Topics treated for Meetings from 21. to 23. March 2016 in Neuss

General

Status of Shidao and other HTR Projects in China

The construction of the reactor pressure vessel and metal components inside the reactor was finished and they were transported to the site on 07/03/2016.

Status of HTR Projects in other countries in the world, e.g. Indonesia, Saudi Arabia?

Meanwhile, China Nuclear Engineering Group Corporation (CNEC) signs the memorandum of understanding (MOU) on cooperation with Dubai Nuclear Energy Committee and provides King Abdulaziz City for Science and Technology (KACST) with the design scheme of HTGR sea water desalination. They have also reached a consensus on signing the memorandum of understanding on cooperation with Saudi Energy City. On April 21, 2015, they signed the MOU with South African Nuclear Energy Corporation (NECSA).

Indonesia and Japan joined together on 04/08/2014 to develop HTGR. Indonesia plans to put HTGR into operation in 2020.

key elements of the demo program of the HTR –PM in Shidao

Comparison to NuScale minimal size 50 MWel

Comparison to PRISM

PRISM is a SFR. A small module reactor.The power output is 311MWe.Pool-type, cheap and flexible for experiments, power is not high.

Physics

Which are the highest reachable temperatures of the primary-he-gas - depending on the core calculation and core reactor design;

The maximum fuel temperature should be below 1600℃. The decay heat can be removed passively.

Which design parameters are applied to avoid the additional thermal stresses: divergent moving/stretching of the steel pressure vessels will influence the hot-gas-duct between these two abovementioned vessels ?

Nuke fuel (pebbles)

Pebble - Fuel design, fabrication, testing, qualification in detail

A pilot fuel production line has been built to fabricate 300,000 pebble fuel elements per year. This line is closely based on the technology of the HTR-10 fuel production line.

In addition, the key systems and equipments of the plant will be rigorously tested in large-scale experimental rigs in order to guarantee the safety and reliability of all components. Furthermore, international mature technologies and successful experiences will be absorbed through international technical consultations

And an irradiation test on the fuel element from this production line is under way.

Is fuel design accepted and approved ?

What needs still to be done ?

How to maintain the boundary between fuel ball zone and graphite ball zone, how to ensure the reflector graphite withstanding the whole reactor life time, how to mix the outlet hot helium from the fuel zone and the cold helium from the graphite zone, etc.

To what degree is the Institute of Nuclear and NewEnergy

Technology (INET) seriously interested in reducing the waste ?

Reprocessing. Developing now

What method will be used ? Petten might have an interesting offer

Hydro,PUREX

What are the plans for dealing with irradiated graphite?

Design

1. Design of

    SHTR-Power plants/

    Heat Producers;

(S(mall)HTR 50 MWth up to 100 MWth;

2. Why did China choose **two** steel pressure vessels for Shidao:

   one for the core and

   the second for heat exchanger,

   (Germany opted for one pressure vessel (of prestressed concrete) including one integrated Helium-circuit)

3. Comparison of the two lines

   Chinese modular line

   vs.

   Large single core line of reactors with prestressed concrete vessel up to 1.200 MW

4. What advantages are seen in the installation of several modular cores in several steel pressure vessels instead of one large prestressed concrete pressure vessel (pcpv) up to highest performances;

Engineering, construction

Status of the steam generator:-

Helical coil tube bundle type or

multi-coil type?

Which one is approved ?

Efficiency of the approved design

The steam generator consists of 19 separate helical tube assemblies; each assembly has 5 layers and includes 35 helical tubes, as shown in Fig 2. To ensure two-phase flow stability, throttling apertures are installed at the entrance of all helical tubes. The assembly type design of the steam generator uses the experiences from the steam generator employed in the HTR-10. In-service inspection is possible. For full verification of the steam generator assembly full scale testing will be performed.

The main helium blower, designed as a vertical structure, is installed on the top of the steam generator inside the steam generator pressure vessel. The electric motor is mounted on an insertable assembly; the motor is driven by the converter outside of the pressure vessel. A magnetic bearing system is envisaged.

The main helium blower is a “heart” of the nuclear steam supply system (NSSS). It forces the helium coolant to flow in the primary loop. It operates at 7MPa, 250oC helium condition. The helium flow rate is 96kg/s and the pressure rise is 200kPa. The main helium blower is installed on top of the steam generator, as shown below.

The Figures pleas see in the Website or ask from the Webmaster

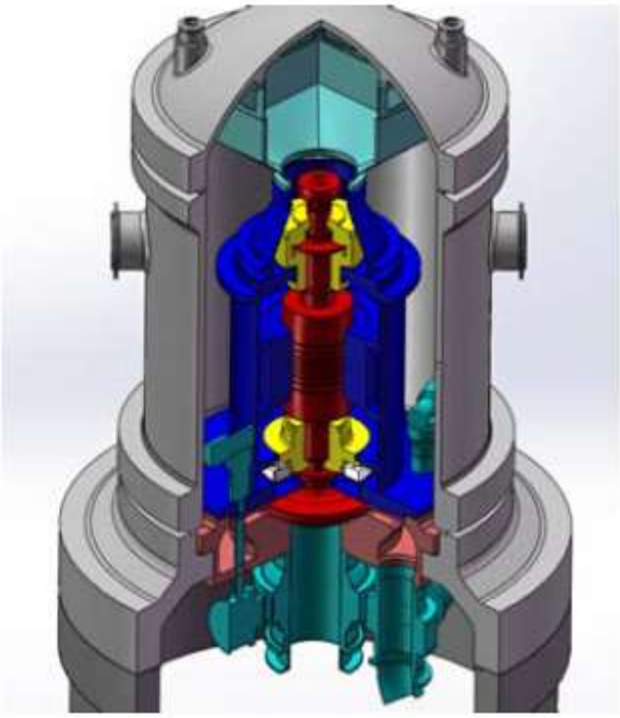

Fig.1

On 25/01/2016, the first helical tube assembly finished installation in HTR-PM

Helical coil tube bundle type (once through):

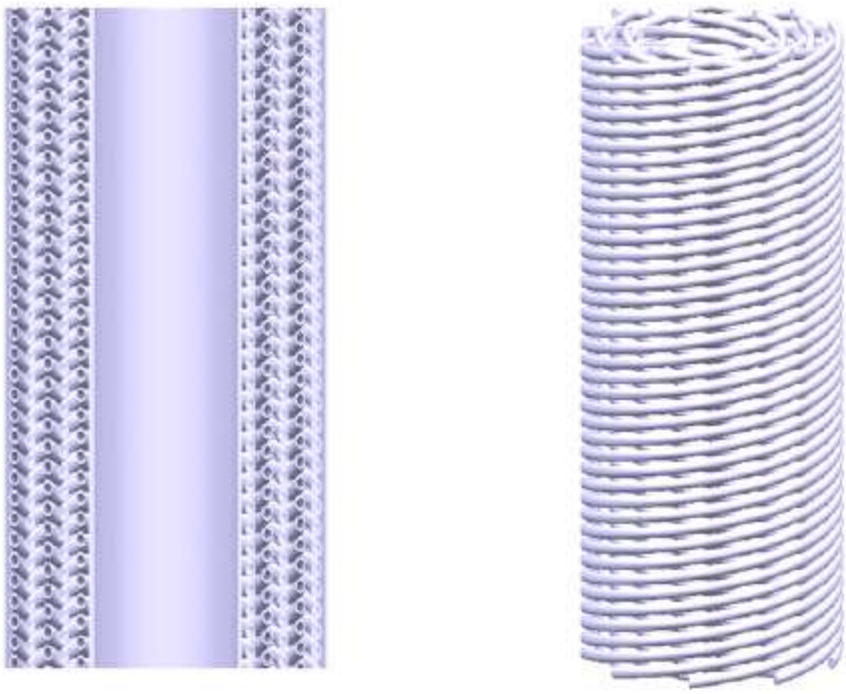

Fig 2

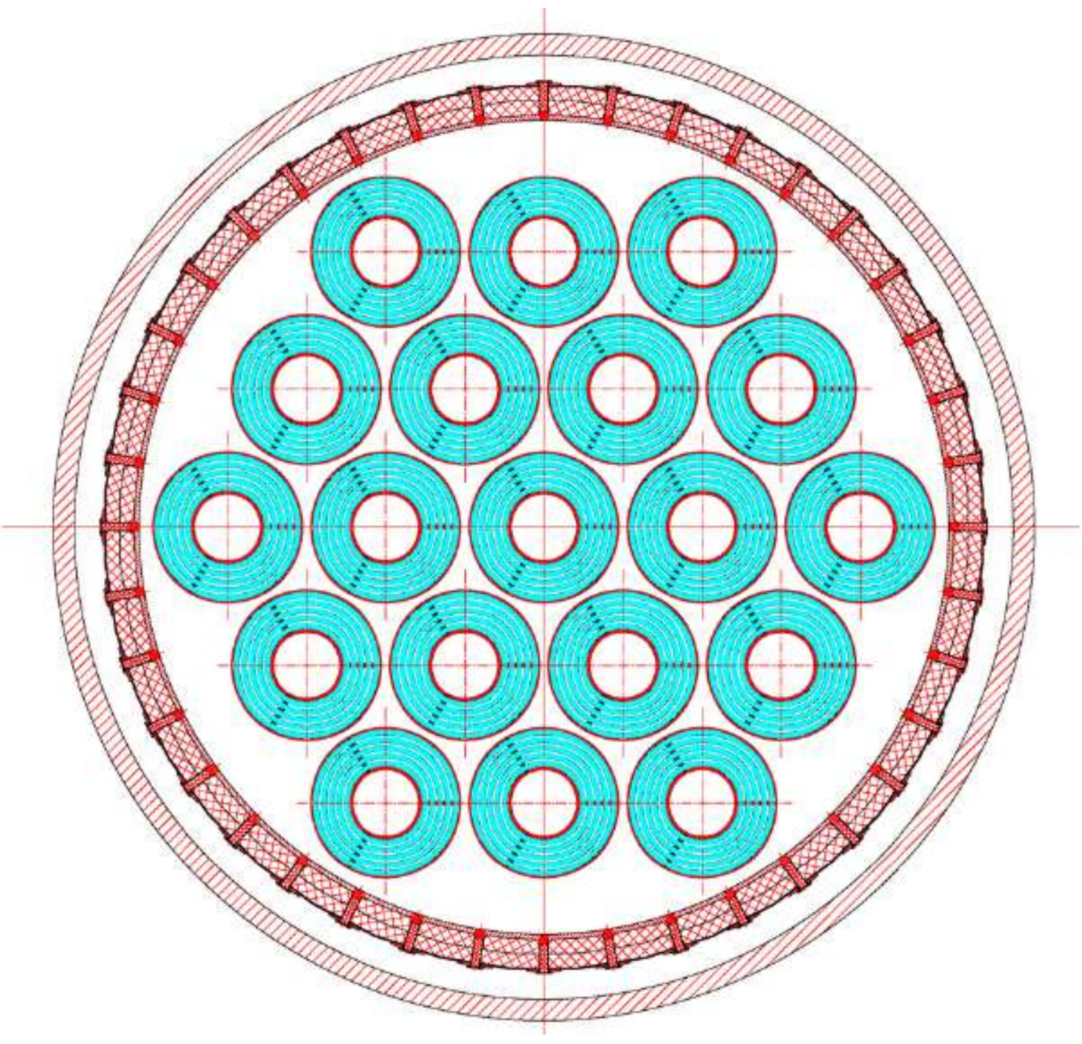

Fig 3

The efficiency is high. For example, HTGR plants can achieve a thermal efficiency of 42% by even employing subcritical superheated steam turbines or reaching ~45% when supercritical steam turbines are installed. The efficiency could be improved even further when adopting direct helium gas turbines with recuperators or when choosing a combined cycle.(Gen3 only around 30%)

Manufacturing of Modules

When mass producing such modules, what is the expected cost benefit against

First of a Kind (FOAK) and

nth of a Kind (NOAK)?

What is the minimal size in MW th ?

The construction cost target for the nth-of-a-kind (NOAK) equilibrium plant is 1300 USD/kWe in order to be competitive in China.

Safety

Comparison of the safety concepts of both lines:

Modular

Large single core

The “safety” requirement means the HTR-PM will comply with the inherent safety principles of the MHTGR, which must be able to remove the decay heat passively from the core under any designed accident conditions, and should keep the maximum fuel temperature below 1600 ◦C in all cases so as to contain all fission products inside the SiC layer of the TRISO coated fuel, and assure the low fuel temperature (lower than 1100 ◦C) under normal operation and large negative temperature coefficient.

(1) By using spherical fuel elements containing TRISO coated particles one can assure that all relevant radioactive fission products will effectively be retained for at least 500 h when, during accidents, a maximum temperature of 1620 ◦C is not exceeded.

(2) The pebble-bed core design allows the spherical fuel elements to constantly pass though the core by gravity from up to down. This fuelling scheme avoids loading the core with excess reactivity. The elaborate reactor core design ensures that the fuel element temperature will never exceed the safety limit of 1620 ◦C for any operating or accident condition.

(3) Two independent shutdown systems are installed: a control rod system and a small absorber sphere (SAS) system, both placed in holes of the graphitic side reflector. For shutdown purposes the rods and the small absorbers are released and drop into the reflector borings by gravity. This will improve the reliability of the shutdown systems.

(4) The active core zone is encased by a bulky layer of graphite and carbon bricks without metallic components. This ensures that the core internals can withstand and endure very high temperatures.

(5) The reactor core and the steam generator heat transfer bundles are installed in two different pressure vessels, which are connected by the hot gas duct pressure vessel. The primary pressure boundary comprises all three vessels. These vessels are all protected by the cold helium gas (250 $^\circ$C). This ensures that moderate vessel temperatures are reached during reactor operation and in accident scenarios.

(6) All three primary loop pressure vessels (RPV, SGPV and the HDPV) are located in a concrete cavity, which protects the primary loop from external loads.

The HTR-PM will realize the following safety features:

(1) the radioactive inventory in the primary helium coolant is very small when the reactors are working at normal operation conditions. Even if this limited amount of radioactivity would be released into the environment following an accident, there is no need to take any emergency measures;

(2) for any reactivity accident or for a loss of coolant accident the rise of the fuel element temperature will not cause a significant additional release of radioactive substances from the fuel elements;

(3) the consequences of water or air ingress accidents depend on the quantity of such ingresses. The ingress processes and the associated chemical reactions are slow, and can readily be terminated within several dozens of hours (or even some days) by taking very simple actions.

Inherent safety:

- Retention of radionuclides: the TRISO fuel design guarantees that below the design temperature of 1600oC, radionuclides are efficiently retained within the coated fuel particles. Therefore, the amount of radionuclides in the primary helium coolant is very limited. Even if these limited radioactive materials are released to the environment following an accident, the doses to the public are below the limit so that technically no offsite emergency measures are required.

- Self reactivity control: negative temperature coefficient and a large margin between the operational temperature and design limit assure that when the reactor temperature rises due to decay heat in an accident, the reactor will selfshutdown by the negative temperature feedback and the fuel temperature will not exceed the limit.

- Self decay heat removal: without active core cooling, the decay heat can be removed from the core via conduction and radiation in an intrinsic manner.

Will the modular technology meet the following safety requests, proposed by Prof. Dr. K. Kugeler, former head of nuclear research department of RWTH-Aachen and FZ-Jülich and German Nuclear Reactor Safety Commission;

3.1) Safety against earthquake basic 6:

The earthquake in Shandong province is quite frequent. HTR-PM should be designed with enough ability to withstand earthquake at least 6.

3.2) Helium circuit safe against terroristic attacks of any kind;

The safety feature of HTGR is very good. Even if attacked by guided missiles, large scale of radiation contamination will not happen. If the missile hits the reactor core, which is the worst case, it can only cause the radiation dose within a few yards higher than the intervention level. Terrorists will not choose to attack HTGR if they only want to release large amount of radioactive substances.

3.3) Removal of decay heat by itself;

Self decay heat removal: without active core cooling, the decay heat can be removed from the core via conduction and radiation in an intrinsic manner.

3.4) Core immunity against air ingress;

The consequences of water or air ingress accidents depend on the quantity of such ingresses. The ingress processes and the associated chemical reactions are slow, and can readily be terminated within several dozens of hours (or even some days) by taking very simple actions.

3.5) "Zero-Emission-Concept";

In case of a crack of a heat exchanger tube, will any problems arise with core reactivity changes ?

Contribution of German Experts:

Safety Experiences with AVR and THTR-300 plants

Additional safety Requirements of HTR-PS versus LWR-PS;

-Design of very large (V)(T)HTR-Power plants up to 3.000 MWth;

Economics

Electricity Cost in US$/kWhe with

AP 1.000 0.07 euros/kwh

EPR 0.043 euros/kwh (generation cost)

HTR Shidao 0.06 euros/kwh

Capital cost in US$/kWe with the same 3 designs

Some details of the calculations for cost justification:

Total capital investment

260.000.000 USD

Years of construction to be financed before grid connection

2 years

Interest rate applied

Projected cost of production after grid connection per year

Fuel

Personnel

Capital cost (depreciation, how many years, interest)

Other cost

Cost of modular HTRs vs. Conventional construction

The initial investment is much smaller. The construction period (2 years) is shorter than the period for PWR (5-6years). The interest is reduced so the investment can be reduced by 20%.

Difference in capital outlay and annual cost.

Usage

Since the PBMR is variable in size and capacity: can it be produced for large Ocan ships ? Replacing current Diesel-Engines – of max 100 MWel – by 2 or three very small modular PBMR would save much oil and weight. For ships of 20.000 TEU the global market might be 20 units. Which could make serial production of PBMR economic.

I haven’t heard that China plans to use HTGR for large ocean ships. But China decided to use SMR for ship propulsion. The ACP100 is a small reactor type launched by

China National Nuclear Corporation. It is a modular pressurized water reactor. The thermal design power is 310 MWth and the electric power is 100MWe.

What size and safety enclosing is needed ? Oil bunkers can be done away with.

What would be the price and economic calculations, when made in China.?

Highlights of Mr. Guo Wentao's CV:

Master degree of Nuclear Engineering in Swiss Federal Institute of Technology, Lausanne(EPFL) and in Swiss Federal Institute of Technology, Zurich(ETH),

Full marks in the exam on Nuclear Energy System

Bachelor degree of Nuclear Engineering in Phelma of INPG, Grenoble,France

Full marks in the exams on mathematics and heat transfer

Bachelor degree of Nuclear Engineering in Harbin Institute of Technology (a top ten University in China)

Assistant consultant at Swiss Nuclear Forumin Bern, Switzerland

Interview with nuclear experts in Tsinghua University

Ten reports on nuclear energy development situation in China

Graphs about reactor type evolution and nuclear facility distribution

Provided information and data on nuclear energy thatare needed by the clients

Third prize of Energy-Saving and Emission Reduction Competition in China

scientific research about the use of the waste straws

provided a better way of transferring straws into ethyl alcohol

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Third prize of scholarship in Harbin Institute of Technology

Third prize of MCM in America

Worked with students to solve a given math problem in 4 days. Made a computer program to compute the result-

Information from our Guest from China

Precursory to our meeting from March 21. , we received some information from Mr. Guo Wentao to specific points, which are listed below.

3. Read and think between the lines to elaborate more questions to be discussed with him when here

Some Points from our email exchange_

Points from mail exchange up to now:

1. Yes, the spent pebbles are also included in the fuel cycle.

2. The spent pebbles can be shredded and re-enriched. This is called reprocessing. It is technically feasible and similar to the technology used in PWR. At present, China is still developing this reprocessing technology and tends to apply it in the future.

3 & 4. At present in China the reprocessing technology of pebbles hasn't been applied. The spent fuels are just stored. When a fuel element is discharged from the bottom of the RPV to the fuel handling system, its burn-up is measured immediately. If its burn-up does not reach the design burn-up limit, it will be recharged into the reactor core from the top of the RPV; otherwise it will be identified as a spent fuel and sent to the spent fuel storage system. In the spent fuel storage system, spent fuels are put into a storage canister. Each storage canister contains 40,000 spent fuels. After a storage canister is full with spent fuels, it is sealed and moved to the ventilated storage well. Each storage well contains five vertically placed storage canisters. The overall capacity of the spent fuel storage facilities in the nuclear island of a HTR-PM600 unit is set to adopt spent fuels from six reactor modules for the interim storage of ten years. Spent fuels after ten years of storage will be moved from the nuclear island to a large intermediate storage building on the site and stored there during the rest service time of the plant.

5. The fuel used in HTR is called TRISO.Each fuel particle is a UO_2 kernel of 0.5mm in diameter coated by a buffer layer, an inner PyC layer, a SiC layer and an outer PyC layer. It doesn't contain Th. Th is used in molten salt reactors.

Questions:

you have an extensive explanation of the fuel cycle in your paper which I did not study intensively, since I have only few questions:

- Are the spent pebbles included ?

- If so – can they be shredded and re-enriched for second use ?

- Or is it better so leave them spent in a storage until radiation is low enough
- And if so – how many years are estimated

are the pebbles containing only U or also TH, and in which relation roughly ?

Topics for March 21-23

Electricity Cost per kWh in USD-Cent		
Some details of the cost justification calculations		
Cost of modular HTRs vs. Conventional construction		
Mass production of such modules		
What minimal size in MW th		
Comparison to NuScale minimal size 50 MWel		
Comparison to PRISM		
Status of the steam generator: - Helix or - Schillerhairstyle design Which one is approved ?		
Efficiency of the approved design		
Pebble - Fuel design in detail		
Is fuel design accepted and approved ?		
What needs still to be done ?		
To what degree Is INET seriously interested in reducing the waste ?		
What method will be used ? Petten might have an interesting offer		
Status of other HTR Projects in China		
Status of HTR Projects in other countries in the world, e.g. Indonesia?		
key elements of the demo program of the HTR –PM		
Comparison of the two lines		
- Chinese modular line		
vs.		
- Large single core line of reactors with prestressed concrete up to 1.200 MW		
Comparison of the security concepts of both lines		
experiences with AVR and THTR-300 KKW		
Additional safety Requirements of HTR-PS versus LWR-PS;		
- Design of very large (V)(T)HTR-Power Stations up to 3.000 MWth;		
Design of SHTR-Power Stations/Heat Producers; (S(mall)HTR 50 MWth up to 100 MWth;		

AB

Im Vordergrund stehen für Kosten und Wirtschaftlichkeit und das Ziel der Wettbewerbsfähigkeit mit Kohlekraftwerken (<5Ct./KWh), was m.E. nur mit drastischer Kostensenkung durch Serienfertigung transportfähiger Module in einer Fabrik und Verzicht auf überflüssige Sicherheits-/Kühleinrichtungen zu erreichen ist. Unter Betrachtung der Marktchancen sehe ich nicht den HTR, sondern den einfachen Reaktor für 400-500 Grad Dampf mit einer Leistung von 50-100 MWel im Vordergrund, also den NuScale oder auch den PRISM. Frage, ob das auch mit dem PBR geht und wie viel der dann kosten würde. Ansonsten weiß ich nicht, was der Chinese über das hinaus, was er bereits geschrieben hat, vortragen kann und will.

Mfü

Fragen an Wang Heitao:

- Ich wüsste gerne mehr über den Status des Dampferzeugers. Weil sich aktuell kein Hersteller findet, welcher das klassische Helixmodell bauen könnte, haben die Chinesen das "Schillerlockendesign" erfunden. Meinen Berechnungen nach ist dieser nicht besonders effizient. Ist das Problem gelöst und ist diese Komponente akzeptiert und fertig?
- Ist der Brennstoff bereits genehmigt? Wenn nicht, was muss noch getan werden?
- Wie seriös ist INET an einer Müllreduktionsmethode interessiert? Wir hätten da etwas anzubieten…
- Status anderer HTR Projekte in China und im nicht-chinesischen Ausland (z.B. Indonesien)?
- Worin besteht eigentlich das Demonstrationsprogramm des HTR-PM?

UC

Ich habe mir überlegt und würde referieren:

1. AVR: 1. Teil meines Vortrages Nizza und Erläuterung zu den Kritiken der sogenannten Expertenkommission, deren Vertreter wären mir willkommen.

2. THTR-300 Konstruktion und Erfahrungen. 2. Teil meines Vortrages aus Nizza.

3. Vorstellung eines THTR-600/1200 MWel.

In dem Bericht von Prof. Dr. Haitao finde ich nichts, d.h. keine zu lösende Frage, die aus den Erfahrungen in Schmehausen nicht zu beantworten, fundiert, wäre.

Es wäre sicher hochinteressant, wenn wir mal einen Vergleich der China-Strategie, kleine Reaktoren, Modulbauweise, mit meinem Konzept: Einzelanlage so groß wie möglich, also bis 1.200 MWel mit Spannbetonbehälter machen könnten, das sollte im Programm ermöglicht werden. Vor allem der Vergleich des Sicherheitskonzeptes beider divergierender Konzepte wäre prima.

Auch würde ich dann mal mein Konzept über kleinere Reaktoren vorstellen, wäre völlig neu.

Schön wäre es dann, wenn die Herren Prof. Dr. Lohnert und Hurtado dabei sein würden, ist aber nicht nötig, wären mir aber herzlich willkommen.

Sinn macht das nur in Dortmund Hamm, Jülich bringt überhaupt nichts, höchstens einen schlechten Eindruck.

Ich würde dann auch die beiden chinesichen Professoren aus Karlsruhe vom KIT dazu bitten, mit denen Kugeler und ich die Besprechung vor einigen Jahren hatten. Wenn das so ist, würde ich auch Kugeler bitten, zu kommen. Dann hätte alles Hand und Fuß.

Wenn in Dortmund, dann bin ich gerne dabei, nach Jülich zu fahren, lohnt für mich die Benzinkosten nicht.

Tagungsort in Dortmund wäre dann entweder das neu Mercure Hotel in Dortmund/früher Römischer Kaiser, oder der Westfälische Industrieklub, 200 m entfernt vom Hotel.

In Dortmund würde ich alles gerne organisieren.

Sollte man auch-ggfs. durch Lohnert- Prof. Zhang-Chiao einladen, natürlich nicht auf unsere Kosten.

Information from our Guest from China

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1. Some of you readers may already know some of these facts, others do not.
2. Do not expect our guest to answer questions, that are not yet put
3. Read and think between the lines to elaborate more questions to be discussed with him when here

WE will publish here his CV as soon as available

Next semester I will write my master thesis in Paul Scherrer Institute. I think I can have some flexibility in time. ………………… Beside, I can't speak German. I made the interview in English and the German version is translated by my colleague.

Questions:

- would you like to come here for:

- Getting together with some of the old HTR men
- Having a talk with a small group of interested HTR people (it seems that your German is good, or I would make the interpreter)
- Visiting sites of early HTR research and development
- Letting us know more of the Chinese Sitatuion

- if so, I would try to arrange for such with people and institutions

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