Volume 2 Numbers 1-4 New Series 1978

# PROGRESS IN NUCLEAR ENERGY

Volume 2 Number 1 New Series 1978

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Executive Editors
M.M.R. WILLIAMS London
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Progress in Nuclear Energy, Vol. 2, pp. 1–28. Pergamon Press 1978. Printed in Great Britain

# THE USE OF NUCLEAR ENERGY FOR DISTRICT HEATING

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(*Received* 25 *March* 1977)

**Abstract**—So far only one reactor—the Ågesta reactor, south of Stockholm has been used to supply a sizeable district heating scheme. For 10 years this pilot scheme delivered 10 MW of electricity to the grid and initially 50 later 70 MW of heat to the suburb 'Farsta' of Stockholm, with a very good reliability record. As yet it has had no successors anywhere in the world. Ågesta was of course too small to give good economics, but it gave valuable experience. As the citizens of Farsta had become accustomed to the smokeless nuclear heat, there were many protests from the public when Ågesta was shut down to allow the nuclear effort in Sweden to be concentrated on bigger units.

Since the oil crisis, nuclear district heating schemes have, however, been studied with increasing effort in a number of countries as one of the possible ways of achieving lower heat costs, conserving the limited oil and natural gas resources, and reducing air pollution. In this article the author describes the basis for assessing the performance and economics of such schemes. To do this it has been necessary to treat not merely the nuclear plants but also the entire system of transport distribution and storage of heat. Many of the numerical examples in this area have been taken from the Swedish scene with which the author is best acquainted but also many comments on conditions in other countries are included.

Also the institutional obstacles which often stand in the way of a wider use—and the manner in which they are starting to be tackled by several countries—are discussed. The subject is treated in a manner which it is hoped will be useful also to those without previous experience of district heating.

## 1. A CASE FOR LOOKING AT NUCLEAR DISTRICT HEATING

Nuclear power plants have so far been designed almost without exception as electricity producers. This is understandable in so far as they are intrinsically complicated and thus have a fairly high 'minimum cost' even at low output. Hence they need a large minimum output before their low fuel cost can compensate for the high capital cost. This makes it necessary to use a distribution medium capable of distributing large outputs over wide areas—and electricity is an excellent distribution medium for this purpose.

However, electricity is not cheap. For one thing the efficiency of generating electricity is low—typically 33% for current nuclear plants. And in addition expensive rotating conversion machinery—the turbogenerators are needed. The high price is acceptable when it comes to driving machines or producing light—but there is a very large energy market—40–50% of the energy needed in most central and northern European countries—which needs only low grade heat, mostly below 100°C. Space heating, hot tap water production, industrial processes such as drying and street snow melting schemes are the major ones. For these, electricity is as yet used only to a very limited extent.

Moreover low grade heat can be distributed effectively, for instance by warm water, mainly for heating purposes, and schemes using this principle have become known as 'district heating schemes'. Much of the heating of the more densely populated parts of most cities in Northern and Eastern Europe is supplied by such schemes, and many other European cities have such schemes. Tables 1[1] and 2 give some data. Thus in principle *also a low grade heat distribution instrument exists* of which nuclear reactors could avail themselves. This can be done in two ways. Firstly, for large central electricity producing power plants some or even all of the two thirds of the heat normally being rejected could be recovered and used for heating. This is not done without some sacrifice, namely that of producing somewhat less electricity in order to achieve warm water of adequate temperatures. But the sacrifice is small—1 kWh electricity per 5–10 kWh of heat made available for district heating, depending on temperature. Thus this 'reject heat' is very cheap at source—1/5th to 1/10th of the cost of a unit of electricity. But as the big nuclear power plants have to be located at some distance from centres of population, significant heat transport costs have to be added to these low heat source costs.

The other approach is to produce low grade heat directly in smaller low temperature reactors made so

Table 1. Connected district heating loads for some European countries (Ref. 1)

*(A) Western Europe excluding industrial heat loads*

| | Western Germany | Sweden | Finland | Denmark | Holland | Austria | Switzerland | France |
|---|---|---|---|---|---|---|---|---|
| Year | 1975 | 1975 | 1975 | 1975 | 1975 | 1975 | 1974 | 1973 |
| Connected load, MW | 23,545 | 9701 | 2750 | 9885 | 1093 | 1705 | 582 | 5233 |
| Population, millions | 61.9 | 8.2 | 4.6 | 5.0 | 13.4 | 7.5 | 6.4 | 51.8 |
| MW per million inhabitants | 379 | 1183 | 815 | 1989 | 81 | 227 | 91 | 100 |

*(B) Eastern Europe (plus Western Germany) including industrial heat loads*

| | Western Germany | U.S.S.R. | Poland | Czecho-slovakia | Rumania | Bulgaria | Hungary | Eastern Germany |
|---|---|---|---|---|---|---|---|---|
| Year | * | 1975 | 1975 | 1975 | 1975 | 1975 | 1975 | 1975 |
| Connected load, MW | *ca.* 49,400 | 494,000 | 39,500 | 35,400 | 15,800 | 9300 | 4700 | 7700 |
| Population, millions | 61.8 | 216.3 | 32.9 | 14.5 | 20.7 | 8.5 | 10.4 | 17.0 |
| MW per million inhabitants | 799 | 2006 | 1201 | 2438 | 764 | 1094 | 446 | 451 |

* District Heating Loads 1975, Industrial Loads 1974.

Table 2. District heating data from some West European countries with highly developed system (based on Unichal Statistics)

| Item | | Country: Germany | Sweden | | Finland |
|---|---|---|---|---|---|
| 1. Population | millions | 62 | 8 | | 4 |
| 2. Number of heat utilities | | 109 (16)* | 50 | (9)* | 29 |
| 3. Heat supplied by district heating stations | GWh(t)/yr | 42,300 | 16,200 | (10,600) | 6800 |
| 4. Total connected heat load | MW(t) | 22,300 | 9300 | (5760) | 4221 |
| 5. Maximum heat demand during year (4 hr period) | MW(t) | 9200 | 6500 | (3500) | |
| 6. Annual utilization period | | | | | |
| (a) network = (3)/(4) | hr | 1450 | 1750 | (1840) | 1620 |
| (b) gen. plant = (3)/(5) | hr | 3520 | 2500 | (3020) | |
| 7. Length of primary networks | km | 5100 | 1960 | (1320) | 906 |
| 8. Connected heat load/m | kW/m | 4.4 | 4.7 | (4.4) | 4.7 |
| 9. Back pressure electricity production | GWh(e)/yr | (4476)* | | (2690) | 2623 |
| 10. Installed back pressure capacity | MW(e) | | 1450 | | 473 |
| 11. Percentage of houses connected | | | | | |
| (a) in cities with district heating schemes | % | | | | 38.6 |
| (b) in whole country | % | | | | 14.1 |
| 12. Year for statistics | | 1974 (1973) | 1973/74 | (1973) | 1974 |

* Refers to heat utilities forming part UNICHAL, i.e. the international organization of district heating utilities (mainly larger utilities).

simple that we can hope that they will be permitted to be built more closely to smaller cities. As the conversion efficiency is nearly 100% (compared to 33% with electricity production) the heat at source should still be much cheaper than the cost of electricity (though not as cheap as reject heat) and heat transport costs may be smaller than for reject heat, because of the closer location to the consumers.

With the advent of the 'fuel crisis' which sharply increased fossil fuel costs and spread awareness of the strictly limited resources of the valuable hydrocarbons still available to mankind, several nations began to study more seriously one or both of the above approaches to nuclear district heating. They offer in principle a means of allowing nuclear energy to take over substantial parts of a large energy market now mainly reserved for fossil fuels and thereby relieve the pressure on these restricted resources—especially oil and gas. They also improve the efficiency of using nuclear fuel and would, when compared to using nuclear electricity for space heating, reduce the overall nuclear reactor capactiy needed.

However, nuclear district heating is not the answer to all heating problems. This article attempts to describe the possibilities and limitations, the type of areas where it would achieve great economic and environmental benefits, and the areas where it would not compete, the technology and also some of the institutional problems which have hampered its introduction but which are being now addressed seriously in several countries.

## 2. THE HEATING LOAD

An essential requirement for a nuclear district heating scheme is a large heat load served by a distribution system. In countries where district heating is already widely used, this requires often merely interconnecting several existing local networks, and perhaps extending them. Where no district heating systems exist, they can be built up quickly using a step-by-step approach. In Sweden, for instance, some municipal areas which did not have district heating systems built up an interconnected local of 300–400 MW within five years of the start. The process is as follows.

First, of course, a district heating authority with the task of financing and promoting the scheme is set up. In Sweden these are generally owned by the municipality. A cash flow scheme is prepared, which shows over what period initial loans can be repaid and a break-even of costs is obtained. The physical installation process proceeds on the following lines.[2]

### *Step* 1

In some specially suitable densely built-up areas (or new building estates), movable water boilers are installed capable of serving a few thousand people each. Hot water mains are laid in the streets, or in older down-town areas often through cellars, and substations are built in the houses separating the high pressure primary water from the lower pressure space heating water and the hot tap water.†

These two secondary systems are normally kept separate (see Fig. 1) because the tap water contains oxygen which would result in corrosion of steel radiators and common brass fittings. To persuade the owners of individual boilers to connect to the network, a compensation is offered for the value of the existing boiler depending on its age.[3] The sums for

† In some countries, e.g. Germany, the primary water is usually led directly into the space heating systems of the houses, after passing pressure reducing valves. This gives somewhat less protection to the consumer than completely separate secondary systems with limited water volumes, but can, in some cases, be slightly cheaper.

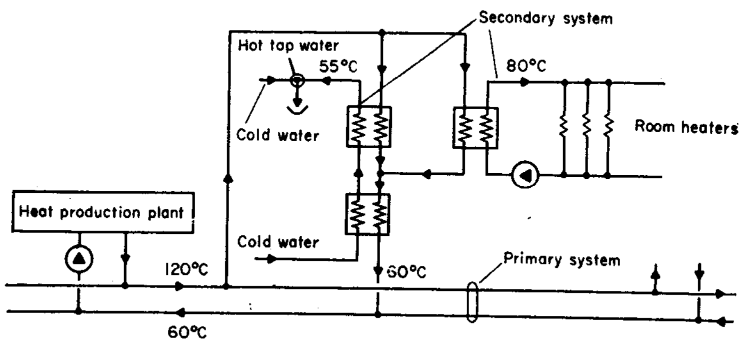



Fig. 1. Typical indirect district heating scheme (Sweden: temperatures apply on coldest winter day).

compensation and for building the network are repaid from the difference between the cost of operating efficient central boiler plants using cheap heavy oils, and the sales price of heat which is based on what it would cost to supply heat from less efficient domestic boilers requiring lighter and more expensive fuels.

*Step* 2

Several of the 'district heating islands' from step 1 are interconnected. A larger permanent central boiler plant is built to cover the needs of the bigger interconnected area. Some of the smaller boiler plants previously installed are retained for peaking purposes. However, most of them are moved to new 'district heating islands'. Eventually an entire area often housing 50,000–100,000 people is connected corresponding to a heat load of 400–800 MW. It is very important to ensure *full connection* within the area, so as to keep the costs of the network per kW lower. So far this has been achieved using purely voluntary methods in Sweden—except where new housing was concerned on municipal owned land.

*Step* 3

In Sweden district heating systems cover the more densely populated parts of the fifty larger towns—i.e. nearly all municipalities of 30,000 or more inhabitants. In some cases also the one family housing districts in the outskirts have been connected, but more often these are still supplied by individual boilers or electricity. The problem of such districts and how they could be connected in future is dealt with in Section 3.3.

Figure 2 shows a typical load duration curve for such an area. The mean duration referred to the simultaneous maximum heat demand is often close to 3000 hr/yr for larger areas, somewhat less for smaller areas due to diversity. This compares quite well even with central European experience (e.g. Germany, see Table 2) as the colder Swedish climate is compensated by higher insulation standards, giving roughly similar heat demands per person and similar annual durations of the demand.

Figure 2 shows also typical primary system delivery and discharge temperatures for Sweden, where the local systems are usually designed for a maximum delivery temperature of 120°C and return temperature of 60°C on the coldest day. Lower temperatures apply for the rest of the year. Summer temperatures are governed by the hot tap water temperature (~55°C) and dimensions of the heat exchanger for hot tap water.

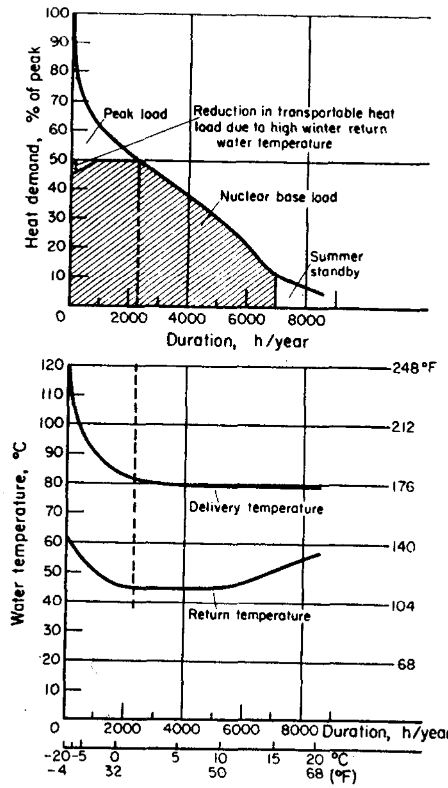



Fig. 2. Heat load duration, load allocation and water temperatures under typical conditions in Sweden (Stockholm).

Some countries use higher coldest winter day delivery temperature than 120°C in order further to reduce required pipe dimensions. However, this introduces higher pressures and a higher class of piping and also reduces the power output detainable by backpressure generation. It is a question of trade-off between these advantages and disadvantages.

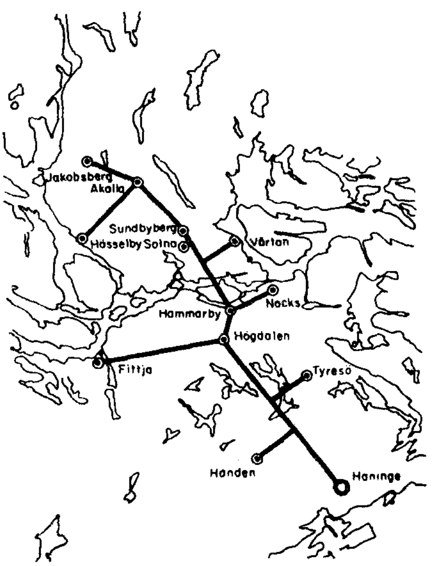
*Step* 4

Once a maximum demand of 400–800 MW is obtained one can consider building a fossil fuel heat electric station or a heat only reactor. In either case these units would only take the base load part of the demand—roughly 50% of the maximum demand but 85% of the heat energy—leaving the cheaper hot water boilers to cover the peaks and to act as reserve to the main base load unit. Of course the base load unit has to be planned well ahead, so that it is ready to come into service when the heat demand is sufficient to allow it to operate at a reasonable annual load factor. This load factor is then gradually increased as the system grows and the base load units share of the maximum demand falls from perhaps 70% in the first year to 50% and eventually even less.

Large nuclear heat/electric stations housing reactors of standard central station size (e.g. 2000–3000 MW thermal rating) have generally to be located at some distance from the concentrated areas of population. To justify the cost of heat transport over long distances, even bigger heat loads than those corresponding to systems of 400–800 MW maximum demand are often required. Hence this solution is often reserved for bigger cities, where several local networks which have evolved in different parts of the city and its surrounding municipalities can be interconnected by a *regional network* which is then supplied from the nuclear plant. Figure 3a shows such a network projected for greater Stockholm.[4] In some cases several cities in a region can also be covered by a regional network. Figure 3b showing a project planned for Southern Sweden is an example.[4a] It should be stressed that no decision to proceed with either of these projects has been taken, but both have been costed and shown to be economically viable. Table 3 lists a number of cities or regions for which such large regional networks have been or are being studied.[5–9]

Whilst the three step development described above (with the third step as yet only at the planning stage) is typical of many European countries, there are exceptions. In Northern America for instance and some European cities, notably Paris, district heating was started early using steam from the small electricity generating stations in the down-town areas. As fairly high pressure steam is required to obtain reasonable transport and distribution costs, the steam could do very little work in a turbine before being extracted for dispatch to the district heating network. Therefore it has not been found economic in the North American or Paris scheme to adopt combined electricity and heat generation. Stage two has never been reached. Whereas the Paris scheme was successful in reaching a very large load (<2000 MW) the North American schemes stagnated probably mainly as a result of the introduction of cheap fuel, particularly gas during the period between the two world wars. Present loads are shown by Table 4.[10] For natural gas, the same type of fuel applies in both central and domestic boilers so that the advantages of central boilers are reduced.

Even apart from these considerations steam schemes are now generally considered to be somewhat more expensive than water schemes and to involve more severe technical problems such as corrosion in the condensate lines (where condensate is recovered) so that all newer district heating schemes use water. Steam could still have a future for bulk heat transport in areas having a very large proportion of industrial consumers requiring process steam—sometimes in 'three pipe schemes' with separate delivery pipes for steam and water and a common return pipe, all in the same trench.



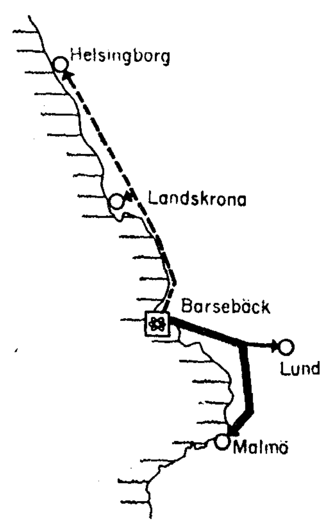




Fig. 3. Projected regional district heating networks.
(a) Greater Stockholm (scale: 1·85 mm to 1 km, approx.)
(b) Southern Sweden (scale: 1 mm to 1 km, approx.)

Table 3. List of some major nuclear regional district heating projects under study

| Country | Project name | Approximate heat transport rate MW | Status—(detailed or outline project study) | Literature reference |
|---|---|---|---|---|
| Sweden | Barsebäck/Malmö-Lund | 950 | detailed | 4 and 20 |
| | Greater Stockholm | 2100 | detailed | 4 and 20 |
| | Greater Gothenburg | ~1000 | outline | 20 |
| Finland | Greater Helsinki | 2000 | detailed | 5 |
| Germany | Grids for Berlin, Hamburg and Ruhr district | several thousands | more or less detailed | 1 |
| Canada | New Pickering (and other cities) | several hundreds | feasibility study | 6 |
| Denmark | Gylling Naes/Storårhus | 700 | outline | 7 |
| France | Saclay and surroundings* | 100 | detailed | 19 |
| Switzerland | Bern, Basel | hundreds | outline | 8 and 9 |
| Czechoslovakia | Brno | ~1000 | outline | |

* Heat only; all other projects refer to combined heat/electric stations.

Table 4. The five largest steam district heating systems (from IDHA Statistics, calendar year 1975)

| | Annual heat sent out GWh/yr | Max hourly heat sent out MW |
|---|---|---|
| New York | 14,300 | 4220 |
| Paris | 4560 | 1460 |
| Philadelphia | 2990 | 822 |
| Detroit | 2250 | 685 |
| Boston | 2230 | 675 |

Note: converted from given steam sent out rates at assumed 2700 kJ/kg, as the systems concerned have no condensate collection.

## 3. THE COST AND COMPETITIVITY OF HOT WATER DISTRIBUTION

The experience from Sweden is not necessarily applicable everywhere, as economics depend on fuels used and other local conditions. Nevertheless cost data from Sweden can help other countries which have not used district heating as widely to judge costs—when due respect is payed to points of difference. All costs will be given in mid-1975 prices converted from Swedish Crowns to U.S. $ at the then applicable rate of Sw Cr 4.5 = $1. Heat and electricity quantities will both be expressed in kWh.†

### 3.1. *Distribution costs*

The Swedish district schemes built so far have had distribution network costs averaging about $67/kW maximum demand—when translated to 1975 prices. Assuming that capital charges and maintenance costs amount to 10%‡ of the investment per year this gives an average of $6.7/kW/yr, or for a utilization period of 3000 hr/yr a contribution to the heat cost of 2.2 mills/kWh.

In practice, costs can of course differ widely depending on load density and local conditions. Figure 4 shows typical types and costs of mains applicable when ground conditions are reasonable.[11] For larger mains, steel pipes are generally laid

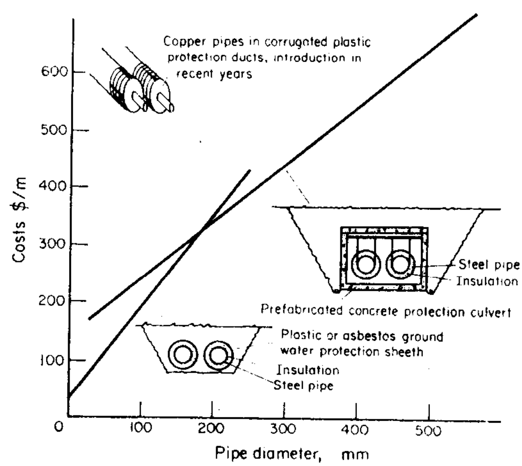



Fig. 4. Costs for conventional hot water distribution pipes (cost covers delivery and return main 120/60°C, 6 bar pressure).

† 1 kWh = 3413 BTU = 3.6 MJ.

‡ This was a usual figure in the early 1970s in Sweden, but international financing rates give somewhat higher costs in most countries today.

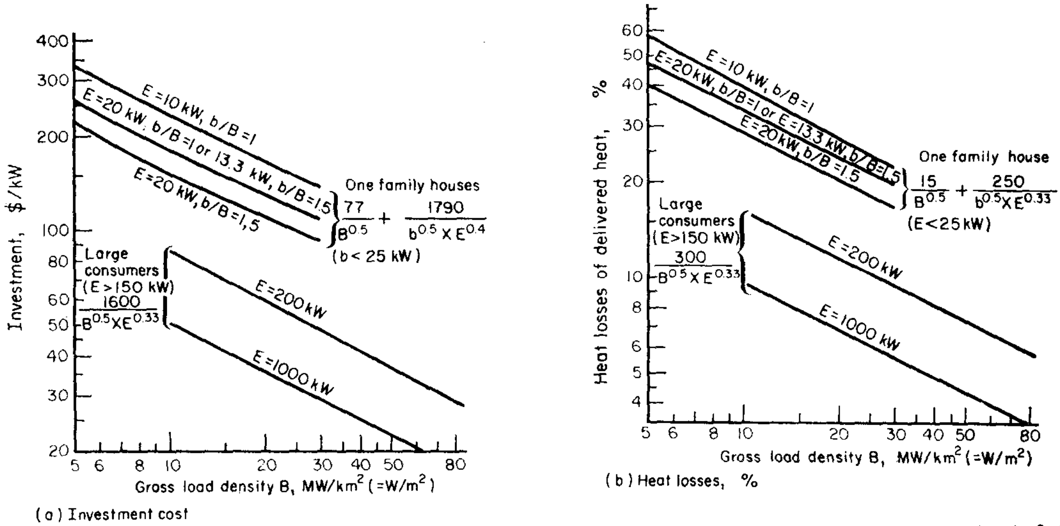



Fig. 5. Heat network cost and losses: influence of type of housing and load density according to Netzler (ref. 12). (Netzler's 1974/75 Crowns have been converted to 1975 \$ by dividing by 3.9). E = connected heat load per consumer, kW. B = gross heat loading for a housing area including green areas separating smaller sub-areas, mainroads etc. within the area, $MW/km^2$. b = net heat loading for a sub-area with small houses, including smaller green areas, local roads, etc.

underground in concrete prefabricated (or site-made) protection culverts which keep the ground water out. For small mains fully prefabricated pipes with steel pressure pipes, insulation and a protective plastic outer pipe is used, in both cases with internal expansion bends at intervals. Lately pre-stressed ground-locked pipes of the second type have been used in some cases at moderate pipe diameters to avoid expansion bends the pipe being without stress at intermediate temperatures. Cellar-mounted pipes have costs very similar to those for the underground pipes shown on Fig. 4 (up to 200 mm diameter). In one-family house districts, prefabricated insulated copper pipes have been used in recent years as these avoid the risk of corrosion pipe damage by ground water when the protection pipe develops a leak.

Figure 5 shows the formula and curves developed by Netzler[12] which attempt to take account of load density, consumer 'size', proportion of larger and smaller green areas in the district, etc. They give investment costs per kW and percent heat losses. The solid lines in Fig. 6 represents an attempt to evaluate the sum of the following costs for the data of Netzler on the assumption that the heat is supplied by a heat-only central boiler plant:

*Production costs*

(1) Capital charges and maintenance costs on the central boiler plant at \$4/kW/yr plus 20% for standby = 4.8/kW maximum demand per year and an overall generation utilization period of 3000 full-load hr/yr (gives 1.6 mills/kWh of heat).

(2) Fuel costs assuming a boiler efficiency of 90% and heavy oil price (= world market price + local

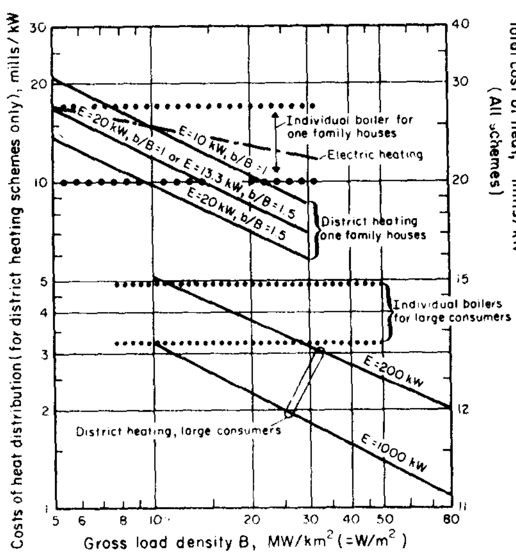



Fig. 6. District heating distribution costs as function of load density; comparison with other heat sources (1975 costs). Total costs for district heating assume heat production in oil-fired hot water boilers (see Fig. 5 for definition of E, B and b).

cost of transport and national and local storage) of $8.8/Gcal (gives 8.4 mills/kWh).

(1) + (2) = 10.0 mills/kWh of heat.

*Distribution costs*

(3) Capital charges and maintenance costs on network worked out at 10% of the investment per year and 2500 hr/yr mean utilization of the network.

(4) Cost of heat losses at the same price as (1) and (2) but 5000 hr/yr heat loss utilization.

(5) Cost of pumping power and pumping stations taken as 15% of (3).

### 3.2. *Comparative costs of other heat services*

For comparison purposes also the cost of heat from individual boilers is added, represented by the broken curves. For apartment houses individual boilers have been assumed to have a mean efficiency of 75% and oil price of $10.2/Gcal—giving a total of 11.7 mills/kWh and for one-family houses an efficiency of 60% and oil price of $11.5/Gcal (light, low sulphur content oil) giving 16 mills/kWh(t). To be fully comparative, capital charges and maintenance costs for the individual boilers and oil tanks should also be considered. These are, in general, considerably higher than the sum of the capital charges and maintenance costs for:

(a) the central boiler plant (included in the costs on Fig. 6), and

(b) those of the consumer substations (excluded from Fig. 6 as they are financed usually by the consumer).

Additions of 1.5–3 mills/kWh have been made as a correction for this difference for big consumers and 4–7 mills/kWh for one-family houses. This gives total comparative costs of 13.2–14.7 and 20–27 mills/kWh, respectively.

It will be seen that on this basis the individual boilers cannot compete with the central district heating boilers in the apartment house districts or in the denser one-family house areas. In the less dense one-family house areas they can, on the other hand, hold their own.

In countries using natural gas as fuel, the difference between performances of central and individual boilers would be less than in the case of fuel oil and also the difference in fuel prices would disappear. Especially when the gas distribution network already exists, district heating by heat only boilers is therefore in a weaker competitive position in such cases than indicated by Fig. 6.

The chain dotted line shows comparative costs of electricity supply. In practice this cost of electricity production could vary quite a lot depending on the 'mix' of different types of generating plant. In addition it would be affected by whether or not the space heating peak load coincides with the overall system electricity peak. In the present presentation the assumption was made that no exact coincidence occurs and that the plant supplying the space heat load could be credited with a relatively high load factor or utilization period—5000 full-load hr/yr, indeed much higher than for the heat demand curve. (This assumption would be optimistic, i.e. excessive, if the space heat load became a large fraction of the demand.) Using 1975 Swedish costs for nuclear plant this would give about 200 mills/kWh or with a small addition for a contribution to the system generation reserve and the appropriate portion of electricity transmission and bulk distribution costs, about 25 mills/kWh. The portion charged for distribution is relatively small, as only the marginal increase of the network needed in any event for other services needs to be considered.

Electric heating and hot tap water installation in houses costs about the same as for water-borne heat systems, when the cost of the substation is excluded in the latter case. It has been assumed in deriving the electricity cost curve that the cost of these substations is offset by the cost of consumer connections and the last part of the electricity distribution to individual consumers for average load densities. A slight correction for the influence of load density on distribution networks costs has been applied.

Comparing the cost characteristics obtained on these somewhat simplified assumptions, it will be seen from Fig. 6 that electric space heating is out of the question in apartment houes districts but that it can compete in the lower density one family housing districts.

### 3.3. *Newer distribution technologies*[13–15]

In recent years, common substations have begun to be used in Sweden for groups of 50–300 one-family houses, which have a common secondary system. The latest development which is at the demonstration stage is the use of temperature resistant plastic pipes (see Fig. 7a) which are wound on drums in lengths of 100–200 m and can be laid directly into grooves of insulation blocks placed into the ground, thereby greatly reducing the manual work on site. The first projects suggest that this can reduce the cost of

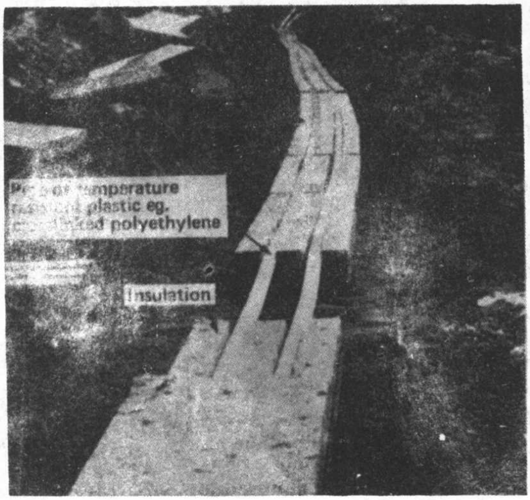



Fig. 7a.

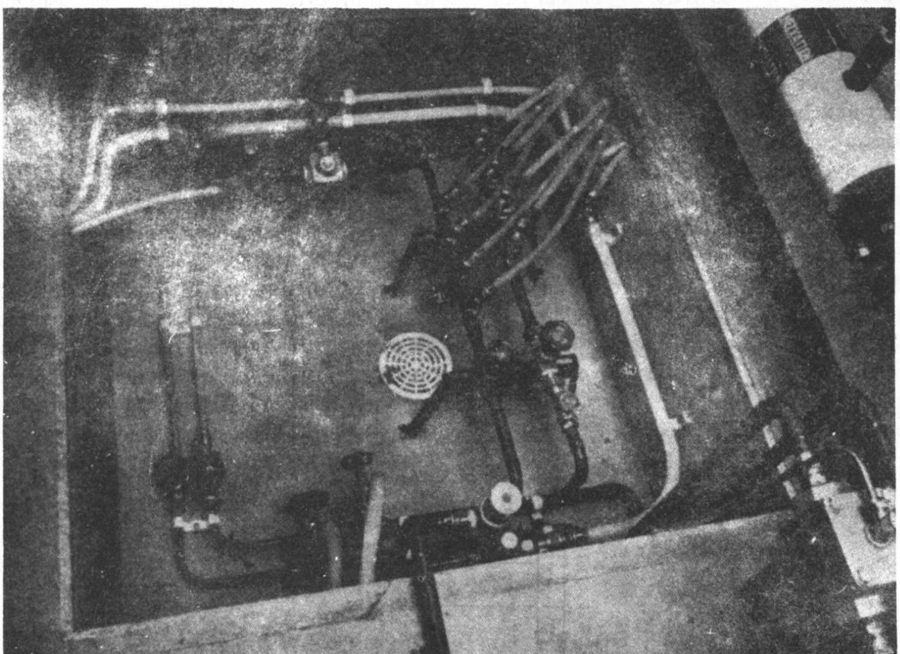


Fig. 7b.

Fig. 7. New plastic pipe systems for water distribution.

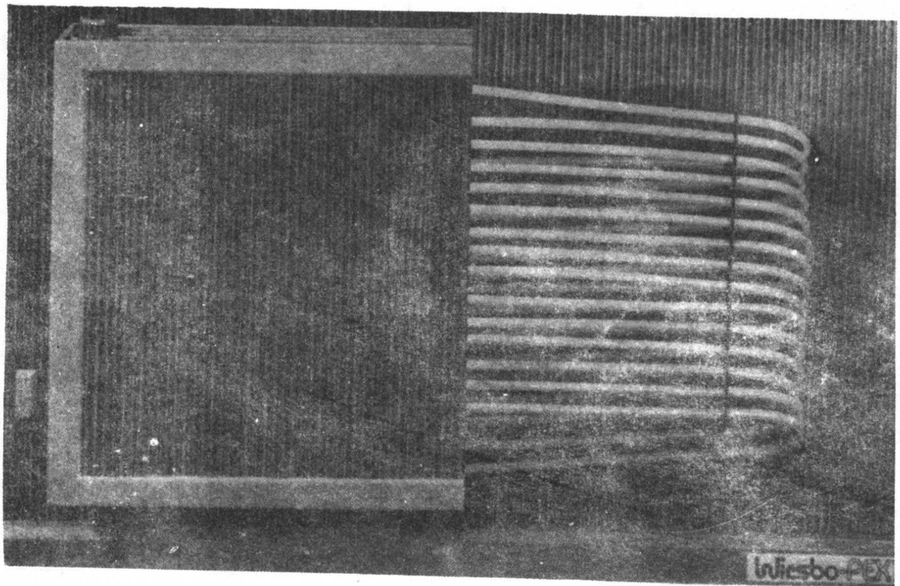



Fig. 7c.

piping in one-family house districts by about 40%. Some 30 km of such piping has been laid in districts with existing one-family houses in the Swedish city of Växjö.

For new housings, the plastic pipes open the way to a common system for hot tap water and heating water, as illustrated by Fig. 8, provided copper or plastic radiators are used to avoid corrosion by oxygenated water. By avoiding the need for separate hot tap water heat exchangers in each house (or the use of duplicate heating and hot tap water pipes from the common substation) further substantial cost reductions are achieved. Figure 7b shows one way of drawing such plastic pipes through empty channels left in the building walls. Figure 7c, which shows a plastic tube radiator, shows an alternative way of drawing the plastic pipes behind floor skirting.

Once these types of systems have become standard practice, it should be economic to supply most one-family house districts by district heating. This would considerably extend the connectable consumer load in most cities and create greater (and therefore more favourable) heat demands for possible nuclear schemes.

### 3.4. *Environment and fuel conservation considerations*

Apart from costs, the effect on environment is being given stronger consideration in most cases as time passes. In Sweden it will be impossible in future to meet air quality regulation with individual oil fired boilers in the large cities and even that factor will work strongly for the restriction of the field of application for domestic oil fired boilers to outlying rural areas only. District heating boilers protect the near environment by high stacks and fuel gas cleaning

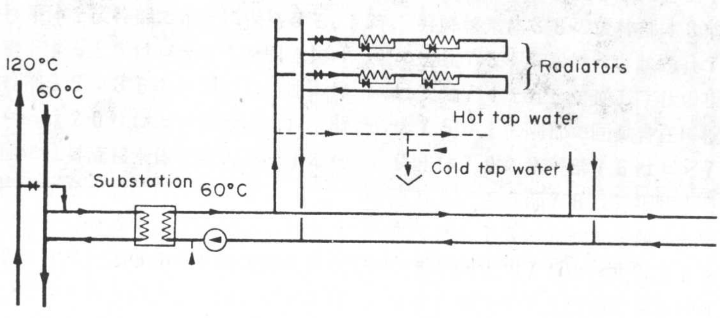



Fig. 8. Common distribution system for hot water and space heating.

arrangements. This environmental consideration would not however apply in countries where the fuel is natural gas.

Electricity is even kinder to the near environment, but is wasteful on overall fuel requirements and requires generation capacity, hence blocking significant parts of attractive coast line and causing thermal pollution. The exact balance between the environmental impacts of oil fired district heating and electric heating (the latter through additional electricity generation) is influenced by the overall outlook of nuclear energy.

Combined heat/electric stations conserve fuel and boiler capacity compared to separate generation and reduce pollution—for a given fuel type. Given an overall acceptance of nuclear energy, the use of nuclear district heating should be the best solution for the environment avoiding, as it does, all low level or high level air pollution by combustion products and increasing the efficiency of fuel usage.

### 3.5. *Summary of discussion*

The discussion in this section has shown that, already, district heating schemes supplied by heat-only boilers have a strong competitive position in all except one-family house districts with large lots, when oil at world market prices is the fuel. Newer developments will tend to extend the economic field of application even to these latter schemes, where electricity is the main competitor today.

In proceeding to treat heat/electric stations, it will therefore generally be sufficient to show that these can produce heat (and supply it to the local point of the distribution network) at a lower cost than it could be produced by heat-only boilers—to be able to conclude that such district heating schemes are also competitive with individual boilers and electric space heating. This applies at least when oil or coal at world market prices are the competing individual boiler fuels.

When natural gas is the fuel the competitive position of district heating becomes weaker, and often other central heat sources than a hot water boiler would be necessary to justify district heating in such cases on pure economic ground. Conservation grounds are of course especially important for pure high quality fuels like natural gas and should therefore restrict its longer term use where district heating with other fuels is feasible.

## 4. THE COST OF REJECT HEAT AT SOURCE

### 4.1. *Electricity sacrifice due to heat rejection*

In a condensing type steam station, the steam in the turbine condensers is condensed at a uniform temperature, $T_c$, which depends on the cooling water available. For the relatively cold water in Sweden, $T_c$, would average about 30°C over the year. In these circumstances about two-thirds of the heat released by the nuclear fuel in typical water reactors would be rejected.

Assume that instead some steam is bled off the turbine at a higher temperature, $T_r$, and that a heat rate $Q_r$ MW is transferred to district heating water before the condensate is returned to the turbine circuit. The work, $P_r$, this steam could have done in the turbine if it had been allowed to expand to the temperature $T_c$ is

$$P_r = Q_r\,\eta\,(T_r - T_c)/(T_r + 273) \qquad (1)$$

where the bracket terms represent the ideal Carnot efficiency and $\eta$ the correction factor for blading efficiency, generator efficiency and other imperfections. It has usually a value of about 0.72. Typically if $T_r = 100$°C, $T_c = 35$°C and $\eta = 0.72$ we obtain an electricity sacrifice of 0.125 kWh electricity per kWh of heat given to the district heating water, i.e. a ratio of 1:8. Assuming the turbine costs are not influenced by the bled steam feature, the costs for the station will remain unchanged, as neither the reactor nor reactor heat rate are affected. The revenue to the utility will be unchanged if heat is charged at one-eighth of the price of electricity (as 8 units of heat can be sold per kWh of electricity sacrificed), e.g. at 2.5 mills/kWh of heat if electricity costs 20 mills/kWh. With costs and revenue unchanged, this would be a 'fair price' for the heat at source. As we shall see later, the assumption that turbine costs are not changed is only approximately true, and this increases the price in practice to a value slightly higher than that derived above. Nevertheless the above approach gives a good approximation and shows how cheap the cost of reject heat can be at the source—i.e. at the power station sites.

In practice one wishes to heat district heating water with a return temperature $T_1$ to a delivery temperature $T_2$, while taking steam at the lowest possible mean temperature $T_r$. Assume for example that $T_1 = 60$°C and $T_2 = 120$°C so that $T_1 - T_2 = \Delta T = 60$°C. If a 5°C temperature difference is needed at the hot end of the condenser for heat transfer, $T_r$ becomes $120 + 5 = 125$°C when all steam is bled off at the same temperature. If instead the steam is bled off at three temperatures, 125°C, 105°C and 85°C respectively, as illustrated on Fig. 9, and used to heat the water in three stages 20°C per stage, then the mean value of $T_r$ becomes 105°C, i.e. 20°C lower. For

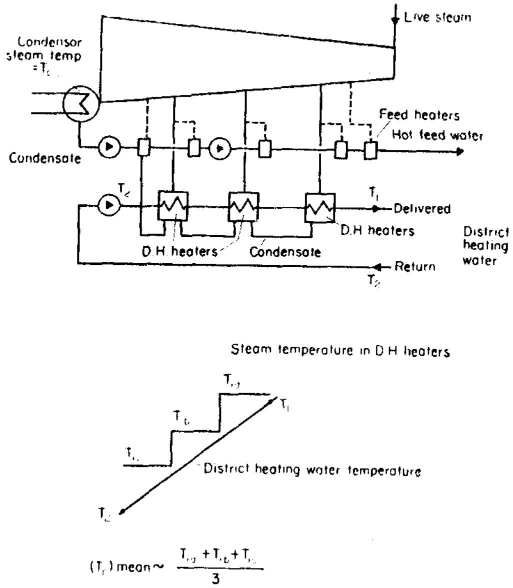



Fig. 9. Illustration of temperatures in three stage bled steam system for heating the district heating water.

$T_c = 35°C$ the electricity sacrifice is thereby lowered from 0.163 to 0.133. Hence electricity sacrifice can be kept low by using:

(a) relatively low district heating water temperatures (especially $T_1$), and

(b) having several steam stages, $N$, at different temperatures as illustrated by Fig. 9.

More generally we can write for $T_r$ in equation (1):

$$T_r = (T_1 + T_2)/2 + \Delta T/2N + \delta \qquad (2)$$

where $\delta$ = temperature difference between steam and water at hot condenser end (about 5°C), and

$$\Delta T = T_1 - T_2.$$

Whilst a low value of $T_1$ gives a low electricity sacrifice and therefore a low cost of heat at source, it also diminishes the temperature difference $\Delta T$ for a given return water temperature, and thus increases the required water flow rate and pipe diameter and cost. This creates a trade-off problem we shall return to in passage 5.2.

### 4.2. *Turbo generator arrangements*

Figure 10 compares four turbogenerator arrangements for a 3000 MW(t) reactor. With a standard condensing turbine, view (a) and four low-pressure (LP) cylinders, about 1020 MW electricity is produced. The three LP cylinder pass-out arrangement, view (b), allows up to about 1000 MW of heat to be

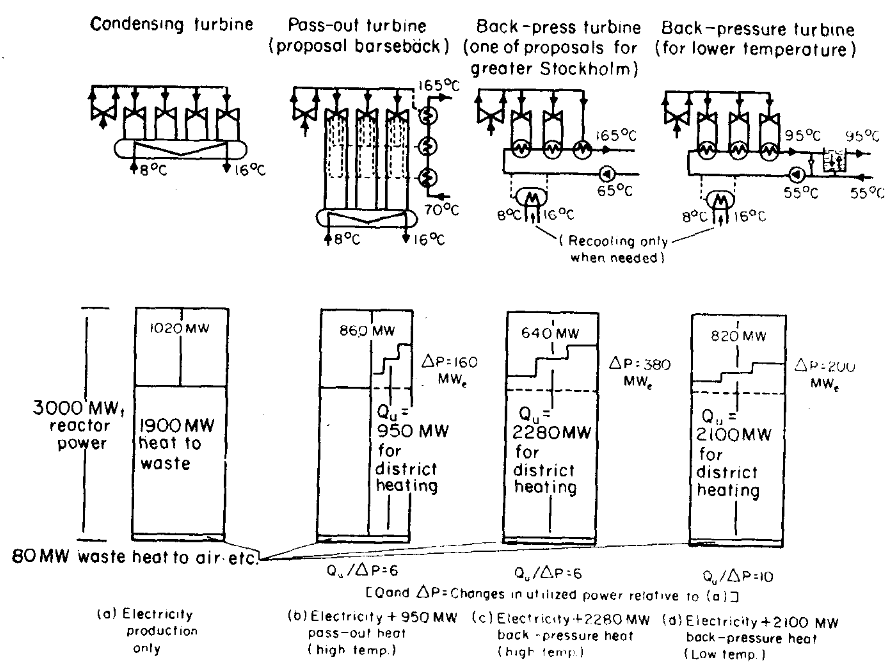



Fig. 10. Turbo-generators for large nuclear stations (with and without district heating).