IAEA HIGH TEMPERATURE GAS COOLED REACTOR ACTIVITIES

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Abstract:

IAEA activities on high temperature gas cooled reactors are conducted with the review and support of Member States, primarily through the International Working Group on Gas Cooled Reactors (IWGGCR). This paper summarises the results of the IAEA gas cooled reactor project activities in recent years along with ongoing current activities through a review of Co-ordinated Research Projects (CRPs), meetings and other international efforts. A series of three recently completed CRPs have addressed the key areas of reactor physics for LEU fuel, retention of fission products, and removal of post shutdown decay heat through passive heat transport mechanisms. These activities along with other completed and ongoing supporting CRPs and meetings are summarised with reference to detailed documentation of the results.

1. INTRODUCTION

International interest in HTGR technology has been increasing in recent years due to a growing recognition of the potential of HTGR designs to provide high efficiency, cost effective electricity generation appropriate for the conditions in developing countries, and in the longer term to provide a source of high temperature process heat. The international exchange of information and co-ordination of HTGR research through the IAEA has helped to establish the foundation for the future development and deployment of HTGR technology. The gas cooled reactor activities of the IAEA are conducted with the active participation and advice of the International Working Group on Gas Cooled Reactors. An overview of the IAEA gas cooled reactor activities, modular HTGR technology, and full text versions of IAEA technical documents are available on the Internet at http://www.iaea.org/inis/aws/htgr/index.html.

2. INTERNATIONAL WORKING GROUP ON GAS COOLED REACTORS

The International Working Group on Gas Cooled Reactors is a continuing working group within the framework of the International Atomic Energy Agency with the purpose of advising the Director General of the IAEA and promoting the exchange of technical information in the field of gas cooled reactors. The first meeting of the IWG-CGR was held in 1978, with the most recent meeting (16^{th}) held in June 2000. The focus of interest of this working group is on helium-cooled thermal reactors utilized in steam cycle or direct cycle nuclear plants for electricity and/or heat production, but the scope also includes carbon-dioxide-cooled thermal reactors and, to the extent not already covered by other international organisations, gas-cooled fast reactors.

The IWG-GCR currently includes participants from the following countries:

China	France	Germany
Indonesia	Japan	Netherlands
Poland	Russian Federation	South Africa
Switzerland	United Kingdom	United States of America

The IWG-GCR meets approximately every 18 months to exchange information regarding ongoing and planned activities related to gas cooled reactor technology in participant countries. The results and recommendations of IAEA meetings and Co-ordinated Research Projects related to gas cooled reactor technology held since the previous meeting are presented and reviewed. Other issues and activities of current interest to the Member States are discussed along with recommendations regarding future plans for the IAEA gas cooled reactor project.

3. CO-ORDINATED RESEARCH PROJECTS

Research efforts supported by the IAEA are normally carried out within the framework of Co-ordinated Research Projects (CRPs). CRPs are developed in relation to a well defined research topic on which a number of institutions agree to collaborate, and represent an effective means of bringing together researchers in both developing and industrialised countries to solve a problem of common interest. Each CRP is essentially a network of 5–15 national research institutions mandated to conduct the research within the countries concerned, each being represented by a chief scientific investigator (CSI). A network of institutions is thus established which works within an operational framework for research with a similar and well defined global or regional thematic or problem focus.

Advanced HTGR designs currently being developed are predicted to achieve a high degree of safety with substantially reduced safety related demands on plant operations and licensing oversight through reliance on inherent safety features. These anticipated benefits derive largely from the ability of the ceramic coated fuel particles to retain fission products under normal and accident conditions, the neutron physics behaviour of the core, the chemical stability of the core and the ability of the design to dissipate decay heat by natural heat transport mechanisms without reaching excessive temperatures. In support of licensing and commercial deployment of advanced HTGRs, these features must be demonstrated under experimental conditions representing realistic reactor conditions, and the methods used to predict the performance of the fuel and reactor must be validated against experimental data. Three recently completed CRPs which have been directed toward these considerations are summarised below. Another recently completed and an ongoing CRP directed toward maximising the value of the test programs of the two new experimental HTRs (HTTR and HTR-10) are also summarised. A new CRP directed toward the conservation and application of HTGR technology is under development.

3.1. CRP on validation of safety related physics calculations for low enriched HTGRs

This CRP was formed to address core physics needs for advanced gas-cooled reactor designs. It was focused primarily on development of validation data for physics methods used for core design of HTGRs fuelled with low enriched uranium. Experiments were conducted for graphite moderated LEU systems over a range of experimental parameters, such as carbon-to-uranium ratio, core height-to-diameter ratio, and simulated moisture ingress conditions, which were defined by the participating countries as validation data needs. Key measurements performed during the CRP provide validation data relevant to current advanced HTGR designs including measurements of shutdown rod worth in both the core and side reflector, effects of moisture on reactivity and shutdown rod worth, critical loadings, neutron flux distribution and reaction rate ratios. Countries participating in this CRP included China, France, Germany, Japan, the Netherlands, Poland, the Russian Federation, Switzerland, and the United States of America. Work under the CRP has been completed and a final report is expected to be completed in late 2000.

3.2. CRP on validation of predictive methods for fuel and fission product behaviour in gas cooled reactors

This CRP was formed to review and document the experimental database and predictive methods for HTGR fuel performance and fission product behaviour under normal operation and accident conditions, and to verify and validate methodologies for the prediction of fuel performance and fission product transport. Areas addressed included HTGR fuel design and fabrication, TRISO fuel performance under normal operation, fuel performance and fission product behaviour during heatup under both non-oxidising and oxidising conditions, ex-core fission product transport during normal and accident conditions, and prospects for advanced fuel development. Countries participating in this CRP included China, France, Germany, Japan, Poland, the Russian Federation, the United Kingdom and the United States of America. The results have been documented and published as an IAEA-TECDOC [1].

3.3. CRP on heat transport and afterheat removal for gas-cooled reactors under accident conditions

Within this CRP, the participants addressed the inherent mechanisms for removal of decay heat from GCRs under accident conditions. The objective was to establish sufficient experimental data at realistic conditions, and validated analytical tools to confirm the predicted safe thermal response of advance gas cooled reactors during accidents. The scope included experimental and analytical investigations of heat transport by natural convection, conduction and thermal radiation within the core and reactor vessel, and afterheat removal from the reactor vessel. Code-to-code and code-to-experiment benchmarks were performed for verification and validation of the analytical methods. Countries participating in this CRP included China, France, Germany, Japan, the Netherlands, the Russian Federation and the United States of America. Work under the CRP has been completed and a final report in the form of an IAEA-TECDOC [2] is available for downloading from the GCR Project web site.

3.4. CRP on Design and evaluation of heat utilisation systems for the high temperature test reactor (HTTR)

The high temperature capability of HTGR technology has long been recognised as offering the potential for extending the application of nuclear power to a broad range of current and future industrial process heat needs. This CRP was formed to advance the understanding and development of this potential through the examination of specific high temperature process heat applications and identification of prospective experimental programmes on heat utilisation systems which could be carried out by the HTTR. Heat utilisation systems addressed included steam reforming of methane for the production of hydrogen and methanol, carbon dioxide reforming of methane for the production of hydrogen and methanol, thermochemical water splitting for hydrogen production, combined coal liquefaction and steam generation and high temperature electrolysis of steam for hydrogen production. Countries participating in this CRP included China, Germany, Indonesia, Israel, Japan, the Russian Federation and the United States of America. Work under the CRP was completed in 1999, and the results will be documented in a final report in the form of an IAEA-TECDOC.

3.5. CRP on evaluation of high temperature gas cooled reactor performance

The 30 MWt prismatic fuelled HTTR in Japan and the 10 MWt pebble bed fuelled HTR-10 in China will be conducting experimental programmes in support of HTGR development. The primary objectives of this CRP are to evaluate HTGR analytical and experimental

performance models and codes in conjunction with the start-up, steady state and transient operating conditions of the HTTR and the HTR-10, to validate the results achieved in earlier CRPs related to reactor safety, and to assist in the development, performance and evaluation of benchmark code-to-experiment research activities in support of the testing programmes for the HTTR and HTR-10. Utilisation of these test reactors affords an opportunity to validate the analytical findings of the earlier CRPs and represents the next logical step in HTGR technology development. Countries participating in this CRP included China, France, Germany, Indonesia, Japan, the Netherlands, the Russian Federation, South Africa and the United States of America. Work under the CRP is continuing, with completion scheduled for 2002.

3.6. Pending CRP on conservation and application of HTGR technology

During the past several meetings, the IWG-GCR has been concerned with preservation of HTGR technology developed in earlier programmes (e.g. in Germany, the United Kingdom and the United States of America), and its application in support of future programmes (e.g. in China, Japan, and South Africa). Formation of a new CRP is in process to address the recommendations of the IWG-GCR and related consultancy meetings regarding these concerns. The objective the CRP will be to identify research needs and exchange information on advances in technology for a limited number of topical areas of primary interest to HTR development, and to establish, within these topical areas, a centralised co-ordination function for the conservation of HTGR know-how and for international collaboration, utilising electronic information exchange, data acquisition and archiving methods. The topical areas identified include high temperature control rod development, research and irradiation testing of graphite for operation to 1000°C, R&D on very high fuel burnup, including plutonium, qualification of pressure vessel steels to 500°C, R&D and component testing of high efficiency recuperator designs, and materials development for turbine blades up to 900°C for long life creep. The CRP is under development, with results to be documented in a final report in the form of an IAEA-TECDOC.

4. TOPICAL MEETINGS ON HTGR TECHNOLOGY

In addition to long term efforts associated with CRPs, the IAEA fosters the international exchange of information on HTGRs through the organisation of topical meetings on subjects of interest to Member States. When appropriate, the results of these exchanges are documented in reports issued by or with the support of the IAEA. Several meetings held in recent years and their resulting reports are briefly summarised below.

4.1. Uncertainties in physics calculations for gas cooled reactor cores

A Specialists Meeting was held on the subject of uncertainties in physics calculations for GCR cores at the Paul Scherrer Institute in Switzerland in May 1990. The meeting was attended by representatives from Austria, China, France, Germany, Japan, Switzerland, the Russian Federation and the United States of America. A total of 19 papers were presented in the topical areas of comparison of predictions with results from existing HTGRs; predictions of performance of future HTGRs; and critical experiment planning and results. The papers were compiled and published as an IAEA document [3] on the proceedings of the meeting.

4.2. Behaviour of gas cooled reactor fuel under accident conditions

A Specialists Meeting was held on the subject of behaviour of GCR fuel under accident conditions at the Oak Ridge National Laboratory in the United States of America in November 1990. The meeting was attended by representatives from France, Germany, Japan, the Russian Federation, Switzerland, the United Kingdom and the United States of America. A total of 22 papers were presented in the topical areas of current research and development programmes for fuel; fuel manufacture safety requirements and quality control; modelling of fission product release; irradiation testing/operational experience with fuel elements; and behaviour at depressurisation, core heat-up, power transients and steam/water ingress. The papers were compiled and published as an IAEA document [4] on the proceedings of the meeting.

4.3. The status of graphite development for gas cooled reactors

A Specialists Meeting was held on the subject of graphite development for gas cooled reactors at the Japan Atomic Energy Research Institute in September 1991. The meeting was attended by representatives from France, Germany, Japan, the Russian Federation, the United Kingdom and the United States of America. A total of 33 papers were presented in the topical areas of graphite design criteria, fracture mechanisms and component tests; graphite materials development and properties; and non-destructive examinations, inspections and surveillance of graphite materials and components. The papers were compiled and published as an IAEA-TECDOC [5] on the proceedings of the meeting.

4.4. High temperature applications of nuclear energy

A Technical Committee Meeting on the subject of high temperature applications of nuclear energy was held at the Japan Atomic Energy Research Institute in October 1992. The meeting was attended by representatives from China, France, Germany, Japan, Poland, the Russian Federation, Venezuela, the United Kingdom and the United States of America. A total of 17 papers were presented in the topical areas of industrial/user needs, potential applications of high temperature nuclear process heat and system economics; reactor and heat utilisation system technology and safety; and component and system design, development and testing. The papers were compiled and published as an IAEA-TECDOC [6] on the proceedings of the meeting.

4.5. Response of fuel, fuel elements and gas cooled reactor cores under accidental air or water ingress conditions

A Technical Committee Meeting on the subject of response of fuel, fuel elements and gas cooled reactor cores under accidental air or water ingress conditions was held at the Institute for Nuclear Energy Technology in China in October 1993. The meeting was attended by representatives from China, France, Germany, Japan, the Netherlands, Switzerland, the Russian Federation, the United Kingdom and the United States of America. A total of 19 papers were presented in the topical areas of experimental investigations of the effects of air and water ingress; predicted response of fuel, graphite and other reactor components; and options for minimising or mitigating the effects of air or water ingress. The papers were compiled and published as an IAEA-TECDOC [7] on the proceedings of the meeting.

4.6. Development status of modular HTGRs and their future role

A Technical Committee Meeting on the subject of development status of modular HTGRs and their future role was held at the Netherlands Energy Research Foundation in November 1994. The meeting was attended by representatives from China, France, Germany, Indonesia, Japan, the Netherlands, Switzerland, the Russian Federation and the United States of America. A total of 33 papers were presented in the topical areas of status of national GCR programmes and experience from operation of GCRs; advanced HTR designs and predicted performance; and future prospects for advanced HTRs and the role of national and international organisations in their development. The papers were compiled and published as an ECN report [8] on the proceedings of the meeting.

4.7. Graphite moderator lifecycle behaviour

A Specialists Meeting on the subject of graphite moderator lifecycle behaviour was held in Bath, United Kingdom in September 1995. The meeting was attended by representatives from France, Germany, Japan, Lithuania, the Russian Federation, the United Kingdom and the United States of America. A total of 27 papers were presented addressing a range of topics including irradiation behaviour, graphite performance assessment methodologies, oxidation effects, material properties and development of new materials. The papers were compiled and published as an IAEA-TECDOC [9] on the proceedings of the meeting.

4.8. Design and development of gas cooled reactors with closed cycle gas turbines

A Technical Committee Meeting on the subject of design and development of gas cooled reactors with closed cycle gas turbines was held at the Institute for Nuclear Energy Technology in China in August 1996. The meeting was attended by representatives from China, France, Germany, Japan, the Netherlands, the Russian Federation, South Africa and the United States of America. A total of 16 papers were presented in the topical areas of summaries of national and international activities in gas cooled reactors; design of HTGRs with closed cycle gas turbines; licensing, fuel and fission product behaviour; and gas-turbine power conversion system development. The papers were compiled and published as an IAEA-TECDOC [10] on the proceedings of the meeting.

4.9. High temperature gas cooled reactor technology development

A Technical Committee Meeting on the subject of HTGR technology development was held in Johannesburg, South Africa in November 1996. The meeting was attended by representatives from China, France, Germany, Indonesia, Japan, the Netherlands, the Russian Federation, South Africa, the United Kingdom and the United States. A total of 32 papers were presented covering a large range of topics including GCR programme development; GCR safety and management; development of the pebble bed modular reactor plant in South Africa; HTR plant system and component design; and technical developments in GCR design. The papers were compiled and published as an IAEA-TECDOC [11] on the proceedings of the meeting.

4.10. Technologies for gas cooled reactor decommissioning, fuel storage and waste disposal

A Technical Committee Meeting on technologies for gas cooled reactor decommissioning, fuel storage and waste disposal was held at Forschungszentrum Jülich, Germany in September

1997. The meeting was attended by representatives from China, France, Germany, Japan, the Netherlands, the Russian Federation, Slovakia, Spain, Switzerland, South Africa, the United Kingdom and the United States of America. A total of 25 papers were presented in the topical areas of status of plant decommissioning programmes; fuel storage, status and programmes; and waste disposal and decontamination practices. The papers were compiled and published as an IAEA-TECDOC [12] on the proceedings of the meeting.

4.11. High temperature gas cooled reactor applications and future prospects

A Technical Committee Meeting on HTGR applications and future prospects was held at the Netherlands Energy Research Foundation in November 1997. The meeting was attended by representatives from China, France, Germany, Japan, the Netherlands, the Russian Federation, South Africa, the United Kingdom and the United States of America. A total of 21 papers were presented in the topical areas of status of GCR programmes, HTGR applications, and HTGR development activities. The papers were compiled and published as an ECN report [13] on the proceedings of the meeting.

4.12. Safety related design and economic aspects of high temperature gas cooled reactors

A Technical Committee Meeting on safety related design and economic aspects of HTGRs was held at the Institute for Nuclear Energy Technology in China in November 1998. The meeting was attended by representatives from China, France, Germany, Indonesia, Japan, the Netherlands, the Russian Federation, South Africa, the United Kingdom and the United States of America. A total of 24 papers were presented in the general topical areas of status of design and development activities associated with safety related and economic aspects of HTGRs; and identification of pathways which may provide the opportunity for international co-operation in addressing these issues. Publication of the proceedings of the meeting as an IAEA-TECDOC is in process.

4.13. Gas turbine power conversion systems for modular HTGRs

This Technical Committee Meeting, scheduled for November 2000, is intended to foster the international exchange of information on gas turbine power conversion systems and components for modular HTGRs. The overall objectives are to provide a current overview of designs under consideration, information on the commercial availability or development status of key components, exchange of information on the issues involved and potential solutions, identification of further development needs for both initial deployment and longer term performance enhancement, and the potential for addressing needs through international collaboration. The proceedings of the meeting will be published as an IAEA-TECDOC.

5. OTHER IAEA ACTIVITIES IN SUPPORT OF HTGR TECHNOLOGY DEVELOPMENT AND APPLICATION

In addition to the CRP and meeting activities discussed previously, the IAEA has supported the development of HTGR technology through production of additional documents and establishment of a database for irradiated graphite as summarised below. An important new activity is the application of IAEA nuclear safety standards to HTGRs.

5.1. Hydrogen as an energy carrier and its production by nuclear power

This report [14], developed under contract to the IAEA, documents past activities as well as those currently in progress by Member States in the development of hydrogen as an energy carrier and its corresponding production through the use of nuclear power. It provides an introduction to nuclear technology as a means of producing hydrogen or other upgraded fuels and to the energy carrier hydrogen and its main fields of applications. Emphasis is placed on high-temperature reactor technology which can achieve the simultaneous generation of electricity and the production of high-temperature process heat.

5.2. Irradiation damage in graphite due to fast neutrons in fission and fusion systems

This report was developed with the joint support of the IAEA and the United Kingdom Health and Safety Executive to document information that has been accumulated and understanding that has been gained from research on the subject of radiation damage in graphite. Topical areas addressed include fundamentals of radiation damage in graphite due to energetic neutrons; the structure and manufacture of nuclear graphite; dimensional changes in graphite and the thermal expansion coefficient; stored energy and the thermo-physical properties of graphite; mechanical properties and irradiation creep of graphite; the electronic properties of irradiated graphite; pyrocarbon in high temperature nuclear reactors; and radiolytic oxidation in graphite. An IAEA-TECDOC [15] is available for downloading from the GCR Project web site.

5.3. International database on irradiated nuclear graphite properties

In conjunction with support from Japan, South Africa and the United Kingdom, the IAEA is establishing an international database on irradiated nuclear graphite properties. The objective of the database is to preserve existing knowledge on the physical and thermo-mechanical properties of irradiated nuclear graphites, and to provide a validated data source for all participating Member States with interest in graphite-moderated reactors or development of high-temperature gas cooled reactors, and to support continued improvement of graphite technology for applications. The database is currently under development and includes a large quantity of irradiated graphite properties data, with further development of the database software and input of additional data in progress. Development of a site on the internet for the database, with direct access to unrestricted data, is also currently in progress.

5.4. Application of IAEA nuclear safety standards to HTGRs.

In July 2000, the IAEA Nuclear Safety Department, in conjunction with CEA (France), held a workshop on Safety and Licensing Aspects of Modular High Temperature Gas Cooled Reactors. A consultancy held in parallel with the workshop, and additional meetings planned for 2001 are intended to provide a general approach for the design and safety assessment of modular HTGRs, including methods of analysis and criteria, implementation of defence in depth, and achievement of the fundamental safety functions and their implication on the safety classification of structures, systems and components. Existing experimental data and analytical methods and results of relevance to the safety assessment of modular HTGR designs, and existing licensing experience and applicable precedents will be summarized, and the applicability of the existing IAEA Safety Standards to HTGRs will be assessed.

REFERENCES

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[2] IAEA-TECDOC-1163, "Heat Transport and Afterheat Removal for Gas Cooled Reactors Under Accident Conditions", 2000

[3] IWGGCR/24, "Uncertainties in Physics Calculations for Gas Cooled Reactor Cores", April 1991.

[4] IWGGCR/25, "Behaviour of Gas Cooled Reactor Fuel Under Accident Conditions", November 1991.

[5] IAEA-TECDOC-690, "The Status of Graphite Development for Gas Cooled Reactors", February 1993.

[6] IAEA-TECDOC-761, "High Temperature Applications of Nuclear Energy", August 1994.

[7] IAEA-TECDOC-784, "Response of Fuel, Fuel Elements and Gas Cooled Reactor Cores Under Accidental Air or Water Ingress Conditions", January 1995.

[8] ECN-R-95-026, "Development Status of Modular HTGRs and Their Future Role", September 1995.

[9] IAEA-TECDOC-901, "Graphite Moderator Lifecycle Behaviour", August 1996.

[10] IAEA-TECDOC-899, "Design and Development of Gas Cooled Reactors with Closed Cycle Gas Turbines", August 1996.

[11] IAEA-TECDOC-988, "High Temperature Gas Cooled Reactor Technology Development", December 1997.

[12] IAEA-TECDOC-1043, "Technologies for Gas Cooled Reactor Decommissioning, Fuel Storage and Waste Disposal", September 1998.

[13] ECN-R-8-004, "High Temperature Gas Cooled Reactor Applications and Future Prospects", September 1998.

[14] IAEA-TECDOC-1085, "Hydrogen as an Energy Carrier and Its Production by Nuclear Power", May 1999.

[15] IAEA-TECDOC-1154, "Irradiation Damage in Graphite Due to Fast Neutrons in Fission and Fusion Systems", 2000