KERNFORSCHUNGSZENTRUM

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KFK 1002

Institut für Kernverfahrenstechnik

The Separation Nozzle Process for Uranium Enrichment

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by

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The Separation Nozzle Process for Uranium Enrichment

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In recent years we have developed a method for U^{235} enrichment called the separation nozzle process (1). It is based on pressure diffusion in a gaseous mixture of UF_6 and an additional light gas flowing at high speed along curved walls. At the Turin meeting on Isotope Separation held in October of last year, we have presented papers on the Principles and Economic Aspects of the Separation Nozzle Process (2) and on the Operation of a 10-stage Separation Nozzle Pilot-Plant (3). In our opinion the published figures have shown that the separation nozzle process holds considerable promise to become an alternative to the classical diffusion process.

The main purpose of today's presentation is to give some information about the progress we have made in the last 8 months. As we cannot expect that everybody is acquainted with the separation nozzle process we shall also give an account of the principles and the results formerly obtained.

Fig. 1 shows a cut through the separation nozzle system. A mixture of about 5 mole% UF_6 and 95 mole% He is expanded through a slit-shaped nozzle. The jet flows along a curved wall and is subsequently divided into two fractions which are pumped off separately. The deflection of the jet by the curved wall results in a partial spatial separation of the components, the gas moving close to the deflecting wall becoming enriched in the heavy isotope, while the light one accumulates in the remaining fraction. The helium admixture increases the velocity of UF_6, thereby improving the separation effect.

In practical application the elementary effect, as in the other separation processes, must be multiplied in a cascade arrangement. In coupling together the individual separating elements we have adjusted the UF_6 cut at such a level that the separative work for the demixing of the uranium isotopes is conserved whereas the separative work for the demixing of He and UF_6 is largely lost. The residual helium transported to the cascade head is separated there from the UF_6 and is returned to the foot of the cascade.

For the experimental demonstration of the gas-dynamic stability of a separation nozzle cascade working with a He-UF_6 mixture, a 10-stage pilot plant was built in Karlsruhe; it began operating at full capacity in November 1967 (3). Fig. 2 shows this installation as seen from the control desk. As the arrangement is U-shaped, only half of the separation stages can be seen. Fig. 3 shows the variation along the cascade of the enrichment factor which refers to one end of the cascade. The overall enrichment factor agrees within the limits of error with the value calculated on the basis of the separation factor of the individual stage. At present the pilot-plant is used to check the feasibility of a computer program for calculating the behavior of technical cascades.

After the successful implementation of the pilot plant, development and design work was started on a separating stage to be constructed on an industrial scale. In the separation nozzle process the optimal inlet pressure of the feed gas is inversely proportional to the characteristic dimensions of the slit-shaped separation nozzle system. Since, for economic reasons, high inlet pressures are desirable, separation nozzle systems with particularly small characteristic dimensions were built and were tested experimentally.

In Turinowe have presented results obtained with laboratory-type separation nozzle systems. In the meantime, in cooperation with industry, a method for inexpensive mass-production of separation

nozzle-systems with optimum inlet pressure of 600 mm mercury has been developed. Prototype-elements of that kind were tested successfully.

Fig. 4 shows schematically the design of the tube-shaped separating elements to be used in the industrial-scale separating stage. Ten slit-shaped separation nozzle systems are arranged on the circumference of an aluminium tube of 2 m in length with an external diameter of about 10 cm. The inside of the tube is subdivided by means of partition walls into 10 channels. Five of theses channels are used for the inlet of the feed gas and five for leading off the heavy fraction. The light fraction flows radially outwards into a tank encasing the separating elements.

Fig. 5 shows the entire separating stage. The tank contains 100 of the separating tubes described above. It forms, together with a two-stage radial compressor, a self-contained structural unit which can be tested and, if necessary, exchanged as a whole. The expected separating capacity is 1700 kgSW/year under full load when a mixture of He and UF_6 is used; this is about one-third of the separating capacity of the largest American diffusion stages. One such separating stage is now being constructed by industry.
Fig. 6 shows a drawing of the building which will contain the stage and its accessories. In the basement you may recognize the frequency converter, which feeds the stage with a current of 300 cycles. The roof supports the cooling tower. The separating stage is expected to be ready for testing at the end of this year.
Fig. 7 shows the building site as of May 1969.

In Turino we presented a detailed cost analysis on the basis of the state of development at that time (2). The calculation was carried out for a so-called demonstration plant with a net output of 600 000 kg SW/year. The specific investment, exclusive of the power plant, turned out to be 123 $/(kg SW/year). Within the margin of error this value corresponds to the figure published for the

American diffusion plants which are ten times larger. The specific energy consumption, however, was expected at that time to be higher by a factor of 2.2 as compared to the corresponding published figure for the American plants operating under full load.

In an attempt to overcome the drawback of the relatively high energy consumption we first concentrated on the possibility of using hydrogen instead of helium as the accelerating gas. In an earlier paper (1), we have already stated that more favorable results can be obtained with hydrogen. Our Turino cost analysis was nevertheless based on helium since, at that time, we did not have sufficient knowledge about the chemical properties of hydrogen-UF_6 mixtures. In the meantime a series of experiments and a careful analysis of published data have shown that no difficulties at all are to be expected when working with hydrogen under the conditions projected. We therefore base our present calculation on the use of a UF_6-hydrogen mixture with 5 mole% of UF_6. By switching from helium to hydrogen we have saved 30% both with regard to specific energy consumption and specific investment cost.

Our next point was to find the cheapest way of energy supply. In our former calculations a separate power station with a 300 cycle generator and 90% on-line time was anticipated. It turned out, however, that this solution would not derive full benefit from the fact that a separation nozzle plant has a very short equilibrium time and can be stopped and restarted without appreciable technical difficulty or economic loss. We now proceed on the assumption that comparatively small plants will be integrated within a large electrical grid system. Their power supply could be shut off in the unlikely case that the grid system is in danger of being overloaded. Under these restrictions an electricity price of 4 mills/kWh appears conservative, even under European conditions. On the other hand, we have to consider additional investment costs and additional power consumption for the frequency conversion.

The following cost estimate appears reasonable in the present state of development:

Tab. 1: Expected Separative Work Costs in $/kgSW of a Separation Nozzle Plant with a Net Output of 700 000 kgSW/year.

Electricity (4 mills/kWh)	22.0
Depreciation (25 years)	5.2
Interest (7.5%)	5.0
Additional Costs	2.8
Total	35.0

Basis of Calculation:
90% on line time. Total investment, incl. energy distribution and frequency conversion, 91 million $. Total power needed,500 MW. Specific power consumption,5500 kWh/kgSW. Specific investment, 130 $/(kgSW/year).

The price of a separative work unit turns out to be 35.0 $. This is still 35 % more than the guaranteed U.S. price. When judging this result, however, one must bear in mind that the separation nozzle process is a comparatively new one. In addition to our technical development work we are continuing an extensive program of basic research. We are convinced that a deeper understanding of the separation mechanism will result in further economic improvements.

References:

1) See e.g. E.W. Becker, K. Bier, W. Bier, R. Schütte, D. Seidel, Angew. Chemie, Internat. Edition in English, 6, 507-518 (1967).

2) E.W. Becker, W. Bier, R. Schütte
Principles and Economic Aspects of the Separation Nozzle Process, KFK 853 (October 1968); see also E.W. Becker, W. Bier, G. Frey, R. Schütte, atomwirtschaft 14, 249-251 (1969).

3) E.W. Becker, G. Frey, R. Schütte, D. Seidel,
Operation of a 10-Stage Separation Nozzle Pilot-Plant, KFK 854 (October 1968); see also: atomwirtschaft, 13, 359-362 (1968).

Figure Captions

Fig. 1: Cut through the separation nozzle system with a schematic representation of the streamlines.

Fig. 2: 10 stage separation nozzle pilot plant.

Fig. 3: Experimental enrichment factor A of U^{235}, relative to the heavy fraction of stage 1:
D = Nozzle feed, M and K = light and heavy fraction at stages 1 - 10.

Fig. 4: Tube-shaped separating element to be used in the full-scale separating stage.

Fig. 5: Full-scale separating stage now being constructed by industry.

Fig. 6: Drawing of the building which will contain the full scale separating stage and its accessories.

Fig. 7: Building site as of May 1969.

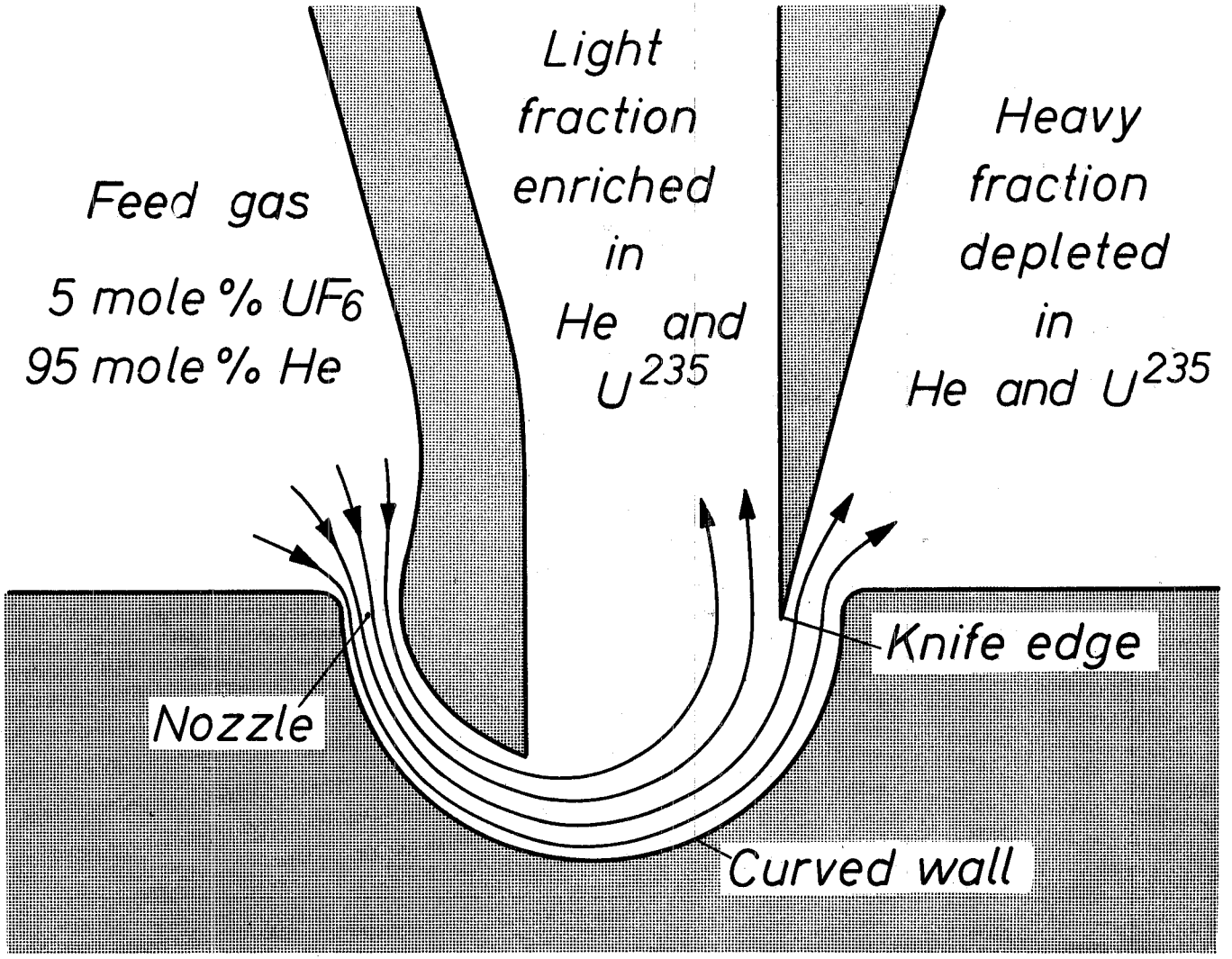
Feed gas
5 mole % UF_6
95 mole % He
Light fraction enriched in He and U^{235}
Heavy fraction depleted in He and U^{235}
Nozzle
Knife edge
Curved wall

Fig. 1

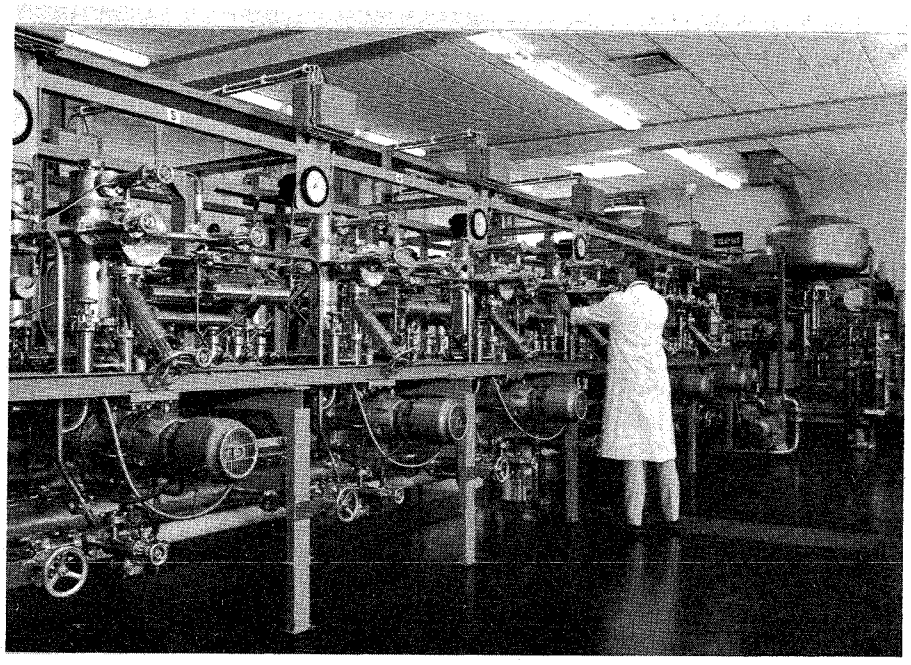

Fig. 2

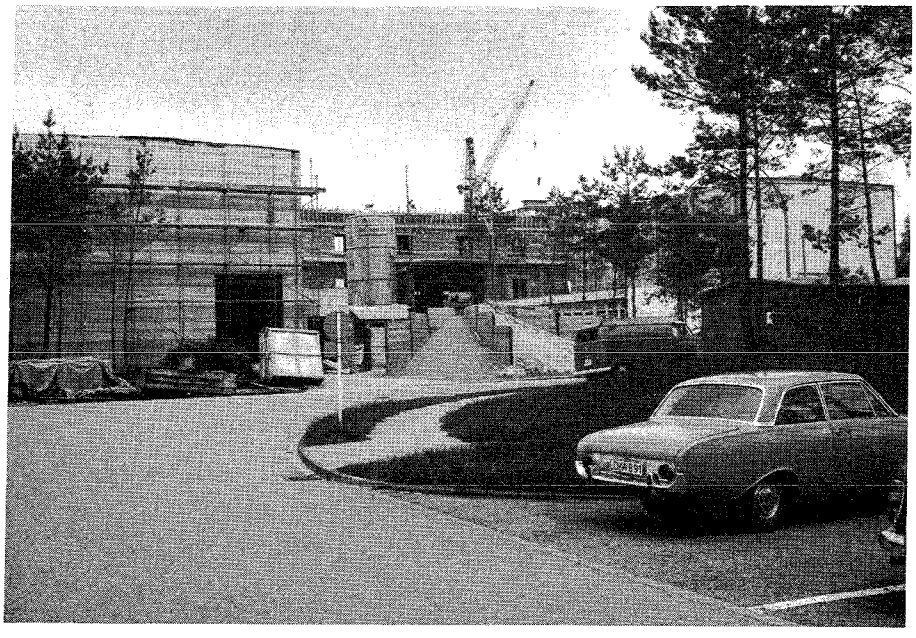

Fig. 7

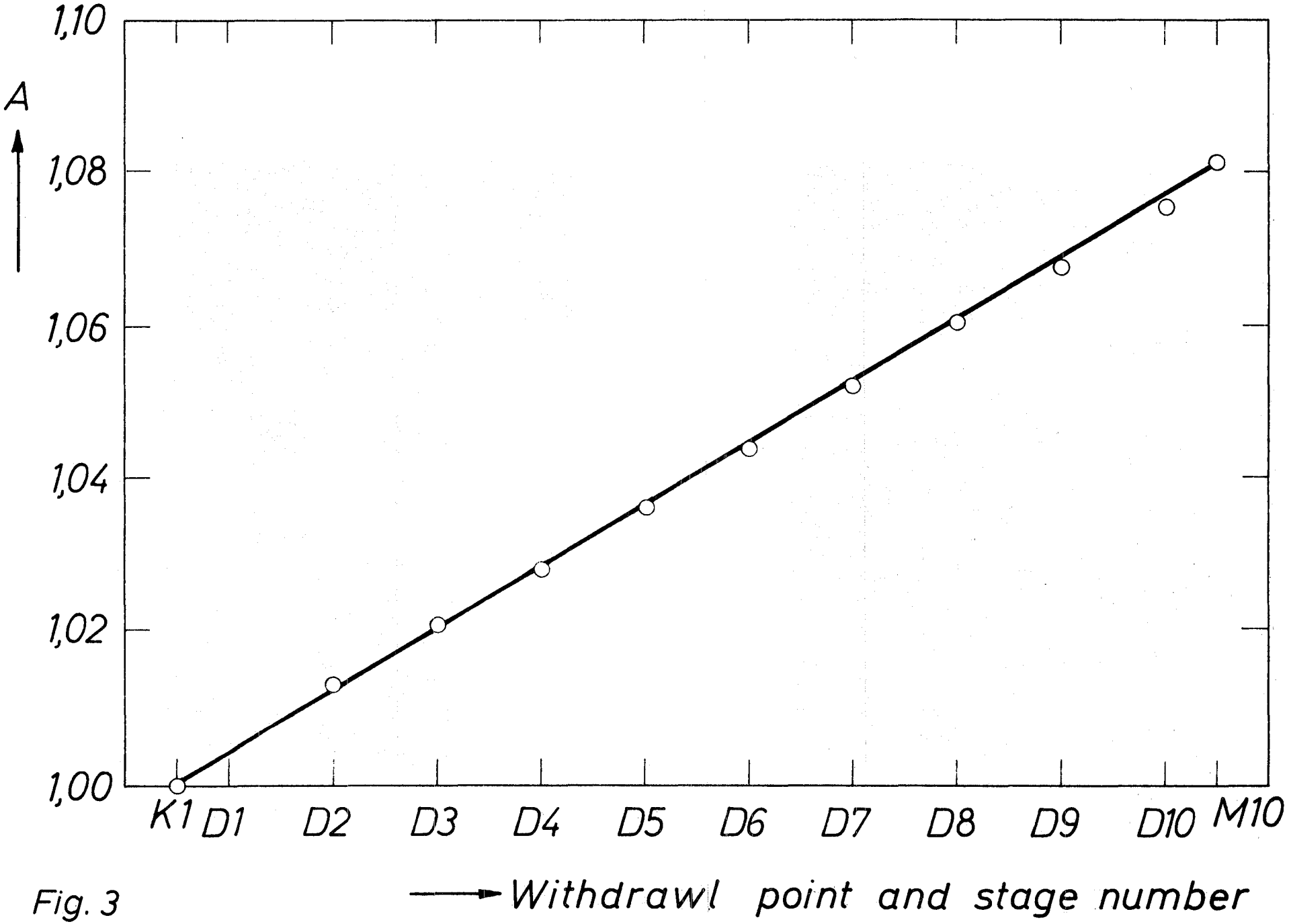
1,10
A
1,08
1,06
1,04
1,02
1,00
K1
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
M10
Withdrawl point and stage number

Fig. 3

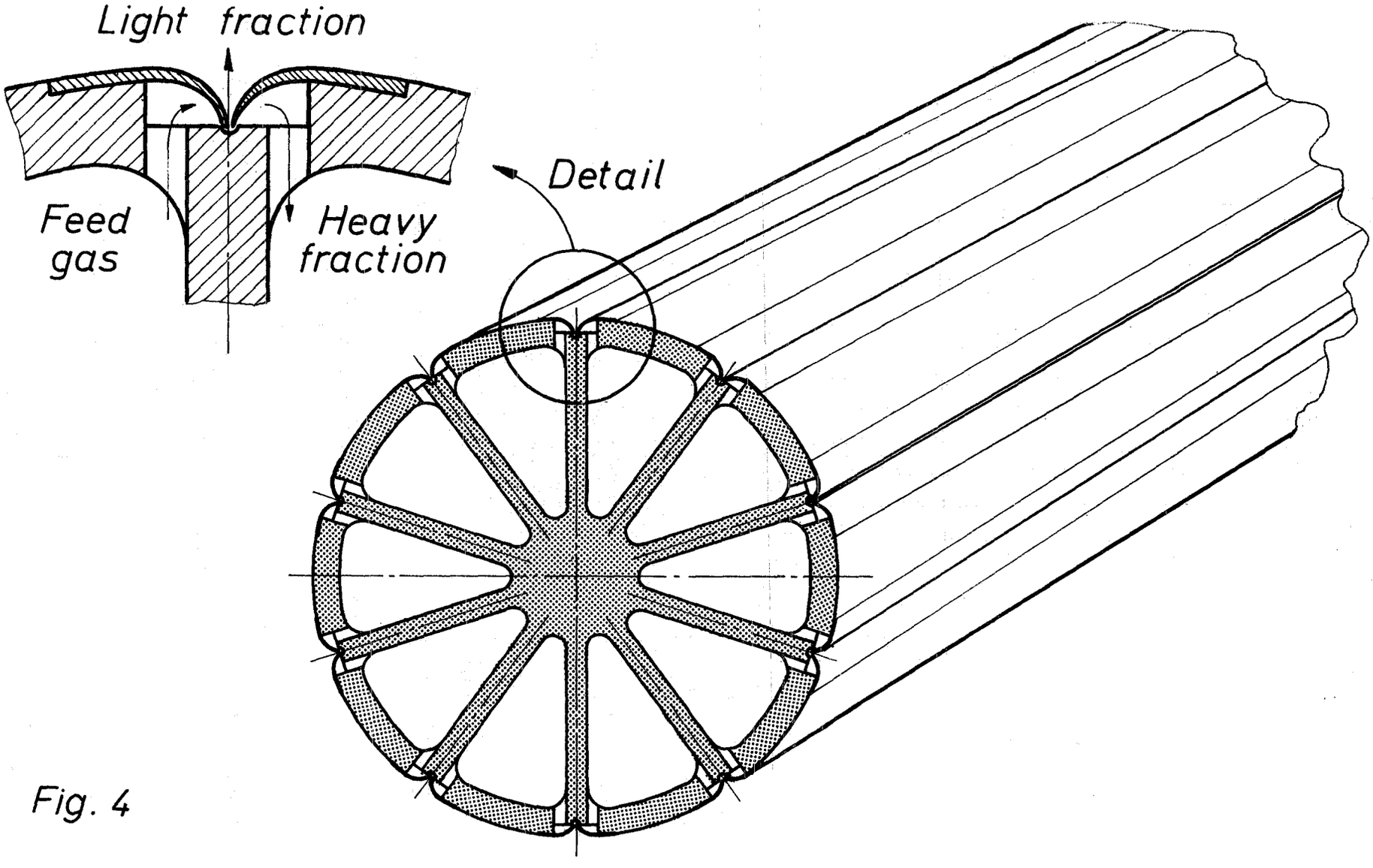

Fig. 4

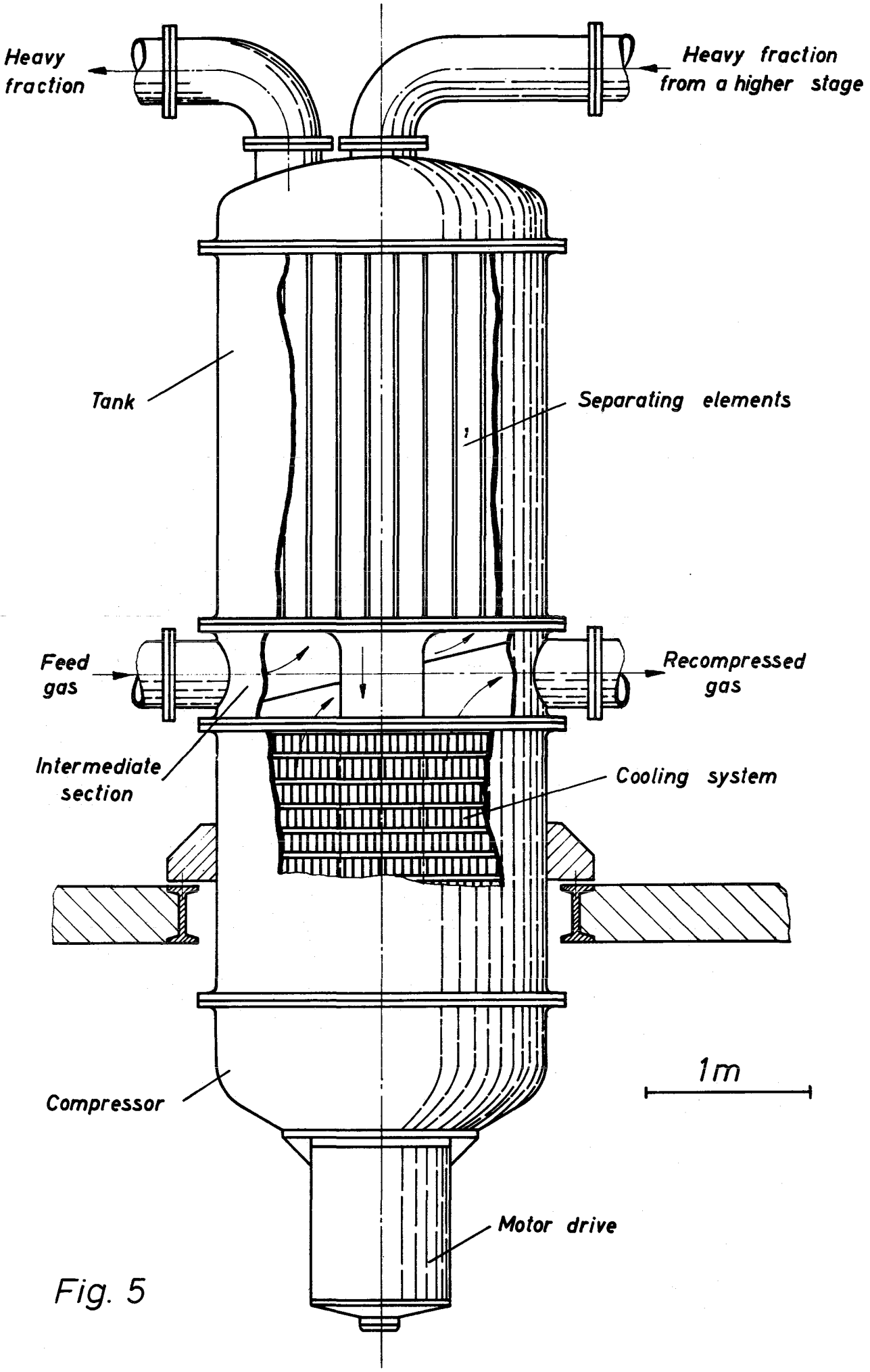
Heavy fraction
Heavy fraction from a higher stage
Tank
Separating elements
Feed gas
Recompressed gas
Intermediate section
Cooling system
1m
Compressor
Motor drive

Fig. 5

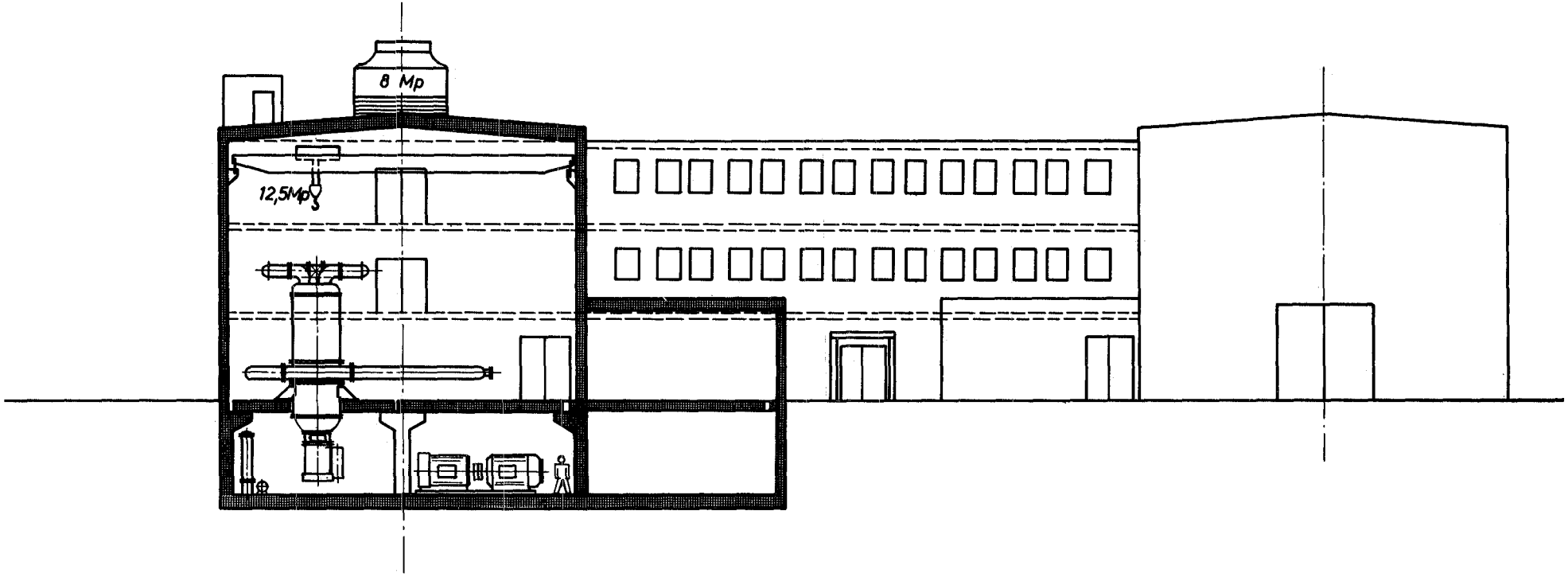

Fig. 6