5,' (-)')
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
 6080 FORMAT(//5X,'NUMBER OF SIDE FLOWS')
 6090 FORMAT(12X,'SF*  = ',I5,' (-)'/12X,'SF** = ',I5,' (-)'
     1,/12X,'SP*  = ',I5,' (-)'/12X,'SP** = ',I5,' (-)')
 6095 FORMAT(1H0,5X,'RATIO OF L/LOPT =',F10.3,' (-)',/)
 6100 FORMAT(//5X,'SPECIFICATION OF FEED FLOWS')
 6110 FORMAT(12X,'( )X DELTA-T (SEC)')
 6120 FORMAT(2X,10I13)
 6130 FORMAT(/12X,'F(',I3,') (TON-U/YR)')
 6140 FORMAT(3X,1P10E13.5)
 6150 FORMAT(//5X,'SPECIFICATION OF FEED SIDE FLOWS')
 6160 FORMAT(/12X,'SF*(',I3,') (TON-U/YR)')
 6170 FORMAT(//5X,'SPECIFICATION OF PRODUCT SIDE FLOWS')
 6180 FORMAT(/12X,'SP* (',I3,')',1X,3A4)
 6190 FORMAT(/12X,'SP**(',I3,')',1X,3A4)
 6220 FORMAT(22X,I3,3X,I3,4X,I3)
 6230 FORMAT(//5X,'CONDITIONS IN NUMERICAL CALCULATION AND PRINT')
 6240 FORMAT(/12X,'TIME INTERVAL DELTA-T = ',I7,' (SEC)')
 6250 FORMAT(/12X,'NUMBER OF TIME STEPS  = ',I7,' (-)')
 6260 FORMAT(/12X,'PRINT OPTION',10X,'=     L ,  L* ,  L**',5X
     X,'  N ,  N* ,  N**',5X,'OTHERS')
 6270 FORMAT(/12X,'PRINT INTERVAL         = ',I7,' (-)')
 6271 FORMAT(/12X,'CALCULATION MODEL      =    MODEL  KCALX'
     1       /37X,9I7)
 6272 FORMAT(/12X,'CONDITION OF EMPTY     = ',1PE15.5/)
 6280 FORMAT(/12X,'SF**(',I3,') (TON-U/YR)')
 6290 FORMAT(37X,I3,I5,I6,7X,I3,I5,I6,I11,I5)
 6300 FORMAT(15X,'--- NO DATA ---')
 6310 FORMAT(//5X,'SPECIFICATION OF CUT')
 6320 FORMAT(/12X,'CUT(',I3,') (-)')
 6330 FORMAT(3X,45(1H.))
 6335 FORMAT(//)
 6400 FORMAT(//5X,'REFLUX FLOW BETWEEN SIDE FLOWS')
 6410 FORMAT(12X,'FROM ',A4,'(',I3,')  TO  ',A4,'(',I3,')')
 6420 FORMAT(1H0,11X,'NF(',I3,') (-)')
 6440 FORMAT(//5X,'SPECIFICATION OF REFLUX FLOWS')
 6450 FORMAT(12X,A4,'(',I3,')',4X,3A4)
 6500 FORMAT(////7X,55(1H.)/1H0,9X,'FLOW RATE RATIO',8X
     1      ,'STAGE SEPARATION FACTOR'/10X,'L / LOPT  (-)',16X
     2      ,'GAMMA  (-)'/1H0,6X,55(1H.))
 6510 FORMAT(12X,F5.2,19X,1PE12.5)
 6520 FORMAT(/7X,55(1H.))
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE INTCUT(NT)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X             ,FEED(50),CUT(200,2),XNF(50)
     X             ,SND(200,2),SNDD(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
C
      IF(NT.GT.ICUT(1)+1) GO TO 140
      JT=1
  110 DO 120 J=1,IS3
      CUT(J,1)=CUTI(J,JT,1)
  120 CONTINUE
      DO 130 J=1,IB3
      CUT(J,2)=CUTI(J,JT,2)
  130 CONTINUE
      GO TO 180
  140 IF(NT.LT.ICUT(MAXCUT)+1) GO TO 150
      JT=MAXCUT
      GO TO 110
  150 DO 151 JT=1,MAXCUT
      IF(NT.LT.ICUT(JT)+1) GO TO 152
  151 CONTINUE
  152 JT1=JT-1
      DIV=FLOAT(NT-(ICUT(JT1)+1))/FLOAT(ICUT(JT)-ICUT(JT1))
      DO 160 J=1,IS3
      CUT(J,1)=CUTI(J,JT1,1)+(CUTI(J,JT,1)-CUTI(J,JT1,1))*DIV
  160 CONTINUE
      DO 170 J=1,IB3
      CUT(J,2)=CUTI(J,JT1,2)+(CUTI(J,JT,2)-CUTI(J,JT1,2))*DIV
  170 CONTINUE
  180 RETURN
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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```
      SUBROUTINE INTERG(XI,YI,X,N,YO,Z)
C
      DIMENSION XI(N),YI(N)
C
      IF(X.GT.XI(1)) GO TO 10
      YO=YI(1)
      Z=0.0
      RETURN
   10 IF(X.LE.XI(N)) GO TO 20
      YO=YI(N)
      Z=0.0
      RETURN
   20 DO 30 I=2,N
      IF(X.LE.XI(I)) GO TO 40
   30 CONTINUE
      WRITE(6,6000)
      STOP
   40 I1=I-1
      Z=(YI(I)-YI(I1))/(XI(I)-XI(I1))
      YO=YI(I1)+Z*(X-XI(I1))
      RETURN
 6000 FORMAT(1X,'*** SUB INTERG *** GAMMA TABLE INPUT ERROR')
      END
```

Source Listing - V. 4.0 < INTERY : ccslc.f > Tue Nov 19 12:56:27 1991 Page 0030

```
      SUBROUTINE INTERY(IX,XI,XII,K,N,XO,XOO)
C
      DIMENSION IX(1),XI(1),XII(1)
C
      IF(N.EQ.0) RETURN
      IF(K.GT.IX(1)+1) GO TO 10
      XO =XI(1)
      XOO=XII(1)
      RETURN
   10 IF(K.LT.IX(N)+1) GO TO 20
      XO =XI(N)
      XOO=XII(N)
      RETURN
   20 DO 30 J=1,N
      IF(K.LT.IX(J)+1) GO TO 40
   30 CONTINUE
      WRITE(6,6000)
      STOP
   40 J1 =J-1
      DIV=FLOAT(K-(IX(J1)+1))/FLOAT(IX(J)-IX(J1))
      XO =XI(J1)+(XI(J)-XI(J1))*DIV
      XOO=XII(J1)+(XII(J)-XII(J1))*DIV
      RETURN
 6000 FORMAT(1X,'*** SUB INTERY *** TIME TABLE INPUT ERROR')
      END
```

Source Listing - V. 4.0   < INTERZ : ccslc.f >   Tue Nov 19 12:56:27 1991   Page 0031

```
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE INTERZ
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM4/ SFD(200,2),SFDD(200,2),SPD(200,2),SPDD(200,2)
     X            ,FEED(50),CUT(200,2),XNF(50)
     X            ,SND(200,2),SNDD(200,2)
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X            ,SPNDD(200,2),SUMFN
      COMMON/COM9/ XLDD0(200,2),XNDD0(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      DIMENSION DUM(50)
C
      CALL ZERO0(DUM,50)
      CALL ZERO0(SFD  ,1600)
      CALL ZERO0(SFND ,1600)
C
      NT=NTIME
      SUMF=0.0
      SUMFN=0.0
      DO 100 K=1,NFEED
      CALL INTERY(IFEED(1,K),FEEDI(1,K),XNFI(1,K),NT,MAXF(K),FEED(K)
     X           ,XNF(K))
      SUMF=SUMF+FEED(K)
      SUMFN=SUMFN+FEED(K)*XNF(K)
  100 CONTINUE
      DO 200 M=1,2
      IF(M.NE.1) GO TO 110
      ISB=IS3
      GO TO 120
  110 ISB=IB3
  120 DO 150 J=1,ISB
      CALL INTERY(ISFD(1,J,M),SFDI(1,J,M),SNDI(1,J,M),NT,MAXSFD(J,M)
     X           ,SFD(J,M),SND(J,M))
      SFND(J,M)=SFD(J,M)*SND(J,M)
      CALL INTERY(ISFDD(1,J,M),SFDDI(1,J,M),SNDDI(1,J,M),NT,MXSFDD(J,M)
     X           ,SFDD(J,M),SNDD(J,M))
      SFNDD(J,M)=SFDD(J,M)*SNDD(J,M)
      CALL INTERY(ISPD(1,J,M),SPDI(1,J,M),DUM,NT,MAXSPD(J,M),SPD(J,M)
     X           ,DUM)
      IF(KCALX(4).EQ.1) SPD(J,M)=SPD(J,M)*XLD(J,M)
      IF(SPD(J,M).GT.XLD(J,M)) SPD(J,M)=XLD(J,M)
      SPND(J,M)=SPD(J,M)*XND(J,M)
      CALL INTERY(ISPDD(1,J,M),SPDDI(1,J,M),DUM,NT,MXSPDD(J,M)
     X           ,SPDD(J,M),DUM)
      IF(KCALX(4).EQ.1) SPDD(J,M)=SPDD(J,M)*XLDD0(J,M)
      IF(SPDD(J,M).GT.XLDD0(J,M)) SPDD(J,M)=XLDD0(J,M)
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.     ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SPNDD(J,M)=SPDD(J,M)*XNDD0(J,M)
  150 CONTINUE
  200 CONTINUE
C
      IF(MAXFXD.EQ.0) RETURN
C
      DO 250 K=1,MAXFXD
      DO 240 I=1,2
      IF(NBR(I,K,1).EQ.999) GO TO 240
      IF(NBR(I,K,1).LT.0) GO TO 205
      J=NBR(I,K,1)+1
      IF(J.GT.IS3) GO TO 300
      M=1
      GO TO 210
  205 J=-NBR(I,K,1)
      IF(J.GT.IB3) GO TO 300
      M=2
  210 IF(NBR(I,K,2).LT.0) GO TO 215
      MA=1
      MB=NBR(I,K,2)+1
      IF(MB.GT.IS3) GO TO 300
      GO TO 220
  215 MA=2
      MB=-NBR(I,K,2)
      IF(MB.GT.IB3) GO TO 300
  220 CALL INTERY(ISPR(1,I,K),SPRI(1,I,K),DUM,NT,MAXSPR(I,K),TEMP,DUM)
      IF(I.NE.1) GO TO 230
      IF(KCALX(4).EQ.1) TEMP=TEMP*XLD(J,M)
      SPD(J,M)=SPD(J,M)+TEMP
      IF(SPD(J,M).LE.XLD(J,M)) GO TO 225
      TEMP=TEMP-SPD(J,M)+XLD(J,M)
      SPD(J,M)=XLD(J,M)
  225 SPND(J,M)=SPND(J,M)+TEMP*XND(J,M)
      SFD(MB,MA)=SFD(MB,MA)+TEMP
      SFND(MB,MA)=SFND(MB,MA)+TEMP*XND(J,M)
      GO TO 240
  230 IF(KCALX(4).EQ.1) TEMP=TEMP*XLDD0(J,M)
      SPDD(J,M)=SPDD(J,M)+TEMP
      IF(SPDD(J,M).LE.XLDD0(J,M)) GO TO 235
      TEMP=TEMP-SPDD(J,M)+XLDD0(J,M)
      SPDD(J,M)=XLDD0(J,M)
  235 SPNDD(J,M)=SPNDD(J,M)+TEMP*XNDD0(J,M)
      SFDD(MB,MA)=SFDD(MB,MA)+TEMP
      SFNDD(MB,MA)=SFNDD(MB,MA)+TEMP*XNDD0(J,M)
  240 CONTINUE
  250 CONTINUE
C
      RETURN
  300 WRITE(6,6000) (NBR(I,K,N),N=1,2)
      STOP
 6000 FORMAT(1X,'RECYCLE FLOW INPUT ERROR: NBR',2I10)
      END
Seq.     ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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```
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE MOVE
C
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
C
      DO 200 M=1,2
      IF(M.NE.1) GO TO 110
      ISB=IS3
      GO TO 120
  110 ISB=IB3
  120 DO 150 J=1,ISB
      WLD(J,M)=XLD(J,M)
      XLD(J,M)=YLD(J,M)
      WND(J,M)=XND(J,M)
      XND(J,M)=YND(J,M)
      WLDND(J,M)=XLDND(J,M)
      XLDND(J,M)=YLDND(J,M)
  150 CONTINUE
  200 CONTINUE
C
      RETURN
      END
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

Source Listing - V. 4.0   < OUTPUT : ccslc.f >   Tue Nov 19 12:56:27 1991   Page 0034

```
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE OUTPUT(KPRNT0,UINV0,UINV,U5INV0,U5INV)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X     ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X     ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X     ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X     ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X     ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X     ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X     ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X     ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X     ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X     ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X              ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X              ,XLIMIT(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X            ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM6/ UNIT,SFND(200,2),SFNDD(200,2),SPND(200,2)
     X             ,SPNDD(200,2),SUMFN
      COMMON/COM7/ KPRNL(3),KPRNF(3),KPRNP(3),KPRNN(3)
      COMMON/COM8/ XLDND(200,2),YLDND(200,2),NCOUNT(200,2),
     X             WLD(200,2),WND(200,2),WLDND(200,2),
     X             DLD(200,2),DND(200,2),DLDND(200,2),
     X             DDLD(200,2),DDND(200,2),DDLDND(200,2)
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      DIMENSION KPRNT0(1)
      CHARACTER*4 KPRNL,KPRNF,KPRNP,KPRNN
C
      KPRNT1=KPRNT0(7)
      DO 10 I=1,6
      IF(KPRNT0(I).GT.0) KPRNT1=1
   10 CONTINUE
      IF(KPRNT1.LE.0) RETURN
      NT=NTIME-1
      ZMP=TPL(1)*ANP
      ZMW=TWL*ANW
      ZMF=TFL*ANF
      UINV1=UINV*UNIT
      U5INV1=U5INV*UNIT
      EINV=0.0
      IF(UINV.NE.0.0) EINV=U5INV/UINV
      DIF5=ZMF-(ZMP+ZMW)+(U5INV0-U5INV+SFNBAL)*UNIT
      DIFU=TFL-(TPL(1)+TWL)+(UINV0-UINV+SFBAL)*UNIT
      WRITE(6,6010) NT
      WRITE(6,6020) TPL(1),TWL,TFL,UINV1, DIFU,KPRNL(1),SUML
      WRITE(6,6080) ZMP,   ZMW,ZMF,U5INV1,DIF5,KPRNL(2),SUMLD
      WRITE(6,6030) ANP,   ANW,ANF,EINV,       KPRNL(3),SUMLDD
      IF(DUT.NE.99999.) WRITE(6,6031) DUT
      IF(DUT.EQ.99999.) WRITE(6,6032)
      IF(KPRNT0(1).LE.0) GO TO 100
      WRITE(6,6070) KPRNL(1),(XL(IS1-J+1,1),J=1,IS1)
      WRITE(6,6050)          (XL(J      ,2),J=1,IB )
      IF(KCALX(1).EQ.0) GO TO 100
      WRITE(6,6051)          (XL(IS3-J+1,1),J=1,IS1)
      WRITE(6,6050)          (XL(IB +J  ,2),J=1,IB )
  100 IF(KPRNT0(4).LE.0) GO TO 110
      WRITE(6,6040) KPRNN(1),(XN(IS1-J+1,1),J=1,IS1)
      WRITE(6,6050)          (XN(J      ,2),J=1,IB )
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

```
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
            IF(KCALX(1).EQ.0) GO TO 110
            WRITE(6,6051)           (XN(IS3-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XN(IB +J  ,2),J=1,IB )
      C
        110 IF(KPRNTO(2).LE.0) GO TO 200
            WRITE(6,6070) KPRNL(2),(XLD(IS1-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XLD(J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 200
            WRITE(6,6051)           (XLD(IS3-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XLD(IB +J  ,2),J=1,IB )
        200 IF(KPRNTO(5).LE.0) GO TO 210
            WRITE(6,6040) KPRNN(2),(XND(IS1-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XND(J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 210
            WRITE(6,6051)           (XND(IS3-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XND(IB +J  ,2),J=1,IB )
      C
        210 IF(KPRNTO(3).LE.0) GO TO 300
            WRITE(6,6070) KPRNL(3),(XLDD(IS1-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XLDD(J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 300
            WRITE(6,6051)           (XLDD(IS3-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XLDD(IB +J  ,2),J=1,IB )
        300 IF(KPRNTO(6).LE.0) GO TO 310
            WRITE(6,6040) KPRNN(3),(XNDD(IS1-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XNDD(J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 310
            WRITE(6,6051)           (XNDD(IS3-J+1,1),J=1,IS1)
            WRITE(6,6050)           (XNDD(IB +J  ,2),J=1,IB )
      C
        310 IF(KPRNTO(5).LE.1) GO TO 320
            WRITE(6,6090) (XLDND (IS1-J+1,1),J=1,IS1)
            WRITE(6,6050) (XLDND (J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 320
            WRITE(6,6051) (XLDND (IS3-J+1,1),J=1,IS1)
            WRITE(6,6050) (XLDND (IB +J  ,2),J=1,IB )
        320 IF(KPRNTO(2).LE.1) GO TO 330
            WRITE(6,6110) (DLD   (IS1-J+1,1),J=1,IS1)
            WRITE(6,6050) (DLD   (J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 330
            WRITE(6,6051) (DLD   (IS3-J+1,1),J=1,IS1)
            WRITE(6,6050) (DLD   (IB +J  ,2),J=1,IB )
        330 IF(KPRNTO(5).LE.1) GO TO 350
            WRITE(6,6100) (DND   (IS1-J+1,1),J=1,IS1)
            WRITE(6,6050) (DND   (J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 340
            WRITE(6,6051) (DND   (IS3-J+1,1),J=1,IS1)
            WRITE(6,6050) (DND   (IB +J  ,2),J=1,IB )
        340 WRITE(6,6120) (DLDND (IS1-J+1,1),J=1,IS1)
            WRITE(6,6050) (DLDND (J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 350
            WRITE(6,6051) (DLDND (IS3-J+1,1),J=1,IS1)
            WRITE(6,6050) (DLDND (IB +J  ,2),J=1,IB )
        350 IF(KPRNTO(2).LE.1) GO TO 360
            WRITE(6,6140) (DDLD  (IS1-J+1,1),J=1,IS1)
            WRITE(6,6050) (DDLD  (J      ,2),J=1,IB )
            IF(KCALX(1).EQ.0) GO TO 360
            WRITE(6,6051) (DDLD  (IS3-J+1,1),J=1,IS1)
            WRITE(6,6050) (DDLD  (IB +J  ,2),J=1,IB )
        360 IF(KPRNTO(5).LE.1) GO TO 400
Seq.  ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.     ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      WRITE(6,6130) (DDND  (IS1-J+1,1),J=1,IS1)
      WRITE(6,6050) (DDND  (J      ,2),J=1,IB )
      IF(KCALX(1).EQ.0) GO TO 370
      WRITE(6,6051) (DDND  (IS3-J+1,1),J=1,IS1)
      WRITE(6,6050) (DDND  (IB +J  ,2),J=1,IB )
  370 WRITE(6,6150) (DDLDND(IS1-J+1,1),J=1,IS1)
      WRITE(6,6050) (DDLDND(J      ,2),J=1,IB )
      IF(KCALX(1).EQ.0) GO TO 400
      WRITE(6,6051) (DDLDND(IS3-J+1,1),J=1,IS1)
      WRITE(6,6050) (DDLDND(IB +J  ,2),J=1,IB )
C
  400 RETURN
 6010 FORMAT(/1X,'*',I8,'X DELTA-T (SEC)'
     X      /T25,'PRODUCT',T40,'WASTE',T54,'FEED'
     X      ,T62,'INVENTORY',T73,'MAT.BALANCE'
     X      ,T86,'TOTAL FLOW RATE SUMMED UP OVER STAGES')
 6020 FORMAT(1X,'U AMOUNT      (GR)',1P5E13.5
     X      ,T86,'        SIGMA ',A4,'=',1PE12.5,' (TON-U/YR)')
 6030 FORMAT(1X,'AVERAGE ASSAY (-)',1P4E13.5,'  -----------'
     X      ,T86,'        SIGMA ',A4,'=',1PE12.5,' (TON-U/YR)')
 6031 FORMAT(T86,'SEPARATIVE WORK ','=',1PE12.5
     X      ,' (TON-SWU/YR)')
 6032 FORMAT(T86,'SEPARATIVE WORK ','=',' ***********'
     X      ,' (TON-SWU/YR)')
 6040 FORMAT(1X,A4,1P10E12.5/(5X,1P10E12.5))
 6050 FORMAT(5X    ,1P10E12.5/(5X,1P10E12.5))
 6051 FORMAT(1X,'2-ND',1P10E12.5/(5X,1P10E12.5))
 6070 FORMAT(/1X,A4,1P10E12.5/(5X,1P10E12.5))
 6080 FORMAT(1X,'U235 AMOUNT  (GR)',1P5E13.5
     X      ,T86,'        SIGMA ',A4,'=',1PE12.5,' (TON-U/YR)')
 6090 FORMAT(/1X,'L*N*',1P10E12.5/(5X,1P10E12.5))
 6100 FORMAT(/1X,'DN* ',1P10E12.5/(5X,1P10E12.5))
 6110 FORMAT(/1X,'DL* ',1P10E12.5/(5X,1P10E12.5))
 6120 FORMAT(/1X,'DL*N',1P10E12.5/(5X,1P10E12.5))
 6130 FORMAT(/1X,'D2N*',1P10E12.5/(5X,1P10E12.5))
 6140 FORMAT(/1X,'D2L*',1P10E12.5/(5X,1P10E12.5))
 6150 FORMAT(/1X,'D2LN',1P10E12.5/(5X,1P10E12.5))
      END
Seq.     ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

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Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE PCARD
C
      DIMENSION DATA(20)
C
      REWIND 1
      ND=0
      WRITE(6,6000)
  100 READ(5,5000,END=11111) (DATA(I),I=1,20)
      ND=ND+1
      WRITE(6,6010) ND,(DATA(I),I=1,20)
      WRITE(1,5000) (DATA(I),I=1,20)
      GO TO 100
11111 REWIND 1
      RETURN
 5000 FORMAT(20A4)
 6000 FORMAT(1H1//55X,'INPUT DATA IMAGE'/T54,20('*')
     X      /T30,'1',7X,'10',8X,'20',8X,'30',8X,'40',8X,'50',8X,'60'
     X      ,8X,'70',8X,'80'
     X      /T30,8(9(1H.),1H+))
 6010 FORMAT(T20,I5,5X,20A4)
      END
Seq.   ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
      SUBROUTINE SUM(JUMP)
C
      COMMON/COM1/ IS,IB,NSTOP,NDELT,INTVLP,KCALX(8),KPRINT(8)
     X    ,NFEED,IFEED(50,50),MAXF(50),ISFD(50,200,2),MAXSFD(200,2)
     X    ,ISFDD(50,200,2),MXSFDD(200,2),ISPD(50,200,2)
     X    ,MAXSPD(200,2),ISPDD(50,200,2),MXSPDD(200,2)
     X    ,NSFD,NSFDD,NSPD,NSPDD,NBR(2,200,2),MAXFXD,MAXG
     X    ,ICUT(50),MAXCUT,ISPR(50,2,200),MAXSPR(2,200)
     X    ,JH(200,2),JHD(200,2),JHDD(200,2),IS1,NTIME,MODEL
     X    ,RATIO
      COMMON/COM2/ FEEDI(50,50),SFDI(50,200,2),SFDDI(50,200,2)
     X    ,SPDDI(50,200,2),CUTI(200,50,2),SPRI(50,2,200),XLDI(200,2)
     X    ,XNFI(50,50),SNDI(50,200,2),SNDDI(50,200,2),SPDI(50,200,2)
     X    ,XLOPT(200,2),GAMI(200),RLOPTI(200),XNDI(200,2)
      COMMON/COM3/  XL(200,2),XLD(200,2),XLDD(200,2),YLD(200,2)
     X             ,XN(200,2),XND(200,2),XNDD(200,2),YND(200,2)
     X             ,XLIMIT(200,2)
      COMMON/COM5/ SUML,SUMLD,SUMLDD,TFL,TPL(2),TWL,TFLN,TPLN(2),TWLN
     X            ,ANF,ANP,ANW,DUT,SFBAL,SFNBAL
      COMMON/COM0/ ICAS,IS2,IS3,IB2,IB3,SUMF
      COMMON/COMA/ EMPTY
C
      SUML=0.
      DO 10 J=1,IS3
      SUML=SUML+XL(J,1)
   10 CONTINUE
      DO 20 J=1,IB3
      SUML=SUML+XL(J,2)
   20 CONTINUE
      SUMLD=0.
      DO 110 J=1,IS3
      SUMLD=SUMLD+XLD(J,1)
  110 CONTINUE
      DO 120 J=1,IB3
      SUMLD=SUMLD+XLD(J,2)
  120 CONTINUE
      SUMLDD=0.
      DO 210 J=1,IS3
      SUMLDD=SUMLDD+XLDD(J,1)
  210 CONTINUE
      DO 220 J=1,IB3
      SUMLDD=SUMLDD+XLDD(J,2)
  220 CONTINUE
      JUMP=0
      IF(SUMLD.LE.EMPTY) JUMP=1
      RETURN
      END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```

Source Listing - V. 4.0 < ZERO0 : ccslc.f > Tue Nov 19 12:56:27 1991 Page 0039

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Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
              SUBROUTINE ZERO0(XX,N)
        C
              DIMENSION II(N),XX(N)
        C
              DO 10 I=1,N
              XX(I)=0.
           10 CONTINUE
              RETURN
        C
              ENTRY NINE1(II,N)
        C
              DO 30 I=1,N
              II(I)=999
           30 CONTINUE
              RETURN
              END
Seq.    ....+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
```