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URANIUM ENRICHMENT BY THE SEPARATION NOZZLE PROCESS +)

by

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Summary

The separation nozzle process for the enrichment of the light uranium isotope U-235 has been developed at the Karlsruhe Nuclear Research Center as an alternative to the gaseous diffusion and centrifuge processes. Since 1970 the STEAG company, Essen, has been involved in the commercial implementation of the nozzle process.

A first separation nozzle demonstration plant with a separative capacity of 180 t SWU/a shall be erected in Brazil with the participation of the Brazilian company NUCLEBRAS and the German companies STEAG and INTERATOM. Methods for the mass production of separation elements were developed by industry and extensive performance tests were carried out on commercially fabricated separation elements. Two prototype separative stages were successfully tested in Karlsruhe. Besides further plant components, a prototype of a UF_6 recycle facility was developed which serves the purpose of stripping the UF_6 from the light auxiliary gas to be recycled in a separation nozzle cascade.

The performance level achieved to date characterizes the separation nozzle process as reliable and feasible economically. Therefore, the erection of a separation nozzle demonstration plant can be recognized as the implementation of an enrichment process which combines a reliable and comparatively simple technology with a high potential for further improvements.

Zusammenfassung

Das Trenndüsenverfahren zur Anreicherung des leichten Uranisotops U-235 wird am Kernforschungszentrum Karlsruhe als Alternative zum Gasdiffusions- und zum Zentrifugenverfahren entwickelt. Seit 1970 beteiligt sich die STEAG AG, Essen, an der technischen Weiterentwicklung des Verfahrens.

Im Rahmen der Entwicklung der Anlagentechnik wurden in Zusammenarbeit mit der Industrie Verfahren zur Massenfertigung von Trennelementen ausgearbeitet. Die technischen Trennelemente zeichnen sich durch eine hohe Trennleistung und eine hervorragende Dauerstandsfestigkeit aus, was durch ausführliche Testreihen unter Verfahrensbedingungen demonstriert werden konnte. Bereits 1970 wurde eine Prototyp-Trennstufe in Karlsruhe errichtet und erfolgreich erprobt. Eine zweite fortgeschrittene Prototyp-Trennstufe, deren Konstruktion besonders auf die Serienfertigung der Stufenkomponenten ausgerichtet war, ist seit Ende 1973 in Betrieb. Mit einer UF_6-Abscheidungsanlage, die für die Abtrennung des UF_6 vom leichten Zusatzgas in einer Trenndüsen-Kaskade notwendig ist, konnte der geforderte hohe Abscheidungsgrad problemlos erreicht werden.

Eine erste Trenndüsen-Demonstrationsanlage mit einer Trennleistung von 180 t UTA/Jahr soll unter Beteiligung der brasilianischen Gesellschaft NUCLEBRAS und der deutschen Firmen STEAG und INTERATOM in Brasilien errichtet werden. Dies stellt einen wichtigen Schritt in der industriellen Anwendung des Trenndüsenverfahrens dar, das sich durch eine einfache Technik und ein hohes Entwicklungspotential auszeichnet.

1. Introduction

The separation nozzle process for the enrichment of U-235 has been developed at the Karlsruhe Nuclear Research Center as an alternative to the gaseous diffusion and centrifuge processes (Refs. 1-5). Isotope separation is effected by the same basic mechanism as in the centrifuge method. However, the serious mechanical problems of highly stressed rotating machines are avoided, since the separating centrifugal forces are generated in the nozzle method by deflection of a high speed jet consisting of uranium hexafluoride and a light auxiliary gas.

Since 1970 the German company STEAG has been involved in the technological development and commercial implementation of the nozzle process (Ref. 6). In June 1975, the Brazilian company NUCLEBRAS and the STEAG company signed agreements by which they intend to cooperate in the field of uranium enrichment using the separation nozzle process. As a first step in the Brazilian/German cooperation, a separation nozzle demonstration plant with a capacity of 180 t SWU/a shall be erected in Brazil. For the erection and operation of the demonstration plant a Brazilian/German company will be founded with the participation of the German companies STEAG and INTERATOM.

2. Separation Elements

Fig. 1 shows a cross section of the nozzle system used in the commercial implementation of the process. Gaseous uranium hexafluoride mixed with hydrogen expands along a curved fixed wall. At the end of deflection the flow is split up into a lighter and a heavier fraction by means of

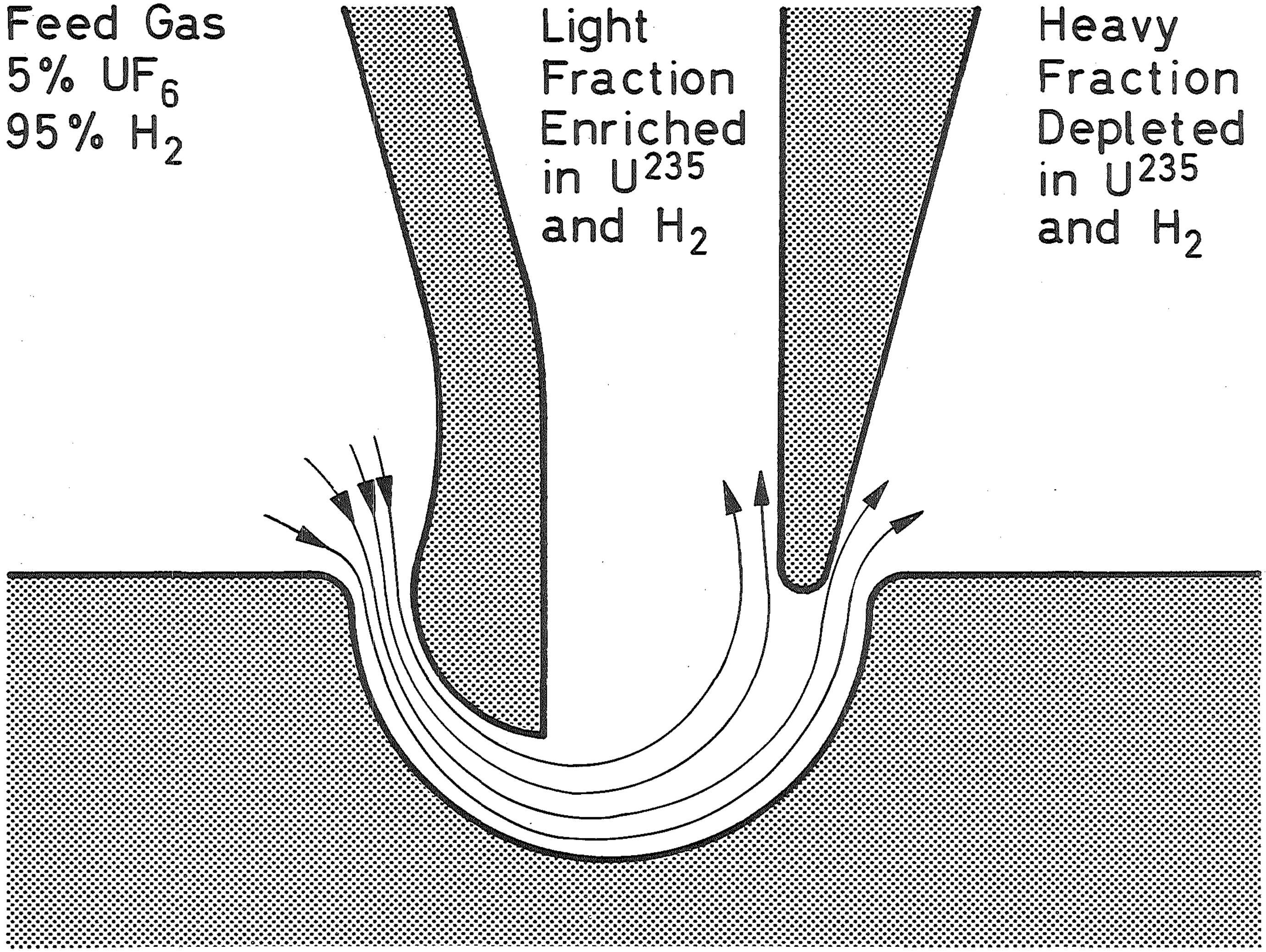

Fig. 1. Cross-section of the separation nozzle system used in the commercial implementation of the separation nozzle process.

a skimmer. The light auxiliary gas which is present in a large molar excess increases the flow velocity of the UF_6 and, hence, it increases the centrifugal force determining the separation. In addition, the auxiliary gas enhances isotope separation by delaying the sedimentation of the UF_6 in the centrifugal field of the curved flow (Ref. 7).

According to the gas-kinetic scaling relations, the optimum operating pressure of the nozzle system is inversely proportional to its characteristic dimensions. Thus, a separation nozzle with the smallest practical dimensions is the most attractive, economically, due to the savings in equipment sizes associated with a high operating pressure. Fig. 2 illustrates the design of a commercial separation element manufactured by the MESSERSCHMITT-BÖLKOW-BLOHM company, Munich. An extruded aluminium tube, which is shown schematically in the lower part of Fig. 2, serves as the basic unit of the commercial separation element. This tube is subdivided by partition walls into sector-shaped chambers marked by the letters F and H, respectively. It carries 10 slit-shaped nozzle systems on its periphery. As shown in detail in the upper part of Fig. 2, the separation nozzle system proper consists of the deflection groove machined in the tube and aluminium strips, the edges of which are designed as the skimmer and the nozzle wall, respectively. The aluminium strips are fixed in the dovetail grooves of the tube and held in place by balls forced in between the strips. The deflection groove of the nozzle system normally has a radius of curvature of 1/10 mm.

The feed gas for the nozzle systems is introduced at one end of the tube into the channels marked F; the heavy fraction is withdrawn at the opposite end of the tube from the channels marked H. The light fraction is pumped off from the space around the tube.

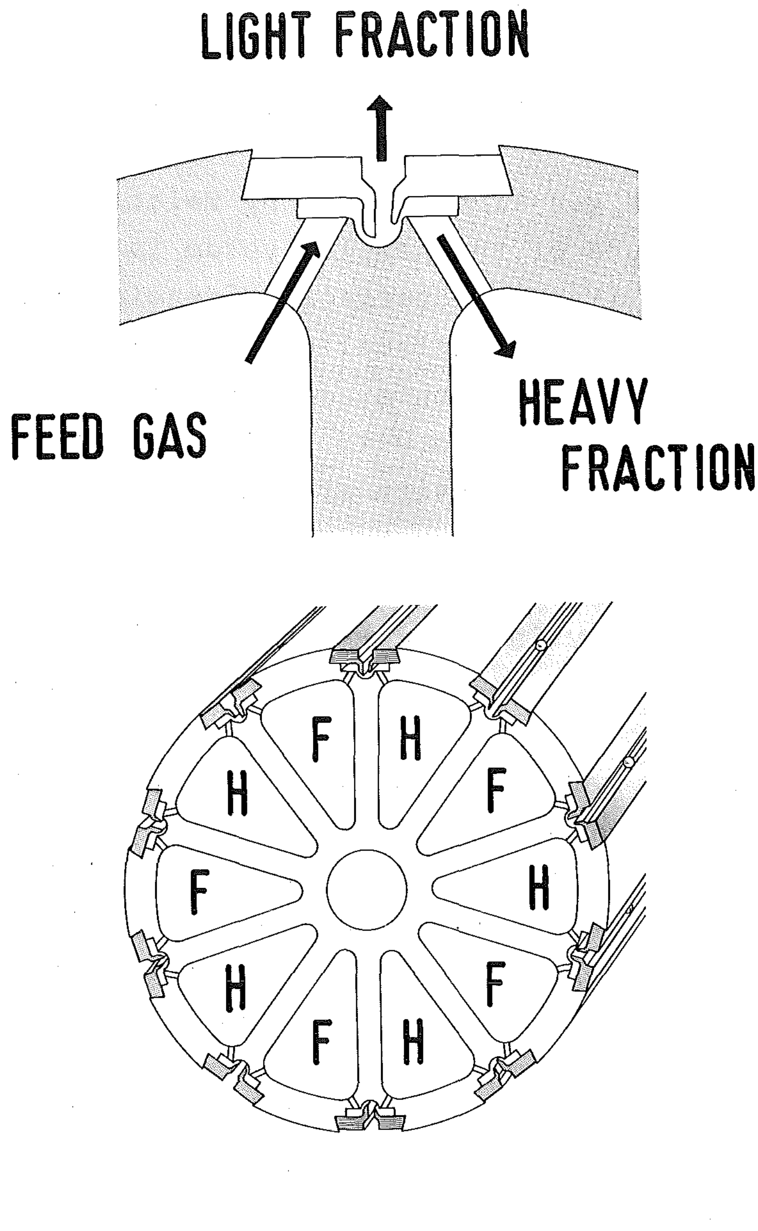

Fig. 2. Schematic representation of a commercial separation element tube manufactured by the MESSERSCHMITT-BÖLKOW-BLOHM company, Munich.

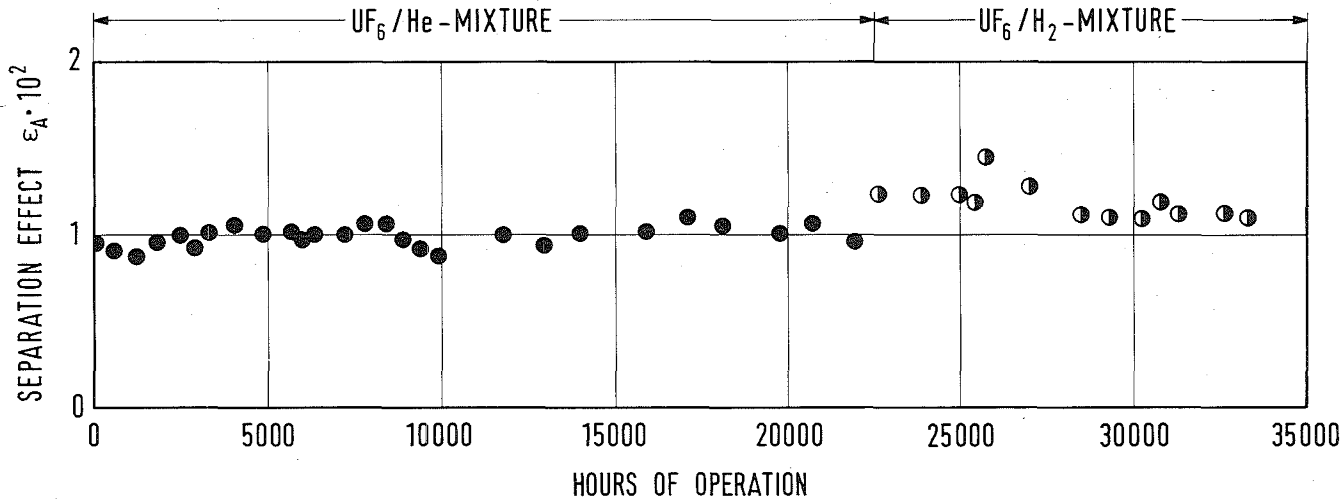

Fig. 3. Endurance test of a commercially produced separation nozzle element, carried out with He/UF_6- and H_2/UF_6-mixtures.

Fig. 3 represents the results of endurance tests performed on a section of a commercial separation element under process conditions with He/UF_6- and H_2/UF_6-mixtures, respectively. Obviously, the performance of this separation element has not changed within the error limits over a period of more than 4 years.

It is evident, that the compactness of the separation elements influences the equipment size and the cost incident to it. Therefore, the SIEMENS company, Munich, has developed another method for the commercial production of separation elements for further possible reductions in the equipment size. The method is based on the stacking of photo-etched metal foils.

Fig. 4 shows a separation nozzle structure produced by the etching technique. Considering that the radius of curvature of the deflection wall is only 1/10 mm, the picture demonstrates the accuracy of the fabrication method.

Fig. 5 illustrates the assembly of a photo-etched separation element. On the left side, a section of a metal foil strip is shown. A large number of separation nozzle structures together with the ducts for the feed gas and the heavy fraction, are photo-etched at the edges of the foil strip. As shown in the middle of the picture, approximately 100 such metal foil strips are stacked one above the other, covered with cover plates and clamped together. In this way, a compact separation nozzle chip is produced. The feed gas is introduced through the holes of the upper cover plate and the heavy fraction is removed through the holes of the lower cover plate; the light fraction leaves the chip at both sides. About 100 such chips are arranged in a tube as shown on the right side of the picture. The two

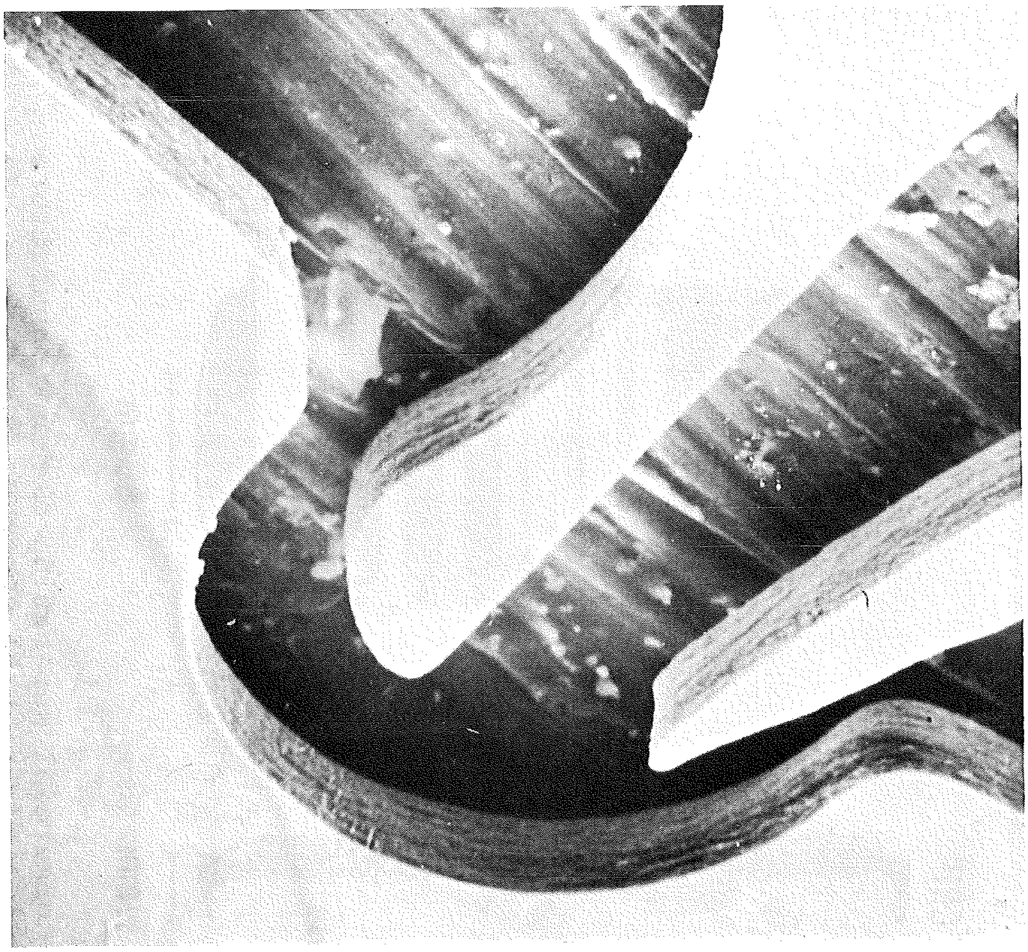

Fig. 4. Separation nozzle structure produced by means of photo-etching techniques (SIEMENS company, Munich).

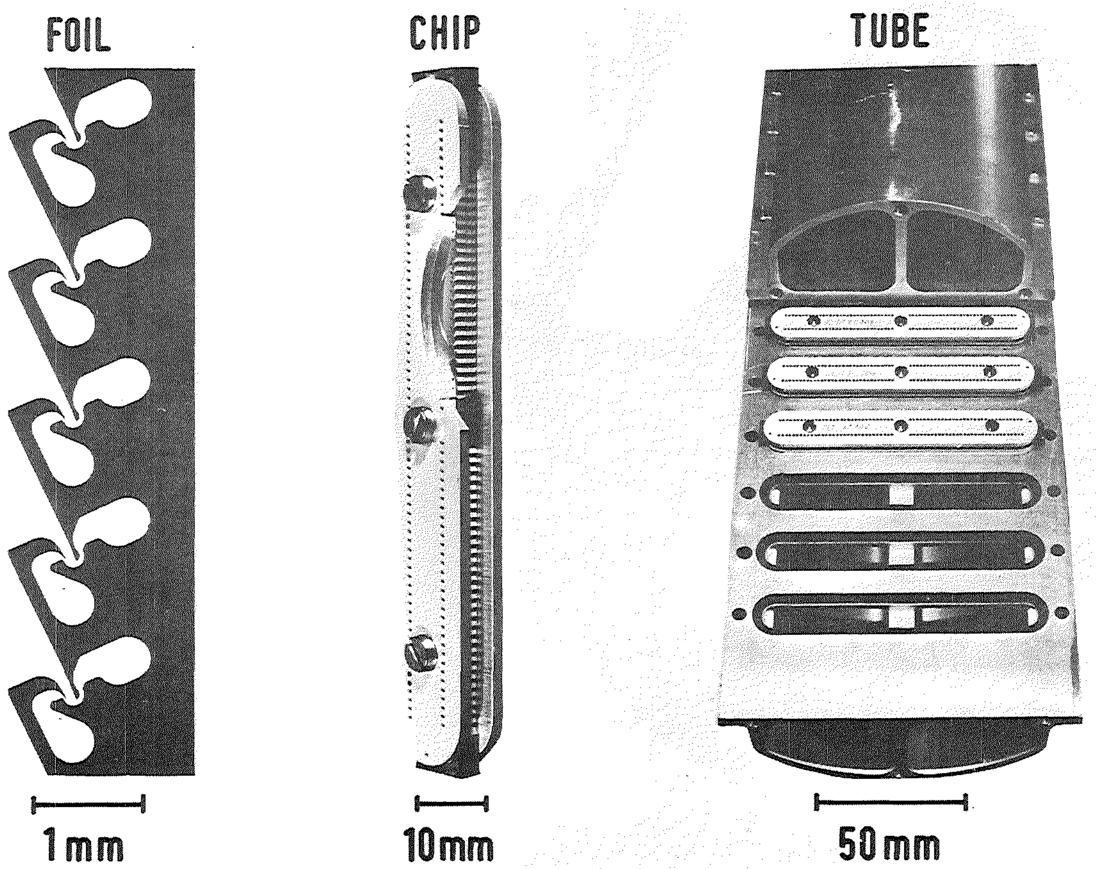

Fig. 5. The assembly of a commercial separation element manufactured by means of photo-etching (SIEMENS company, Munich).

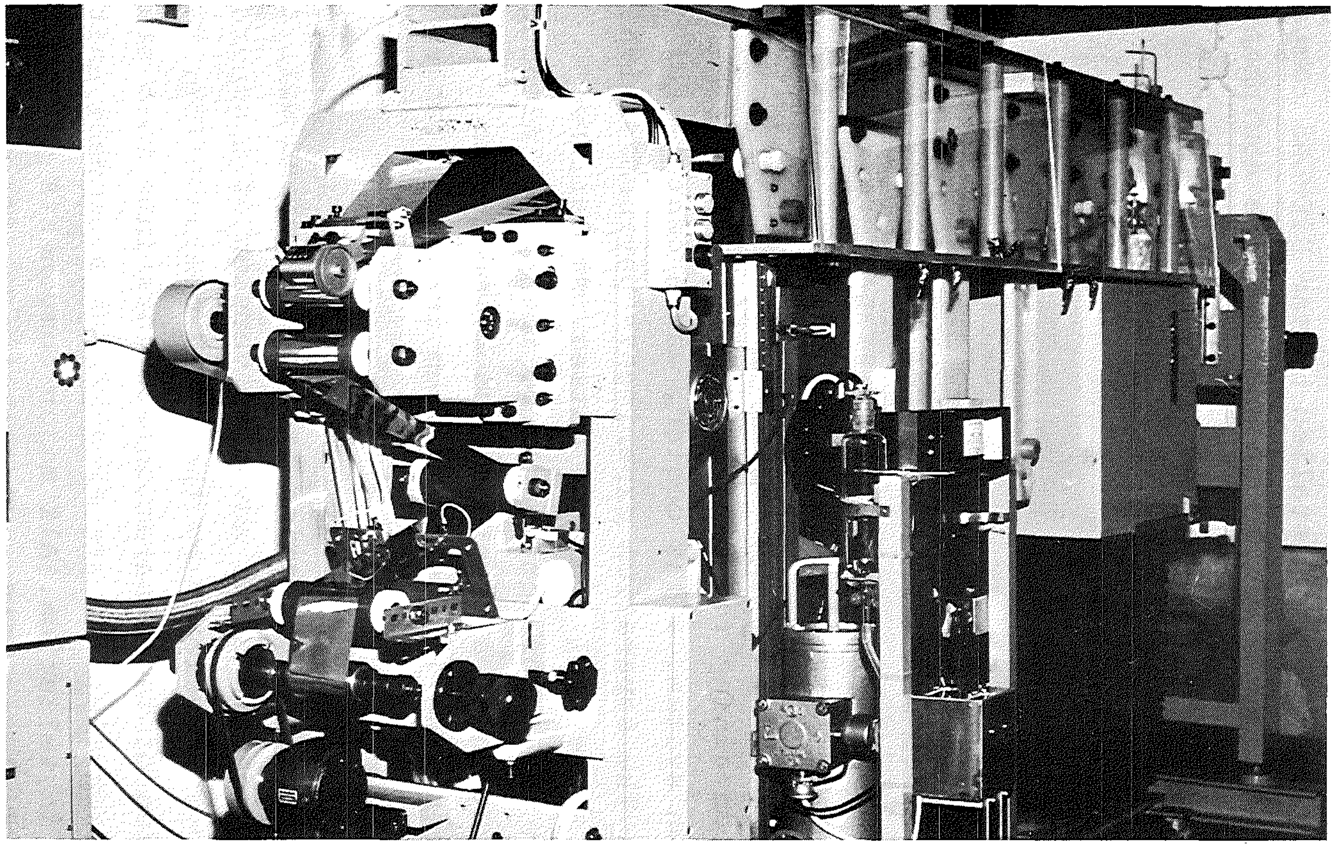

Fig. 6. Section of the automatic production line for manufacturing photo-etched separation nozzle elements: The setup for metal foil coating with a photo-sensitive resist. (SIEMENS company, Munich).

tube halves serve to introduce the feed gas and to remove the heavy fraction. The light fraction leaves the separation element tube between the two halves.

An automatic production line for manufacturing photo-etched separation elements was installed by the SIEMENS company in Munich. As an example of the production line equipment, Fig. 6 shows the setup for metal foil coating with a photo-sensitive resist.

3. Separative Stages

A large number of commercial separation elements have been tested in two prototype separative stages. Fig. 7 shows the first prototype stage installed in Karlsruhe in 1970. The stage is constructed as an integrated unit. It consists of a tank containing the separation elements, a gas distribution system, a gas cooler, and a centrifugal compressor. The separation experiments performed with this stage were successful from the outset. No failures occurred in the major components of the stage, although they were put under a severe stress by more than 400 starts and by testing the limits of maximum load and stable operation.

On the basis of the operating experience gained with the first prototype stage, an advanced version of a separative stage has been developed by the STEAG company. Fig. 8 shows the insertion of the separation elements into this stage. The separation elements are arranged as a compact unit to allow easy installation. All major components of the STEAG stage were designed with a view to the requirements of mass production.

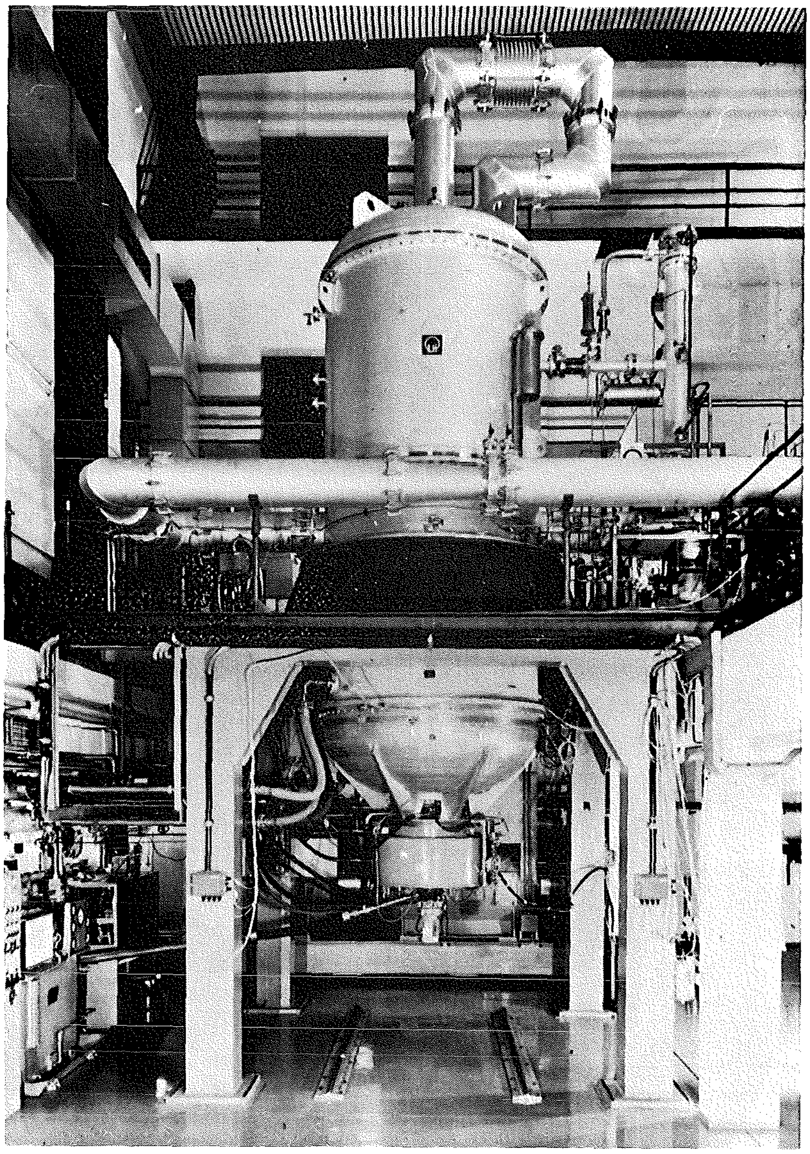

Fig. 7. View of the first prototype separative stage installed in 1970.

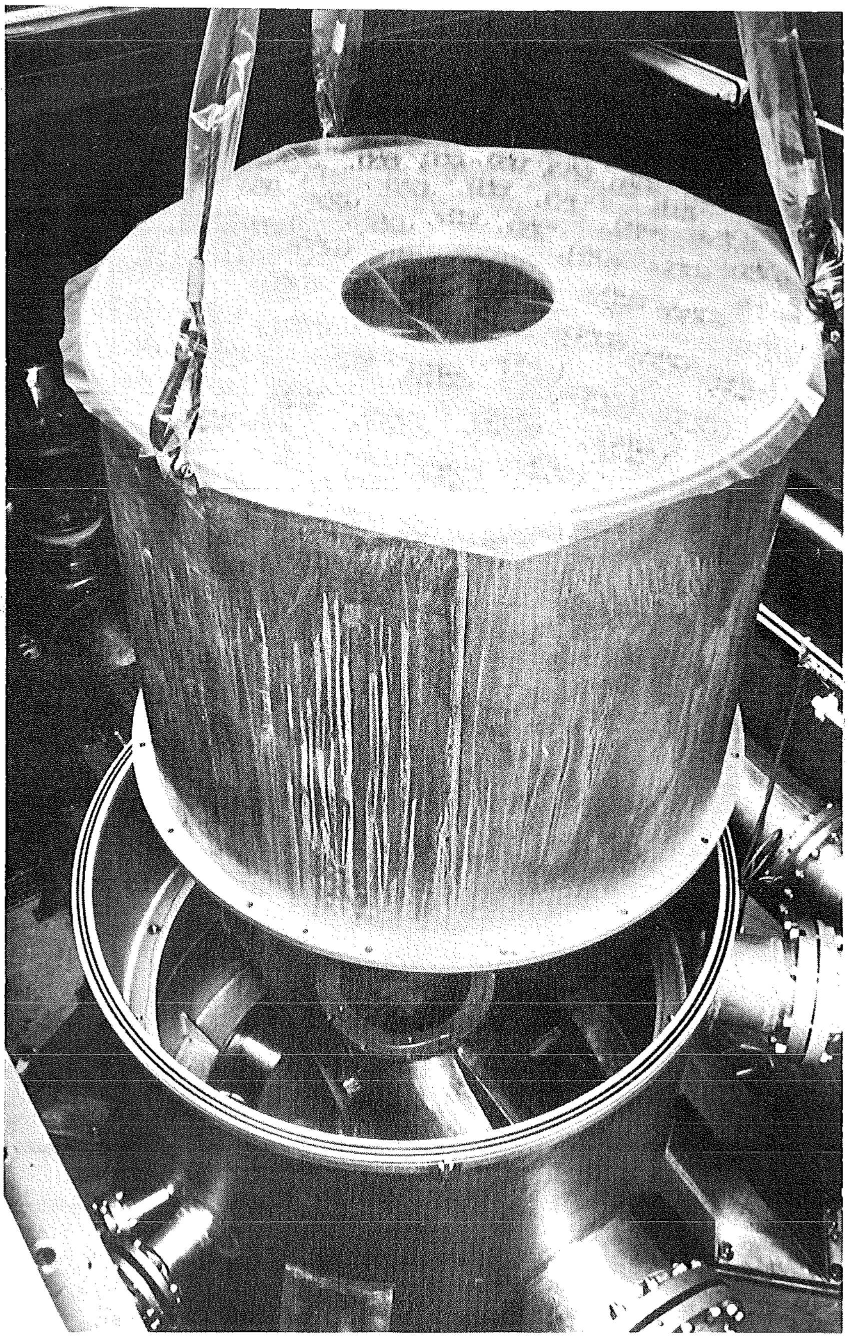

Fig. 8. Insertion of the separation element unit into the separative stage developed by the STEAG company, Essen.

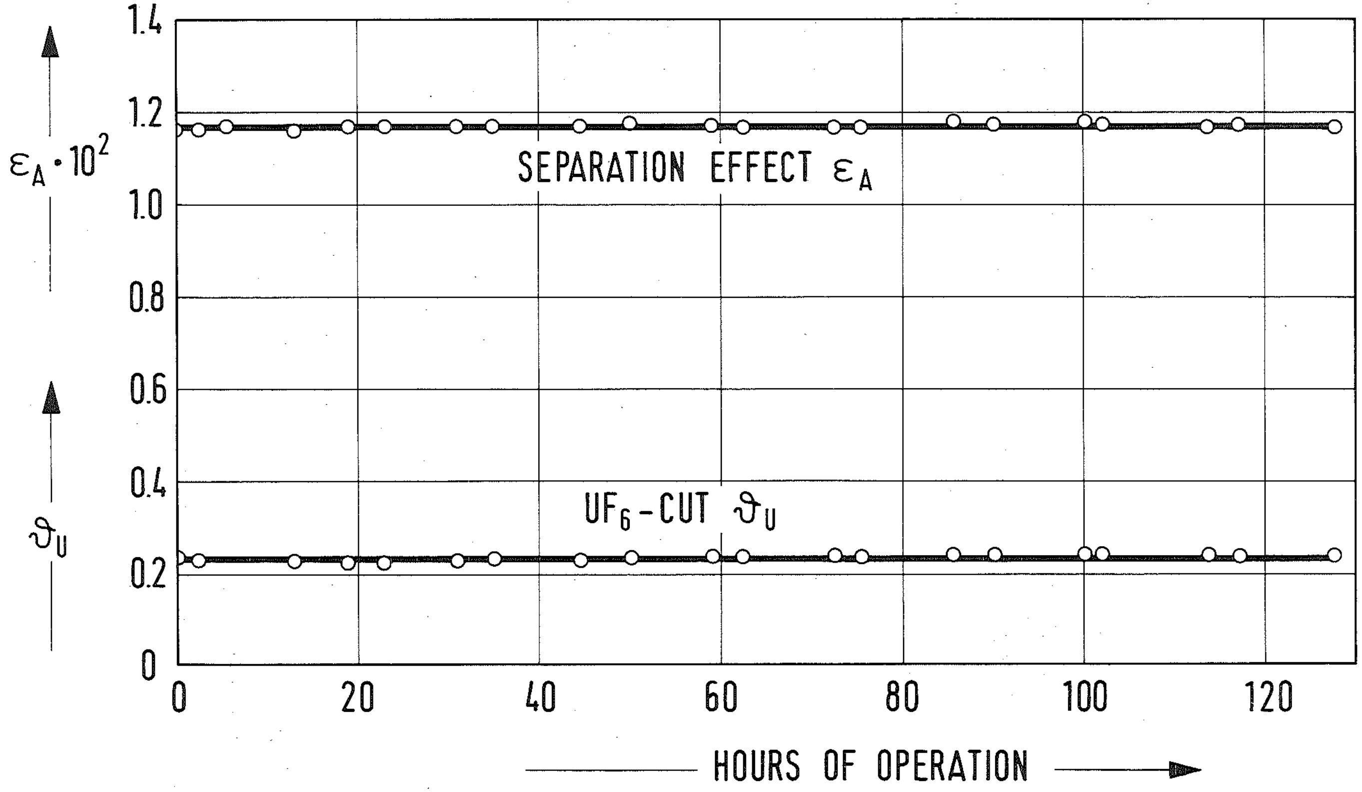

Fig. 9. Results of the acceptance test of the STEAG separative stage.

Fig. 9 represents the results of the acceptance test of that stage. The separation experiments were performed with an H_2/UF_6-mixture. The stable operation of the separative stage is demonstrated by the constant separation effect and UF_6-cut.

4. Cascade Design

Fig. 10 represents a side view of the projected stage arrangement for the industrial-scale utilization of the separation nozzle process. Groups of stages are each mounted in a concrete plate and supported by a base plate carrying the electric motors. In the right group of Fig. 10 an intermediate state of assembly is illustrated.

Fig. 11 shows a schematic representation of an industrial separation nozzle cascade using two types of separative stages. A total of about 500 separative stages must be connected in series in separation nozzle cascades in order to produce enriched uranium containing 3 % U-235 and to strip to some 0.3 % the U-235 content in the waste uranium.

Furthermore, Fig. 11 illustrates the transport of the light auxiliary gas in a separation nozzle cascade. The net upward flow of the auxiliary gas must be recycled from the top to the bottom of the cascade sections. This operation is performed by means of so-called UF_6 recycle facilities. Such a facility comprises a special separation nozzle stage which partially strips the UF_6 from the auxiliary gas thereby limiting the UF_6-holdup of the system. The remaining UF_6 content of the gas stream is then frozen out in a low temperature heat exchanger system which is run in cyclic operation.

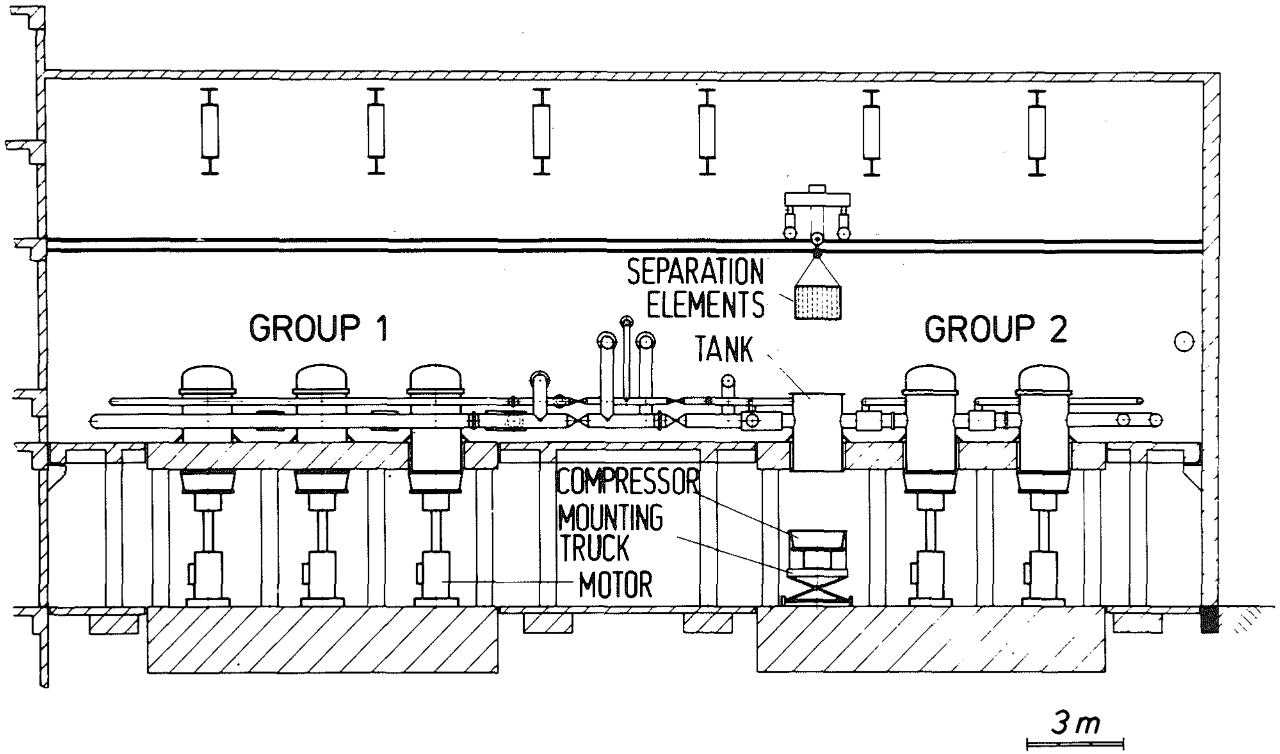

Fig. 10. Side view of the stage arrangement planned for a separation nozzle demonstration plant.

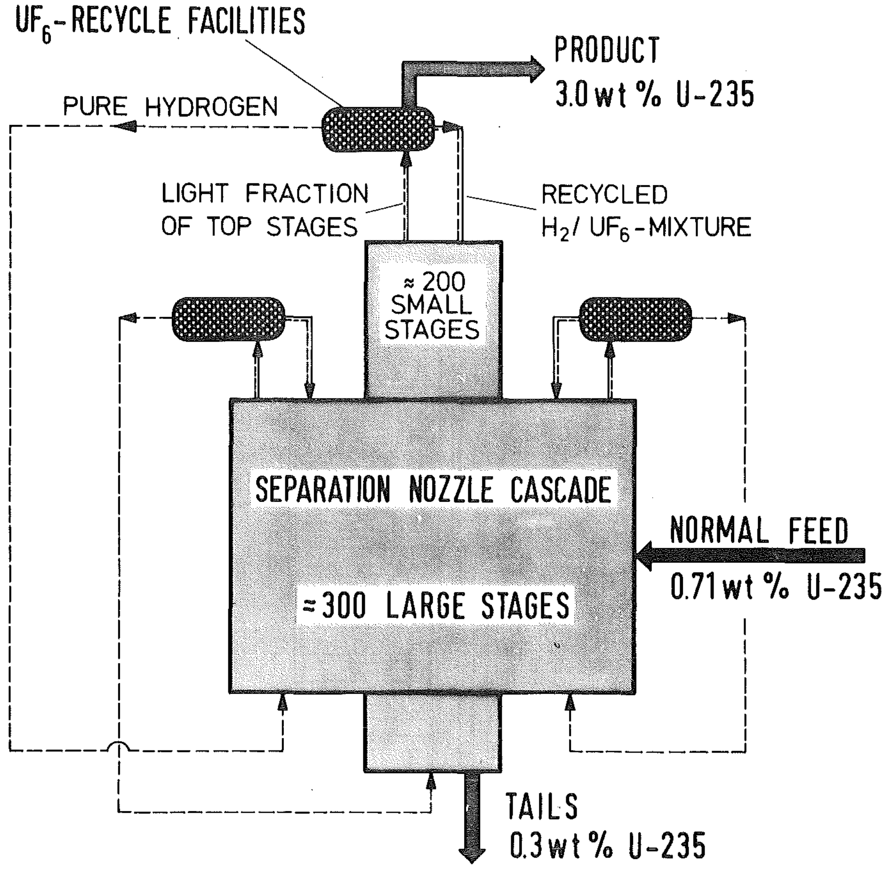

Fig. 11. Schematic representation of a separation nozzle cascade with UF_6-recycle facilities.

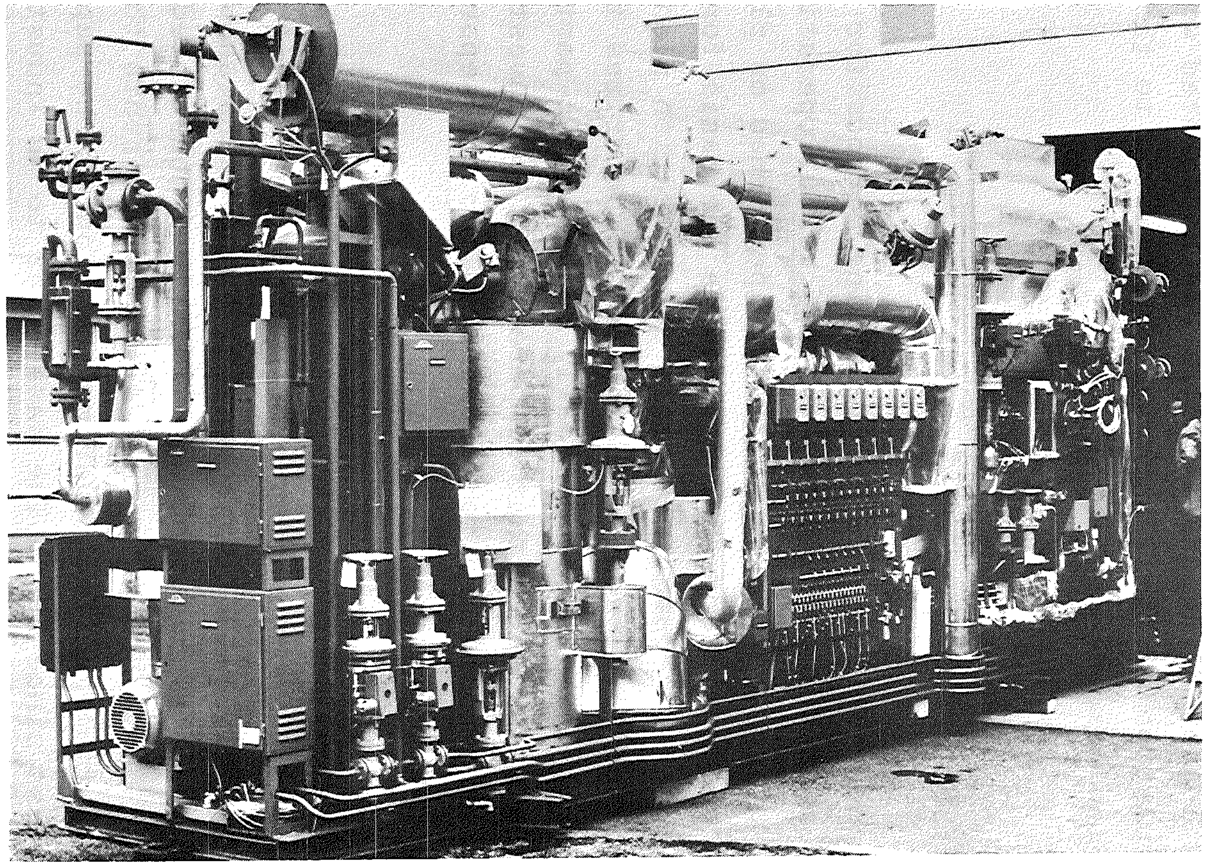

Fig. 12. View of the low-temperature freeze-out system of a UF_6-recycle facility manufactured by the LINDE company, Munich.

A prototype of such a freeze-out system was built by the LINDE company, Munich. It consists of a heat exchanger unit with an associated cooling system. Fig. 12 gives a view of the arrangement. The experiments performed with UF_6/H_2-mixtures under process conditions have demonstrated that an extremely low UF_6-content in the light gas processed can be achieved without difficulty. Accordingly, only negligible losses of separative work are associated with the recirculation of the light gas from the top to the bottom of the cascade sections.

5. Conclusions

The development of reliable manufacturing methods for commercial separation elements, the successful operation of separative stages, and extensive tests performed on plant components and auxiliary systems provide the basis for the construction of a separation nozzle demonstration plant. The performance level achieved to date characterizes the process as reliable and economically feasible. In particular, it is generally accepted that comparatively low investment and maintenance costs are to be expected for the separation nozzle process.

On the other hand, the nozzle process appears to have the disadvantage of a comparatively high specific power consumption. This situation, however, by no means should be regarded as a static one, as evidently demonstrated by Fig. 13. The curve shown in this diagram represents the reduction in the specific power consumption of the separation nozzle process since 1968. The data refer to an industrial-scale plant, i.e. the compressor efficiency, the cascade efficiency, the power consumption of the auxiliary systems,

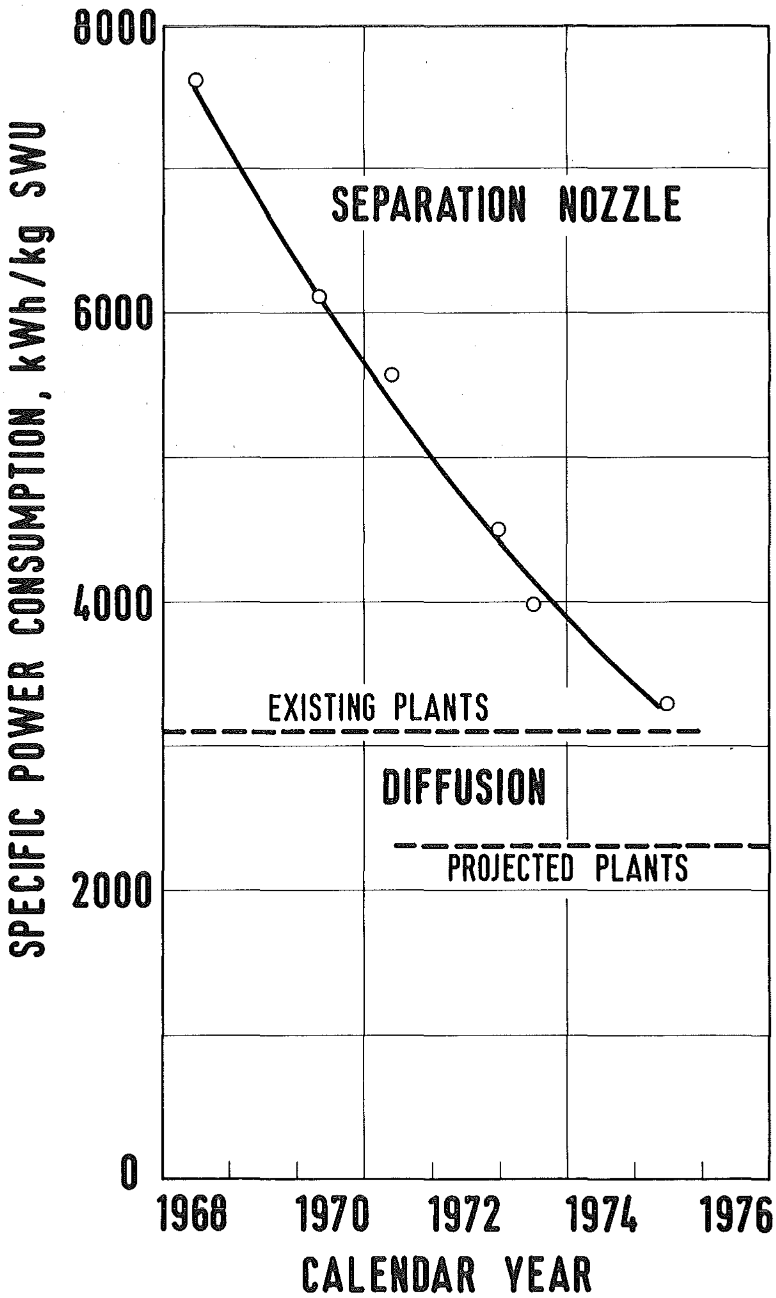

Fig. 13. The reduction in the specific power consumption of the separation nozzle process since 1968. The data were calculated for an industrial-scale separation nozzle plant and include the cascade efficiency, the compressor efficiency, the power consumption of the auxiliary systems, and the pressure losses in the piping of the cascade.

and the pressure losses in the piping were taken into account. At the present state of development, the power consumption of the separation nozzle process is still slightly higher than that of the existing U.S. gaseous diffusion plants. However, considering the slope of the power consumption curve, there is no doubt that a further significant reduction of the specific power consumption is to be expected.

In conclusion, it can be stated that the erection of a separation nozzle demonstration plant in Brazil can be recognized as the implementation of an enrichment process which combines a reliable and comparatively simple technology with a high potential for further improvements.

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