1. INTRODUCTION

The Specialists Meeting on "Process Heat Applications Technology" was held at Kernforschungsanlage Jülich, Federal Republic of Germany, 27-29 November 1979.

The meeting was sponsored by the International Atomic Energy Agency (IAEA) on the recommendation of the International Working Group on High Temperature Reactors (IWGHTR) and was attended by 39 participants from Austria, France, Federal Republic of Germany Italy, Japan, The Netherlands, Poland, Switzerland, United Kingdom, United States of America and two international Organizations, the Commission of the European Communities and the International Atomic Energy Agency.

The purpose of the meeting was to provide a forum for exchange of technical information on heat exchanging components for process heat application with High Temperature Reactors in order to provide a comprehensive view of the present status and of directions for future application and development.

The meeting was opened by Mr. Engelmann who welcomed the participants on behalf of the Kernforschungsanlage Jülich, by Mr. Däunert on behalf of the German Minister for Research and Technology and by Mr. Dee on behalf of the IAEA.

The meeting was divided into three sessions:

A) Design Requirements
B) Design Construction and Prefabrication Tests for Special Components
C) Selected Problems

During the meeting papers were presented by the participants on behalf of their countries or organizations. The presentations were followed by open discussions in the general area covered by the paper.

At the end of the meeting a round table discussion was held emphasizing some of the main problems that are to be seen in the development of intermediate heat exchanges.

A list of participants and the agenda of the meeting are given as appendices to this report.

2. OPENING REMARKS

2A. P. ENGELMANN

Member of the Board of Directors
KFA-Jülich GmbH.
Jülich
Federal Republic of Germany

Gentlemen!

I would like to welcome you to this specialists meeting at KFA Jülich. The relatively large number of participants to this meeting shows, that a number of countries are interested in the HTR for nuclear process heat. I hope that this interest will be growing so that we find active partners abroad who can help us to solve the technical problems connected with this technology.

It is clear to us, that the high operating temperatures of some of the crucial components as well as the coupling of a nuclear reactor with a coal gasification unit lead to a rather complex plant. The goal of designing and building a prototype plant for nuclear process heat therefore is a great challenge for our physicists and engineers. We are fully aware of the problems yet to be overcome and of the time and resources needed to realize this project, but we are also aware of the large potential of this new technology for solving some of our outstanding energy problems.

At KFA the idea of nuclear process heat has originated about 10 years ago. In 1975 a common project with 4 industrial partners, PNP, was founded and by now a reference design of a 500 MW(th) prototype station is well under way. At KFA, about 500 people are working in the field of HTR development, mainly in the r+d area. At German industry, a similar number is working on design problems and component technology. So a sound basis exists for a successful development program, provided that funding is continued and that the German Government also in the future firmly supports the development and commercial applications of nuclear power. I expect that Dr. Däunert who represents the Federal Government at this meeting, will confirm that these two conditions will be fulfilled.

Let me conclude my opening remarks with welcoming you again and wishing you a successful meeting and an enjoyable stay at Jülich. You are all invited to a receiption given by the board of directors of KFA tonight at 6 p.m. in our See-Kasino. I am looking forward to see you there again.

2B. U. DÄUNERT

Bundesministerium für Forschung und Technologie
Bonn

On behalf of the German Minister for Research and Technology I have the honour to welcome you here in the Jülich Nuclear Research Center. As the present chairman of the International Working Group on High Temperature Reactors of the IAEA I am really pleased to see that our proposal to hold this specialists' meeting on "Process Heat Applications Technology" was as well accepted.

In these days everybody speaks about energy problems and the oil crisis. First of all one has to see that the so called "oil crisis" is only a first indication that most of the fossile resources are running short or running off completely in a foreseeable future comparable to a time span one needs for the development and introduction of a new technology. The role which e.g. process heat applications could play is evident before this background, anticipated this technology is fairly well developed and available at an industrial scale.

Secondly, I would like to stick for a short while with the unavoidable development time necessary for a full scale deployment. Having in mind, that in case of a new reactor type one needs the steps of an experimental facility in the 20 to 50 MW size, an intermediate step in the 500 MW range and finally the demonstration in a commercial size of about 3000 MW each of them taking roughly 10 years time, we are now 20 to 30 years far from nuclear process heat application to an amount that the energy market could be influenced.

Personally I made the experience that the exchange of knowledge or even better the information about failures one has made is as much easier as you are far from the commericalisation. In so far this specialist meeting should have a good chance to be a very fruitful one. Looking on the list of participants you will recognize that engineers and scientists of 10 countries have come to meet here, demonstrating, that that there is a certain interest in each of the countries. The interest may be different in the different countries but surely the difficulties will nearly be the same in each of them. Materials, components, the problem of Tritium permeation are only a few of them to be discussed during this specialist meeting.

I am deeply convinced that the development of a new technology is only possible by means of international cooperation and its introduction and deployment only on the basis of world wide acceptance.

The third point I would like to make is how to justify such a long ranging and costly development. In our times we normally are used to settle a new project on the basis of a cost-benefit analysis. You will find, there is no doubt, people who can tell you the estimated cost figure of a gigacalorie by means of process heat application and those figures really are looking nice - but how far are those estimates really reliable, missing basic technical information ? Such exercises may be the main reason to discuss later on enormous surplus costs of a new project operating on a wrong basis. There must be more than the pure economic view to justify the development of new technologies. This is evidently the assurance of a sufficient long term energy supply in a future where the argument of amortisation may no longer play the highest priority. In the meantime, that is in the next two decades we should try to establish jointly the technical basis, which is the prerequesit for any application.

3. SUMMARY AND CONCLUSIONS

3A. Session I: Design Requirements
Chairman: J. Malherbe

The objectives presented in the papers of this session are related to the coal liquefaction or gasification with special mention to the steam gasifier and the steam reforming of the methane for producing hydrogen.

The size of the reactor is chosen between 500 MW and 840 MW in view of the extension for commercial size to 3000 MW; but this size corresponds to a high production of heat. The present heat market may experience some difficulties with synthesis gas for chemical industry. For SNG production the commercial size could be connected on established N.G. network.

The cogeneration of electricity and heat is generally such as to satisfy the needs of the plant and to reduce the amount of electricity to be sold.

The economy of the system is presented in the GA paper in which is pointed out the advantage of nuclear coal liquefaction even with use of a low cost of coal. Studies on the economy have also been carried out in France, Japan and Germany, with the conclusion that the nuclear gasification is competitive with autothermal processes.

A performance code is presented by GA which determines the size and investment cost of the components.

The German proposal foresees that the steam reformer is installed within the pressure vessel whereas for the steam gasifier an intermediate Helium Loop is provided. For GA and CEA the steam reformer is designed with an intermediate circuit; this design increases the extension of heat supply towards other applications.

Related to the intermediate circuit use, the problem is put on the distance between the nuclear reactor and the process heat plant. This problem is connected with the possibility of explosion.

The level of temperature depends on the application but two levels are met:

- either 850 °C with a possible realization with the present technology or 950 °C with the connected R+D on materials (problem of extrapolation of ASME Code). It is pointed out that 950 °C is a necessity for the steam gasifier.

A discrepancy in the choice of pressure which could be related to the level of temperature:

- either 70 bars at 850 °C or 40/50 bars at 950 °C
  This is linked to the behaviour of the IHX components of the system.

For the core, it is mentioned by M. L'Homme the use of low enriched cycle, which is also taken into account in Germany and US.

The size of the IHX is varying between 125 MW and 400 MW with a discrepancy in the specific heat transfer area which has been pointed out and is due to the flow rate difference. Inside the IHX the primary flow is in each case shell side and secondary flow tube side.
Helium circulators are generally motor driven.

Reformers are designed with an external helium heating (PNP and GA), or with helium heating within the tubes (CEA) for the steam reformer of the CEA or the steam gasifier of the PNP.

In concluding remarks we can point out the temperature of ASME Code N 47 up to 850 °C. That necessitates an important R+D for designing a helium reactor at very high temperature.

3B. Session II: Design Construction and Prefabrication Tests for Special Components

Chairman: K. Sanokawa

In this session design aspects, constructions are well as some experimental data of heat exchanger, steam reformer, steam gasifier and steam generator have been presented. Final remarks on each main item could be made as follows.

Steam Reformer

Five different design works (CEA, GHT, GAC, UKAEA, HRB), three experiments on single tube (KFA), duplex (KFA, GE) and multi-tube (CHIYODA) reformers were reported. The reformed gas temperature were in the range between 730 °C and 850 °C and the pressures were between 17 and 72 bar due to the H_2 contents. In most designs the catalyst was placed inside the tubes, while helium flows outside. However, one design (CEA) proposed that the catalyst was placed outside the tubes. It seems that each design has advantages as well as disadvantages, so that more experimental data are needed.

Intermediate Heat Exchanger

Two design studies (CEA, NOVATOM, GHT) and one operating experience (IHI) were presented. As for the problems to be solved might be summarized as follows:

(1) Design criteria, especially at elevated temperature

(2) Analysis and experiment for safety problems

(3) Operating experience for longer time

(4) Reliable long-life materials under actual condition

(5) In-service inspection

No severe problems were reported as far as heat transfer and thermal insulation were concerned.

Some comments have been given on the analysis of a bundle with helically coiled tubes as it is used in the steam generators of the THTR. This type of bundle is very advantageous due to the insensitiveness to hot streaks and transient conditions. As the bundle tubes are sensitive to creep damage, this failure mode has been discussed in detail considering the influence of relaxation on creep damage.

Steam Gasifier

One design shows a steam gasifier for the PNP plant heated by helium of the intermediate heat transfer circuit. A small section of the heating service is already tested in a semitechnical plant.

Materials

Concerning the materials data necessary for the design and construction of high temperature components, a survey of the materials development program for HTR nuclear process heat application (FRG) has been presented. The main tasks of this program are the evaluation of material properties, the investigation of operational parameters as well as fabrication and reliability. At present the time dependent strength properties for 8 materials up to 10.000 h are available. The aim of this developing program is to provide the design data for a design life up to 100.000 h.

Hydrogen Permeation

In a single tube reformer the decrease of hydrogen permeation due to formation of oxide layers was measured (KFA), and it was shown that calorizing was a recommendable method for the reduction of hydrogen permeation at elevated temperature (JAERI).

3C. Session III: Selected Problems

Chairman: C.B. von der Decken

1. Results from integral tests of single reformer tubes under simulated nuclear reactor conditions

- Integral tests of full-size reformer tubes were carried out
- Results with respect to following topics have been reported:

Heat transfer:	especially at process gas side
Chemical conversion:	depending on different temperature distribution, feed gas composition, catalyst arrangement
Pressure loss:	in different catalyst arrangements and return pipes
Hydrogen permeation:	through the reformer tube wall into helium system

Operational behaviour of a reformer tube

Influence of geometrical parameters and constructional details on the process

- The knowledge to all these topics could be improved by these experiments very much.

2. Mechanical design aspects of HTR-heat exchanger components

- Today the data of materials for the RSO and IHX are not ensured by standards
- Design temperatures exceed 820 °C (ASME, Code Case N 47)
- A new material code for temperatures of RSO + IHX is not finished up to now
- 1 % creep limit for 100.000 h is not experimentally substantiated; Larson-Miller-methode preliminary used for estimations.

Problems of critical components:

- Heat exchanger tubes and the gas collector for the IHX
- Primary stresses of the gas collector are very low $\leq 1 \frac{N}{mm^2}$, so the safety margin to Hastelloy X and IN 617 seems to be sufficient
- Questions: Will the very low stress of $1 \frac{N}{mm^2}$ be expected as a design basis and to which extent have secondary stresses to be taken into account?

3. Development and test evaluation of Duplex steam reformer tube

- The Duplex tube is an alternative solution for an IHX
- The Reduction of Hydrogen and Tritium Permeation is possible
- Detection of tube rupture can be indicated
- Manufacture experience have been reported
- Results from operation of the Duplex tube in EVA I were dealt with
- The results were in good agreement with computer code calculations
- First results from post experiment material examinations did not indicate significant changes

3D. Round Table Discussion

1. Feasibility of the IHX at wall temperature above 8oo° for long lifetime

The main feasibility problem in the development of an IHX for high temperature application is to be seen in the qualification of suitable materials and in the generation of a design code covering the temperature range from 816° C up to about 1ooo° C. Data on long time behaviour of the materials envisaged for the IHX are available from measurements under HTR-helium and process gas environment up to about 1o.ooo hrs and can be extrapolated up to 3o.ooo hrs. The results for IN 617 are thought to be sufficient to serve as a basis for the lay out of test components and test rigs.

The design of an IHX has to be assessed on the basis of an overall load study, not only looking on creep behaviour. It is expected, that primary stresses can be kept rather small by special designs and that secondary stresses as well as creep fatigue damage may become a limiting factor. Preliminary calculations show considerable secondary stresses already at small temperature gradients, but a final conclusion can not yet be drawn as basic uncertainties due to hold time effects and local discontinuity effects have not been investigated to a sufficient extent.

Development and testing of materials that will show the appropriate data under HTR-conditions and the experimental verification of the component design are most important. It was pointed out that such experimental verification tests are necessary and helpful even though the behaviour of commercial alloys will not be sufficient for the layout of a high temperature IHX with the anticipated long life time in a nuclear plant.

2. Suitability of Incoloy 8oo

Incoloy 8oo with modifications (Incoloy 8o2, Incoloy 8oo H) is a common material for steam generators of fast breeder and HTR power-plants. However, the material seems not to be suitable for the high temperature section of an IHX for HTR-process heat applications at wall temperatures above approx. 8oo°C.

Recent experiments show that the material strength properties are influenced by the impurities of the helium atmosphere. Whereas Incoloy 8oo may be acceptable under oxidizing conditions up to 8oo°C or even higher, tests performed in carburizing atmosphere show a significant reduction of the strength data. It should be mentioned that both conditions have to be considered, as indicated by the experience gained from various projects (Dragon, FSV, THTR and future projects).

The interactions between impurities and the alloys in the high temperature environment are sufficiently understood by the approach of equilibrium thermodynamics. The main problem, however, is to be seen in the definition of the actual reactor atmosphere under various operating conditions. The carburizing or oxidizing resistance of a material is of prime importance for material selection and influences the material development programm.

3. Tritium problem

The problems related to tritium permeation have not been discussed in detail. The importance to minimize the tritium content of the product gas to a level as low as possible has been recognized.

Stable coatings on the surfaces of the heat exchanger components (incl. steam reformer) would meet such requirements best. The problems of the development of such coatings are related to material aspects. Therefore, they have not been debated within the frame of this round table discussion.

4. Importance of Inservice Inspection Capability of Large Heat Transfer Components

The licensing procedure for nuclear components asks for full inservice inspection capability. To fulfil these requirements special inspection methods are developed in several countries. The heat exchanger designs presented show a compromise between expected function (simple design) and accessability for ISI. However, it was pointed out that at this time there are no fully appoved measurement methods available for austenitic steel and nickel based alloys.

5. Explosion Hazards

Explosion hazards are thought to be a very important safety problem. The Working Group proposed to have a special discussion on this topic in a future Specialists Meeting.

6. Action List

i Mr. Quade agreed to provide a summary on R & D - work carried out for steam reformers and IHX in context with HTR-process heat projects. He will provide a draft of such a paper and he will contact all the specialists involved in R&D and ask for contributions.

ii Mr. Niemeyer will prepare a similar paper concerning the various designs of IHX and steam reformer carried out up to now. He will proceed as mentioned above.