The city of Uppsala is situated 40 miles north of Stockholm. It has a population of 140,000 of which 110,000 live in the central part of the city. The climate is maritime with a yearly average temperature of 42 °F (5.8 °C). The monthly average temperature in January is 24 °F (-4.2 °C) and in July 63 °F (17.3 °C). Dimensioning outside temperature is -6 °F (-21 °C).

The district heating system was started in 1960 and grew rapidly. Figure 1 shows the connected heat load as a function of time with a projection up to 1985. A plan of the distribution network is shown in figure 2. At present we cover between 75 and 80% of the total heat demand in the distribution area. Our objective is to cover 95% by 1985.

Before describing the production of heat it might be advisable to give some facts on the distribution system. With the exception of a small separate network for 250 psi (1.7 MPa) steam to some nearby industries, which use steam as process heat, all heat is distributed as hot water with a forward temperature of minimum 175 (80), maximum 250 °F (120 °C) and a return temperature of min 130 (55) to max 160 °F (70 °C). System pressure is 250 psi (1.7 MPa) and all consumers are connected via heat exchangers. Schematic diagrams of the house installations for an apartment house and for a one-family house are given in figures 3 and 4, respectively. In these diagrams temperatures at maximum load are shown. The variation of forward and return temperatures, water flow and load with the outside temperature is given in figure 5. As shown in figure 1 our connected heat load is 750 MW at present. The estimated maximum load to be produced is about 500 MW, giving a coincidence factor of 0.7.

Returning to figure 1, it can be seen that already in the mid sixties we were able to draw the conclusion that the growth of the district heating was fast enough to warrant the installation of a combined heat and power plant in the early seventies. It was also apparent that the possible power
FIG. 1 - Connected Heat Load.
Fig. 2 - Distribution Network.
production from such a combined plant might very well exceed the power
demand of the city. Therefore the Fyriskraft AB was founded as a joint
venture between the Swedish State Power Board and the city of Uppsala.
An agreement on the construction of a jointly owned heat and power plant
was reached in late 1969. The plans were approved by the City council early
in 1970 and at the same time the plant was ordered. The boiler plant was
delivered by Burmeister & Wain, Copenhagen, Denmark and the turbine plant
and all other mechanical and electrical equipment were supplied by Kraft­
werk Union, Erlangen, Germany, who also supplied the engineering for the
complete plant.

However, already at this stage we had run into environmental difficulties.
Our plans called for the supply of about 350 MW heat from this plant.
Our original project therefore envisaged two units, each supplying 175 MW
heat and 100 MW electricity. The district heating network was planned for
a possible heat and power plant in an industrial area in the southeast
part of the city. When we presented to the public our plans for a power
plant of 2 x 100 MW to be located in this area we were met by a virtual
barrage of opposition from, in particular, the environmentalists and
obviously a municipal organization such as ours must be very sensitive to
such opposition. The city of Uppsala has a characteristic skyline dominated
by the cathedral from medieval times and the castle built during the early
16th century. A power plant, even in an industrial area of the city, would
interfere with this skyline and was thus not acceptable. We studied various
other locations where the influence on the skyline would be less, but they
were all found unacceptable due to the high costs of the necessary heating
piping to connect it with the existing network. Thus, we were eventually
forced back to the original site but with a version with one unit of 200 MW
only, which was to be built partially underground. Today the only distur­
bance of the skyline is the 100 m high chimney. This chimney should have
been higher but was not allowed to excel the spires of the cathedral. This
now imposes some restrictions on the quality of oil we may use. We are not
allowed to burn oil with higher sulphur content than 2%. There were other
technical and financial consequences that could not be avoided. Prices
increased substantially during the time we studied alternative sites, the
design with the plant partly underground caused increased costs, and finally
- and perhaps the most serious - the boiler plant was compressed between the
demand that the plant could not be built too high on one hand and the
necessity of not going too deep with regard to the ground water level on
the other.
FIG. 3 - House Installation: Apartment House.
FIG. 4 - House Installation: One-Family House.
With the exception of the problems due to the skyline mentioned above the layout of the plant is fairly conventional, as shown in figure 6. A flow diagram is shown in figure 7. In other respects, however, the plant is a standard oil-fired plant. Some points may, however, be of some interest:

1. Steam data
   It should be noted that for a combined heat and power plant the efficiency as such is not so interesting as the power yield, i.e. the ratio between power production and heat production. In figure 8 this ratio, $\alpha$-value, is represented as a function of the admission pressure before the turbine at different processes. Steam (and reheat) temperature is 1000 °F (535 °C), district heating forward temperature 185 °F (85 °C) and return temperature 130 °F (55 °C). It should be noted that the admission pressure is in fact less important than the choice of process, i.e. with or without reheat, and the arrangement of water heating, i.e. heating in one or several stages. The $\alpha$-value is also very sensitive to changes in district heating temperature, an increase of the forward/return temperature to 250/160 °F (120/70 °C) will diminish the $\alpha$-value by about 15%.

2. Cooling
   The site chosen for the plant offers no cooling water facilities. Rather than building a conventional condensing plant with cooling towers and heat extraction we therefore chose a pure back pressure turbine with a cooling plant coupled to the district heating network so that power production can be maintained at low heat load by recooling the district heating water. Operating purely in this way the plant will have an efficiency of 34% which is adequate for peak power.

3. Turbine
   With the above in mind we chose a standard 250 MW unit although without a condensing cylinder which gives 200 MW at full load. Steam conditions are 2600 psi (18,1 MPa), 1000/1000 °F (535/535 °C). In other respects the turbine is conventional, the IP-cylinder being two-flow but asymmetric in order to retain the advantages of the two-stage heating at part load.
FIG. 5 - District Heating Temperatures, Load and Water Flow.
FIG. 6 - Plant Layout.
4. Boiler
The boiler is built for oil only so that the steam temperature is limited to 1000 °F (535 °C). The boiler is a once-through Benson boiler equipped with a water separator between the evaporating section and the superheater. At low load (below 35%) water is recirculated from the separator to the feed water tank. The firing equipment consists of 11 front burners. The furnace is built for pressurized firing, i.e. without any induced draft fan. We have installed an electrostatic precipitator in order to keep the dust content of the flue gases as low as possible. The installation of such a precipitator after an oil-fired boiler may seem somewhat unwarranted. It was, however one of the conditions that we had to fulfil in order to get the construction permit.

5. Miscellaneous
In other respects the mechanical and electrical equipment is conventional. It should be noted, however, that in order to get as simple an installation as possible we have refrained from the duplication or splitting up of important components. We have, for instance, only one air preheater and one forced draft fan. The boiler feed pump arrangement consists of one turbine-driven full load pump and one electrically-driven half load and start-up pump. The district heating pumps are one exception. These pumps, which safeguard the cooling of the plant, are divided into one forward and one return pump on the same motor shaft. The motor has a thyristor speed control. The pumps have a maximum volumetric flow of 50000 gpm (12000 m³/h) at a total height of 600 feet (190 m). We have two such groups, of which one is a 100% stand-by unit with automatic changeover in case of fault.

The control equipment for the plant is also conventional but contains sufficient computer capacity to facilitate the current accounting between the partners and for the storing and printout of deviations from normal. Furthermore we have a separate mini-computer for the logging and storing of values within the normal range and for efficiency calculations. The latter is particularly important in a part load plant such as ours where various measured values cannot be compared on a day-to-day basis without recalculating them to a standard state.
Numbers refer to fig. 6

FIG. 7 - Flow Diagram.
Presently we are adding a hot water storage tank with a capacity of about 8,000,000 gallons (30,000 m³). The tank will operate as a stratified accumulator between the temperature limits 130 to 195 °F (55 to 90 °C). It will operate under atmospheric pressure and is connected to the heating network via a pump and water turbine unit according to figure 9. We will use the tank mainly under the following three operating conditions:

1. At maximum heat demand, i.e. for loads above the heating capacity of the turbine, we can equalize the short peaks in the district heating and thus avoid the installation of a further hot water boiler.

2. At heat loads equal to the maximum heating capacity of the turbine the heat demand actually varies so that day demand exceeds the turbine capacity but night demand drops below this capacity. Due to the equalization between night and day with the aid of the tank we can increase the back pressure production.

3. During spring and fall, particularly during September, the heat demand is decidedly smaller than the power demand. The cooling plant has a capacity of only 120 MW. We can increase the cooling capacity by charging the tank during daytime and discharge to the cooling plant at night.

The construction of the plant proceeded without any disturbance. The generator was synchronized for the first time on July 25th 1973, one month ahead of schedule. The plant was to be handed over by February 1st 1974 at the latest. This could not however, be achieved, particularly due to severe operational difficulties with the boiler. These problems have been described elsewhere (VGB Power Stations 1977). The main cause can be traced to the fact that the boiler furnace was actually somewhat underdimensioned because of the environmental and other pressures we had to cope with during the early stages of the project. The problems were, however, corrected and we went into operation again on October 15th 1974 and started commercial operation from February 1st 1975. Since then the plant has been in continuous operation without any noteworthy disturbances. The availability has been excellent, as is shown in figures 10 and 11. In these figures all outages have been shown, divided into forced outages, planned outages for servicing that can be done at a suitable time, planned outages due to power
130/185°F Hot Water Temperature

2 Stages with reheat
1 Stage without reheat

FIG. 8 - Power Yield.
exchange with the plant stand-by and yearly overhaul. You will note that the operating season 1974-1975 was virtually free from any disturbance. The two stops in December represent two weekends during which we built in and took out some temperature measurement equipment in the reheater. The 1975-1976 season also was troublefree, the outage around December 1st was due to preparations for the acceptance test, which was carried out during the beginning of December 1975. During the season 1976-1977, however, we were forced to go out of operation four times in order to overhaul the forced draft fan. The maintenance work on this fan during the summer 1976 had not been thorough enough, for which we had to suffer later. All these outages could, however, be made during weekends. The total outage time excluding the summer overhaul in the 1975-1976 season was 4.56 %. If the preparations for the acceptance test are disregarded the total outage time amounts to 1.08% of which 0.96% was due to forced outage. For the 1976-1977 season total outage time amounts to 2.07% of which 0.41% is due to forced outage. The time for summer overhaul may seem long. During the period mid June to mid August the heat demand, however, is so low that even no-load operation is hardly possible. The operation during this period is uneconomical and thus uninteresting.

The $\alpha$-value during the season 1976-1977 was, on average, 0.55. The heat balance for the year 1977 is shown in figure 12. You will note that most of the heat is produced through combined production. Hot water boilers are used during the summer months, when the power plant is standing by or under overhaul and also during some winter months as reserve for the power plant and for peaking, i.e. at loads above maximum turbine capacity. There is also a small amount produced every month in transportable hot water boiler plants serving smaller networks not yet connected to the main network.

The power balance is shown in figure 13. The two partners in the joint venture, Uppsala Kraftvärme AB (UKAB) and the Swedish State Power Board (SV), each have at their disposal 50% of the power production. Figure 13 represents the power balance of UKAB for 1977. During the winter months the bulk of the power demand is covered by back pressure power, i.e. power from the combined production. During part of May and June the marginal costs of the national power pool were below our production costs, so that we could draw power from the pool with the plant standing by. The corresponding energy is represented by the horizontally shaded area. During the winter months the back pressure production may exceed the demand during
FIG. 9 - Hot Water Accumulator.
FIG. 10 - Plant Availability.
FIG. 11 - Plant Availability.
nights and weekends giving a certain excess power, totally 5 GWh, which is sold back to the pool. As heat and power demand do not coincide in time, the power production can be increased and the demand balanced by creating an extra heat demand through the cooling of the district heating hot water in the cooling plant. In figure 13 this power is designated as recooling power. As you can note from the figure most of this power was actually not produced but drawn from the pool. Only in January and the end of April were pool prices high enough to warrant actual production. As is evident from figure 13, the production is, even with the aid of recooling power, not sufficient to cover the demand, particularly during the summer months, and we therefore also have a supply of contract power from the State Power Board. Finally, due to forced and planned outages particularly in January and December, we purchased emergency power from the Power Board.

The power balance highlights some of the difficulties that confront a utility that has not earlier had any power production of its own. It is obvious that if UKAB had built a plant of its own it would have had substantial excess of power, which could have been difficult to sell. The alternative, installation of a smaller plant, would have resulted in higher specific capital costs and higher specific running costs. It was advantageous to make an agreement with an established power producer. The basic structure of the agreement was that the Swedish State Power Board were to pay UKAB a certain annual sum for the right to produce back pressure power and UKAB in turn a certain annual sum to the joint venture company Fyriskraft AB for the right to produce heat in the joint venture company. For UKAB these payments when capitalized approximately balanced each other. Further important parts of the agreement were provisions for contract power, emergency power and power exchange. The demand for power in Sweden approximately follows the same pattern as in Uppsala with a peak in December or January and a minimum in July. The back pressure power produced in combination with district heating is therefore very valuable, particularly as about 60% of the power produced in Sweden is hydro power which is more abundant in summer than in winter. Against this background the agreement for contract power stipulates that no demand charges are to be paid during the months May through August. Even more important was the agreement on emergency power. With only one producing unit the consequences in case of a forced outage could be disastrous. The agreement stipulates a fixed charge in the order of 3 $/kW, a day charge in case of outage of about 0.15 $/kW, day and an energy charge corresponding to the running costs in
FIG. 12 - Heat Balance.
FIG. 13 - Power Balance.
an oil-fired condensing plant. The day charge is not paid for planned outages during weekends and holidays.

The agreement for exchange power stipulates the conditions and payments for the purchase and supply of interruptible power. Basically they amount to the following:

When we buy interruptible power in lieu of back pressure we pay the average of our marginal cost and pool marginal cost. When we sell excess back pressure production we get somewhat less than the average of our marginal cost and pool marginal cost. When we purchase in lieu of recooling power we pay somewhat more than the average of pool marginal cost and our marginal cost and when we supply excess recooling power we get our marginal cost. The deviation from the straightforward payment of the average reflects the difference in bargaining position between the small and the large utility.

The comparison of our costs with, for example, US costs is somewhat problematic particularly in these times of varying exchange rates. However, for a larger Swedish utility the main alternative to a combined heat and power plant is nuclear power and, therefore, a comparison between a heat and power plant and a nuclear plant is suitable. The installation cost for Fyriskraft was $41,000,000 or 200 $/KW. No. 2 unit of a Swedish nuclear plant taken into operation at the same time, cost $170,000,000 for 580 MW or 290 $/kW. Total production costs 1977 for Fyriskraft were 1.8 c/kWh at a capacity factor of 0.4. An economical capacity factor for a combined heat and power plant is about 0.45. The nuclear plant had production costs of 1.5 c/kWh at a capacity factor of 0.7. Operating at 0.45 it would have produced at the same cost 1.8 c/kWh.