Report of the 4th Research Coordination Meeting
on the CRP
"Evaluation of High Temperature Gas Cooled Reactor Performance"

VIC, Vienna, Sep. 30-Oct. 4, 2002

The fourth Research Coordination Meeting (RCM) for the CRP on "Evaluation of HTGR Performance" was held at the Vienna International Center, Vienna (Sep. 30 – Oct. 4 2002). The participants include Mr. M. Methnani of IAEA and Chief Scientific Investigators (CSI) from China, France, Germany, Indonesia, Japan, the Netherlands, Russia, South Africa, Turkey, UK (observer), and the United States. Mr. K. Kunitomi (JAERI) and Mr. S. Ball (ORNL) co-chaired the meeting. A list of participants is attached to this report as Attachment 1.

The meeting mainly covered the following topics:

1. Present status of on-going projects
2. Benchmark results & analysis for HTTR & HTR-10
3. PBMR resonance self-shielding in WIMS
4. Review of TECDOC I and plans for TECDOC II
5. Meeting recommendations

1. Present status of on-going projects

HTTR (Mr Kunitomi)

The HTTR reached the full power of 30 MW and reactor outlet coolant temperature of 850 C on December 7, 2001. After several tests in the full power operation, operational licensing of the HTTR was issued by MEXT (Ministry of Education and Culture, Sports, Science and Technology). The high temperature operation with its thermal power of 30 MW and reactor outlet temperature of 950C will be carried out in 2002. In addition to the HTTR program, basic design of the GTHTR300 (Gas Turbine High Temperature Reactor 300) has been conducted, and R&Ds for the power conversion unit have started.

HTR-10 (Mr Sun)

Hot functional commissioning tests have been mostly finished with the power of the main helium blower and with some nuclear power of 300kW. The test reactor facility is ready for power escalation commissioning tests. In the last quarter of 2002, test operation up to 30% rated power is planned. In the first half of the coming year, the test reactor is expected to reach full power. After certain time of power operation, safety demonstration tests shall be performed to study and demonstrate the safety features.

Irradiation of INET-manufactured fuel has been continuing. The irradiation burn-up has reached 85,000MWd/t, noting that the goal burn-up is 100,000MWd/t. The irradiation results have remained positive and satisfactory up to the achieved burn-up level.
Within the frame of the national high technology development program, it has been proposed to couple a gas turbine system to the HTR-10 reactor for the development of gas turbine technologies; and the Chinese government has approved the proposal. Technical feasibility and design variants are being investigated. In parallel, efforts are being made for the proposal of building HTGR industrial demonstration plant.

PBMR (Mr Mulder)

The status of the PBMR project was reported in terms of the set commercial goals. It was highlighted that the PBMR project aims to:

- Develop a commercial HTGR
- Use existing technology (nuclear and gas turbine) in a commercial configuration
- Exploit the strengths of Eskom and involve other key partners
- Achieve a long term (25 year) IRR of +20% by competing in the world markets.

•**Key considerations**:

- Demonstrated technology
- A commercial order from a credible customer (Eskom).

•**Targets:**

- $1000/kWe installed
- 24 months construction time
- 400m EPZ.

An overview was presented of the HTGR historical background as well as that of the PBMR. Subsequently, an overview was presented of the manpower and expenditure to date on the PBMR project. Key suppliers were mentioned of the various large and long lead components. Key activities currently ongoing or recently concluded had been mentioned together with the names of associated companies.

An overview was also presented of the design philosophy, design processes followed, together with major test rigs erected or involved in validating codes, design methodologies, or in understanding characteristic behaviour.
The strategies to be followed in achieving the set goals of safety and economics were discussed in some detail.
On the technical side an overview was given of the current design values. Of particular interest were the safety aspects involved and methods of achieving these. Once again, the design issues involved were discussed, whilst highlighting the resultant design changes brought about in achieving these set requirements.
A presentation was made of the HTR-10 equilibrium layout results. Results of the benchmark calculations for the HTR-10 were subsequently presented.
Finally, an overview was presented of the Business Case and underlying fundamentals.

GT-MHR(Mr Kuzavkov)

Current design features of the GT-MHR Plutonium Burner concept were described and discussed. The preliminary design of the GT-MHR was completed in 2002, with OKBM as the chief Russian design organization. The RF Scientific and Technical Council of MINATOM reviewed the design, and recommended continuation of the project at least through the final design stage.

The Final Design stage was initiated. Two core variants of the core design are being considered (Pu for excess weapons material disposal – and utilization, and Uranium – for commercial reactor deployment). An active R&D program, including many experimental activities, was continued, with an emphasis on power conversion system components and systems. Cost and schedule projections were also presented.

Construction of the bench-scale fuel production facility is underway. First batches of Pu fuel for irradiation testing are expected by 2004.

HTGR related activities in France (Mr Raepsaet)

Two main branches can be identified in these activities:

1. Thermal-High Temperature Gas-Cooled Reactors: With joint efforts involving CEA, FRAMATOME-ANP, EDF and support from the European union, it consists of a common R&D program in the following technical areas: core physics, materials, modeling tools, re-establishing lost knowledge in lab-scale fuel fabrication and qualification, as well as Helium technologies.
2. Fast High Temperature Gas-Cooled Reactors: This branch examines the potential of epithermal and fast gas-cooled reactors as future nuclear systems (4th generation), promising improved efficiency by minimizing waste production, saving resources and providing an integrated process for fuel reprocessing (a closed fuel cycle).

There will be a strong synergy between the two branches and emphasis will be made on experimental tools such as Helium loops and a demonstration reactor, in order to qualify and validate both thermal and fast technologies.

HTGR related activities in Germany (Ms Ohlig)

The HTGR related activities in Germany are mainly involved in the following fields:

1. Within the framework of the 5th EU R&D Programme on:
   - Nuclear Physics and Fuel Cycle Studies (HTR-N),
   - Nuclear Physics Analysis at Hot Conditions (HTR-N1),
   - Fuel Technology (HTR-F),
2. Within the framework of the IAEA CRP-5 on "Evaluation of the High Temperature Gas Cooled Reactor Performance".

Moreover, studies on the safety concept of the South African PBMR (Pebble Bed Modular Reactor) are performed concerning core design, extreme accident behaviour and contributions to the treatment of radioactive materials of this reactor etc. This project is supported financially by the PBMR (Pty.) Ltd. in the frame of a licensing contract. Other companies involved in this contract are: HTR-GmbH and the Westinghouse company.

HTGR related activities in Indonesia (Mr Aziz)

Involvement of BATAN (National Nuclear Energy Agency of Indonesia) in HTGR goes back to early 1980`s, when Indonesia considered to use HTGR for enhanced oil recovery, in Duri, Sumatera. However, a more intense involvement in the evaluation of HTGR was started in the second half of 90`s, when Indonesia joined the International Working Group on Gas Cooled Reactor and subsequently participated in the Coordinated Research Program on the Evaluation of High Temperature Gas Cooled Reactor Performance (CRP-5).
The small and medium sized reactor is considered suitable for small and isolated islands far from electric grids, that suffer from electricity and fresh water shortages. HTGR has been thought as an important option, both for cost-effective electricity production and for desalination, due to its higher temperature discharge to the environment.
Currently, one of BATAN`s research centers has been assigned to study development in the technology and the present status of HTGR.

HTGR related activities in Netherlands (Mr De Haas)

At NRG work is ongoing on the ACACIA concept (60 MW thermal / 23 MW electric), a reactor meant for powering bulk industries or remote areas.
To keep maintenance and operational costs as low as possible, the reactor is fueled as a static "cartridge" core. This means that after some years, the entire core is replaced by a new one consisting of an inner reflector and a fresh annular pebble bed. To keep the swing in K-eff, due to burn-up, as low as possible, the inner reflector is provided with burnable poison regions. The study comprises the optimization of the loading of burnable poison and core geometry to obtain a flat K-eff and maximize burnup. Other studies concern burning civilian Pu from reprocessed LWR fuel in continuous reloading HTR's (MEDUL concept).
At IRI, the concept of burnable poison kernels in the fuel has also been the focus of a study, with the aim of flattening K-eff as function of burnup.

HTGR related activities in Turkey (Mr Kadiroglu)

Turkey was introduced to HTGR technology in 1987 with a proposal to build a 20 MW pebble bed heating reactor (GHR20) designed by HTR (BBC at that time) at the Beytepe campus of Hacettepe University in Ankara. A feasibility study was completed in 1989 and a search for financial recourses started. Due to political, financial and company originated difficulties the project died in 1990. Nevertheless, since that time, HTGR stayed as the prime interest of the Nuclear Engineering Department of Hacettepe University.

Despite two main financial crises in a year and an unacceptable inflation, the Turkish economy is still growing. The growth in electricity production is around 8%. Indigenous energy resources, namely hydro and lignite, are limited and are used to full extent. Imported natural gas is the main fuel in electricity production. Turkey has no other alternative than to go nuclear in the near future.

Turkey changed many of its laws in recent years due to globalization and for the integration to European Union. Presently, the state monopoly on electricity generation has been lifted and governmental guarantees on international loans for any economical activity, including electricity production, has been voided. It is rather difficult for free enterprise in Turkey to obtain very large sums of credit to build large nuclear power plants. Thus small nuclear power plants gained importance in Turkey in recent years. With its low capital cost, short construction period and small power HTGR's can be an attractive option for private utilities. With superb safety characteristics licensing and public acceptance would not be a major problem.

Based on these thoughts Turkey requested to be a member of the CRP-5 in 2000 and accepted as an observer in 2001. Since then, HTR-10, HTTR and ASTRA benchmark problems have been studied at the Nuclear Engineering Department of Hacettepe University. Interest in HTGR technology among other universities and research organizations in Turkey are declared for future studies.

HTGR related activities in UK (Mr Newton)

The UK industry has no specific co-ordinated programme on HTR reactors. However, the potential of the HTR design leads to specific parts of the UK industry to have a significant interest in the technology. For example, BNFL have a large financial investment as a partner in the South African PBMR and SERCO Assurance are developing methods to model the variety of proposed HTR designs. The HTR has also been included as a possible future nuclear power generating option in a recent UK government review paper.

As a specific activity, UK industry has been requested by the NEA to provide copies of the DRAGON reactor archive for inclusion in the NEA IRPhE database on knowledge preservation. As part of this exercise it is intended to examine the archive reports to see if a reactor benchmark can be identified, particularly, in relation to the start-up commissioning core

HTGR related activities in USA (Mr Ball)

•The U.S. is a major participant in the design effort for the GT-MHR Plutonium Burner (in Russia). The project is supported financially ~50/50 by the US DOE-NNSA and MINATOM, with substantial contributions as well from Japan, France, and the EU (via ISTC projects). The major US technical support participants are ORNL and General Atomics. The project is currently in the final design stage, with a number of major R&D activities in progress. The Preliminary Design was completed in 2002.

•In the recent Generation IV Reactor initiative (sponsored by US DOE), one of the four technical working groups was dedicated to gas reactors. Two thermal HTR concepts were selected as near-term deployment options (GT-MHR and PBMR), and one (VHTR) was chosen as a year 2030 deployment option.

•US industry, utility, and regulatory interest in the PBMR has dwindled, at least temporarily, with the withdrawal of Exelon support for building PBMRs in the US, while interest in the GT-MHR concept for both electrical and hydrogen production has increased.

•A new DOE-sponsored HTR fuel development program (focused on actinide burning) has also been initiated in 2002.

2. Benchmark results & analysis for HTTR & HTR-10

2.1. HTTR thermal-hydraulic benchmarks

2.1.1. HTTR-VC – Vessel Cooling benchmark

The HTTR-VC benchmark, calculations of vessel cooling system performance, had participation by four member states. Reactor data provided by JAERI for the full-power (30 MW) 850 C operation allowed for completion of the benchmark. (Data for the 9 MW operation was presented at the previous RCM.) Table 11 summarizes the calculated and experimental results for VCS power removal at 30 and 100% power levels.

In all cases, power removed by the VCS was underestimated by the calculations. JAERI had observed that hot cavity air leakage and circulation behind the cooling panels was considerably greater than initially expected. This degraded the effectiveness of radiation shields that were to reduce power removed by the VCS. Modeling of the effects of this leakage problem appeared to underestimate this effect to a greater or lesser extent in each of the calculations. The models used ranged from very detailed CFD calculations (France) to simplified empirically-derived models based on the JAERI scaled VCS experiment analyzed in CRP-3 (U.S.).
Predictions of maximum vessel temperatures were generally good; however, the vessel temperatures are more dependent on conditions within the vessel than on VCS performance.
The predictions for VCS power at the two operating conditions ranged from ~10% low to ~40% low compared to the measured values. This indicates a typical uncertainty range for VCS performance predictions – based on previous experience with CRP-3 benchmarks for the JAERI VCS mockup experiments. Clearly additional experience in VCS performance calculations would be useful.

Table 1 Comparison between analytical results and experimental results

Country		Analytical results				Experimental results
		Japan	Russia	USA	France	
9MW operation	VCS heat removal	0.2 MW	0.133 MW	0.180 MW	0.178 MW	0. 22 MW
	RPV temperature (EL. 19-27 m)	～ 170 C	165 C	159 C		～ 170 C
30MW operation	VCS heat removal	0.77 MW	0.494 MW	0.67 MW	0.555 MW	0.81 MW
	RPV temperature (EL. 19-27 m)	370-380 C	330-360 C	330 C		340-360 C

2.1.2. HTTR-LP – Loss of Power benchmark

Results of the HTTR loss of offsite power test from 30MW (full-power operation) were presented by JAERI. Test results from the 50% power LP case had been presented at the previous RCM. Japan and three other countries submitted calculations for both the LP cases.
The LP tests proved to be rather uneventful, as predicted, with the core temperatures decreasing gradually from the start of the transient. Following the reactor scram and main circulator coastdown, the two auxiliary cooling system circulators started up and ran for the first 40 minutes. After that, one of the two auxiliary circulators was stopped to reduce core thermal stresses associated with a rapid cooldown.
Analyses of the cooldown transients by Russia (VGM code), Japan (ACCORD code), and USA (GRSAC code) were presented and found to be in general agreement with the experimental results. For the 30 MW case, however, a discrepancy was observed between the Japanese calculation and measurement of auxiliary cooler heat removal rate vs. that predicted by both the RF and US codes. There are also some discrepancies between the calculated cooldown rates for the core. These differences are being investigated by the three parties involved.
The South African analysis of the LP tests did not complete the temperature transient analyses due to an initial misunderstanding of the benchmark guidelines. They do plan to complete these analyses within the next few weeks, however, now that the benchmark statement has been clarified.

2.2. HTTR reactor physics benchmarks

The results of the revised calculations were presented by Ms. Ohlig in Germany, Mr. Raepsaet in France and Mr. Kuzavkov in Russia. Mr. Kadiroglu in Turkey introduced the calculation method and condition of the benchmark problems. The results of the benchmark problems (HTTR-FC, HTTR-CR, HTTR-EX HTTR-SC and HTTR-TC) are shown in Tables 1 – 10 below:

Table 1 HTTR FC (diffusion calculation)

Member state	Number of fuel columns	Keff	Excess(%dk/k)
Japan	17	1.0005	0.05
France	17	1.0061	0.61
Germany	18	1.008	0.79
Indonesia	18	1.0058	0.577
Russia(OKBM)	16	1.005	0.498
Experimental results	19		

Table 2 HTTR FC (Monte-Carlo Calculation)

Member state	Number of fuel columns	Keff	Excess(%dk/k)
Japan	18	1.0061	0.61
France	18	1.0085	0.85
Netherlands(IRI)	17	1.0062	0.62
Russia(IBRAE)	16	1.006	0.596
Russia(RRCKI)	17	1.004	0.398
Turkey	15	1.005	0.50
Experimental results	19		

Table 3 HTTR CR (diffusion calculation)

Member state	Control rod position at critical (mm)		
	18 col.	24 col.	30 col.
Japan	3035	2055	1665
France			1787
Netherlands(NRG)			1615
Russia(OKBM)	2710	1960	1660
Experimental results		2215	1775

Table 4 HTTR CR (Monte Carlo calculation)

Member state	Control rod position at critical (mm)		
	18 col.	24 col.	30 col.
Japan	2810	2080	1800
France			1779
Netherlands (IRI)			1705
Russia(IBRAE)	2590	1950	1700
Russia(RRCKI)	3060	2010	1540
Turkey	2850	2100	1640
USA			1590
Experimental results		2215	1775

Table5 HTTR EX (diffusion calculation)

Member state	% dk/k		
	18 col.	24 col.	30 col.
Japan	1.2	9.2	12.6
France	1.7 to 2.7	9.1 to 9.9	12.0 to 12.7
Germany	0.79	8.6	11.8
Indonesia	0.577	6.472	8.517
Netherlands(NRG)			13.8
Netherlands(IRI)			16.5
Russia(OKBM)	2.68	9.73	11.14
Experimental results		7.7	12.0

Table 6 HTTR EX (Monte Carlo calculation)

Member state	% dk/k		
	18 col.	24 col.	30 col.
Japan	0.61	9.06	12.5
France	0.85		12.15
Netherlands(IRI)	2.4		13.8
Russia(IBRAE)	2.7	10.83	13.55
Russia(RRCKI)	1.7	9.8	13.4
Turkey	2.981	10.689	13.525
USA			12.28
Experimental results		7.7	12.0

Table 7 HTTR SC (diffusion calculation)

Member state	% dk/k	
	Ref.CR	All CR.
Japan	8.3 CR-block and 8.94 for CR-hex	44.6
France	10.83	56.31
Netherlands(NRG)		37.5
Russia(OKBM)	8.43	52.37
Experimental results	12.0	46.0

Critical position at 480k, C, R1, R2 and R3 calculated at 1825 mm(full out) by Japan

Table 8 HTTR SC (Monte Carlo calculation)

Member state	% dk/k	
	Ref.CR	All CR.
Japan	9.53	45.1
France	8.56	46.32
Netherlands(NRG)	9.88	47.78
Russia(IBRAE)	9.61	40.40
Russia(RRCKI)	9.55	50.81
Turkey	7.75	37.96
USA		45.0
	12.0	46.0

Table 9 HTTR TC (diffusion calculation)

Member state	% dk/k/K x 10^{-4}					
	290	320	360	400	440	470
Japan	-1.15 to - 1.39 over entire range					
France	-1.5 to -1.6 between 300 and 420k					
Netherlands(NRG)	-1.52(Average)					
Russia(OKBM)		-2.33	-2.19	-1.97	-1.82	-1.81
Experimental results	-1.3 to -1.4*					

*Evaluated from measured control rod positions and calculated control rod worth curve

Table 10 HTTR TC (Monte Carlo calculation)

Member state	% dk/k/K x 10^{-4}					
	290	320	360	400	440	470
Japan		-1.23	-1.66	-1.63	-1.56	-0.91
Netherlands(IRI)	-1.47 (Average)					
Russia(IBRAE)		-1.95	-1.73	-1.65	-1.77	-1.45
Russia(RRCKI)		-1.1	-1.7	-0.9	-1.8	-1.3
Turkey	～-1.2@ 450k					
USA	-.75 @ 550k					
Experimental results	-1.3 to –1.4					

Following are some of the cited uncertainty areas and different modeling options, which may have contributed to discrepancies in the results presented:

1. Uncertainties in the level of impurities in the dummy blocks
2. Uncertainties in water content of graphite pores
3. Uncertainties in Monte Carlo modeling of coated fuel particles and differences in geometry representation, which may include any of the following options:
   - Explicit geometry
     - Regular array placement
     - Random placement
   - Statistical geometry
   - Homogeneous representation of coated particle region, explicit geometry elsewhere.
4. Choice of selected cross section data library and version (JEF, ENDF,JENDL, etc.)
5. Uncertainties in the modeling of neutron streaming with diffusion methods
6. Difficulty in modeling harmonics in thin annular cores with diffusion methods. This can be mitigated by:
   - Detailed leakage feedback
   - Use of fine group constants or super cell calculations

Recommendations for future studies include:

1. Comparison of results from old and new versions of ENDFB libraries (ENDF/B-VI-4). According to Mr Carlson, versions older than ENDF/B – VI-4 may have graphite scattering law errors.
2. Further investigation of coated fuel particle modeling.
3. Additional experiments and analyses for temperature and burnup dependence of temperature coefficients.
4. Investigation of streaming especially in empty control rod channels and of methods used to calculate anisotropic diffusion coefficients for whole core calculations.
5. Two core physics benchmarks will be proposed after authorization from JAERI, namely:
   - HTTR – PCR: Calculation of control rod insertion depth at 15 and 30 MW powers.
   - HTTR – PTC: Calculation of temperature coefficients at 15 and 30 MW powers.

2.3. HTR-10 reactor physics benchmarks

Mr. Sun reviewed the HTR-10 core physics benchmark problems and the calculation results of INET as well as the available experimental results. Mr. Raepsaet of France, Mrs. Ohlig of Germany, Mr. Mulder of South Africa and Mr. de Haas of the Netherlands presented the calculation results of their calculations relevant to HTR-10 benchmark problems. The calculation results of HTR-10 benchmark problems which have been available up to this meeting are summarized below. Meeting participants reviewed the TECDOC sections relevant to the HTR-10 core physics benchmark problems. General conclusions and recommendations, analysis of possible reasons for the calculation result differences among the participating institutions, which are huge in some cases, were discussed. Results of these discussions will be included in the TECDOC.

Summary of HTR-10 Defined Physics Benchmark Results Presented at 4th RCM

	B1 (cm)		B21 (Keff)		B22 (Keff)		B23 (Keff)		B31 (%)		B32 (%)		B41 (%)		B42 (%)	
Country	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M
China	125.8	126.1	1.1197	-	1.1104	-	1.0960	-	15.24	16.56	-	1.413	18.27	19.36	1.619	1.793
France	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Germany*	124.2 126.8		1.13725 1.12665		1.12404 1.11331		1.10693 1.09588		-- 16.60		-- 1.56		-- 20.50		-- 1.97	
Indonesia**	107 120		1.2193 1.1381		1.1983 1.1149		1.1748 1.0844									
Japan	113								18							
Netherlands	125.3		1.1176		1.1085		1.0963		11.86				13.61			
Russia	136	137.3	1.1182	1.1076	1.1079	1.0933	1.0927	1.0794	15.50	17.90						
S. Africa																
Turkey***	119.27	129.7 135.3		1.0941 1.0809		1.0802 1.0380		1.0671 1.0035		18.73 21.88		2.53 4.60		20.02 23.65		
USA****		127.5 128		1.1319 1.1298		1.1279		1.1245		16.50 16.56						

D/T: Diffusion/Transport,   M: Monte Carlo

*: The first row of data is obtained with 2-dimensional VSOP, and the second row of data with 3-dimensional VSOP.

**: The first row of data is obtained with the DELIGHT code, and the second row of data SRAC code.

***: The first row of data is obtained with the ENDF/B-IV nuclear data set, and the second row of data with ENDF/B-V nuclear data set.

****: The first row of data is obtained with the UTXS nuclear data set, and the second row of data with ENDF/B-VI nuclear data set.

Summary of HTR-10 Revised Physics Benchmark Results Presented at 4th RCM

	B1 (cm)		B21 (Keff)		B22 (Keff)		B23 (Keff)		B31 (%)		B32 (%)		B41 (%)		B42 (%)	
Country	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M	D/T	M
China	122.558	122.874	1.135779	1.13813	1.126158	-	1.111115	-	14.46	15.31	1.277	1.343	17.23	18.28	1.540	1.572
Germany*	121.0 123.3		1.1468 1.1368		1.1334 1.1232		1.1160 1.1054		-- 15.73		-- 1.48		-- 19.31		-- 1.86	
France**		115.36 117.37		1.15679 1.14737						13.06 13.44		1.35 1.31		13.66 13.80		1.52 --
Indonesia																
Japan																
Netherlands	122.1															
Russia																
S. Africa	122.537		1.12861		1.11956		1.10469									
USA																

D/T: Diffusion/Transport, M: Monte Carlo

*: The first row of data is obtained with 2-dimensional VSOP, and the second row of data with 3-dimensional VSOP.

**: The first row of data is obtained with simplified PB modeling, and the second row of data with improved PB modeling.

3. PBMR resonance self-shielding methods in WIMS

SERCO Assurance made a presentation in two sections; the first on the resonance self shielding methods applied in WIMS illustrated in the application to the PBMR and; the second on the algorithms in the MONK Monte Carlo code for modeling the PBMR core.

The WIMS resonance self shielding methods apply a mathematical sub-group treatment that avoids the assumption of black fuel and the calculation of a Dancoff factor. The method fits the parametric form of the resonance integrals as a function of the scattering per atom of resonance nuclide after temperature interpolation of the resonance integrals. The fitting process yields a set of sub-group cross-sections and sub-group weights for which sub-group fluxes can be calculated for a totally general geometry. These fluxes when integrated over the problem with the sub-group cross-sections and weights yield the broad energy group cross-sections. The power of this method lies mainly in the ability to treat any complexity of geometry. In particular application to the PBMR, collision probabilities are first calculated for the coated particles and a homogeneous total cross-section is derived which gives the same neutron transmission probability across the coated particle. This cross-section is then used for the central region of the fuel pebble to derive collision probabilities for the pebble. The two sets of collision probabilities are then combined to give probabilities connecting the coated particle and the pebble. This process can also be extended to super cells with interacting fuel batches at different burn ups or to include a general ratio of fuel and graphite pebbles. Sub-group fluxes solved for this system allow the resonance self shielding of all interactions to be taken into account in preparing broad group cross-sections.

The MONK Monte Carlo code has several algorithms to model the 61% packing density of pebbles in the PBMR. To avoid long artificial streaming paths in the core two specific methods have been developed:

- Starting with a regular hexagonal close packed arrangement of spheres, groups of four spheres are randomly removed and a single sphere placed at the center of the void formed. This process is repeated until the 61% packing density is obtained.

- Planes of hexagonally structured spheres are placed one above the other at random orientations and off-sets and the spheres in each plane are individually lowered to make contact with the spheres below. This produces a random irregular packing without artificial streaming paths.

Both the above methods avoid the use of regular array packing which gives an artificially high k-effective.

4. Review of TECDOC I & plans for TECDOC II

A draft copy of TECDOC I was reviewed at the meeting and plans for TECDOC II were discussed by the CSIs.

TECDOC I

Of major importance was to determine the reasons for benchmark analysis differences between code results and the actual results obtained from the HTTR and HTR-10 reactors for inclusion in TECDOC I.. Recommendations for further investigation to improve on codes and models were also determined by the CSIs. The agreed upon recommendations and reasons for differences between code and test results are contained within this meeting summary and will also form the basis for the final chapter (Chapter 5) of the first CRP-5 TECDOC.

Other final changes in the first CRP-5 TECDOC were also agreed upon including the content of the HTTR and HTR-10 benchmarks, chapter designation and the final schedule for submittal of this document to the IAEA for publication. The chapter designation is as follows:

Chapter 1;	Introduction
Chapter 2;	HTTR Core Physics Benchmarks
Chapter 3;	HTTR Thermal Hydraulic Benchmarks
Chapter 4;	HTR-10 Core Physics Benchmarks
Chapter 5;	Results and Results and General Conclusions

Chapter 5 (General Conclusions) will contain a collation of all benchmark results and the reasons for differences with the actual test results along with recommendations for further improvements in the codes and models

The schedule for submittal of the first TECDOC for publication is as follows:

- Complete write-up of Results and Conclusions chapter and other agreed changes in the document to be completed (by Mr. Brey) by early December 2002
- Review and agreement of final TECDOC (by the Co-chairmen, Messers. Kunitomi and Ball) completed by December 22, 2002.
- Submittal of final document to Mr. Methnani for publication by IAEA by December 31, 2002.

TECDOC II

Regarding TECDOC II, the key areas of investigation were to determine the benchmark problems to be investigated in the HTTR and HTR-10 along with an understanding of Member State participation. The ASTRA and GT-MHR benchmarks previously agreed upon were also reviewed for Member State participation. This information has been included within this meeting report.

Messers. Kunitomi and Sun are to provide the details for these new benchmark problems associated with the HTTR and HTR-10 reactors and send them to all CSIs by e-mail by 1 January 2003. Mr. Mulder will evaluate the possibility of including a benchmark problem associated with the PBMR. He will send this benchmark information to the CSIs by January 2003 as appropriate.

The schedule for TECDOC II development was discussed. It was strongly recommended by the CSIs that a 5th RCM be held in 2004. Without a final RCM, it is very difficult to provide a reasonable discussion between Member States on their individual benchmark investigations and to formulate good recommendations if the CSIs are not able to meet in a common forum. It was also understood that the IAEA Business Collaborator be used for the sharing of information between CSIs and for collation of TECDOC II material.

A schedule was proposed and adopted for the development of this document that includes:

- All CSIs provide interim information on their benchmark investigations to the Business Collaborator by 1 Jan. 2004.
- All CSIs are to provide their final documentation for TECDOC II into the Business Collaborator 2 months ahead of a 5th RCM, or if the 5th RCM is held in conjunction with the HTGR meeting now scheduled for Spring of 2004, that the CSIs be far enough along with their investigations to be able to present their results at this meeting and to come to agreement on reasons for the differences between their results and the facility test results and make recommendations for improvement in the codes and models.
- A target of the end of 2004 for submittal of the TECDOC II document to the IAEA for publication was agreed upon. It is understood that to meet this target will require the CSIs to provide their final benchmark investigation material to the Business Collaborator (or to the person chosen to collate/edit the TECDOC) well in advance of 31 December 2004 (a minimum of two months is required for this effort).

The content of the TECDOC II was agreed as follows:

Chapter 1; Introduction
Chapter 2; ASTRA Benchmarks
Chapter 3; GT-MHR Benchmarks
Chapter 4; HTTR Benchmarks
Chapter 5; HTR-10 Benchmarks
Chapter 6; Results and General Conclusions

5. Meeting recommendations

1. All new benchmarks and data are to be sent to all CSIs by January 1, 2003.

2. All participants will upload TECDOC II material, including benchmark data, results and analysis, on the Business Collaborator (BC). A link to BC can be found at the IAEA HTGR website www.iaea.org/htgr.

3. The following schedule has been proposed:

- Interim draft in: by Jan. 1, 2004
- Final draft in: by June 1, 2004
- Distribution of edited draft for review by CSIs: by Sep. 1, 2004
- Submission to IAEA for publishing: by Dec. 1, 2004

4. A fifth RCM has been strongly recommended by the meeting participants, to be held in 2004, in order to discuss and analyze new results.

Attachment 1

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