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APPLICATIONS OF NUCLEAR POWER OTHER THAN FOR ELECTRICITY GENERATION

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Preface

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1. Introduction

The original thrust for the development of peaceful applications of nuclear power was technological innovation. When in 1955 nuclear power started to be developed on a broader international basis it was the spearhead of modern technology. It was only later that electronics and space research at least paralleled nuclear power in that function. Given that intent it was most natural for nuclear power to concentrate on electricity production. One may reflect on the fact that the fusion branch of nuclear power--which is very much an advanced technology--almost automatically and without hesitation concentrates on the production of electricity. In spite of a very intense competition with artificially cheap fossil fuel, nuclear electricity generation became commercially competitive and thereby feasible during the second half of the 1960s.

Since only a few years ago the scope of development has included not only technological innovation but equally the broader question of providing enough and secure energy for our decade and the decades thereafter. As everybody knows this requires more than just the production of electricity. In Western Europe 55-65% of the primary energy demand is met on the basis of imported oil and only a lesser part of it goes into the production of electricity. And this is where the problem is. This paper will therefore follow the general question of what is implied if more than nuclear electricity is to be produced. Eight specific contributions by distinguished authors are appended to this paper, and reference to these is made throughout. Also, due account is taken of the fact that other papers on the subject are to be found in volume XIII of the Proceedings of the European Nuclear Conference on Nuclear Energy Maturity.

2. Primary Energy Shares and End Use of Energy

Marchetti has studied the energy shares in the US from 1850 onward. The results are given in Figure 1. F is the relative market share. One can observe the steady decline of wood which had a share of practically 100% in 1850. It took 60 years to reduce its market share to about 50%. At the same time the more convenient primary energy, namely coal, penetrated the market, and it took coal 66 years to gain a market share of 50%. The advent of oil gradually forced coal out of the market.

Oil is now experiencing a maximum and is about to decrease its market share. Natural gas is in progress; it has had a steadily increasing market share since the beginning of this century. It may be important to observe that this market behavior does not reflect concerns about reserves or resources. Oil, for example, pushed coal out in spite of the fact that there is less oil than coal. Rather, the dynamics of this behavior of primary energy shares is governed by market features and price mechanisms.

Data of the Federal Republic of Germany confirm this behavior of the market [1]. In Figure 2 only the data from 1950 onward are given. One can still see the rest of the market share of wood, but the projections as announced by the German Government are also presented. For nuclear, a market share of about 15% is expected upon the assumption that all of it would go into the production of electricity. The market trend for coal continues to point downward. But there is the component that is labeled "additional coal".

This means a qualitatively new approach to the uses of coal that has been induced by the energy crisis. In contrast to the past, therefore, not only market forces but also explicit planning and exogenous influences may come into the picture. The problem of adequate resources and a sufficiently secure supply is of importance here. To the largest possible extent, however, this additional coal must be made to fit market tendencies and features. This poses a major problem for coal and requires much analysis and attention. The point is to assure an approach to what is labeled additional coal which is sufficiently different from the downward-trending traditional uses of coal. This is probably very difficult to achieve, mainly from an organizational and institutional point of view. But this is not the subject of this paper [2].

We here follow the applications of nuclear power other than for electricity generation. This is not reflected in the curve of Figure 2 labeled "nuclear power"; but like "additional coal" it arises from the necessity to ease the energy crisis.

Let us therefore consider the final uses of energy, again by the example of the Federal Republic of Germany. Figure 3 gives data of 1970. 40% of the final uses, which are equivalent to 227 M tons of coal equivalent, go into the industrial sector. Only 6.4% are electrical; 24% are for thermal applications at more than 200°C, 9.5% at less than 200°C. The sector of residential and commercial applications is the largest, with 42%. Here 37.4% go into thermal applications at less than 200°C, and only 4.6% are electrical. The remaining 18% go into transportation, with electricity constituting only 0.4%. The electrical application only makes up 11.4% of the final uses.

3. Various Industrial Applications and District Heating

Now, if there is so much need for thermal power below and above 200°C, why not produce that energy by nuclear reactors? Vendryes (see Appendix A) gives a quick survey of non-electrical applications in general. Also De Beni gives such a survey (see Appendix B). Llewelyn (Appendix C) has elaborated on the total power demand and size of the various applications of industrial heat in Great Britain, as outlined in Figure 4. The total capacity is as high as 81 GW. The breakdown is given. Food, engineering, chemicals and iron and steel make up the largest shares. But most of these demands for process heat are in small, geographically widespread, bits and pieces. This is most obvious in the case of food and textiles. Only in the not so large 4.1 GW of the cement sector are these average unit sizes of 70 MW. As is well known, these sizes are too small for nuclear power. Only iron and steel offer larger establishment sizes, and indeed, the high temperature gas cooled reactor community has looked into this possible application quite extensively. Hryniszak (see Appendix D) has elaborated on such applications. But this is no more (and not less) than 7% of the final uses of energy. Important as the nuclear share of these 7% may be, it cannot alter significantly the profile of the general energy problem. There is also much talk about the use of nuclear energy for district heating, particularly so if waste heat from nuclear electric power stations could be used. Bonnenberg (see Appendix E) has studied the related questions in greater detail for the case of the Federal Republic of Germany. Again it appears that only a fraction of the demand is sufficiently concentrated to allow for the application of nuclear energy, whose overriding feature is its high density. Bonnenberg gives 30 Gcal/km^{2}h as the lower limit for the applicability of district heating. This, by the way, equals 35 W/m^2 while the radiation received from the sun averaged over all latitudes and longitudes (and thereby also over day and night) equals 160 W/m^2. Roughly 80 W/m^2 of these 160 W/m^2 are used to drive the rain/evaporation cycle and 70 W/m^2 to make up for the net IR radiation from the surface. It may be useful to keep such figures in mind as a yardstick.

The figure of 30 Gcal/km^{2}h implies that communities with fewer than 20,000 inhabitants usually do not fall into this category. But these communities make up 48% of the total in case of the F.R.G. Nuclear district heating therefore is linked to larger urban complexes (conurbations). In Figure 5 this fact is illustrated. In 1972 there were only five such conurbations in Germany that were thus suitable for nuclear district heating. Their total power capacity is 18.6 GW with a load factor of 0.2. This is consistent with the distances to be bridged by thermal energy transportation. It is seen that distances up to 30 km can be bridged economically.

Besides district heating, a small heat supply and industrial uses can also be adapted to that (Figure 6 illustrates this). Bonnenberg anticipates a potential share of 32% for heat at temperatures smaller than 200°C to be transported over distances up to 30 km or so. Under present circumstances (1975) the potential share would be 26% instead, which would make up 13% of the total end use of energy. The requirement for capital investment in case of the F.R.G. is in the order of $75 B.

The present tendency to use waste heat from nuclear electric power stations therefore have a solid background. It must be kept in mind, however, that this requires the adaptation of these plants--at present the waste heat temperatures are still too low. The centralized supply of hot water so envisaged is already consistent with the main feature of the market for the end use of energy. The market prefers easily applicable forms of energy, and because of this trend has become specialized and highly fragmented. In fact, this is why the market forces referred to when primary energy shares were considered created pressures to go from coal, a solid fuel, to oil, a liquid fuel, and now to natural gas, which by its nature is a gaseous fuel.

4. Secondary Energy Shares

In Figure 7 these trends are presented for the case of the Federal Republic of Germany. One easily recognizes the increasing shares of electricity and gas and the decrease in the shares of liquids and particularly of the solid forms of energy end uses. Consistent with the marks above, there is the special case of hot water from dual-purpose nuclear power stations. The column "end uses" makes somewhat qualitative (not fully self-consistent) implications about the use of these secondary forms of energy in the various sectors of demand.

At this point in our reasoning we can already see better the conditions for nuclear power if it is to be applied to more than the generation of electricity: it must fit the future features of the end uses of energy as closely as possible. And this means that a substitute for natural gas must be produced.

In line with the earlier argument about "additional coal": coal must also offer its potential in its gaseous rather than in its solid form. All of the above analysis equally applies to coal. In addition there is the fortunate feature that coal and nuclear power together are able most naturally to produce such a substitute for natural gas. Again we refer to the contribution by Hryniszak (see Appendix D).

At Brookhaven Hoffman et al. [3] have studied the question how large the electric share of the final energy demand might be. They did this in great detail using an extended linear programming procedure. The results of the study are given in Figure 8. While in 1970 the share is as low as 10%, it might essentially double by the year 2000 and thereby automatically increase the use of nuclear power. The interesting thing is that even if it were intended to put more weight on electricity, its share would not be larger than 24%. This tentatively underlines the necessity to look into other applications than the generation of nuclear electricity. From what has been said, it follows that such applications must overwhelmingly come through a gaseous secondary energy system that complements electricity.

Let us therefore consider the consumer costs in such secondary energy systems. In Figure 9 consumer costs for electricity and for natural gas are compared. Natural gas is at present still very much cheaper than electricity. If we allow a certain increase of consumer costs, gas production costs at 2 $/M BTU for such a substitute of a natural gas seems to be acceptable. The gasification of coal has to be oriented towards that figure. Coal gasification means the addition of hydrogen to coal. So far hydrogen prices have been too high to make this approach a smooth one. The high price for hydrogen today inhibits not only the commercially easily acceptable coal gasification, but also the more explicit push forward of a consumer technology adapted to pure hydrogen as a secondary fuel. Today one has to expect hydrogen production costs at 4-6 $/M BTU. Here is the place for a fairly fundamental observation and suggestion: the average load factor of nuclear power stations may be 0.7 (or even lower). This is so because electricity in particular cannot be stored. But the production capacity has to be designed for more than full load requirements. Therefore there is a free built-in production capacity in the generation of nuclear electricity.

5. Off-Peak Electrolysis

The proposal now is to make use of that capacity for the production of electrolytic hydrogen. For a nuclear plant the marginal fuel costs may be as low as 2 mils/kWh. Assuming a 2500 hr/yr off-peak situation and 80 $/kW capital costs for such electrolysis, at 12% interest and 93% efficiency an energy price for the hydrogen output is obtained which amounts to 1.6 $/M BTU. This picture is outlined in Figure 10. One realizes the big difference as compared to the other hydrogen production processes. The key here, of course, is to consider only the marginal costs for the production of electrolytic hydrogen from off-peak power. For a nuclear power station this figure is small. The other key is the low capital figures that were assumed for electrolysis. We will elaborate on that shortly. The point is that such an approach makes things move smoothly in the right direction, namely the fostering of a substitute for natural gas. Cheap hydrogen from off-peak electrolysis expedites the modern uses of "additional coal" and at the same time slowly but steadily prepares the use of hydrogen as a secondary fuel. Such an approach does not preclude the possibility of producing hydrogen for instance by thermochemical water splitting or other means; instead, it prepares the way for other means as they are conceived.

Such preparation should be started early as it requires the penetration of markets by new technologies. Fisher and Pry of General Electric have studied this kind of market penetration [4]. They found that an exponential logistic curve (Figure 11) fits such market penetrations by new technologies exceedingly well. The logistic curve used by them is the ratio of market-penetrated (F) to non-penetrated (1 - F) as a function of time. In fact the market penetrations of primary energy also fit that logistic curve behavior, and this is why they were plotted in terms of the ratio F/1 - F. It is then important to realize the time periods for the gain or loss of a market share of 50%. Marchetti has evaluated these time constants. They are given in Figure 12 for the United States. All of them are longer than 50 years; they are even longer for the world. If, because of the energy crisis, we want to accelerate matters and stay in tune with such market forces, we must obey and anticipate these market features as closely as possible. While this has been exemplified for primary energy it essentially applies also to secondary energy systems. It is therefore a key consideration that hydrogen be introduced in the secondary energy market as early and as smoothly as possible. This could be stimulated by electrolytic hydrogen from off-peak nuclear electricity.

How much energy can therefore be expected from nuclear sources at the end of this century? Figure 13 gives a projected answer to that question. Let us assume that electricity has a share of 20% of all secondary energy, and that all of it is provided from nuclear sources. Then roughly 7-8% could be gained by electrolysis from off-peak nuclear electric power. Conservatively, about 5% could be taken from waste heat (although the potential is larger, as we saw); 6-7% could be local nuclear process heat. The total would be at 40%. Thus there is a potential for applications of nuclear power other than for electricity generation which is essentially equal to that of electricity generation without going to drastically new approaches on the nuclear side--in other words, merely by extrapolating the present situation.

A question that has been left open is the following: Where does electrolysis stand?

So far electrolysis has been applied only for special purposes, mostly in cases where extremely clean hydrogen was required. La Roche has made a contribution to this paper on this subject (see Appendix F). The experience of Brown Boveri in Baden, Switzerland, is that the present capital costs are at 300-500 $/kW, including electrical equipment such as transformers, rectifiers, etc. The scale to which such capital costs apply is in the few MW range. One of the largest electrolysis plants built so far has been that for the Assuan Dam. It has a capacity of 140 MW. La Roche expects capital costs for units of a few hundred MW to be in the order of 100-150 $/kW if three or four years of development work are put into it. Nuttall and Titterington of General Electric recently reported [5] 334 $/kW capital costs as of today; for 1985, they expect capital costs to be as low as 70 $/kW. Capital costs will of course also depend on the efficiency of electrolysis. At present, figures of 70% are often referred to, but 85%, 90% and more appear to be within reach.

We have made the observation that an extrapolation of the present technological situation would yield secondary energy shares of as high as 40%. As indicated in Figure 13 the remainder would have to be covered by fossil sources unless a new and large scale effort were made to pave the way for a still wider application of nuclear power.

6. Large Scale Production of Hydrogen

One possible route of extension without taking the power from off-peak at the low level of marginal costs would, of course, be electrolysis. Instead, it would be a base load approach. Because hydrogen could be stored, a load factor of close to 100% could be anticipated and might help to ease the situation. A market for oxygen might help as well. In any event, such an application of electrolysis requires a much more rigorous development program than the mere gradual improvement of the present electrolysis technology discussed.

The other major route for the production of hydrogen is thermolysis as pioneered by De Beni and Marchetti at Ispra [6,7]. The basic idea is the following. The chemical binding energy of water is such that a temperature of about 3000°C is required to split the molecule. For nuclear heat a temperature of 3000°C is not feasible. If instead the chemical binding energy were applied in stages, however, nuclear process heat could make it. This of course implies a staged chemical process whose net result would be the production of hydrogen and oxygen from water, requiring chemical agents whose function is to transfer free energy. De Beni identified the first chemical scheme as early as 1969 [8]. It implied the use of bromine, mercury and calcium. The maximum temperature required was 730°C, and that means 850°C at the core outlet of the reactor. The drawbacks were obvious: high inventory costs, and the possibility of leakages and thereby pollution, corrosion and material circulation.

It can be expected that more than one scheme for the thermolysis of water could be identified. Knoche and coworkers at Aachen, Germany, have computerized the combinations of chemical processes in order to search for feasible combinations. The feasibility of such combinations has been much increased by the fact that recently the attainable temperature of high temperature gas-cooled reactors has been raised significantly. Throughout 1974 the German AVR reactor at Jülich successfully operated at an outlet temperature of 950°C, and further improvements have to be expected [9]. The German effort in the high-temperature gas-cooled reactor field is significant and has been more and more closely connected with the effort of General

Atomic in the United States [10]. At the International Institute for Applied Systems Analysis, Manne and Marchetti have looked into the question of optimal R&D policies for more than a thousand chemical processes, and the optimal allocation of funds [11].

Marchetti (see Appendix G) gives the latest thinking in this field, and we follow this contribution, here partly verbatim. The aim must be to identify a process that avoids scarce and expensive elements, that is consistent with environmental requirements, that is acceptable from the corrosion point of view, and especially, that deals with gaseous or liquid chemical agents only; and last but not least, a process that is simple.

In view of what is at stake, namely the potential of 60% of future secondary energy demands, it seems obvious that much more effort should go into this kind of chemistry. The race has just started. Nevertheless it may be useful to consider the recently proposed Mark 9 process, which is depicted in Figure 14. The advantages of Mark 9 as compared with the early proposals are the following:

- Only cheap and abundant materials are used;
- There is a large body of experience for handling chlorine and iron compounds.

The stumbling block still is that Mark 9 also requires the manipulation of solids and makes this kind of process questionable. There are proposals from Jülich (Schulten) that indeed require no solids, except perhaps as catalysts. Also, at Los Alamos (Bowman) a very simple process has been proposed:

$$H_2SO_4 \qquad \text{thermal} \qquad H_2O + SO_2 + \frac{1}{2} O_2 \qquad (1)$$

$$2\ H_2O + SO_2 \qquad \text{electrolysis} \qquad H_2SO_4 + H_2\ . \qquad (2)$$

Step (1) is a thermal decomposition of sulphuric acid; it is produced in industry and is not too difficult. It occurs gradually from about 400°-800°C. It provides 85% of the free energy needed to decompose a molecule of water. Only the remainder must come in the form of electricity, that is through electrolytic cells which have to be developed ad hoc as the economy of the cycle requires a high concentration of sulphuric acid for step (1).

7. A Scenario for an All-Nuclear Supply of Energy

In view of these long range considerations, let us now go to the extreme and follow the idea of supplying all secondary energy on the basis of nuclear energy. Let us further assume that in the long range the requirement will arise to make use only of abundantly existing isotopes, that is U238 and Th232. This necessarily implies breeding. Fortunately combinations of developed reactors exist that allow for an all-nuclear supply of energy. Figure 15 shows a combination of fast breeders with high-temperature gas-cooled reactors. The net requirements for U233 of the HTR are met by the production of such U233, for instance in the radial blankets of fast breeders. Such crossing of the fuel cycles has been proposed by Fortescue at General Atomic, and at Karlsruhe.

The scheme given in Figure 15 assumes that an approximately equal share of energy goes into the production of electricity and into that of hydrogen (or another gaseous secondary energy). A rapid expansion requires for instance the Pu output of LWR's, and to that extent the use of cheap uranium (outlined in Figure 16). At the International Institute for Applied Systems Analysis, reactor strategies for the transition from fossil to nuclear fuels have been studied by Häfele and Manne [12]. The scenarios that were envisaged provide for 360 million people and an asymptotic demand of 10 kW/capita or 20 kW/capita. Figure 17 identifies certain features of the fuel cycle of such an all-nuclear scenario society. Under asymptotic conditions 751 tons of U238 and 951 tons of Th232 per year have to be processed. This implies the processing of 924 tons of Pu and 363 tons of U233. The total power provided is 2 × 1800 GWth or 3.6 TWth. Altogether 1,382 tons of fission products have to be handled, but also 17 tons of actinides and 27 tons of Pa and Np. In using today's technology 9 tons of Pu and 4 tons of U233 would be lost, partly as scrap and partly as effluents to the ecosphere. It should be made abundantly clear what has been said: these amounts are diverted from the main stream if the scenario of an all-nuclear society with today's technology is being considered. The possible realization of such scenarios is, however, decades away and there is much time and opportunity for the related technological improvement.

8. Deployment of a Large Scale Fuel Cycle

The 924 tons of Pu and 363 tons of U233 which have to be handled within the 360 million population all-nuclear scenario point to the high degree of meticulousness that would have to be exercised. The principal dimension of this problem is introduced, however, with the first few elements of the fuel cycle. This can be exemplified by one of the crucial issues, that of required physical protection. Figure 18 identifies four classes of protection. Irradiated material requires almost no protection; it is highly self-protecting, and large amounts of such material are bound to be available as more and more nuclear power stations are in operation. The second class is made up of fresh uranium with enrichments of less than 5%. It is not self-protecting but requires enrichment for explosive applications. Fair amounts of such material are already in use. The third class consists of Pu and U233. These materials are not really self-protecting and no enrichment is needed; they therefore do require significant physical protection. The large amounts of such material come timewise after the reprocessing of irradiated material. The fourth class obviously comprises 90% enriched material, which requires high degrees of physical protection.

The large fuel cycle to be envisaged if all or a significant share of future energy demand is to be met by nuclear power raises the question of the sequence of decisions that are still pending. With nuclear power reaching its maturity, we are at the advent of nuclear power on a truly large scale, and it is therefore appropriate to consider the decision tree for the truly large scale and peaceful deployment of nuclear energy. The decision tree is outlined in Figure 19. The first decision is whether or not to employ nuclear power. If not, perhaps coal or solar could be alternate options. The next decision is whether or not to reprocess irradiated material. If not, storage that can after all be of only intermediate nature must be opted for; if yes, the decision whether or not to use Pu must be faced. If not, Pu must be stored. If for economic as well as ecological reasons this is considered to be infeasible and unwise, Pu must be used and Pu fuel elements must be fabricated. Therefore the next question is the co-location of such Pu fuel fabrication plants with reprocessing facilities. If the answer is no, refined Pu must be transported, which in the case of our model society in the scenario considered above would be in the order of 924 tons. It is material of class 3 of the four classes of physical protection. If the answer is positive, the next question is whether or not to eliminate also the transport of fabricated, and to that extent protected, Pu fuel elements. The decision tree shown follows both options. If the decision is to transport newly fabricated Pu fuel elements, adequate physical protection for class 3 must be provided for them on the way to the nuclear power stations which produce both forms of secondary energy: electricity and gas. In the long run it may be interesting to consider the status of the implied allocation of the fuel cycle. It could be national, multinational or even international. Going back to the other branch of the decision tree, the other option would be to eliminate transport of all class 3 materials. This necessitates the co-location not only of the fuel cycle facilities but also of reactors that are designed for the use of Pu. Then a type of reactor must be chosen that accepts the Pu produced annually.

Let us consider a LWR population of 80 GWe. The yearly output of Pu is in the order of 12 tons. This would make up the first core inventories of four fast breeders per year. It would therefore take roughly 20 years if, in line with the above given scheme of LWR's, FBR's and HTR's, one wanted to replace 80 GWe of LWR's by a corresponding capacity of fast breeders. Such FBR's would be co-located with the Pu fuel cycle facilities, and in fact, also the HTR's would be co-located, as U233 falls within the same class 3 of physical protection, as explained above. This reasoning therefore leads us to the concept of energy parks.

Here, too, the status of such energy parks must be considered. As with fuel cycle co-locations it may be a national, a multinational or even an international one. Fuel cycle co-locations or energy parks--in both cases it may be desirable not to foreclose options and to choose the site for these co-locations or parks in such a way that in the long run all options are kept open as much as possible.

9. Comprehensive Co-Locations

The considerations above therefore highlight the problem of siting. But the striving for ecological consistency also enhances this problem. One may recall the fuel cycle data given in Figure 17.

Figure 20 identifies the power output of such comprehensive co-locations or energy parks. On a very large scale they would provide both secondary forms of energy. Electricity would have to be transported in the high GW range. On that scale the transportation of hydrogen may be cheaper. Such hydrogen may be used in refineries, as an additional input to natural gas pipelines, or it may be transported to coal mines for coal gasification, or, finally, to produce electricity at the level of the substations.

Figure 21 gives a rough idea of the present pipeline system in Western Europe. The reason for using this figure is simply to show that already such pipelines are bridging large distances, and that already the input to such pipelines is almost pointwise. This is indeed consistent with the scheme of energy parks. It further, somehow suggests a split. The nuclear power stations of such parks may preferably be used for the production of hydrogen--but it is obvious that much more analysis is required before a firmer statement of this kind can be made.

Before this reasoning is continued, one should recall that these considerations are for a medium-term and long-term range, and definitely go beyond 1985. Their background is the transition from fossil fuels to nuclear fuels and the applications of nuclear power other than for electricity generation.

10. Artificial Islands

The pipeline system of Western Europe in particular points to Rotterdam and Antwerp.

In a much broader context Langeraar has considered the problem of building artificial islands for specific industrial processes in the North Sea. Industries from the United Kingdom, France and Sweden, but mainly from the Netherlands were interested and participated in the investigations. A preliminary study was concluded in March 1972. Langeraar has made a special contribution to this paper (see Appendix H), which will be followed closely and partly verbatim in the following.

The main subject of this investigation was a relatively small island which was to be used for the handling of specific waste materials of different origins, such as urban, chemical, steel, etc. One of the conclusions runs as follows:

> "Technological experience, expertise and know how in the Netherlands are sufficient and available for the construction of artificial islands in the southern North Sea at a price per square meter which is not unreasonably higher than that on the mainland."

It is not the purpose of this paper to suggest that energy parks will necessarily be built on such artificial islands. The intention is rather to point to the wide spectrum of possibilities that must be considered in the evaluation of the location of energy parks. Also, the ideal is not to propose such islands for nuclear waste disposal, even though Lageraar et al. were indeed thinking of the disposal of ordinary waste. Here the idea is rather to point out how close places in or on the North Sea are to the sites of big refineries, particularly in Rotterdam and Antwerp. Hydrogen produced by nuclear power in general and that of nuclear energy parks in particular could readily be used in these refineries. This would have a direct impact on the oil situation as the lighter fraction could be made to have a larger share. But the use of such hydrogen for coal gasification must be equally kept in mind.

Following our reasoning of the deployment of large scale nuclear power and its fuel cycle, we have been led to the scheme of energy parks and consequently to the problem of secondary energy. It is therefore interesting to consider a decision tree not only for the deployment of nuclear energy but also in more general terms for advanced energy systems.

11. A Decision Tree for Advanced Energy Systems

One again follows the decision tree as given in Figure 22 and faces the decision whether or not to employ nuclear power. If not, then at least for Europe, the only alternative to nuclear power can be additional coal if a truly large system (a few TW) is to be considered. In that case a similar decision tree must be used. The next step is to decide whether or not to employ nuclear power for the generation of electricity only. If yes, then the next question is whether or not to intentionally increase the electrical share. If not, additional coal comes into the picture again, as only up to 20% of secondary energy can be supplied by nuclear. If the electrical share is intentionally increased, the nuclear share will have to rise accordingly. If instead the answer is to produce not only electricity from nuclear sources, the next decision to be faced is that on storage and transportation. If there should be no large scale storage and transportation, only local, autonomous applications can be envisaged. We saw that only a share of 5-7% of secondary energy can be envisaged. If the decision is in favor of storage and transportation, a network of a gaseous secondary energy must be installed in which energy is fed in at centralized places such as large power stations or energy parks and perhaps a central grid for hot water. The next question is whether or not to make the secondary energy forms mutually convertible. If no, the answer is that the reliability of each of these forms must be established separately and electricity remains non-storable. If yes, then hydrogen is the most immediate choice. Electrolysis and fuel cells would allow for such mutual conversion.

If hydrogen were the second carrier of secondary energy it could also integrate other sources of primary energy as they may come up. This applies to solar energy in particular. If solar energy ever becomes cheap enough to be used on a truly large scale then it will be in southern parts, and large distances have to be bridged. Solar power also necessarily requires storage. Daily and yearly cycles of solar radiation must be bridged, and this can be accomplished by a large hydrogen pipeline system by its very nature. But also if for instance large scale sources for hydropower which are far away were engaged, hydrogen is the natural partner. Such hydropower would produce ammonia and/or hydrogen, it would be transported accordingly and would be readily accepted at the feeding points of the envisaged kind of coupled secondary energy system. To that extent such an approach allows also for the possible diversification of primary energy.

12. Modes of Geographical Deployment

Both from the side of primary energy and from that of secondary energy we have been led into considerations of the geographical deployment of energy systems. Already several years ago, when major technological developments were to be envisaged, the dimension of time was well recognized. This awareness led to technological strategies such as phased approaches and target dates for certain identified partial steps. As nuclear energy is maturing the dimension of space must also be recognized. After embracing the dimension of time, technological strategies must now also embrace the dimension of space. This may be illustrated in Figure 23 which tries to summarize this reasoning. It shows modes for the geographical deployment of nuclear energy.

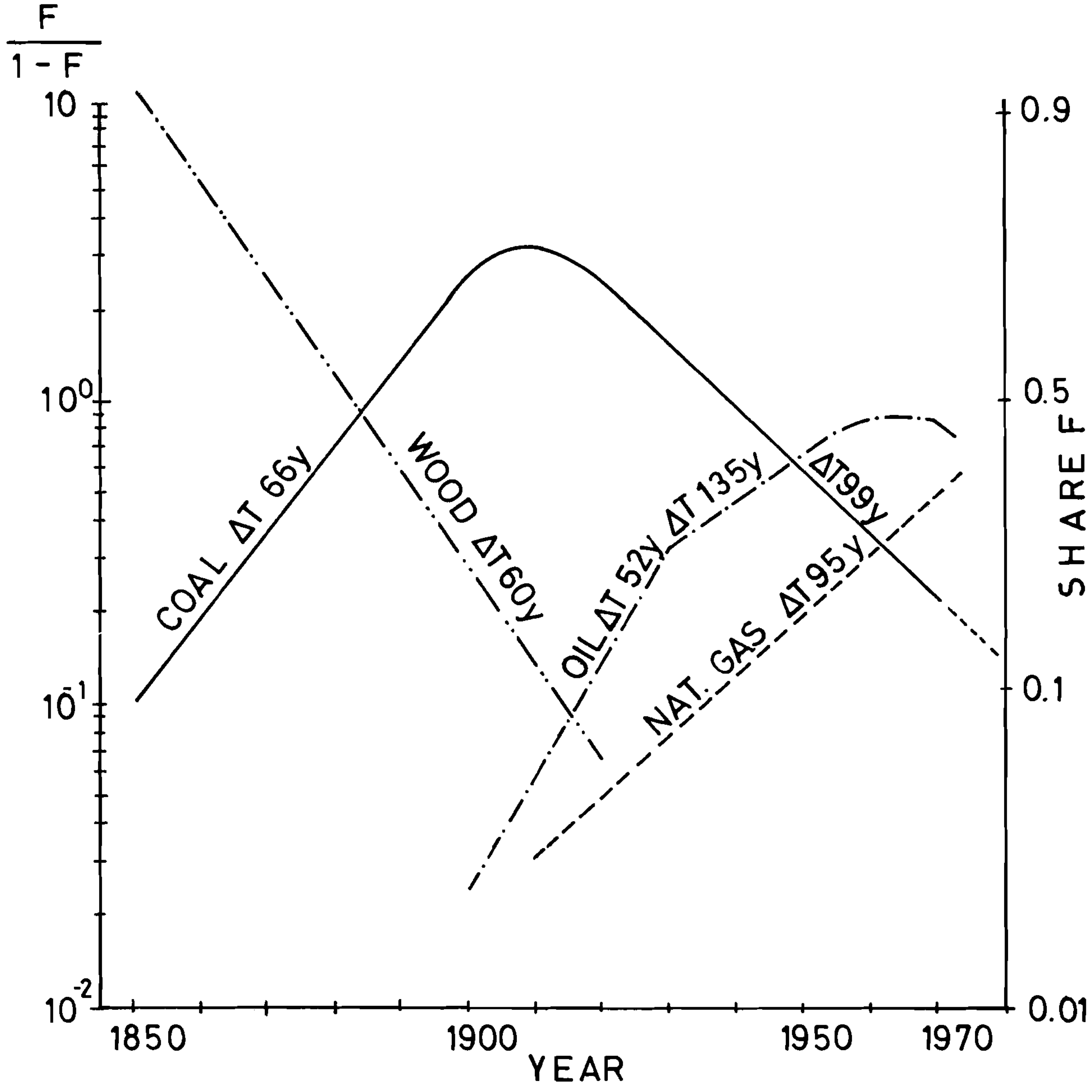
In this scheme time is given as the abcissa and the ordinate is the scale of primary energy. One sees the downward trend of conventional coal and the maximum of the use of oil as explained earlier in Figures 1 and 2.

LWR's using U235 as a fuel are then used in local nuclear plants much in the way they are used today. As these stations operate they produce Pu which poses its own problems. Pu and U233--and that implies the Thorium cycle--somehow tend towards the mode of comprehensive co-locations or energy parks. This leads to centralized supplies of secondary energy in both forms, electrical and gaseous. The gaseous carrier allows for storage and transportation and thereby also, if feasible, to the gradual diversification of primary energy. Other options of primary energy therefore may or may not enter the picture.

Such a build-up and extension of a modern energy system will probably use additional coal for purposes of coal gasification. Accordingly, such additional uses of coal were shown in Figure 2. Of course, all curves are qualitative and not the result of numerical calculations.

In closing it should be stressed that the considerations of the second part of this paper were long range ones and of a conceptual nature. They were meant to indicate the context within which the large scale deployment of nuclear power for all energy needs has to be seen. The first part of the paper, on the other hand, was meant to point to the more medium term applications of nuclear power other than electricity generation. But the logic of these other applications leads to the concepts of the second part of this presentation.

PAST ENERGY SHARES IN THE US



AFTER: MARCHETTI, IIASA

FIGURE 1

PAST AND INTENDED ENERGY SHARES IN THE FRG

1975-1985: „ENERGIEPROGRAMM" OF THE FRG

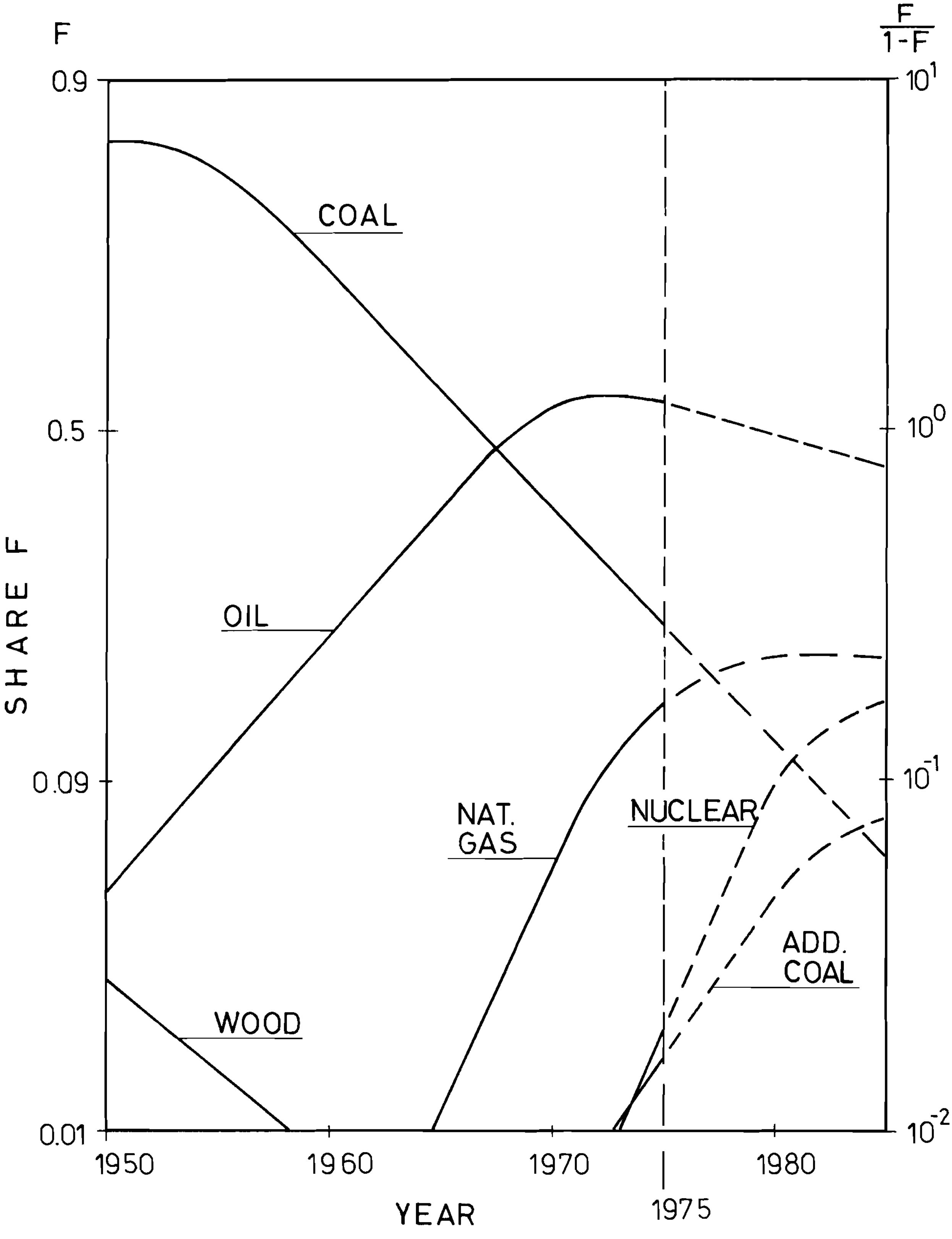
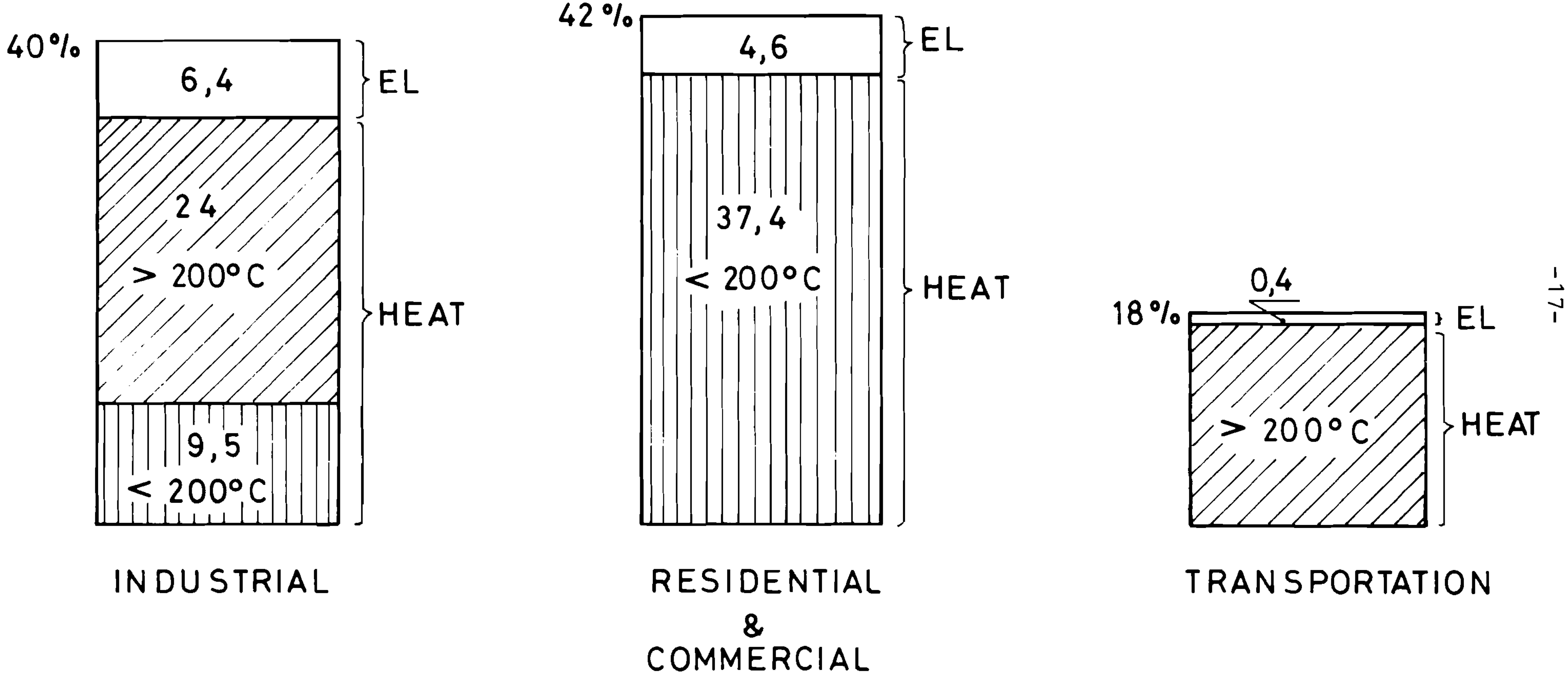


FIGURE 2

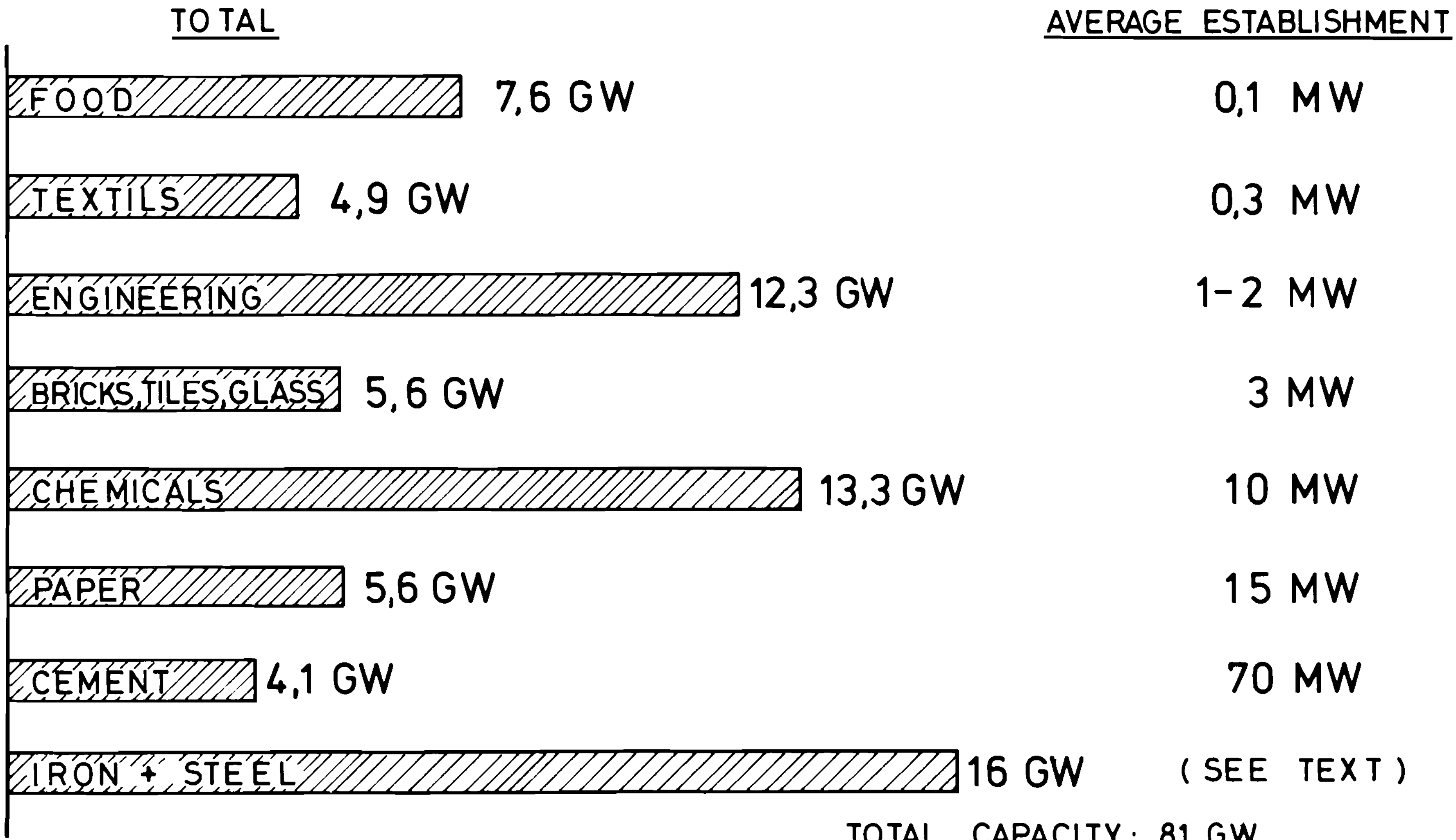
FINAL ENERGY USE IN THE FRG (1970)



100% ≙ 227 MILL tce (FINAL)

FIGURE 3

TOTAL POWER DEMAND FOR INDUSTRIAL HEAT IN GREAT BRITAIN

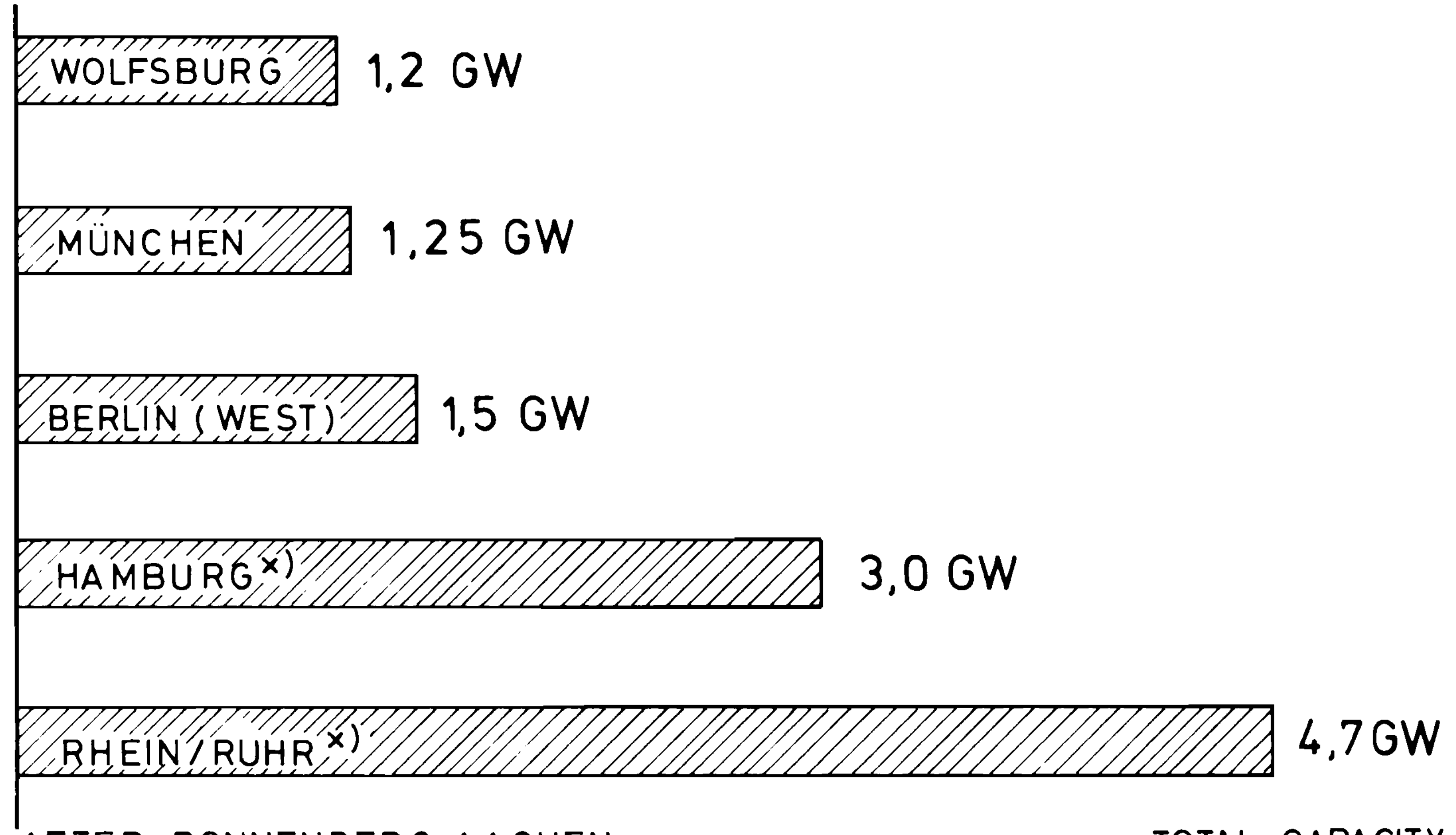


AFTER: LLEWELYN, UKAEA

TOTAL CAPACITY: 81 GW
ANNUAL LOAD FACTOR: 0.8

FIGURE 4

SIZE OF DISTRICT HEATING NETWORKS IN THE FRG (1972)



AFTER BONNENBERG, AACHEN

$^{x)}$ONLY POTENTIALLY ONE SYSTEM.

TOTAL CAPACITY : 18,6 GW

ANNUAL LOAD FACTOR : 0,2

FIGURE 5

DISTRICT HEAT SUPPLY IN THE F R G

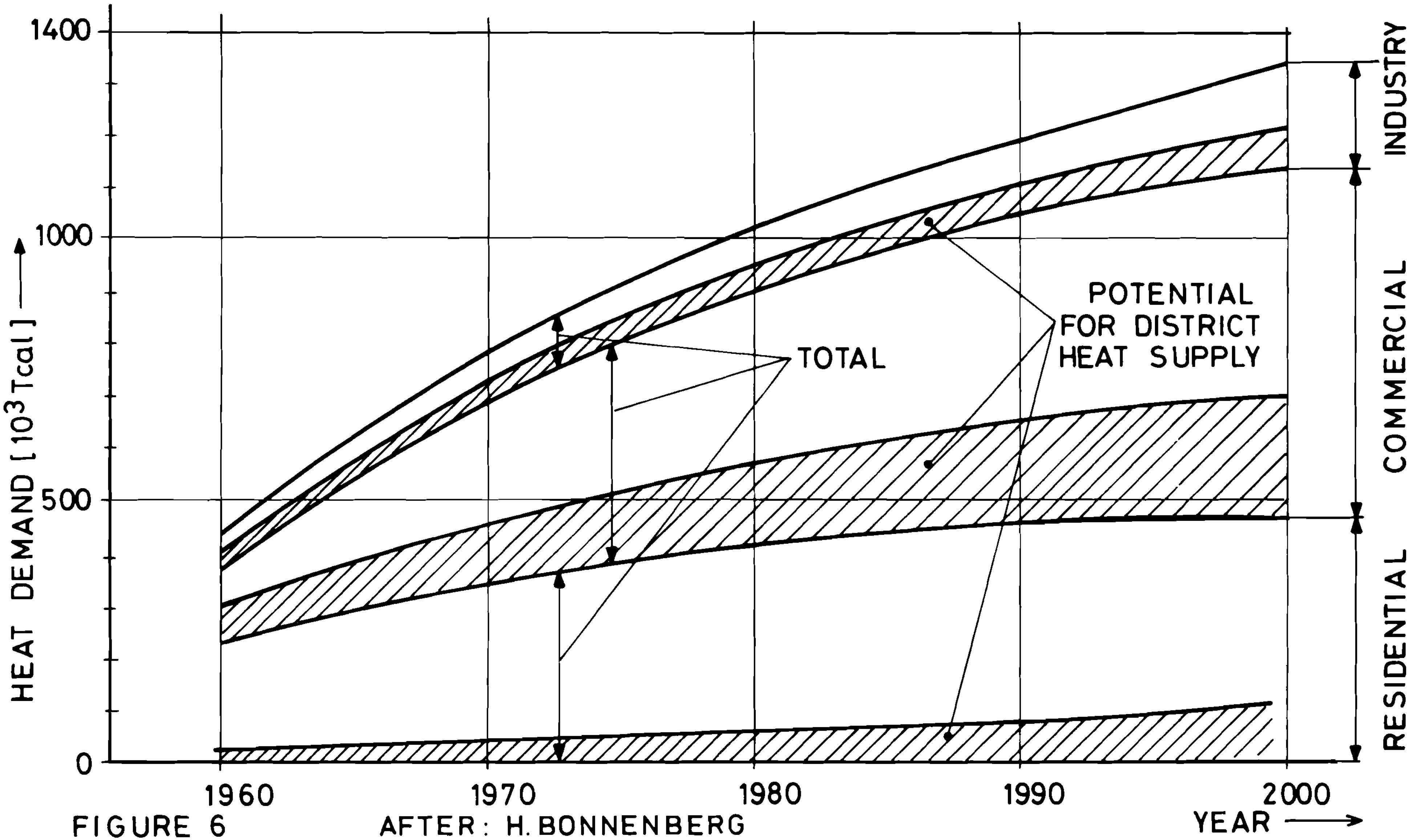


FIGURE 6 AFTER: H. BONNENBERG

PARTITIONING AND FINAL USE OF SECONDARY ENERGY (FRG)

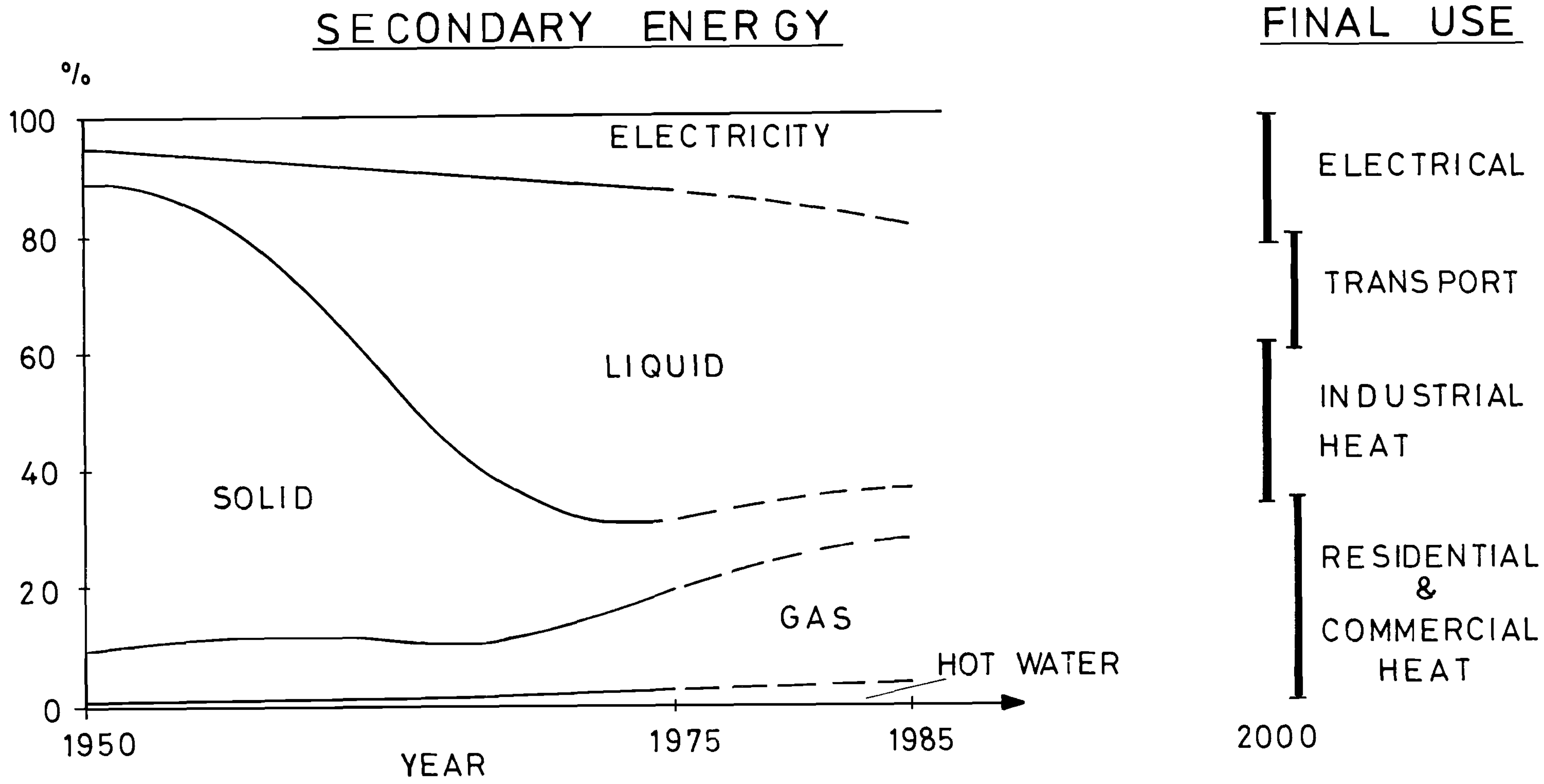


FIGURE 7

PROJECTED SHARES OF ELICTRICITY IN FINAL ENERGY DEMAND

	1970	1985	2000
PRESENT TREND	10 %	14 %	21%
ENHANCED ELECTRIC	—	17%	24%

AFTER: M.BELLER, E.A. CHERNIAVSKY, K.C.HOFFMANN, R.H.WILLIAMSON, USA

FIGURE 8

SOME COST COMPONENTS OF SECONDARY ENERGY SYSTEMS (FRG, 1973)

	TRANSMISSION (6 GW, 100 km, $\frac{8000\text{h}}{\text{YEAR}}$)	DISTRIBUTION (POP.DENSITY~1000/km^2)	CONSUMERS COST
ELECTRICITY	0,16 $\frac{\$}{\text{MILL BTU}}$ (380 kV)	5,2 $\frac{\$}{\text{MILL BTU}}$ (5600 h/YEAR)	13 $\frac{\$}{\text{MILL. BTU}}$
NAT. GAS	0,034 $\frac{\$}{\text{MILL BTU}}$	4,2 $\frac{\$}{\text{MILL BTU}}$ (1600 h/YEAR)	5,2 $\frac{\$}{\text{MILL BTU}}$

AFTER: H.G. THISSEN, JULICH, FRG
W. BUCH, SALZGITTER, FRG

FIGURE 9

HYDROGEN PRODUCTION COSTS

	COAL GASIFICATION	*FUEL OIL OXIDATION*	*METHAN REFORMING*	*ELECTROLYSIS*
ENERGY INPUT [$ /MILL BTU]	2,0	1,75	2,5	0,6 x)
HYDROGEN OUTPUT [$ /MILL BTU]	6,5	3,5	4,5	1,6 xx)

x) BASED ON OFF PEAK POWER AT 2 $\frac{\text{MILLS}}{\text{KWh}}$ FOR 2500 h/YEAR

xx) BASED ON 80 $\frac{\$}{\text{KW}}$ (1985), 12% INTEREST AND 93% EFFICIENCY

FIGURE 10

PENETRATION OF MARKETS BY NEW TECHNOLOGIES

the logistic curve

$$\boxed{f = \frac{1}{1+e^{-\alpha(t-t_o)}} , \qquad \frac{f}{1-f} = e^{+\alpha(t-t_o)}}$$

f : FRACTION OF THE MARKET PENETRATED
t_o: TIME AT WHICH $f=0.5$
α: CHARACTERISTIC OF TRANSITION

after : F. C. Fisher and R. H. Pry : A Simple Substitution Model of Technological change

FIGURE 11

PENETRATION PERIODS

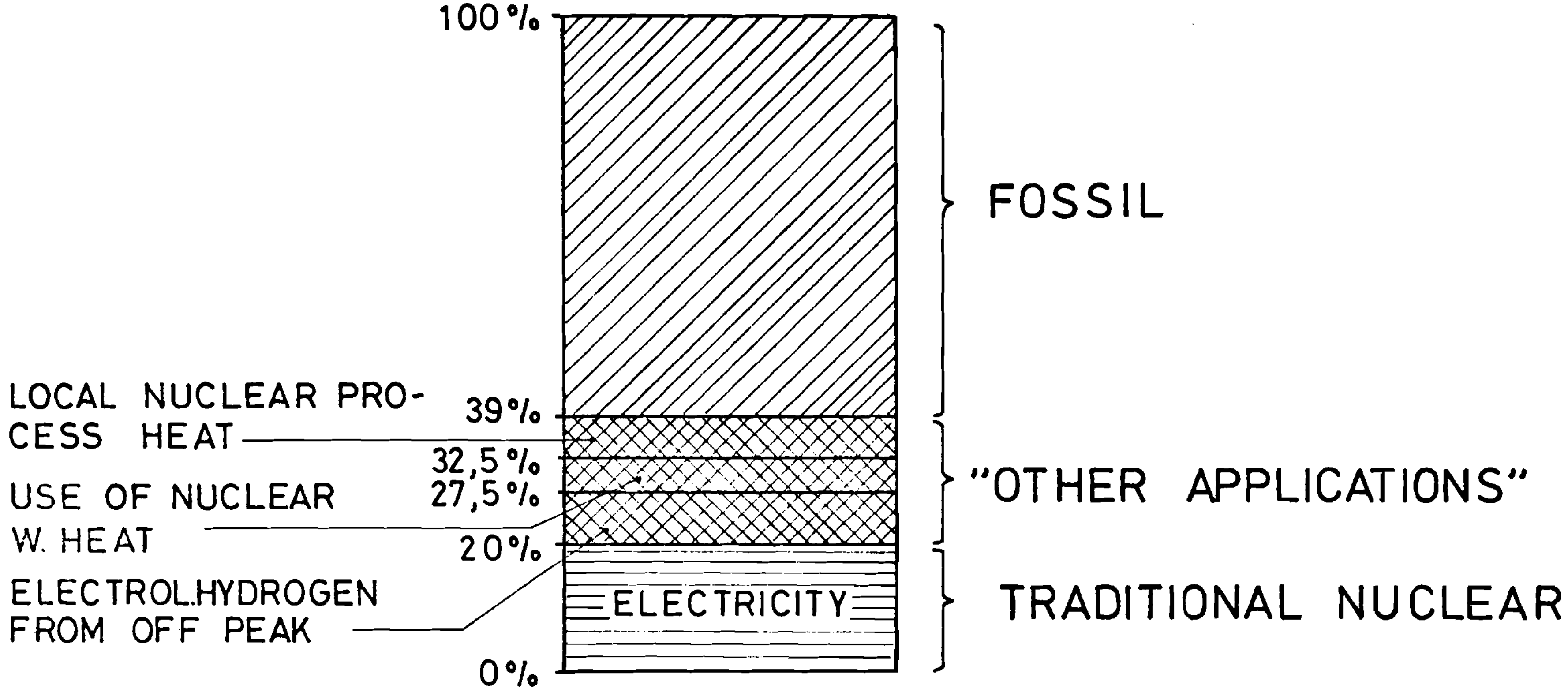
ΔT: PERIOD FOR GAINING OR LOSING A MARKET SHARE OF 50 %

	WOOD	COAL	OIL	GAS
ΔT [YEARS]	60	66	52/135	95

AFTER MARCHETTI, IIASA

FIGURE 12

PROJECTED SHARES OF SECONDARY ENERGY ORIGINATING FROM NUCLEAR POWER



REFERENCE CASE : FRG (2000), 400 MILL $\frac{\text{tec}}{\text{YEAR}}$ SECOND ENERGY $\triangleq$ 100%

FIGURE 13

MARK 9 PROCESS OF THERMOCHEMICAL WATER SPLITTING

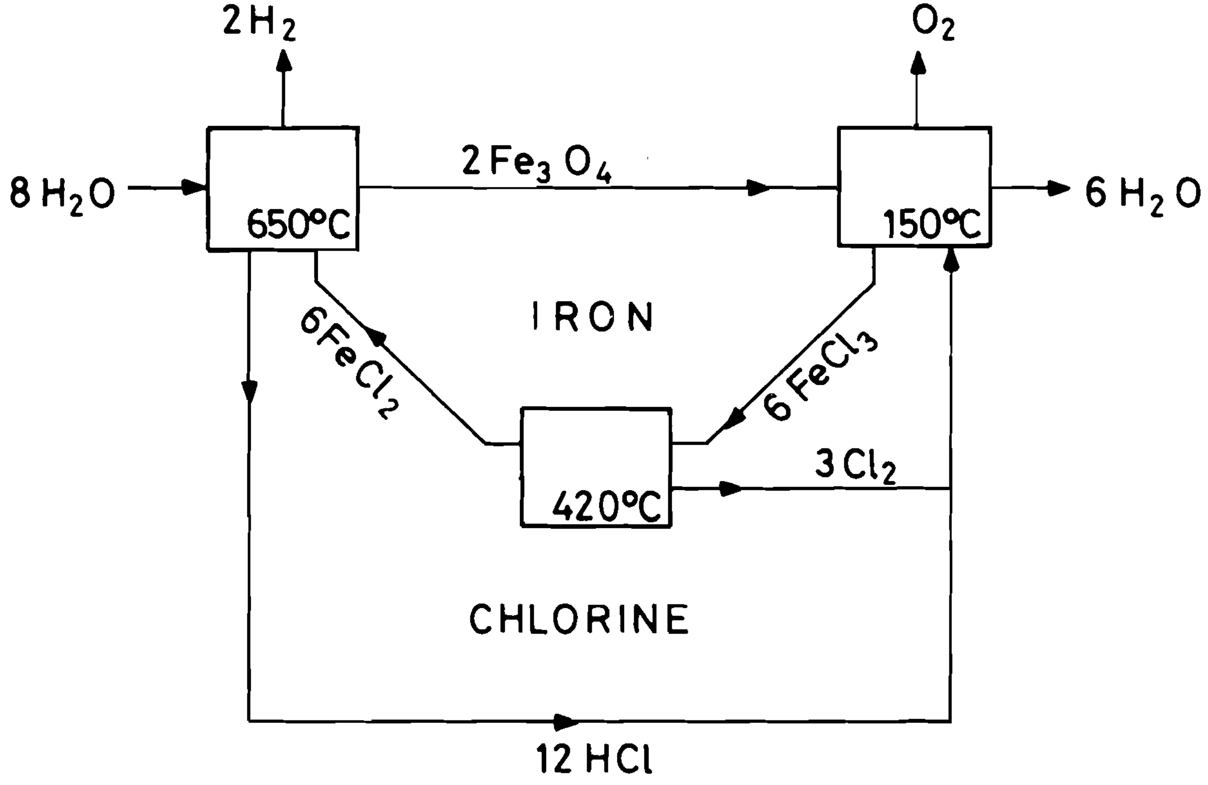


FIGURE 14

ASYMPTOTIC INTEGRATED REACTOR SYSTEM

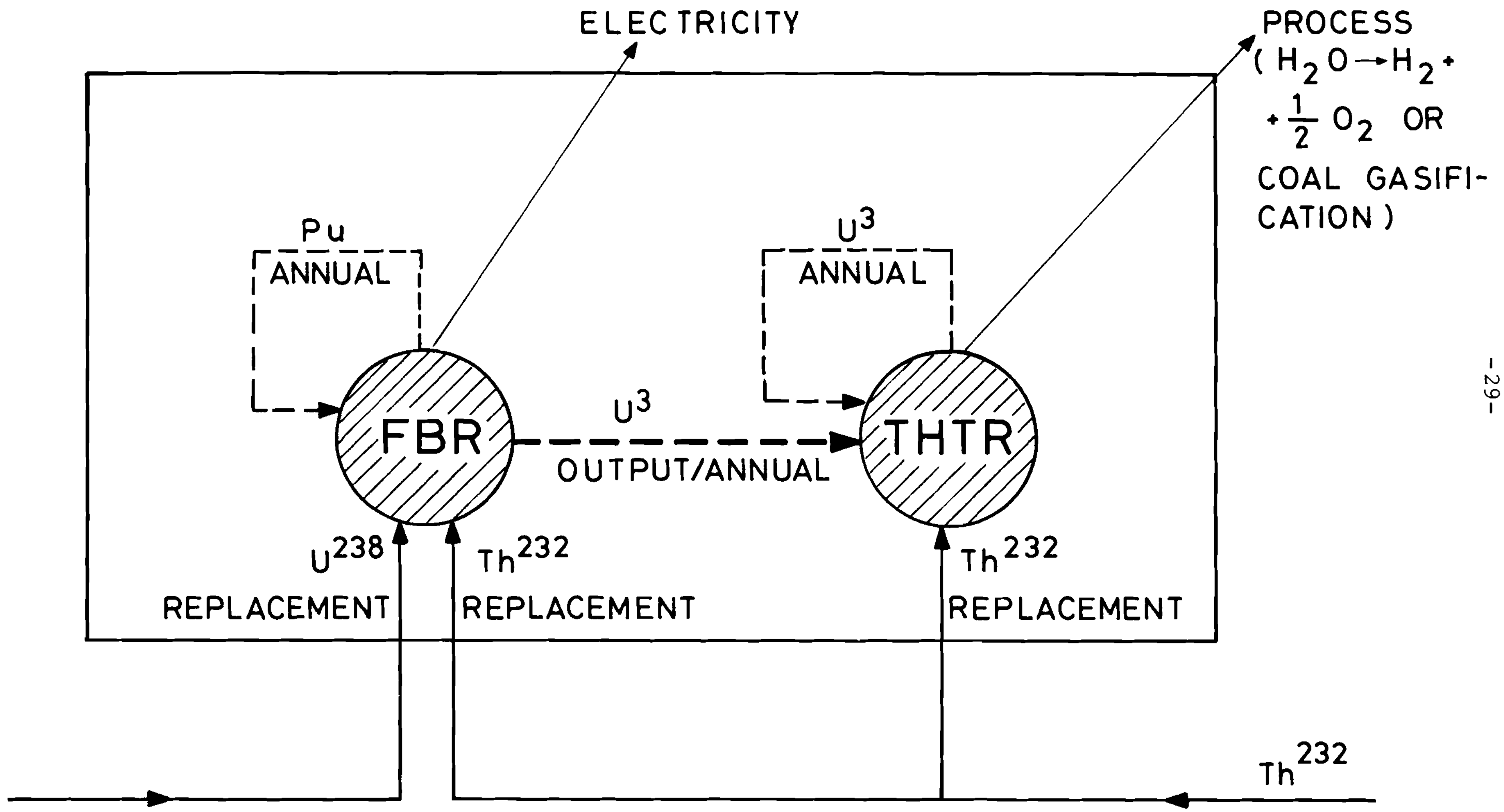


FIGURE 15

TRANSIENT REACTOR SYSTEM

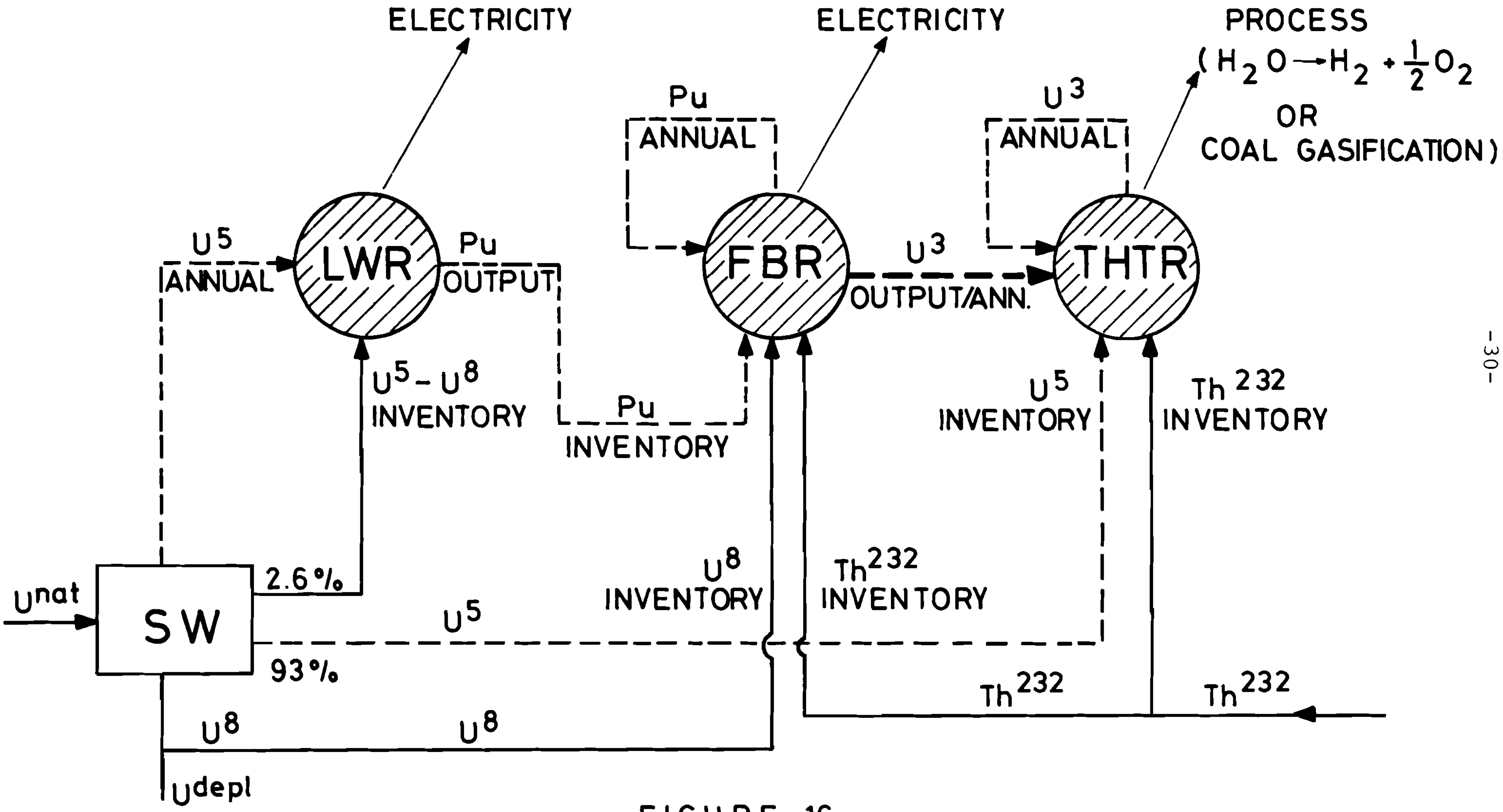
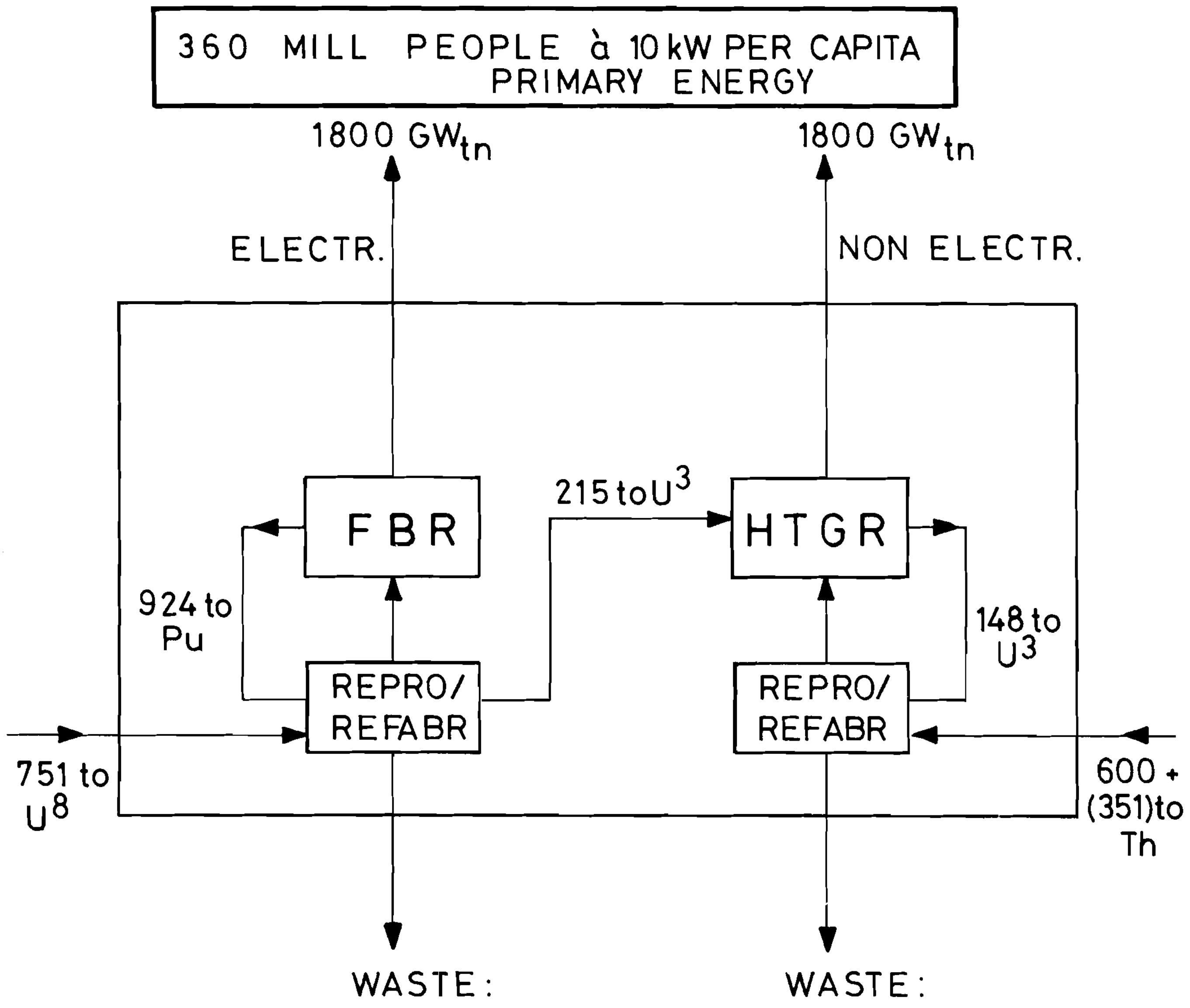


FIGURE 16

A FUEL CYCLE FOR AN ALL NUCLEAR SOCIETY [YEARLY THROUGHPUTS]



FISS. PROD.	: 622 to	FISS. PROD.	: 691 + (69) to
ACTINIDES	: 17 to	Pa + Np	: 27 to
Pu	: 9 to	U^3	: 4 to

FIGURE 17

FOUR CLASSES OF REQUIRED PHYSICAL PROTECTION

CLASSES	*CHARACTERISTICS*	*TIMING*	*REQUIRED PROTECTION*
IRRADIATED MATERIAL	SELF DEFENDING	TO COME	VERY SMALL
MATERIAL ENRICH. < 5%	NOT SELF DEFENDING ENRICH.REQUIRED	IN USE	SMALL
Pu, U^{233}	NOT SELF DEFENDING NO ENRICH.REQUIRED	TO COME AFTER REPROCESSING	SIGNIFICANT
MATERIAL ENRICH. > 20%	READY MATERIAL	NO LARGE AMOUNTS SO FAR HTGR ?	HIGH

FIGURE 18

DECISION TREE FOR THE DEPLOYMENT OF PEACEFUL NUCLEAR ENERGY

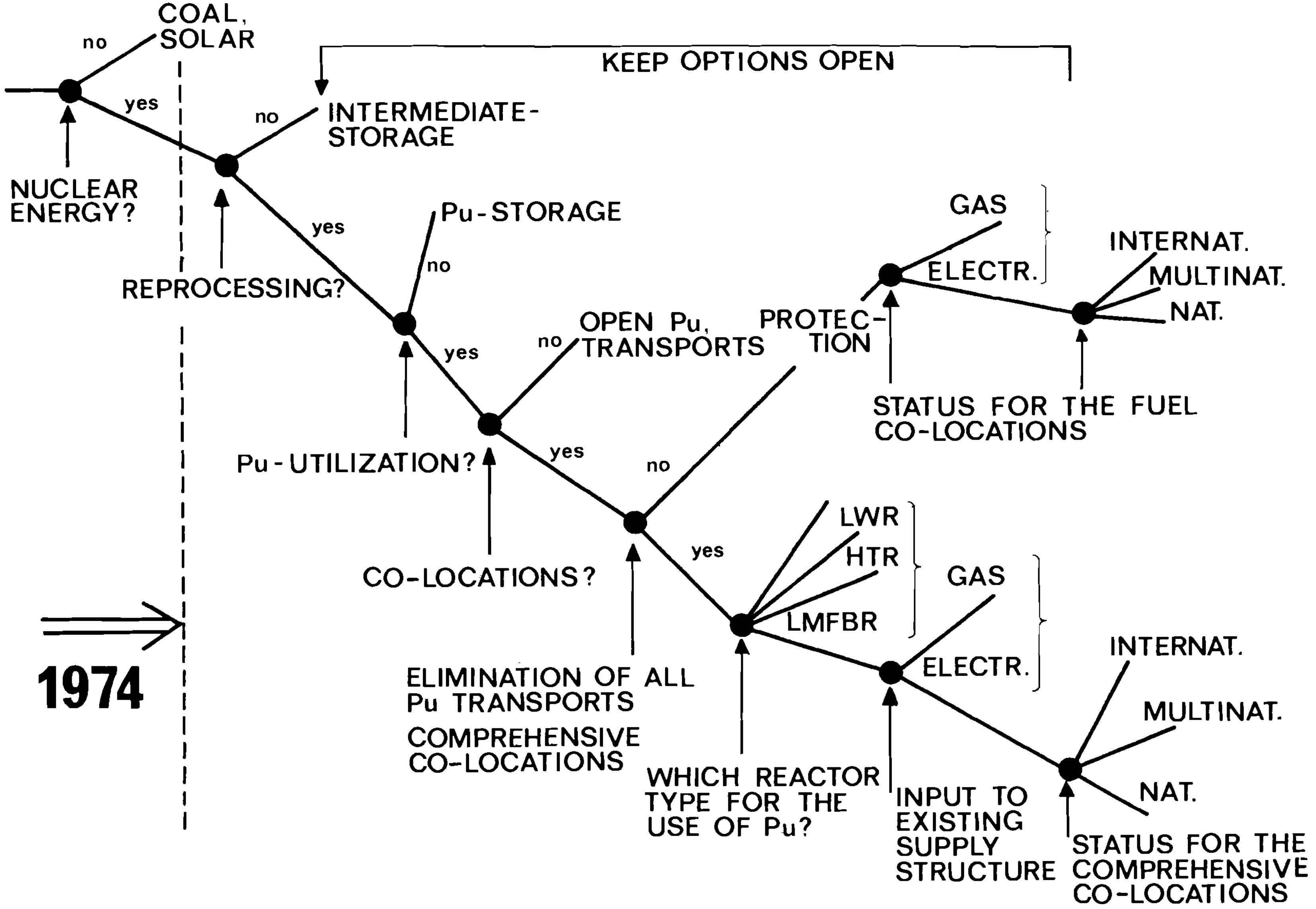


FIGURE 19

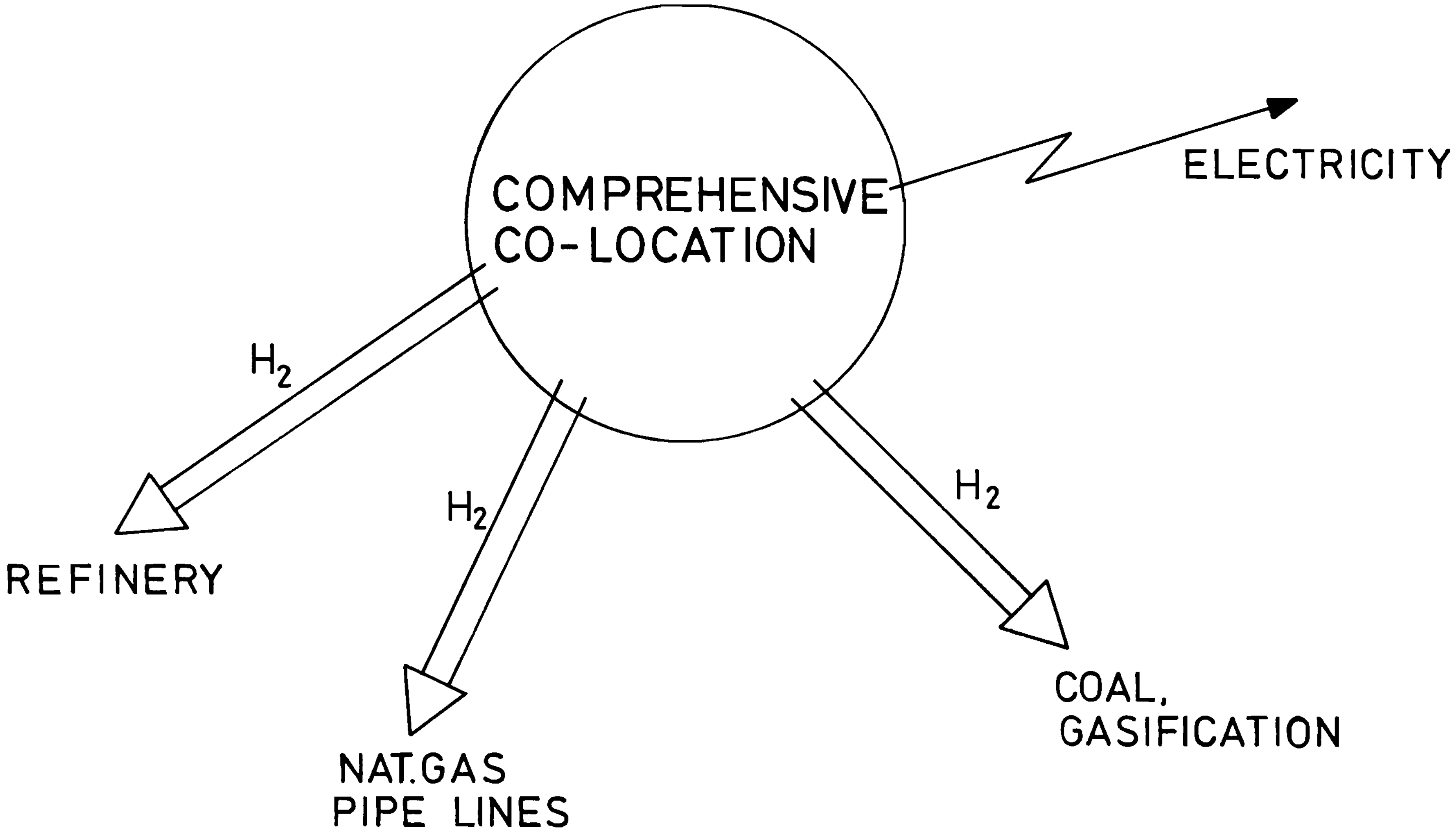

COMPREHENSIVE
CO-LOCATION
ELECTRICITY
H_2
REFINERY
H_2
NAT.GAS
PIPE LINES
H_2
COAL,
GASIFICATION

FIGURE 20

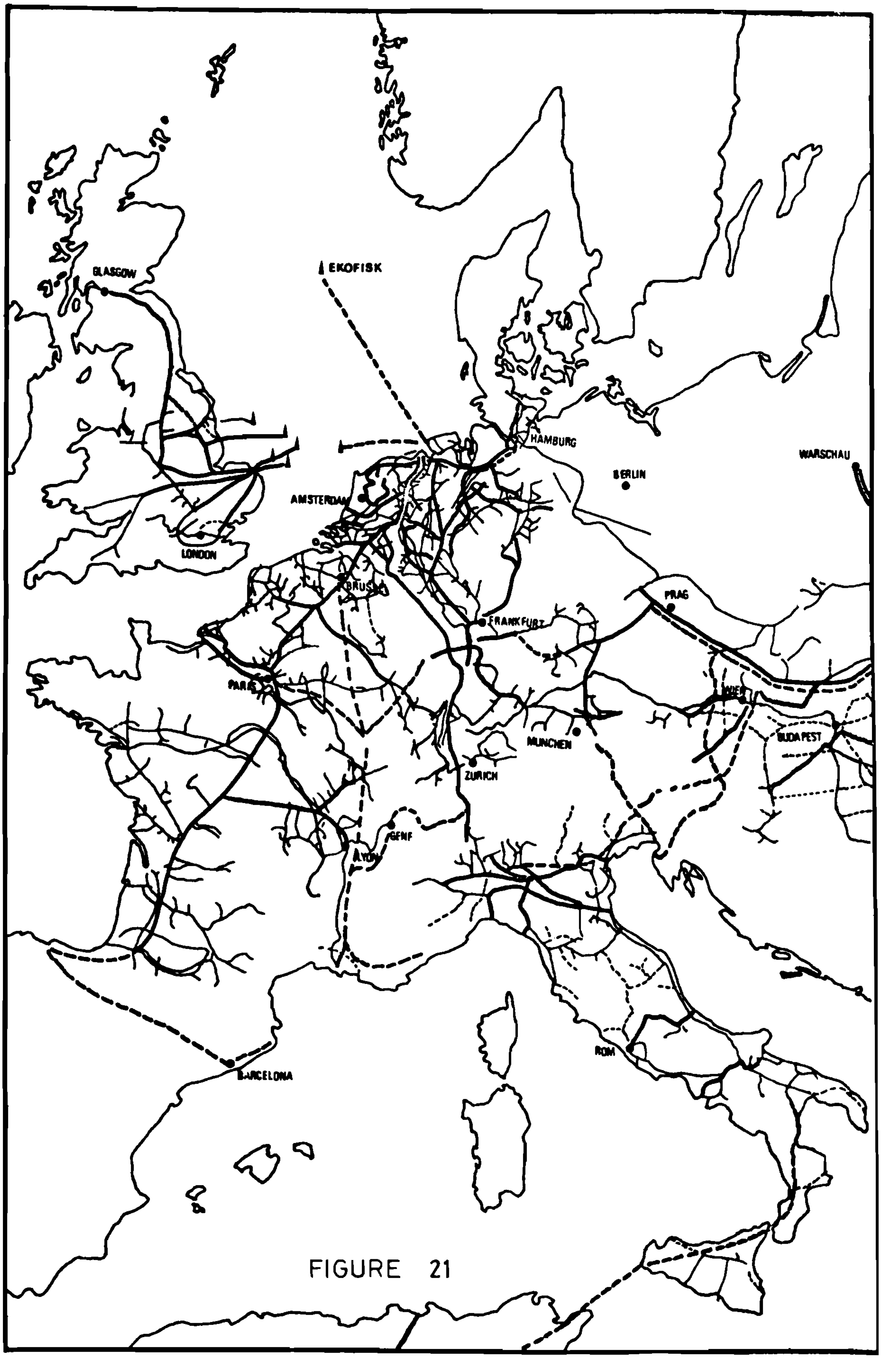

EKOFISK
GLASGOW
HAMBURG
WARSCHAU
BERLIN
AMSTERDAM
LONDON
BRUSSEL
PRAG
FRANKFURT
PARIS
WIEN
BUDAPEST
MUNCHEN
ZURICH
GENF
LYON
ROM
BARCELONA

FIGURE 21

A DECISION TREE FOR ADVANCED ENERGY SYSTEMS

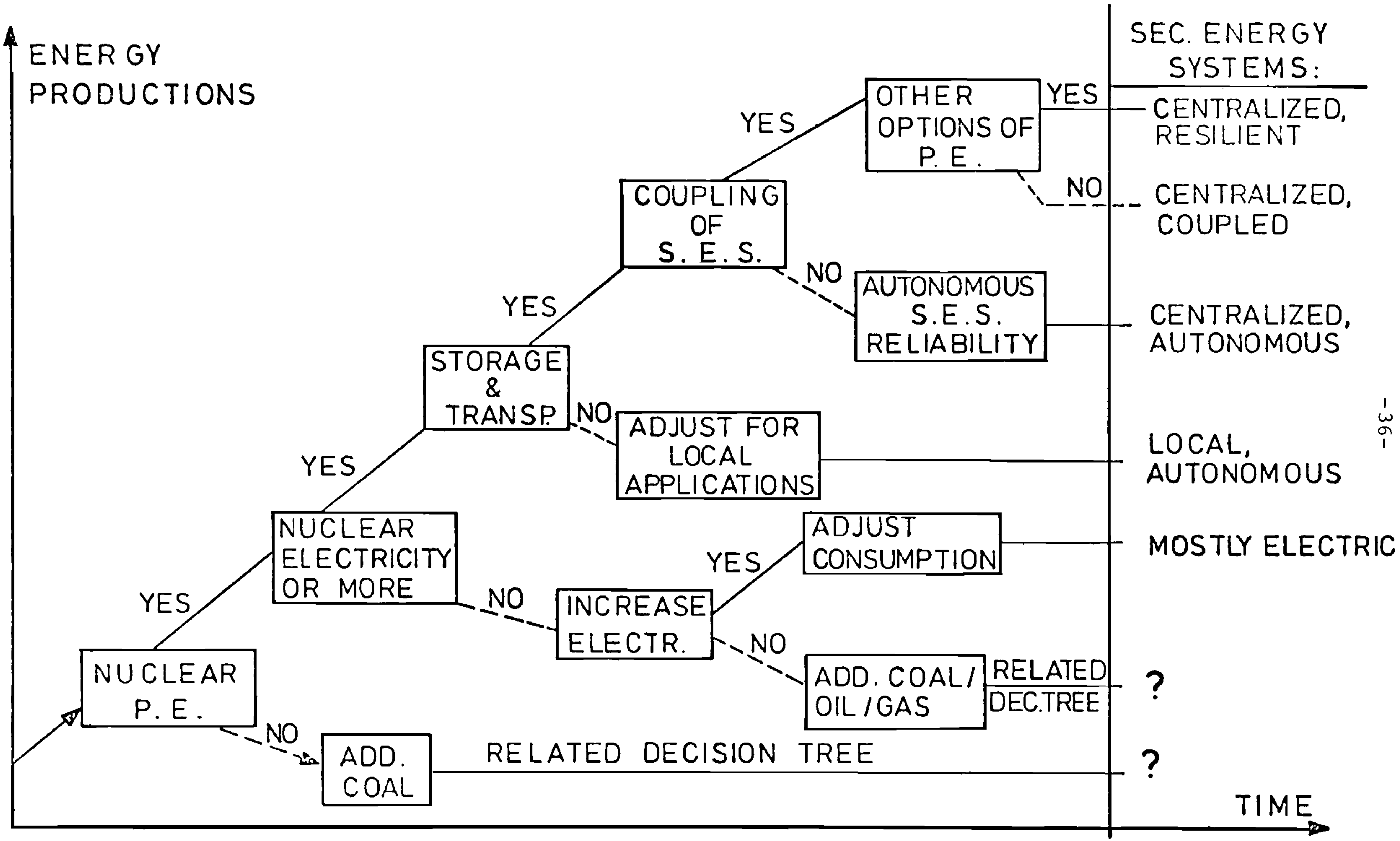


FIGURE 22

MODES FOR THE GEOGRAPHICAL DEPLOYMENT OF NUCLEAR ENERGY

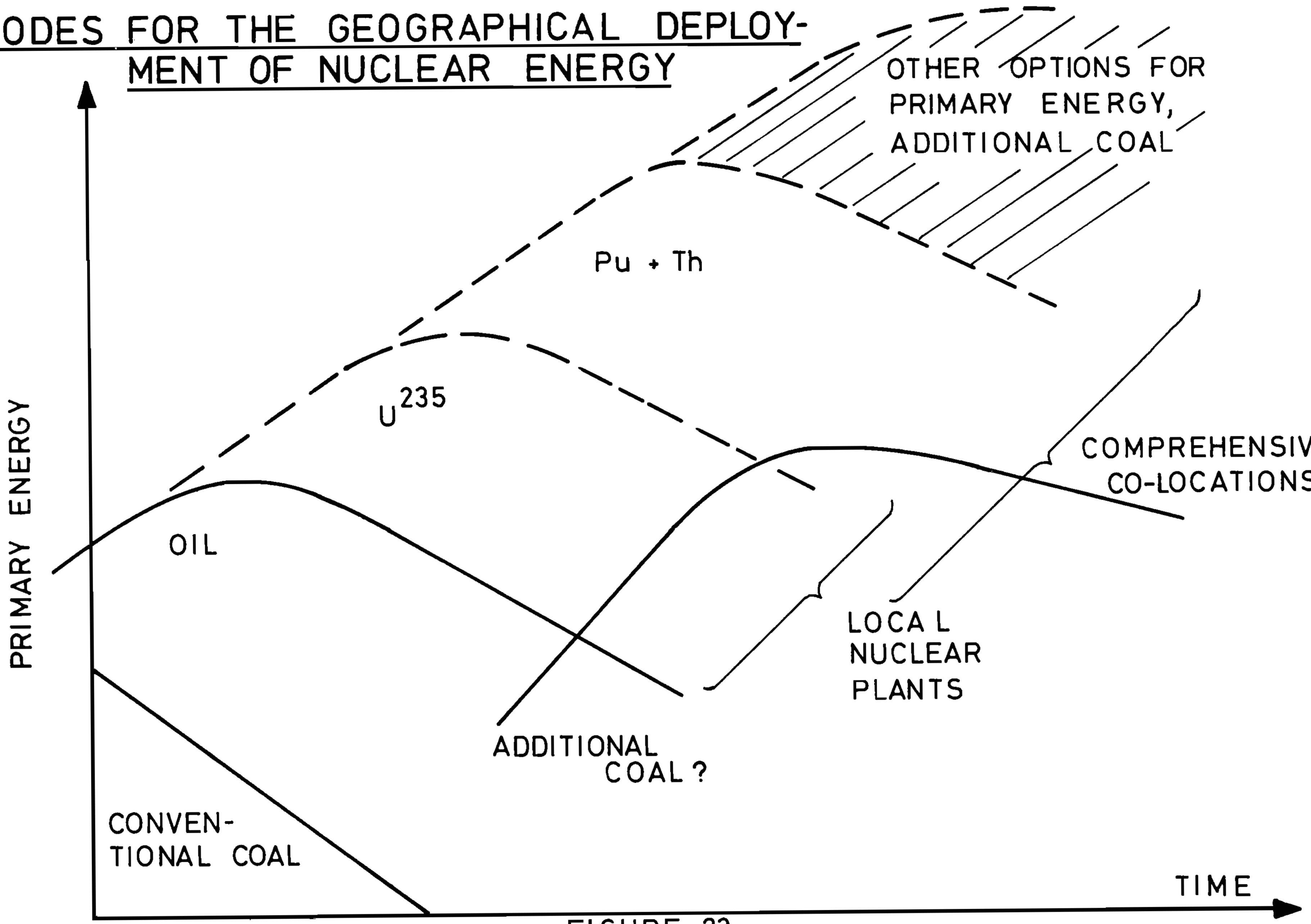


FIGURE 23

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APPENDIX A

Categories of Non-Electrical Applications of Nuclear Power

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Commissariat à l´Energie Atomique, France

- The energy crisis following the increase of the fuel products reminded us that a nuclear reactor can also produce heat or vapor before producing electricity, and that for other applications (industrial heat, urban heating, ship propulsion...) nuclear energy was able even now to show its competitiveness.

- One can distinguish two types of LWR and HTR which by way of different qualities of the steam produced naturally have two distinct fields of application.

I) Low and Medium Heat, temperature below 300°

Important percentage (75%) of the quantity of total steam produced for the industry in France.

1) Industrial heat produced by the big mixed plants (electricity, steam)

- Recalling characteristics of steam produced by a LWR: 40 or 60 bars and 250 to 300°C.

- Estimation of costs of the steam produced depends on the distribution of the total costs to production of electricity and of steam and on the costs of electricity.

- Comparison of the costs of steam produced and the cost of the steam obtained from plants using fuel depends on:
    - fuel price
    - ratio of energy and steam produced
    - total capacity (steam + electricity) of the mixed nuclear plant.

- Present electro-nuclear plants, the order of magnitude of the cost of steam production would be about 40% of that of production.

2) Industrial heat produced by small plants (power 1500 MWth)

- Nuclear energy is competitive for a price of fuel of 3 centimes if the size of reactors (only heat production) reaches 100 MWth.

- The CEA has developed two techniques with limits of about 300 MWth.
    - The integrated CAS reactor type (CAP prototype in Cadarache) for the range of 135,250 and 330 MWth. Production up to 500 t/h saturated steam at 45 bars.
    - The PRIAM steam loop reactors for more power. Production of overheated steam at 56 bars form 500 t/hr.

3) Urban heating

- Essential characteristics of the demand for heat
- Main nuclear heating systems which can be foreseen

  A. Mixed reactor (electricity-heat) supplying big urban area of the country,

  B. Hybrid plant using both nuclear fuel and oil from the big existing networks,

  C. Hybrid plant (nuclear and fuel oil) connected to the heating network at a low temperature(110°).

4) Desalination

If we accept that small nuclear plants are now competitive from 100 MWth in the case 100% heat, the whole market of the future distillation plants of more than 30,000 m^3/day is open to them. This includes plans for small plants studied by the CEA:

Integrated LWR: CAS

Variable capacity	135	250	or	330	MWth
Fresh water produced	30000	80000	to	100000	m^3/day
Electricity complement	20	30	to	50	MWe

5) Ship propulsion

- In this field the CEA developed its own technique. The PAT prototype reactor (prototype à terre = on land prototype) of the submarine reactors started in 1964 and up to now has had 40 000 hours of operation. Inspite of the recent troubles of the Mutsu, the CEA considers this field very important for the future. Various nuclear equipment firms have now initiated to work together to apply this technique to non-military purposes. With the increase of fuel oil prices, it will be competitive at around 80 000 cv and many possibilities are offered:

- tanker
- methane ship
- container.

II) Industrial applications of HTR

1) In the refineries

- direct heating by helium in the secondary heat loop for heating at 750°C of the distillation and reforming furnaces.
- use of steam to 480°, 80 bars.

2) In the steel industry

- transformation of methane and iron ore pre-reduction.

3) Gasification of coal and lignite

For the SNG production.

Method of less interest to France than to the FRG and the USA.

4) Hydrogen production

Preliminary studies have been carried out. It is necessary to choose among the numerous thermochemical cycles that have been proposed.

APPENDIX B

Hydrogen and Other Energy Vectors

G. DeBeni
Eratom, CCR ISPRA

Applications of nuclear energy are in every case possible only through an energy vector. Even the primary coolant is a vector which transfers the heat of fission (why not fusion?) to the utilisation.

For stationary applications many energy vectors other than electricity can be considered: helium, steam or hot water, reformed gas (EVA-ADAM), hydrogen (or S.N.G.).
Now we have to consider the following properties:

1) Interface between nuclear reactor and the energy vector
2) Distance at which energy can be economically transported by the energy vector (and possibility of storage)
3) Maximum temperature at which energy can be made available by the energy vector (or, more in general, kind of uses that can be fed by the energy vector).

Hot helium

1) No interface if we consider the primary helium
2) No distance in integrated reactors, otherwise not more than 50 - 100 meters (gas turbine, methane steam reforming or other applications just outside the nuclear reactor). No storage possibility.

3) Temperature of the nuclear reactor itself.

Steam or hot water

1) Very simple interface: heat exchanger
2) Distance is evaluated up to 20 - 30 km. A certain storage possibility: underground hot water with its problems.
3) 200 - 300°C.

Reformed gas (EVA-ADAM concept)

1) Some more complex than a heat exchanger: simple chemical reactor
2) Distance can be 50 km, may be more (transport cost per calorie is about 11 times more than natural gas)*
   A certain possibility of storage underground, but also possibility of different leakage rate between H_2 and CO with deviation from the stoechiometric ratio.
3) 500 - 600°C for $CH_4 + H_2O$ system.

Hydrogen (or S.N.G.made by H_2 from water splitting and coal)

1) Quite complex; sophisticated chemical plant.
2) 500 - 1000 km. Great possibility of underground storage.
3) 2000°C or more; chemical uses, local electricity production, etc.

---

* Let us suppose that the transportability of $CO+3H_2$ mixture is similar to H_2; its heating power is 49 Kcal, i.e. about 12 Kcal/mol, H_2 has ~ 60 Kcal/mol, so the transport of the mixture costs 5 times more than H_2. H_2 transport costs is 1.4 times the transport cost of CH_4; then $5 \cdot 1.4 = 7$ times the CH_4 transport cost. When transformed in CH_4, this CH_4 has an "apparent heating value" of 49 Kcal/mol, i.e. the cost of back transport is 4 times that of CH_4; the sum is 11.

Summarizing the first two properties in a scheme we have:

Energy vector	Interface	Distance
Helium	No interface	50 - 100 m
Hot water or steam	Heat exchanger	20 km
EVA-ADAM	Simple chemical reactor	50 - 100 km
H_2 (S.N.G.)	Complex chemical plant	500 - 1000 km

It is clear that the ability of an energy vector to transport energy over long distances has to be paid by a more complicated (and expensive)interface.

Apart from few particular regions the distribution of energy demand is such that hydrogen has the better chances as energy vector for large power plants and tends to be the only solution of off-shore power plants.
Compared to electricity, hydrogen has the advantages of the storability, permitting the continuous full power operation of the production plant; and the economic transportability over very long distances, permitting very large production plants inserted on the transmission network.
The production of other synthetic fuels (methanol, S.N.G.) calls for hydrogen and coal as raw materials, and limitations on siting can be caused by the coal availability.

(Ammonia can be produced by nuclear energy, water and air, but its use as energy vector seems not well accepted).
As a consequence: hydrogen, produced by nuclear energy and via a thermochemical process.

A thermochemical process is a sequence of chemical reactions running at different temperatures, in which the chemical compounds are continuously recirculated, and whose overall result is the splitting of water in its elements, hydrogen and oxygen, consuming only heat. A thermochemical process behaves as a heat engine and thus needs a high temperature heat source and a heat sink at low temperature; the product of this "engine", however, is not "work", but a chemical substance, so it can be calculated that its theoretical efficiency is about 10% higher than that calculated for work production within the same temperature conditions.

A comparison has to be made with hydrogen produced by water electrolysis. The frame of this comparison is simple because the theoretical efficiency for the transformation of heat into hydrogen is the same for both processes. The comparison will be made on the basis of practical efficiency, fixed and operating costs.

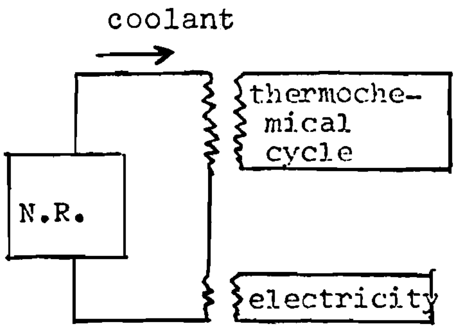
The efficiency of water electrolysis is quite low in spite of all the efforts made during the many years of industrial exploitation of this technique.

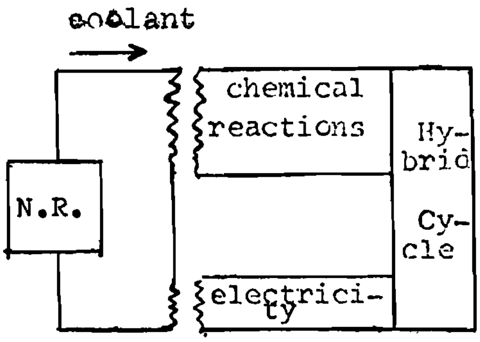
Ameliorations can surely be obtained, but water electrolysis is still a process with low efficiency and with relatively low power density.

In thermochemical processes causes of inefficiency are present because the properties of elements and compounds do not match with the ideal working compound. The choice of elements and reactions is limited by the necessity of a complete recirculation of the chemicals.

Nevertheless a wider choice is available if it is possible (and convenient) to close the cycle with an electrochemical reaction. The convenience of hybrid cycles (partially chemical and partially electrochemical) is also motivated by the frequent availability of electricity in hydrogen production plants because the thermochemical process consumes often only the hottest part of the heat available from the nuclear reactor, the remaining heat being used for electricity production.

A simple scheme is the following:





Fixed and operating costs can be evaluated only very roughly because information on the behaviour of construction materials and on reaction kinetics is still insufficient.

Nevertheless we can say that, in order to be competitive, the chemical plant can cost, within a large approximation, two times the cost of the nuclear reactor source of heat.

APPENDIX C

The Possible Market for Nuclear Process Heat

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London, England

Definitions

Industrial process heat is taken to be the energy content of all primary fuels consumed by industry. It therefore excludes electricity provided from an external source. Industry in this context means manufacturing industry and excludes the service sectors and the energy "industries".

This definition must be regarded as a very general one as some industries generate electricity from their fuel input and all industries use part of their fuel for space heating.

The overall UK energy scene

The following comments apply to the UK but are probably also broadly representative of other industrialised countries.

The total UK primary energy usage is some 9×10^6 TJ of which some 3% is consumed by the energy sector itself, 45% is consumed in energy conversion processes (mainly electricity and coke ovens), and 52% or 4.5×10^6 TJ is consumed directly in such sectors as domestic heating, transportation, industry, etc.

The total industrial consumption is some 2.3×10^6 TJ of which 0.6×10^6 TJ is taken by the iron and steel sector which is considered separately. The remainder (1.7×10^6 TJ) may be divided as below.

	%
Engineering (including non-ferrous metals)	19.0
Food, drink and tobacco	12.0
Chemicals	20.0
Textiles	7.5
Paper and printing	8.5
Bricks, tiles, etc.	4.5
China, glass	4.0
Cement	6.0
Others	18.5

How nuclear energy could meet industrial needs

Industrial needs for heat embrace a wide range of processes but the majority fall into one of two categories:

1) processes involving the removal of water or the heating of a wide variety of materials. This in general involves steam at conditions up to about 250 p.s.i.saturated, i.e. temperature of up to 200°C; and

2) processes involving the firing of kilns, melting of metals, heat treatment, etc. where temperatures generally in excess of 1,000°C are necessary.

These industrial needs must be considered from two viewpoints, viz.,

a) the present process technologies and spectrum of products,
b) new processes and products.

In the case of a), nuclear plant which may be regarded as having been developed and available could meet the technical needs of the low temperature category 1) above. In general these are the AGR, PWR, BWR and SGHWR. The needs of category 2), however, require further development of nuclear technology or alternatively the linking together of nuclear and fossil sources to "top-up" the quality of energy from the nuclear source.

In the case of b) such activities as coal gasification and liquefaction and hydrogen production can be envisaged. In addition to the requirements to develop suitable nuclear heat sources, the technology of the production processes themselves require development, and work would also be needed to develop the interface between the reactor and process sides.

These considerations suggest that nuclear energy could be expected to penetrate the industrial field initially by meeting the low temperature requirements with existing proven concepts and, on a larger timescale, begin to meet the higher temperature required. The rate of penetration would be determined, in large measure, by the cost of the development work and the resultant process as mentioned above. Few reliable cost estimates yet exist.

If it were nevertheless assumed that nuclear energy could eventually meet the whole of the present needs of the above industrial sectors at an annual load factor of say 0.8, the aggregate capacity required would be about 65 GW(H) distributed as follows:

	MW(H) aggregate	MW(H) average establishment
Engineering	12,300	1-2
Food, drink, tobacco	7,600	0.1
Chemicals	13,300	10
Textiles	4,900	0.3
Paper and printing	5,600	15
Bricks, tiles, etc.	3,000	3
China, glass	2,600	3
Cement	4,100	70
Others	11,700	-
TOTAL	65,100	

If we made some further broad assumptions on life of plant and growth of demand the annual requirement would be some 4-6 GW(H) as a maximum. Such a requirement would in fact not be much less than the anticipated annual nuclear capacity for electricity consumption.

If, however, the distribution of energy consumption within a sector is considered the second column above may be derived. This indicates the average consumption by establishments and it is evident that the application of nuclear energy "in house" in industry would involve very small units. Such average figures obviously conceal wide variations but available evidence indicates that there are probably fewer than ten establishments with demands in excess of 200 MW(H) in the UK.

This difficulty has led in the past to consideration of nuclear/industrial complexes where it is envisaged that industry would be located near nuclear plants to provide the necessary demand. Industry however selects its location for a number of reasons, i.e. raw material, supply, labour demand, market considerations, etc. and such a proposal involves major infrastructural changes.

Consideration would therefore be given to the concept of a localised "thermal utility" in which steam, generated at a nuclear source, is distributed by pipe line to a number of industrial establishments. A one metre pipe can transport some 300 MW(H) with a heat transfer oil, 700 MW(H) with hot water and more than 1,000 MW(H) with steam at SGHWR conditions. The information available suggests that the technology exists to transport steam of BWR/SGHWR conditions, i.e. pipe manufacture, accommodation of expansion, traps and valves and that thermal losses can be limited to low levels with practical insulation thickness. A current U.K.A.E.A.-sponsored study is examining this concept for distances up to 20 km or so. This study may be extended to higher steam qualities where the consumer may elect to generate electricity in back pressure or condensing plant in addition to meeting his process steam needs.

For the new process applications, work is currently in hand to establish overall energy balances for the large number of potential processes and the quality of energy required.

A major problem in studying industrial energy requirements is the paucity of statistical information. The Federal German Government proposal to derive an energy atlas is an approach which deserves wider consideration.

Nuclear steelmaking

Of the heat used by industry reference has been made above to the high proportion that is consumed by the iron and steel sector, where the units could be of sufficient size to justify consideration of nuclear heat application to single production sites. Apprehensions regarding the price and availability of coking coal in the long-term increase the apparent attractions of a nuclear steelmaking route.

Activity to assess and optimise the possibilities of this application of nuclear heat has intensified over the last four years. The European Nuclear Steelmaking Club was initiated in 1973 and has already reported on studies on energy consumption patterns in steelmaking processes, and on reducing gas production options, and embarked on further studies. Feasibility studies have been arranged by the German Iron and Steel Institute, and a Task Force on Nuclear Energy in

Steelmaking has been set up by the American Iron & Steel Institute. In Japan, the Research Association for Nuclear Steelmaking Engineering is conducting a six-year development programme.

The analyses of the first working party of ENSEC indicated that the blast furnace/oxygen steelmaking route could acquire up to 80% of its total energy requirement from nuclear sources. Processes based upon direct reduction followed by electric arc steelmaking could draw almost 100% of their energy requirements from a high temperature reactor integrated with the gas-making plant. However, a steelmaking complex has to operate at a high availability level, and the decision was made by ENSEC at its first general meeting in November last year that if nuclear heat is to be based on integration of the nuclear and steelmaking stages, the additional nuclear role then becomes one of ensuring availability of reducing agent.

Introduction of a nuclear contribution to steelmaking must essentially be a long-term proposition and at best a demonstration plant is unlikely to be in operation before the mid- to late-1980's. If all the problems of scale, plant availability, materials and reactor performance can be overcome and the economics of the route demonstrated on this timescale, it has been estimated that in the early years of the 21st century the cumulative potential UK market for nuclear plant for the production of reducing gases will be about equivalent to one year's installation of nuclear plant for electricity generation at that time.

Nuclear desalination

Following the example of oil-fired generating/distillation plants producing electricity and desalinated water, hopes ran high in the 1960's for nuclear-powered plants to do the same. Until recently these hopes have remained unfulfilled. No nuclear powered desalination plant has been constructed outside Russia.

The reasons for this are complex:

1) Only sizeable affluent industrial/urban communities need large quantities of water.
2) Only those living in coastal areas with unrealiable conventional water supplies (e.g. either through climate or dependence on foreign sources) will turn to desalinated water, since even at times of low oil prices, desalinated water by the nature of the distillation process, is several times more expensive than most conventional water supplies.
3) Large developed communities do not settle in arid areas without some special attraction. Oil provided this attraction, cheap fuel for desalination plants, and surplus revenues with which to industrialise and expand desert communities. Hence, a large part of the market for desalination plant has been in oil producing states. Industrialised countries such as the U.K., with adequate rainfall but with distribution problems, were daunted not only by the cost

of desalination but also by the problem of managing a large integrated power/water system, and are finding other solutions to their distribution problems.

4) In an era of falling real oil prices, nuclear power could not compete either for electricity generation or as a source of heat for desalination. Attempts to reduce unit costs by scaling-up were self-defeating because they put the plants beyond the needs of most of the market (even in the U.S.A.).

Since then improvements, particularly in design optimisation, have been made in the efficiency both of nuclear reactor designs and of desalination plant, which have made the economics of a combined plant more attractive. Added to this, the sudden fourfold increase in oil prices has made nuclear generating stations and nuclear powered desalination plant very competitive with oil-fired plant - although the comparison with the cost of conventional water supplies has not of course improved to any useful extent.

Because they can sell their oil abroad at prices much higher than the cost of extraction, the oil producing countries have an incentive to substitute imported fuels for their own domestic purposes. There should thus be an expanding market for nuclear plant both for electricity and for desalination, and the high capital cost of these plants offers an attractive application for oil funds.

Power consuming rather than heat consuming desalination plant using high efficiency techniques like Vapour Compression Evaporation will give lowest water costs, with the added advantage of greater flexibility of siting, of design optimisation and of independent operation. To assess the possibilities, individual economic studies are needed using "shadow"prices for imported capital goods and real interest rates appropriate to each country concerned.

Nuclear propulsion

Merchant ship propulsion by nuclear means has been considered over a comparatively long period. The successful operation of the Soviet Union's ice-breaker "Lenin" brought into operation in 1959, the United States cargo and passenger ship "Savannah" in 1962, and the Federal Republic of Germany's bulk carrier "Otto Hahn" 1968, has enabled valuable prototype nuclear ship experience to be accumulated. In the context of a highly competitive industry, however, it was difficult to illustrate sufficient economic advantage to the nuclear vessel to attract ship owners. The deciding factor in the comparison is the price of bunker fuel, and with a large price rise in this commodity in late 1973, the prospects of nuclear propulsion were radically altered.

A programme aimed at the construction and operation of a nuclear lead ship could realistically hope to have the ship in commercial operation in about 7 years. The price and availability of bunker fuel in 1980-2000 therefore seems to be the main relevant factor in assessing the economic viability of the first ship, the success of which could influence the pattern of marine propulsion for quite a long time. The price of nuclear fuel, which can also be expected to rise, also affects the comparison but to a much lesser extent.

The most promising initial applications of marine nuclear propulsion on a significant scale seem to be in fast container ships and/or in large oil tankers. Comparison of the resource cost of operation of these ships when powered by nuclear means with that of conventional such container ships and tankers indicates that nuclear at present-day oil prices has a marked advantage. This conclusion seems to apply for tankers in the range 250,000-500,000 tons (16-18knots) and container ships of capacity 1800-2500 containers (~ 27 knots), even at uranium prices as high as $ 50/lb U_3O_8. Most people do not anticipate a radical fall in oil prices from today's values (although there may be some fall in real terms over the next few years, before the upward trend is resumed) so that the nuclear advantage is unlikely to be nullified. It should be stressed that this comparison is based on resource cost and a shipowner will make different assumptions, especially regarding the cash flow of the investment programme.

As well as the economic aspects, other operational features of the nuclear ship must be evaluated, e.g. siting of operational berths, maintenance yards, and refuelling facilities, insurance and legal aspects, routing, crew training, possible salvage problems, and eventual dismantling and disposal. Studies to remove the uncertainties associated with these aspects will of necessity be international in character and it is encouraging that steps in this direction have already been taken. The outcome of the evaluation of these safety and operational aspects could, of course, affect the economic comparisons referred to above.

APPENDIX D

Process Heat from Reactors

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1. Coal and the high temperature gas cooled reactor. Important factors in evolving a future energy pattern.

In view of the importance of deciding on a short, medium and long term energy policy, the highly industrialised as well as industrialising countries are at present engaged in comparing different "energy models" so as to establish their advantages and disadvantages. Different ways of producing, converting, transporting and finally distributing energy carriers on a regional as well as national basis are studied so as to decide on policy as well as strategy. In such endeavour the importance of using an optimum "mix" of fossil as well as fissile fuels becomes increasingly clear, whereby it is understood that such optimum will change with time. For short and medium term applications making the most purposeful use of indigenous as well as imported fuels is apparent in this context. The importance of blending nuclear energy into the established conventional energy pattern is definitely realised.

Such emphasis could for instance be on electricity generation (Fig.1) and transmission over long distances. An adequate number of large, highly efficient fossil and fissile fuel burning powerplants can give a multifuel capability, especially if a regional or national grid is available. However, it must be remembered that only about a quarter of the OECD powerplants for instance are polyvalent, i.e. can alternatively burn one or two different fuels in addition. Planning ahead with regard to achieving the optimum fuel mix may therefore prove difficult not least because of the long time it takes to complete such powerplants.

At present about one third of the total energy required of highly industrialised countries like the UK is provided for by electricity. Although the contribution of nuclear powerplants is still relatively small, a gradual increase in their number is foreseen in many countries which could in due course change the pattern. Whenever electricity is taken from the mains it should be remembered that about three quarters of the energy provided for by the fuel burned in the powerplant has already been wasted, making employment of such electricity where further energy losses must be expected rather uneconomical. Seeing that the difference between maximum and average efficiency of modern plants on one hand and this efficiency and the average efficiency of all plants on the other hand can be more than six percentage points each, the importance of raising this efficiency by bringing more modern powerplants into operation and by using them as far as possible at maximum efficiency becomes obvious.

Such operation can be facilitated by employing electric heating, although less economic when compared with other systems, as well as extending the usage of electricity to cover energy requirements of transport. As far as the latter application is concerned, difficulties encountered when trying to store electricity either in batteries or in the form of hydrogen makes progress rather slow. However, provided that compact light-weight batteries could be further developed to a satisfactory state, electric propulsion of road vehicles may become economic, but it has to be remembered that not all energy requirements can be met by electricity, air transport being a typical example. Therefore for this and other reasons the future usage of hydrogen not only as a fuel but also an essential for many important chemical processes, is becoming more evident.

At present nuclear heat produced in different types of reactor is mainly used for generating either saturated or superheated steam, which in turn is employed in turbogenerators for electricity production. Additional application of the steam produced say for district heating or process purposes such as desalination is possible. In view of the relatively low temperature level at which the reactors are operating, hydrogen could only be produced by electrolosis of water. Even when employing the most advanced methods, the cost of hydrogen, especially when used as a fuel would be at present prohibitive. However, this picture may change if the advantages with regard to fuel costs claimed for the fast breeder reactor are realised.

Achieving stability in energy supply is essential for further raising the standard of living on a world-wide basis. It is therefore necessary to aim for a fuel mix, where the possibility of endangering its supply is reduced to a minimum. Even if only one half of the present known coal deposits can be economically exploited by using proven mining methods, they may last for at least a century if all present-day energy demands have to be met. (Fig.2). However, it is assumed that the actual deposits may be more than ten times larger than those already known. This could mean that long after deposits of crude oil and natural gas have been exhausted, even when employing improved methods of exploitation, there could still be coal available. As such coal is indigenous to most industrialised as well as industrialising countries, using it on an increased scale seems to be worthwhile considering, especially if in addition and possibly in combination, nuclear fuels can be employed. Such fuel strategy could in all probability be continued until the time when other sources of energy (e.g. solar) can gradually affect the energy pattern.

Gaseous fuels burn with the highest efficiency, leading to minimum demand of energy as well as minimum air pollution. Short necessary residence time for the fuel in the combustion space allows high volumetric rating, thus compactness with all its consequential advantages. High thermal loading is facilitated by the use of modern engineering ceramics.

Proven processes for the gasification of coal are known. Their further development, partly already in a pilot stage is proceeding. During such gasification, agents contributing to air pollution can be removed to a large extent. The calorific value of the gas produced can be increased considerably by hydrogenation, the result is a synthetic gas very similar in property to that of natural gas. The hydrogen required can in turn be produced either by reforming say such gases or splitting water, either thermochemically or thermally. An important characteristic affecting economy is the high temperature level at which such processes have to be operated. Under normal circumstances the heat required to perform such gasification is derived from the coal itself. If however nuclear heat is employed, then the investment of coal can be almost halved. By doing so coal reserves can be stretched, and at the same time pollution of the atmosphere further reduced.

It is anticipated that in raising the operating temperature of the HTR, nuclear energy can be employed for such a purpose. Other advantages of the HTR have already been highlighted. Possibility of using both uranium as well as thorium, of thermal as well as fast breeding, of simplification as well as improvement in efficiency by using a single closed gas turbine cycle, especially when the development to a higher temperature level succeeds, have been mentioned in this context. It has also been pointed out that the technology developed could find further application if fusion becomes a reality in the future. Furthermore, advantages when converting heat directly into electricity have been underlined.

Thus, as an alternative, emphasis could be on gaseous fuels transported in a network of pipelines to the centres of usage. (Fig.1). Such transport being less energy consuming than that of electricity. When supply of natural gas starts to decline, synthetic gas could gradually subsidise it. If in the final stage of such development hydrogen only has to be used, appropriate adjustment to the pipelines would be required. Such gaseous fuels can be employed for domestic and industrial heating. The usage of very compact light-weight ceramic space heaters could lead to a considerable increase in their efficiency, especially if they are combined with a waste heat recovering heat exchanger of a similar type. Reduction in air pollution is another important advantage. Univalent powerplants burning either oil or coal can be converted to gaseous fuels without undue difficulty. However such conversion does not lead to a powerplant making the best use of the advantageous properties of gaseous fuels. They are a "natural" for gas turbines capable of further improvement in their efficiency by raising their maximum operating temperature. Very high temperatures could be achieved if ceramic engineering materials are employed. Combining such gas turbines with waste heat recovering steam turbines can raise the efficiency of the combined powerplants by up to ten percentage points when compared with present-day powerplants using solely steam turbines. Combined gas/steam turbine plants could in due course consist of standardised modules produced in workshops thus reducing considerably construction time as well as improving availability and reliability.

In the transport sector a gradual switching from present-day liquid fuels to those produced say by liquifaction of gaseous fuels and finally to those derived from hydrogen, as for instance methanol, could be envisaged.

Decisive for the choice of an energy pattern, which could be an optimised combination of the two patterns mentioned, must be amongst others reduction in waste in energy and resources as well as of pollution of environment. In the former endeavour widened outlook comparing total energy output with total energy input must affect economic considerations. In the latter, emphasis on either economic or ecological advantages could affect decision making. In this connection, and as far as nuclear energy is concerned, minimising inherent risks by further advancing technology so as to make it acceptable to the public may be affected by the desire for high living standards.

Raising further standards, may they be related to reactors or their fuel and waste management, will demand more, expensive research and development. Thus expanding the use of nuclear energy into industrial activities other than electricity generation has to be carefully planned so as to minimise costs as well as time taken. In all these development trends a safer and at the same time more extensive use of nuclear energy will require international collaboration. Although the need for such collaboration is obvious, achieving it on the basis of an agreed international operation backed by an adequate organisation will not prove easy. However, the first and foremost requirement for success will be a specific development aim from which the necessary research and development requirements will arise.

It seems important that as early as possible a selective method can be employed so as to reduce the number of development alternatives to a minimum. The step from a pilot to a commercial plant stage, especially in view of the large amount of heat which has to be generated in a nuclear reactor so as to become economical, will prove both money as well as time consuming. Reaching as soon as possible a state where such selection can be made is therefore imperitive.

There are basically three approaches feasible when deciding on the development route of process plants employing nuclear heat:

1. Integration of all three processes, nuclear heat generation, production of hydrogen and its employment in say gaseous fuel conversion of coal in one plant.
2. Separation of the nuclear process from the non-nuclear processes resulting in two plants in close proximity so as to minimise temperature and pressure losses of the helium linking these plants.
3. Separation of all processes whereby the nuclear and the hydrogen plant would have to be next to each other because of the above reason, although the third plant linked with the latter by piped hydrogen could be situated wherever convenient. In this case hydrogen could also be used by those industries needing it, but not in quantities large enough to justify a nuclear plant for sole use.

It seems on reflection that plant arrangements which permit a separation of the nuclear from the non nuclear part of the process plant are at present preferred. In this case not only development time, but costs can be minimised. The different separate plants concerned can be developed in parallel applying the kind of technology required and in part at least already established. Initial operational risks can also be reduced by separating the nuclear part of the plant from the rest. Furthermore, especially when a gaseous fuel such as hydrogen is used as the link there seems to be a greater versatility, an extension of application.

If the employment of separate plants for each of the three processes is acceptable, then the following development programme could be envisaged.

1. <u>Nuclear heat generating plant.</u>

Such plant will consist of an HTR core, heat exchangers to transfer the heat from the contaminated helium to the heat transporting gas preferably helium as well, and the gas circulation system.

Important development goals will be to increase the temperature capability of the core from 800 to 1000°C. To facilitate an early start of the development, the possibility of using initially additional electric or gas heating to increase the temperature of the helium until such time when it finally can be heated in the core only to its ultimate temperature is contemplated. Furthermore, a reliable heat exchanger operating at such high temperatures has to be provided for. This means producing a compact design minimising heat losses as well as accommodating in the plant the core, the heat exchangers and the circulation system in a useful manner.

To a large degree the development aims of both the core as well as the heat exchangers are closely linked with the application of advanced ceramic engineering materials.

2. <u>Hydrogen generating plant.</u>

A great deal of development work has already been undertaken, especially with regard to finding suitable thermochemical processes. A large number of such processes seem to exist, demanding different temperature levels for their operation. In all these processes the final product is hydrogen and oxygen. Although the main aim is to produce the former, finding a suitable usage of the latter in a way which improves economy is an important development goal as well.

The thermochemical processes employ chemicals of different kinds. Again application of ceramic materials may be asked for as many of such materials can resist corrosion at even high temperature levels.

3. <u>Actual process plant.</u>

Many processes can benefit from nuclear heat. Apart from fuelmaking as already mentioned, steelmaking but also smelting, chemistry of basic materials and others come into the picture in this context. Especially in view of the energy situation there is a continuous trend of development mainly towards reducing energy required as well as resources. It may well be that the possibility of employing nuclear heat will accentuate such trends, as a matter of fact there are already signs of increased activities, some of them having reached pilot plant stage, whereby apart from reliability and availability, improvements in process efficiency is one important goal.

Although each of the three developments mentioned is necessary so as to realise a process plant employing nuclear heat, the development of the part producing this heat is essential. When assessing requirements concerning research and development but also design and production aspects, the overwhelming importance of developing a ceramic engineering capability becomes obvious.

Operation of the gas cooled reactor in question demands materials, being reliable over extended periods under very high temperatures and pressures, as well as suffering no adverse effects due to the attack from the heat transporting gas helium, with which the structures are in contact. The essential parts of the nuclear heat producing system are heat exchangers which have to be developed to high efficiencies as well as reduction in size in order to ascertain economy.

The usefulness of metals decreases as operating temperature increases. Thus, with the high temperatures being demanded, the use of metals must come to an end, particularly if - as in the case of heat exchangers - artificial cooling of most of their structure is out of the question, hence metals have to be replaced by ceramics, and it seems of great importance that such ceramics are not only indigenous to, but also available in large quantities in industrialised countries. Most of the ceramics have the additional advantage that investment in energy to produce them is considerably lower than that for high temperature metals. (Table 1) Such advantage has a favourable effect on cost.

2. Non metallic materials and reactor core development.

It has been stated that the core of the HTR is a particular type of non metallic heat exchanger. The materials used are, apart from graphite, oxides, carbides and nitrides of the fuel as well as of silicon. These materials can stand up to 1600°C in a non oxidising atmosphere such as helium.

On one side of the matrix, i.e. the heat exchanging part, the fuel provides the "heating medium", on the other the helium absorbs the heat released by this fuel. This matrix may consist of stationary, hexagonally shaped graphite elements penetrated by suitably arranged circular fuel and flow channels (Fig.3). The fuel oxide - carbide or - nitride, is used in the form of a multitude of very small particles surrounded by graphite as well as silicon carbide shells. The matrix can also be made up from mobile spherical elements with such coated fuel particles suitably dispersed in the graphite. Such elements being randomly arranged in the form of a pebble bed.

Consistency of quality, matching the different properties of the ceramics employed, as well as dimensions to ensure safe operation under very high temperatures (and internal pressures) is an important development trend. Improvement in graphite properties by further advancing methods of forming, baking and impregnating as well as graphitising during the processing of low ash petroleum cokes, binders and resin materials and reduction of porosity are other development aims.

3. Compact ceramic helium to helium heat exchangers.

(a) Operational considerations.

Adhering to the principles of maintaining small pressure differentials between the two heat exchanging gases facilitates the design as well as the operation of the heat exchangers at the high temperatures required. In the case of such a pressure balance it seems possible to consider not only the recuperative (heat exchange performed continuously by conducting heat through the material separating the heat exchanging gases) but also the regenerative (heat exchange performed periodically due to charging and discharging of heat by the material surrounded by the heat exchanging gases) mode of heat exchange as well. Such considerations must be favourably affected by the relaxation in the performance required from the seals separating the gases at similar pressure. However, the carry over of the contaminated into the non contaminated gas must be prevented by a suitable system of scavenging.

b) Ceramic Material Considerations.

Silicon carbide is one of the best known carbide ceramics. In recent years it has been recognised as a leading candidate for advanced technology, and it has already made inroads into some areas of general engineering application.

Of all the known ceramics silicon nitride has probably the most favourable engineering properties. It has a high strength, its value depending on the manufacturing process adopted. It is excellent as far as corrosion resistance at high temperatures is concerned, and exhibits a superior thermal shock resistance when compared with most other ceramics.

Recent work in the field of nitrogen ceramics has led to the development of sialones, i.e. silicon - aluminium - oxygen - nitrogen compounds. These materials seem to have attractive properties which are still being evaluated.

Engineering components (Fig.4) can be produced from these advanced ceramic materials by a number of fabrication routes which have received much attention in recent years. The engineering properties of these ceramics, such as their strength, their impermeability are somewhat dependent upon density, and it is therefore desirable to achieve its maximum value. Thus there is a constant search for new processing techniques which could meet this requirement.

c) General Design Considerations.

Designing with ceramics requires a different approach than when designing with metals. Most designers due to their education and training are "metal minded" and as the use of ceramics spreads, design methods may have to change. Great strides have been made in evolving such methods.

The size as well as the shape of the helium to helium heat exchangers affect possibilities of location as well as ways and means of support. Size, location and support in turn affects containment as well as costs.

The size of the matrix, i.e. the heat exchanging and thus by far largest part, depends on the area and length of flow paths for the heat exchanging gases and the volume of walls separating them, say in the case of a recuperator. The flow path area is inversely proportional, the flow path length is proportional to the operating pressure. As this pressure is very high, emphasis must be on reducing the length of the flow path. This affects the choice of the type of matrix considerably.

Adopting the regenerative mode of heat exchange offers the advantage of a wider choice. The rotary type of regenerative heat exchanger (Fig.5) can in addition lead to a simple space saving duct and header system, important where high temperature operation is required. As a result, some attractive solutions to the problem of designing a compact heat exchanger suited to work in conjunction with the core of an HTR can be envisaged. On the other hand, in the case of such a regenerative heat exchanger, the provision for the rotor drive can add to the problem of containment.

For ducting as well as insulating purposes the non metallic materials which can also be produced in the form of foams could play an important role.

c) Historical Technological Development.

At an early stage the UK took the initiative to develop advanced ceramic engineering materials. These materials are not only important for the core of the HTR, but their application is also the key to the successful employment of nuclear heat for essential industrial processes. Studies relating to direct conversion of heat into electricity were undertaken by the Central Electricity Generating Board, the National Coal Board, International Research Development Company, and industry. For direct conversion, heat exchangers are required which have to operate at temperatures as high as 1600°C. It was therefore imperitive to investigate the possibility of using ceramic materials. Thus an extensive study concerning the behaviour of most of the known ceramics as well as ways and means for their application was mounted. Tests were undertaken for 1000 hours duration under the expected operational conditions (Fig.6) Based on such tests, design studies, extensive if their exploratory nature is taken into account, led to the establishment of at least a basic knowledge as far as large, recuperative and regenerative ceramic heat exchangers are concerned.

The experience gained in these studies has proved valuable in connection with the development of advanced ceramic materials for a number of engineering applications (Fig.7), important to energy conversion such as further development of piston engines as well as gas turbines. Under the auspices of the National Research and Development Corporation and the Atomic Energy Research Establishment in Harwell, industry in the UK is involved in the development of compact, recuperative and regenerative ceramic heat exchangers similar in design if not in size to the proposed helium to helium heat exchanger in question. To avoid duplication of effort, to reduce outlay, it may prove advantageous to extend development to include such nuclear applications, especially as some international collaboration is already progressing. The USA and the Federal German Republic are already supporting industry in the advancement of the ceramic material technology.

TABLE 1.

COMPARISON OF THE AVAILABILITY OF HIGH TEMPERATURE ALLOYS AND SILICON NITRIDE AS WELL AS COUNTRIES OF ORIGIN AND ENERGY INVESTMENT

ELEMENT	[x] CRUSTAL ABUNDANCE WT %	SOURCE	ELEMENT CONCENTRATION IN SOURCE WT %	COUNTRIES OF SOURCE ORIGIN (ORE)	WEIGHT PERCENTAGE	ENERGY INVESTMENT kWh(th)/kg
Ni	0.01	PENTLANDITE	1	ALBANIA, CANADA, CELEBES, CUBA, GREECE, GUATEMALA, NEW CALEDONIA, SOUTH AFRICA. USA, USSR.	53	38
Cr	0.02	CHROMITE	35	ALBANIA, PHILIPINES, RHODESIA, SOUTH-AFRICA, TURKEY, USSR, YUGOSLAVIA.	20	40
Co	0.003	CHALCOCITE PENTLANDITE	1	CANADA (ass with Ni) ZAIRE (ass with Cu)	18	24
Ti	0.44	RUTILE ILMENITE	59 19	AUSTRALIA, CANADA, FINLAND, GAMBIA, INDIA, JAPAN, MALAYA, NORWAY, SIERRA LEONE, SPAIN, SOUTH AFRICA, USA, USSR,	2	154
Al	8.10	BAUXITE (CRYOLITE)	26	AUSTRALIA, BRAZIL, FRANCE, GUIANAS, GUINEA, GREECE, GHANA, ITALY, INDONESIA, MALAYSIA, SPAIN, YUGOSLAVIA, USA, USSR.	1.5	64
ALLOY					100	36

Si		QUARTZ SANDSTONE	45	WORLD WIDE	60	18
N	80	AIR	80	WORLD WIDE	40	0.7
SILICON NITRIDE					100	18.7

[x] NOTE. WEIGHT OF CRUST = 2.4×10^{19} tons

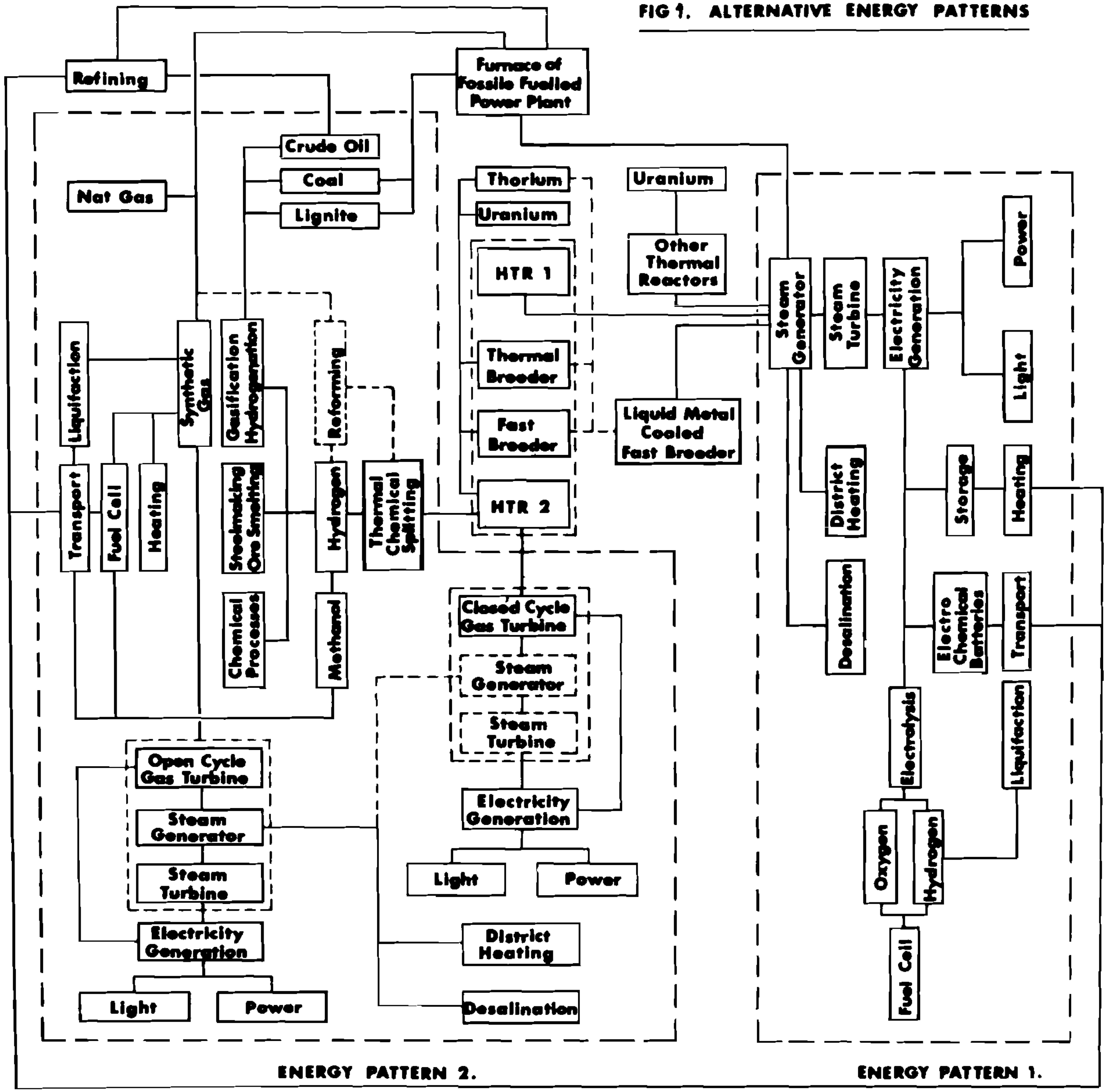
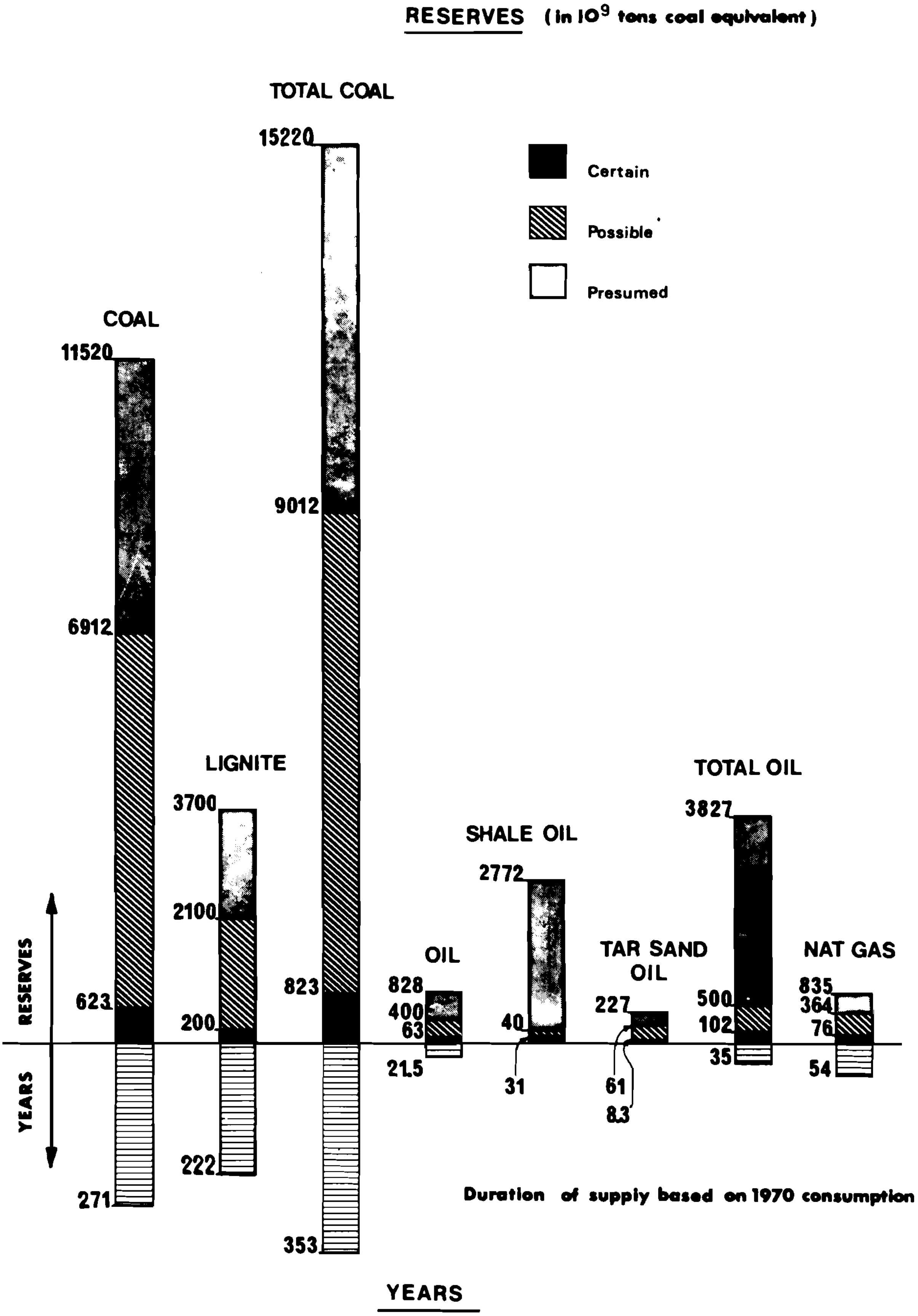


FIG 1. ALTERNATIVE ENERGY PATTERNS

FIG 2. RESERVES OF FOSSIL FUELS



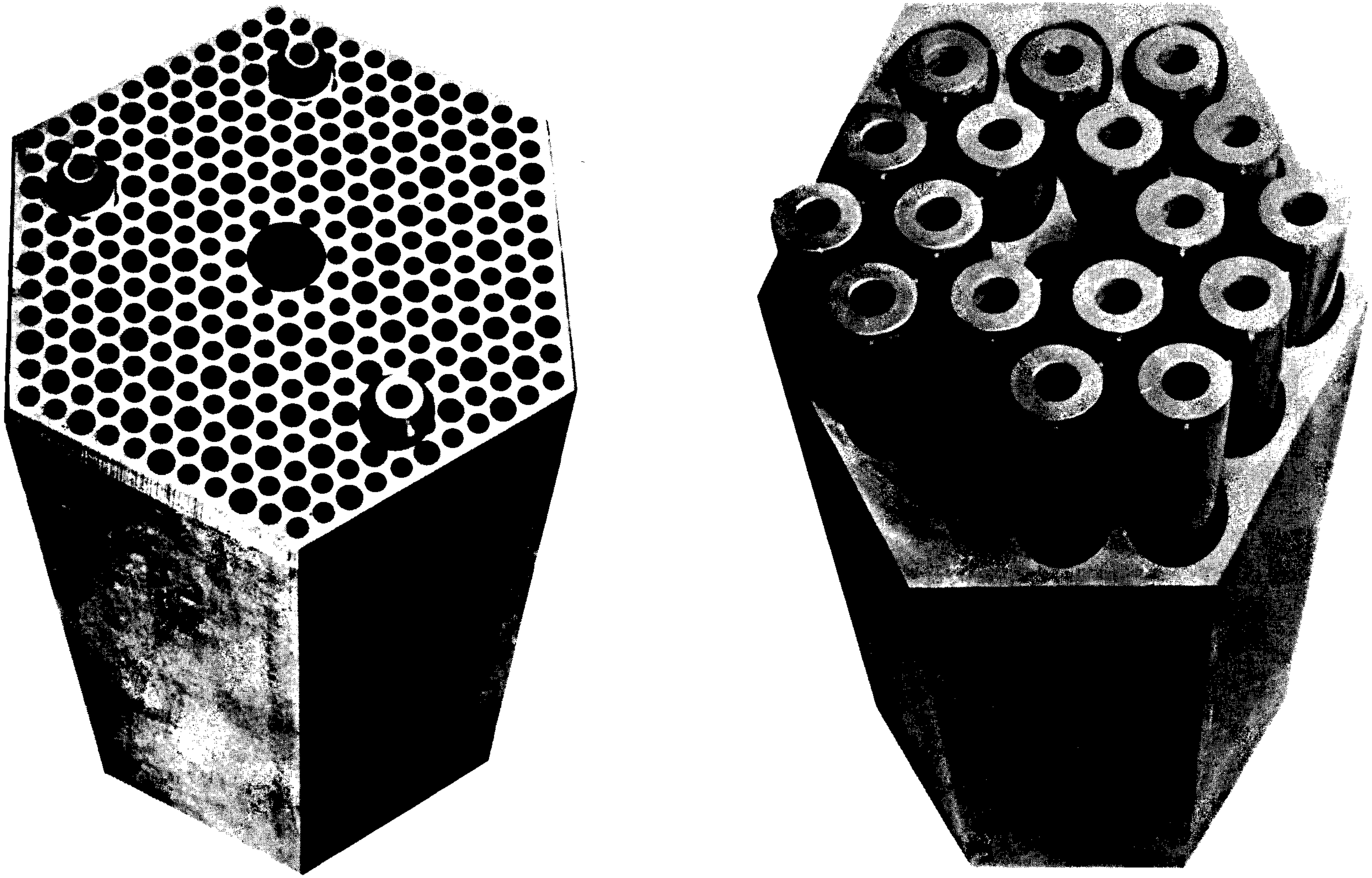


FIG.3 INTEGRAL FUEL MODERATOR BLOCK FOR HTR CORE

SEPARATE FUEL PIN AND MODERATOR BLOCK FOR HTR CORE.

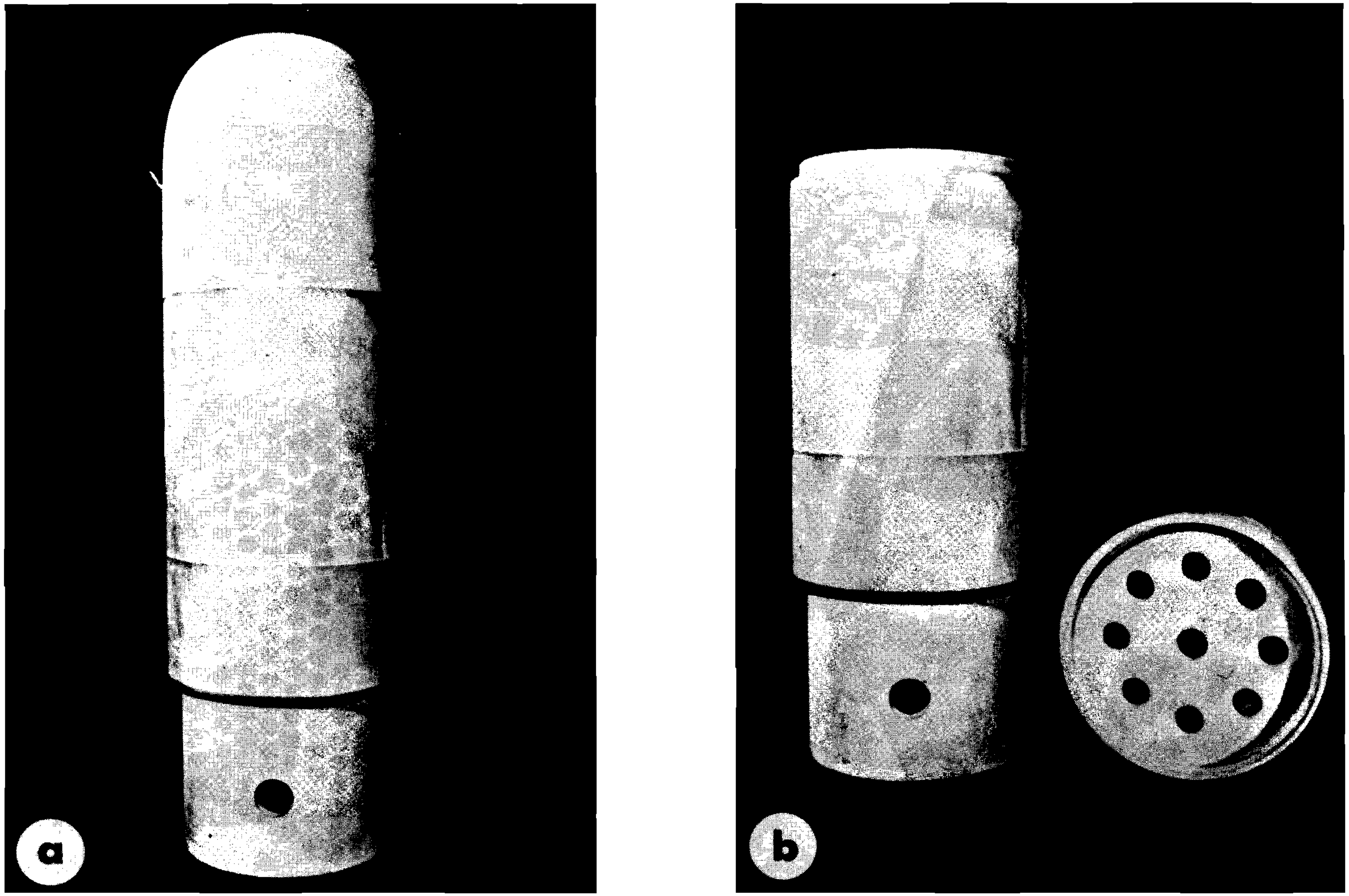
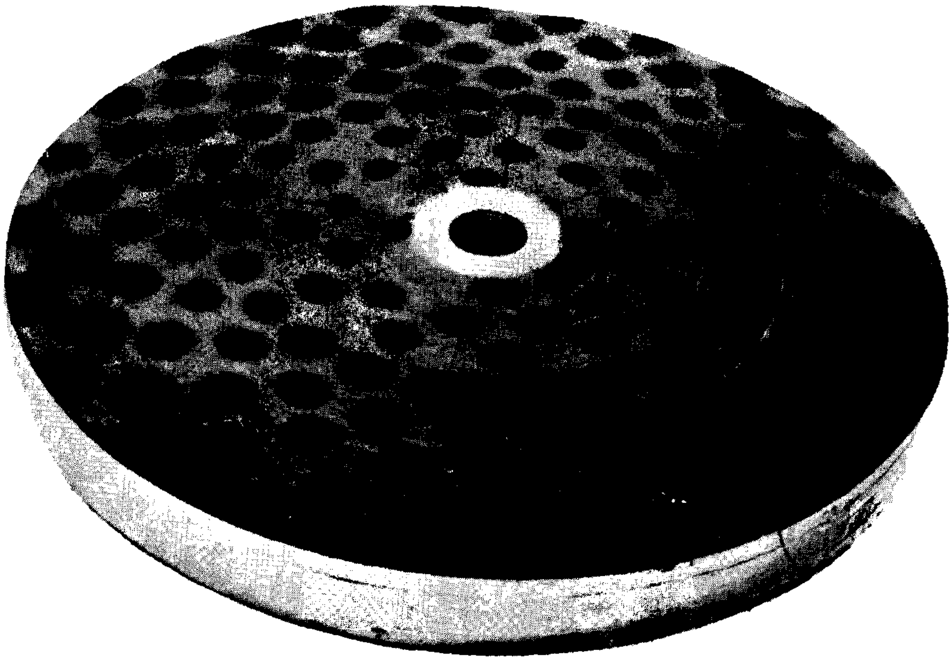
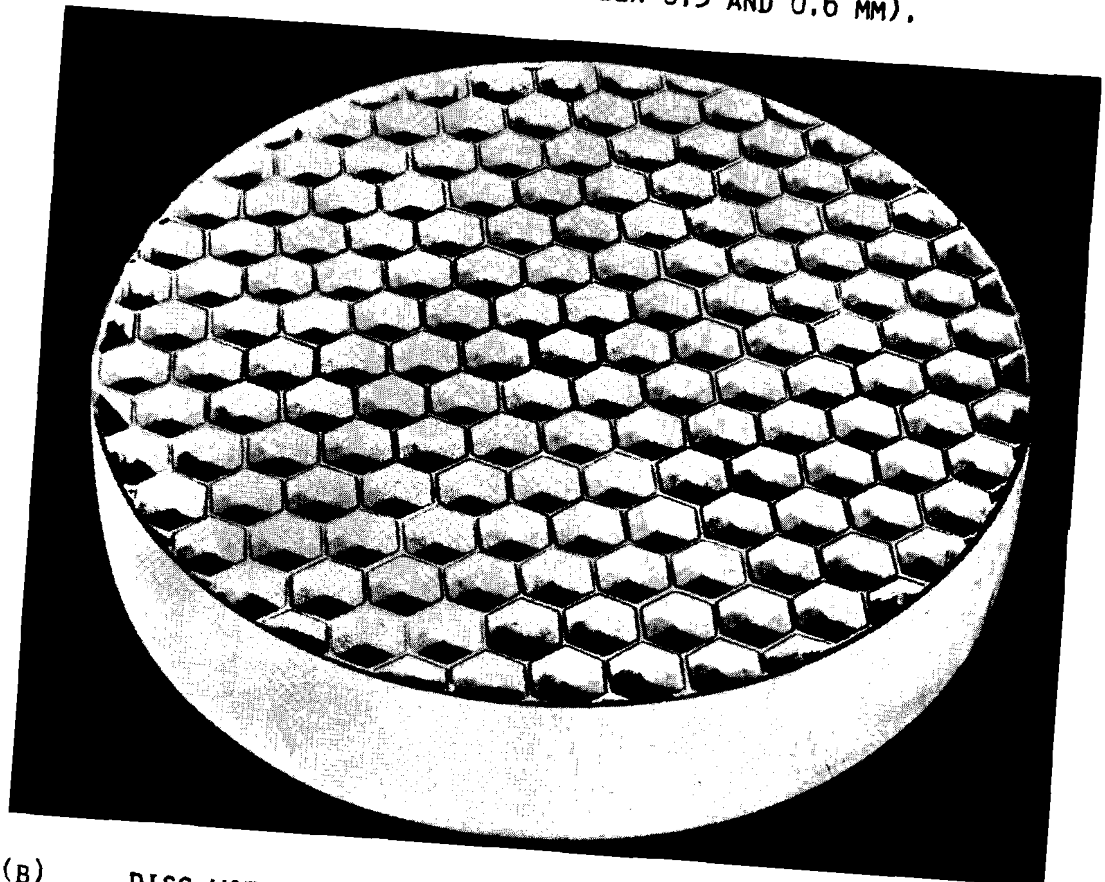


FIG. 4 PARTS FOR A REFORMER MADE FROM SILICON NITRIDE (STATE AFTER NITRIDING)

FIG. 5



(A) DISC WITH AN INTEGRAL PLATE TYPE MATRIC HAVING A SMALL EQUIVALENT DIAMETER (BETWEEN 0.5 AND 0.6 MM).



(B) DISC WITH AN INTEGRAL HEXAGONAL GRID WHICH CAN BE FILLED WITH DIFFERENT TYPES OF MATRICES SUCH AS THE FOAM TYPE.

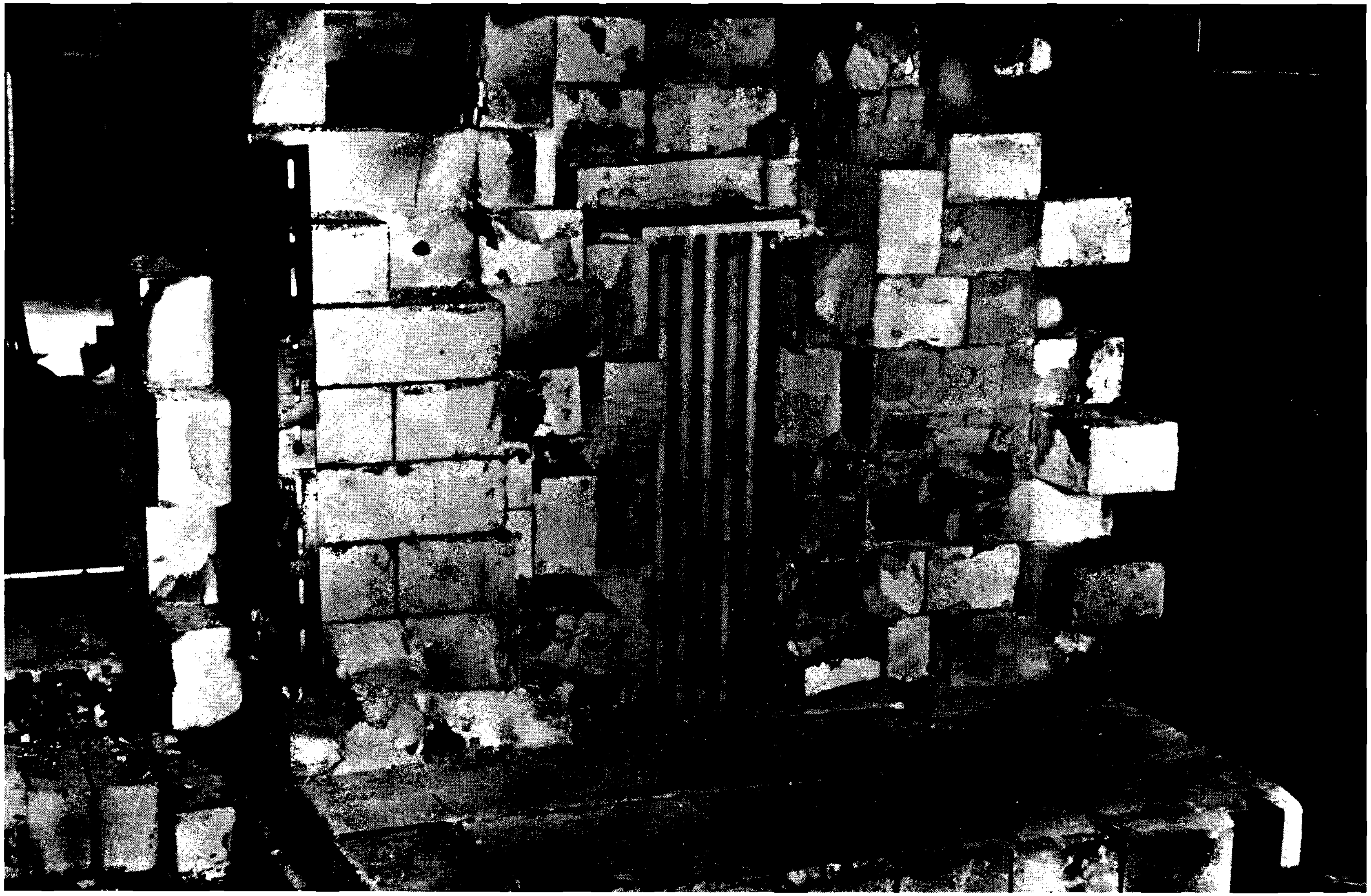
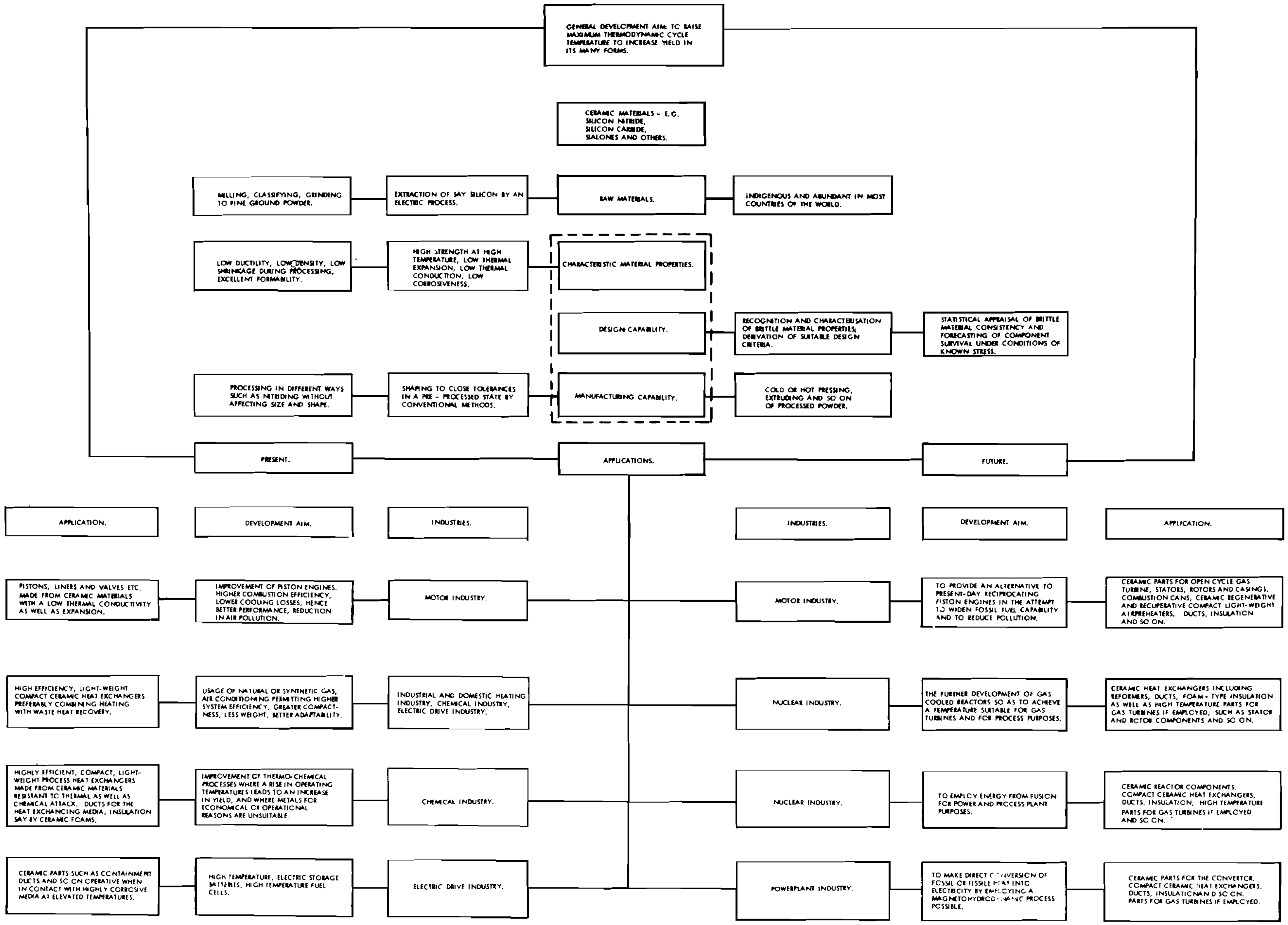


FIG. 6 HIGH TEMPERATURE TUBULAR MATRIX IN TEST POSITION.

FIG 7 ENGINEERING APPLICATIONS OF CERAMIC MATERIALS



APPENDIX E

District Heat from Nuclear Power Plants - Adjusting to Customer Needs?*

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Due to a long term shortage of the energy sources oil and natural gas, as well as to economic reasons (possible price rises, particularly of the fossil energy sources), rational use of energy is gaining increasing importance. With regard to power plants, this means a more comprehensive use of waste heat, particularly relevant to district heating of private and public households and for industrial purposes. This also applies to the future use of waste heat from nuclear power plants, perhaps to an ever greater extent for other reasons than those given above. The FRG is one of the most intensely used areas in the world: both with regard to population density and to industrial and agricultural use, this country ranks among the first together with Belgium, the Netherlands and Japan. On the average, all the other important industrialised countries are less intensely used, sometimes to a considerable extent, such as the US, which is used to a lesser degree by a factor of fifteen. Therefore and

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*Translation from the original German version "Fernwärme aus Kernkraftwerken - eine marktgerechte Forderung ?"

also in the light of the planned additional nuclear installation programs, the FRG will have the highest energy density in the world besides Japan. The energy program of the government of the Federal Republic of Germany projects power generation from nuclear reactors of approximately 50 000 MW for 1985 - 1988. Forecasts for 1995 - 2000 estimate a production of about 100 000 MW, which, according to the present siting policy, would necessitate about 50 nuclear power plant sites with one, two, three and four units. This means that the FRG will, on the average, have one nuclear power plant every 70 km by the end of the 1990's. Furthermore this implies [1] that in our small country approximately 3000 tons of heavy metal would have to be reprocessed annually and that vast amounts of radioactive material would have to be transported. For 100 000 MW the annual amounts to be transported have been estimated as follows: 5800 tons of spent fuel elements (80% LWR, 20% HTR), about 325 tons of fission products, about 790 tons of cladding material, and about 15000 tons of operational wastes from nuclear power plants and reprocessing plants. These high figures do not only point out the general significance of energy saving, but also show clearly that nuclear energy has to be used in an optimal way and that the planning of "unnecessary" nuclear power plants must be avoided.

Table 1 shows the waste heat capacity and the waste heat energy of the nuclear power plants calculated for given full load operation hours.

Table 1: Installed capacity, waste heat capacity and waste heat energy used of the nuclear power plants

Installed capacity	waste heat capacity		waste heat energy used		Mio tSKE*
GW	GW	Tcal/h	1500 h/a	3000 h/a	6000 h/a
50	100	86	19	38	76
100	190	163	36	72	144

The question arises as to whether these amounts could be employed in the Federal Republic of Germany through the use of district heating. On the one hand this is a question of the market structure, on the other hand it is a question of the distances of nuclear power plants from the district heating markets.

The market structure is characterised by the type of customers as well as by the customer density. The market for low-temperature heat up to about 200°C, is divided into two spheres: room heating and hot water supply for households and small scale users, and process heat for industrial purposes. The temperature range for room heating and hot water supply lies between about 70°C and 110°C, that of process heat between 100°C and 200°C.

As to households, the only potential customers of district heating are collectively heated flats in multi-family houses - new and old alike provided they are restored under reorgani-

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* 1 t SKE ("coal units") $\hat{=}$ $2.73 * 10^{10}$ Watt seconds

zation schemes and/or switched over from single to collective heating. As to the customer density mentioned above, its present lower marginal value for district heating applicability lies at about 30 Gcal/km^2. This marginal value cannot be reached in low housing areas. This particularly applies to rural areas and to regions where single-family houses prevail. Such regions would not come into the scene even if the marginal value were lowered due to a possible rise in fuel prices. Thus communities with less than 20 000 inhabitants do not fall into this category since the percentage of stove-heated flats (about 61% in 1975) as well as that of single-family houses (about 75% in 1975) is very high. In 1975, communities with less than 20 000 inhabitants account for about 48% of the total housing stock of the FRG. So, if we return to the assumption that these communities can be neglected and that district heating is applicable only to collectively heated flats in multi-family houses, and if we take into account the declining heat demand in new buildings and the rising average number of full-load operative hours of 2900 h/a as a maximum, we obtain a realistic district heating potential of private households for room heating and hot water supply of 21 Tcal/h (8.85 Mio tSKE/a) for 1985, and of a maximum of 41 Tcal/h (17.1 Mio tSKE/a) for the year 2000. For the years 1985 and 2000, this corresponds to a share of 14% and almost of 26%, respectively, of the total heat demand of households to be foreseen for the years in question [2].

In the sector small scale users we assume that all public buildings and about 60% of the other small scale users are potential customers of district heating. Given the same period of use as with the households, the 1985 maximum district heating potential of this sector is 63 Tcal/h (26 Mio tSKE/a), while that for the year 2000 is 79 Tcal/h (33 Mio tSKE/a).

Thus the total district heating potential of the sector households and small scale users appears to be - at best - 84 Tcal/h (35 Mio tSKE/a) for 1985, and 120 Tcal/h (50 Mio tSKE/a) for the year 2000.

It is difficult to assess the district heating potential of process heat below 200°C for industrial purposes because of uncertainties in production forecasting and the introduction of new production methods. The following industries are relevant to the temperature range in question: the chemical, textile, synthetics, woodpulp and paper industries, as well as the production of food and luxuries. The chemical industry cannot realistically be connected to communal heating systems because of the high degree of operation reliability required, because of the plant internal intereactions and because of the high percentages of self-produced and/or utilized waste heat energy. As to the other industries, there are certain restrictions on account of their seasonal fluctuations (e.g. the sugar industry).In view of these aspects, and given an assumed average period of use of the maximum load of 4950 h, we may predict a district heating potential for industrial purposes of 11 Tcal/h (7.7 Mio tSKE/a) for 1985, and a potential of 14 Tcal/h (9.6 Mio tSKE/a) for the year 2000 [2].

In all, the maximum district heating potential calculated for 1985 amounts to 95 Tcal/h (42.7 Mio tSKE/a), while for the year 2000 it would be 134 Tcal/h (59.6 Mio tSKE/a). For 1985, this corresponds to about 27%, and for 2000, to about 32%, of the total demand for heat below 200°C.(Fig.1)

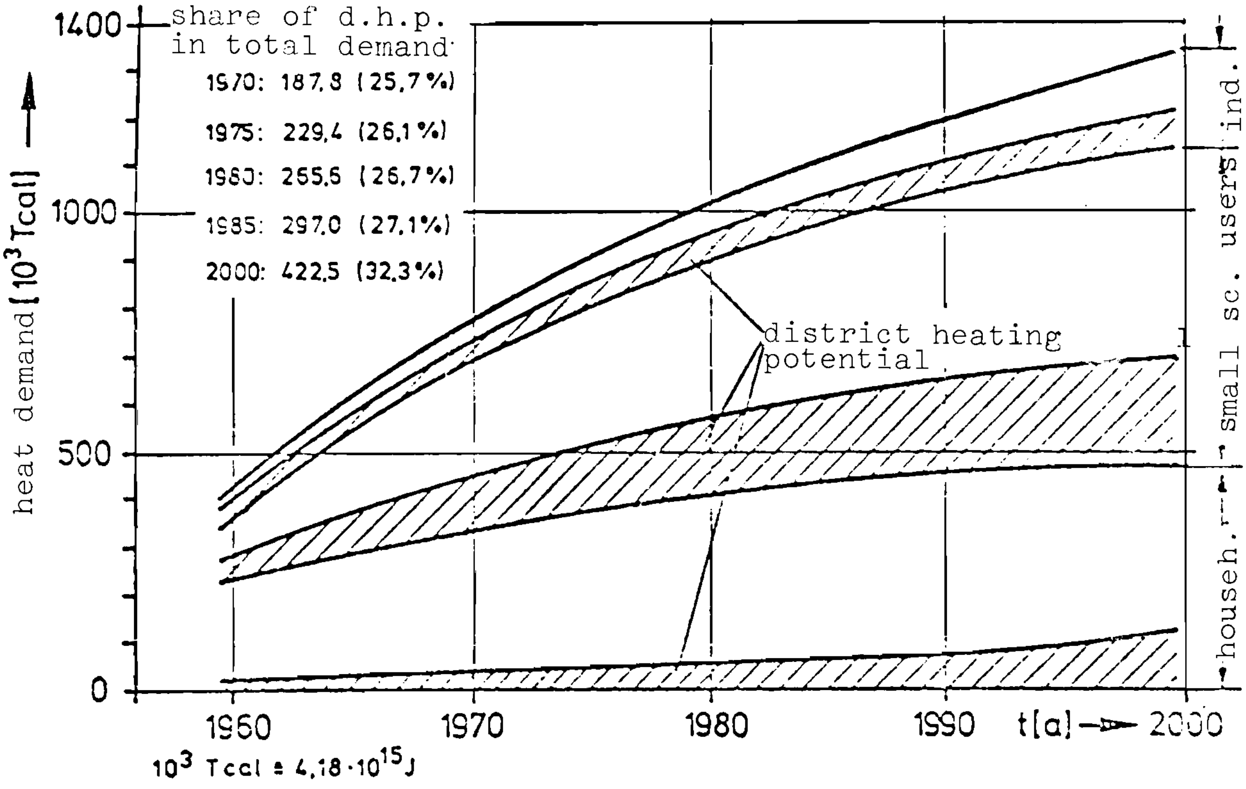

Fig. 1: heat demand forecasts and district heating potential for room heating and hot water supply in the sector households and small scale users and for process heat below 200°C in industry (without the chemical ind.)

The heat demand outlined above is subject to seasonal and daytime fluctuations. The so-called ordered annual demand line broadly reflects these fluctuations.

The real customer potential will be smaller than the calculated district heating potential since in many cases energy supply systems connected to a network have already been installed.

As to the question of sites for future nuclear power plants with regard to the regional distribution of potential district heating customers, the following can be said: as mentioned above, about 48% of the flats in the FRG - and this percentage is similar to that of the population - are to be found in communities with less than 20 000 inhabitants where district heating is not considered applicable. Of the remaining 52%, around 81%, i.e. 42% in all, are in the so-called conurbations, which account for only 6.3% of the total area of the Federal Republic [3]. The Federal Republic of Germany has, in all, 24 areas which are defined as conurbations, plus West-Berlin. In 1972 [4] the sum of the ratings for district heating in the Federal Republic, including West-Berlin, was 16.1 Tcal/h; of this percentage, only 11,8% was intended for industrial heat. The feed for that was $32 \cdot 10^3$ Tcal/a (4.5 Mio tSKE/a), the maximum thermal load was 10.5 Tcal/h, and the period of use of the maximum load was about 3000 h/a. In 1972, 86% of the sum of the ratings for district heating was to be found in the 24 conurbations mentioned above, including West-Berlin (84% without West Berlin). The remaining 14% or 16% respectively, referred to communities which, although not located in the conurbations, have clearly more than 20 000 inhabitants.

Thus district heating up to now has primarily been used in the densely populated areas of the Federal Republic; this confirms the above statements on customer density. Another application of district heating will also primarily take place in these areas only in which - as mentioned above - 42% of the population is concentrated in 6.3% of the total territory. Therefore, with regard to the use of nuclear power plants for district heating the question arises of what can be the maximum distance between the nuclear power plants and the densely populated district heating areas, for reasons of nuclear safety on the one hand, and for economic reasons on the other. An analysis [5] of the sites of nuclear power plants primarily designed for power generation which are to be expected by the middle of the 1980's and which are now being operated, built, planned or discussed, shows that of the 38 000 MW under consideration already 65% are less than 30 km from the regions with considerable demand for district heating. 42% are nearer than 20 km. Detailed studies have shown that such a distance certainly is still acceptable from an economic point of view as far as the transportation of hot water is concerned. If we apply this 42% share to the late 1990's with their 100 000 MW's - corresponding to a waste heat capacity of 163 Tcal/h - the waste heat capacity of nuclear power plants would be 68 Tcal/h for the above calculated district heating potential of 134 Tcal/h.

The initial postulate to use future nuclear power plants, if possible, as heating plants with regard to a "minimization" of nuclear technology is put on a realistic basis by the deliberations addressed in this context.

At the same time it seems to become obvious that a regional district heating network based on conurbations would be preferable compared to a supraregional network that would have to cross many regions without district heating applicability.

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APPENDIX F

Modern Technology Electrolysis for Power Application

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Introduction

There is now a very well developed literature available on this topic which does give the impression that a fair judgement of it should be possible. This is however in certain very important aspects not the case. We will try to bring out these and show that the electrolysis route to hydrogen has a very good potential not only to offer an immediately available means to start with the nuclear hydrogen production but to stay in business. It is at least an open question whether thermolysis of water will in the end be a more economical route.

Thermodynamical efficiencies

After some misunderstandings on thermodynamic definitions it is by now again clear that both thermolysis and electrolysis are theoretically constrained by the same relationship; e.g. the increase in free energy in the split product is equal to the amount of work recoverable of the heat input degraded, be it directly in a thermolysis process or in the combination of a thermoelectrical process.

A first assumption to reconsider is that the work generating efficiency by turbo-generators is constant. Development of helium driven gas turbines to exploit the temperature of gas-cooled high-temperature reactors demonstrates that the turbine-generator unit will certainly not stay restricted to comparatively low temperatures and low,constant efficiency.

Moreover, since high temperature stress corrosion and corrosion in high temperature chemical reactors are intimately related, it is at least unlikely that turbines will not climb the same temperatures as chemical reactor vessels and heat exchangers needed for thermolysis. A more realistic assumption is therefore to allow efficiencies in both cases to climb proportional to the Carnot efficiency possible with the degraded heat.

This reduces the analysis at the situation to discussion of the losses.

In electrolysis we incur the following losses:

- work extraction by heat engine generator

$$\zeta = 1 - \eta_c \cong 0.1 \div 0.2$$

- electrolyser losses $\zeta = 1 - \eta_e \cong 0.1 \div 0.4$

  ohmig resistance of electrolyte and structure,
  including d.c. - a.c. converters

- overvoltage on electrolyser cells
  concentration polarization
  activation overpotential on electrode

which gives total loss

$$\zeta_{tot} = 1-(\eta_c \cdot \eta_e) = 0.2 \div 0.5$$

These losses are very well understood.

Comparing to thermolysis we have there:

- heat exchanger losses

  $\frac{\Delta T}{T}$, of the order 0.05 per exchanger

  $$\Sigma \; 0.1 \div 0.4$$

- diffusion losses (e.g. as in coal gasification)

  $\Delta T/_T$..which for optimum process devices should have roughly the same order of magnitude as heat transfer losses (Onsager-Casimir theorem)

- material transport and product separation losses (very dependent on process, high for solid reactants)

- mismatch of thermochemical cycle to ideal Carnot cycle (could be alleviated by combining with electricity generating system. Using not used excess heat of different temperature levels)

A quite general statement is that the losses on the thermolysis route do not tend by any principle to be smaller than on the electrolysis route.

By the above discussion we tried to show that there is no ground for a statement that one or the other route to convert degradable heat into chemical energy, e.g. hydrogen by splitting water, has by principle superior potential.

So let us consider where we are now: water electrolysis is a technology that has been around for some 60 years, although developed and used for special applications only. So the application to power conversion is a new one. The use of modern technology in this field is also comparatively new and it is therefore reasonable to assume good potential for further development down the learning curve of electrolysis for large scale power applications. However, what we find in literature today is little more than extrapolations based on laboratory work, and if one does search this down to its originators it is a very restricted body of information.

It is remarkable to what a degree real development work on the electrolysis route is missing compared to the funds that are being poured into the thermolysis route. The more so if one considers that, judged from present knowledge of the electrolyser route to hydrogen, it appears to be feasible to reach the goal of deployment of large power electrolysing plants within some 5 years from now.

Of the three basic steps and technologies that comprise the electrolysis route to hydrogen two are very well mastered already on a large scale

- power extraction from heat degradable by conventional electricity generating equipment

- conversion of a.c. to d.c. power, e.g. equipment for d.c. power transmission links

The third, electrolysis of water, has been developed since some 60 years for special applications on a very limited scale. Major steps of hardware development incorporating modern materials technology lie ahead and look feasible, since the problems to be mastered are well understood.

The point we tried to make clear was not to show electrolysis to be a superior route to hydrogen but the one of two theoretically equivalent methods that has good potential to show up as combining less technological risk with a much earlier implementation date in our energy systems.

Power applications of water electrolysis

Against this background let us put together a brief analysis of the possibilities and constraints that the future development of water electrolysis for power application is likely to encounter.

The first constraint is the existence of a minimum cost-efficiency that does make hydrogen production attractive. Here quite a lot of system analysis work has been done which we do not try to reproduce here, but there may be a few points to be made.

Depending on climate there are two fossil fuel substitution models; e.g.

1) heavy space heating will result in a system of electricity, district heating by waste heat and hydrogen by daily and seasonal off-peak power,

which will result in up to 15% or more
of the total demand in the form of hydrogen.

2) minor space heating will result in an almost dual system of electricity and hydrogen only. Then hydrogen will have to be produced by dedicated plants in addition to off-peak plants.

The first case will be predominant in Europe, where incidently also the time scale of fossil fuel substitution is much more urgent than in other regions, e.g. the USA, where moreover the second case is predominant.

Calculation for the minimum cost constraint is very dependent on the substitution model, and it is easy to see why an analysis made elsewhere cannot be applied, if the breakdown of energy and heat demand by the end user differs.

If hydrogen by off-peak power may well be an important feature in Europe, a full load factor dedicated plant technology could be the answer elsewhere.

Costs

Present cost of electrolysis is another statement which needs clarification. By the figures given in the table below it is seen that the information based on laboratory work tends to be optimistic. Costs for present hardware show that still a determined effort is necessary to realise the development potential of the ageold special application technology.

1 $ = 3 SFr.

	1 MW	3 MW	100 MW
BBC-electrolysis (74)	1.3		72 Mio SFr.
Allis-Chalmers * (68)			20
Allison, Energy Depot ** (65)		10	(110)
GE *** (85)			(45)
(2000)			(15)

* based on laboratory, Costa & Grimes

** based on laboratory, project energy depot

*** based on laboratory and small scale special applic.

BBC figures prices of actual hardware

(...) with scale up factor 0.93 extrapolated to 100 MW plant size.

Yet still another point is that not necessarily all substitution energy for fossil fuels is delivered by nuclear heat, even in the immediate future there are potentials like hydroelectric power in Greenland, which appear to be of a size approaching 1 TW at bus-bar electricity costs around 3-7 mils/kWh. This in our opinion is a case where only electrolysis with its direct coupling to electric energy is applicable. It will be also the essential means that solves the problem how to collect, store and transport these huge amounts of hydroelectric energy available.

Again reference is made to the work done on energy depot for the U.S. army in the sixties. Hydrogen is made transportable either by liquefaction, which costs about 27% of the energy content, or by synthesis of ammonia, which costs some 5-8% of the original energy content. The cost estimates presently available are shown in the table below.

	100 MW plant size		
electrolyser	(110)	70%	project "energy depot"
NH_3-synthesis	(47)	30%	

In a worst case assumption, taking the NH_3-synthesis cost to stay constant at about $ 300/eb NH_3/hr, this will give with 8000 hr full load operation about 2 to 3 mils/kWh additional cost compared to about 6 mils/kWh for the liquefaction.

So even with the electrolysis hardware available at present this would result in ammonia f.o.b. Greenland at about 10 - - 14 mils/kWh, which as a rough estimate already is not way off a comparison with distilled oil products. (The present OPEC net rent is around 5-8 mils/kWh energy content.)

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APPENDIX G

On Thermochemical Watersplitting

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Fission and fusion, which appear to be the most reliable relay to the fossil fuels, generate energy in form of heat. In order to make this energy transportable and storable, and give it maximum flexibility in use, it has been proposed to transform it into two energy vectors, electricity and hydrogen.

For making electricity from heat, from almost a century of laborious invention and development market forces have selected a few variants of a simple methodology, that of producing mechanical energy with a thermomechanical cycle, to be transformed into electrical energy in an AC-Generator.

All other methods have been ruthlessly eliminated by the rules of competition, or relegated in quantitatively unimportant biological niches, or still awaiting their chance in the laboratories (see the MHD).

Hydrogen, on which the consensus of the energy community has concentrated for the second energy vector, has to be produced from water, and the methodology of its production is still an open question, as it was for electricity a century ago, and it may well take a few tens of years before selection will indicate the final winner.

We will resume here the reason why we think thermochemical (or hybrid) cycles, have the best chances of being finally victorious, even if the intermediate phases may well be better played by other concepts (Edison heartily preferred DC to AC for many good reasons. The only bad one, the absence of a static transformer, did finally prove to be the Achilles heel of DC).

What the system is demanding:

1) To decompose water into hydrogen and oxygen. In chemical terms, this problem can be stated as that of transferring free energy (58Kcal/mole) into the water molecule. Now the shortest route to transfer free energy from a high temperature heat source to a chemical system is to heat it, and use chemical reactions with separation of the products in order to impede the loss on cooling of the free energy acquired by heating the system.

2) To decompose water on an immense scale. The analysis of the hydrogen system, due to the flexibility in use, and transportability of the vector, leads to systems of continental scale, if hydrogen is gaseous, or of world scale, if hydrogen is liquid.

   The consequence of that will be the concentration of the generation in fewer and fewer points in order to reap the benefits of the economies of scale which may be huge if the technology can follow the demand for size.

   Now chemical plants appear, in the last two centuries, to have grown with demand, to sizes overshadowing all other technology in terms of materials processed, energy manipulated, mass of machinery or investment per plant and so on.

3) <u>To minimize capital investment</u>.
The problem of investments in the energy system will appear as central in western economies as soon as they will move out of the relatively cheap oil. Hydrogen will insure maximum utilization factor of this capital independently of the process used, but it must be clear that the process has to be genuinely adapted to scale up. Multiplying modularly small plants does not really help. The economies of number never won over the economies of scale.

4) <u>To be compatible with nuclear technology</u>, if possible the one already existing. This means first that the spectrum of heat vs. temperature available from a reactor matches snugly with that required from the process. Second that the interface does not require a too complex chemistry and metallurgy.

An obvious internal condition in order to activate the potential indicated in points 1-3 is that a champion process can be found, satisfying the principles of simplicity and fitness which is the key to success. Now as every trainer knows, in order to find a champion one has to have a large population base. Also this point is satisfied by thermochemical cycles, of which at least four thousand are known today and many more are possible. It is in the natural resistance of nature that the good one will be found after some effort, but it is very improbable that the good one does not exist.

Thermochemical cycles have been studied in Ispra since 1969, and perhaps in a dozen places now, in Europe, US, and Japan. The time past and the experience gained start to be sufficient for a first look at the evolutionary lines.

The first process studied in Ispra, Mark I:

1) $CaBr_2 + H_2O \xrightarrow{750^\circ} CaO + 2HBr_2$

2) $Hg + 2HBr \xrightarrow{100^\circ} HgBr_2 + H_2$

3) $HgBr_2 + CaO \xrightarrow{25^\circ} HgO + CaBr_2$

4) $HgO \xrightarrow{500^\circ} Hg + \frac{1}{2} O_2$

has the merit of being the first, and compatible with High Temperature Reactor technology, at least for what concerns the quality of the heat required. But the defects are numerous and they will be listed here in order to define desirable targets for the new processes.

a) It uses scarce and expensive elements, Hg and Br

b) It uses poisonous and environmentally objectionable elements and compounds

c) It uses very corrosive compounds for which the proper metallurgy has to be developed

d) It requires manipulation of solids which have to be separated from liquids, dried, and transferred to high temperature reactors and back

e) It is generally speaking, too complicated.

It must be clear that all points are daily bread for the chemical industry, but they have always been a hindrance to very large scale very low cost operations we are aiming at.
A lot of work has been spent in delving into the physical chemistry of Mark-1, and the first consequence of weight has been that the data for a rough design of a plant have been made available. This design has shown that in spite of the many drawbacks a process like Mark-1 may fall in the right ball park economically speaking. A very stimulating result for further searching.

The second process I will quote, in order to give a feeling for trends, is Mark-9.

1) $6FeCl_2 + 8H_2O \longrightarrow 2Fe_3O_4 + 12HCl + 2H_2$

2) $2Fe_3O_4 + 3Cl_2 + 12HCl \longrightarrow 6FeCl_3 + 6H_2O + O_2$

3) $6FeCl_3 \longrightarrow 6FeCl_2 + 3Cl_2$

The advantages of Mark-9 over Mark-1 are that:
point (a) is solved as Fe and Cl are cheap and abundant.
Points (b) and (c) are eased in the sense that a large body of experience exists in the manipulation of Cl and Fe compounds.
Point (d) is still open as lot of solids exist and this has in fact proven to be a stumbling block for kinetic reasons. This is perhaps a more important point than the problems of manipulation. Fluidized beds and fluidized transfer are reasonably efficient, but a reproducible kinetic for a solid cycled through

a chemical process thousands or million of times may be a pure dream.

Point (e) is eased by three reactions only and a lower maximum temperature.

The third process I am quoting (Jülich) has no solids, except, if necessary, as catalysts.

1) $CH_4 + H_2O \longrightarrow CO + 3H_2$

2) $CO + 2H_2 \longrightarrow CH_3OH$

3) $CH_3OH + SO_2 \longrightarrow CH_4 + SO_3$

4) $SO_3 \longrightarrow SO_2 + \frac{1}{2} O_2$

Water has not been explicitly indicated but it exists all over the process.

This process is superior to Mark-1 on all points (a) to (d). It is still a bit too complicated. Reactions tend to be incomplete with some need for separations. Reaction (3) is thermodynamically possible but its kinetics and univocity is still to be explored.

The fourth process (Los Alamos), is the quintessence of simplicity, at a cost.

1) $H_2SO_4 \xrightarrow{\text{thermal}} H_2O + SO_2 + \frac{1}{2} O_2$

2) $2H_2O + SO_2 \xrightarrow{\text{Electrolysis}} H_2SO_4 + H_2$

The step 1, thermal decomposition of sulphuric acid, is practiced in industry and it is not too difficult. It occurs gradually from about 400° to 800°C. It provides 85% of the free energy to decompose a molecule of water. The rest should come in form of electricity, through electrolytic cells which have to be developed ad hoc as the economy of the cycle requires high concentrations of H_2SO_4 for step 1.

A hydrogen acceptor with a free energy of formation at room temperature of perhaps 10kcal/mole H_2, could substitute electrolysis according to the formula

2b) $2H_2O + SO_2 + 2(Me) — H_2SO_4 + 2(MeH)$

3) $2(MeH) \xrightarrow{(500^{\circ}C)} 2(Me) + H_2$;

various laboratories are engaged in the closure of reaction 1 via 2 or 2b plus 3.

The separation of oxygen from reaction 1 does not appear too difficult, through condensation and washing with feed water. Electrolysis may provide H_2 already at high pressure from reaction 2. Sulphur compounds have to be properly interfaced with the environment, but they belong to the natural cycle. Not to count the hundred million of tons of SO_2 produced in the combustion of fossil fuels.

My opinion is that this fourth process already shows the signs of convergence in the search of thermochemical water splitting and perhaps most of the R&D for the next five years should concentrate around that core.

The basic criticism has been raised against thermochemical water splitting, that the amount of materials to be manipulated largely exceeds existing chemical operations, and that even small fractional losses can have important effects on the economy and the environmental embedding of the system.

It is certainly true that the circulation of materials is terrific, but it is in the same ballpark of the materials circulated to produce electricity or to cool a reactor for similar power outputs. E.g. in case of process 4, if the electrolytic step can produce H_2SO_4 at sufficient concentration, the amount of H_2SO_4 circulating in the heat exchangers will be less, molewise, than the circulation of steam in a power plant of similar output.

Concerning the losses, a similar analogy can be identified. The leaktightness of an HTGR reactor system or of the steam system of a boiling water power station provide an example of technologically and economically achievable tightness largely sufficient for a thermochemical plant.

APPENDIX H

Artificial Islands for Waste Disposal

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History

During the summer of 1971 the Board of Directors of Bos Kalis Westminster Dredging Group NV decided to initiate a study of the possibility and viability of the construction of an artificial island in the North Sea. This preliminary study was concluded in March 1972; it was presented to the Netherlands Government at the end of that month. The main subject of this investigation was a relatively small island to be used for the disposal of waste of different origins, such as urban, chemical, steel, etc.

Two conclusions of this preliminary study must be highlighted:

1) Technological experience, expertise and know-how in the Netherlands are sufficient and available for the construction of artificial islands in the southern North Sea at a price per square meter which is not unreasonably higher than that on the mainland.

2) Provided the Netherlands Government has at its disposal comprehensive environmental legislation with the control organization inherent thereto, it might be purposeful to create on the island a large national waste disposal and recycling industry, outside urban concentrations and easier to control.

In a conservative cost-effectiveness analysis this study has shown that such a waste disposal and recycling industry would be preferable from a general environmental point of view and would be able to operate at a lower price and more efficient than is possible under the present situation where government and industry proceed independently.

Quite a number of industries became interested in the possibilities mentioned in the study and asked about the modalities of participation in further investigations. These industries came from the United Kingdom, France, Sweden, but mainly from the Netherlands. During the summer of 1972 preliminary discussions took place between interested industries and after having understood the Government´s viewpoint to be that a further feasibility study was a task for the industries concerned, Bos-Kalis was asked to act as the project manager for such a further study. On 27 February 1973 the North Sea Island Group was officially established. At present this Group has 26 industrial participants. Government observers in the Group come from three ministries, i.e.

- the ministry of transportation and waterways,
- the ministry of economic affairs,
- the ministry of national health and environmental hygiene.

Also some embassies of countries around the North Sea are represented as observers in the Group.

Participation and cooperation between members of the Group is based on the fact that any industry or institution can adhere to it, provided they bring in experience and know-how complementary to those already present in the members of the Group, or when their participation may be expected to influence positively the realization of the aims and purposes of the Group.

These aims and purposes can be described as follows:
"to investigate the possibilities of construction and exploitation of an island for industrial purposes in the North Sea, through the concerted action and efforts of the participating members; also with a view to enabling the realization of such construction possibly through government contracts".

All participating industries have one representative in the General Meeting of the Group. Professor W. Langeraar is the Chairman of the General Meeting.
The Steering Committee under the General Meeting consists of seven members and has as its Chairman the past-President of the Chamber of Commerce of Rotterdam, Mr. W.H. Fockema Andreae.

The Steering Committee is assisted in its task by a number of Working Groups.

During the first session of the General Meeting a preliminary outline for the feasibility study was accepted as well as a budget of 2,000,000.- guilders. At a later session the Engineering Bureau of Hydronamic BV at Sliedrecht was charged with the overall management of the feasibility study. The study started in June 1973. It consists of two phases.

The subjects to be studied during phase A were:

- Juridical aspects, international law questions
- Economic considerations
- Technical considerations, construction and location.

For those who have occupied themselves with the question of construction of artificial islands in the sea, possibly outside of territorial waters and consequently beyond the limits of national sovereignty, it will not come as a surprise that the international law questions are coming first on the list of problems to be investigated. If, under international law, the construction of such islands either within or outside territorial waters under no circumstance were permitted, the whole feasibility study could be discontinued.

It was decided to ask a small group of well-known international lawyers to prepare the report on the juridical problems. The North Sea Island Group was pleased to find available Dr. L.J. Bouchez (University of Utrecht), Prof. R.Y. Jennings Q.C. (Cambridge), and Prof.Dr. G. Jaenicke (Heidelberg), to prepare this study. Their report is now available for those interested outside the North Sea Island Group and can be obtained from the Secretariat of the Group at 20 Rosmolenweg, Papendrecht, Netherlands.

This extremely valuable and highly interesting report starts from the assumption that the North Sea Island Group would not venture upon the construction of an artificial island in the North Sea without the authorisation and sponsorship of the appropriate government as such authorisation would, in their view, be a legal requirement. One would hardly contemplate making, without government backing, so large an investment in a venture which would manifestly entail international responsibilities and repercussions.

However, as there is as yet no body of international law which expressly regulates the construction of artificial islands, even though it is one of the subjects in the very long agenda of the ongoing international Conference on the Law of the Sea, it has been necessary to discover the legal position by a process of deduction from the corollaries of general principles of international law and from the rules of international law applicable to analogous situations and activities.

On the basis of these deductions the juridical report comes to the conclusion that since the North Sea has continuous continental shelf, an artificial island in the high seas of the North Sea can only be constructed on the continental shelf of one of the coastal states. And since an artificial island may substantially affect the "sovereign rights" of the coastal state in respect of the natural resources of the continental shelf; and since the coastal state´s interests are directly affected by permanent structures before its coast; it follows that the coastal state has the right to give or refuse its consent to the construction and use of such an island.

Following this it is clear that the report continues to state that the coastal state may take the necessary measures to protect its exclusive competence to authorise the construction of an artificial island and to prevent, in the last resort with appropriate enforcement measures, any unauthorised construction of an artificial island on its continental shelf. The coastal state has jurisdiction to regulate, in its municipal law, the procedure under which such authorisation may be obtained, and to apply criminal sanctions to any unauthorized construction. In exercising its legislative and enforcement jurisdiction over artificial islands, the coastal state may in principle extend any rule of its municipal law to activities taking place on the island if it considers such extension necessary.

It is evident that the report goes into a number of other questions as well, such as the need for safety zones during the construction stage, the construction of islands within territorial waters, the problems of liability of the authorizing coastal state, unjustifiable interference with other permitted uses of the seas by third states or their nationals, but for the time being the most important outcome of the report for the North Sea Island Group was the certainty that no major legal obstructions exist prohibiting the construction.

In March 1974 the Interim Report on phase A of the feasibility study was completed and its three volumes were given restricted circulation because of the preliminary nature of the report. Only the fourth volume, the Juridical Report, can be considered final. In phase A the conclusion is reached that on the basis of technical and economic considerations three locations are to be studied further, i.e. West of Hook of Holland, East of Great Yarmouth, and the location on the Brown Ridge near the tidal amphidromic point in the southern part of the North Sea.

Phase B of the study has now started in which social aspects and the inherent labour problems, e.g. the cost factor of the labour aspect, will be studied, together with management and exploitation problems as well as environmental questions.Also the problem of financing will be gone into and the economic aspects related to the establishment of a cluster of different industries on the island, enabling to make provisions for collective infrastructural layout and arrangements.

It is especially the environmental problem, not only related to the construction of the island itself, but also to its occupation and the need of the industries thereon to dispose of their waste and effluents, that has to be studied carefully. Related thereto is the establishment on the island of a multi-purpose waste disposal and recycling plant and its influence on the total environmental impact of the island.

For this reason the North Sea Island Group has set up a Working Group consisting of a number of "user-industries" which consider construction of plants on the island. They could invite whoever they deemed necessary to guide them in their deliberations and in proposing applicable and adequate measures to reduce the negative impact of the island on the environment to a minimum. At the same time a governmental Working Group started its work and as this group comprises representatives from all ministries which are in one way or another responsible for certain environmental aspects, it is justified to express the hope that their findings will reflect the viewpoint of the Government as a whole. At a later stage it may be necessary to reconcile what is politically and governmentally desirable, with what is scientifically justified and industrially feasible. This "user-industry" group and the governmental group together carry out the required technology assessment necessary to enable us to foresee what will be the impact on the environment of such an artificial island in the chosen location. The required technological-economic-social-juridical assessment is carried out by the North Sea Island Group as a whole.

Now that phase B of the study has proceeded for eight months it looks as if the location West of Hook of Holland becomes the most interesting. There are four political mainstreams which influence the West Hook of Holland location in a positive way. They are:

1) the deepening of the approach channel to Rotterdam and Europoort and the need for construction of an offshore shelter harbour for damaged ships,
2) the future full occupation of the land around the Europoort harbour for which an artificial island will become a complementary, if not also a supplementary, aspect,
3) the problems related to the acceptance of LNG tankers in harbours with a constant high-density traffic stream, and
4) the necessity of nuclear energy for the Netherlands and the fact that an off-shore power plant will find unlimited amounts of cooling water with little impact on the environment.

It is the viewpoint of the North Sea Island Group that after the termination of the feasibility study in the spring of 1975, industries interested to carry the concept of an artificial island further into the stage of actual construction, should pool their resources in a development and exploitation company of which the form and modalities are now under consideration. It is already clear, however, that government support and participation in one way or another, is desirable. After the termination of the feasibility study the North Sea Island Group may cease to exist or may be asked to carry out further complementary studies. At the same time, however, a new body should be in existence consisting of industrial partners who want to be financially involved in the possible realization and exploitation of an artificial island, which body should have legal status and should carry on the deliberations with the government authorities.

The construction of an artificial island in the North Sea is legally acceptable and technologically possible. The feasibility study already has shown that it is economically interesting. Social and labour implications will prove to be most important parameters on which further cost-benefit analyses are to be based, whereas the environmental impact will influence our well-being for better or for worse, but unless I am very much mistaken, for the better. Government support, participation and protection, however, are needed, especially in this very first endeavour in the North Sea.