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PARAMETER STUDY ON JAPANESE PROPOSAL OF ITER HYDROGEN ISOTOPE SEPARATION SYSTEM

January 1991

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As part of Japanese design contribution in the ITER activity, conceptual design of an entire ITER tritium system and their safety analysis have been carried out through the three-year period since 1988. The tritium system includes the following subsystems;

- Fuelling (gas puffing and pellet injection) subsystem,
- Torus vacuum pumping subsystem,
- Plasma exhaust gas purification subsystem
- Hydrogen isotope separation subsystem,
- NBI gas processing subsystem,
- Blanket tritium recovery subsystem,
- Tritiated water processing subsystem,
- Tritium safety subsystem

Hydrogen isotope separation system is a key subsystem in the ITER tritium system because it is connected to all above subsystems. This report describes an analytical study on the Japanese concept of hydrogen isotope separation system.

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Keywords: Fusion Reactor, ITER, Tritium System, Hydrogen Isotope Separation, Cryogenic Distillation Column, Tritium Inventory, Helium Heat Load, Tritium Safety

ITER 用水素同位体分離システム設計
日本案の分離特性解析

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(1990年12月11日受理)

国際熱核融合実験炉（ITER）の燃料系概念設計において，日本はトリチウムにかかわるすべてのサブシステムに着目したプラント全体としての一貫性のある設計を行なった。ITER のトリチウムシステムは，以下のような多数のサブシステムから構成されるものである。

- 燃料供給系（ガスパフ系，ペレット入射系）
- トーラス排気系
- プラズマ排ガス精製系
- 水素同位体分離系
- NBI まわり重水素ガス処理系
- ブランケットトリチウム回収系
- 一次冷却水トリチウム処理系
- トリチウム安全設備系

水素同位体分離系は，プラズマに供給するトリチウムと重水素を所定の濃度に分離・濃縮するためのものであり，しかもほとんどのサブシステムから回収されるトリチウムを処理する役目を持っている。

本報は，日本が提案したITER用水素同位体分離システムについて実施したパラメータ解析及び設計（製品流D－T組成とトリチウムインベントリー，蒸留塔寸法及び，冷凍負荷との関係）の結果をまとめたものである。

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1. Introduction

Two major design concepts of ITER hydrogen isotope separation system (hereafter, ISS) have been proposed. One is the Japanese proposal composed of three independent separation systems; they are ISS(1) for processing plasma exhaust gas, and ISS(2) for both NBI regeneration gas and pellet injector propellant gas, and ISS(3) for blanket tritium recovery. The other is an integrated ISS proposed by Canada. It has been designed to treat all hydrogen isotopes from above tritium subsystems and tritiated water processing subsystems of primary cooling water and liquid waste processing. The Japanese design has taken into consideration large flexibility to meet uncertainty in the operation mode of ITER itself and its supporting subsystems.

Different fuelling technology such as gas puffing, pellet injection with single and double stages gas gun, centrifugal pellet injection, and neutral beam injection will be applied to the ITER. If the above fuelling subsystems can satisfy the plasma requirement of fuel composition of 50%D-50%T, the product tritium concentration from ISS can widely be changed between 60%T and pure tritium. Therefore requirement of tritium concentration for the hydrogen isotope separation system, which has the role to supply fuel gas (D-T) to all fuelling subsystems, has not been fixed yet.

Tritium inventory and ohter major parameters such as sizes and helium load of distillation of the ISS using cryogenic distillation column method are strongly influenced by the tritium concentration in the product stream.

The purpose of this analysis is to study the relationship between product tritium concentrations (60, 70, 80 and 90%T) and column parameters of the ISS.

2. Model of ISS

2.1 Process Model

Figure 1 shows the feature of Japanese proposal of ISS composed of two-interlinked distillation column. Each column has a feed back stream extracted from middle position of column. The isotopic equilibrators attached in the feed back streams are to dissociate bimolecules such as

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HT and DT. The isotopic reactions are 2HT → T2 + T2 for column 1 and 2DT → T2 + D2 for column 2.

2.2 Distillation Column Model

Figure 2 shows a schematic structure of the cryogenic distillation column, which is composed of shell & tube type condenser, packed section with Dixon Ring of 3mm in diameter, and reboiler with outer heater. A small cylindrical tank is inserted to minimize volumetrically liquid tritium inventory in the reboiler.

3. Design of Distillation Columns

To determine the major parameters of distillation columns against the different product tritium concentrations, the following design conditions were used.

(1) Feed gas flow rate
    75mol/h from plasma exhaust gas purification system

(2) Feed composition
    H: 1%, D: 49.5%, T: 49.5%

(3) Tritium concentration in top flow of Column 1
    less than 1mCi/litter-STP (40ppm)

(4) Tritium concentration in top flow of Column 2
    less than 0.1%

(5) Product tritium concentration (in bottom flow of Column 2)
    60%T, 70%T, 80%T, and 90%T

(6) Height equivalent to a theoretical plate (HETP)
    5 cm

(7) Maximum gas velocity in the column
    10 cm

(8) Total number of theoretical stages
    Column 1: 100
    Column 2: 60

(9) Feed stage position
    Column 1: 55th from top stage
    Column 2: 60th from top stage

(10) Middle extraction position
    Column 1: 60th from top stage

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    Column 2: 60th from top stage
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Column 2: 70th from top stage

(11) Middle extraction flow rate

60% of inner gas flow rate at the lower part of Columns 1 and 2.

The values in the items (1) through (4) were the reference parameters of ITER, and the values in the items (8) through (11) were determined to minimize tritium inventory in the columns.

Calculation results are summarized in Table 1. Figure 3 shows material flow balance in the reference case of the ISS, where isotopic composition of the product stream is 70%T-30%D.

4. Calculation Methods of Column Parameters

4.1 Column Performance

Concentration profiles for six species of hydrogen isotopes (T2, D2, H2, DT, HT and HD) were determined in the column design. Where the recycle ratio was converged as to meet the requirements of top tritium concentrations in the Columns 1 and 2.

4.2 Column Sizes and Helium Heat Load

Following to above convergence calculation, sizes of column, helium heat load for distillation, etc. were estimated as follows.

(1) Packed section diameter; d (cm)

$$d = \sqrt{G/((\pi/4) \times V_G)}$$

G(cm^3/sec); maximum gas flow rate in column

= gas flow rate at Top in cases of this study

V_G(cm/sec); maximum gas velocity designed

(= 10 cm/sec in this study)

(2) Packed section length; I (cm)

$$I = HETP \times M$$

M; Total stage number

(H E T P = 5 cm in this study)

(3) Helium heat load for feed; Q_F (W)

$$Q_F = \frac{H}{3600} \times (F + F')$$

Column 2: 70th from top stage

(11) Middle extraction flow rate

60% of inner gas flow rate at the lower part of Columns 1 and 2.

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$$Q_F = \frac{H}{3600} \times (F + F')$$

H(J/mol) ; feed gas enthalpy change
(= 664 J/mol in this study
assuming D_2 enthalpy changes from 50K to 20K)

F(mol/hr) ; feed gas flow rate

F'(mol/hr); middle extraction gas flow rate

(4) Helium heat load for condenser; Q_C (W)

$$Q_C = \frac{H_{GL}}{3600} \times W$$

H_{GL}(J/mol); sublimation enthalpy
(= 1276 J/mol in this study assuming D_2 at 20K)

W(mol/hr); hydrogen isotopes condensation rate
(= liquid flow rate at top)

(5) Total helium heat load; Q (W)

$$Q = SF_1 \times (Q_F + Q_C)$$

SF_1(-); Safety factor considering heat loss
(= 1.5 in this study)

Q_F, Q_C; above (3)(4)

(6) Reboiler heat load; U (W)

$$U = SF_2 \times H_{GL} \times V/3600$$

V(mol/hr); gas flow rate at bottom

H_{GL}(J/mol); showed above (4)

SF_2(-) ; Safety factor considering heat loss
(= 1.5 in this study)

(7) Condenser heat transfer area; A_C (cm^2)

$$A_C = Q_C/(h \times T)$$

h(W/cm^{2}K); condenser heat transfer coefficient
(= 0.012 W/cm^{2}K = 100 kcal/m^{2}hrK in this study)

T(K); temperature difference between hydrogen gas and helium gas (= 1.0K in this study)

Q_C(W); helium load for condenser (above (4))

(8) Reboiler heat transfer area; A_R (cm^2)

$$A_R = U/H$$

H(W/cm^2); heat transfer density from reboiler heat transfer wall to liquid hydrogen
(= 1.0 W/cm^2 in this study)

U(W); reboiler heater load (above (6))

(9) Condenser diameter; d_C

$$V_C = SF_3 \times A_C/A$$

$$d_C = (V_C/(\beta\pi/r))^{1/3}$$

$V_C(cm^3)$; condenser volume

$A_C(cm^2)$; condenser heat transfer area (above (7))

A(-); ratio of heat transfer tube area to condenser volume (= 1.4 in this study assuming 1 cm diameter tubes with 1.5 cm pitch)

$SF_3(-)$; safety factor for condenser volume

$\beta(-)$; ratio of condenser length to condenser diameter

(10) Condenser length; l_C (cm)

$$l_C = \beta \times d_C$$

β, d_C; above (9)

(11) Reboiler diameter; d_R (cm)

$$d_R = \gamma \times d$$

d(cm); packed section diameter (above (1))

$\gamma(-)$; ratio of reboiler diameter to column diameter (= 1.0 in this study)

(12) Reboiler length; l_R (cm)

$$l_R = A_R/(\pi \times d_R)$$

$A_R(cm^2)$; reboiler heat transfer area (above (8))

$d_R(cm)$; above (11)

On above equation, reboiler heat transfer area is assumed to be inner wall of reboilr.

(13) Total column length; l_T (cm)

$$l_T = d_C + l_C + d + l + d + l_R$$

Here, the column structure shown in Fig. 2 is assumed.

4.3 Tritium Inventory

(1) Condenser inventory; I_C(g)

$$I_C = (t_L \times A_C + \alpha \times P/700 \times V_C) \times X_C) \times \rho_L$$

t_L(cm); liquid hydrogen isotope thickness on heat transfer tube (= 0.01 cm, in this study)

A_C(cm^2); condenser heat transfer area (above 4.2(7))

α(-); ratio of gas hydrogen isotope density to liquid hydrogen isotope density at pressure of 700 Torr (= 1.31×10^{-2} in this study)

P(Torr); operation pressure
= 700 Torr for column 1
= 600 Torr for column 2

V_C(cm^3); condenser volume (above 4.2(9))

X_C(-); tritium concentration at condenser

ρ_L(g/cm^3); density of liquid T_2 (= 0.27 g/cm^3 in this study)

(2) Reboiler inventory; I_R(g)

$$I_R = (\pi/4) \times \{d_R^2 - (d_R - 2g)^2\} \times l_R \times \rho_L \times X_R$$

d_R(cm); reboiler diameter (above 4.2(11))

l_R(cm); reboiler length (above 4.2(12))

g(cm); gap between reboiler inner wall and inner spacer (= 1.0 cm in this study)

ρ_L(g/cm^3); above (1)

X_R(-); tritium concentration at reboiler

(3) Packed section inventory; I_P(g)

$$I_P = (\pi/4) \times d^2 \; HETP \times \rho_L \times \{K_L \times \sum_{i=1}^{M} Xi + (1 - K_L) \times \alpha \times \frac{P}{700} \times \sum_{i=1}^{M} Yi\}$$

d(cm); packed section diameter (above 4.2(1))

H E T P; above 4.2(2)

ρ_L(g/cm^3); above (1)

K_L(-); volume ratio of liquid hydrogen isotopes in packing space

α(-); above (1)

P(Torr); above (1)

Xi(-); tritium concentration in liquid hydrogen isotopes at i-th theoretical stage

Yi(-); tritium concentration in gas hydrogen isotopes at i-th theoretical stage

M; total theoretical stage number
= 100 for column 1
= 80 for column 2

(4) Total tritium inventory; I (g)

$$I_T = I_C + I_R + I_P$$

I_C, I_R, I_P(g); above (1)(2)(3)

5. Results of Calculation

5.1 Distillation Column Performance

Isotopic composition of the top and bottom streams in the Column 2 are shown for the different product tritium concentrations (60%, 70%, 80% and 90%). The concentration profiles of D2, DT and T2 in the columns are shown in Figs. 4 - 8. Table 2 summarizes isotopic composition in feed and extraction streams. Figure 9 shows material balance sheet for the reference case of 70%T-30%D.

5.2 Sizes of Distillation Columns

Table 3 summarizes the calculation results of sizes, helium heat load and tritium inventory of each distillation column. The influence of the product tritium concentration on these parameters in the Column 2 can be seen in Figs. 10 - 12. Both tritium inventory and helium heat load exponentially increase with tritium concentration. Total tritium inventory and total helium heat load in the reference case are respectivley 40% and 56% of that of 90%T-10%D.

5.3 Design of Reference ISS

Based on the above analysis of distillation column against different product tritium concentration in the second column, the reference ISS (product concentration of 70%T-30%D) with two-interlinked columns was designed. Figs. 13 and 14 show dimensions of major parts of Column 1 and 2, respectively. Figure 15, cryogenic assembly of the two columns, shows schematic structure of thermal shielding with liquid nitrogen and outer vacuum jacket. From the viewpoint of tritium safety handling, the vacuum jacket can serve as the secondary barrier of tritium containment.

M; total theoretical stage number
= 100 for column 1
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Figure 16 reveals space requirement for the reference ISS, in which the emergency suppression tank can contain whole hydrogen isotope inventory in case of loss of helium refrigerant accident. Small components such as bellows, pumps and surge tanks will be installed in tritium-tight gloveboxes for the secondary tritium containment and in situ maintenance.

6. Conclusion

Many design parameters of ITER and its supporting systems have been revised by the progress of system design and their technology in the ITER conceptual design activity (CDA). The design requirements such as tritium concentration and feed flow rate of hydrogen isotope separation system must also be reviewed with the changes of the ITER parameters.

In the first year of CDA, we have proposed a flexible separation system composed of three independent cryogenic distillation subsystems by taking into consideration large uncertainty of ITER operation. In the second year we have analysed the effect of changes of the tritium enrichment (from 60%T through 90%T) in the distillation column parameters. For the case of higher enrichment of tritium of 90%T-10%D, the tritium inventory and the helium heat load in the second column are about five times of that for the enrichment of 60%T-40%D.

Major column parameters determined by this study of the Japanese proposal of the ISS are as follows;

		Column 1	Column 2
Total length	(cm)	601.8	504.7
Column diameter	(cm)	4.9	5.6
Tritium inventory	(g)	83.9	128.9
Helium heat load	(W)	226.7	243.6

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Table 1 Design Conditions of ITER Isotope Separation System
(Feed stages; 55th in Column 1, 60th in Column 2)

		COLUMN 1	COLUMN 2			
TORITIUM CONCENT-RATON	FEED	49.5%	50%			
	TOP	≦0.4ppm *	≦0.1%			
	BOTTOM (PRODUCT)	50%	60%	70% (Ref.)	80%	90%
FLOW RATE (mol/hr)	FEED	75.00	74.00	74.00	74.00	74.00
	TOP EXTRACTION	1.00	12.33	21.14	27.74	32.75
	BOTTOM EXTRACTION	74.00	61.67	52.86	46.26	41.25
	MIDDLE EXTRACTION	169.35	98.05	193.40	310.68	528.00
	INNER GAS AT TOP	319.75	200.41	359.33	554.80	917.00
	INNER GAS AT BOTTOM	282.25	163.41	322.33	517.80	880.00
TOP RECYCLE RATIO (−)		318.75	15.25	16.00	19.00	26.00
THEORI-TICAL STAGE No. (−)	TOTAL	100	80	80	80	80
	FEED **	55	60	60	60	60
	MIDDLE EXTRUCTION **	65	70	70	70	70
OPERATION PRESSURE		700 Torr	600 Torr			
H.E.T.P		5.0 cm				
INNER GAS VELOCITY (MAX.)		10.0 cm/sec				

* 0.4ppm tritium is corresponding to 1 mCi/Nℓ tritium
** STAGE is numbered from Top to Bottom.
; These values are results of convergence calculataion to attain Top tritium concentration. designed.

Table 2 Isotopic Composition in Feed and Extraction Streams
(Feed stages; 55th in Column 1, 60th in Column 2)

		COLUMN 1		COLUMN 2		
PRODUCT TRITIUM DESIGNED		——	——	60%	70%	90%
FEED (mol. ratio)	H	0.010	9.4E-5	9.4E-5	9.4E-5	9.4E-5
	D	0.495	0.498	0.498	0.498	0.498
	T	0.495	0.502	0.502	0.502	0.502
TOP EXTRACTION (mol. ratio)	H	0.743	5.4E-4	3.3E-4	2.5E-4	2.1E-4
	D	0.026	0.999	0.999	0.999	0.999
	T	2.4E-7 *	7.9E-4 *	6.3E-4 ***	4.7E-4 **	5.4E-4 **
BOTTOM EXTRACTION (mol. ratio)	H	9.4E-5	5.4E-6	7.1E-7	1.8E-7	4.8E-8
	D	0.498	0.398	0.298	0.198	0.101
	T	0.502	0.602	0.702	0.802	0.899

* COLUMN 1 Top tritium is 0.24ppm ≦ 0.4ppm (DESIGN CONDITION)
** COLUMN 2 Top tritium are 0.04~0.08% ≦ 0.1% (DESIGN CONDITION)

Table 3 Comparison of Column Specifications
(Feed stages; 55th in Column 1, 60th in Column 2)

		COLUMN 1	COLUMN 2			
PRODUCT TRITIUM DESIGNED			60%	70%	80%	90%
SIZE OF COLUMN (cm)	DIA. OF PACKED SPACE	4.9	4.2	5.6	6.9	8.9
	LENGTH OF PACKED SPACE	500.0	400.0	400.0	400.0	400.0
	TOTAL LENGTH	601.8	483.9	504.7	523.7	550.0
TRITIUM INVENTORY (g)	PACKED SPACE	67.9	54.3	102.2	171.5	345.2
	REBOILER	16.0	10.7	26.7	50.7	101.2
	TOTAL	83.9	65.0	128.9	222.2	446.4
HELIUM LOAD (W)	FEED & RECYCLE	38.2	24.9	42.5	64.1	104.2
	CONDENSER	113.0	66.7	119.9	186.8	313.4
	TOTAL *	226.7	137.4	243.6	376.4	626.4

* TOTAL HERIUM LOADS are 1.5 times of FEED & RECYCLE LOAD and CONDENSER LOAD

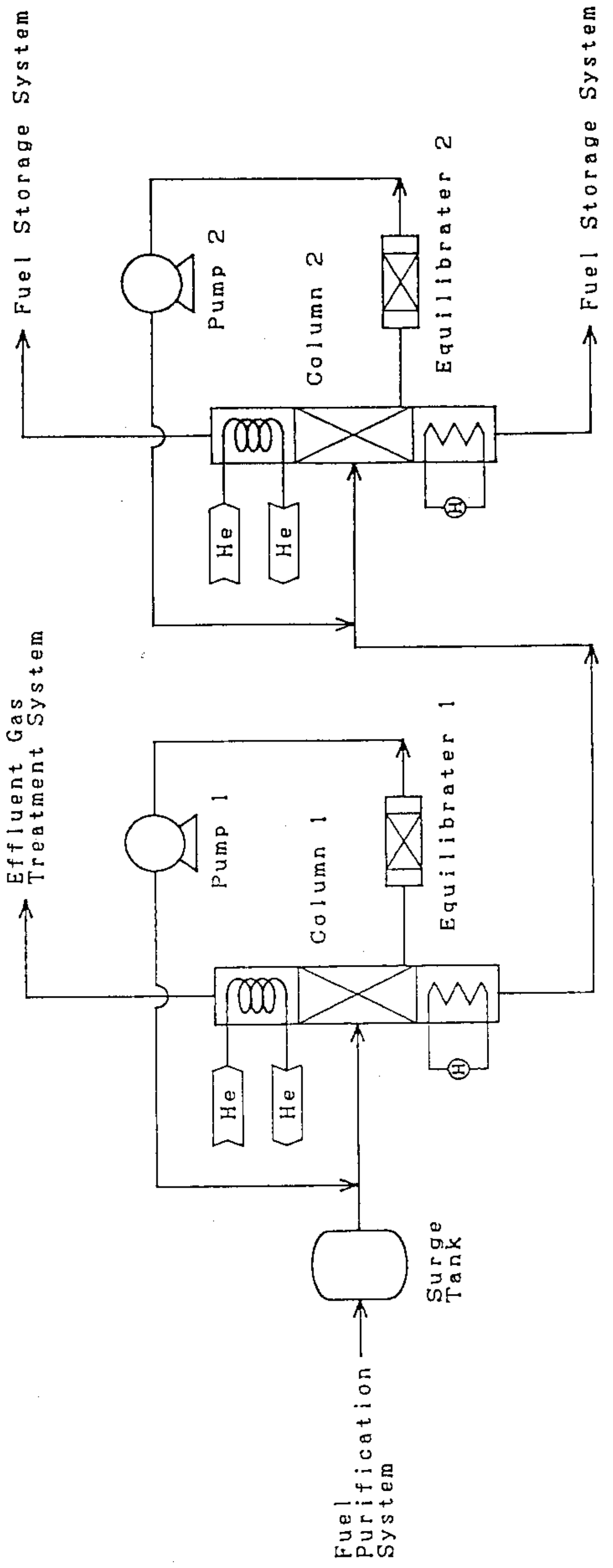


Fig. 1 Model of Japanese Proposal for ITER Isotope Separation System

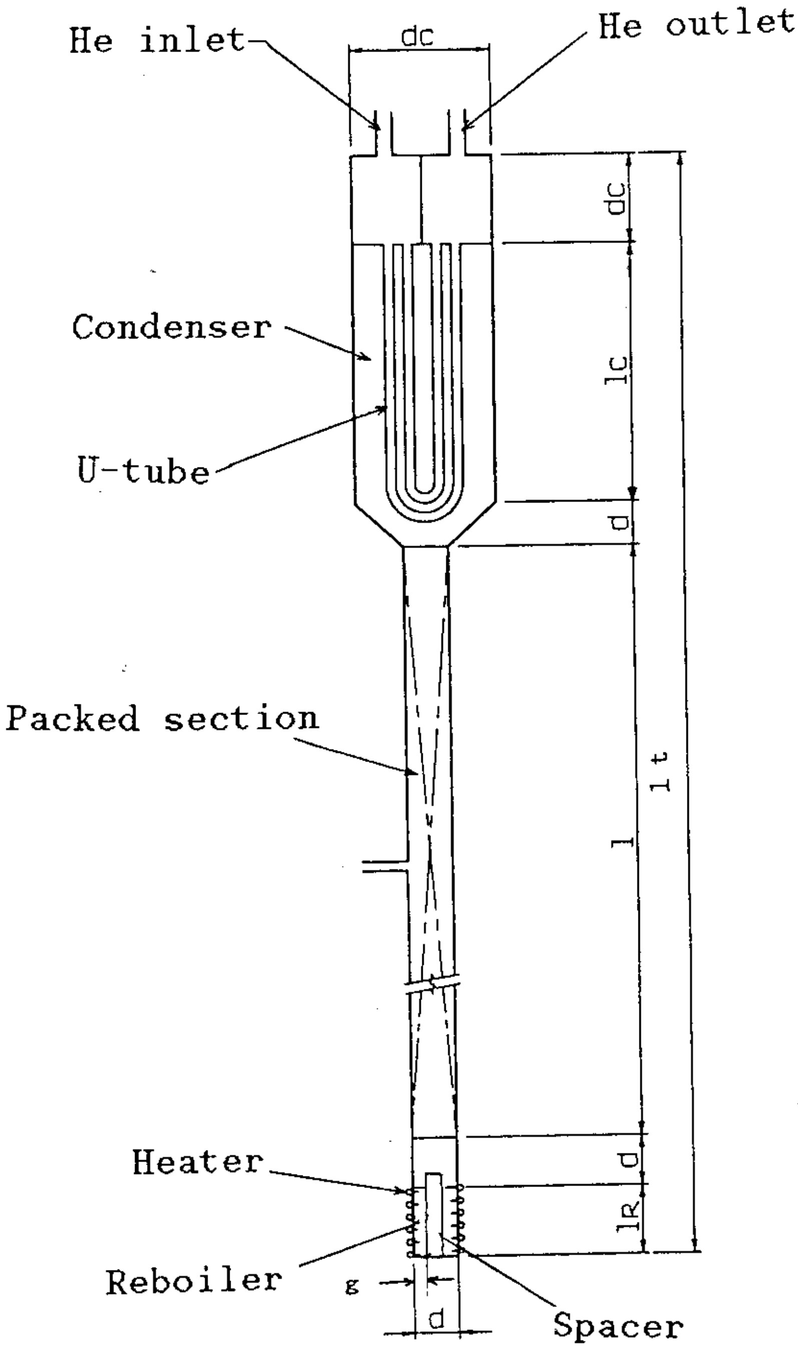


Fig. 2 Model of Cryogenic Distillation Column

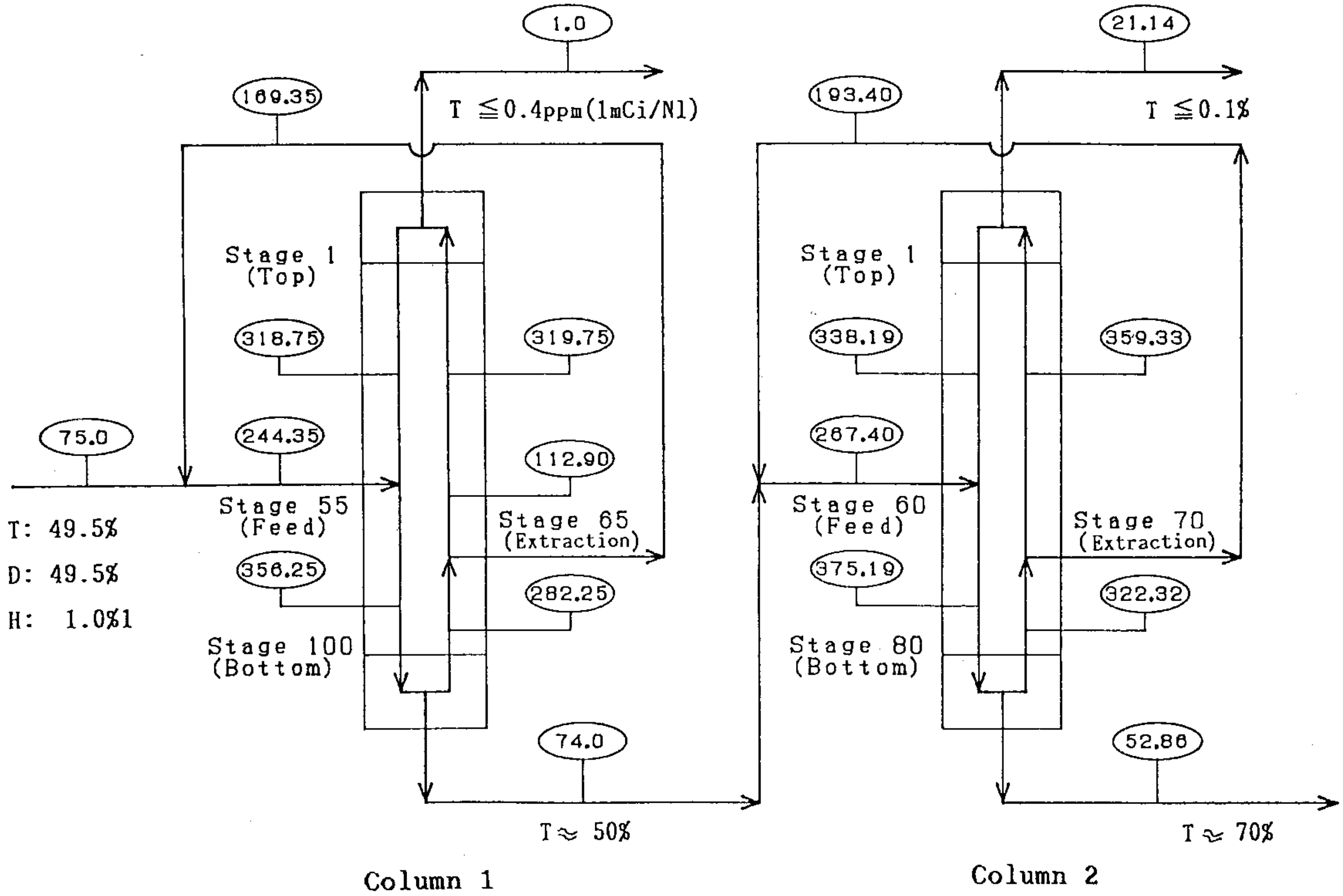


Fig. 3 Flow Balance in the Reference Isotope Separation System
(Product tritium concentration: 70%T-30%D)

Unit (mol/hr)

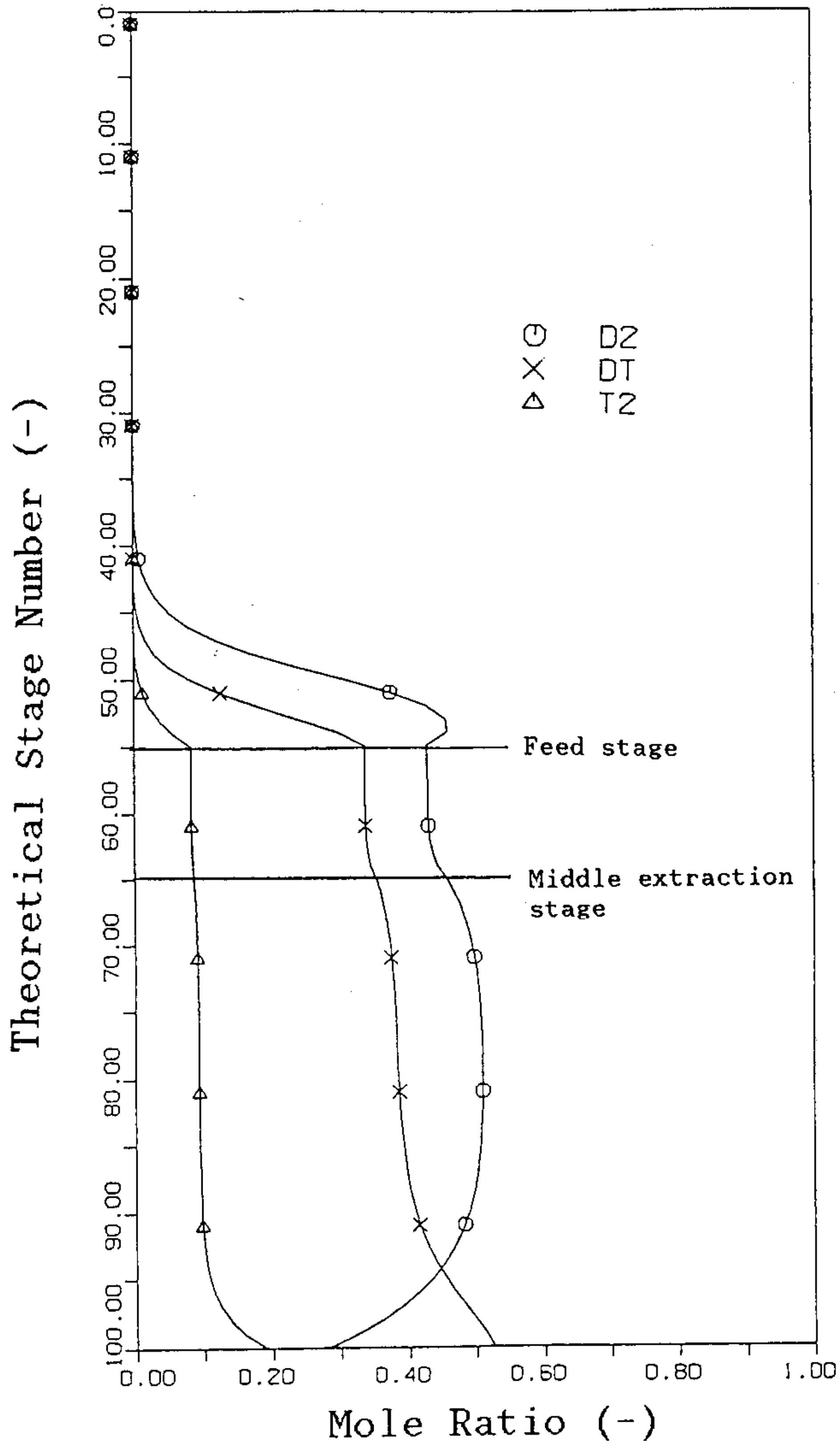


Fig. 4 Concentration Profiles in the Column 1

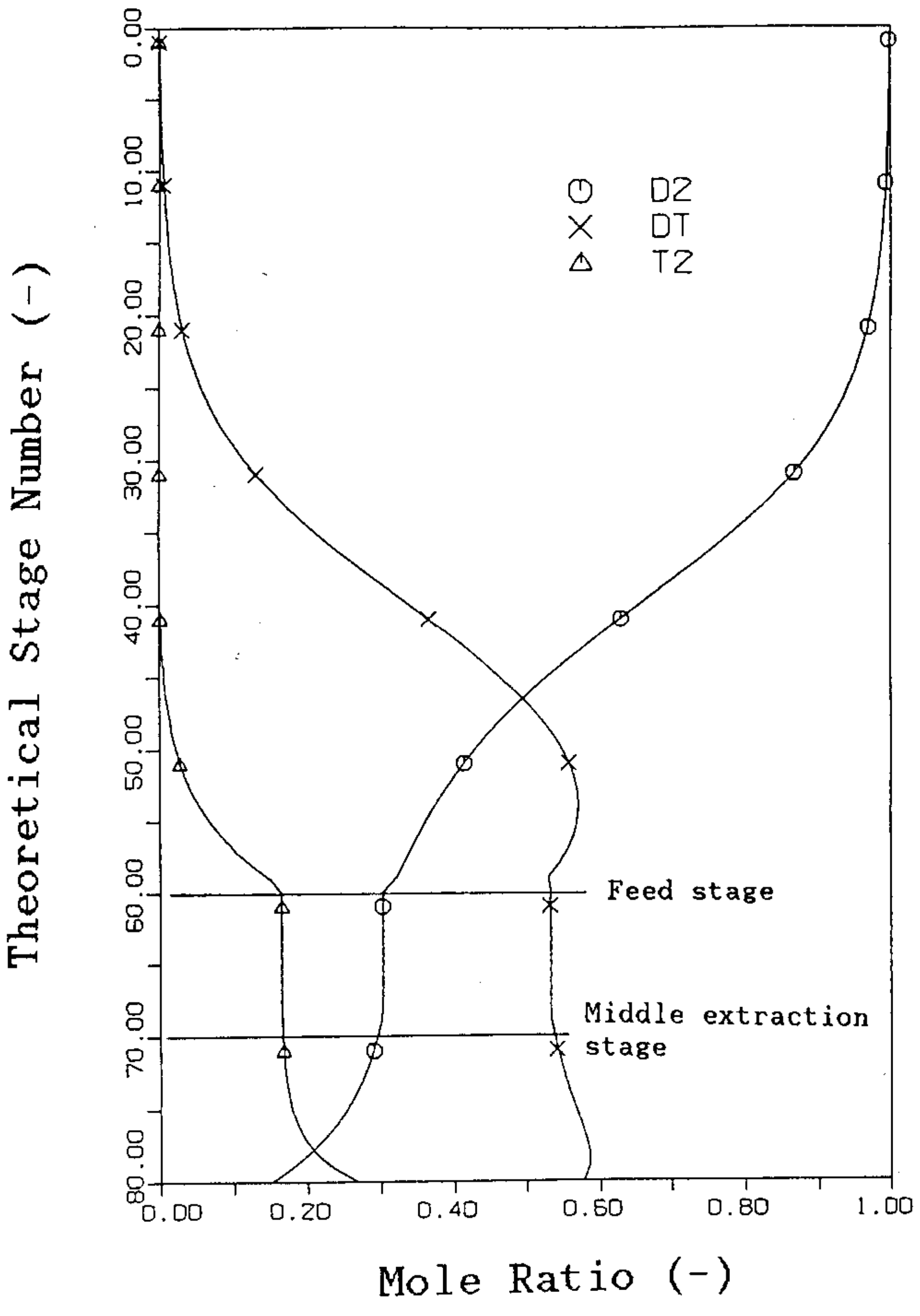


Fig. 5 Concentration Profiles in the Column 2
(Product tritium concentration: 60%T-40%D)

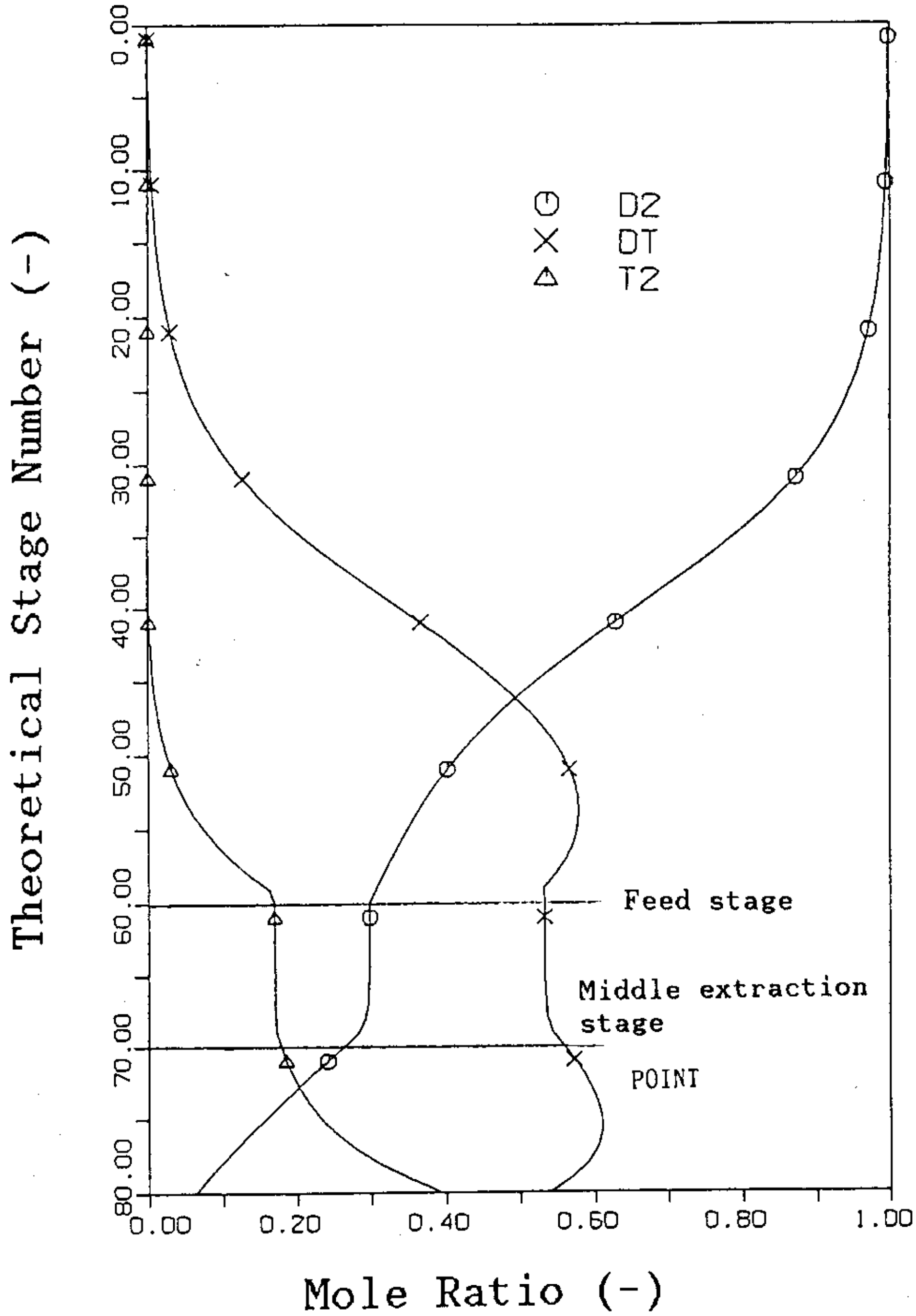


Fig. 6 Concentration Profiles in the Column 2
(Product tritium concentration: 70%T-30%D)

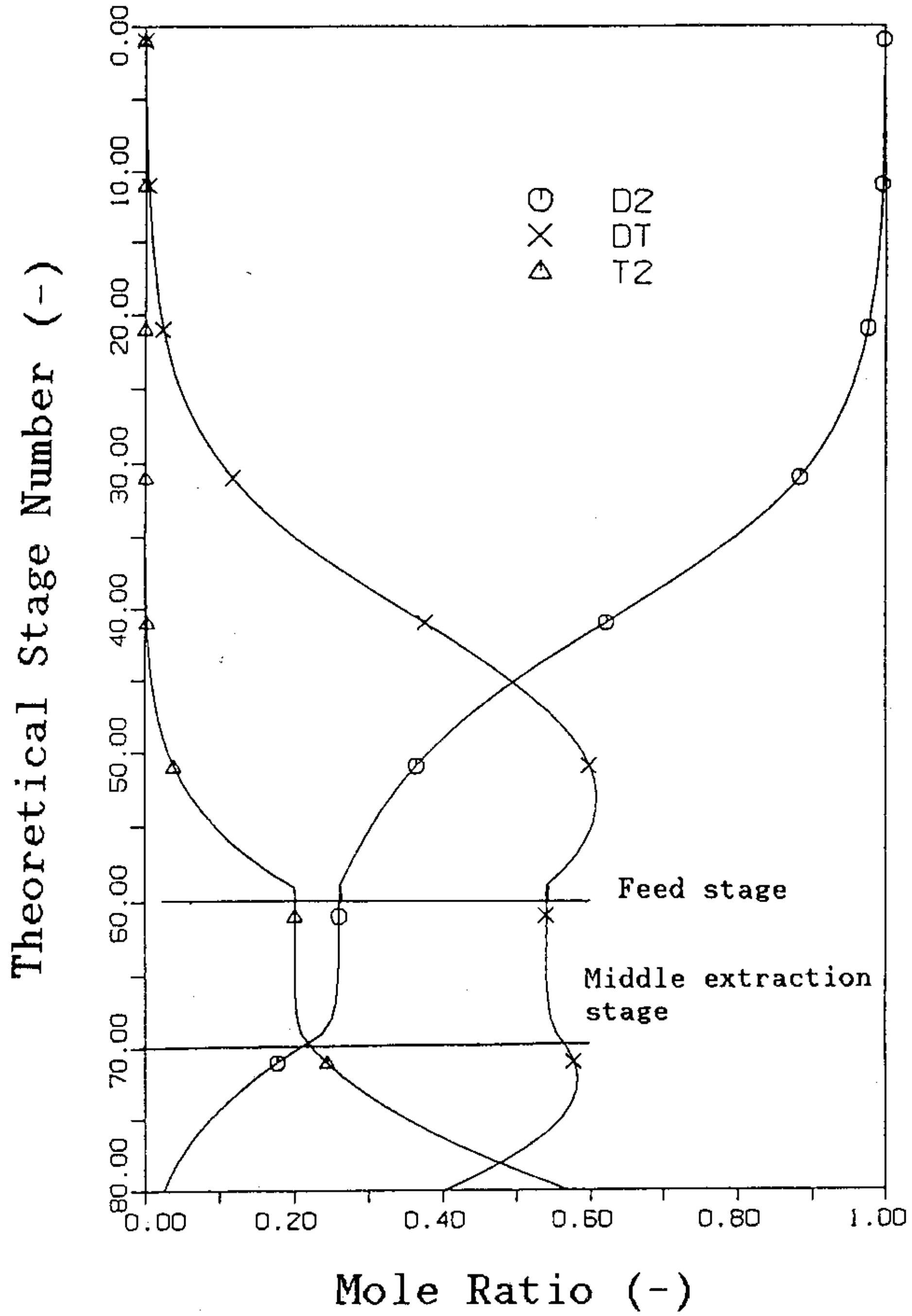


Fig. 7 Concentration Profiles in the Column 2
(Product tritium concentration: 80%T-20%D)

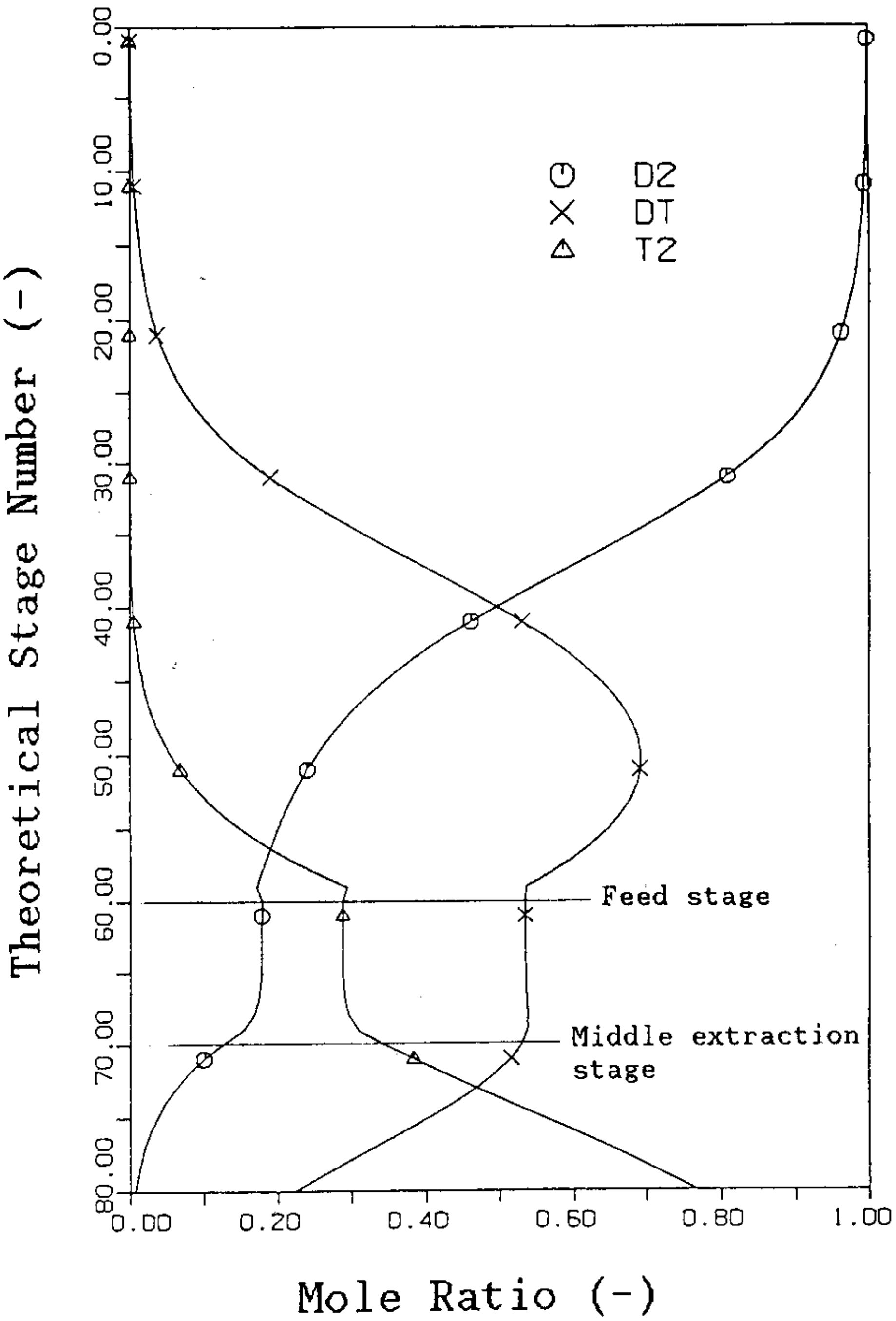
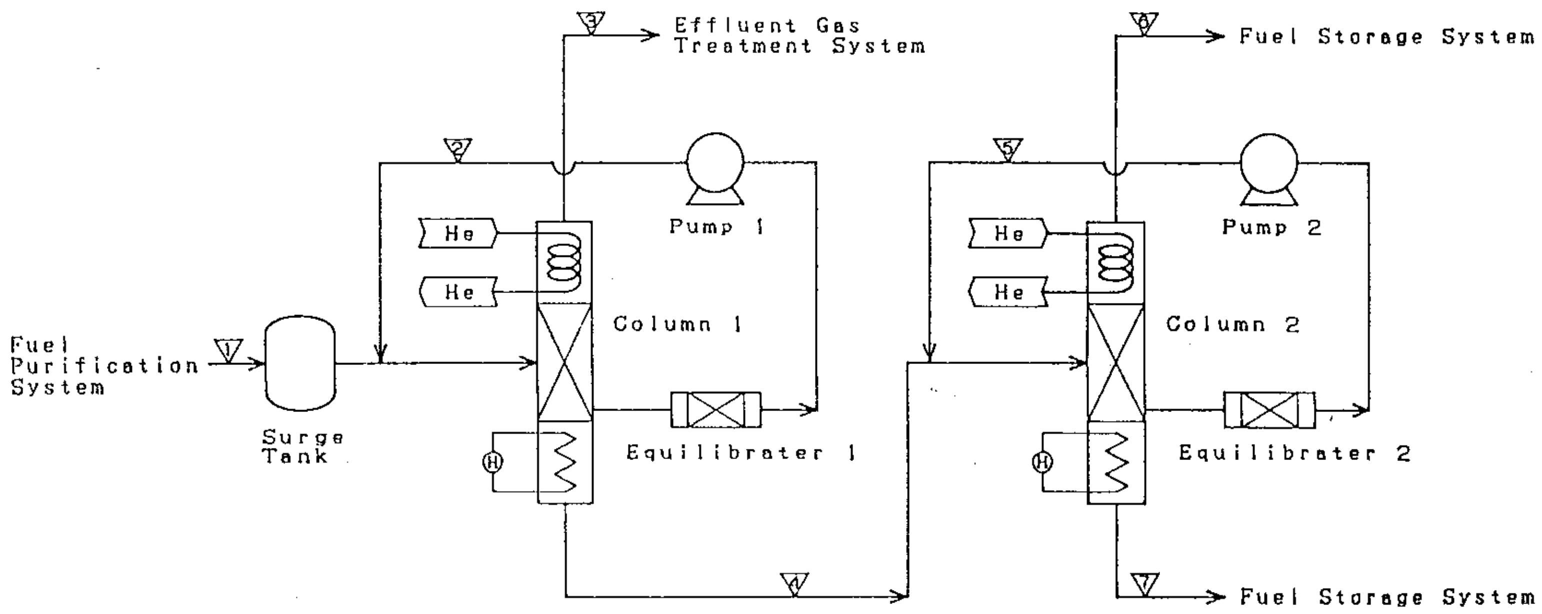


Fig. 8 Concentration Profiles in the Column 2
(Product tritium concentration: 90%T-10%D)



Point		Column 1			Column 2			
		1	2	3	4	5	6	7
Flow Rate (mol/hr)		75.0	169.4	1.0	74.0	193.4	21.14	52.86
Atom CONCENT-RATION(-)	H	1.0 E-2	5.0 E-2	7.43 E-1	9.3 E-5	3.5 E-5	3.3 E-4	7.1 E-7
	D	4.95 E-1	6.79 E-1	2.57 E-1	4.98 E-1	5.42 E-1	9.99 E-1	2.98 E-1
	T	4.95 E-1	2.71 E-1	2.4 E-7	5.02 E-1	4.58 E-1	6.3 E-4	7.02 E-1

Fig. 9 Material Balance in the Reference Isotope Separation System

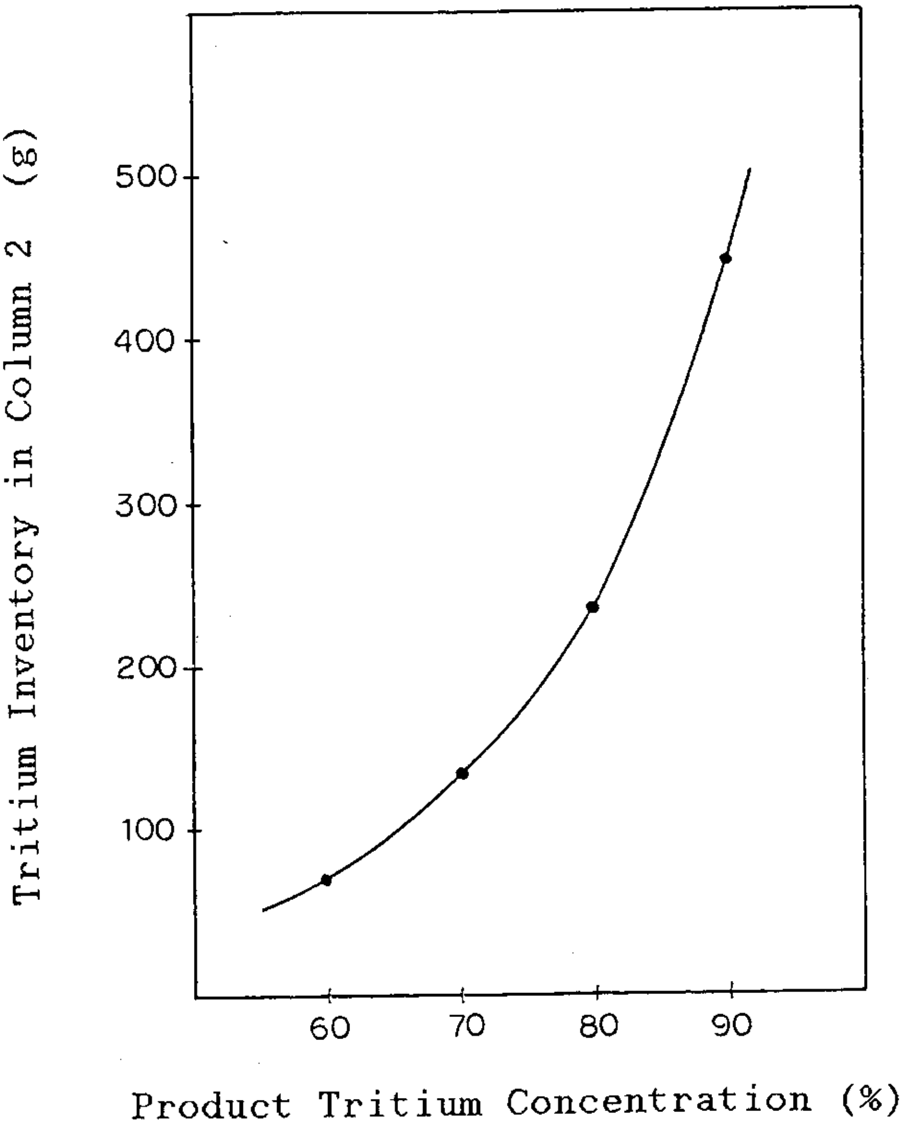


Fig. 10 Relationship between Column 2 Tritium Inventory and Product Tritium Concentration

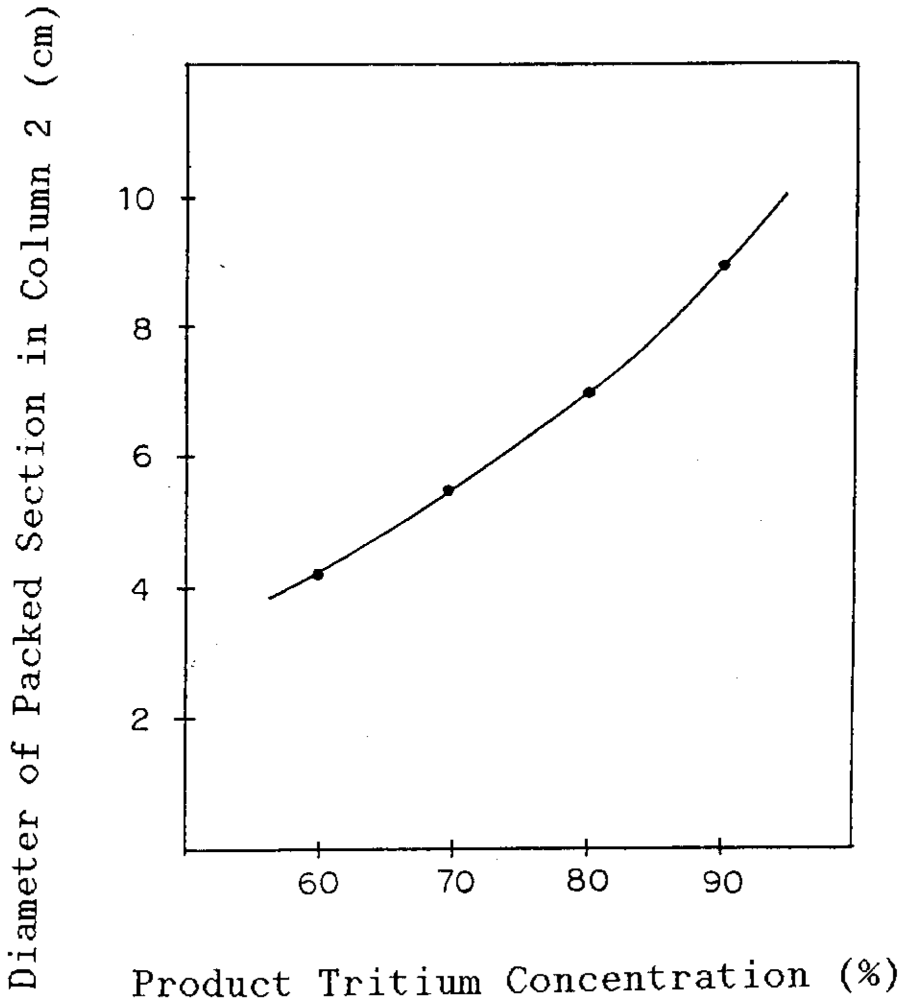


Fig. 11 Relationship between Column 2 Diameter and Product Tritium Concentration

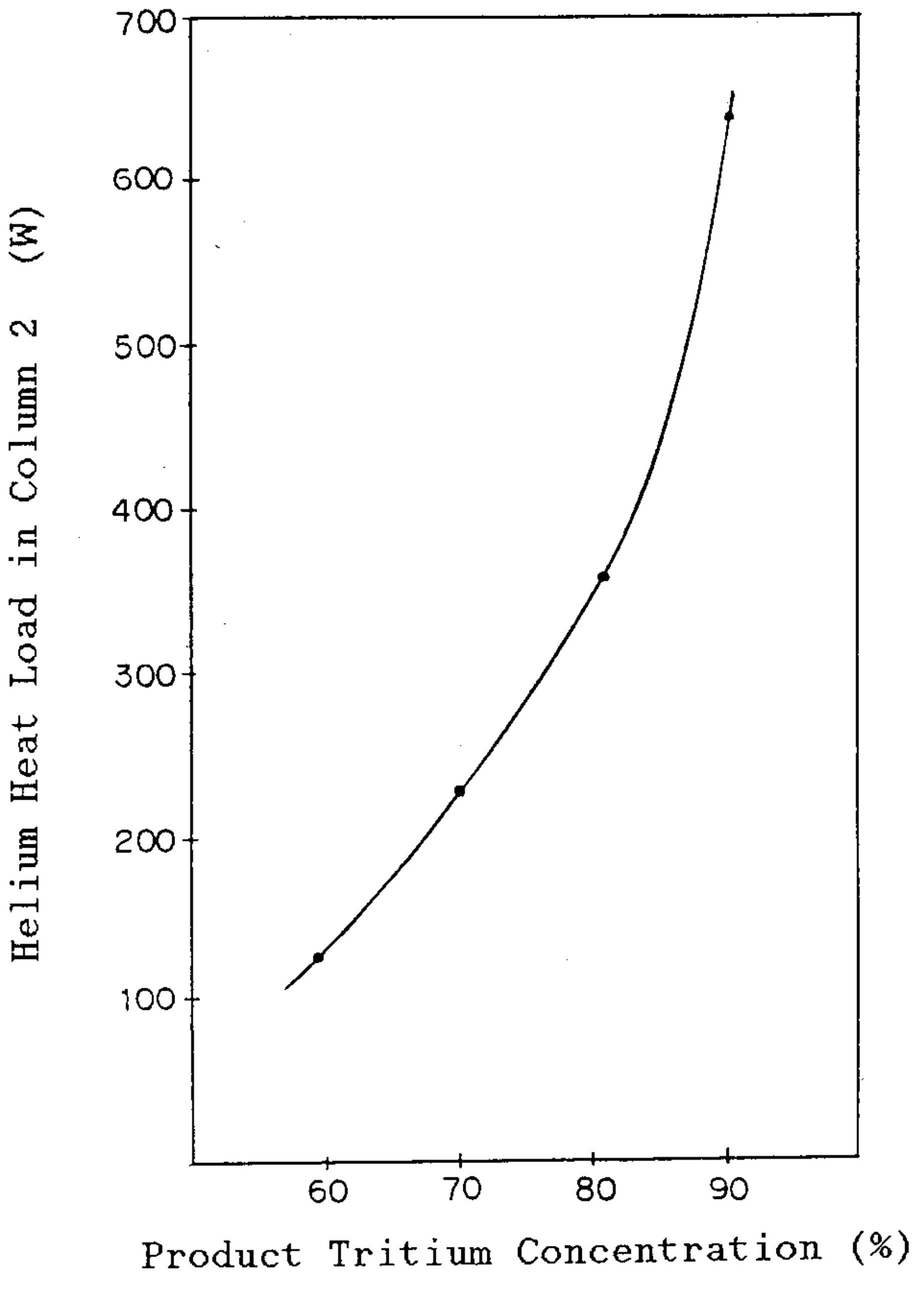


Fig. 12 Relationship between Column 2 Helium Heat Load and Product Tritium Concentration

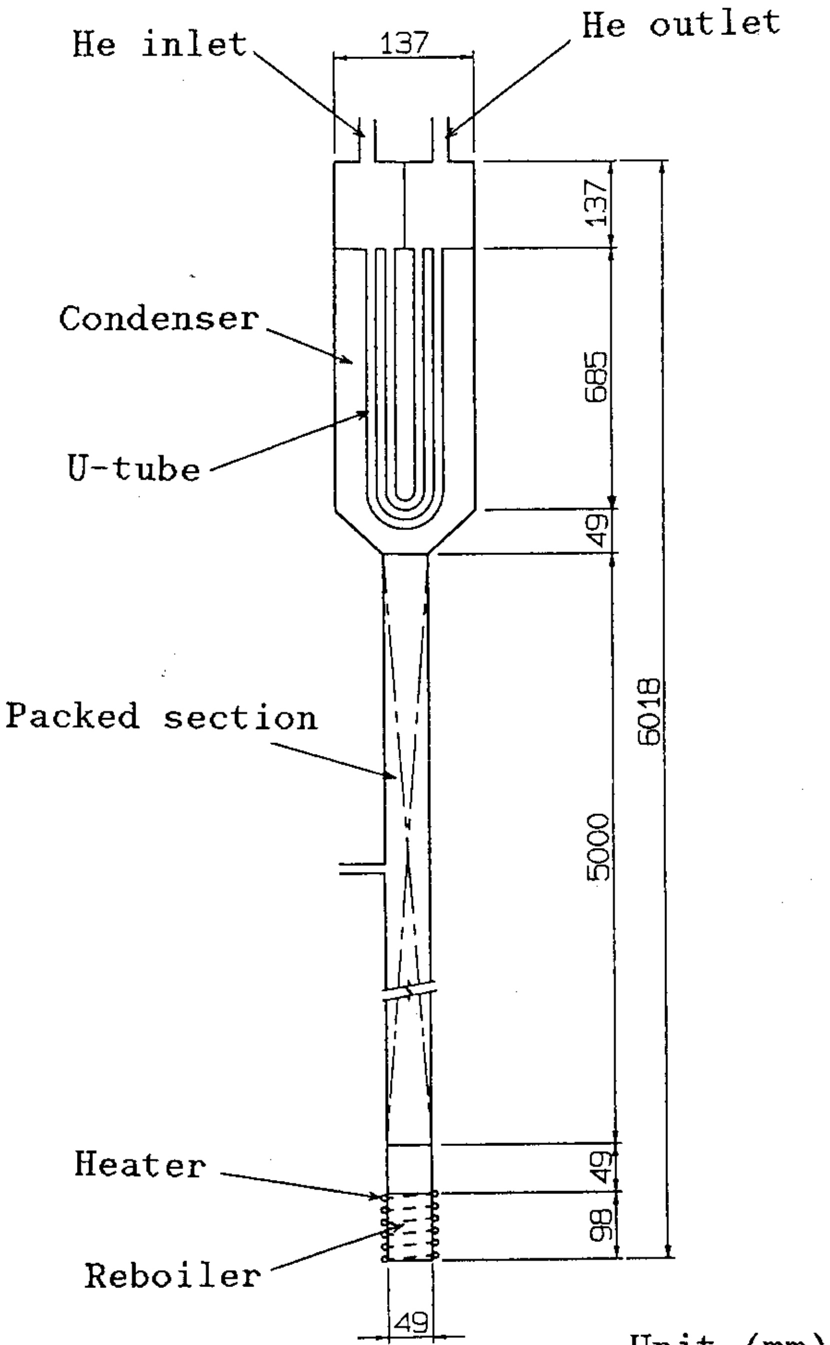


Fig. 13 Dimensions of Column 1 in the Reference Isotope Separation System

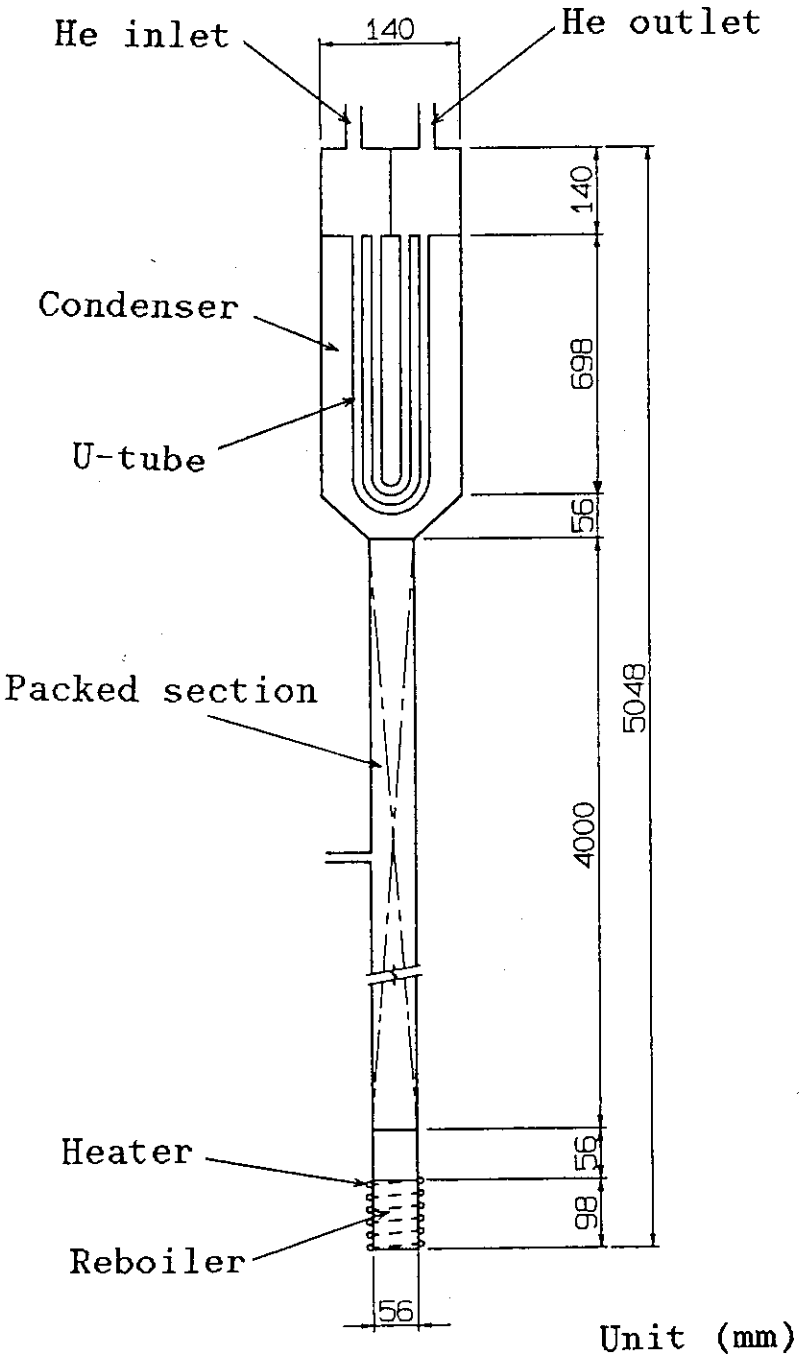


Fig. 14 Dimensions of Column 2 in the Reference Isotope Separation System

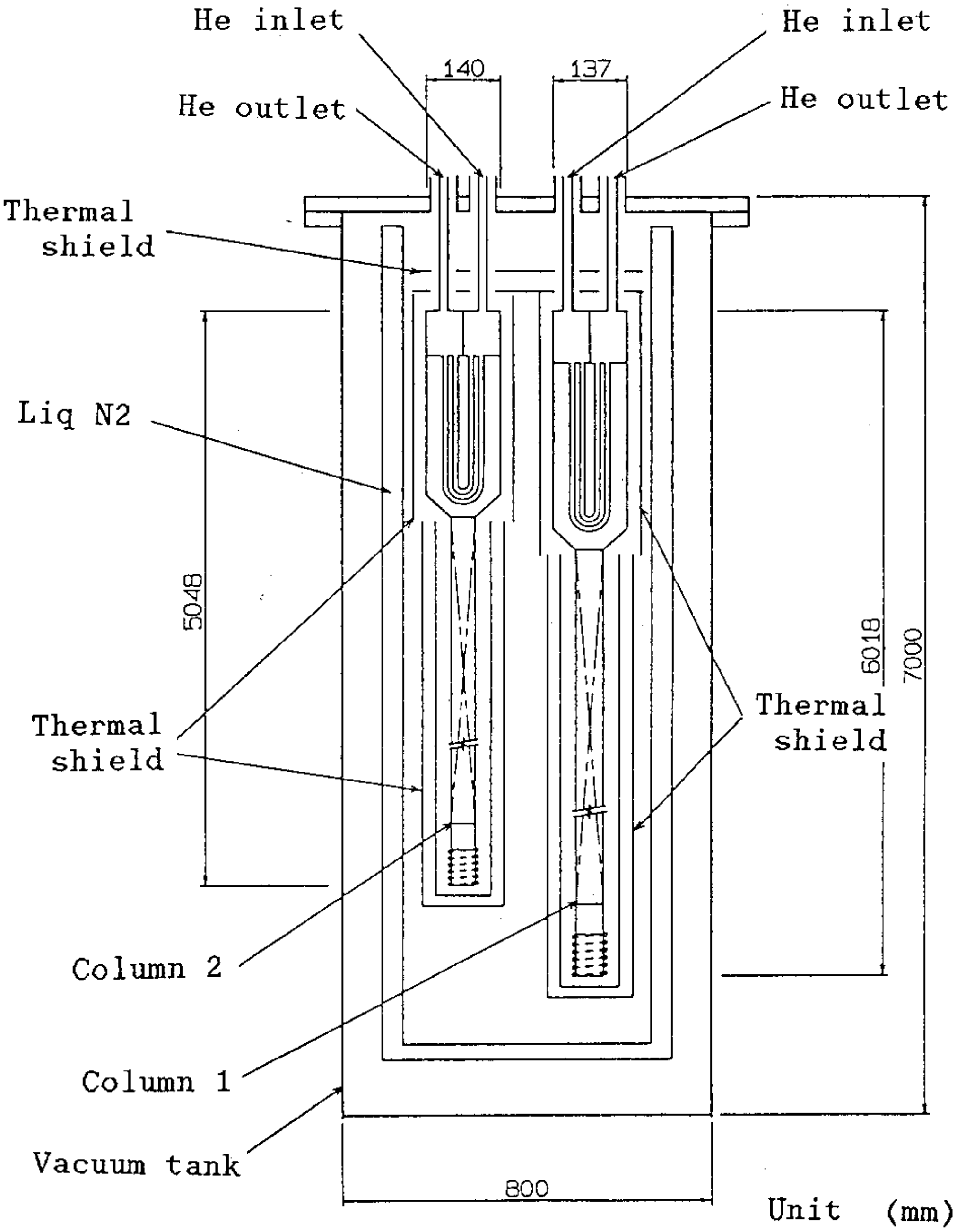


Fig. 15 Conceptual Setup of Distillation Columns for the Reference Separation System

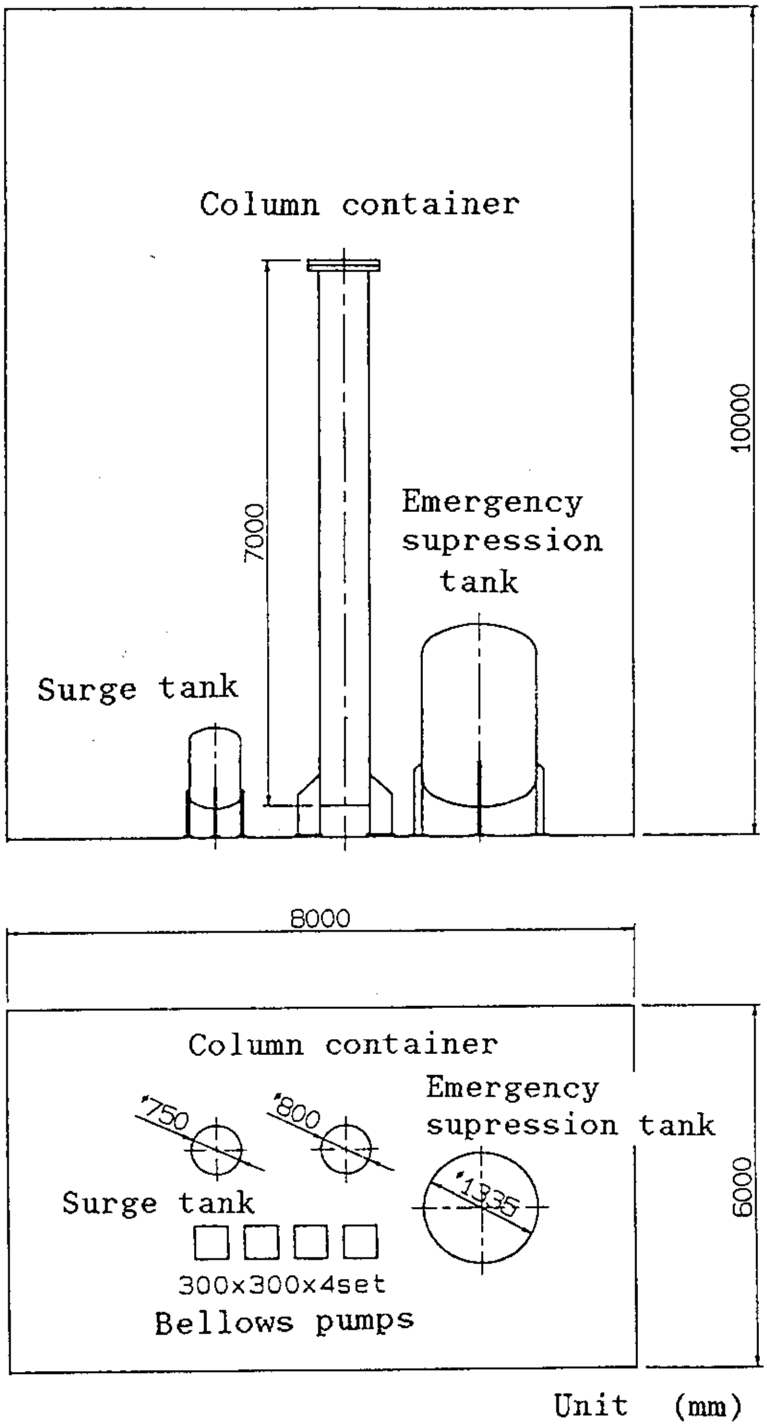


Fig. 16 Conceptual Layout and Dimensions of Reference Isotope Separation System

Appendix Influence of Change in Feed Stage Positions on the Column Design

When the requirements of isotopic compositions in the inlet and outlet streams of the ISS are fixed, the stage positions of feed and middle extraction are one of the key parameters of column optimization.

In order to compare with previous design of the second column (feed; 60th stage, middle extraction; 70th stage), four cases of the second columns with the feed of 50th stage and the middle extraction of 60th stage was studied. Table A-1 summarizes the column design conditions, where all parameters except feed and middle extraction stages are same as that in Table 1.

Calculation results are shown both in Tables A-2 and A-3 and Figs. A-1 - A-4. Tritium inventory, column diameter and helium heat load of the second column are compared with that for the column of 60th feed stage and 70th middle extraction stage in Figs. A-5 - A-7. It is apparent that optimum stage position of these parameters varies with product tritium concentration. In case of the Japanese reference ISS (product tritium concentration; 70%T-30%D), tritium inventory for the feed stage of 50th is slightly greater than that for the feed of 60th, but differences of the column diameter and helium heat load among two cases are very little.

Table A-1 Design Conditions of Isotope Separation System with Feed Stages of 55th in Column 1 and 50th in Column 2

		COLUMN 1	COLUMN 2			
TORITIUM CONCENT-RATON	FEED	49.5%	50%			
	TOP	≤0.4ppm *	≤0.1%			
	BOTTOM (PRODUCT)	50%	60%	70% (Ref.)	80%	90%
FLOW RATE (mol/hr)	FEED	75.00	74.00	74.00	74.00	74.00
	TOP EXTRACTION	1.00	12.33	21.14	27.74	32.75
	BOTTOM EXTRACTION	74.00	61.67	52.86	46.26	41.25
	MIDDLE EXTRACTION	169.35	114.47	193.40	285.71	390.45
	INNER GAS AT TOP	319.75	228.20	359.33	513.19	687.75
	INNER GAS AT BOTTOM	282.25	191.16	322.33	476.19	650.75
TOP RECYCLE RATIO (—)		318.75	17.50	16.00	17.50	20.00
THEORI-TICAL STAGE No. (—)	TOTAL	100	80	80	80	80
	FEED **	55	50	50	50	50
	MIDDLE EXTRUCTION **	65	60	60	60	60
OPERATION PRESSURE		700 Torr	600 Torr			
H.E.T.P		5.0 cm				
INNER GAS VELOSITY (MAX.)		10.0 cm/sec				

* 0.4ppm tritium is corresponding to 1 mCi/Nℓ tritium
** STAGE is numbered from Top to Bottom.
; These values are results of convergence calculataion to attain Top tritium concentration. designed.

Table A-2 Isotopic Composition in Feed and Extraction Streams
(Feed Stages; 55th in Column 1 and 50th in Column 2)

		COLUMN 1	COLUMN 2			
PRODUCT TRITIUM DESIGNED		——	60%	70% (Ref.)	80%	90%
FEED (mol. ratio)	H	0.010	9.4E-5	9.4E-5	9.4E-5	9.4E-5
	D	0.495	0.498	0.498	0.498	0.498
	T	0.495	0.502	0.502	0.502	0.502
TOP EXTRACTION (mol. ratio)	H	0.743	5.5E-4	3.3E-4	2.5E-4	2.1E-4
	D	0.026	0.998	0.999	0.999	0.999
	T	2.4E-7 *	8.8E-4 **	9.8E-4 **	9.6E-4 **	7.5E-4 **
BOTTOM EXTRACTION (mol. ratio)	H	9.4E-5	1.2E-6	4.3E-8	5.6E-9	1.2E-9
	D	0.498	0.398	0.298	0.198	0.101
	T	0.502	0.602	0.702	0.802	0.899

* COLUMN 1 Top tritium is 0.24ppm ≦ 0.4ppm (DESIGN CONDITION)
** COLUMN 2 Top tritium are 0.04~0.08% ≦ 0.1% (DESIGN CONDITION)

Table A-3 Comparison of Column Specifications
(Feed Stages; 55th in Column 1 and 50th in Column 2)

		COLUMN 1	COLUMN 2			
PRODUCT TRITIUM DESIGNED		——	60%	70%	80%	90%
SIZE OF COLUMN (cm)	DIA. OF PACKED SPACE	4.9	4.3	5.6	6.7	7.7
	LENGTH OF PACKED SPACE	500.	400.0	400.0	400.0	400.0
	TOTAL LENGTH	601.8	486.9	504.7	520.0	534.2
TRITIUM INVENTORY (g)	PACKED SPACE	67.9	64.9	115.9	183.1	265.8
	REBOILER	16.0	12.2	26.5	46.3	73.3
	TOTAL	83.9	77.1	142.4	229.4	338.1
HERIUM LOAD (W)	FEED & RECYCLE	38.2	27.0	42.5	59.5	78.8
	CONDENSER	113.0	73.2	119.9	172.1	232.2
	TOTAL *	226.7	150.3	243.6	347.4	466.5

* TOTAL HERIUM LOADS are 1.5 times of FEED & RECYCLE LOAD and CONDENSER LOAD

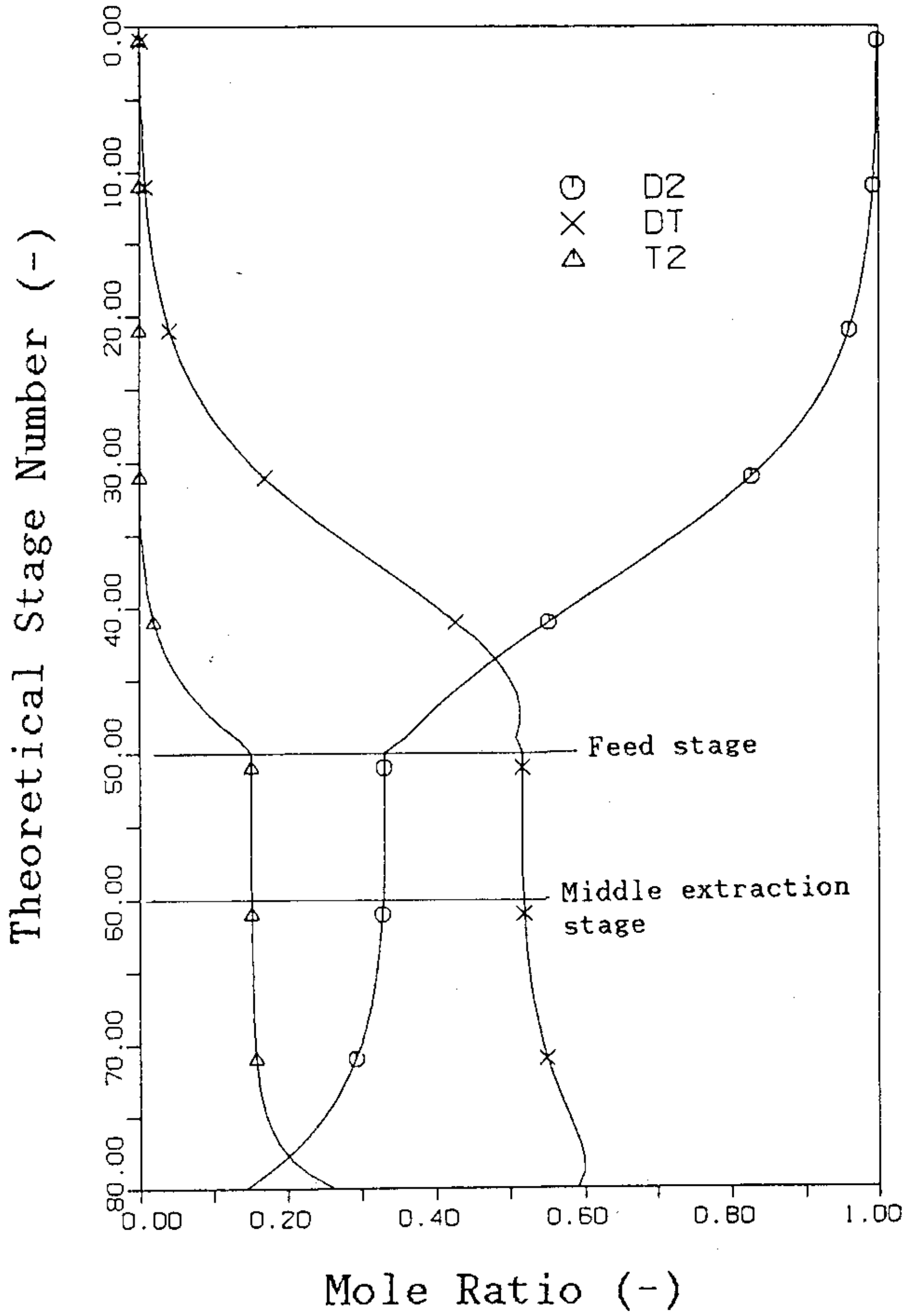


Fig. A-1 Concentration Profiles in the Column 2 (Product tritium concentration: 60%T-40%D)

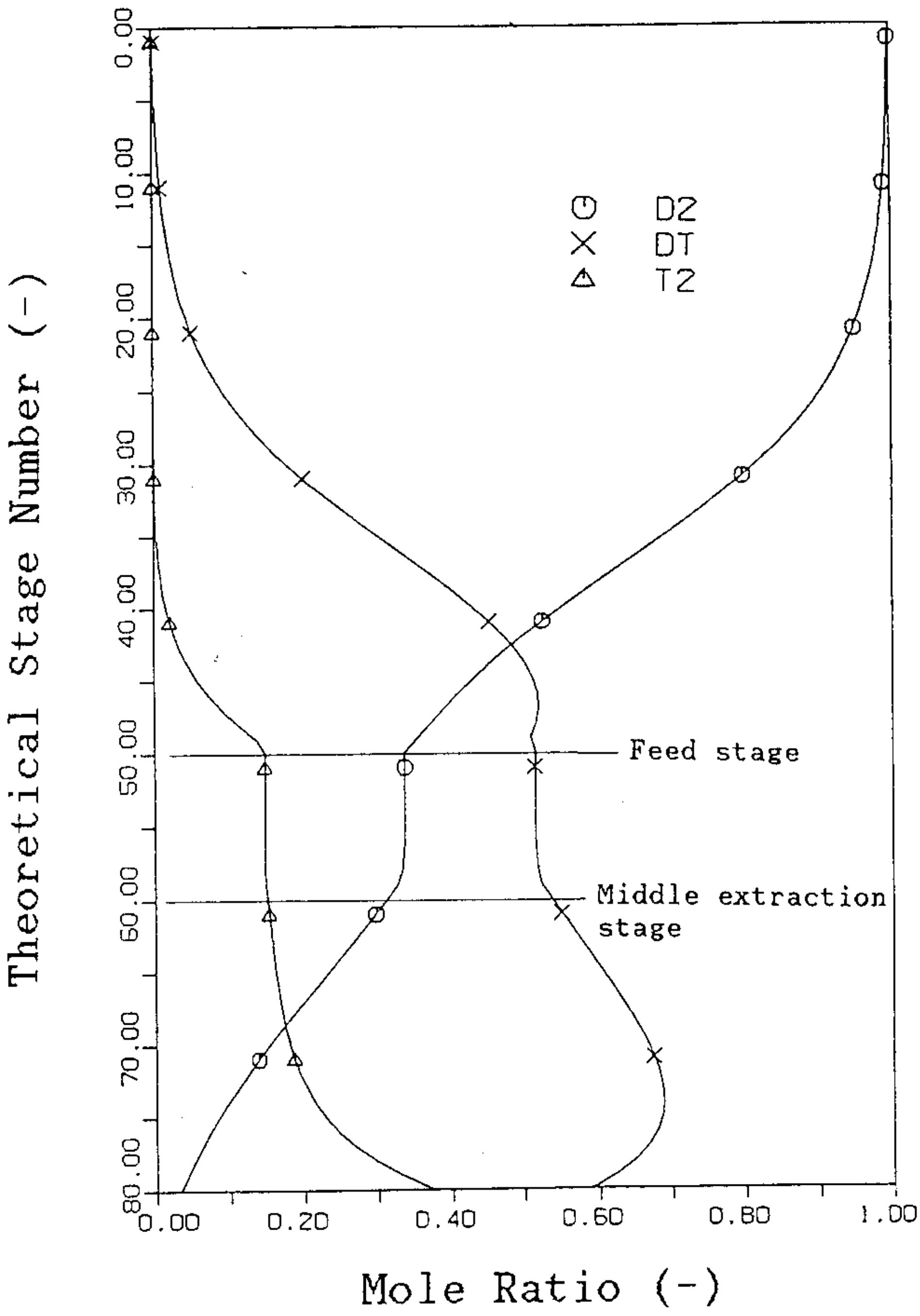


Fig. A-2 Concentration Profiles in the Column 2
(Product tritium concentration: 70%T-30%D)

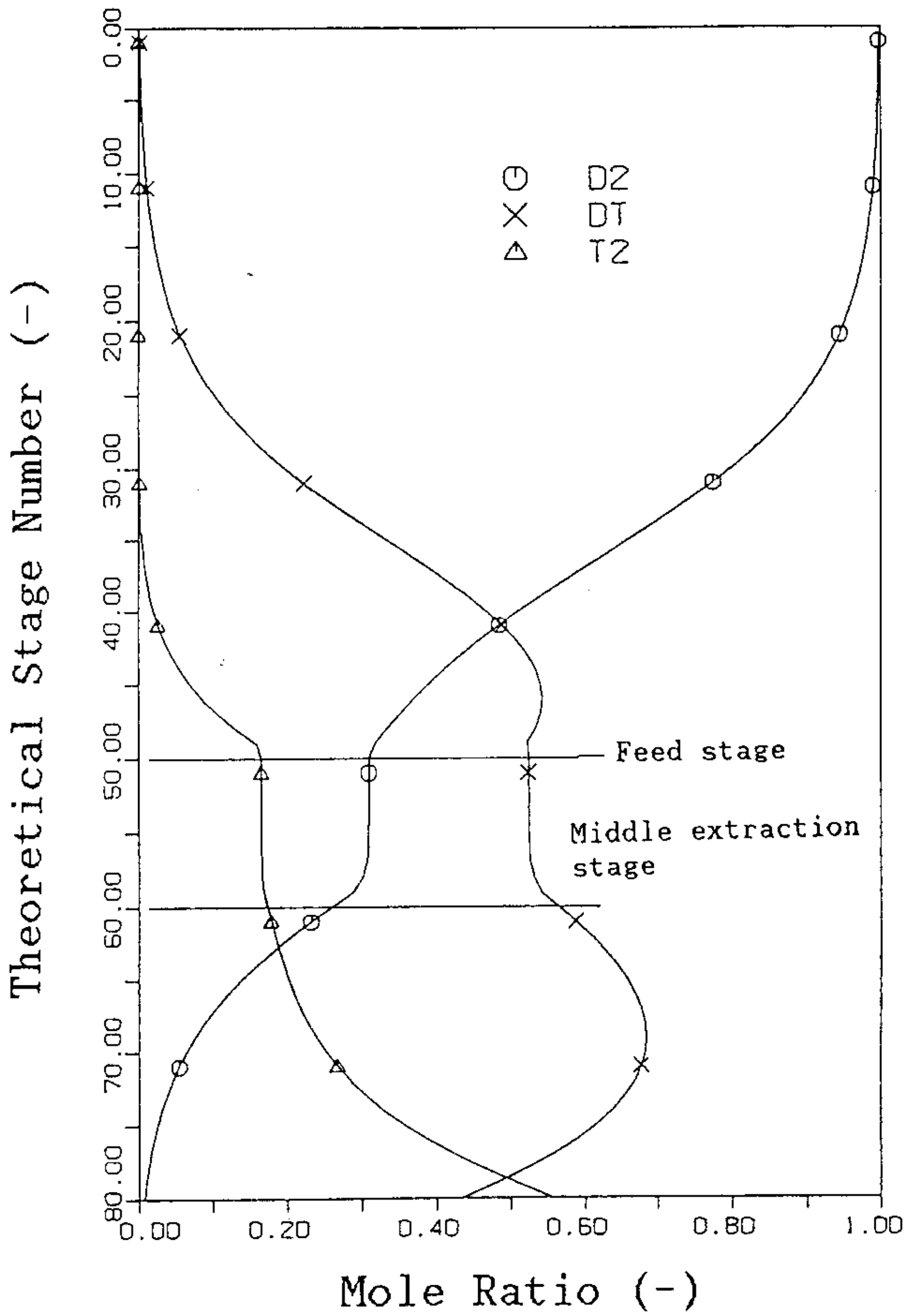


Fig. A-3 Concentration Profiles in the Column 2
(Product tritium concentration: 80%T-20%D)

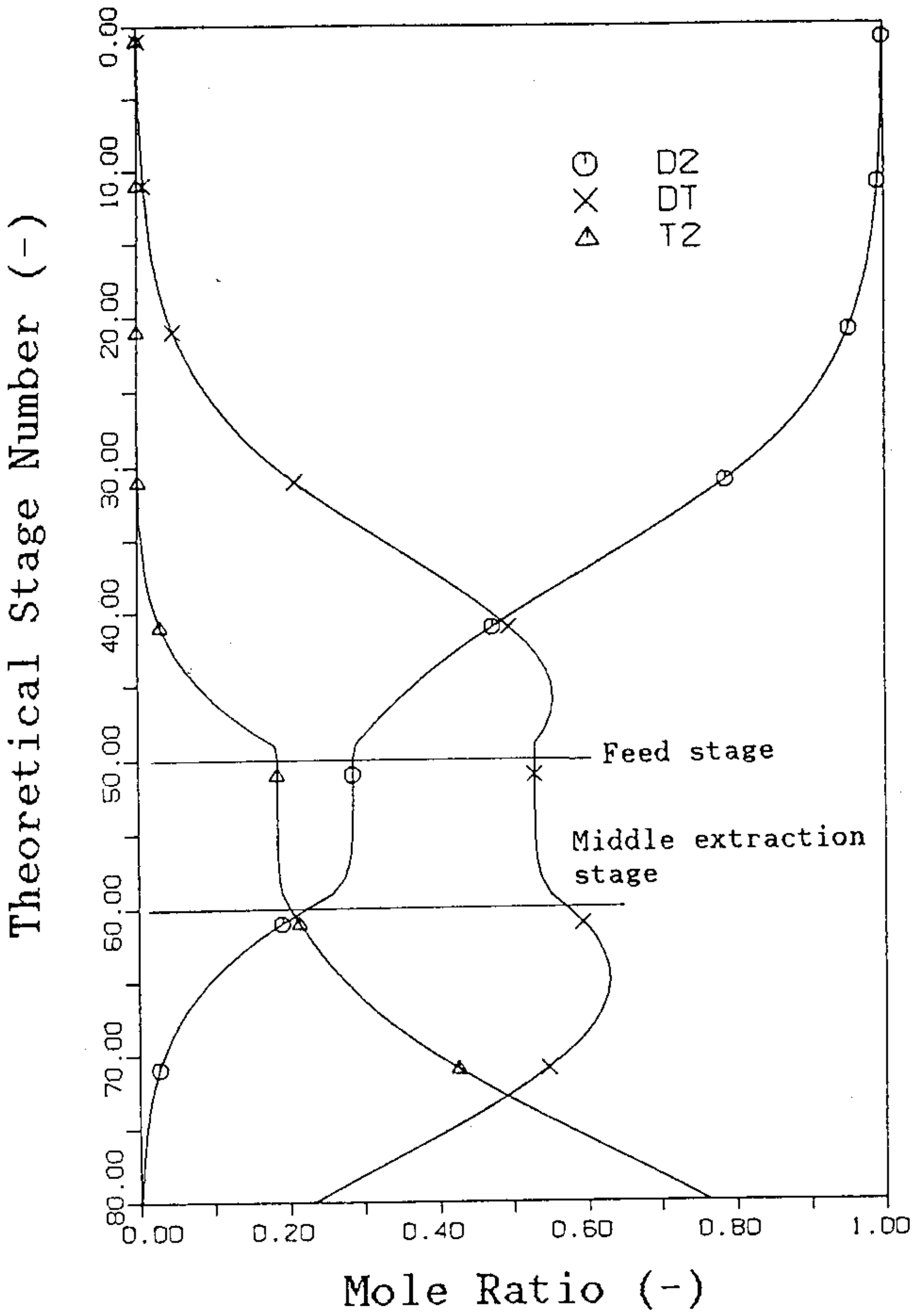


Fig. A-4 Concentration Profiles in the Column 2
(Product tritium concentration: 90%T-10%D)

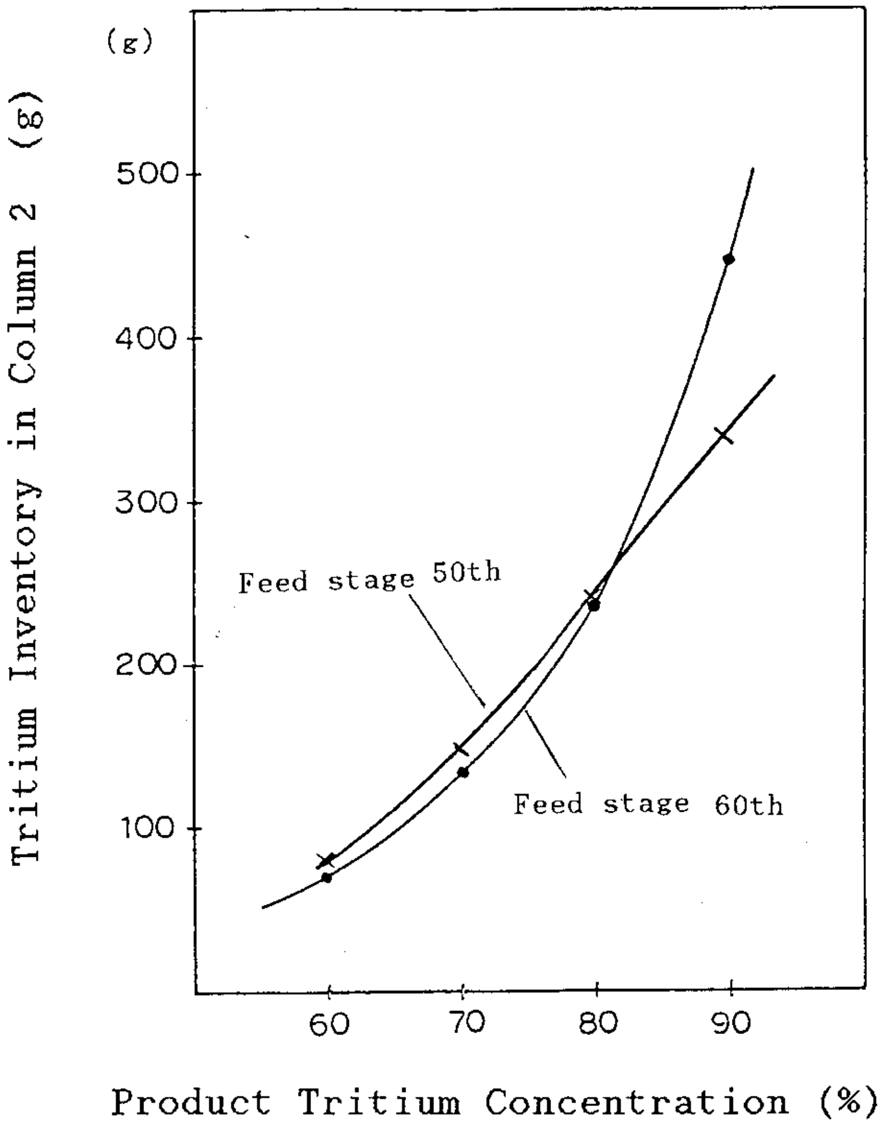


Fig. A-5 Comparison of the Column 2 Tritium Inventory in Different Feed Positions

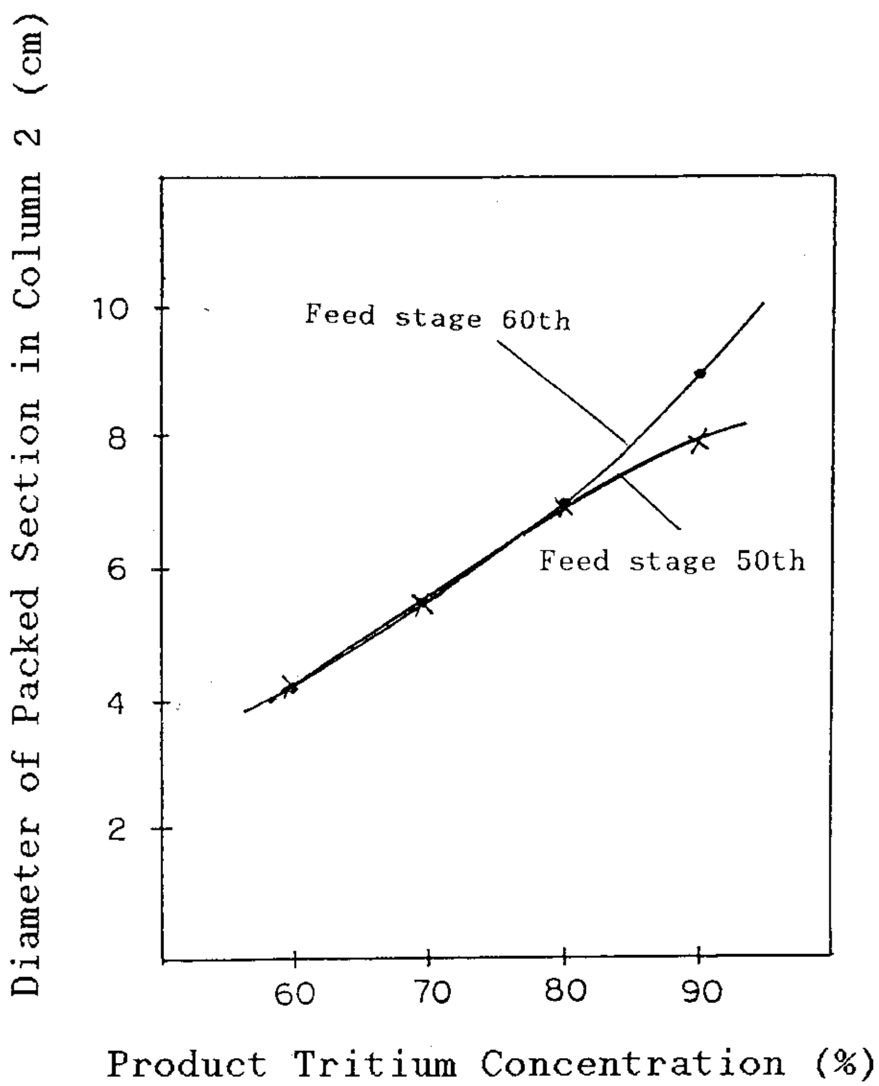


Fig. A-6 Comparison of the Column 2 Helium Heat Load in Different Feed Positions

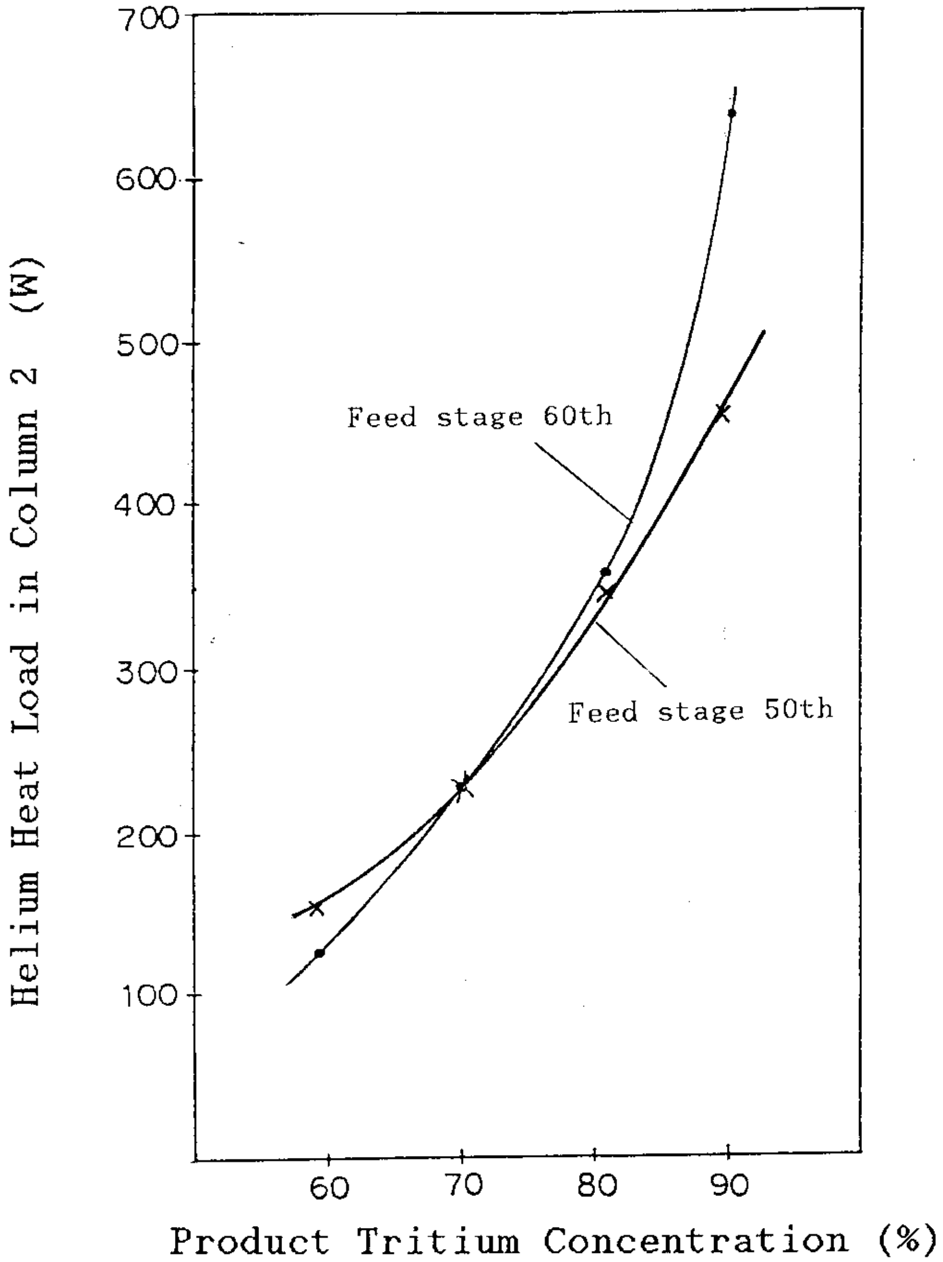


Fig. A-7 Comparison of the Column 2 Packed Section Diameter in Different Feed Positions