CONF-810804--26

Paper for presentation at 20th National Heat Transfer Conference, Milwaukee, Wisconsin, August 3-7, 1981; and for publication in Proceedings.

CONF-810804--26

DE83 009033

ISOTOPIC ENRICHMENT OF FUELS FOR D-T FUSION REACTORS*

by

B. Misra, R. G. Clemmer, and P. A. Finn

Argonne National Laboratory
Fusion Power Program
Argonne, Illinois 60439

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

The submitted manuscript has been authored by a contractor of the U. S. Government under contract No. W-31-109-ENG-38. Accordingly, the U. S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U. S. Government purposes.

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

MASTER

*Work performed under the auspices of the U.S. Department of Energy.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ISOTOPIC ENRICHMENT OF FUELS FOR D-T FUSION REACTORS*

by

B. Misra, R. G. Clemmer, and P. A. Finn

Isotopic enrichment scenarios using cryogenic distillation were developed for a near-term D-T burning fusion-reactor design (ETF) as well as for a commercial fusion-reactor design (STARFIRE). The analytical results of studies of spent-fuel reprocessing for ETF show that isotopic enrichment can be carried out to meet fuel-purity requirements by a system consisting of a 5-column distillation cascade and two chemical equilibrators. For STARFIRE, the analytical results show that, for a fixed number of columns and chemical equilibrators in a reprocessing system, the compositions of the recycle streams depend strongly on whether the two fuel streams (plasma exhaust and blanket) are processed separately or mixed and then processed as a single stream.

Type the title of the paper, the author(s) and the abstract on a separate sheet of regular bond paper. This material will be set by the printer.

The design-base operating parameters that have been developed for currently-conceived deuterium-tritium (D-T) fueled tokamak fusion reactors show that only a relatively small fraction of the injected fuel reacts during the burn period. Ongoing design studies [i.e., STARFIRE (1)] are continuing to devise means of increasing the burn fraction. Because of the extremely high cost of tritium, as well as the environmental consequences of releasing biologically hazardous tritium, the spent fuel must be recycled to the maximum extent possible. Although the exact details of fueling methods and the purity requirements for D-T reactors have not been developed, NRC standards require that the tritium content of the waste product stream be very low (2). Also, for certain reactor designs, for example ETF (3), it may be necessary to have separate isotopically pure streams of tritium and deuterium. The consensus view of several recent studies (4-9) is that where large quantities of mixed fuel are involved, separation or enrichment by cryogenic distillation is the most practical and economical method. Since previous studies have dealt primarily with reprocessing of plasma exhaust and since the effluent from the blanket processing system is considerably different, this study was undertaken to assess the implications of reprocessing the plasma exhaust in conjunction with the effluent from the blanket processing system. The atom fraction of protium in the spent fuel may be of the order of 1-2%, but the protium fraction in the blanket processi fuel may be much higher, especially if light water is used as the heat transport medium i the blanket. In addition, the fuel from the blanket processing system contains essential no deuterium-bearing species. A series of parametric studies was carried out to assess how the composition of the light and heavy fractions from the distillation column are influenced by different fuel processing scenarios.

Argonne National Laboratory, Argonne IL 60439

EQUILIBRIUM CONSIDERATIONS

Before analyzing the various steps required to develop the distillation cascades for the spent fuel from plasma exhausts and the bred fuel from breeding blankets, it is essential to consider the equilibrium relationships among the isotopic species of hydrogen. For the sake of simplicity, let us consider the equilibrium between the princip constituents (i.e., deuterium and tritium in ETF spent fuel, and protium and tritium in t bred fuel from the STARFIRE blanket). When deuterium and tritium are mixed and allowed to equilibrate, the following reaction takes place

$$D_2 + T_2 \rightleftharpoons 2DT \qquad (1$$

Based on the initial molar ratio D_2/T_2 of 3/ for ETF, the equilibrium compositions at 50 K

*Work performed under the auspices of the U.S. Department of Energy.

and 300 K were calculated based on existing equilibrium constant data (10) for Equation (1). For the bred fuel from the blanket, the equilibration reaction of importance is

$$H_2 + T_2 \rightleftharpoons 2HT \qquad (2)$$

Using a ratio of 19/1 for T_2/H_2, equilibrium compositions of the fuel mixture at 50 K and 300 K were calculated. The compositions of the fuel mixtures before and after equilibration are given in Table 1.

An examination of the data presented in Table 1 shows that only 1/3 of the tritium in the initial ETF fuel mixture remains as T_2. For the blanket effluent, essentially all of the protium impurity is present as HT. Hence, complete isotopic separation is impossible based on cryogenic distillation alone. At some appropriate stage in the distillation cascade, the reverse reactions [see Equations (1) and (2)] must be promoted in an isotopic equilibrator. For separation of protium from tritium, it has been pointed out by the previous studies (5,7) that the following reaction may be more useful compared to Equation (2).

$$HT + D_2 \rightleftharpoons DT + HD \qquad (3)$$

Since HD is more volatile than DT, the separation of protium from tritium can be carried out in a distillation column after equilibration of HT with D_2 supplied from an external source.

DISTILLATION CASCADE DEVELOPMENT

Cascade Arrangement for ETF

For the sake of simplicity, the flow rate to the distillation cascade was assumed to be 100 moles per unit time. The composition of the three isotopic species in the spent fuel was estimated to be: 49 atp (atp = atom %) tritium; 49 atp deuterium; and 2 atp protium. When such a gas mixture is equilibrated at 300 K, the six isotopomeric species (in descending order or volatility) have the following composition

H_2	HD	HT
5.36×10^{-4}	2.06×10^{-2}	1.83×10^{-2}
D_2	DT	T_2
2.42×10^{-1}	4.75×10^{-1}	2.43×10^{-1}

A computer program that was developed for design and analysis of interconnected distillation columns and chemical equilibrators (8) was used to estimate the composition of the product streams. A schematic of the distillation cascade is shown in Figure 1. The analytical results are summarized in Table 2. (The first six columns show the mole fraction of the products and the last three columns show the atomic percentages of the three isotopic species of hydrogen.

Distillation Cascade for the STARFIRE Design

For one set of STARFIRE (1) operating conditions, the tritium flow rate from the plasma exhaust gases was estimated to be 750 g/day, and the flow rate of tritium from the blanket processing system for the same set of STARFIRE operating conditions was estimated to be 562 g/day. In the absence of any experimental data, it was assumed that the ratio of protium to tritium in the fuel from the blanket processing system is the same as that in the exhaust gases. The fuel from blanket processing is assumed to have been equilibrated at 300 K. Although the concentration of deuterium in the blanket effluent fuel is essentially zero, the non-linear equations for the chemical equilibrator were solved by assuming the presence of a very small amount (2×10^{-3} atp) of deuterium (to avoid singularity problems in the solution algorithm). After equilibration, the fuel from blanket processing has the following composition:

H_2	HD	HT
2.38×10^{-2}	1.79×10^{-4}	7.52×10^{-2}
D_2	DT	T_2
4.14×10^{-10}	3.82×10^{-5}	9.22×10^{-1}

Thus, we have the flow rates and the composition of the two feed streams which are to be processed through a cryogenic distillation cascade.

ANALYTICAL RESULTS

Enrichment scenarios based on two separate cascade arrangements were studied. Figures 2 and 3 show in schematic form the distillation cascades for STARFIRE with interconnected distillation columns. Figure 2 shows a cascade arrangement where the two

fuel streams are processed separately at the initial stages. The heavy fraction from Column A is the tritium product stream. As shown in Figure 2, the product streams from the B-Cascade are: bottom product (heavy fraction) from B-1, heavy fraction from B-5 and the light fraction (top product) from B-4. The top product from B-4 is the waste product stream. The cascade arrangement shown in Figure 3 assumes that the two feed streams are mixed and chemically equilibrated before entering the distillation system. The following table shows how the composition of the fuel stream changes from simple mixing of the two streams (compositions as shown in the previous section) to equilibration at 300 K.

Simple Mixing

H_2	HD	HT
1.82×10^{-2}	3.63×10^{-3}	3.63×10^{-3}
D_2	DT	T_2
1.78×10^{-1}	3.55×10^{-1}	4.41×10^{-1}

Chemical Equilibration at 300 K

H_2	HD	HT
8.90×10^{-4}	1.94×10^{-2}	2.97×10^{-2}
D_2	DT	T_2
1.29×10^{-1}	4.36×10^{-1}	3.85×10^{-1}

The composition of the top and the bottom products for the single column (Column A, Figure 2) and the two cascade arrangements (Figure 2 and Figure 3) are summarized in Tables 3, 4, and 5. Table 3 shows the composition of the product streams when the fuel from the blanket processing system is distilled in a single column (Column A, Figure 2). For the separately-processed streams, the top product from A is mixed with the top product from B-3 before the mixture enters the chemical equilibrator (see Figure 2). The composition of the product streams are summarized in Table 4. Table 5 shows the composition of the product streams where the fuel streams are premixed before distillation. The estimated composition of the product streams for the separately processed fuel streams with chemical equilibrators operating at 50 K is shown in Table 6.

SUMMARY AND CONCLUSIONS

The calculated product compositions for ETF (see Table 2) show that high deuterium and tritium fractions can be obtained by using a distillation cascade consisting of 5 columns. The number of theoretical stages for the five columns are respectively 50, 30, 30, 30, 75. The atom fraction of the deuterium- and tritium-rich products meet the purity requirements for recycle fuel (>98%). The tritium fraction in the waste product stream is less than 0.02%. By using a larger number of theoretical stages, it would be possible to further increase the purity of the product streams. The analytical results for the STARFIRE design show that if a very pure tritium fraction (>99.9) is required, it would be desirable to process the two fuel streams separately (see Fig. 2). The computer calculations for a single column containing different numbers of theoretical stages are shown in Table 3. Essentially pure tritium may be produced from the blanket processing fuel as long as the number of theoretical stages in the distillation column (Column A in Figure 2) is of the order of 30 (see Table 3). The tritium fraction in the waste product stream for processing of STARFIRE fuel separately is 0.15%. However, if the chemical equilibrators are assumed to operate at 50 K instead of 300 K, the tritium fraction in the waste product stream may be reduced to 0.02% (see Table 6). The reason for lower tritium fraction in the waste product at 50 K is due to less favorable chemical kinetics for formation of HT at lower temperatures. However, in practice, it may be desirable to use higher equilibration temperatures (e.g., room temperature) to ensure reasonably fast reaction rates. For processing of mixed fuel in the STARFIRE design, the deuterium and tritium fractions are less than 97%, which may not meet the purity requirements of the recycle fuel.

In the fuel processing scenarios presented above the mole fraction of protium in the blanket processing fuel has been assumed to be only 4%. If light water is used as the heat transport fluid for the breeding blanket, it is conceivable that the protium fraction in the blanket processing fuel may be significantly higher than the values used in the present analyses. Under such circumstances, a single column such as Column A in Figure 2, may not be adequate to produce pure tritium.

Our studies have indicated that the composition of the product streams depend to a lesser extent on the total number of theoretical plates which is in excess of 200 for the 5 column distillation cascade. The product composition depends to a large extent on (1) the cascade arrangement, (2) location of chemical equilibrators, (3) product stream to feed stream flow rate ratios, and (4) column operating pressure. For this study, the three separate fuel processing scenarios as described in the previous sections are based on the same distillation cascade so that the resultant product compositions may be discussed and compared on a common basis. The results obtained with a 5-column cascade seem to meet the currently-conceived purity requirements for fueling tokamak reactors. Whether the protium waste product stream (top product from column 4) can be discharged directly into the ambient will depend primarily on the total quantity of tritium involved rather than on the mole fraction of tritium in the waste product stream. The parametric investigations carried out during this study were limited to distillation cascades containing 5 columns. Because the exact fueling methods and the purity requirements for the recycle fuel have not been established, only limited attempts were made to optimize the distillation cascade in terms of the number of theoretical stages, reflux ratio, operating pressure, and the interconnection pattern between distillation columns. All of the calculations were carried out using a reflux ratio of 5, and with columns 2, 3, and 5 operating at 133 kPa (1000 Torr) and columns 1 and 5 operating at 67 KPa (500 Torr). As the kinetics of the isotopic interactions are not known, no attempt was made to size the chemical equilibrators.

LITERATURE CITED

1. Baker, C. C., et al., "STARFIRE--Commercial Tokamak Fusion Power Plant Study," Argonne National Laboratory Report ANL/FPP-80-1 (1980).

2. NRC Rules and Regulations, Title 10, Chapter 1, Part 20, August 1980.

3. Finn, P. A., R. G. Clemmer, B. Misra, and V. A. Maroni, "ETF Interium Design Description Document," Oak Ridge/FED Design Center Publication, p. 40-46 (1980).

4. Wilkes, W. R., "Hydrogen Isotope Separation System for Tokamak Experimental Power Reactor," Proc. Conf. Radiation Effects and Tritium Technology for Fusion Reactors, Gatlinburg, Tennessee, CONF-750989, p. IV-266, October 1-3, 1975.

5. Misra, B. and V. A. Maroni, "Isotopic Enrichment of Plasma Exhaust from Controlled Thermonuclear Reactors by Cryogenic Distillation," Nuclear Technology, 35, 40 (1977).

6. Anderson, J. L. and R. H. Sherman, "Tritium System Test Assembly Design for Major Device Fabrication Review," Los Alamos Scientific Laboratory Report LA-6855 (June 1977).

7. Bartlit, J. R., W. H. Denton, and R. H. Sherman, "Hydrogen Isotopic Distillation for Tritium System Test Assembly," Proc. of the 3rd Topical Meeting on the Technology of Controlled Fusion, Santa Fe, New Mexico, CONF-780508, p. II-778 (May 9-11, 1978).

8. Misra, B. and J. F. Davis, "Cryogenic Distillation: A Fuel Enrichment System for Near-Term Tokamak-Type D-T Fusion Reactors," Argonne National Laboratory Report ANL-78-96 (February 1980).

9. Finn, P. A. and J. Bartlit, "Tritium and Vacuum Systems," Report INTOR/NUCL/81-1.

10. Jones, W. M., J. Chem. Phys. 16, 1077 (1948).

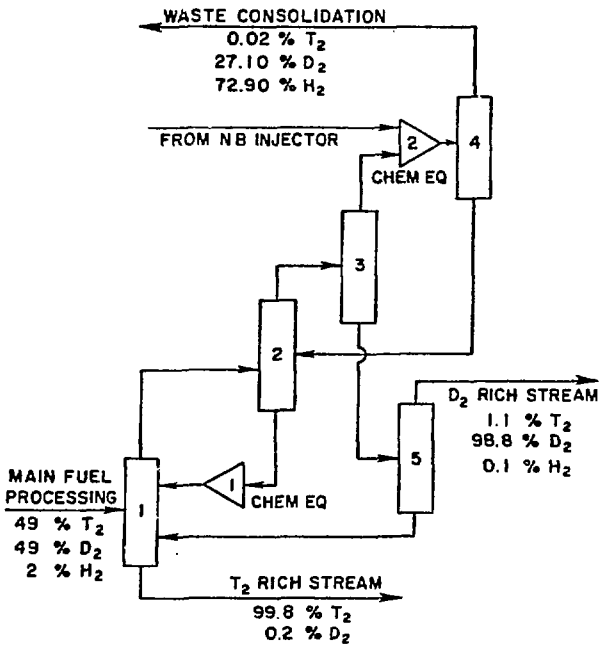

Fig. 1. ETF ISOTOPE SEPARATION CASCADE

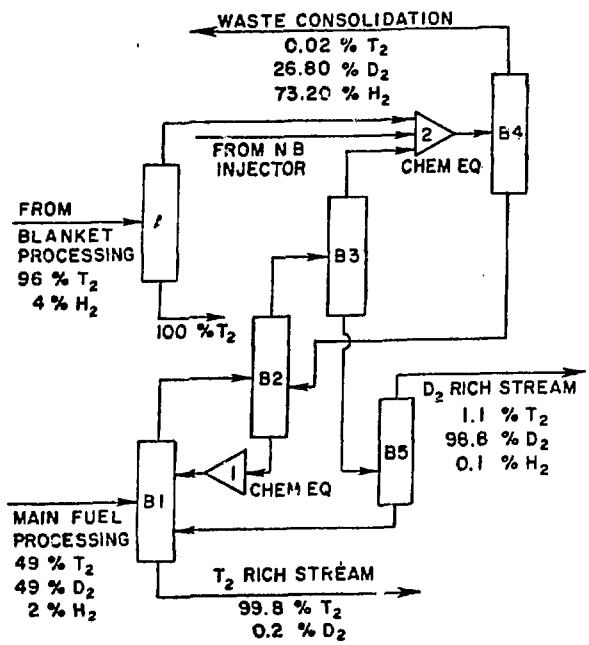

Fig. 2. STARFIRE ISOTOPE SEPARATION CASCADE (SEPARATE FEED)

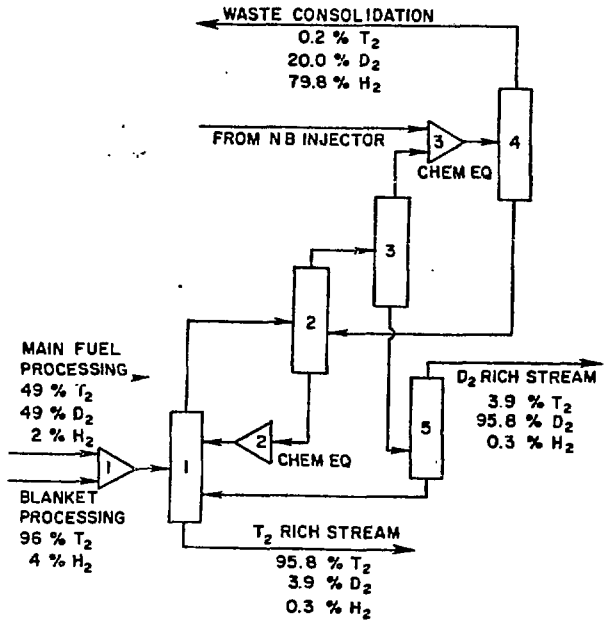

Fig. 3. STARFIRE ISOTOPE SEPARATION CASCADE (MIXED FEED)

Table 1. Composition of Fuel Mixtures Before and After Equilibrium

Initial Composition (Moles)			Final Composition (Moles)					
Spent Fuel, ETF			Equilibration at 50 K			Equilibration at 300 K		
D_2	T_2	DT	D_2	T_2	DT	D_2	T_2	DT
75	25	0	57.8	7.8	34.4	56.4	6.4	37.2
Bred Fuel, STARFIRE			Equilibration at 50 K			Equilibration at 300 K		
H_2	T_2	HT	H_2	T_2	HT	H_2	T_2	HT
5	95	0	1.8	91.8	6.4	0.4	90.4	9.2

Table 2. Summary of Analytical Results for 5-Column Cascade (ETF)

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 1

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.8451650-03	2.5820420-03	1.4717850-03	5.7606670-01	4.1009960-01	6.2908550-03	5.8720-01	7.8240 01	2.1210 01
50	1.0683920-20	1.1764330-13	6.7864300-12	5.1038490-06	3.8294310-05	9.9616550-01	3.4520-10	1.9200-01	9.9800 01*

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 2

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.1777970-02	1.1161990-01	4.0490360-03	7.6618500-01	8.6607480-02	1.1868630-04	8.9610 00	8.6530 01	4.5450 00
30	2.7346840-06	1.0272030-03	7.3013470-04	5.4209930-01	4.4891150-01	7.2291220-03	8.8130-02	7.6700 01	2.3200 01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 3

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	6.3529130-02	2.2214070-01	7.4476930-03	6.9582330-01	1.1373140-02	9.7412310-07	1.7830 01	8.1260 01	9.4100-01
30	4.2726950-07	1.0067840-03	6.4729390-04	8.3626830-01	1.6134080-01	2.3640070-04	8.2740-02	9.1760 01	8.1430 00

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 4

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	4.6524900-01	5.2871450-01	4.6201230-04	6.7707050-03	3.3109630-06	5.4072270-10	7.2950 01	2.7110 01	2.3270-02**
30	3.4941670-02	2.1614010-01	1.5982580-03	7.2913650-01	1.8012460-02	1.7104970-04	1.4330 01	8.4600 01	9.9740-01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 5

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	6.2720310-07	1.4778910-03	9.4972860-04	9.7573540-01	2.1833360-02	4.2131120-08	1.2140-01	9.8740 01	1.1420 00***
75	3.0334170-19	1.4289670-09	9.7354310-07	5.3827290-01	4.6098450-01	7.4158700-04	4.8720-05	7.6840 01	2.3110 01

*Tritium-rich product.

**Protium waste.

***Deuterium-rich product.

Table 3. Distillation Products from Reprocessing Fuel from Breeding Blankets (Number of Theoretical Stages: 15, 30, 75)

SUMMARY OF ANALYTICAL RESULTS FOR BLANKET PROCESSING: NP= 15

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	7.6307590-01	1.6535710-04	1.2499010-04	6.3302620-05	1.6006630-05	2.3153000-01	7.6820 01	1.5400-02	2.3160 01
15	5.6311330-04	1.5939390-06	3.7781120-06	7.1153970-06	9.6749850-06	9.9941470-01	5.6500-02	1.2750-03	9.9940 01*

SUMMARY OF ANALYTICAL RESULTS FOR BLANKET PROCESSING: NP= 30

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	7.7836550-01	1.8436670-04	1.4249480-04	8.3962720-05	2.8277790-05	2.2119510-01	7.7850 01	1.9030-02	2.2130 01
30	6.2677100-06	5.6534750-07	2.8336620-06	5.9980160-06	9.0110230-06	9.9997530-01	7.9670-04	1.0790-03	1.0000 02*

SUMMARY OF ANALYTICAL RESULTS FOR BLANKET PROCESSING: NP= 75

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	7.8334200-01	1.9403190-04	1.4708590-04	8.6570330-05	3.9974330-05	2.1960000-01	7.8350 01	2.0330-02	2.1970 01
75	2.8544100-10	1.0750700-07	2.6314700-06	5.8350920-06	8.4171700-06	9.9998300-01	1.3700-04	1.0150-03	1.0000 02*

*Tritium-rich product.

Table 4. Distillation Products for Separately Processed Fuel (STARFIRE)

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 1

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.8525770-03	3.1916890-03	1.9210920-03	5.2106030-01	4.6217610-01	8.1437700-03	6.4090-01	7.5370 01	2.4020 01
50	1.0094830-20	1.6453290-13	1.7012090-11	4.3189850-06	3.7111130-03	9.9628460-01	8.5380-10	1.8600-01	9.9810 01*

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 2

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	5.3019130-02	1.9790220-01	1.6524670-02	6.3543200-01	9.7519390-02	1.6601640-04	1.6020 01	7.8310 01	5.7190 00
30	2.6252930-06	1.5466850-03	1.4417570-03	4.7487090-01	5.1244550-01	9.6925120-03	1.4970-01	7.3180 01	2.6660 01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 3

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	1.0595290-01	3.9338100-01	2.9798870-02	4.6430430-01	7.0558810-03	6.1910490-07	3.1750 01	6.6450 01	1.8430 00
30	8.0730840-07	2.1096860-03	3.2272240-03	8.0632250-01	1.8800830-01	3.3146800-04	2.6690-01	9.0130 01	9.5940 00

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 4

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	5.9465550-01	4.0102350-01	2.9317300-03	1.9987170-03	1.0867220-05	1.5086080-08	7.9660 01	2.0250 01	1.4710-01**
30	7.8372470-02	3.9039640-01	2.8459570-02	4.3523410-01	6.4997330-02	2.5401400-03	2.8780 01	6.6290 01	4.9260 00

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 5

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	1.1848990-06	3.0964200-03	4.7348520-03	9.6424350-01	2.7994390-02	6.9055130-08	3.9170-01	9.7980 01	1.6360 00***
75	4.6727960-19	2.3802610-09	3.8424640-06	4.6875010-01	5.3020590-01	1.0401720-03	1.9210-04	7.3340 01	2.6600 01

*Tritium-rich product.

**Protium waste.

***Deuterium-rich product.

Table 5. Distillation Products for Premixed Fuel (STARFIRE)

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 1

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.8701640-03	4.0208460-03	2.2866270-03	5.0065640-01	4.6957900-01	1.9940590-02	7.0280-01	7.3750 01	2.5590 01
50	4.0799590-14	1.4150440-09	2.3383050-08	4.5961230-04	5.9944290-02	9.3959610-01	1.2390-06	3.0420 00	9.6910 01*

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 2

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	5.3016120-02	1.9691990-01	1.7363450-02	6.0665790-01	1.2554340-01	6.8699740-04	1.6020 01	7.6790 01	7.2140 00
30	9.4023530-06	2.5823030-03	1.8304220-03	4.5941140-01	5.1301890-01	2.3147520-02	2.2160-01	7.1720 01	2.8060 01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 3

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	1.0601780-01	3.9187930-01	3.1585930-02	4.6126690-01	9.5902900-03	2.7094760-06	3.1780 01	6.6200 01	2.0550 00
30	7.3925960-07	1.9101330-03	3.1371960-03	7.5206190-01	2.4151260-01	1.3714170-03	2.5240-01	8.7370 01	1.2370 01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 4

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	5.9903610-01	3.9654160-01	3.0236820-03	1.9255340-03	1.1013830-05	1.6093960-08	7.9880 01	2.0020 01	1.5170-01**
30	7.9133520-02	3.9013770-01	2.9974310-02	4.3020280-01	6.7754150-02	2.7924910-03	2.8920 01	6.5910 01	5.1650 00

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 5

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	9.4776410-07	2.4468310-03	4.0185800-03	9.1958250-01	7.4224050-02	1.2435230-05	3.2350-01	9.5790 01	3.9130 00***
75	2.9755530-14	1.6133540-07	1.2231970-05	1.5827340-01	8.3551820-01	6.1960450-03	6.1930-04	5.7570 01	4.2370 01

*Tritium-rich stream.

**Protium waste.

***Deuterium-rich product.

Table 6. Distillation Products for Separately Processed Fuel (STARFIRE, Equilibration at 50 K)

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 1

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.8430440-03	2.6024700-03	1.4700770-03	5.8087920-01	4.0656530-01	4.9217110-03	5.8790-01	7.8550 01	2.0390 01
50	1.1093040-20	1.3017960-13	7.5411860-12	5.7692600-06	4.6336640-03	9.9536060-01	3.8350-10	2.3220-01	9.9760 01*

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 2

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	3.2958310-02	1.1249620-01	4.0250300-03	7.6665860-01	8.4970400-02	9.1982680-05	9.0320 00	8.6540 01	4.4590 00
30	2.7726660-06	1.0465360-03	7.3213750-04	5.4727030-01	4.4528750-01	5.6[illegible]750-03	8.9200-02	7.7040 01	2.2870 01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 3

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	6.4094300-02	2.2339440-01	7.4016120-03	6.9382170-01	1.1066560-02	7.4710050-07	1.7970 01	8.1130 01	9.2350-01
30	4.3363280-07	1.0215260-03	6.4753240-04	8.3927390-01	1.5887340-01	1.8322130-04	8.3490-02	9.1920 01	7.9940 00

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 4

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	4.7013210-01	5.2415410-01	4.3624330-04	6.3549660-03	3.0375340-06	4.8451630-10	7.3250 01	2.6840 01	2.1960-02**
30	3.5498270-02	2.1777220-01	1.5815630-03	7.2731290-01	1.7670090-02	1.6502720-04	1.4510 01	8.4490 01	9.7850-01

SUMMARY OF ANALYTICAL RESULTS FOR COLUMN : 5

PROD.COMP	N-H2	HD	HT	N-D2	DT	N-T2	APH	APD	APT
1	6.3659650-07	1.4996550-03	9.5014500-04	9.7637480-01	2.1212530-02	3.1932520-08	1.2260-01	9.8770 01	1.1060 00***
75	3.1522650-19	1.4889970-09	1.0006050-06	5.4640200-01	4.5302240-01	5.7465190-04	5.0080-05	7.7250 01	2.2700 01

*Tritium-rich product.

**Protium waste.

***Deuterium-rich product.