June 12, 2002

MEMORANDUM TO: Farouk Eltawila, Director
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

THRU: John H. Flack, Chief **/RA/ original signed by J. Persensky**
Regulatory Effectiveness Assessment and Human Factors Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

FROM: Stuart Rubin, Senior Technical Advisor **/RA/**
Advanced Reactor Group
Regulatory Effectiveness Assessment and Human Factors Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

SUBJECT: TRIP REPORT FOR TOPICAL MEETING ON HIGH TEMPERATURE REACTOR TECHNOLOGY PETTEN, NETHERLANDS

The purpose of this memorandum is to inform you on the subject foreign trip. The objective of the topical meeting was to provide a forum for international organizations and experts involved in HTR technology development and safety assessment to present papers on their plans and recent significant progress in developing and assessing the technology across a broad range of technical and safety-related areas. HTR technology topical areas included fuel, physics and neutronics, thermal-fluid analysis, system design and analysis, materials and components and, safety and licensing. Additionally, the conference provided a valuable forum for NRC staff participants to discuss specific proposals that would enable NRC to participate in planned or ongoing HTR safety research activities and work groups in various countries. The attached trip report and its attachments detail the significant items of interest from the presentations and these discussions. Presentation materials from the meeting can be made available upon request to any of the listed authors of the trip report.

Attachments: As stated

cc w/att:
J. Craig, AO
J. Dunn Lee, OIP
T. Rothschild, OGC
C. Paperiello, DEDMRS
W. Kane, DEDR
S. Collins, NRR

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DATE	06/12/02*		06/12/02*	

NRC FOREIGN TRIP REPORT

Subject: International Topical Meeting on High Temperature Reactor Technology

Date: April 21-25, 2002

Place: Petten, Netherlands

Authors: Stuart Rubin, RES
Donald Carlson, RES
Joseph Muscara, RES
Undine Shoop, NRR
Shanlai Lu, NRR

Sensitivity: None

Background/Purpose:

The purpose of the trip was to participate in the International Topical Meeting on High Temperature Reactor Technology (HTR-2002). This meeting was organized by the European Nuclear Society (ENS) in cooperation with the International Atomic Energy Agency (IAEA). The purpose of the meeting was for international organizations and experts involved in HTR technology development and safety assessment to present and discuss their plans and recent significant progress in developing and assessing the HTR technology across a broad range of technical and safety-related areas. Additionally, the conference provided a forum for the NRC staff participants to meet with IAEA member state representatives and representatives from the European Community High Temperature Reactor Technology Network (HTR-TN) to discuss the basis for NRC HTGR cooperative research sponsored by the IAEA and European Community.

Abstract: Summary of Pertinent Points/Issues:

The ENS/IAEA Topical Meeting on High Temperature Reactor Technology provided a valuable forum for presentations and discussions on modular high temperature gas cooled reactor technology, design and analysis being conducted internationally. Information collected on many of the topical areas is considered very useful to a number of the technical areas and safety issues associated with both the NRC's ongoing HTGR pre-application reviews and infrastructure development activities within the advanced reactor research plan. Although, the program was crowded with technical topics of importance to both activity areas, the NRC delegation arranged and participated in meetings with organizational representatives from other countries to discuss specific proposals for NRC to participate in planned or ongoing cooperative HTGR safety research programs. In many cases, an acceptable basis for NRC participation was identified. As the next step, proposed written cooperative agreements in the various technical areas were to be developed and transmitted by the coordinator for these cooperative programs and work groups. Such agreements if/when formalized would be expected to provide an effective and efficient means to achieve key HTGR infrastructure development objectives identified in the NRC's Advanced Reactor Research Plan.

ATTACHMENT

Discussion:

On April 21- 25, 2002, five NRC staff members participated in a topical meeting in Petten, Netherlands, on High Temperature Reactor Technology. This meeting was organized by the ENS in cooperation with the IAEA. The objective of the topical meeting was to provide a forum for international organizations and experts involved in HTR technology development and safety assessment to present papers on their plans and recent significant progress in developing and assessing the technology across a broad range of technical and safety-related areas.

The International Topical Meeting was attended by about 170 participants from 18 countries, including representatives from a large number of multi-national organizations. Thirty-eight papers were presented on HTR technology topics including fuel, physics and neutronics, thermal-fluid analysis, system design and analysis, materials and components and, safety and licensing. A copy of the Workshop Program is attached (Attachment A) and copies of individual papers are available upon request from any of the listed authors of this trip report.

Highlights of the presentations most directly related to NRC's current HTGR pre-application and infrastructure development activities are as follows:

International HTR Projects and Programs

Dr. R. Versluis (US DOE) presented the US DOE Program Status in terms of DOE activities with HTR technology. He indicated that the following areas are being funded by DOE: Fundamental thermal fluid physics of high temperature flows in advanced reactors; Advanced ceramic material study for PBMR; design and construction of fuel burn-up measurement; balance of plant; design layout concepts for modular transport unit; scintillation-based in-core, self-powered flow and temperature probe; development and validation of temperature-dependent thermal scattering law; and an international nuclear energy research initiative as well as national laboratory funded programs such as MELCOR study of air ingress in pebble bed reactors (INEEL) and kinetics and fuel management code development (INEEL).

Dr. S. Shiozawa (JAERI) presented the Japanese Position and Status on HTGRs. He indicated that Japan required a demonstration plant to be built before a commercial HTGR is licensed. Their testing reactor program HTTR has been going on for many years. In December 2001, the reactor reached its designed full power of 350 MW_t.

Dr. Y. Xu (INET) presented the Chinese position and status on HTGRs. China's HTR program started in March 1986 and the HTR-10 reactor went critical about 18 months ago. Since then, the effort was made to adjust the entire system including the steam generator and steam turbine. For the next five-year plan, the Chinese government has decided to continue to fund the HTR research project. In addition to the HTR-10, China plans to build a new HTR with 100 MWe capacity.

Dr. Johan Venter, (PBMR) presented the South African position and status on HTGRs. South Africa will continue the PBMR project regardless of Exelon's announced decision to terminate its involvement in the PBMR project. Most of the work now ongoing involves efforts to improve the economic performance of the PBMR plant design since the current design results in costs per kWe at the bus bar which is higher than is considered acceptable for world-wide competitiveness with all forms of electric power production.

Dr. Kodochigov (OKB, Russia) provided a position and status of the Gas Turbine Modular Helium Reactor (GT-MHR) project in Russia. The GT-MHR (GT-MHR) of 600 MWt power is being developed by OKB Mechanical Engineering in the framework of the agreement between US and Russia. Dr. Kodochigov presented the design of this reactor. The fuel will be loaded into the core in an annular region in hexagonal geometry. The reactor is designed to provide a deep burnup of weapons grade plutonium.

Dr. Dominique Hittner (Framatome ANP) provided the European position and status of the HTR-TN program.

Fuel Technology Presentations

Dr. D. Petti (INEEL) presented a paper which compared the performance of TRISO coated particle fuel that had been designed and manufactured in Germany, with TRISO fuel that had been designed and manufactured in the U.S. The paper concluded that during irradiation, the German fuel demonstrated fission product releases that were three orders of magnitude lower than the U.S. fabricated fuel. The differences in performance were traced to differences in fuel quality. The quality differences were caused in significant part to differences in the TRISO coating PyC and SiC microstructures and the degree of bonding between layers. Differences in microstructure and bonding were traced to differences in the German and U.S. fuel fabrication processes. Factors affecting quality achieved included differences in the German versus U.S. fuel fabrication approach. German fabrication was industrial/production scale achieving consistent product specification and quality. U.S. fabrication was both laboratory and production scale resulting in relatively wide variations in particle specifications and product quality. The U.S. fuel was generally irradiated with very accelerated test conditions which may have overly stressed the fuel particles resulting in failure mechanisms which are not activated during actual core conditions.

G. Miller (INEEL) presented a paper on a coated particle fuel performance code (PARFUME) being developed by INEEL. PARFUME is an integrated mechanistic fuel performance model which simulates the mechanical and physio-chemical behavior of coated particles during irradiation. PARFUME is intended to simulate all particle failure mechanisms using a multidimensional finite element technique and to account for the statistical aspect of particle failures. Future efforts include improved coating properties such as creep coefficients, elasticity, fission product chemistry and transport models, treatment of asphericity, partial coating de-bonding and comparison with a range of HTGR fuel data. Considerable effort has been made to include the effects of shrinkage cracks. The current version of the code indicates fair agreement with IPyC and SiC layer failures observed for the New Production-MHTGR fuel irradiation experiments. Future work for code development includes completion of the fission product chemistry models; fission product transport models; code to irradiation data and , including the effects of asphericity and partial debonding between coating layers.

Dr. A. Ougouag (INEEL) presented a paper examining the potential for diversion or clandestine dual use of a pebble bed reactor for the production of plutonium. The paper conclude that clandestine use of a pebble bed reactor to produce plutonium for weapons would be impractical and very slow and, would result in plutonium yields of very low quality.

Mr. Rodriguez (General Atomics) presented a paper exploring the possibility of deep burn transmutation of nuclear waste using PBMR. The benefit of this approach is the reduction of high level radioactive material to be disposed. Obviously, this would require the re-processing of the current LWR spent fuel.

Other papers on the HTGR fuel technology included papers by: A. Languille (CEA, France), who provided a summary of the High Temperature Reactor Fuel Technology Program in Europe (HTR-F); E. Brandau. (Brace GmbH)), who presented a paper on the production of UO_2, ThO_2 and PuO_2 fuel kernels for HTGRs; B. Bonin (Comega) who presented a paper on studies of HTR fuel cycles involving plutonium.

Physics and Neutronics Presentations

Mr. Reitsma (NESCA) presented a paper about the method of equivalent cross-sections based on combining transport and diffusion methods. This investigation is of interest because modeling strong absorber regions with diffusion theory is a well-known problem since the diffusion theory breaks down in highly absorbing regions. This study is important because of PBMR's unique control rod configuration and material composition. A similar approach could be used in the NRC's 3-D diffusion equation solver.

Dr. Kukharkin (Kurchatov Institute) presented a description of the ASTRA critical facility including a description of the possible critical configurations that the facility is capable of emulating and code comparison results. The ASTRA facility is designed of reactor grade graphite to provide maximum configuration flexibility. This is achieved by having few fixed parameters so that the core can emulate pebble bed, hexagonal, or square graphite matrix configurations. The MCU program complex was used to generate anticipatory criticality information. This code system uses the continuous energy monte-Carlo method with an original system of data libraries. It also incorporates a method to calculate for the discrete fuel kernels within the matrix rather then using a homogenized approach. The code similarly treats the discrete distribution of poisons.

Dr. H. Gougar (INEEL) presented a description of the PEBBED code. This code allows the coupling of pebble flow with the neutronics. Currently, the neutronics calculator of the code uses a finite difference technique though an it is planned to replace it with a more advanced solution technique. This code uses an algorithm to compute the entry-plane density of each nuclide of interest in the burn up calculator portion of the code based on pebble loading and recirculation. This allows for burn up, and subsequent nuclide calculation while tracking the pebble during each pass of the pebble through the core.

Thermal-Fluid Analysis Presentations

Prof. E. Laurien (University of Stuttgart) presented a paper on 3-D fluid flow code developed by his research group, based on CFX-4 to analyze the in-core fluid field. The purpose of this code is to address possible eccentric misplaced package of fuel or a single control rod ejection. Although the code uses very fine mesh to resolve the fluid flow field, the heat transfer coefficient and local loss coefficients are still calculated using empirical correlations. The code relies on the old experimental results. When asked if their 3-D code mesh size is fine enough to resolve the boundary layer flow, he responded that the approach can not take into account the porosity variation across the core.

Prof. Greyvenstein (Potchefstroom University, RSA) and his colleague made a presentation on a system code that they had developed to model the PBMR. The code is called FLOWNET which is similar to the NRC TRAC code. FLOWNET employs a cylindrical 3-D mesh to model the in-core flow and 1-D flow models to calculate the flow through the turbine/compressor and the balance of plant. The code is first used to do component matching and to determine the detailed steady state performance of the system. It was recently demonstrated that the code is able to simulate the start-up process as well as load follow and a load rejection scenario.

Engineering, Design, and Applications

Dr. Yan (JAERI) presented a paper about the design and development of GTHTR300 which uses only one horizontally mounted turbine/compressor set. The simplicity and economic features are the advantages of this design. It was pointed out during his presentation that the vertical turbine/compressor system imposes a much higher load on the bearing. Additionally, the current magnetic bearing test data does not cover the conditions of the PBMR turbine system. Therefore, a compressed air/helium bearing is being considered to replace the magnetic bearing system.

Materials and Components Presentations

Three papers were presented in this session. Two of the papers related to materials and components. The third paper provided a comparison of the cycle efficiency between direct cycles of carbon dioxide and helium. Thermodynamic calculations showed the carbon dioxide cycle to be about 4 % more efficient than the helium cycle.

R. Simon (EC-retired) provided a historical overview of the DRAGON high temperature experimental reactor design, operation, and testing conducted from 1964 to 1975. The DRAGON reactor was particularly suitable for testing fuel elements and structural materials. Operation of DRAGON showed this reactor to be stable and produced a large amount of performance data for a variety of fuels and coated particle fuel elements. The results showed that the fuel could withstand a high degree of overheating with little release of radioactivity.

G. Hall (University of Manchester) presented a paper on initial results from his doctoral studies on the relationship between irradiation induced dimensional change and the coefficient of thermal expansion. Essentially, he is studying the phenomenon of “turnaround”. This relates to the experimental findings that graphite initially experiences shrinkage with increasing radiation dose, then with increasing radiation dose a zero volume change is experienced, and at even higher radiation doses swelling of graphite occurs. Current theory predicts the behavior only for low radiation exposures, i.e. nearly linear shrinkage. Hall’s thesis study is an attempt to predict and model the full behavior, including turnaround. The work presented showed that the current theoretical relationship can be modified to show the turnaround. However this initial work was an empirically-based mathematical curve fitting exercise to a set of data. As such it cannot be used to predict the behavior of different graphites with confidence. However the author is conducting investigations to determine how changes in various graphite parameters and properties affect the irradiation behavior. This information would then be used for providing a physical basis for the mathematical parameters. If successful, the new correlations and formulations could be used to reliably predict the irradiation behavior of different graphites.

Safety and Licensing Presentations

Dr. D. Petti (INEEL) presented a paper which studied HTGR air ingress scenarios using the MELCOR code modified for the pebble bed reactor design and materials properties. INEEL modified the mass equation solver of the MELCOR code and added an explicit mass diffusion solver to address the air diffusion into the PBMR system after a postulated depressurization loss of helium accident. The study indicated that it would take about 200 hrs for the air to reach the reactor core for a break in the hot gas cross connect duct near the bottom of reactor vessel. Sensitivity studies show that for high graphite kinetic oxidation rates, most of the oxygen in the air would oxidize the nuclear graphite blocks of the lower core support structure rather than the outer graphite matrix of the fuel pebbles. However, for lower oxidations rates, oxygen in the air would still be present when the air reached the fueled core region allowing increase oxidation of the graphite fuel matrix material. Even in the latter case because of the relatively low core temperatures after 200 hours of conduction cooldown significant fuel oxidation was not predicted to occur.

Dr. G. Brinkmann (Framatome ANP) presented a paper on whether an HTR needs a containment or a confinement structure. Each plant needs to be analyzed based on the core and plant configuration in relation to the licensing limits for fission product release during an accident. Defense-in-depth, defining three barriers to the release of fission products, was used to justify a confinement instead of a containment. The first barrier is the fuel particle with it's multiple protective coating layers. The second barrier is the primary gas envelope which must be designed in a way that will not create a cross connection to another secondary gas envelope and be designed so that through wall cracks do not occur. The third barrier is the confinement envelope which should work with other barriers to minimize the radiological impact of an accident. Therefore, the design of the confinement envelope may differ for each HTR depending on the quality of the first barrier, and the calculations and design of the second barrier. The HTR-Modul confinement envelope consisted of the reactor building, the secured sub-atmospheric pressure system, and the building pressure relief system and HVAC isolation system.

Pending Action/Planned Next Steps for NRC:

During and after the conference, NRC staff participated in a number of side meetings to identify and assess the NRC's opportunities for cooperative research through ongoing and planned activities of the International Atomic Energy Agency (IAEA) and the European Commission (EC). Included in the following discussions are a number of pending actions and planned next steps that arose from these side meetings.

International Atomic Energy Agency

Ongoing and planned IAEA activities in the HTGR technology arena are being conducted through two Coordinated Research Projects (CRPs): the new CRP-6 on HTGR Fuel Technology and the ongoing CRP-5 on HTGR Performance. The side meetings on these two IAEA activities are summarized as follows:

CRP-6 (HTGR Fuel Technology)

Stuart Rubin (RES) and Undine Shoop (NRR) participated in an IAEA consultancy on HTGR Fuel Technology which was held in conjunction with the HTR-2002 Conference. IAEA member states represented at the consultancy meetings were Belgium, China, France, Germany, Japan, Netherlands, Russia, South Africa and the US (NRC, DOE, INEEL, GA, MIT). Also represented were the European Commission and the IAEA. The overall objective of the consultancy was to address a recommendation from the IAEA Technical Working Group on Gas Cooled Reactors (TWG-GCR). The TWG recommended a new coordinated research project on coated particle fuel technology. The purpose of the consultancy was to develop a basis for agreement on the scope and purpose for Coordinated Research Project Number 6 (CRP-6) on HTGR fuel. The areas of interests and current plans of the individual member states were discussed to provide a basis for defining the scope of CRP activities. A basis for general agreement was developed on the scope and content of CRP-6 fuels research activities. It was noted that the scope of topics should be rationalized and focused on a few tasks for which the CRP could produce substantive new information.

The participants in the consultancy identified the following as potential areas of common interest: fuel performance data; fuel performance modeling and characterization data; fuel operating experience, fuel irradiation and accident condition testing, and fuel licensing issues. Fuel fabrication technology for quality and performance was to be further evaluated. Lead countries (and organizations) for each area were identified to develop plans for each topical area. The U.S. was selected to coordinate and document proposed and planned international research activities related to fuel behavior modeling (INEEL) and licensing safety criteria (NRC). Proposed research plans for each activity area were to be developed by the lead organization that was assigned to each area. The participating IAEA member state representatives agreed in principle to support extra budgetary funds for CRP-6. It was estimated that a total of about $50K in extra budgetary funds would be needed and would be cost-shared by member states. It was recommended that the IAEA should begin planning to hold the first research coordination meeting on the CRP in Vienna in November 2002. The IAEA Technical Officer (Mabrouk Methnani) who presided over the meeting was to document and transmit the results of the CRP-6 planning meting for review and comment by the member state representatives with the aim of formalizing the proposed CRP in the near future. Preliminary discussions projected that the next meeting would take place in the late Fall 2002.

CRP-5 (HTGR Performance)

Donald Carlson (RES) met with Jim Kendall and Mabrouk Methnani for a short discussion on potential NRC staff participation in the International Atomic Energy Agency's Coordinated Research Project on Evaluation of HTGR Performance, CRP-5. The project was started in October 1997 and is scheduled to be completed in October 2004. Jim Kendall provided a summary paper about CRP-5, which is included as Attachment B, as well as the minutes from the second and third project coordination meetings that were held in October 1999 in China and in March 2001 in Japan. The scope of CRP-5 comprises the analysis of reactor physics benchmarks and thermal hydraulic transient benchmarks and the demonstration of safety characteristics for modular HTGRs. Benchmark problems have been defined for comparing analytical predictions against measured data from the HTR-10 and HTTR projects and from the critical experiments conducted for the PBMR project in the Kurchatov Institute's ASTRA facility. A code-to-code benchmark problem has also been defined by the GT-MHR project and selected earlier experimental benchmarks from the international HTR-PROTEUS program are being reevaluated with newer codes and methods. CRP-5 builds upon results from two closely related CRPs that were completed in recent years, specifically the CRP on Validation of Safety Related Physics Calculations for Low Enriched HTGRs and the CRP on Heat Transport and Afterheat Removal for Gas-Cooled Reactors Under Accident Conditions.

Mabrouk Methnani briefly described the workings of the project. IAEA Member States participating in CRP-5 include China, France, Germany, Indonesia, Japan, the Netherlands, the Russian Federation, South Africa, and the United States. The U.S. has been represented to-date by Syd Ball of ORNL and Andy Kadak of MIT, neither under NRC sponsorship. Syd Ball has assumed lead responsibilities for drafting the TECDOC report that will summarize the first phase of the project. To have NRC staff participate in the CRP-5 activities, the NRC needs to send a letter to Mr. Methnani proposing participation and requesting instructions for accessing and using the working area on the IAEA web site, where the CRP-5 benchmark specifications are posted and participants can exchange information. The next CRP-5 coordination meeting will be in October 2002 in Vienna, Austria.

European Commission

Representatives from RES (Stuart Rubin, Joseph Muscara, Donald Carlson) arranged and participated in a series of meetings with the leaders and members of selected research projects of the European Commission's High Temperature Reactor Technical Network (HTR-TN) in conjunction with the HTR-2002 conference. The HTR-TN research projects involved Fuel Technology (HTR-F), Materials (HTR-M), Safety Approach and Licensing Issues (HTR-L) and Reactor Physics and Fuel Cycle Studies (HTR-N). Additional meetings were conducted to discuss the area of thermal-fluid analysis, which may be developed as a future HTR-TN technical project. These meetings followed-up on a April 19, 2002, meeting at NRC Headquarters between RES management and staff and the Chairman of the HTR-TN Steering Committee, Dominique Hittner (Framatome ANP) and Georges van Goethem. The April 2002 meeting was arranged and conducted to discuss potential areas of interest for cooperative research between NRC and the HTR-TN. The purpose of the meetings at the HTR-2002 Conference was for EC and NRC research area counterpart leaders to discuss specific detailed proposals for cooperative research activities. The objective of these discussions was to establish a specific framework for cooperative research between the NRC and HTR-TN in each of the technical project areas. The basis for the RES staff discussions was the research activities documented in the NRC Draft Advanced Reactor Research Plan. The outcomes of these meetings are as follows:

HTR-F (Fuel Technology)

Stuart Rubin (RES) met with Dominique Hittner and Alain Languille (CEA), Technical Coordinator, HTR-F and other technical representatives participating in HTR-F work group to discuss HTGR research program plans related to fuel irradiation testing, fuel accident condition testing, fuel behavior model development, fabrication technology, compilation and analysis of historical fuel irradiation and accident simulation testing. Representatives from the US DOE (Alice Caponiti) and the Idaho Engineering and Environmental Laboratory (David Petti) which are engaged in discussions with NRC to develop an NRC/DOE cooperative fuel irradiation testing agreement, also participated in these meetings. Discussions focused on the plans of each organization for conducting fuel irradiation and accident condition testing on low enriched uranium German archive fuel pebble elements and plans for fuel behavior model development. The HTR-F plans involved irradiating the German fuel at nominal operating temperatures but to very high burn up (15-20% FIMA) followed by accident heatup testing. The NRC/DOE proposed cooperative test plans included us irradiating fuel German fuel to high burn up (11% FIMA) but at significantly higher operating temperatures and fast fluence followed by accident condition tests which would explore the margins of fuel integrity. Dominique Hittner, concluded that the HTR-F and the NRC/DOE testing plans were complimentary and that the US research plans in this area and the other areas (e.g., code development) would provide an acceptable basis for the US participation in HTR-F.

As the next step, Hittner requested that the HTR-F Technical Coordinator, document a summary of the key planned research discussion points to be used as a basis for US (NRC and DOE) participation in HTR-F. The documented summary would provide the basis for developing an NRC/HTR-F and DOE/HTR-F cooperative research agreements. It was believed that such agreements could be signed in the near future.

HTR-L (Safety Approach and Licensing Issues)

Stuart Rubin (RES) met with Jacques Pinson (Tractebel Energy Engineering), Technical Coordinator, HTR-L and other technical representatives participating in the HTR-L working group. The purpose of the meeting was to discuss objectives and activities associated with HTR-L and the plans and activities within the NRC to develop a new regulatory framework for licensing new reactors including advanced reactor designs. The focus of the HTR-L is to develop a safety approach and the identification of key issues for licensing HTGRs in Europe. The documented plans that had been developed for HTR-L activities were provided at the meeting. The HTR-L working group activities to implement these plans were just beginning and were expected to last about three years. The HTR-L Technical Coordinator expressed a strong interest in NRC participation in HTR-L working group activities. He indicated that a formal cooperative agreement would not be necessary for NRC participation. The next meeting of the group was anticipated to occur toward the end of CY 2002. If acceptable, the next steps would be for the NRC to identify an appropriate representative to participate in HTR-L and for that individual to contact the Technical Coordinator on plans for attending the next working group meeting.

HTR-M (Materials)

On February 21, 2002 Joseph Muscara (RES) had transmitted to Derek Buckthorpe (his EC contact for high temperature materials research cooperation) descriptions of research needed for high temperature materials for application to HTGRs. Research areas of interest for metallic components related to a) carburization, decarburization, and oxidation in helium coolant with impurities, b) effects of helium impurity environment on fatigue and creep life, and on stress corrosion, crevice corrosion and cyclic cracking, c) thermal aging and sensitization, d) studies on components removed from service (AVR), and e) in-service inspection and monitoring. Research areas of interest for graphite related to a) irradiation studies of current graphites, b) correlations between as-manufactured properties and post-irradiation properties, c) oxidation studies, d) through-thickness property variability, and e) design, fabrication and material specification standards. Buckthorpe held a meeting in Brussels with his European HTR-M program colleagues on March 4, 2002 to discuss the proposed research.

On April 23, 2002, Muscara met with Dominique Hittner, Chairman of the HTR-TN Steering Committee; Buckthorpe, Technical Coordinator for HTR-M; EC official Michel Hugon; and other European representatives participating in HTR-TN work. In addition, Bill Shack from ANL, and Robert Versluis and Alice Caponiti from DOE participated in the meeting. The purpose of the meeting was to discuss research of interest in high temperature materials and potential for EC and NRC cooperation in this research area. Hittner indicated strong interest and support for the research we had proposed and indicated the EC would welcome NRC cooperation in HTR-M.

The current HTR-M program is funded under the EC 5th Research and Technological Development Framework Program. The next HTR-M program will be conducted under the 6th Framework Program which will start in 2003 and continue for five years. Hittner indicated that he had discussed NRC cooperation with other EC officials and concluded that the most straight-forward way to participate in the 5th HTR-M program is through invitation by EC of NRC staff to participate in program meetings and activities. Development of a more formal agreement was thought possible, but would be difficult and too time consuming since the contracts for individual projects of the HTR-M program are already in place with the names of each European participant listed on each contract. Formal participation in the 6th Framework Program would be easier, and the NRC would be listed as a partner in each of the projects of the 6th HTR-M program. No exchange of funds would be involved; cooperation would be through exchange of research results between the EC and NRC from their high temperature materials research.

Muscara then summarized key work of interest to NRC including work on graphite correlations, on components removed from service, on the effects of the environment on materials degradation, and on in-service inspection and monitoring. Hittner summarized current key EC work on irradiations of a higher temperature pressure vessel steel, and of graphite. This work was discussed in more detail on the next day. Hittner indicated that many of the research areas we identified would be included in the 6th Framework Program. Hittner took the action to interact with AVR staff to establish the availability of AVR components. Muscara provided criteria for selection of such components if available. It was concluded that, if components were available, an international program should be established including EC, US, and other countries to conduct studies of components removed from AVR. In addition, research on in-service inspection and monitoring could be conducted with broader international cooperation since validation of this work would require the use of test reactors. DOE representative Versluis mentioned research planned at ORNL on irradiation testing of SGL graphite. He agreed to coordinate with similar work planned by the EC and to share the results with NRC and the EC.

It seems that the EC will conduct much of the research work on high temperature materials of interest to NRC in its 5th and 6th Framework Programs. Some of the key work possibly not fully addressed in the EC programs is in the areas of a) effects of the helium environment with impurities on degradation of materials, b) evaluation of in-service inspection programs and monitoring, and c) correlations of virgin graphite properties and manufacturing parameters to post-irradiation graphite properties. Exchange of NRC research results in these areas could be used for cooperation with the EC HTR-M programs. Finally, Muscara indicated that NRC/Research has begun to co-sponsor development of an ASTM standard for nuclear grade graphite and invited the Europeans to participate in this activity. There was interest in this participation.

On April 24, 2002 Muscara and Shack (ANL) discussed with Rantala (JRC) high temperature metals work being conduced at the Joint Research Center at Petten , and toured the materials testing laboratories. Some of the work relates to fatigue and creep testing of a 9% chromium pressure vessel steel in the welded condition. Rantala indicated that welding of this steel had produced some small cracks. Following this meeting, Muscara met with Buckthorpe and other EC technical personnel involved in work for HTR-M for more detailed presentations of the current EC high temperature metals and graphite work. A higher temperature 9% chromium pressure vessel steel, which may be selected for a European HTGR and for the General Atomics GT-MHR is being evaluated. Irradiation tests are being conducted along with fatigue, creep-fatigue, tensile and fracture tests. Both heavy-section base metal and weldments are included in the studies. The high temperature properties of two different turbine blade materials, one forming an aluminum oxide protective layer, the other a chromium oxide layer, are being evaluated. Extensive characterization and irradiation testing of five different graphites (2 from UCAR, 2 from SGL, 1 from a Japanese source) is just beginning. Also graphite oxidation tests are being planned.

As the next step, the HTR-M Technical Coordinator, Buckthorpe, and Muscara will develop a list of key research areas and descriptions of work to be exchanged for inclusion in a cooperative agreement between the EC and NRC.

HTR-N (Reactor Physics and Fuel Cycle Studies)

After the conference, Donald Carlson (RES) met for four hours with Dominique Hittner and Werner von Lensa, Technical Coordinator, HTR-N, to discuss the HTR-N project. The stated objectives of HTR-N are “to validate codes for calculating HTR core physics, to assess the feasibility of different types of core and fuel cycle concepts, and to assess the potential of HTR for solving the main waste issues.” Significant HTR-N activities to-date include the coordination and reporting of European participation in the HTTR and HTR-10 neutronics benchmarks through the IAEA's CRP-5. The structure of the HTR-N activities is diagramed in Attachment C. Additional information on HTR-N is available in the attachments to the NRC staff's summary of the April 19, 2002, meeting with Dominique Hittner and Georges van Goethem at NRC headquarters.

Dr. Carlson led a lengthy discussion of the HTGR nuclear analysis issues described in the Draft NRC Advanced Reactors Research Plan and provided a 4-page summary of the issues (see Attachment D) for this purpose. Drs. Hittner and von Lensa expressed particular interest in having HTR-N address, with NRC, a series of scoping calculations on the time evolution of postulated reactivity and power transients as well as a basis for defining credible design basis and beyond design basis power transients in selected modular HTGR designs. Heinz Werner of FZJ was identified as being able to provide comprehensive information about Germany's past work on several NRC nuclear analysis issues concerning pebble bed reactors. Dr. von Lensa expressed interest in expanding the scope of HTR-N to include NRC-identified nuclear analysis issues in the areas of waste management and material safeguards and security. It was noted that studies on decay heat and associated repository volume requirements should address several different HTGR fuel design types (i.e., Japanese pin-in-block, American compact-in-block, and German pebble fuel elements) in various disposal scenarios. Dr. Hittner made a note to add to the planned HTR-M activities the theoretical and experimental evaluation of heat sources from the annealing of high-energy neutron-induced damage in graphite during reactor heatup accidents. Previously planned HTR-N activities on waste degradation include leaching experiments on TRISO fuel particles. Preliminary results on unirradiated particles are not considered representative of irradiated fuel. Proposed tests include leaching experiments on irradiated TRISO fuel in the form of bare fuel kernels, defective or failed coated particles, and intact coated particles. A more comprehensive summary of the discussions is provided as Attachment E.

Thermal Fluid Analysis

Donald Carlson (RES) met for 30 minutes with Dominique Hittner, Yuanhui Xu (INET, China), Suyuan Yu (INET, China), and Peter Pohl (AVR, Germany) to discuss possible future activities in the area of thermal fluid analysis. Dr. Hittner indicated that: HTR-TN projects may now pursue a pre-test analysis of the HTR-10 melt-wire experiments that are proposed to start in mid 2003; INET would welcome assistance in producing the necessary melt-wire pebbles or acquiring them from Germany or other sources; China's HTR-10 safety test program is still not well established; EC and U.S. will interact with INET and NNSA on developing test plans; the U.S. may offer assistance on quality assurance and testing techniques; HTR-10 is considering experiments on fission product transport and plateout; JAERI's draft HTTR test plan is being provided to the EC. The U.S. and HTR-TN participants will have a chance to comment on the HTTR test plan and offer cooperation on test equipment and analysis.

<u>Other Side Meetings and Discussions</u>

Shanlai Lu (NRR) met with Mr. Frederik Reitsma, who is the chief scientist of NECSA of South Africa. They discussed the possibility of PBMR axial flux distribution stability due to large aspect ratio of the PBMR core. It has been a concern that the second order harmonics of the flux distribution may become dominant in a PBMR core and the flux perturbation due to control rod move may trigger axial direction flux oscillations. He indicated that a PhD thesis has been done in Germany in 1998 regarding this issue. According to that thesis, the critical length of the reactor core is about 11 meters. If the core height is higher than 11 meters, the reactor may be subject to oscillatory flux distribution.

Points for Commission Consideration or Items of Interest:

Trip report is believed to be of general interest to the Commission.

Attachments: As stated