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Interoffice Memorandum

To: J.K. Park, DIR-NENP

From: I. Khamis, NPTDS

Through:

Clearance: T. Koshy, SH-NPTDS

Reference:

Date: 2012-01-14

Subject: Report on 1st RCM on CRP Examining the Techno-Economics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP Software

Place of Meeting:	IAEA Headquarters, Vienna
Date of Meeting:	05-07 November 2012
Program code:	1000026/2012.03.01/RBF-MP1-2012/613224-\NHR-\TRV-Non Staff RCS/NENP-NPTDS
Scientific Secretary:	Mr Ibrahim Khamis

ATTENDING EXPERTS

Name	Country/Organization	Date
R. Boudries	ALG/CDER	5-7 Nov.
A. Bohe	ARG/CNEA	"-"
E. Dewita	INS/BATAN	"-"
X. Yan	JPN/JAEA	"-"
T-H. Lee	ROK/KAERI	"-"
S. Revankar	ROK/Pohang University of Science & T.	"-"

1. Background

The potential of hydrogen production using nuclear energy has lead the IAEA to carry out an active programme on the subject including meetings for information exchange on the status of nuclear hydrogen production, on future challenges to nuclear hydrogen production with emphasis on safety of coupling and on future aspects of hydrogen economy. The IAEA has developed the Hydrogen Economic Evaluation Programme HEEP, which is computer software that allows analyzing various options for a future hydrogen economy. Being the first-of-a kind, HEEP needs to be benchmarked for

various scenarios of hydrogen production and distribution. The CRP has been planned based on extensive feedback from many participants in technical meetings on hydrogen production, and will be conducted by the Nuclear Power Technology Development Section.

2. Objectives of the meeting

The purpose of the meeting is to:

- Develop a detailed overall work plan of the CRP and discuss expected outcome,
- Review and discuss preliminary work-plans of each participant,
- Discuss generic case studies, and
- Harmonize and integrate individual plans within the overall work-plan of the CRP.

3. Agenda

See attachment ANNEX A.

4. Summary of the work done and results achieved

The IAEA (Scientific Secretary) presented an overview of the CRP: motivations, objectives, expected outcomes, schedule, and other *administrative* issues and approaches related to the overall management of the CRP. He discussed the motivation of the CRP which included: establish platform for information exchange between MSs, assess various hydrogen production options and technologies including transportation and storage, evaluate technical and economic potential of hydrogen production using nuclear power, coordinate efforts of Member States (MSs) on hydrogen production using nuclear power, and improve HEEP through benchmarking and upgrade of its library. In addition, he discussed the overall objectives of the CRP and the specific objectives of the 1st RCM as to: examine aspects of nuclear hydrogen production, validate HEEP through benchmarking exercises, and promote international collaboration among IAEA Member States. Moreover, he presented summarized plan of case studies, participants work plans, and explained the expected outcome of the CRP in terms of publishing an IAEA technical report summarizing and discussing the CRP's results and additional scientific publications by CRP participants.

Algeria (Ms Boudries) Our main aim is to carry a technico-economic evaluation of the hydrogen production capacities of renewable energy systems, more particularly solar photovoltaic systems. This permits also the introduction of a set of computer program libraries that could be included in HEEP to give it more flexibility. So in our case:

- The origin of the energy for hydrogen production will be solar
- The system for the production of this energy will be photovoltaic
- The feedstock for the production of hydrogen will be water
- The process for the production of hydrogen will be electrolysis

In this study, we will be considering a system that includes a solar PV unit, a regulation unit, and electrolysis unit with the water treatment system. The photovoltaic unit comprises mainly the field of photovoltaic arrays for collecting and converting solar energy into the energy (electrical or both electrical and thermal) needed for the electrolyzer. It also includes the tracking system that allows the optimum solar energy harvesting. The regulation unit comprises the system for conditioning and shaping the power coming from the photovoltaic unit. Besides the power conditioning unit, a unit for energy storage for use might be considered. The electrolysis system comprises mainly the electrolyzer stack where water is split into hydrogen gas and oxygen gas. Besides that, one must take into consideration the auxiliary systems such as the control unit, the water supply and treatment unit and the produced gas separation unit. In this study, are considered:

- different types of photovoltaic technologies
- different positions and orientations of the photovoltaic systems (fix or tracking)
- different configurations and technologies of the electrolyzer

Argentina (Ms Bohe) For the nuclear hydrogen production through thermo-chemical water splitting cycles and gasification coal with water, the coupling between a high temperature gas reactor (HTGR) with 900-950 °C gas outlet temperature and a hydrogen generation plant based on metallic chlorides cycles is being evaluated. Following the encouraging laboratory experimental results on thermo-chemical reactions, some considerations about the techno-economical feasibility of this concept are being now required in order to evaluate its competitiveness in comparison with the current conventional hydrogen production technologies applied in our country. In this sense, the participation in the validation process of an important analysis tool like the IAEA Hydrogen Economic Evaluation Programme (HEEP) software will be very important to give us the capability of making such cost assessments related with the nuclear hydrogen production.
For this purpose, the following methods, procedures and techniques will be implemented during the first year of the Project. Measurement of the reaction rates at different temperatures, flow rates, and partial pressure of gaseous species using a specialised experimental set up. Development of catalytic surfaces in order to make the reactions faster. Determination of the best pathway for the production and regeneration of the dry ferrous oxide. Determination of the chemical composition of products as a function of time, in order to detect the intermediate compounds of the different chemical species. For these analyses Atomic Absorption and UV/Visible Spectroscopy, X-Ray. Development of a global kinetic model to be applied for simulating the thermo-chemical reactions. Proposal of the different steps that indicate which is the reaction mechanism that lead to the most efficient pathway for the hydrogen production, will be determined.
With respect to the application of the IAEA HEEP software, one member of the Scientific Project staff will be specifically commissioned for training in the use of the code during the first year, in order to manage properly the input database, to learn about the modelling details and to get experience in the analysis of code results. In parallel, the commissioned person will begin to collect all the cost-relevant input data with Argentina's economy specific information, in order to contribute to the expansion of the current HEEP database.
Through this Scientific Project, it is also expected to provide significant contributions to the expansion of the IAEA HEEP software capabilities; to the founding of a solid data base of HEEP software including additional libraries of specific processes for hydrogen production; and to the information updating on the analysis of comparative assessment of hydrogen production with various energy options. From Argentina's point of view, the main research outputs are expected to be the elucidation of kinetics and fundamental mechanisms of thermo-chemical reactions in the Cl-Fe family of cycles and gasification reactions to improve their overall performance at laboratory scale; the enhancement of our cost assessment capabilities related with hydrogen production through the use of the HEEP software; and some preliminary conclusions about the competitiveness of nuclear hydrogen production alternative in comparison with the current hydrogen production processes.

Japan (Mr Yan) Nuclear energy has the potential to be a major safe, secure, economical energy source essentially free of carbon emission for a wide range of non-electric applications in the industrial, agriculture and transportation sectors, mainly through hydrogen production. The worldwide efforts currently underway to make this application a reality were reviewed in the first RCM of the CRP on Examining the Techno-Economics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP Software. And techno-economic aspects of different hydrogen production processes were discussed. They include various thermochemical processes, water and steam electrolysis, hydrocarbon reforming, coal gasification, and possible synergic production and comparison with production via solar energy route. Most participants at the meeting identified the high temperature gas cooled reactor with 950°C outlet temperature as the suitable nuclear reactor to be coupled to the hydrogen production processes of their interest. In this particular area, nuclear hydrogen production technologies developed in Japan Atomic Energy Agency were presented, including

construction and operation of the high temperature test reactor (HTTR), a 30MWt 950°C engineering test HTGR, and research and development of a thermochemical water-splitting process, namely the iodine and sulfur process. In the aftermath of the Fukushima nuclear accident, the importance of nuclear reactor safety in support of industrial hydrogen production is emphasized. Here, the HTGR provides a clear advantage of inherent and passive safety as demonstrated in a recent safety test, in which the HTTR was exposed to but survived without any radioactive release and reactor damage a Fukushima-like station blackout event involving a loss of forced cooling without reactor scram. While such safety advantage of the HTGR permits the proximity of the reactor to heat users, the hydrogen production applications introduce additional external events such as heat load transients, chemical explosion and toxicity, which should be taken into account in the techno-economic evaluation. Because of the 950°C temperature capability, the HTTR as an available test reactor appears readily to be connected to diverse processes such as I-S, Fe-Cl thermochemical processes, HyS process, steam reforming of methane and gas gasification, to demonstrate thermally efficient, potentially cost-effective nuclear hydrogen production. JAEA is prepared to contribute to the CRP according to the following work plan: a) to familiarize with the use of HEEP with selected case calculations, b) review nuclear reactor plant design and cost data, IS process plant design and cost data, performance and cost sensitivity parameters from JAEA`s industrial performance and cost database, c) assess the techno-economics of an HTGR hydrogen cogeneration system, d) provide HTGR reactor design and cost data to other participants as necessary to add in their evaluation, and e) to prepare report and presentation on the above results, e) perform benchmark analysis of GTHTR300C-IS or similar cogeneration systems with HEEP and to report and discuss the benchmark results, and f) document final research results and make contributions to IAEA TECDOC.

Indonesia (Ms Dewita) Steam reforming is one of hydrogen production method by using natural gas as raw material and fuel. In Indonesia, steam reforming of natural gas or syngas is called as Steam Methane Reforming (SMR) is the most common method of producing commercial bulk hydrogen as well as the hydrogen used in the industrial synthesis of ammonia and urea (fertilizer plant). The reforming reaction is strongly endothermic, it supply by combustion of natural gas. Combustion of natural gas to supply reaction heat will reduce conversion of natural gas to hydrogen. High Temperature Gas Cooled Reactor (HTGR) reactor is one of nuclear reactor that operates at the high temperature. HTGR type reactor is a potential for cogeneration process, especially to supply heat for hydrogen production process. There is seem challenge in the development of similar technology to produce hydrogen by replacing combusting natural gas with helium from HTGR type reactor. Advantageous effect of nuclear heat supply for the endothermic heat of reforming reaction, thus reducing the fuel consumption to be used for the heating (more natural gas for raw material) and consequently no combusted carbon dioxide emission. Research will focused on the pre-design of hydrogen production plant including the economic and technology aspects using steam reforming method. HEEP programme will be used also as an economic analysis tool.
In the first CRP meeting, All of participant presented the scope, objectives, overall plan of their research. Therefore, I got a lot of information about research that will do by participants from several countries, such as : India, Korea, Japan, Argentina, Algeria and Indonesia. Techno-Economic aspects of different hydrogen production process were discussed. One of the objectives of participant research are economic analysis of hydrogen productions for various methods such as : IS cycle and Thermochemical by using HEEP Program. A part of participant research use all of nuclear heat for hydrogen production and the others research use nuclear heat for produce both of electricity and hydrogen production. HEEP Programme is a computer software that allows analysing various options for a future techno economic aspects of hydrogen production. Therefore, the overall objective of this CRP is to validate the HEEP software through benchmarking exercise and promotion of international collaboration among IAEA members, and assess techno economic aspects of hydrogen production based on country's spescific details. Expected research output of this CRP are expand HEEP capabilities to enable the analysis of techno economic aspects of hydrogen production, establish solid data base of HEEP including additional libraries of specifics processes for hydrogen production and up-to-date information on the analysis of comparative assessment of hydrogen production with various

energy options. Generally, I know how to using the HEEP Program but I don't know how to using HEEP Program in detail, so I hope there is training for all participants to study about HEEP Program.

Rep. of Korea (Mr Revankar) The meeting was run with plenty of time allocated for discussion on the on each of the 5 proposals presented. The theme of the CRP being nuclear hydrogen technology assessment and economic evaluation with the use of HEEP software, the following observations were made : (i) The software at the outset seems straight forward enough to use with simplistic cost computation for three base units, nuclear plant, hydrogen plant and hydrogen delivery to arrive at the cost of the hydrogen generated. (ii) The engineering details or the models embedded specifically for the nuclear plant cost estimation seemed too rudimentary and did not address component based costs for most components in all three major units for more realistic values. (iii) This gives an opportunity to develop and add engineering based nuclear plant reactor cost model and hydrogen plant cost model that will account specific components for each type of hydrogen plant. (iv)There is also opportunity for each member to collaborate with other CRP member to develop and add new cost estimation modules to HEEP on new hydrogen plants and nuclear plants. (v) The HEEP should contain CRP members agreed benchmark reference nuclear plant model and hydrogen plant model which is based in detailed realistic (more current) component and costs. The workplan includes the following:

- Perform 5 case example cases for training and comparing existing HEEP capability (1st year)
- Develop a base economic models for SI cycle, Hy-S cycle and High Temperature Electrolysis (HTE) using ASPEN Economic Evaluation Software for (during first year), and perform comparative study with HEEP. (1st year)
- Perform case studies with PBMR 268MWt VHTR and for each case of SI cycle, Hy-S cycle and HTE (1st and 2nd year)
- Develop and add new cost modules to HEEP based on optimized flowsheet for SI cycle (2nd 3rd year)
- Identify technology improvements and develop assessment module for in SI cycle, Hy-S and HTE cycle for implementation in HEEP
- Development of safety and control system for couple (N-plant and H2 plant) cost estimation module for HEEP (3rd year)

In terms of collaborative work with other CRP members:

(1) Development cost models for of PV based H2 generation through electrolysis
(2) Development of nuclear plant based on components cost estimation model
(3) Optimized SI cycles cost model

Rep of Korea (Mr Lee)

Mr. LEE Tae Hoon provided a presentation on benchmark analysis of the IAEA HEEP Software for nuclear hydrogen process. He justified why we need the development of nuclear hydrogen production technology from the viewpoints of status of energy supply, domestic energy resources status and the needs of large-scale, self-sufficient energy resource. He introduces not only energy supplying and consuming situation in Korea but also the KAERI R&D program to develop VHTR technology which is consisted of phase 2. On the other hand, he mentioned the key technology area for the hydrogen production using a VHTR as followings 1) design code development & verification 2) Very high temperature He experiment 3)VHTR material data base 4) TRISO technology development 5)Thermo-Chemical H2 production technology. He also mentioned about final objectives of CRP project, work plan and strategies for 3 years. KAERI is going to update levelized unit hydrogen production cost using modified G4-ECONS and compare its results with that of HEEP. In addition, he showed the VHTR R&D video clip which introduced VHTR, nuclear hydrogen production plant, and its applications.

5. Conclusions and Recommendation.

5.1. Conclusions

Participants agreed to the following workplan for the CRP:

- Run the five case studies to test HEEP, with input files to be given by IAEA to CSIs, and provide results and feedback regarding HEEP and its utilization by end of April 2013.
- Calculate their individual case studies for their national projects using national programmes and HEEP and perform comparison of results. It was evident that a need for continuing consultations among participants and information sharing is important to harmonize expected outcomes of the CRP.
- Results will be discussed in the upcoming 2ed RCM, and three potential cases will be determined as generic test cases for the overall benchmarking of HEEP.
- A new database based on the practical industrial experience presented by the Japanese CSI related to the HTTR could be added to HEEP
- Hydrogen production cost is easily influenced by each countries energy policy, hydrogen production method and so on. HEEP could be enhanced further by adding hydrogen production processes including steam reforming of methane and coal gasification, solar energy as well as nuclear power plant. HEEP needs to be updated to include renewable option especially for solar hydrogen production

5.2. Recommendations

- IAEA should hold a technical meeting for HEEP users in 2013.
- Establish a network for sharing information and research collaboration.
- Next RCM is planned for tentatively second week of December 2013

Agenda
1st RCM on CRP Examining the Techno-Economics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP Software"
Room F0814

05-07 November 2012
Vienna, Austria

Monday, 05 November 2012

Opening Session		
9:30	Welcoming and opening remarks	Khamis, IAEA Koshy, IAEA
9:45	Introduction of participants, adoption of Agenda, Selection of Chairman	All participants
0:00	An overview of the CRP	Khamis, IAEA
0:15	*Coffee Break*	
0:30	Presentation 1: Examining Techno-Economics of Nuclear Hydrogen Production using HEEP	Ms Boudries, Algeria
1:15	Presentation 2: Techno-economical Feasibility Study on Nuclear Hydrogen Production through Thermochemical Water Splitting Cycles	Ms Bohe, Argentina
2:00	*Lunch Break*	
3:30	Presentation 3: Contribution to HEEP Software on Cu-Cl Thermochemical Cycle	Mr Dincer, Canada
4:15	Presentation 4: Evaluation of the Techno-Economics of Nuclear Hydrogen Production using HTGR in China	Mr Zhang, China
5:00	*Coffee Break*	
5:15	Presentation 5: Evaluation of Hydrogen Transportation and Distribution Cost in Germany using HEEP	Mr Verfondern, Germany
6:00	Open Discussion	
7:00	Wrap up of Day 1	
8:00	Invited Dinner	

Tuesday, 06 November 2012

Opening Session		
9:30	Presentation 1: Benchmarking Exercises through International Collaboration to Validate HEEP and establish HEEP Database	Mr Malshe, India
0:15	Presentation 2: Steam Reforming Method for Hydrogen Production using Nuclear Heat	Ms Dewita, Indonesia
1:00	*Coffee Break*	
1:30	Presentation 3: Benchmark Analysis of the IAEA HEEP Software for Nuclear Hydrogen Production Plant	Mr Kim, Rep Korea
2:15	*Lunch Break*	
4:00	Presentation 4: Nuclear Hydrogen Generation Technology Development and Analysis of Coupled Hydrogen Production Plant and Nuclear Reactor	Mr Revankar, Rep Korea/USA
4:45	Presentation 5: Assessment of Economic Competitiveness of Hydrogen Production in Pakistan	Mr Athar, Pakistan
5:30	*Coffee Break*	
6:00	Presentation 6: Examining the techno-economic aspects of nuclear hydrogen production	Mr Yan, USA/Japan
7:00	Wrap up of Day 2	

Wednesday, 07 November 2012

9:30	Discussion on: (1) Plan for next year: common issues (2) Specific work plans of each CSI (3) Modifications to work plans	All participants
1:00	Discussion on: - Conclusion and recommendations - Future RCM	All participants
1:30	Discussion on: Finalization of RCM report	All participants
2:00	*Closing Remarks*	All participants
2:15	End of the Meeting	