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D.E. Carlson

Briefing on

Visit of the NRC Delegation to Germany

on

Safety Aspects of HTR Technology
July 23 - 26, 2001

Stuart Rubin, RES
August 1, 2001

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The NRC Delegation

Howard Faulkner - Office of International Programs

Stuart Rubin - Advanced Reactors Group, RES

Donald Carlson - Advanced Reactors Group, RES

Amy Cubbage - Future Licensing Organization, NRR

Undine Shoop - Reactor Systems Branch, NRR

Alex Murray - Special Projects Branch, NMSS

Vanice Perin - Special Projects Branch, NMSS (NRC Observer)

Agenda : Safety Aspects of HTR Technology

Day 1: GRS Offices, Cologne

- Overview on HTR Development in Germany (HTR GmbH ABB and Siemens)
- Overview of German Safety Assessment of HTR-Module (TUV Hanover)

Day 2: FZJ, Research Centre, Jülich

- Overview of Research and Development at the FZJ Related to HTR Technology (Julich Research Center)
- Pebble Fuel R&D and Industrial Production in Germany (Tessag NUKEM)
- Pebble Fuel Irradiation and Post-Irradiation Testing for Establishing the 1600 °C Limit for Assured FP Retention (Julich Research Center)
- HTR Nuclear Graphite R&D and Production (Kernforschungsanlage GmbH)
- Pebble Bed Heat Transfer and Fluid Flow (Julich Research Center)

Agenda : Safety Aspects of HTR Technology (Continued)

Day 3: FZJ, Research Centre, Jülich

- AVR Operating Experience and Lessons Learned (AVR GmbH)
- THTR Operating Experience and Lessons Learned (BfS KTA, HKG GmbH)
- THTR Core Physics and Pebble Flow (BfS)
- Visit Experimental Test Facilities: Passive Decay Heat Removal, HTR Air Entry and Corrosion Effects on Pebble Core (Julich Research Center)
- Visit AVR Fuel Intermediate Storage Facility & Hot Cells (Julich Research Center)
- Visit to AVR (Being Dismantled) (Julich Research Center)

Agenda: Safety Aspects of HTR Technology (Continued)

Day 4: GRS Offices, Cologne

- Safety Assessment of HTR Module (TUV Hannover)
- Safety Assessment (Design and Operation) of THTR (TUV Rhein-Westfalia)
- THTR Licensing Safety Issues (Ministry of Economy)
- German HTR Codes and Standards (BfS KTA)
- German Transfer of Know-how to ESKOM for a PBMR Development, Design and Safety Assessment (HTR GmbH ABB and Siemens, Julich Research Center, TUV)
- Aspects of waste management (Julich Research Center)

Selected Technical and Programmatic Highlights of Trip to Germany

Status of HTR Activities in Germany

A huge investment (3B DM) in HTR technology was made to develop Pebble bed HTRs in Germany; A very large technical information base exists

Politics ("Greens") have resulted in laws to phaseout use of nuclear power plants in Germany

AVR has been shutdown and THTR was prematurely shutdown for non-safety, non-technical reasons

Only a relative handful and near-retirement core of HTR technical experts remain (from the former thousands) who are involved in limited scope HTR design, technology and safety work

German HTR expertise and experience remains a world class leader

Selected Technical and Programmatic Highlights of Trip to Germany

Fuel Element Manufacture

NUKEM company has developed a manufacturing process for low defect TRISO fuel for which MTR irradiation testing, HTR operating experience and heat up testing demonstrate excellent particle integrity and reliable fission product retention during postulated accidents up to 1600^{0}C

UO2 Kernel and Particle Coating manufacturing processes steps were explained. Particle characteristics must be highly controlled and well characterized with established methods to ensure consistent and repeatable particle quality.

NUKEM is providing ESKOM with expert consulting on the development of a replication of the German Fuel manufacturing process for PBMR pebble fuel manufacture.

Selected Technical and Programmatic Highlights of Trip to Germany

Fuel Element Irradiation Testing:

Julich Research center has developed reference irradiation programs and equipment to conduct irradiation testing and HTR accident simulations for pebble fuel elements and particles

Used for fuel: proof testing, fission product transport in intact particles and fuel elements, release from broken particles, particle performance

Broad spectrum of testing and HTR operating experience has demonstrated German TRISO Fuel integrity up to 1600 ^{o}C

Julich is supporting ESCOM for Palindaba fuel irradiation testing program

Note: The higher (than German) fuel particle failure rates in-reactor and for accident simulations for GA fuel is attributed to low density PyC overcoat shrinkage caused by irradiation in-reactor

Selected Technical and Programmatic Highlights of Trip to Germany

Nuclear Graphite

Arrangement of carbon at the atomic level determine graphite properties (e.g.,strength, anisotropy)

Nuclear graphite for permanent core components must be nearly isotropic - but not isostatically molded.

Special coke processing and careful vibrational molding yield the best graphite grades with respect to isotropy strength and homogeneity.

The expected lifetime of graphite core materials has to be verified by stress analysis using reliable irradiation data.

Today, none of the formally widely tested graphites is still available.

Graphite for the PBMR reflector should be produced on a best guess basis using existing procedures and experience.

Data for stress analysis calculations should be deduced from similar materials tested in former irradiation programs.

An international database with data from former nuclear graphite test programs should be supported by users.

For future HTR projects development and irradiation testing of new graphites should be resumed as soon as possible.

Selected Technical and Programmatic Highlights of Trip to Germany

German HTR Codes and Standards

HTR Safety codes and standards were being written in Germany while HTRs were being designed, developed, built and operated in Germany (Pre-1990)

Some of the codes and standards were finalized and used in the design of HTRs but never endorsed by the regulatory authorities

Most codes and standards that were written are in varying stages of completion and review

Codes and standards considered in the safety analysis reports and safety evaluation reports as contributing to design and safety requirements.

The existing KTA HTR codes and standards are in German and a complete set was provided to the NRC delegation upon our request

The German Federal KTA standards development group would like to find support for continued work on HTR codes and standards

German Federal Government no longer supports the development of HTR codes and standards

Selected Technical and Programmatic Highlights of Trip to Germany

THTR Operating Experience

THTR, a pebble bed reactor, was operated at power from 1986 to 1989

Reliablity and Availalbilty were Reasonably Good for a Demonstration plant design

Operational problems were not viewed as serious technical or safety issues and included:

- Broken Pebble Fuel elements due to CR Scram Insertions in to the Pebble Core
- Broken Fuel elements did not cause increased TRISO particle failure or release but led to fuel handling system unreliability problems
- Fuel handling system did not work above 40 % power and fuel handling/core reloading was restricted to weekends when power was reduced below 40%
- Predicted pebble flow profile through core was significantly off requiring increased operational efforts to establish correct profile for operational nuclear analysis thermal flow analysis and fuel management tasks
- Core He coolant bypass flow was found to be 18% versus the predicted 7 percent
- Elevated Temperature gradient at core exit to SGs led to thermal overstress of a significant number of central bolts fastening metallic insulation plates; Failure of graphite retaining pin
- Inadequate filters to collect graphite dust generation in core led to offsite release

Plant was permanently shutdown in 1989 for political & financial risk issues - not technical issues

Selected Technical and Programmatic Highlights of Trip to Germany

Experimental Test Facilities: Air Entry into HTR Pebble Core (NACOK)

Air flow entry into core can cause accelerated graphite core materials corrosion/oxidation

PBMR and HTR Module have coolant pipe entry/exit only at bottom of RPV (Diving Bell)

NACOK test facility built to determine air entry phenomena

Test results for HTR Module found 80 h grace time before diffusion of air would give way to free convection of air flow through core

Current efforts include developing emergency response arrangements/equipment to block off air entry at postulated pipe break location

(Personnel entry into break area may be problematic due to radiation and temperature levels)

Future experiments are planned to evaluate effects of moisture entry in pebble core

Experimental Test Facilities: Passive Decay Heat Removal from Pebble Core

Test facility Built to test HTR passive decay heat removal phenomena

Results used to successfully benchmark thermal analysis codes for accident analysis

Selected Technical and Programmatic Highlights of Trip to Germany

Safety Assessment of HTR Module

TUV (regulatory safety assessment contractors) conducted their traditional deterministic (SRP-like) license application evaluation of HTR Module in late 1980s

Evaluation was to assess compliance with applicable technical rules and requirements

Evaluation was similar to Ft. St. Vrain Safety evaluation of LWR rules to an HTR

Licensing Bases Events completeness assessed and expanded

Assumptions in evaluation of events follow traditional Chapter 14 and 15 Safety Analysis Approach (e.g., single failure, no-credit for non-safety-related SSCs)

Basic Safety Criteria: shutdown (sub-critical), decay heat removal, contain fission products

Suite of reactor core analysis codes (VSOP); Spectral, Diffusion, Burnup, Core Temps.

Safety margins, consideration of uncertainties and defense-in-depth revealed and quantified

HTR Inherent safety aspects are generally credited only in design basis and beyond events

Statistics is inherent pebble core safety analysis methods: fuel performance, pebble flow, pebble packing, pebble burn-up distributions, power distributions, coolant flow paths, etc.

Evaluation led to recommendations to address deficiencies relative to technical requirements

Safety evaluation report (900 pages) is in German and was not made available to NRC

Selected Technical and Programmatic Highlights of Trip to Germany

Know-how transfer from FRG to ESCOM

MOU iin 1996 (**ESCOM** w/ **German working group, HTR GmbH**): intent of Germans to support ESCOM PBMR development and access to German know-how

Agreement 1996 (**ESCOM** w/ **HTR GmbH**): Supply HTR Moduel SAR and support ESCOM's feasibility study of PBMR HTR

License Agreement 1999 (**HTR Gmbh w/ ESCOM**): Access to HTR technology technical documents including fuel technology from document archives; technical assistance and consulting on specific work.

Agreement on Technical Assistance 6/2001 (**W Reactor GmbH** with **PBMR Pty**) Layout design, construction and calcs of reactor components and systems; Investigate reactor specific issues (graphite dust, solid FP plate-out, He issues [bearings, seals, coatings])

License Agreement 2000 (**Julich** Research Center w/ **ESCOM**):

Access to all Julich Research Center technical documents on experimental work supporting design and development of the HTR (plant concept, fuel development, and behavior, AVR operational experience and test results, reactor ceramic materials technology, reactor hi temp ceramic materials, reactor components, fuel proof test experiments, nuclear waste management)

Contract 2001 (**TUV Hanover** with **ESCOM**):German safety evaluation for PBMR in support of PBMR licensing

Conclusion

- Over a period of more than 30 years and the expenditure of over 3 Billion DM, Germany has built a vast infrastructure of information which supports the design, analysis, technology development basis and safety assessment of Pebble Bed HTRs.

- In Germany, a formally large infrastructure of human capital with Pebble Bed HTR design, analysis, technology development and safety assessment expertise and experience has now dwindled to a relatively small number of technology leaders and technical experts.

- Today in Germany, organizations with Pebble Bed HTR design and technology development know-how are eager to show what they know in order to utilize and sell the vast infrastructure of HTR information and remaining expertise through license and contract agreements with foreign organizations that seek information, advice and assistance on Pebble HTR design, technology and safety assessment.