Organisation for Economic Cooperation and Development
Nuclear Energy Agency
Committee on the Safety of Nuclear Installations

OECD—NEA—CSNI Specialist Meeting
HIGH TEMPERATURE GAS COOLED REACTOR SAFETY
Current Status and Perspective
Petten, The Netherlands, 13–15 May 1975

PROCEEDINGS

Volume A

— Report on the meeting
— Programme
— Abstracts
— Discussions
Organisation for Economic Cooperation and Development

Nuclear Energy Agency

Committee on the Safety of Nuclear Installations

OECD - NEA - CSNI Specialist Meeting

High Temperature Gas Cooled Reactor Safety

Current Status and Perspective

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Volume A
- Foreword
- Contents
- Summary Programme
- Programme Group
- Report on the Meeting
- List of Participants
- List of Contributions
- Programme
- Abstracts
- Discussions

REACTOR CENTRUM NEDERLAND
High Temperature Gas Cooled Reactor Safety
Current Status and Perspective

OECD - NEA - CSNI Specialist Meeting
Petten, The Netherlands, 13-15 May 1975

Distribution: 80 Participants
40 CSNI-Members
20 NEA
20 RCN

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Petten, July 1976
Foreword

The Committee on the Safety of Nuclear Installations of the Nuclear Energy Agency of OECD has sponsored a meeting on the Safety of High Temperature Gas Cooled Reactors. The meeting was hosted by Reactor Centrum Nederland at Petten from 13-15 May 1975. There have been 80 participants from 14 different countries and International Organisations and 23 papers have been presented in 6 sessions.

The potential of helium cooled reactors for electricity production and process heat has been reason to discuss the safety merits of this reactor system. Both the safety of the prismatic fuel and the pebble bed fuel type of HTGR have been considered in the context of their proposed applications. Gas cooled fast breeder reactors were not included in the programme.

The meeting was grouped in 8 different sections:

- invited papers
- fission product behaviour
- specific accident considerations
- containment aspects
- ultimate accidents
- process heat applications
- safety requirements
- panel discussion

The proceedings are contained in two volumes:

Volume A - abstracts and discussions
Volume B - programme and papers.

In Volume A is included a report on the meeting to CSNI by E.V. Gilby. A summary of the meeting was presented by K.B. Stadie at the IAEA-NEA Symposium on Gas Cooled Reactors in October 1975 in Jülich. An appreciation of the meeting has been made by F.P.O. Ashworth and H.J. de Nordwall of the late Dragon Project. Their digestion of the papers and a tabulation of the proposals for HTGR safety research and development have been issued as DP Report 964.

Thanks are due to the Programme Committee and in particular to N. de Boer for preparing the meeting, to Ada Hink and Else Endel for their help in organising this meeting and editing these proceedings and to R. Blackstone for his quick review of what is contained in this Volume.

Petten, 1st July 1976

R.G. Schöltvinck
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary Programme</td>
<td>6</td>
</tr>
<tr>
<td>Programme Group</td>
<td>6</td>
</tr>
<tr>
<td>Report on the Meeting</td>
<td>7</td>
</tr>
<tr>
<td>List of Participants</td>
<td>11</td>
</tr>
<tr>
<td>List of Contributions</td>
<td>13</td>
</tr>
<tr>
<td>Programme</td>
<td>15</td>
</tr>
<tr>
<td>Abstracts and Discussions</td>
<td>18</td>
</tr>
<tr>
<td>Panel Discussion</td>
<td>86</td>
</tr>
</tbody>
</table>
Summary Programme

Tuesday 13th May
Invited Papers
Session I : Fission product behaviour

Wednesday 14th May
Session II : Specific accident considerations
Session III : Containment aspects
Session IV : Causes and consequences of ultimate accidents

Thursday 15th May
Session V : Special problems arising from applications other than electricity production
Session VI : Requirements in the field of HTGR safety
Panel : Future requirements and international collaboration in the field of HTGR safety

Programme Group

N. de Boer OECD/NEA
E.V. Gilby United Kingdom
C. Kelber United States
R.G. Schölinck The Netherlands
K.B. Stadie OECD/NEA
G. Wolany Germany
STEEERING COMMITTEE FOR NUCLEAR ENERGY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

Report on the Specialist Meeting on the Safety of High Temperature Gas-cooled Reactors

Proposal for the setting up of an ad hoc Working Group on the Assessment of High Temperature Reactor Safety

The Specialist Meeting on the safety of high temperature gas-cooled reactors, which the Committee approved at an earlier meeting, was hosted by the Reactor Centrum Nederland (RCN) and held from 13th - 15th May 1975.

The summary of the results of the Specialist Meeting was prepared by Mr. E.V. Gilby, United Kingdom.

The Specialist Meeting was concluded by a Panel which made recommendations and received offers for collaborative efforts in the area of high temperature gas-cooled reactor safety. These proposals were subsequently reviewed by the Programme Group at a meeting on 11th June 1975, and are given below:

1) to review the appreciation of the 1975 Specialist Meeting on HTGR safety, as prepared by the OECD Dragon Project,

2) to consider national studies on HTGR Accident Initiation and Progression Analysis with a view to making submissions to the Committee on such things as:

   (i) relative priority of HTGR safety topics,

   (ii) suitable topics for future specialist meetings.

The Committee is invited to note the report and approve the proposal to set up an ad hoc Working Group on HTGR safety, based on the text defined above.
Session III - Containment Aspects

Only two papers were presented in this session. One of these presented the arguments for an outer containment for an HTGR, while the other paper concluded that such containments may not necessarily be required. During discussion an important aspect which arose was the possible need to provide an outer containment as a certain way of protecting the vessel from a crashing aircraft. If aircraft crash design criteria are adopted which require the use of an outer strong building, then this could lead to changes in the safety case as regards internal accidents. The discussion also served to show that there are disadvantages about the use of the pressure tight containment.

Session IV - Causes and Consequences of Ultimate Accidents

Two papers were presented in this session, one from Germany and one from General Atomic in the USA. This session was of particular interest to most delegates, because previously in the HTGR field it had not been customary to follow the example of other reactor discussions in considering very low probability ultimate accidents. The analyses presented included consideration of such unlikely events as a complete loss of convective cooling with continuous failure to re-establish coolant flow. Because of the particular properties of the HTGR core, even although high temperatures were predicted, the ultimate consequences in no way resembled those predicted for other thermal reactors. Discussion seemed to reflect the view that HTGR's may be seen to have safety advantages, if controlling the consequences of ultimate accidents was considered to be an important safety issue.

Session V - Special Problems from Applications other than Electricity Production

There has been considerable international discussion about the possible use of HTGR's for applications other than the production of electricity. Many applications involve placing HTGR's relatively close to chemical plants and the UK paper in this group of three papers discussed this problem in some detail in terms of a probability argument. The stringency of the requirements imposed on nuclear plants are not necessarily matched up by those customarily placed on chemical plants and it was considered that the failure of adjacent chemical plant could give rise to a relatively high level of risk to the reactor. Relative siting of the reactor and plant can play some part in improving the situation but this is an area which merits considerable further investigation for some of the applications envisaged for HTGR's.

Session VI - Requirements in the Field of HTGR Safety

In this session a paper from Dragon staff gave a full account of work that would be required for an analysis of the risk associated with an HTGR. A UK paper indicated the nature of the criteria that were being developed for application to HTGR and other reactors within the UK.
### List of participants

<table>
<thead>
<tr>
<th>Country</th>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>J.Y. Béon</td>
<td>Technicatome - Saclay</td>
</tr>
<tr>
<td></td>
<td>J. Brisbois</td>
<td>CEA - Saclay</td>
</tr>
<tr>
<td></td>
<td>J. Charles</td>
<td>SHTR - Paris</td>
</tr>
<tr>
<td></td>
<td>L. Guccia</td>
<td>CEA - Saclay</td>
</tr>
<tr>
<td></td>
<td>Ph. Lebouleux</td>
<td>CEA - Saclay</td>
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<td></td>
<td>C.G. Moreau</td>
<td>CEA - Grenoble</td>
</tr>
<tr>
<td>Germany</td>
<td>S. Brecht</td>
<td>STEAG - Essen</td>
</tr>
<tr>
<td></td>
<td>C.B. von der Decken</td>
<td>Kfa - Jülich</td>
</tr>
<tr>
<td></td>
<td>H.P. Drescher</td>
<td>Bonnenberg + Drescher</td>
</tr>
<tr>
<td></td>
<td>J. Engelhard</td>
<td>Jülich</td>
</tr>
<tr>
<td></td>
<td>J. Fassbender</td>
<td>AVR - Jülich</td>
</tr>
<tr>
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<td>H.W. Gabriel</td>
<td>Kfa - Jülich</td>
</tr>
<tr>
<td></td>
<td>G.J. van Glabbeek</td>
<td>HRB - Mannheim</td>
</tr>
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<td></td>
<td>N. Iniotakis</td>
<td>HRB - Mannheim</td>
</tr>
<tr>
<td></td>
<td>O. Kellermann</td>
<td>Kfa - Jülich</td>
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<td>K. Kietzer</td>
<td>IRS - Köln</td>
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<td>W. Kröger</td>
<td>TUV - Essen</td>
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<td>P. Kubaschewski</td>
<td>Kfa - Jülich</td>
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<td>U. Kujath</td>
<td>HRB - Mannheim</td>
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<td>K. Kugeler</td>
<td>HRB - Mannheim</td>
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<td>K. Münchow</td>
<td>Kfa - Jülich</td>
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<td></td>
<td>K.W. Otto</td>
<td>Kfa - Jülich</td>
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<td></td>
<td>K. Petersen</td>
<td>RWTH - Aachen</td>
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<tr>
<td></td>
<td>J.A. Redondo</td>
<td>Kfa - Jülich</td>
</tr>
<tr>
<td></td>
<td>H. Rehn</td>
<td>HRB - Mannheim</td>
</tr>
<tr>
<td></td>
<td>H.A. Ritter</td>
<td>NIS - Nanau</td>
</tr>
<tr>
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<td>H. Sameith</td>
<td>Min. AGS - Düsseldorf</td>
</tr>
<tr>
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<td>K. Schifferstein</td>
<td>BMFT - Bonn</td>
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<td>G. Schröder</td>
<td>IRS - Köln</td>
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<td>R. Schüler</td>
<td>STEAG - Essen</td>
</tr>
<tr>
<td></td>
<td>D. Wahl</td>
<td>TUV - Essen</td>
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<td>H. Witulski</td>
<td>RWE - Essen</td>
</tr>
<tr>
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<td>G. Wolany</td>
<td>Min. WMV - Düsseldorf</td>
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<tr>
<td>Italy</td>
<td>G. Basso</td>
<td>BMI - Bonn</td>
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<tr>
<td>Japan</td>
<td>S. Mitake</td>
<td>CNEN - Roma</td>
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<td></td>
<td>M. Ono</td>
<td>JAERI - Tokai Mura</td>
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<td>A. Tachibana</td>
<td>EPD Co. - Tokyo</td>
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<td></td>
<td>H. Yoshikawa</td>
<td>JAPCO - Tokyo</td>
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<td></td>
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<td>Mitsubishi - Tokyo</td>
</tr>
</tbody>
</table>
OECD-NEA-CSNI
HTGR Safety Meeting
RCN-Petten, 13-15 May 1975

List of contributions

Invited Papers

SNI 4a  Current safety considerations and their effect on HTGR safety
        F.R. Farmer (UKAEA-SRD)

SNI 4b  HTR - Safety philosophy in the Federal Republic of Germany
        O. Kellermann (FRG-IRS)

SNI 4c  HTGR safety research objectives
        R.D. Schamberger (USNRC)

SNI 4d  Design features of high temperature reactors
        L. Shepherd (OECD Dragon Project)

SNI 4/1 Gas-cooled reactor safety technology
        F.P.O. Ashworth and J. Kirk

SNI 4/2 Methods for the prediction and achievement of a low circuit activity
        R.L. Faircloth and A.N. Knowles

SNI 4/3 Some comments on fission product behaviour in HTGR's and its impact on safety
        F. Abbey

SNI 4/4 Behaviour of fission products in case of a depressurisation accident
        C.B. von den Decken, N. Iniotakis and K.H. Münchow

SNI 4/5 The environmental impacts of the HTGR 1160 and the risk assessment
        H. Eisele, H.W. Gabriel and J.A. Redondo

SNI 4/6 The depressurisation accident in steam cycle HTGR's - graphite corrosion in core and its consequences for reactor safety
        H. Jauer, P. Kubaschewski and H. Werthmann

SNI 4/7 Requirements for the afterheat removal systems of high-temperature reactors in the Federal Republic of Germany
        K. Schifferstein
OECDEA-CSNIE
HTGR Safety Meeting
RCN-Petten, 13-15 May 1975

PROGRAMME OF THE MEETING

Tuesday, 13 May

Registration

Opening of meeting by J. Pelser, Reactor Centrum Nederland
Welcoming address by K.B. Stadie, OECD - NEA - CSNI

Chairman: J. Pelser

| Invited          | F.R. Farmer (UKAEA-SRD):                                                                 |
| Paper            | Current safety considerations and their effect on HTGR safety                       | 18 |
| Invited          | O. Kellermann (FRG-IRS):                                                              |
| Paper            | HTR - Safety philosophy in the Federal Republic of Germany                            | 19 |
| Invited          | R.D. Schamberger (USNRC):                                                            |
| Paper            | HTGR safety research objectives                                                      | 22 |
| Invited          | L. Shepherd (OECD Dragon Project):                                                   |
| Paper            | Design features of high temperature reactors                                         | 24 |

Session I: Fission product behaviour

Chairman: R.D. Schamberger

| Paper           | F.P.O. Ashworth and J. Kirk:                                                          |
| SNI 4/1         | Gas-cooled reactor safety technology                                                 | 25 |
| Paper           | R.L. Faircloth and A.N. Knowles:                                                     |
| SNI 4/2         | Methods for the prediction and achievement of a low circuit activity                | 28 |
| Paper           | F. Abbey:                                                                             |
| SNI 4/3         | Some comments on fission product behaviour in HTGR's and its impact on safety       | 30 |
| Paper           | C.B. von der Decken, N. Iniotakis and K.H. Münchow:                                 |
| SNI 4/4         | Behaviour of fission products in case of a depressurisation accident                 | 32 |
Session IV: Causes and consequences of ultimate accidents

Paper
SNI 4/13
K.W. Otto, H. Bonka, J. Lukascevicz and R. Schulten:
Temperature behaviour of high-temperature reactors
in the case of hypothetical accidents

Paper
SNI 4/14
F.A. Silady and V. Joksimovic:
Consequences of unrestricted core heat-up event

Thursday, 15 May

Session V: Special problems arising from applications other than electricity production

Chairman: C.B. von der Decken

Paper
SNI 4/15
G.D. Bell and J. Shepherd:
Safety problems arising from process heat applications
of HTGR's

Paper
SNI 4/16
R. Schulten, K. Kugeler, C.B. von der Decken and
R. Hecker:
Studies for intermediate heat transfer loops in
process heat reactors

Paper
SNI 4/17
H. Barnert, K. Petersen, M. Schäfer, H.J. Scharf,
J. Engelhardt and G. Schroeder:
Safety aspects of the PR 500 for the combined production
of electricity and district heat

Session VI: Requirements in the field of HTGR safety

Paper
SNI 4/18
F.P.O. Ashworth and H.J. de Nordwall:
The status of information required for an independent
analysis of risks associated with an HTR

Paper
SNI 4/19
D.R.H. Fryer:
A review of certain gas-cooled reactor safety issues

Panel:
Future requirements and international collaboration
in the field of HTGR safety

E.V. Gilby (Chairman)
C.B. von der Decken
J. Fassbender
R.D. Schamberger
L.R. Shepherd
K.B. Stadie
Joksimovic:

Could you elaborate on what kind of higher safety standards you are going to apply to HTGR's?

Kellermann:

We think of higher safety standards for HTGR's because of their potential of being built close to urban areas. This does not necessarily mean more hardware in systems and circuits. A specific answer to your question can only be given in a defined application.

Joksimovic:

I did not understand your statement with regard to passive failures.

Kellermann:

The single failure criterion has to be applied for active components, for passive components it seems desirable to be applied, but it is not a general rule on inter meshing of passive components can lead to shorter and safer chains.

Joksimovic:

What kind of (ATWT or) ATWS criteria are going to be used for judging HTGR's?

Kellermann:

Besides stringent investigations of the shut-down systems, the known relevant US-NRC guides for LWR's are applied in principle.

Fryer:

Is the load time diagram for aircraft impact a requirement of IRS or is it a proposal from the designers?

Kellermann:

The load time diagram is a simplified result of IRS calculations for a military plane (Phantom). The result is in good agreement with similar calculations of industry. The diagram became part of the criteria of the Federal Minister of the Interior.

Fryer:

What account is taken of fire following aircraft impact?
- Question: for a hardened containment which provisions do you make to assure similar protection for the decay heat removal chain?

Kellermann:

All parts of the nuclear plant, water and energy supply etc., which are needed for shut-down and long term decay heat dissipation have to be protected against aircraft impact, either by building structures and/or by redundancy - which includes locally distant arrangement of redundant systems.

Jacobi:

I have the following questions about sabotage:
- Is the saboteur model still "one man with one suitcase of dynamite?"
- What will happen if the reactor is left to operate by itself (as a consequence of a saboteur group forbidding to take any action by operating personnel). Is it going to be an automatic shut-down. Are regulations in Germany asking for this?

Kellermann:

The sabotage model has been developed during the last years in cooperation with Governmental specialists. The work of the relevant group is confidential. Information on those questions can only be given during a definite licensing procedure.
Farmer:

I was surprised to hear you suggest the need for full scale validation tests and the possibility of proving reactor safety by experiment. Is not this in principle almost impossible, it would require too many experiments. In 1964 a discussion in USA proposed a reactor depressurisation experiment to show that there would be little or no release of fission products (LOFT).

If the experiment had been made in 1965 (or later) it would not have "proved" anything other than the result of the one experiment.

Schamberger:

Validation experiments, in whatever scale, require careful planning and execution to produce useful information. The intent of my comments about full scale validation was to indicate, that there may be problems such as the core and core support seismic response for which physically scaled model tests may be inappropriate, either to develop an understanding or to validate an analysis.

Ono:

In the U.S. ORNL people carry out the national R&D program and this program started last year. But the USACRS people pointed out so many additional R&D items as an obligation for the construction permit of the Summit power plant. Can I understand it this way that the R&D items which are pointed out by the ACRS are additional requirements for the ORNL research program?

Schamberger:

Requirements associated with the licensing process, including those derived from ACRS concerns, may be met by the ORNL program or by other activities such as the development program at General Atomic (Refer to V. Joksimovic for schedule).

Tattersall:

Does Dr. Schamberger see any anomaly in a Safety Authority generating data for safety evaluation?

Schamberger:

Not really. A regulatory authority should be in a position to confirm or extend data, particularly in relation to low probability accidents.
GAS-COOLED REACTOR SAFETY TECHNOLOGY

by

F.P.O. Ashworth* and J. Kirk**

In common with all commercial reactor systems, the safety of the HTR largely depends upon the integrity of the fuel cladding. Whilst some limited release of actual fission products is usually permissible, in both normal and fault conditions, the vast majority are retained within the fuel and cladding. The demonstration that only acceptably small releases occur in the HTR requires an understanding of the transient responses of the core and associated plant to fault disturbances, and of the fission product retaining properties of the core and primary circuit.

The paper discusses these aspects of the HTR with particular reference to the integral graphite block system with low enriched uranium fuel clad in high integrity particle coatings, which is being developed in the U.K.

The adequacy of any part of the technology is decided by the final stage in the process of acquiring basic data, predicting behaviour in specified conditions, proving these predictions and extrapolating the predictions to the power reactor. This extrapolation is often the most difficult and expensive step and the vital role of the Dragon Reactor Experiment at this stage will become evident in the brief survey of the current technology.

__________

* OECD Dragon Project, United Kingdom.
** BNDC, United Kingdom.
Mancini:

Just a short comment on this question.
I think that a measure of $\bar{\phi}$ during operation of the reactor would be very valuable as indication that one could relax on quality assurance programme before the fuel charge, being able to discharge faulty fuel during operation without big economical penalties.
I agree with Mr. Ashworth in the importance he has attached to the degradation estimate of the core since the beginning of its life. Furthermore I would stress the importance of evaluating the statistical random differences within the core in fuel properties, mass flow, temperatures, etc. etc. I think it is very important to take these uncertainties into account in the fission product release prediction. For instance these uncertainties could affect the Cs release in a BISO core up to two orders of magnitudes.

De Nordwall (continuation of answer from Ashworth to J. Shepherd):

A method for measuring SiC barrier layer failure consequences may not be needed in a power reactor, but it is necessary in an experimental reactor testing a variety of BISO fuel.
I would ask Mr. Joksimovic to indicate what information is likely to be available from Peach Bottom to complement the series of validation processes described by Mr. Ashworth.

Joksimovic:

I have not been able to find time lately to study Peach Bottom decommissioning program, hence I cannot answer your question directly, however, I would be glad to do so.
R.L. Faircloth and A.N. Knowles "Methods for the prediction and achievement of a low circuit activity"

No questions, no remark.
F. Abbey "Some comments on fission product behaviour in HTR's and its impact on safety"

Schamberger:

Please indicate the extent of your consideration of the low probability - potentially severe consequence events.

Abbey:

The paper represents, in this area, an attempt to use the Rasmussen report - WASH 1400 - as a model and aid in listing some of the important factors which would have to be taken into account in analysis of such accidents, particularly so far as fission products and fissile and fertile material behaviour is concerned. There is a small amount of relevant basic data which is I think well known. But we have not as yet made much progress in applying the data to the situations to be analysed - that lies in the future.

Flowers:

Some years ago Dr. De Nordwall and I designed an in-pile loop, called PLUTO LOOP B, specifically to study the behaviour of fission products in an HTR during accident sequences. The particular situation described by Mr. Abbey in which loss of forced cooling leads to overheating of the block, cannot be easily investigated in the loop described by Mr. Ashworth this morning because the accident involved the fuel as well as the external circuit. It is this kind of accident study which requires a well instrumented loop in a Materials Testing Reactor, rather than out-of-core modifications to the Dragon Reactor gas circuit.

Abbey:

I agree.
C.B. von der Decken, N. Iniotakis, K.H. Münchow "Behaviour of fission products in case of a depressurisation accident"

Presented by C.B. von der Decken

Stibbe:

What is the nature of the dust in the helium flow mentioned in the lecture. Will the dust be activated and so increase the radioactive content in the gas?

Von der Decken:

I can answer this but I think Mr. Engelhard can answer this better.

Engelhard:

The dust concentration measurements in the AVR primary circuit range from 2-40 µg/Nm³. Normally about 70% of the dust is graphite material. The rest consists of metallic materials, mainly iron.

De Nordwall:

Though the iron, chromium group elements appear in dust, they have low capture cross sections that keep these activities below those of cesium. Also the activation products do not pose serious radiological problems.

Fryer:

In estimating release following depressurisation what assumptions were made regarding surface temperatures upon which the description is presumably dependant, both in the short and long term?

Von der Decken:

The temperature distribution is assumed to be the same as for normal operation and not decreasing during the short time of depressurisation. For the long term just to show the trend the same assumption has been made. If a more detailed description of the accident is made, corresponding calculations could be made for these cases.

Flowers:

You assume in figs. 2 and 3 that your rather level Cs profiles result from a combination of diffusion into the surface and a finite heat of adsorption. Could you not also fit the data with a mass transfer limited plate-out with negligible gas stream depletion over the length of sections studied. If so this would allow you to drop two of your three disposable constants.

Von der Decken:

The fit of the data you have in mind is not possible consistently for the different experiments. If you would do so you would have to assume for example a locally variable desorption energy or something like this and end with a large number of disposable constants which do not have any real physical meaning.
THE ENVIRONMENTAL IMPACT OF THE HTGR 1160 AND THE RISK ASSESSMENT

by

H. Eisele, H.W. Gabriel and J.A. Redondo,
Hochtemperatur Reaktorbau GmbH, Mannheim, Germany

After giving a short description of the environmental impact during normal operation, the lecture will give an overview of the accident conditions, the resulting environmental impact and the design consequences arising out of these disturbances (especially DBDA).

As a part of the design consequences, there is described the arrangements of the buildings in order to take into account the disturbances coming from outside of the plant (airplane crashes, explosions).

Using those conditions, a consideration basic will illustrate the safety philosophy favoured by HRB. The goal is a more objective risk assessment. In support of this philosophy, certain probability considerations will be made; the contrasting MCA-concept will also be mentioned.

As a part of above-named considerations, the design of the core cooling systems will be described.
THE DEPRESSURISATION ACCIDENT IN HTGRs WITH STEAM CYCLE
- GRAPHITE CORROSION IN THE CORE AND ITS CONSEQUENCES
ON REACTOR SAFETY

by

H. Jauer, P. Kubaschewski and H. Werthmann
Hochtemperatur Reaktorbau GmbH, Germany

The depressurisation accident with following air ingress into the core is discussed for the 300 MWe-THTR and for the HTGR-1160 MWe nuclear power stations with respect to the consequences of graphite corrosion, and the resulting loss of strength, and the formation of combustible gases. The results are: the graphite burn off in less than 5%-wt and therefore tolerable, no inflammable gases are formed.
REQUIREMENTS FOR THE AFTERHEAT REMOVAL SYSTEMS OF HIGH TEMPERATURE REACTORS IN THE FEDERAL REPUBLIC OF GERMANY (FRG)

by

A. Schifferstein

Institut für Reaktorsicherheit der TÜV, Germany

The requirements for the after heat removal systems of the THTR-300 MWe Prototype nuclear power station (THTR-300) and of the HTR-1160 MWe Demonstration Plant (HTR-1160) are discussed. The safety criteria of the Federal Ministry of the Interior require that the single failure criterion has to be applied and that the emergency core cooling system (ECCS) has to be capable of sufficiently removing residual heat from the core, also when parts of the system are under repair or under functional testing.

During the construction period of the THTR-300, the design criteria for nuclear power plants in the FRG changed essentially with respect to protection against external impacts such as air-plane crashes, pressure waves from chemical explosions etc.

The after-heat removal system of the THTR-300 is discussed in its original design and in its present stage. Ameliorations have been adopted to meet as far as possible the new requirements of protection against external impacts. In addition to the normal heat removal system, which is also designed to take off the after-heat even in the case of a fault in the primary circuit, two separate after-heat removal loops of 100% each have been installed. As the only common active components, these loops have, together with the normal heat removal system, essentially the H2-blowers and the steam-generators both of which are located within the prestressed concrete reactor vessel (PCRV).

The core auxiliary cooling system (CACS) of the HTR-1160 is independent of the main loop cooling and consists of three loops with a capacity of 50% each. It is evident that this system does not meet the above-mentioned safety criteria for emergency core cooling systems (ECCS). During repair or testing, the capacity of the CACS would be reduced to 50% by the single failure criterion. A final decision has not yet been taken in the FRG.

There is a trend in safety philosophy towards a restricted acceptance of probability methods in safety evaluation of systems. The German Reactor-Safety-Commission (RSK) has already a guideline which says that during short periods of repair in the ECCS of a pressurized water reactor, a single failure must not be supposed in passive systems under the
K. Schifferstein "Requirements for the afterheat removal systems of HTGR's in the Federal Republic of Germany"

Joksimovic:

I would like to make three points.

1. Power reduction would be required in the U.S. if one CACS loop is inoperable after a certain period of time. In our current applications, Summit and Fulton, we have proposed 7 days. USNRC has not disagreed with this approach.

2. Now can we quantify HTGR inherent safety characteristics in a way that the German licensing authorities would give us credit? Perhaps you can give us an example.

3. On page 3 of the paper you have stated that design basis events need not be combined with external events on the basis of very low probability of combined events. Could you give us an example which natural phenomena do have to be combined with design basis event.

Schifferstein:

1. I mentioned the power reduction of the plant during repairs of the CACS as a possibility to meet the safety criteria for ECCS, but I mentioned too that the PWR guide-lines of the RSK admit that a single failure in a passive component must not be supposed during short period of repairs in the ECCS under the condition that the reliability of the ECCS does not diminish significantly. I suppose that the discussion about the CACS of the HTR could lead to a similar result.

2. With respect to the core auxiliary cooling system (CACS) the damage to the plant and to the environment should be analysed in detail under the assumption that the CACS fails completely after a severe accident as for example the loss of main loop cooling.

3. Natural events which should be combined with the design basis accident (DBA) have to be defined dependent on a special site. Loads could be the load of snow and storm for example. The discussion on the combination of the DBA with earth-quake is going on in the RSK.

Vieider:

Mr. Schifferstein could you please indicate your estimate for the failure probability of the HTR decay heat removal system?

Schifferstein:

For the HTR 1160 the manufacturer gives a figure of $10^{-4}$ for the failure of 2 of 3 core auxiliary cooling loops per demand.
SAFETY CHARACTERISTICS OF THE EXPERIMENTAL
MULTI-PURPOSE HIGH-TEMPERATURE GAS-COOLED REACTOR

by

S. Mitake, M. Ezaki and K. Suzuki
Japan Atomic Energy Research Institute, Japan

The design study of an experimental multi-purpose high-temperature gas-cooled reactor and its cooling facilities has been conducted. The related investigation has shown that the safety characteristics are significantly affected by the particular features of the experimental reactor (outlet-gas temperature 1000°C) which is composed of a steel reactor vessel, pin-in-block type fuels, intermediate heat exchangers and steel coolant ducts.

In the case of the normal operation, calculation was carried out for amounts of activities circulating in the reactor coolant, removed by the purification system and released to environment through the ventilation system, as well as activities deposited on the inner surface of coolant ducts. Release of metallic fission products diffused from fuel and their deposition on the inner surface of coolant duct were investigated precisely, paying attention to effects of fuel and duct surface temperatures on these physico-chemical behaviours.

The analysis was performed for consequences of reactor plant condition in hypothetically postulated accidents, such as, loss of capability of main cooling system, unavailability of coolant circulation in the core and loss of primary coolant. Requirements for the design of engineered safety systems were indicated. Heat removal from the outside of the reactor vessel is effective as one of the emergency reactor cooling systems when the core cooling by the forced circulation is not expected. The leak tight compartments confining the reactor and primary coolant system contribute to mitigate the hazards caused by normal and accidental release of the coolant.

Studies on the dynamics and control of the reactor plant in transients revealed that nuclear characteristics and heat capacity of the core gives the stable responses. One of the problems to be overcome is the plant control so that the temperatures of components must be placed below their accepted design levels.
J. Shepherd:

In fig. 5 you show tritium arising from both lithium-6 and boron-10. What fraction of the total tritium arises from the boron reaction? I am not suggesting that tritium is a major hazard but I would be interested to know the relative magnitude of the two source terms.

Mitake:

About 19% of the total tritium arises from the boron reaction. Ternary fission and helium-3 reaction are also a source of tritium and these two processes contribute about 10%.
To guarantee an exact identification of the defect heat exchanger unit its humidity has to exceed to others at least by the measuring fault of the detectors. As the measuring range is approximately 1000 vpm this difference should be 700 vpm or more. This necessity causes complications when analyzing smaller leaks which normally precede a rupture of a steam tube. If such a leakage does not exceed 100-200 g/sec it will not be identified automatically but nevertheless will raise the average humidity of the primary circuit above 1000 vpm within 2 minutes thereby exceeding the measuring range of all detectors. If now, after these 2 minutes, the steam tube breaks there is no possibility of detecting the damaged unit by any instrumentation of the primary circuit.

These aspects need a detailed treatment of the different possibilities of leakages and ruptures at the steam generators. Their instrumentation has to be designed not only for controlling an immediate 2 F-rupture of a tube but also for smaller leaks or increasing leaks which all may lead to different logical input signals of the reactor safety system.
CONSEQUENCES OF HTGR WATER INGRESS EVENTS INTO PRIMARY COOLANT SYSTEM

by

A.W. Barsell*, V. Joksimovic*, M.B. Peroomain*

and B. Pellaud**

Event sequences and simulated responses of a large high-temperature gas-cooled reactor (HTGR) are presented for postulated steam/water inleakage into the primary coolant system. Effects of core graphite oxidation by steam in the fuel elements and core support posts are assessed for a spectrum of leak rates from a steam generator tube failure, ranging from slow inleakage where time is available for orderly plant shutdown, to an offset shear tube rupture with automatic plant protection system action. Reaction of the steam with the fuel and attendant fission product release to the primary coolant are also evaluated.

For the postulated offset tube rupture, accident sequences are traced and consequences assessed for primary coolant pressure increase and possible PORV pressure relief as well as gas and fission product blowdown to the containment. The sequences consider the mitigating effects of plant protection systems of moisture detection and leaking steam generator dump, as well as the effects of rapid post-trip core cooldown by the main cooling loops or extended cooldown duration using the core auxiliary cooling system. The consequences include the effects of blowdown on the containment pressure and temperature and the potential for generating flammable mixtures of reaction product gases CO and H₂ air.

The analyses were performed using the Oxide-3 computer code, developed specifically for these purposes. Core geometry consists of 20 regions of specified flow and power densities and one variable-power axial segment for each fuel element row and one each in the top and bottom reflectors. In each segment a triangular element of symmetry around an element coolant channel is modeled with 17 nodes. In-volume diffusion of steam and reaction product gases is calculated along with local chemical reaction and transient temperatures in the fuel and graphite. Mass continuity and state equations are solved for all gaseous species throughout the primary coolant system. Models for the pressure relief system and for the containment thermodynamics response are included.

Rapid cooldown of the core and not the amount of steam ingress was found to be the most important effect mitigating core graphite oxidation. Slow steam leaks where the operator shuts the plant down at, say, 30 min. can correspond

* General Atomic Company, San Diego, United States
** General Atomic Europe, Zurich, Switzerland
A.W. Barsell, V. Joksimovic and M.B. Peroomain "Consequences of HTGR water ingress events into the primary coolant system"

Presented by V. Joksimovic

Drescher :

What's about the ingress of water during the start-up experiments of the Fort St. Vrain reactor?

Jojimovic :

At FSV we have experienced a large water ingress event, which amounted to approximately 4000 gallons of water. It should be noted that the water did not come from the steam generators. At the time of incident the reactor was subcritical. Consequences of this event have resulted in long term plant unavailability. There were no safety repercussions whatsoever.

Mancini :

I would like to make some comments to the presentation of Mr. Joksimovic. First of all I think a mechanistic link between depressurisation and boiler tube rupture cannot be dismissed unless a detailed analysis is carried out. Let me recall some design and operation uncertainties to which the boilers are subject: tube thickness, tube material, tube welding, creep data, local heat transfer coefficients, water side corrosion, tube gas and water flows, water treatment plant malfunction, water steam flow pulsations, vibration, thermal cycling, higher local heat fluxes with consequent higher creep rates.

In work now being published as DPR, I have also investigated the water gas accident. The main differences in respect to G.A. work: different fuel geometry (T.I. instead of block type), smaller primary circuit break, different after heat removal sequence, different codes used (Tuber instead of Oxide). Another main difference arises from the fact that we investigated such an accident in a parametric way, using the total inventory of water ingressing in the primary circuit, its flow rate, the time of tube burst after depressurisation, and the type of containment. The conclusions are different in that the major hazard from flammability point of view, are attained for late tube burst, when the graphite temperature undergoes a maximum (this case has not been investigated by G.A.) and for small water leak rate (2 kg/s, one tube failed). In the case of a coincident failure of primary circuit and boiler tube burst the consequences were minimal because of steam leaving in big quantity the primary circuit and inerting thereafter the containment before reacting with graphite. Furthermore the steam remaining in the primary circuit helps in a better cooling of the core in the first part of the transient, reducing the oxidation rate. As we recognized a flammability hazard for a tight secondary containment for some cases, we advocated a diluent injection in the primary circuit. I do admit that the flammability limits used in our study are more pessimistic than the ones used by G.A. Anyway also with these last limits, in a first check, we could get flammability hazards in a few cases if no diluent injection is adopted.
De Nordwall:

Have you analysed the consequences of a water leak originating in the CACS heat exchanger under pressurized or depressurized conditions?

Joksimovic:

We have analysed CAHE tube leaks under different conditions at GAC from a design standpoint, but no results have been published in the open literature. Basically, the safety implication is not so much core graphite oxidation or PCRV pressure rise, but rather maintaining adequate ultimate core cooling capability. We are accounting for the lower stress conditions, more stringent design (safety system) requirements, and lower probability of tube leaks in our work.

Drescher:

Which is the consequence of the delay time of the H₂O-detectors (22 seconds) on the total amount of water penetrating the primary circuit?

Joksimovic:

It depends on the size of the plant. In case of a 3000 MWt plant it amounts to approximately 3750 Lbs.
Aerosols are retained by adsorption of about 70... 90%. They can be retained almost totally by engineered features which result in the following design criteria; radioactive noble gases could necessitate additional requirements for very large power units.

The containment system:

- should be gastight with a ventilation and filtration system. The retention of fission products is higher - two or three orders of magnitude - than in case of uncontrolled release through the concrete wall. Ground-level release and release at worst conditions can be avoided. The layout of the ventilation system is influenced by required accessibility;

- should have an air purification-/clean-up system and an isolation system to guarantee long-time confinement of fission-products after DBDA;

- needs no active heat removal system because energy of the coolant gas will be transferred to the containment wall and other structures. (Temperatures after heat-up will be about 50...70°C.);

- must withstand accident loads (DBDA), extreme internal loads - especially to be regarded in case of nuclear-process-heat-reactors - and external loads which have to be considered.

The radiation doses could be further reduced by using a high stack and improved filter technique (noble gases).

The size of the structure is relevant to safety. It should be "as small as possible" to facilitate after-heat removal and to reduce air-volume with regard to potential air-graphite-reactions. Inertisation can be regarded as back-up solution.

To meet special siting and safety conditions, the reactor could be sited underground. Effects of hypothetical accidents, including containment failure, are reduced to a tolerable level because fission-products are absorbed and extremely delayed by surrounding soil. Even damaged closure systems can be covered later with material because of HTR-specific delayed progress of accident. Time for pressure balancing between containment and environment is no longer dependent on fracture but on permeability of the surrounding materials and can be extended decisively.

Optimum protection against external loads, high adaptability to future requirements and better conditions for decommissioning are further advantages of underground-siting.
Kröger:

Of course this is a very important problem and it sounds a little bit easy when I say that it is a question of priority. Our goal was the influence on the environmental impact by the containment system and the questions you raised have not been solved in this design. Of course plate out has a positive influence on the environmental impact and a negative effect on the accessibility of the containment.

Mancini:

Has accessibility of the tight secondary containment been taken into account during normal reactor operation in the calculation of attenuation of activity by the containment itself? If one has a high primary circuit leakage rate, the accessibility will dictate the release to atmosphere. In the case of a clean primary circuit (failed fuel particle of the order of $10^{-4}$) is there any need for a tight secondary containment in case of accident (i.e. DBA depressurization)?

Kröger:

To your first question fig. 4 only shows the attenuation by the containment system for the depressurization accident. Accessibility during normal operation has been considered in an other connection. Required accessibility is decisive for the lay-out of the ventilation and clean-up system, dependent on the achievable leakage rate. This is a technical problem.

To your second question: it is not necessary for fulfilling permissible limits, if you take plate-out and filtration inside the unlined containment into account. To keep far below permissible limits, a gas tight containment should be used. This might be important for special conditions e.g. urban siting of large power units. The ability to control f.p. release under all conditions is in principle the most important advantage.
These same conclusions can be made for the off-site doses resulting from the stringent hypothetical radioactivity release associated with site selection. This conclusion is possible because of the inherent safety characteristics of the HTGR which precludes an instantaneous release of fission products from the HTGR core, which in turn drastically reduces the two hour dose at the site boundary.
TEMPERATURE BEHAVIOUR OF HIGH-TEMPERATURE REACTORS
IN THE CASE OF HYPOTHETICAL ACCIDENTS

by

K.-W. Otto*, H. Bonka*, J. Lukaszewicz** and R. Schulten*

The after-heat removal after reactor shut-down is performed today in all reactor types with installations of multiple redundant lay-out. A total falling-out is generally regarded as a hypothetical accident and excluded therefore. It is, nevertheless, studied here the behaviour of a High-Temperature Reactor in an extreme situation like that.

At first are analysed the process-heat reactors PR 500 and PR 3000, developed in the Nuclear Research Center Julich. These are reactors of the pebble-bed type, cooled by helium. The characteristics of construction are: once-through feed-system of fuel elements, a carbon-containment for linear heat isolation, and the arrangement of steam generators, heat exchangers and blowers outside the pre-stressed concrete pressure vessel.

It is assumed in our studies the theoretical case of a simultaneous falling-out of all blowers of the primary circuit. The reactor is then shut-down automatically. A removal of after-heat due to forced-circulation cooling does not occur, thus core and installations increase their heat. The resulting periodical temperature gradient is calculated by a computer programme in a two-dimensional cylinder geometry. It is studied also the influence of an additional falling-out of the linear cooling.

The studies for PR 500, a process-heat reactor of a thermal power of 500 MW and an average power density of 5 MW/m², were performed under the pessimistic assumptions of a stagnation of cooling gas in the primary circuit and a falling-out of the linear cooling, which permits no removal of after-heat. These studies resulted in temperatures of 2300°C at the hottest place of the pebble-bed after two days. Only 10% of the fuel elements exceed the temperature of 2000°C.

Even under most unfavourable circumstances it is thereby guaranteed the dimensional stability of the fuel elements, because the point of sublimation is around 3500°C.

At the boundary layer of pebble-bed and reflector, a maximum temperature of 1500°C is reached after 20 days. The liner heats itself to about 1200°C in the hottest region within 50 days.

* Lehrstuhl für Reaktortechnik der RWTH Aachen, Germany
** Gesellschaft für Hochtemperaturreaktor-Tecnik mbH, Germany
K.W. Otto, H. Bonka, J. Lukasćevićz and R. Schulten "Temperature behaviour of high-temperature reactors in the case of hypothetical accidents"

Presented by K.W. Otto

Bell:

Has account been taken of the requirement to depressurise the reactor at some stage in the accident because of the overheating of the PCRV?

Otto:

This will follow automatically after some hours because of the increase of the liner temperature. Before the PCRV will be overheated, it will have lost its gas tightness.

Mancini:

Have you considered the possibility that high temperature gas streams could endanger boiler tube integrity with consequent water ingress and loss of structural integrity of the pebble fuel?

Otto:

One result of our studies is that after-heat removal by natural convection over the primary circuit must be permitted, not only because of overheating the heat exchanger tubes but also for the top reflector and the coaxial tubes.
The HTGR's graphite moderator, as well as the fuel itself, afford considerable time delay before consequences of the event peak. Graphite strength increases at higher temperatures, reaching a maximum at 2500°C and maintains significant strength at much higher temperatures. Average active core temperatures in a 3000 MWe plant do not exceed 3000°C until after 2 days. The only component to fail which significantly affects the thermal analysis in the first 2 days is the top heat PGRV thermal barrier.

The HTGR's pyrocarbon and silicon-carbide coated fuel kernels provide an important time delay. Significant failure of fuel particles does not occur until well after 1700°C. Furthermore, even failed particles have a finite release rate so that the noble gases are not completely released until 10 hours and halogens until 25 hours.

For the above-stated hypothetical event to mechanistically occur would require the extended failure of all main loops plus their steam motive power and failure of all auxiliary cooling loops plus each loop's electric motive power. The entire class of event trees for a loss of forced circulation has been considered. The most probable sequence of events has been estimated to have a probability of less than 10^-7 per year.
Joksimovic:

The isolatable portion of the SG consists of all piping between the dump valves, feedwater valves and stop check valves. These safety grade valves are located in the containment. Postulated rupture of a pipe just inside these valves after dumping, would depressurize primary coolant to the containment and resulting doses would be of the order of DBA doses. However, such an event has an extremely low probability, because of substantially lower stresses caused by primary coolant compared to secondary coolant pressure.

Massimo:

What sort of operator interventions can we assume can take place in the case of ultimate accidents?

Joksimovic:

In the event of an unrestricted core heat-up considerable study has been performed for the operator actions following a LOFC at the Fort St. Vrain plant. For this HTGR, the LOFC was a design basis accident. The following excerpt is taken from Appendix D of the FSV Final Safety Analysis Report:

Operator actions
The following operator actions have been determined to be either necessary or desirable to mitigate the consequences of this accident:
1. Post scram operations to assure subcriticality.
2. Actions required to re-establish helium circulation (attempts assumed to be unsuccessful for this hypothetical accident).
3. Primary coolant system depressurization.
4. Connection of the high temperature filter absorber units to the plant cooling water system.
5. Operation of the reserve shut-down system.
6. Adjustment of the PCRV cooling system water flow rates and cover pressure to increase cooling ability in areas affected. The cooling water flow to the bottom head, bottom head penetrations and PCRV side wall below the core support floor, will be reduced to approximately 10% of normal flow. Reduced flow to these areas of the PCRV will be adequate during the accident because heat transfer to these areas is negligible. The cooling water flow rate to the top head and PCRV side wall liner region above the bottom of the core support floor will be approximately doubled. The core support floor cooling water flow rate will not be changed, because heat transfer to the floor during the accident is less than during normal operation. The changes in PCRV cooling water flow will be accomplished by remote-manual valves actuated from the control room.
7. Adjustment of the PCRV cooling water system pressure. The gas cover pressure of the cooling water system (normally at about 2 psig of H₂) will be increased to about 30 psig of He. This is accomplished remotely in the control room by activating a separate overriding helium pressure control system for the cooling water supply tank. This 30 psig cover pressure plus the approximately 60 psi pump head will ensure that the saturation temperature of the cooling water will be above about 300 °F at all locations of the PCRV liner cooling tubes, and at least 340 °F at all high flux locations.
Meijer:

It is assumed that during the accident of unrestricted core heat-up, the containment clean-up system remains operative. Is the clean-up system designed to cope with the high gas temperatures in the containment?

Joksimovic:

The clean-up system is qualified to withstand the environment created by postulated occurrence of design basis depressurization accident with respect to pressures, temperatures and radiation levels.

De Nordwall:

How do you convince the public that your bounding analysis is in fact bounding, when you have such a large amount of information to communicate?

Joksimovic:

This aspect presents a considerable problem. We obviously cannot publish all the information our calculation files contain. Hence information of relatively minor importance would have to be revealed only upon specific inquiry from ERDA or licensing authorities.

Farmer:

As far as the continued increase in accident analysis is concerned, I agree with the speaker that one has to keep trying to assess every proposition that is made, providing it is useful. As far as Rasmussen is concerned, I have noted the comments - some optimistic - some pessimistic. I feel that the report gives a good general picture of the reactors analysed, without necessarily agreeing precisely with any of the numbers given.

Von der Decken:

How will be the behaviour of shutdown rods in such an accident. Which might be the consequences of melting of the shutdown rods?

Joksimovic:

The behaviour of the control rods during a LOFC has been extensively analysed for the Fort St. Vrain HTGR where the event was a design basis accident. Major conclusions of that Final Safety Analysis Report are that:

1. Reduction of the boron in the boron carbide ($B_4C$)-graphite compacts of the control rods arise from three different processes:
   a. melting of the metallic control rod cladding, spine and shock absorber materials,
   b. compaction of control rod material ($B_4C$-graphite compacts) due to compressive loading,
   c. diffusion and vaporization of control rod boron.
2. Diffusion and vaporization effects are negligible, relative to the geometric changes caused by structural steel melting and compact compression.
SAFETY PROBLEMS ARISING FROM PROCESS HEAT APPLICATIONS
OF HIGH TEMPERATURE GAS-COOLED REACTORS

by

G.D. Bell and J. Shepherd, UKAEA, Risley, United Kingdom

The nature of circuit activity present in normal operation is assessed and the requirement for an intermediate heat exchanger is considered in terms of the need to isolate the reactor and the process material from each other. Conditions arising from reactor faults are also taken into account.

The interaction of faults originating in the process or industrial complex with the safety of the reactor are examined and conclusions reached about the desirable characteristics of a nuclear reactor operating in such circumstances. The ability of the HTR to meet such requirements is examined.

Indication is given of some aspects of such combined plant which will require further study.
Fryer:

In UK we recognise that large chemical complexes and oil refineries are potential sources to large and spectacular events e.g. missiles, gas cloud explosions, etc., there is evidence of this. Colocation of nuclear plant and such installations must therefore give rise to consideration of interaction between these types of installation. In UK we have already been faced with such a problem and in the light of present knowledge separation has been regarded as the only acceptable solution. The work being carried out by the UKAEA arises from this particular care and it may lead to a relaxation of the current position regarding separation. It may also be that in the course of time that a reduction of the risk from chemical plant may be achieved and thus allow a further relaxation of the present constraints. Regarding the criteria illustrated in figs. 1 and 2 I confirm in replying Mr. Joksimovic that this is a UKAEA position. The regulatory position is set out in my paper, see paragraphs 18 and 19 and also 35, 36 and 37.

Jacobi:

This is a comment more than a question. Referring to fig. 7 of your paper, which shows fire damage costs vs. frequency per year, I would like to say that not only external fire sources should be treated with such a "steep" curve, but also internal fire sources in nuclear power plants.

Bell:

I think I indicated reasonable agreement with the above statement, which again does not really call for a specific answer.
- is a plant with IHX safer than a plant without IHX;
- extrapolation of technology to temperatures above 1000°C.

These flow-sheets are analysed to their requirements on heat transfer area, volumetric power in heat exchangers, blower energy and possibility of arrangements in primary circuit.

The following arrangements of heat exchangers are discussed in more detail:

- IHX in reactor vessel, steam reformer (SR) outside containment;
- IHX in reactor vessel, SR inside containment but in separate cavities;
- IHX and SR in the same cavity in reactor vessel (only 1 wall more);
- IHX and SR in different cavities in reactor vessel;
- IHX in reactor vessel, SR in containment filled with inert gas.

After a discussion of the present state of knowledge of material aspects, design arrangement, and safety, a proposal for an IHX is made for the different kinds of application of nuclear process heat.
Ashworth:

Using Mr. Bell's figures of an accident incidence of $10^{-3}$/year for chemical plant and the target of $10^{-7}$/year for nuclear plant, the combination of nuclear and chemical plant would require engineered safeguards giving a factor of $10^{-4}$. Do you regard the intermediate heat exchanger as providing a significant part of this factor?

Kugeler:

I am convinced that the reliability of chemical components in combination with nuclear plants must and will be much higher than in conventional technology by more effort for testing and quality control. The steam reformer for instance should have the same failure probability as steam generators by a careful design and choice of parameters. In all cases, however, independent from the probability of failure, the safety requirement of the reactor system must be fulfilled, i.e. an explosion of gases must be avoided by an inert gas filling of the containment.

Gabriel:

The goal of such a plant is a safe and reliable operation. What are you thinking in this connection in detail about an inerted containment atmosphere and the replacement of contaminated tubes or heat exchangers? The last point especially in view of experience coming from the chemical industry showing average lifetime of chemical reactors of about 5 - 10 years.

Kugeler:

Only the part of the containment which contains the heat exchangers and the blowers should be filled with an inert gas. All other parts of the containment which must be accessible, are filled with air.
A tube which has failed should not be removed but should be taken out of operation, similar to a pipe of a steam generator in an HTR. The failure of tubes seems to be much more improbable than in conventional steam reformers for the following reasons:
- no pressure difference across the wall in the hot part of the tubes ($\Delta p \approx 30$ bar for conventional tubes),
- no hot spots in tube walls above $950$ °C can occur (in conventional tubes the flame temperature is $1400$ °C and more),
- in axial and azimuthal direction the heat fluxes are nearly constant in nuclear applications,
- no corrosion by sulfur occurs.
Therefore we think that the lifetime of the nuclear heated reformer tubes can be of the order of more than 100,000 h of operation. Then the whole bundle will be replaced. To change the catalysts the openings at the top of the tubes must be accessible every four years. It is known from chemical industry that catalytic reformers which have been operated carefully (i.e. always sufficient steam supply to avoid carbon deposition and deactivation) can use the same catalyst for eight years.

Presented by K. Petersen

No questions, no remark.
F.P.O. Ashworth and H.J. de Nordwall "The status of information required for an independent analysis of risks associated with an HTR"

Presented by H.J. de Nordwall

Tattersall:

As a representative of a utility I would like to congratulate Dr. de Nordwall for making reference to the importance of availability. Whilst safety is accepted as being all important, good availability ranks highly in the requirements of a utility. It would be possible to design a reactor, which would meet all safety requirements, say by the use of multiple containment, but which would be unacceptable to the utility which has to operate and maintain it. It is worth re-iterating that these requirements may lead to more stringent requirements on say fission product release from fuel and on reliability, than safety considerations alone.

Gabriel:

You demand an independent risk analysis to a large extent. To reach such a goal I believe it is necessary to give all detailed know-how of the total system to independent experts. Do you see problems in preservation of know-how? Are there problems of such a magnitude that they will block the goal?

De Nordwall:

I believe that it will eventually be recognised that a freer flow of information will be necessary to make responsible risk judgments and that this diverse review will enhance the stature of HTR. The most probably cause of difficulty is the development of a strong adversary situation, in which the scoring of points in a public debate is allowed to take precedence over scientific judgment.

Abbey:

To follow up the point raised by Mr. Tattersall do you think that the goals you specify in fig. 1 are specific to the HTR, or are they general for any reactor system?

De Nordwall:

They are applicable to any reactor system.

Vieider:

Mr. De Nordwall, you indicated an impressive listing of still required safety assessment work and related experimental work, associated with a general HTR acceptance. Does this imply that you consider the current licensing procedures for the HTR in the USA and Germany to be premature in view of the precedence case consequences created by the licensing of first commercial plants?
A REVIEW OF CERTAIN GAS COOLED REACTOR SAFETY ISSUES

by

D.R.H. Fryer
N.I.I., United Kingdom

The commercial design of High Temperature Reactor
has many features in common with gas-cooled reactors already
licensed and operating in the United Kingdom. There are also
some important differences which have a bearing on safety. The
paper discusses the safety aspects of the commercial HTR in the
light of U.K. experience on gas reactors and concludes that so
far as the United Kingdom is concerned, there is no reason to
believe that it would not be feasible for a commercial HTR to
be designed to be suitable for siting in the United Kingdom.

The paper also reviews the basis of safety philosophy
which would be applied in reviewing an HTR and the procedures
which would be necessary for the clearance of the first off of
a new design.

The place of safety criteria in overall safety
evaluation is discussed and examples given of development in
this area currently underway within the U.K. Nuclear
Installations Inspectorate.

Reference is made to the applicability of probability
methods in safety evaluation.

In conclusion, the paper considers certain specific
issues relating to HTR safety.
Fryer:

There is no standard time for review of a generic design. The NII has to advise on the acceptability of any particular concept and the time required for this will depend on the position of NII studies on the system concerned at the time the question is asked. We wish to minimise the risk of large design changes once construction has commenced, hence for a first of series of standard plant extensive and detailed information should be made available, which must be examined thoroughly. In the case of the UK HTR conceptual design I would say that NII is in a good position, having already devoted substantial effort to the study of fundamentals.

Von der Decken:

Discussing the question of separating nuclear plants from chemical plants you have to define what is a chemical plant. Do you have in mind for the 5 miles distance a real large chemical factory, or do you also include pipelines and ship or road transport of chemicals?

Fryer:

Road transport and ship borne transport of dangerous materials as well as pipelines must all be considered. Each case must be looked at on its merits. In the case of transport some relief may be obtained from the limited residence time close to the nuclear plant. Special arrangements can perhaps be made concerning transport conditions e.g. special routing and pilotage for ships. Pipelines can be routed to avoid nuclear plant and possibly special arrangements can be made for sectioning them with isolation valves etc.

J. Shepherd:

In answer to a previous question by Dr. Von der Decken you said that considerable alleviation of the problem of inflammable substances under transport close to nuclear installations was achieved by the short time in which such materials were in close proximity to the reactor. I seem to remember that at Heysham there is an oil tanker terminal fairly close to the reactors, certainly well within your 5 miles exclusion distance. Has Heysham been treated as a special case or have any extra safeguards been insisted on as tankers are certainly moored here for a very large fraction of the time?

Fryer:

I cannot deal with particular cases and in any case this example is not within my field of responsibility and I cannot therefore give an authoritative answer. My earlier remarks to which you refer were intended to express a principle only.
My intention is that the group sitting here will only occupy a fraction of two hours because I would feel, expect and anticipate that a number of participants on the floor might well have views about where we should go from here and how. And I think that I would like to distinguish those as being two separate questions, where do we go from here and how do we go from here. To a CSNI expert, the situation appears to me to be very simple, that there is no set pattern. We as a group could reach any conclusion, either from the fact that though we saw no need to meet further, if indeed that was the conclusion, or to propose anything that we thought might advance the studies, we feel we should mutually embark on. And these recommendations going up to our parent plenary committee, we would expect them not only to support these, but on the basis that the people of the plenary committee are often the people who command staff and resources, that they might even choose not only to accept our recommendations, but to make the effort available to us to carry them out. What sort of things does CSNI normally support the proof of? Well, as I said, the experience shows many things. Let me try to illustrate the range of possibilities open to us by quoting one or two examples of CSNI sponsored activities, which I feel in the past proved to be very successful. Let me take the case of fast reactors, a subject with which I am reasonably familiar. Having had general discussions of this sort it did appear to the members that there were at least two specialists areas of technology, in which it would be useful if experts got together, not only just to discuss things, but to make recommendations. We chose liquid metal boiling and the general hydraulics and from time to time we asked the experts to give us the best view on what value of superheat should be used in specific accident studies and what restraints and constraints would they put on the use of such information. That group happens to meet every eighteen months, at the intermediate time it produces a newsletter so that there is some continuity between the members. We did something similar in the field of sodium-fuel interactions and it again proved that this idea of meetings at 18 months intervals and intermediate newsletters was a successful idea, but with one specific thing that grew out of that particular group, that I think we could consider here also and that is that, when the sodium-fuel interaction people met together, they quickly discovered that their theoretical codes did not in fact predict for some given specified situation the same answer. And we set up a code comparison bench mark problem type exercise which has proved to be very useful in agreeing basic data and in agreeing mathematical models. Now that particular one suffers from the disadvantage at present that they did not have a good experimental situation, against which they could check their codes. But in the water reactor field there is indeed a code comparison exercise going on, in which two reference problems have been chosen in both of which there either is or will be firm experimental evidence, against which the predictions can be checked. In fact these are pre-prediction exercises, and again it is a method of working together that one might in particular circumstances consider useful. And when you turn more to the material of this conference, what rather defeats me is the multiplicity of such groups, for which I personally could see a useful role. I mean, I only give very broad titles, I see the purely theoretical type of analytical assessment. I could see groups which are
All these have come out of international collaboration, so I feel in the safety evaluation of the HTR we have in many respects got already a framework of collaboration between the national groups for example and in such international organisations as the Dragon project. And certainly this will help I believe, particularly when we are talking about work of a generic nature. Whatever organisation is set up to monitor this on an international basis will be able to fall back on existing frameworks of collaboration. I believe this is rather important.

Now, as I see it, we are faced with a requirement to continue to do a lot of generic work, which I think is mainly in the field of behaviour of materials and fuel and how these perform under the extreme accident conditions. But in addition of course we come down to the sort of thing which I believe was being highlighted by John De Nordwall and others in their papers, a need to do a lot of work on the actual components and how these will behave under extreme conditions. These are two separate situations. I have a feeling that once you come down to the studying of component behaviour under extreme conditions, or even under normal conditions, you are immediately concerned with specific designs or at least things that come close to particular designs. I mean, if we want to know how circulators are going to behave in the event of a depressurisation accident, we really need to be talking about real circulators, that have been developed for real commercial reactors.

On the other hand, there is a whole area relating particularly to fuel and materials behaviour which is common to all systems and in this particular area we are in much stronger position because a lot of the work is being done and merely requires from time to time to be slanted in the right direction, in order to meet the requirements of the people who are concerned with the evaluation of the safety of the HTR.

Let me perhaps illustrate what I mean by this situation. If we take what I think has emerged from this meeting, these discussions of the most significant accident, we tend to come down to this business of depressurisation, loss-of-cooling perhaps, without being able to fall back on the auxiliary cooling systems. We have a situation where very clearly the performance of the fuel and the fuel elements during normal operation can materially affect what happens subsequently. I believe firmly and it is a matter of opinion, that one must operate HTR's as clean systems and a lot of the work we have done in the fuel development has been related to this. Now there are other schools of thought who say you can, you don't have to operate completely cleanly and in the interest of cost, you can make cheaper fuel which will do the job and be no worse after all than in other reactor systems, because you build in safeguards against failure and safeguards that make the normal operation of the reactor all right. But I believe that we ought to move in the direction of working with clean systems, because I can see quite clearly that this is feasible. Moreover, we have done this for many years in the Dragon reactor experiment, even though that is only a one percent scale, one can simply extrapolate and say that this is possible to do in power reactors, given the right specifications for the fuel and the right process control and the right quality assurance on the fuel. I don't think the price of doing this is very high. If you work on that basis you still ought to know a lot more about the fuel. What you do know is that if you have one of these extreme accidents, the depressurization one, then you have a reactor which for several hours is accessible, because
advancing the technology. I think we can move in directions that would be required by any international committee, who consulted us and asked us to do this and it would be helpful to be pressed to do this in fact. It is always helpful to know that somebody requires you to do something rather than to think you are just doing it for the hell of doing it because you got a nice set of equipment and you have got the staff to do it.

So I think as far as the generic work is concerned, speaking as one of the groups in the field, we would be very happy to extend our work in the right direction to suit the requirements of people, concerned with the safety of evaluation of the system. When the time comes and specific designs are being put up as indeed they already are by General Atomic, I think there is a need for national governments to consider sponsoring relatively big experimental set-ups to test these under extreme conditions, and I think this is something that needs to be done where the framework really doesn't exist for doing it at the moment.

Well, that is roughly what I would like to say about this, Mr. Chairman. I am expressing a willingness to work in the generic field in our project at least.

Gilby:

Well, thank you very much indeed Dr. Shepherd. I myself take that as being a very helpful attitude indeed and I hope that during our further discussion we may find some way of making use of this generous offer. I think I would go next to Dr. Schamberger to hear what he feels at this stage of a three-days meeting.

Schamberger:

Exhaustion. I have, as you probably are aware from my conversation the first day of this meeting, a very strong conviction that there is a compelling need for carrying out extensive research activities, which deal with safety related functions and not necessarily just reactor safety for the HTR, because I cannot make a clean distinction between those aspects which are of value in the operational reliability and those which are of value in minimizing the impact or potential impact upon the public. I think there is an indissoluble link which has to be recognized. In the United States there has been in the last six months a legal reorganisation of the regulatory structure so that the Agency of the Government which heretofore both developed or assisted in the development of reactor technology and was responsible for licensing reactors now are in two pieces. Or perhaps even more than that. At least there are two agencies of the government, one which has the formal responsibility for supporting reactor development and one which has the formal responsibility for assuring the public safety. I am associated with the second and my function is related to the development of the technology which is necessary for our licensing people to make the necessary certifications. I don't make such decisions. I am in the process of trying to define a programme which will - over the course of years, and I do not mean one or two - define the information which we believe our licensing people will require by I would guess the mid 1980's, which is the time when I really believe that the commercial HTR's will be a presence rather than a hope. The costs which we foresee are very substantial and I don't
comparing these very carefully thought out programs and try to find in
discussions as much agreement as possible. You will not end up in full
agreement and I think I would like to warn you to try to find very
quickly in one step a complete international program. This is not
possible and you will end up with nothing. You should restrict yourself
to very small steps.
We have working groups already doing the job pretty well in the case of
fission products; I think it is not very official, but they are working.
And in the other areas as Mr. Chairman mentioned, there are possibilities
too. My final point would be some words about large experiments.
Here I think that it is very useful if one or another national program
would define large experiments. These large test-programs should be
discussed in a very broad way, they have to be discussed internationally
to make sure that these will give us some answers. Because just with large
test-rigs there is a great danger that such experiments will give a very
good show-effect, but if you carefully analyse them you get nothing out
of it. To really spend a lot of money on that experiment, you should
think about it very careful and each opinion from every expert is
welcome in such a discussion. Thank you.

Gilby :

Thank you very much Dr. Von der Decken. I think you probably did notice
heads nodding at least amongst the panel at some of the points you made,
and now Dr. Fassbender please.

Fassbender :

Thank you Mr. Chairman. I think I can only amplify what the other members
of the Board have already stated. Perhaps a few words on the necessity of
an international cooperation. Somebody who observed the sessions of this
group might have got the impression that HTR is such a safe reactor that
a large research work in the safety of this reactor is no longer necessary.
I think we should realize that HTR has a time lag of at least five
years compared to the Light Water Reactor and that the safety discussion
with LWR's has reached the stage in which HTR's are just about to reach.
Let us say two years ago there only was slight discussion of things like
core-melting, or melting through of the molten core through the bottom of
the pressure vessel and the bottom of the secondary containment. Today
if you attend a meeting on light water reactors a large part of the papers
will deal with these subjects. Analogous investigations with the HTGR
are just starting and there is a wide field which ought to be covered.
Second point for me is the limited funds which are available compared to
light water reactors and even to fast reactors. If you compare the sums
which are spent on HTGR safety research and on LWR safety research I
think there is a factor of about 1 to 20 or even 1 to 100 if you compare
it on an international scale.
The third point is, I should say, the difficulties which we encounter
in marketing the HTR. In our country, Germany, we have a phenomenon
which seems a bit awkward, that the public is demanding the HTR instead
of LWR. They argue, why do you build LWR's if you have such a safe
reactor as the HTR, which does the same without endangering the surroundings.
A fourth topic might be process heat. It is again the problem of extrapolating the existing data. It is also the problem of actually new questions as we were discussing this morning. I think I don't need to repeat them. One thing I should like to add is: to me the problem seems that international cooperation would be superimposed on already existing strong bi-lateral cooperations on an official or unofficial scale and I think if CSNI tries to put up something it should take notice of what already exists. One should avoid the impression, that an international cooperation which will be created in the future, might be an impediment to the already existing bi-lateral cooperations. Thank you Mr. Chairman.

Gilby:

Well I think the situation, having heard these first contributions from the members of the panel, is some cautious enthusiasm for working together. Enthusiasm for doing it, but caution about how we set about doing it and I think that this caution is probably well justified. I certainly think that Dr. Stadie would not be happy if we go home without achieving something fairly specific. I do think that we have time now for some general contributions from the floor, reactions that anybody might have to what the panel has said or other ideas they may want to contribute. I certainly feel we could take quite a few contributions from the floor, before we need think in terms of specific proposals. Wo would like to say something?

Ashworth:

We presented a status report of the technology, with a considered view on the work which we think should be pursued in this safety related area. And of course we recognize the risk of promoting the question, why is there so much more to do. But I think we ought to bear in mind that safety criteria have changed considerably since we started, even considering safety of HTR's. And there is now a need for a much greater understanding of the phenomena in normal operation and at least some logical assessment of the extreme events. Now what I would like to see is a first start in the sense of where do we go from here to answer the chairman's point. We would like to know whether the definitions of the goals we made are right. Whether those targets we set in areas like corrosion or fission product release behaviour, whether the times five on cesium and so on are the ones which really are required, or that we should go down to something much finer in adequacy or whether we need to validate the models to a much greater degree. I would like to comment on Dr. Von der Decken's point that we also require recognition of the existing working groups. It is a fact that we work, we have had almost naturally developed bi-lateral groups with Germany and France and with the United States, and in many cases these have been repeating work. We talk to the KfA people on topics, we talk the following week with people from the CEA on the same information and it helps us enormously because we, by this iteration, refine our own thinking considerably. But perhaps it should be recognized that that sort of procedure is ongoing and the CSNI might well be interested in recording the kind of activities that are there.

And finally there has been enough in the last three days, I think, to suggest some kind of digestion. We have not really - in the time we have had available - been able to consider in detail the carefully presented papers. The discussions are never long enough or the right people are not
reactors. Especially in this area, this means in the area of accident conditions, I believe there is more clearness in the HTGR system. This also after a safety research programme of more than four years (e.g. Ludwigshafen). In addition I believe that no light water reactor would have been built if a safety programme would be coupled to the first plant. Thank you.

Gilby:

I am not sure that anything that was said was inconsistent with what you said, Dr. Shepherd.

Shepherd:

I was not trying to comment on any other reactor system. I think there was a general remark that I made, that one has been rather lax in the past in carrying out serious safety studies on components in all reactor systems and I believe I said that I think the HTR should maintain itself on a very sound footing in this connection and try and stick to a sensible programme that looks at the reactor not in normal operation simply, but in all sorts of accident conditions. I am not trying to say that we should do it in the HTR, that it is not necessary to do it in other systems. I just think it should be done in every reactor system. Okay, maybe one would never have built a LWR if we had gone through some of these exercises, but that is a historic point. Being extreme, I do not think that we should ever have built water cooled reactors at all, but everybody knows how biased I am in this respect.

Gilby:

Yes, we note that. Yes Mr. De Nordwall.

De Nordwall:

I wonder if I might ask the panel a question. We have among the potential commercial offerings for the HTGR some fairly large differences in design and lay-out. Would the panel feel that as part of the collaborative safety venture, which might be moving towards, it would like to see a real intercomparison of the features of the different designs? And how would it like to go about it?

Gilby:

It is a good question, that I think we faced up to already either in multi-lateral or bi-lateral discussions on other reactors. But I think that the truth of the matter is, that it is often not very profitable, for example to take on one LMFBR as compared with another, the means of providing satisfactory back-up decay heat removal systems, especially when you know that both sets of designers were shooting for the same target and both sets of designers would probably have aimed to produce actual hard-ware, not only which purportedly meets the design target, but which they would hope to show by test, experiment validation, that in fact it does meet the design target. I think it is profitable certainly
Von der Decken:

I would like to make a comment and this brings up some ideas. One of the difficulties we have today with HTR safety problems is that we have in different countries different criteria for the LWR's which are established. We have heard this problem from General Atomic during this conference at one point, I remember. It is not only necessary that we are making up good HTR safety philosophy. In addition we have to ask ourselves, and this is different for the different countries, what do we have to collect on information to convince the people that we can change in one or the other case the rules which have been made for light water reactors. The question is in detail: what do we need of information to do just this? This is, of course, different in different countries but the information that is needed could be gained internationally.

Gilby:

You probably do know, Dr. Von der Decken, that particularly within the community one of the aims, on which there are research groups (discussion groups) going within the framework of the community on both light water reactors and on fast reactors, is not to get similar criteria, but at least to harmonize them for both light water reactors and fast reactors and I can assure you it is not easy, but people are trying. Did Mr. Tattersall want to come back on the comments on his remarks?

Tattersall:

I was not suggesting that we should interfere with normal licensing procedures. I was suggesting that we should not overlook the fact that many of the questions that are asked relate to departures, relatively small departures, from normal operating conditions and I suggest that, even if the criteria are different, licensing authorities may well be asking the same sort of questions.

L. Shepherd:

Could I come back also to another point which Mr. Tattersall made and that was about the component testing? I fully agree that is what I was implying that they should be actual components. One comes then to the question of whose responsibility is it to do this; is it the manufacturer or is it the responsibility of Governmental bodies to do it? I think, one has to recognize that some of these tests to be done properly, it would be very, very expensive and at least it ought to be a joint venture between the manufacturer and Government agencies to do this. But I do feel that in the reactor field we should do the sort of things, which after all are done in aviation, where very expensive test facilities are set up. They test engines and components to destruction and they subject them to tests over very long periods of time compared with their normal life. I think that is essential, if we took it really serious about the safety of nuclear power plant, we should have corresponding facilities run both nationally and perhaps in collaboration with the private industry, to do just this with reactor components.
I am not sure either when these will appear; I believe the original target date was July this year. Like some other documents in this area they are categorized by the title "living", which means "never finished". However, what they do provide, I think these two things together a possible basis for more than one specialist working group now. I would like to suggest that we have a small working group in each of these major component areas, plus the accident progression analysis group and plus the most important one of all, which is the group which defines the overall risk goal which we should be aiming at, because in the absence of that definition I think we have probably the largest opportunity to waste money that has ever been offered to man: a goalless safety study for a reactor. In each of these component technology areas I think the need is then to take what we know about the major risk-goals, as they are applied, and this is the wide risk that I was talking about this morning, as they apply to a likely looking reference reactor and to try and carry through, perhaps on a rather simplified model initially. But ultimately the document will live and grow to the point where it will get adequately sophisticated to deal with the real system. The local need assessment, that is the need assessment within this particular area of technology, be it control absorbers, coolants or fission products, to set down the information which is publicly available. We are not necessarily asking the manufacturer to disgorge his propriety secrets, but we would like to see in one place what is available from other sources in the form of a databook, not the form of a scientific monograph. We have got plenty of those. And then, I think, the exercises raised or mentioned by Mr. Gilby, namely modelling into comparison and the specification of subsequent validation experiments and surveillance, would follow naturally from this.

Gilby:

Well, first of all let me say something I should have mentioned earlier and that is that, within the framework of the IEA, there will be produced a summary document on all safety research - theoretical and experimental - that is going on. Now I know it is easy to say, oh yes, that is another paperwork exercise, but it is something that within the EEC we did three years ago. There were the usual complaints about the fact that, oh it is just putting the same old stuff down in another form, but we did establish a basis of objectives, facilities available, progress to date. It was suggested that would be a one of one there, nobody would ever bother to update it. Well, in fact that has not happened, people do regularly update it and certainly within the EEC it is now usual to see a number of desks in which there is a thick green backed book which is the summary of all ongoing fast reactor safety research work. The EEC is very close to have a similar document for light water reactors, both of which will be fed into the IEA system. So I don't find the word "a living document" always a snag. I think that in many cases there is no finality, because living at least implies that it is updated and used. I also believe that I could not contemplate that a group of people would get together, certainly with U.S. representatives on it, who would fail to make the maximum use of all the work that has been carried out up to this point in time, but I do hesitate knowing our parent group CSNI of proposing too large an initial step. They are very keen to see you propose something
not be prudent, if we launched off too much in too big a field, in too many directions. But it does occur to me that we might at least show our willingness to work together, by for example organizing a small—maybe 15 to 20 people—meeting as an ad-hoc working group on one of the topics that has been suggested from various quarters. I would tend to suggest one of the new topics, on the basis that we would not be just overtaking any other formal or informal activities which might already take part. I don't know whether Dr. Stadie is nodding or shaking his head at me.

Stadie:

As you know, Dr. Gilby, the OECD objective is to foster the collaboration but not to enforce it on member countries and therefore we would only be the resultant of the wishes of a majority or a critical group of member countries. What a critical group would be I do not know. It is certainly more than two, it does not need to be 24; there are not 24 countries here. Now as regards the topics as I mentioned to you, it is a normal procedure that the committee itself needs to approve a major step like setting up a permanent working group. We do have the interim mechanism of bureau meetings, with the bureau consisting of a chairman and two vice-chairmen and with a written approval a meeting on any of the topics you suggest could be implemented later this year. There is also the possibility in view of the potential merging of the activities of IEA and CSNI in the field of nuclear safety, that a special meeting of the committee will be held anyway, so the options are all here. What we need now is, if the group is inclined to do so, to make a recommendation in what field to begin, to test our ability to collaborate.

Gilby:

Well, I noticed Mr. Farmer, please.

Farmer:

Thank you. I have a number of comments, some of which are not necessarily related one to another. I was a little interested just now when Ernest Gilby spoke about the green book that lies on a number of shelves or desks which gives an up-to-date account of current programmes in fast reactor safety research. I still wonder whether in fact the existence of the green book has in any way altered the programme of research. I doubt whether it has. I am not sure who it really is helping, but that is quite by the way.

If you have all as experts been talking about setting up some groups, in the end a safety expert or specialist may decide that certain types of work would be useful and interesting to do, but in the end I have to receive approval from somebody to put some effort into it, so that is the point that I would like to come to. In the U.K. we have a little effort going into HTR's. The Atomic Energy Authority virtually none. It is my responsibility at least to promote some acquaintance with promote reactor safety research and reactor safety technology and as such I could have some interest and spare some effort in HTR's. But if an
De Bacci:

In the field of HTR-R&D the operating organisation, in which the European Community is a major shareholder, in fact the largest shareholder is the Dragon project. We have heard some time ago a statement by Dr. Shepherd saying that, as far as generic safety related work is concerned, the Dragon project has a flexible team and also has a flexible facility. Let us not undervalue this facility, which has been built and cared for for many years with money by the signatories and which at marginal costs can be further improved or slanted towards specific tasks. As far as the European Committee is concerned I can tell you that the E.C. would welcome very much the opportunity to put the expertise of the Project at the disposal of any international initiative. I don't think that this implies that we will ask for money or anything like that. I think that it would be very nice to know that this unique facility which the project manages could be used at advantage of everybody. The reason why I raise this point at this time is that we are currently negotiating an extension of the Dragon agreement. And this time the negotiations are somewhat difficult, for reasons I am not going to enlarge. It would help these negotiations very much, if a statement of interest by other countries than the current signatories were made, I don't know whether at this meeting at this panel or somewhere else. After all the project has already the right structure for an international project, is ready within the sponsoring frame of NEA and it would be just sad that at the time that we are trying opportunities in ways and means of sponsoring similar projects, the project which now works so well, with reputation, with success, should be discontinued. I think that this would be such a loss that no progress that we could make at this panel even in many years could compensate for that. So I am really saying to people who are potentially interested in this business to take note of what I said and to help in what I am trying to do. Thank you.

Gilby:

Well, bearing in mind that we are a meeting of technical specialists, it is certainly open to anybody on either a technical basis or a personal basis, to take up Mr. De Bacci's point. Yes, Mr. Farmer.

Farmer:

Thank you. I was interested in the last statement. I could well think that the major input in the scientific and engineering field can come from organizations such as the Dragon project and from the U.S. They are so obviously enthusiastic and promotional, that I think it would require a slightly different umbrella for the management of the exercise, even if a substantial amount of the effort came from the promotional side. And so I would still be rather interested in what form of framework this could be organized.
on which I think there has been some broad basis of agreement. I rather
fancy that it is up to Dr. Stadie and the CSNI bureau to conduct discussions
both amongst themselves and with the other major interests represented on
CSNI, hopefully long before the next meeting if it is November, to
develop I think in a little bit more detail some of these ideas into a
draft mandate and some draft proposals for who should be on this HTR
safety steering committee, coordinating committee, call it what you like.
So I think recognizing the problem, that is where we should choose to leave
the responsibility, but I would, as we draw to a close, offer first of all
to my colleagues sitting in the audience here whether there are any last
thoughts.

Ashworth:

May I just underline, Mr. Chairman, the offer from the Nuclear Inspectorate
to put forward their criteria on an international scale for discussion
and criticism with particular reference to the HTR. That is quite a new
aspect in my experience. And may I, with Dr. Shepherd's approval, suggest
that we might offer to Dr. Stadie to undertake to organize an appreciation
of the work of this meeting, really to produce the first draft of the
headings of this work, to pass on to the members within, say, two months?

Gilby:

He is nodding, I think.

L. Shepherd:

Mr. Ashworth is authorized to do such an offer.

Gilby:

We accept that offer, thank you very much.
Yes, I am going to give the panel a chance for last words after we have
heard the last words from the floor.

Von der Decken:

I would like just a personal comment on what Mr. De Bacci mentioned.
I think it is quite clear that the few opportunities we have in experimental
high temperature reactors like Dragon, like AVR, we should be all from a
technical point of view happy if we will still have them for some years.
And I think that is very important. As I am sitting here as a private
person, it is from the technical point of view that I can say quite
clearly, we should have the Dragon reactor, we should have the AVR
reactor, as long as possible.

De Nordwall:

I will be very brief. I have a concern which comes from listening to your
comments and your very cautious approach. What I would like to say is
very briefly that I think we are a lot further along the road of