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MULTIPURPOSE NUCLEAR PROCESS HEAT FOR ENERGY SUPPLY IN BRAZIL[1]

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ABSTRACT

The industrialized nations require 75% of the energy as heat and it is likely that developing countries in the course of industrialization will show a comparable energy consumption structure. The High Temperature Reactor (HTR) allows the utilization of nuclear energy at high temperatures as process heat. In the Federal Republic of Germany (FRG) the development in the relevant technical areas is well advanced and warrents investigation as a matter for transfer to Brazil. In Brazil nuclear process heat finds possible applications in steelmaking, shale oil extraction, petroleum refining, and in the more distant future coal gasification with distribution networks. Based on growth forecasts for these industries a theoretical potential market of 38-53 GW(th) can be identified. At present nuclear process heat is marginally more expensive than conventional fossil technologies but the anticipated development is expected to add an economic incentive to the emerging necessity of providing a sound energy base in the developing countries.

1 – INTRODUCTION

The energy demand in industrialized countries, although effected by historic events and geographic locations, is greatly characterized by the industrial structure and the urbanization of their population. Most probably the developing countries will also follow along similar lines. Therefore the pattern of energy use in the industrialized world may serve as a first guide.

However, local conditions such as the need for home heating and availability of raw materials can change the gener[illegible] attern substantially. In emerging economies the heat demand in industry must be satisfied in a com[illegible] [illegible]e fashion to enable the closing of the gap between developed and developing nations.

The high [illegible] [illegible]rature reactor (HTR) is a unique energy source in so far as the energy is provided at a high [illegible]erature level with a potential wide field of applications. This may range from electricity producti[illegible] with high efficiency to process heat for a variety of purposes and large distribution netwo[illegible] based on chemically bound energy carriers. The flexibility of the nuclear fuel cycle enables the [illegible] to be operated on various nuclear materials appropriate to the nacional resource base and capabili[illegible]

Brazil is [illegible] emerging economy with great prospects if the potential riches can be utilized and deployed in a ma[illegible]ner consistent with its economic power and timely requirements. The needs for

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energy in form of process heat may be provided in various ways. Conventional combustion of fossil fuel is a well proved technology, although it is unlikely that these resources will be able to meet the long term demand on a global scale, in particular with the emergence of industry in developing countries. Some of the energy may be substituted by electricity if cheap hydro power can be made available. Alternative sources may be found in renewable energies like solar and geothermal energies, however, these technologies are still in their infancy and their exploitation for large scale industries are more than uncertain.

A new and additional option can be found in nuclear process heat with its many advantages and wide field of applications discussed in this paper.

In the most recent past Brazil has taken its first steps to introduce nuclear power in the form of light water reactors on a large scale. The employment of nuclear process heat from HTR may be another important stride forward to develop its industry.

In this paper we have identified several potential fields of applications which seems particularly suitable for the conditions prevailing in Brazil. Four of the main applications of HTR in Brazil are the steel industry, shale oil production, petroleum refinery and coal gasification. One of the potential advantages of HTR for the Brazilian conditions is the utilization of the thorium fuel cycle. The known Brazilian reserve of thorium amounts to 70,000 tons and the estimated resource is of the order of 1 million tons. Also for uranium the prospects of finding additional ore deposite are promising.

It has been our dominant aim to describe the technical process and point to the potential size of the industry based on growth predictions.

The economic estimates presented in this paper mainly serve to point to essential cost areas for the different process. We are convinced that nuclear energy is a long term economic alternative, although this stands to be proved for specific projects.

Although we have focused the attention on Brazil to provide a concrete platform for the investigation and discussion of nuclear process heat in developing countries, the outcome of the study does, however, have a beating on other emerging economies.

2 – HTR TECHNOLOGY AND PRECESS HEAT APPLICATIONS

The high temperature reactor is a graphite moderated and helium cooled nuclear fission reactor operating either on the low-enriched uranium or the high-enriched uranium-thorium cycle. The latter offers better prospects of fuel utilization reducing the demand on the uranium resources.

The sucessful operation of prototype high temperature reactors in the USA, Britain and West Germany has proved its technology and opened up the possibility of utilizing nuclear process heat at high temperatures.

The graphite fuel and core structure with its high temperature stability enables gas outlet temperatures in the region 750-1100°C. This capability has been demonstrated in the 15 MWe AVR pebble bed research reactor, which for more than a year has been operating at 950°C mixed gas outlet temperature. Both this reactor and the Dragon reactor have for shorter periods achieved helium temperatures of 1000°C.

In particular the pebble bed type of HTR with OTTO-style fuel management (Hansen *et al.*, 1973) offers the promisse of very high outlet temperatures and this type has also been chosen as the basis for the nuclear process heat work in Germany.

In this reactor, the fresh fuel balls in the top core layers produce a large heat output which is then reduced as the fuel is depleted in the lower layers. The coolant which enters from the top of the core and flows downward, results in an equalizing effect on the fuel ball temperatures (Figure 1).

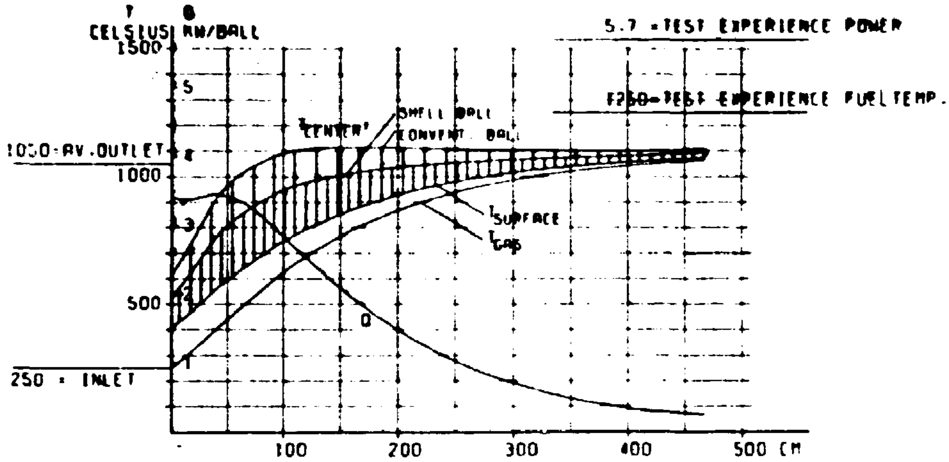

Figure 1 – Power and temperatures at the axis of the core.

The coupling of the nuclear heat with the various chemical processes leads to different designs for the combined plant. For some applications it may be advantageous to integrate parts of the chemical process equipment in the primary gas circuit and house it in a prestressed pressure vessel. Non-integrated schemes where the nuclear island is separated from the rest of the plant, is found desirable for other uses. For a given application specific designs have been worked out and will be assumed to be acceptable for the intended implementation in Brazil.

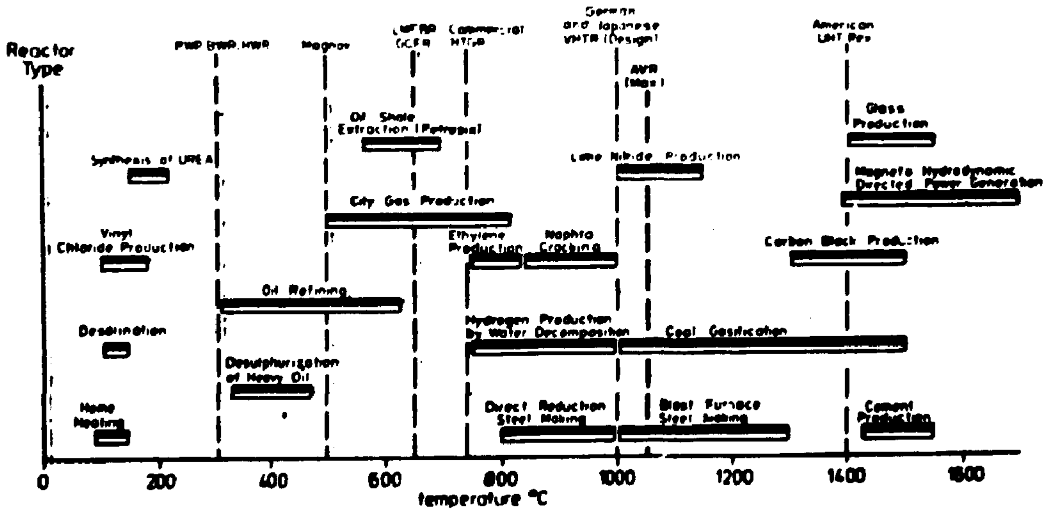

Figure 2 – Temperature requirements for several industrial processes and availability for different reactor type.

2.1 – Process Heat Applications

The energy in the reactor coolant gas delivered at the high temperature level of 750-1000°C can be used for a number of applications (Figure 2). The simplest case is to raise steam in a boiler and there is, in industry, a large demand for steam, saturated and superheated, over a wide temperature range. The transportation distance is limited and the nuclear plant will have to be located at or within 10-20 km from the site of utilization.

Natural gas, oil and coal can be converted into hydrogen, H_2/CO-mixtures, methane or light hydrocarbons by use of high temperature nuclear process heat. There are two main ways of using nuclear heat for conversion of carbonaceous materials (KFA, Jül-1113-RG, 1974):

- use of helium heated steam reformer, which produces hydrogen in combination with various processes consuming hydrogen, and
- use of helium heated coal gasification to convert coal to gas by steam gasification.

The steam reformer process is an endothermic catalytic process with a large heat demand at a temperature level of 750-850°C with pressures of up to 30 b. There are two main reactions depending on temperature, pressure and steam/hydrocarbon ratio in the reformer tube:

$$CH_4 + H_2O \rightarrow 3\,H_2 + CO, \qquad \Delta H = -49 \text{ kcal/mole (205 J/mol)};$$

$$CO + H_2O \rightarrow H_2 + CO_2, \qquad \Delta H = +10 \text{ kcal/mol (41.8 J/mol)}.$$

The product gas of steam reforming in then inserted into various processes of which only a few pertinent to this study are described below.

The direct reduction of iron ore is made either in an exothermic (CO) or a endothermic (H_2) reaction:

$$Fe_2O_3 + 3\,H_2 \rightarrow 2\,Fe + 3\,H_2O, \qquad \Delta H = -195 \text{ kcal/kg Fe (816 J/kg)};$$

$$Fe_2O_3 + 3\,CO \rightarrow 2\,Fe + 3\,CO_2, \qquad \Delta H = +69 \text{ kcal/kg Fe (289 J/kg)}.$$

The reducing gas for this process is produced in the steam reformer using CH_4, natural gas or refinery gas as raw material.

Another area is the hydrocracking of heavy oils to light hydrocarbons or gases such as H_2 and CH_4. The byproducts of the process are used as feed for the steam reformer. Figure 3 shows a whole future spectrum of secondary energy carriers.

2.2 – State of Development

Development work on high temperature reactors started in the late 1950s and resulted in the design and operation of three experimental reactors followed by the construction of two medium sized prototypes for electricity production. Today extensive knowledge and experience have been accumulated in the areas of fuel element core materials and reactor physics. Also a considerable amount of know-how has been gained from the design and operation of major components in the primary and secondary circuit. Not all of this can be directly to the design components for the process heat plant, however, the

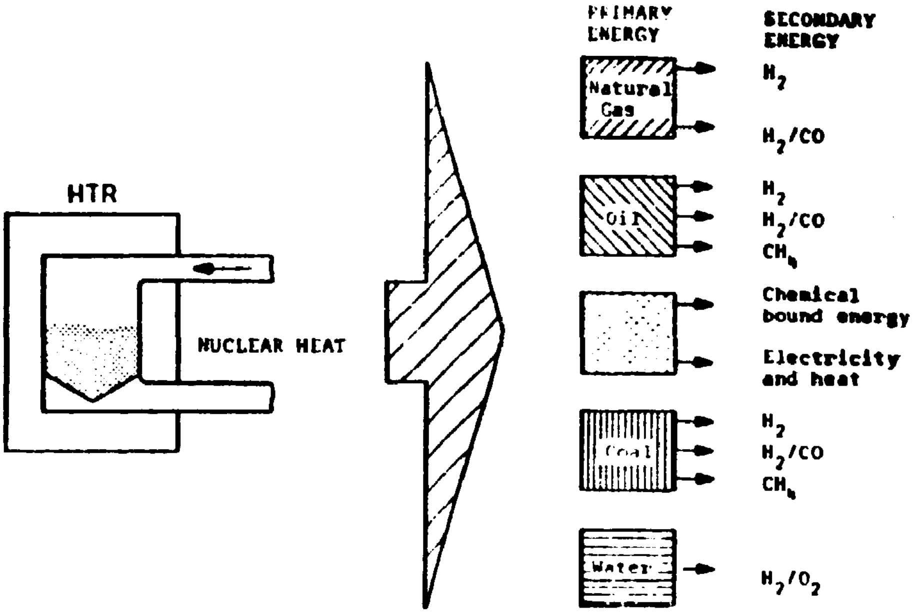

Figure 3 – Potential conversion of nuclear energy into secondary energy carriers.

general nature of the problems are well understood and partly covered by relevant experience. The many years of operation of the experimental reactors have provided a good basis to judge the opering characteristics, the safety features and maintenance problems of HTRs.

The energy market has a large demand for heat and this opens new areas for nuclear energy by direct coupling of nuclear heat into the various chemical processes. The chemical processes themselves and the equipment are well known and have been tried in the chemical industry for many years. In the Federal Republic of Germany two projects have been set up to study specifically the technical problems and to assess the economic potentials.

The project on nuclear process heat (PNP) aims at the gasification of lignite and hard coal and thus involves partners from the coal industry as well as the nuclear industry*. The project on nuclear long distance energy transport (NFE) investigates the problems of producing and transporting chemically bound nuclear energy in a $H_2/CO\text{-}CH_4$ system**. Both projects are performing experimental work for the key chemical processes and this will result in considerable experience by operating such facilities. Work has started on the reference design for a large nuclear process heat plant. The time schedule foreseen for the operation of this demonstration reactor is in the late 1980s and large scale commercial operation starting around 1995 (KFA, Jülich, 1976).

3 – FIELDS OF APPLICATION OF NUCLEAR PROCESS HEAT IN BRAZIL

In this section we give a short overview of the potential applications in steel production, shale oil extraction and petroleum refining in Brazil.

Gasification and liquefaction of coal forms the basis for a number of technologies needed for the utilization of nuclear process heat. The Brazilian coal resources amount to some 11 billion tons

(*) Partners: Bergbauforschung GmbH Essen, Rheinbraun AG Köln, GHT Bensberg, HRB Mannheim, KFA Jülich.
(**) Partners: Rheinbraun AG Köln, KFA Jülich.

although the quality is poor. It is not expected that gasification in general would achieve the same importance as in the FRG where synthetic natural gas is a potential substitute for light oils. However, the utilization of indigenous coal for special applications like nuclear steel making could serve as a stepping stone to acquire the necessary technical know-how for further and wide spread applications in the more distant future.

3.1 – Steel Industry

Steel consumption in less industrialized countries will develop more than in industrialized countries. The reason for this is an expected saturation effect in the industrialized world and on the other hand the increasing industrialization of the developing countries. In the case of Brazil, this development is reflected in the annual growth rate of steel production which over the last years increased 1.5 times the GNP growth rate.

For steel making, the direct reduction of iron ore is growing compared to the conventional blast furnace techniques, Roughly three quarters of the world's steel production is made by reducing iron ore at about 1400°C in a blast furnace using coke as the reductant and subsequent refining of the moltren ore to liquid steel in a top blown oxygen furnace. With the direct reduction route, a hot reducing gas is brought in contact with either pellets of iron ore in a shaft furnace or in a fluidized bed of fine ore particles. The reduction takes place in the solid state at about 850°C and the product is sponge iron or metallized pellets. The sponge iron may be augmented by ferrous scrap and refined in an electric arc furnace to produce liquid steel for subsequent casting and rolling (Monthe, 1975; Barnes, 1976).

In contrast to the blast furnace. the directly reduction process uses a gas (hydrogen, natural gas or synthetic gas) instead of coke as energy carrier and raw material. This has advantages especially for those countries who do not have their own coal resources but enough natural gas and iron ore to produce steel on their own. Even some countries with coal resources are often not able to provide enough coke for steel-production because of the low coal quality. In particular, for these countries, the application of nuclear process heat could be important because in this way low quality coal can be used in combination with a gasification plant to produce the reductant.

In 1975, the world wide direct reduction capacity reached 6×10^6 ton of sponge iron/yr which corresponds to 1% of the total iron production. The wide spread R & D activities in this field certainly will result in a faster growth of direct reduction to some 30×10^6 t/yr in 1980.

Development of Brazilian steel production. Brazil has one of the largest iron ore reserves in the world (82 billion tons) of the highest grade (up to 67% iron) and its steel industry is rapidly expanding. The principal deposits of iron ore in Brazil are shown in Figure 4 and the developments of steel production are shown in Figure 5. In the past, the steel production has risen by 10-15% per yr and the estimates assume an annual average increase of 9% up to the year 2000.

In order to process the ore into steel with conventional blast furnace technology, Brazil will need an increasing amount of coking coal. However, the known coal reserves, 11 billion ton, contain a high ash content (about 20%). This coal need to be mixed with high grade imported coal for efficient operation of the present blast furnaces. The coal requirement for the steel production would accelerate Brazil's dependence on foreign supplies shown in Figure 6.

Another alternative actually available in Brazil is to use wood-coal for steel production. This option, however, is highly dependent on the cost of developing large reforestation areas, transporting wood to the plant sities, and increasing the efficiency of the technology.

The utilization of the direct reduction processes, encreasingly favoured in world steel production, offers one way to diminish the dependence on foreign imports. Moreover, Brazil has already

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Figure 4 — Main iron deposits in Brazil.

Multipurpose nuclear process heat for energy supply in Brazil

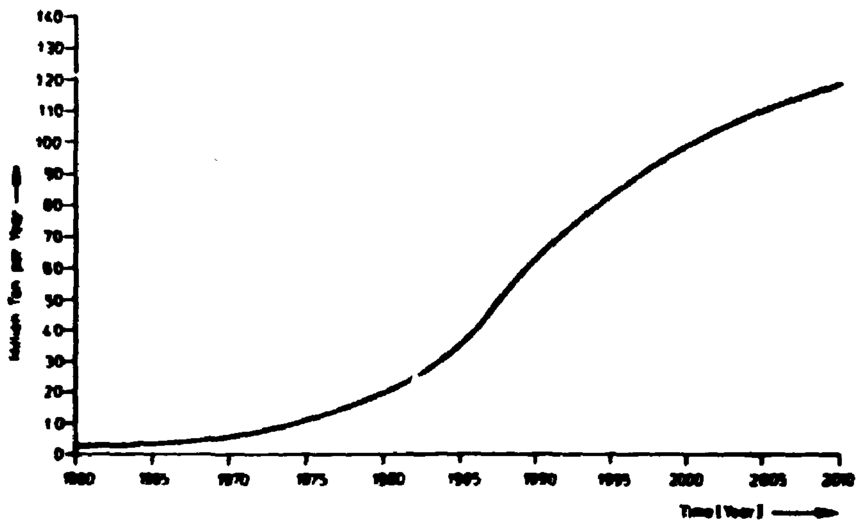

Figure 5 — Development of steel production for Brazil.

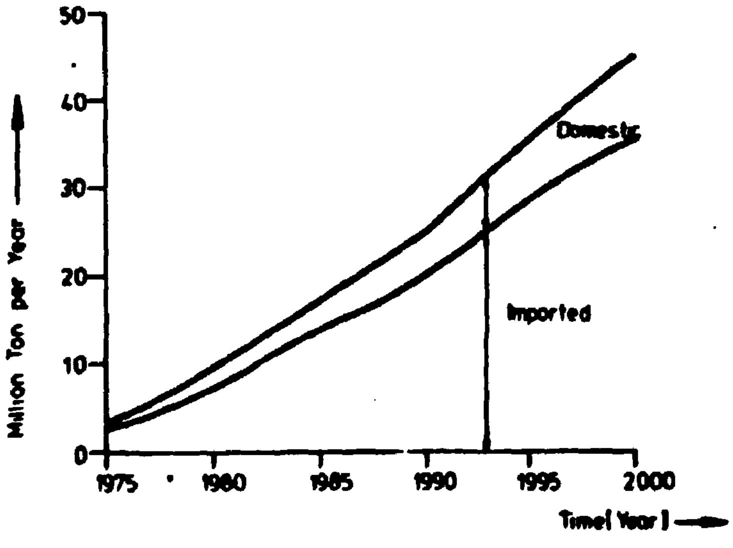

Figure 6 — Forecast of coking coal requirement for Brazil.

an established experience in the conventional direct reduction process and in the year 1978 commissioned the world's largest plant with a capacity of 380,000 t/yr.

Nuclear process heat for steelmaking. As discussed in Section 2.1. the HTR could produce from basic carbonaceous raw materials or a H_2/CO mixture to be used as the reducing agent in the direct reduction process. In addition it would provide all the electricity needed for the electric arc furnace and the subsequent process steps in the steelworks.

A rough breakdown of the energy requirements per ton (1000 kg) of liquid steel is listed below (Barnes, 1976):

	GJ/t
Heat, including H_2 direct reduction furnace	8.5
Electricity, (therm. eq.) arc furnace, hot sponge charge	5.0
Steelworks, casting, rolling etc.	12.0
Total energy DR-EA-steel works	25.5

The nuclear steel making plant could either be designed as an 'integrated comples' with an HTR serving one steel plant exclusively or a 'non-integrated complex'. In the latter case the HTR may be located away from the plant and supplying reducing gas and electricity through distribution lines. The outcome of the many discussions of the virtues of the possible systems indicate a preference for the 'non-integrated' approach. In particular, the practical aspects of availability and flexibility made the European Nuclear Steelmaking Club (ENSEC) decide to base their future research on this system.

In developing countries, however, good reasons could be counted in favour of the 'integrated' system as well, in particular, as in this case maximum use is made of the heat from the HTR. As this paper is mainly concerned with as estimate of the potential size of the market in Brazil global data will be used in the quantification of the nuclear steel making capacity.

The potential market for HTR as a heat and electricity supply for steel production has been estimated by assuming the following conditions:

a) from the year 1990 onwards all the additional market is supplied by steel plants using direct reduction and electric furnace process;

b) the total demand from the breakdown above is roughly 300 kW(th)/t/d so, for instance, a 3000 MW HTR would provide the needs for a sponge iron/steelworks with an annual production of 3.25 Mt, and

c) the thermal energy from the reactor is split between process heat (33%), and steam for electricity production (67%). The electricity production efficiency was assumed to be 40%.

The calculation is based on the demand for reducing gas in the iron ore industry. The electricity may either be used on site in electric furnaces and steelworks or supplied to the national grid.

Economic aspects. Cost calculations and economic evaluations in the starting phase of new technologies can never be as precise as those for conventional processes. But nevertheless is should be possible to make reasonable estimates by analogies.

The main influences on costs are the following factors:

a) the cost of iron ore;

b) the cost of coal for production of reducing gas, and

c) specific siting problems caused by climatological and geological circumstances.

An example for the present Brazilian condition with iron ore cost at $ 18/t and hydrogen cost at about $ 12/Gcal ($ 2.9/GJ) is based on German process heat studies. Foe a plant capacity of 1 million t/yr it shows that the direct reduction route is only marginally more expensive than conventional blast furnace technology.

Although direct iron ore reduction with nuclear energy is not competitive at today's prices it must be expected that a shift in cost of fossil and nuclear fuels due to depletion effects of oil and coking coal resource will change the future picture. Even at equal costs, the nuclear option offers advantages, as it enables the Brazilian steel industry to operate in an independent fashion without relying on imports of coking coal. Under these aspects the theoretical potential market appears attractive and could amount to 30 GW(th) in the year 2000.

3.2 – Extraction of Shale Oil

Brazil is considered to have the second largest world reserve of oil shale (roughly 25% of the total) with total oil content estimated at 800 billion barrels (Ribeiro, 1964). The principal deposits of oil shale are shown in Figure 7.

A shale oil extraction process named PETROSIX has been developed in Brazil which utilizes a vertical Cameron & Jones type kiln with crushed shale in a downward flow. A prototype plant corrently producing 1000 bbl/d has been constructed at Sao Mateus do Sul. The lecated deposit is estimated to contain 600 million barrels of oil distributed over 64 km^2. The oil content of the shale varies from about 6,4% to about 9.1% distributed over two distinct layers of shale formation called Irati (Permian and late Paleozoic, about 300 million yr old).

The process heat is provided by heated recycle has which enters the middle zone of pyrolysis vessel at about 700°C. For the present design all energy needs for PETROSIX are furnished by burning about 14% of the shale oil and all combustible gases produced by the plant.

Technique of nuclear shale oil extraction. For commercial size plants the ratio of the consumed energy content of net oil production is projected to be about 37%. The energy requirement breakdown for a unit size 100,000 bbl/d plant was estimated to be:

electrical energy	370 MWe;
process heat and steams	1800 MW_{th}.

The plant would need 190,000 ton of shale to be mined per day and would produce 1340 ton/d of sulfur as byproduct.

A proposal for a process diagram of a combined HTR, PETROSIX and steam cycle for electricity production is shown in Figure 8 (Pessine, 1978). The heat from the reactor is supplied directly by helium to the processing gas line through a heat exchanger in the upper temperature range 950-700°C and in the lower range 700-250°C to the steam generator for electricity production.

1 - **Devonian Oil Shale of Para-Amazônas**
Outcrops: Bank of Amazônas, Xingu, Tapajos, Trombeta, Curuá, Paramari and Urubú Rivers.

2 - **Cretaceous Oil Shale of Maranhão**
Outcrops: Codo, Barra da Corda, Serra do Desordem

3 - **Cretaceous Oil Shale of Ceará**
Outcrops: Crato

4 - **Cretaceous Oil Shale of Alagoas**
Outcrops: Riacho Docê, Caramagibe Bica da Serra

5 - **Cretaceous Oil Shale of Bahia**
Outcrops: Maraú

6 - **Tertiary Oil Shale of São Paulo**
Outcrops: Paraíba Valley

7 - **Oil Shale of Amapá**

8 - **Permian Oil Shale of Irati Formation**

Figure 7 — Known shale deposits in Brazil.

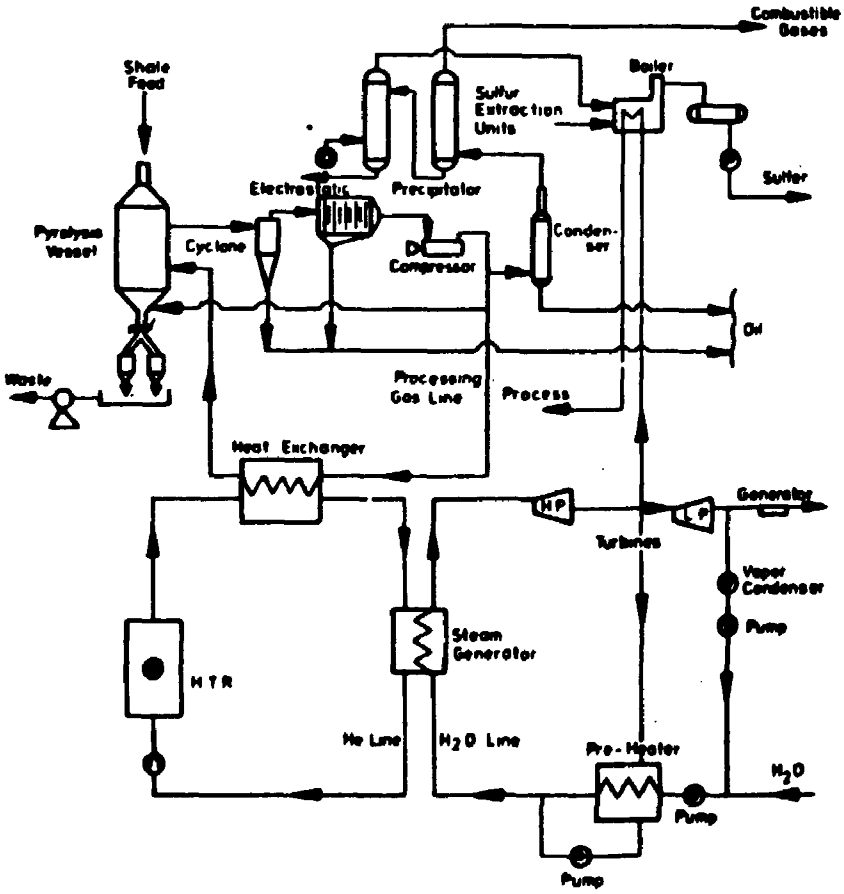

Figure 8 – Process diagram of combined HTR, PETROSIX and steam cycle system.

The use of nuclear energy to supply the electricity and heat will save 14% of the oil and all the byproduct gas which for the 100,000 bbl/d plant amounts to 2.65×10^6 m^3/d mostly of light hydrocarbons. In particular the saving of the gas products constitutes an interesting aspect of the nuclear shale oil scheme. The size of the production could warrant the construction of pipe lines to consumer centres like Sao Paulo or Rio de Janeiro. As mentioned in the outline of direct reduction steel manufacturing the gas could also serve as input to the methane reformer.

Economic aspects and potential demand. In order to consider the economy of the above described system, preliminary cost calculations were done based on a 3000 MW_{th} HTR and studies described in the references (KFA Jül-1148-SE, 1974) and (Bundesanstalt, 1976). The capital expenditures for the shale oil plant itself are considerable and a rough estimate arrives at 2 billion US dollars for the 100,000 bbl/d plant. The results indicate a cost per barrel for the shale oil in the order of $ 15 which imply potential competitiveness considering a future increase in the price of oil.

In assessing the actual applicability and potential demand, the following aspects have to be considered:

a) From the view point of technology, the HTR with the PETROSIX scheme seems the simplest of all possible process heat applications in Brazil. The requirements for temperature of the processing gas (maximum 700°C) and steam are well within the prsent HTR technology.

b) The economics of HTR coupling to PETROSIX is highly dependent on the production cost of the shale oil itself since the basic idea is to substitute part of this oil by nuclear heat. A detailed study of the cost components is necessary before the economics can be firmly established.

There appears, however, to be a large potential demand for shale oil, but again this is strongly dependent on future developments in petroleum prospecting and production. National considerations might guarantee a domestic market for the Brazilian shale oil and an important factor that could effect the scale production is the growth rate of the domestic consumption of oil. Figure 9 shows the extrapolated demand of the 1974 consumption of 830,000 bbl/d at the rate of 2 and 4% per year until the year 2000. An estimated demestic production of conventional oil in Brazil given by the Government is 500,000 bbl/d in 1985 growing to 1,000,000 bbl/d in 1990, and then remaining constant up to the end of the century.

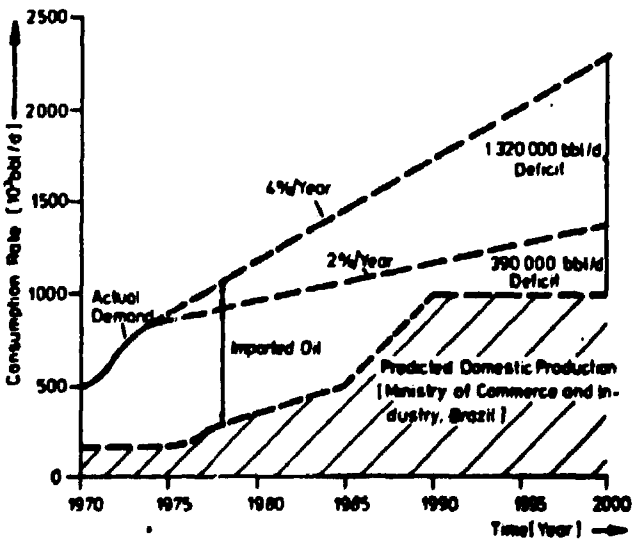

Figure 9 — Oil demand forecast and predicted domestic production.

When assessing the likelihood of the projections it should be born in mind that the 2% p.a. increase in oil demand would correspond to a *per capita* constant consumption. For a 2%/year growth rate (low prediction) the deficit is 390,000 bbl/d in the year 2000. For a growth rate of 4%/year (high prediction) the deficit could be as high as 1,320,000 bbl/d. If we assume that from 1990 all the additional oil demand is met by shale oil extracted via nuclear heat, by the year 2000 for the low prediction case 250,000 bbl/d has to be supplied by shale oil plants based on HTR nuclear heat, equivalent to 6 GW. In the higher and more realistic demand projection a shale oil capacity of 600,000 bbl/d would require 15 GW.

3.3 – Nuclear Process Heat for Petroleum Refining

It is more than likely that hydrocarbon fuels will show signs of depletion towards the end of the century and therefore natural petroleum should be reserved for more noble applications such as petrochemical (feedstock) instead of using it to heat chemical processes.

The total process heat required to feed a 100,000 bbl/d petroleum refinery is equivalent to burning 12,000 bbl/d of oil. For the various refining processes roughly 50% of the energy is required in the temperature range around 350°C, and 50% at temperatures above 430°C. These temperatures are well within of the present HTR technology and would work with increased efficiency when hydrogen is used in refining heavy oil components to light hydrocarbons (Eickhoff, 1976).

In the case of Brazil, although at present 80% of its consumed oil is imported, (total consumption about 900,000 bbl/d) the petroleum refining capacity is above the demand. In 1974 the installed refinery capacity reached 956,348 bbl/d and further large capacity expansion are planned. The country's largest refinery at Paulinia is projected to have a capacity of 252,000 bbl/d.

With these demand forecasts a considerable incentive exists to use nuclear heat as an alternative source of process heat since about 12% savings in oil can be achieved. For a 336,000 bbl/d capacity refinery it is estimed that a commercial size HTR plant of 1900 MWt can provide the heat and electricity required. From that, 36,000 bbl/d represents the savings by utilizing nuclear heat.

The theoretical potential demand is strongly dependent on the growth rate of oil refining capacity in Brazil. Assuming that all the additional refining capacity added after 1990 were to be run by HTR as heat source, the potential market is about 2 GW by the year 2000 if the refining capacity follows the 2% annual growth of oil demand and 8 GW for the 4% growth rate.

4 – CONCLUSIONS

The expanding economy in Brazil as well as the increasing industrialization of the country enhances the importance of a sound and reliable energy base. Heat for the various industrial processes in an important part of this market. One of the new alternatives to meet the demand and so relieve the pressure on the fossil fuel resources is the High Temperature Reactor. The high coolant gas temperature enables the use of the nuclear energy directly as sensible heat in chemical processes as well as for electricity production. In the FRG considerable efforts are undertaken to make nuclear process heat available on a time scale compatible with the likely need for a future substitution of conventional hydrocarbons.

Based on this technology the paper has attempted to assess the potential market for HTR's in steel making, shale oil extraction and oil refining in Brazil. The country's large iron reserves and poor coking coal find in the HTR a suitable means to utilize indigenous resources for directly reduction of iron ore and steel manufacturing. The existence of the world's second largest shale oil deposits in Brazil and an already locally developed technology for shale oil extraction could in combination with nuclear process heat help to develop these additional fossil resources in a more efficient and economic fashion. The estimated large expansion of the oil refining capacity is again another potential market for HTR process heat utilization.

The theoretical potential of nuclear process heat in the various sectors of industry by the year 2000 is shown below:

Iron & Steel Industry	Shale Oil Extraction	Petroleum Refinery	Total Potencial
30 GW	6 – 15 GW	2 – 8 GW	38-53 GW

A realistic estimate of actual number of units to be installed by the year 2000 is strongly dependent on the pace of technological development and economic incentive. Nuclear process heat is at present marginally more expensive than burning of fossil fuels, but the anticipated trends on the world energy market makes the employment of HTR heat increasing more interesting. However, the breakevenpoint is difficult to establish and detailed evaluations of specific projects are required.

Additional arguments can be brought to bear in favour of the nuclear option already today and these are founded on national economic aspects such as independence on energy imports, introduction of highly developed technologies to spur a country's own efforts, and long term future considerations. In particular, the examination of the next 50 years or so reveals the necessity to shift our almost exclusive dependence on the fossil fuel base to alternative energy resources. The timely and early introduction – even on a modest scale – of new technologies such as nuclear process heat could prove to be a step of far reaching importance to many developing countries.

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