IAEA
International Atomic Energy Agency

Interoffice Memorandum

To: J.K. Park, DIR-NENP

From: Ibrahim Khamis, NENP/NPTDS, 22822

Through:

Clearance: T. Koshy, SH-NPTDS

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Subject: Report on two consultant meetings on Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options and on Economic and Safety Issues of Industrial Applications of Nuclear Energy

Place of Meeting:	IAEA Headquarters, Vienna
Date of Meeting:	19-22 December 2011
Program code:	for 11CT14987: 1000025/04.01./ for 11CT15041: 1000027/03.01./ RBF-MP1-2011/613223-NHR-TRV-Non-Staff Other, NENP-NPTDS
Meeting Chairman:	Mr Ibrahim Dincer
Scientific Secretary:	Mr Ibrahim Khamis

ATTENDING EXPERTS

Name	Country/Organization	Date
Mr Grigory Kodochigov	Russian Federation/OKBM	19-22 Dec.
Mr Henry Safa	France/CEA	19-22 Dec.
Mr Ibrahim Dincer	Turkey/Ontario Institute of Technology, Canada	19-22 Dec.
Mr James O'Brien	USA/Idaho National Laboratory	19-22 Dec.
Mr Karl Verfondern	Germany/Research Center Juelich	19-22 Dec.
Mr Lev Kuznetsov	Russian Federation/OKBM	19-22 Dec.
Mr V.K. Srivastava	India/Bhabha Atomic Research Centre	19-22 Dec.
Mr. Xing Yan	USA/Japan Atomic Energy Agency	19-22 Dec.

Background

Nuclear power reactors can operate as dual purpose plants, so called cogeneration plants, providing both electricity and other product such as fresh water through desalination, hydrogen, district heating, or process heat for industrial applications. Dual purpose nuclear power plants significantly increase the overall plant efficiency and with over 700 reactor-years of combined experience are a demonstrated option that can help expanding the market of nuclear power.

Recognized by the IAEA General Conference, seawater desalination using nuclear energy is a technically feasible and cost-effective option which could help meet the growing demand for potable water for all mankind. Industrial heat applications (mainly food processing, paper industry, chemical industry, petroleum and coal processing, and primary metal industries) have generally continuous demand of large amounts of heat usually in form of steam. The heat is suitable to be provided by nuclear energy. For example, the potential of using nuclear energy for oil extraction from tar and oil sands and for enhanced oil recovery operations, particularly from depleted oil deposits seems very promising. Steam injection is used for these extraction applications and steam can also be used for processing the oil after the extraction.

Following the Action Plan for the General Conference GC(55)/12/4 which requested the Director General, subject to the availability of resources, to develop a report that defines all the aspects for a technical and economic feasibility study on using nuclear energy both exclusively for seawater desalination, as well as for cogeneration options (e.g. electricity, seawater desalination, hydrogen production, etc.), the following two consultant meetings on Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options and on Economic and Safety Issues of Industrial Applications of Nuclear Energy were organized.

Objectives of the meetings

The purpose of the consultants meeting on Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options was to define technical considerations for optimal cogeneration systems, evaluate economic competitiveness of cogeneration plants, evaluate main aspects to be highlighted on cogeneration options during feasibility studies of nuclear power and evaluate safety aspects of coupling schemes and products of cogeneration plants.

The purpose of the consultants meeting on Economic and Safety Issues of Industrial Applications of Nuclear Energy was to explore the possibility of using nuclear energy for major industrial applications such as the oil sands/shale recovery, oil enhancement production, for use in refinery and other related applications, collect information on best practices and available experience on such applications, compare advantages and disadvantages of using nuclear power for such applications and discuss various scenarios for the use of nuclear technology into such applications.

The final goal i.e. expected outcome of these activities and the ones to come will be the publication of two technical reports on: opportunities for cogeneration using nuclear energy, and industrial applications of nuclear energy

Work done

The technical meeting was conducted in accordance with the meeting programme discussed at the beginning of the meeting by the Scientific Secretary. The meeting was opened officially by Mr T. Koshy, Head of the Nuclear Power Technology Development Section of the IAEA's Department of Nuclear Energy. The Scientific Secretary Mr Ibrahim Khamis of Nuclear Power Technology Development Section, opened the meeting with words of welcome and thanks to the participants, he provided the background and expectations for the work of the meeting, before handing

over the meeting to the Chairman Mr Ibrahim Dincer. The first and second sessions were devoted to the presentations of the participants. Highlights of each presentation are presented below:

France (H. Safa): Approximately one third of the total world energy consumption is used as heat. About 50% of this heat is utilized for heating residential homes, commercial businesses or public services like hospitals, schools, universities or offices. However, only 12.5% of this specific utilization is today distributed through centralized District Heating and Cooling, representing a world total of 2500 TWh. District Heat networks are developing essentially in large cities of northern European countries whereas construction of District Cooling networks is slowly starting in southern cities where cooling is required in summer time. The presentation analyzed the requirements for implementing cogeneration in present Nuclear Power Plants (NPP) as a heat source to feed existing District Heating networks. In a cogeneration mode, the optimal working temperature is a trade-off between the final electrical efficiency and the amount of delivered heat. The extracted heat has to be transported to the final district heating networks. Heat transport over long distances has long been an impediment to the development of cogeneration because of high thermal losses limiting the use to locations a few kilometres away from the NPP site. This is not anymore the case. Recent improvement in industrial heat piping performance make use of new insulating material with thermal conductivities as low as 0.04 W/m.K in working conditions. This can reduce the losses for a 150 km long line to less than 2% of the total power. A case study was presented in order to analyze the potential benefits such cogeneration options. The French Nogent-sur-Seine nuclear plant located 110 km south-east from Paris where two 1300 MW(e) reactors are operated by EDF. Choosing a working fluid temperature of 120°C, the calculated payback time has been estimated to be of the order of ten years. Also, another additional benefit from nuclear heat recovery is the significant reduction in greenhouse gas emissions. Utilizing the heat generated by a single 1300 MW(e) reactor can save up 1.7 million tons of CO_2 every year. Therefore, nuclear cogeneration has been found to be technically feasible, energetically beneficial and economically profitable while enabling a large reduction in carbon footprint.

India (V.K. Srivastava): In India, nuclear desalination possibilities have been technically demonstrated by coupling the CIRUS research reactor to a 30 m3/day Low Temperature Evaporation plant and the Madras Atomic Power Station to a 6300 m3/day hybrid thermal & Reverse Osmosis desalination plant at Kalpakkam. The presentation discussed experiences gained in design, construction and operation of both these nuclear desalination plants in India. Further, the challenges for cogeneration with nuclear desalination while retrofitting and the consideration in the new project design have been highlighted. The various safety aspects in coupling the nuclear plants to desalination plants have also been elaborated. The use of thermal desalination technologies (using steam from the secondary loop of a nuclear reactor) have shown favourable acceptance by adaptation of stringent safety precautions during design of the coupling system. As shown in the India experimental nuclear seawater desalination plants as well as other plants in the world, fresh water produced from sea water nuclear desalination has no adverse effect on environment and is safe for public/process uses.

Germany (K. Verfondern): There are potential options to connect a nuclear reactor to deliver electricity and process heat, in particular for hydrogen production. For this specific application high temperature gas-cooled reactor, with exit temperatures of the helium coolant of up to 950°C, is the type of reactor which reaches highest overall efficiency when linked to a chemical hydrogen production process. Different hydrogen production processes were also discussed. Steam reforming of methane has been investigated. The feedstock for hydrogen production in the future, however, will be water. Compared to conventional electrolysis, the process in the vapour phase at high temperatures of 800-1000°C has the advantage of the electricity input reduced by about 30%. R&D efforts in various countries are concentrating on the development and optimization of electrolysis cells and the selection of appropriate materials. The development may benefit from the efforts in the area of solid oxide fuel cells representing the reverse process of high temperature electrolysis. Thermo-chemical cycles are composed of several reaction steps which, in the sum, are leading to a decomposition of water into hydrogen and oxygen. Numerous cycles have been proposed in the past and investigated in terms of their characteristics. A few were deemed sufficiently promising and worth further investigation,

among them those of the sulfur family (e.g., S-I) or the Cu-Cl cycle, which are currently investigated in several countries including their potential coupling to a nuclear energy source.

Japan (X. Yan): The worldwide experience in the high temperature nuclear power reactor technology including construction and operation of test and prototype reactors in five countries is reviewed. In particular, the results of the latest tests conducted on JAEA`s test reactor HTTR are presented that include a 950°C long-term operation and a passive safety demonstration of loss-of-forced-cooling without reactor scram. The potential of HTGR for multi-cogeneration is highlighted by the case studies for large-scale production of hydrogen, iron and steel, process steam, desalinated water, and chemical products. Because of the high temperature capability, the HTGR is shown to support diverse routes for thermally efficient hydrogen production including thermochemical and hybrid (thermal plus electrolysis) processes as well as hydrocarbon reforming processes. While the passive safety of the HTGR appears to provide an important advantage of permitting the proximity of the reactor to heat users, the cogeneration applications introduce additional external events such as cogeneration load transients, chemical explosion and toxicity, which must be further investigated to support future licensing activities for HTGR cogeneration system deployment. During the following sessions the consultants, discussed in several breakout sessions, main technical economic and safety aspects of cogeneration and on industrial applications of nuclear energy to be included in the Technical Reports. First drafts of the table of contents were elaborated (included in ANNEX 2 and ANNEX 3) and team leaders were assigned for each chapter.

Russian Federation (L. Kuznetsov): There are vast opportunities for expanding nuclear power for the market of large heat consumers, a market as big as the electric power industry market. The largest consumers of thermal energy are chemical industry, oil refining industry and metallurgy. Thus, introduction of nuclear technologies into these energy consuming industries is an important task. To date, the only nuclear technology capable of replacing fossil fuel in process heat supply is the high temperature gas-cooled reactor (HTGR). HTGR advantages are the possibility to heat coolant at core outlet up to 1000 °C, the possibility to use various power unit schemes (gas-turbine cycle, steam-turbine cycle and the circuit supplying high-temperature heat to industrial applications), passive decay heat removal providing high level of safety even in case of total loss of primary coolant, non-proliferation of fission material based on the properties of ceramic coated fuel particles, low thermal impact to the environment, etc. Due to unique properties in efficiency, safety and ecological compatibility, modular HTGR technology can supply electricity, heat and fuel to individual productions and can solve the issue of economically effective hydrogen production. Preliminary marketing researches of potential consumers show that the preferable HTGR application areas (by power intensity) are: oil refining and petro chemistry, chemical industry and metallurgy. Ecologically safe small and medium NPP of HTGR-based, which do not require large costs, can take important part in the infrastructure of nuclear power industry of current century.

Turkey/Canada (I. Dincer): highlighted current energetic, environmental and sustainability issues and identified cogeneration and multi-generation options for various industrial and non-industrial applications; nuclear-based hydrogen production methods and their practical use, and some cases studies were presented to highlight the importance of nuclear-based cogeneration and multi-generation systems.

United States of America (J. O'Brien): Nuclear energy has the potential to exert a major positive impact on energy security and climate change by coupling it to the transportation sector, primarily through hydrogen production. In the short term, this coupling will provide carbon-free hydrogen for upgrading increasingly lower quality petroleum resources such as oil sands, offsetting carbon emissions associated with steam methane reforming. In the intermediate term, nuclear hydrogen will be needed for large-scale production of infrastructure-compatible synthetic liquid fuels based on biomass, coal, or other carbon sources. In the long term, there is great potential for the use of hydrogen as a direct vehicle fuel, most likely in the form of light-duty pluggable hybrid hydrogen fuel cell

vehicles. Nuclear energy can also be exploited in the petroleum industry for extraction of bitumen using steam assisted gravity drainage (SAGD) or oil shale retorting. Integration of nuclear process heat with industrial processes will result in increased overall efficiencies and reduced carbon emissions.

Conclusions and recommendations

The main objective of the meetings was achieved through the drafting of the table of content for each technical document to be compiled (see Annexes II and III). For the Consultancy Meeting on Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options, the following conclusions and specific recommendations were made:

Conclusions	Recommendations
IAEA's activity on cogeneration is well-timed initiative to overcome current energy, water and environment related problems of the member states.	IAEA should continue supporting these activities.
Cogeneration is a key solution for better use of energy in thermal and electrical forms. Cogeneration is essential to expand and enhance the use of nuclear energy.	IAEA should solicit the participation and contribution of industry and other international organizations to this activity.
There is an increasing interest in non-electric use of nuclear energy for carbon-free cogeneration applications, such as large-scale hydrogen production.	IAEA should consider publishing updated/periodic status reports on such applications and potential technologies.
The use of IAEA DE-TOP will help the member states perform thermodynamic analysis and performance assessment of various NPPs for cogeneration.	The software should be expanded to cover energy analysis and additional cogeneration applications.

For the Consultancy Meeting on Economic and Safety Issues of Industrial Applications of Nuclear Energy, the following conclusions and specific recommendations were made:

Conclusions	Recommendations
The meeting recognizes several potential industrial applications in various sectors that could benefit from nuclear energy.	IAEA should continue to focus on the use of nuclear energy in industries such as petroleum and petrochemical and also expand to additional industries, namely metal, cement, fertilizer and food processing.
Several national and international organizations have recently launched activities related to non-electric applications of nuclear energy.	More coordinated efforts should be established between IAEA and key organizations, such as IEA, OECD, EC, etc.
Although there is an increasing interest in non-electric applications of nuclear energy in industry, the user requirements are lacking.	IAEA should establish common guidelines for development of user requirements for non-electric applications in industry.
Nuclear hydrogen production technologies have advanced in recent years as recognized by IAEA activities.	IAEA should evaluate the potential uses and economics of nuclear hydrogen for industrial applications.

A future work plan for both activities was defined including the collection of contributions and preparation of the first draft. Two additional meetings were scheduled in October 1st 2012 and February 4th 2013 to reach the finalization of the Technical Reports

ANNEX I: Technical Meeting Agenda

ANNEX II: Draft table of contents for Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options

ANNEX III: Draft table of contents for Economic and Safety Issues of Industrial Applications of Nuclear Energy

ANNEX I

AGENDA

Consultants Meetings on Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options And on Economic and Safety Issues of Industrial Applications of Nuclear Energy

19th – 22nd December, 2011

Vienna International Centre (VIC), IAEA Headquarters, Vienna, Austria,
B-Building, Room B-0513 / B-0482

Monday, 19 Dec 2011

09:00	Welcoming and opening remarks	Mr. Koshy, IAEA
09:15	Introduction of participants, election of Chairpersons and adoption of Agenda	All participants / Chairperson
09:30	Objectives and overview of the meetings	Mr. Khamis, IAEA
Session 1: Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options		
09:45	Merits of Cogeneration	Mr Ibrahim Dincer, (UOIT)
10:30	Cogeneration with Nuclear Power	Mr Karl Verfondern, (FZJ)
10:45	***Coffee Break***	
11:00	Cogeneration with Nuclear Desalination	Mr V.K. Srivastava, (BARC)
11:45	Cogeneration with District Heating and Cooling (DHC)	Mr Henry Safa, (CEA)
12:30	***Lunch Break***	
14:00	Cogeneration with applications of High Temperature Reactors HTRs	Mr. Xing Yan, (JAEA)
Session 2: Economic and Safety Issues of Industrial Applications of Nuclear Energy		
14:45	Prospects of nuclear power for petrochemical applications	Mr Waled Al-Bazzaz (KISR)
15:30	Prospects for hydrogen production using nuclear power	Mr James O'Brien (INL)
15:45	***Coffee Break***	
16:00	Analysis of industrial applications	Mr Kun Yuan (INET)
16:45	Analysis of nuclear reactors for industrial applications	Mr Lev Kuznetsov (OKBM)

17:30	Closing of first day
18:00	***Cheese party in the VIC***

Tuesday, 20 Dec 2011

Session 3: Breakout session		
09:00	Organization of the session	Mr. Khamis, IAEA

Room B-0513 ***Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options***	**Room B-0482** ***Economic and Safety Issues of Industrial Applications of Nuclear Energy***
9:30 – 10:30 Discussion on technical aspects of cogeneration (to be included in the TECDOC)	9:30 – 10:30 Discussion on technical aspects of industrial applications (to be included in the TECDOC)
10:30	***Coffee Break***
10:45 – 12:30 Discussion on economics and market potential	10:45– 12:30 Discussion economics and market potential
14:00	***Lunch Break***
14:00 – 15:30 Discussion on safety aspects	14:00 – 15:30 Discussion on safety aspects
15:30	***Coffee Break***
16:00 – 17:00 Draft of TECDOC on Cogeneration	16:00 – 17:00 Draft of TECDOC on Industrial Applications

Session 3: Breakout session		
09:00	Organization of the session	Mr. Khamis, IAEA

Room B-0513 ***Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options***	**Room B-0482** ***Economic and Safety Issues of Industrial Applications of Nuclear Energy***
9:30 – 10:30 Discussion on technical aspects of cogeneration (to be included in the TECDOC)	9:30 – 10:30 Discussion on technical aspects of industrial applications (to be included in the TECDOC)
10:30	***Coffee Break***
10:45 – 12:30 Discussion on economics and market potential	10:45– 12:30 Discussion economics and market potential
14:00	***Lunch Break***
14:00 – 15:30 Discussion on safety aspects	14:00 – 15:30 Discussion on safety aspects

15:30	***Coffee Break***	
16:00 – 17:00 Draft of TECDOC on Cogeneration		16:00 – 17:00 Draft of TECDOC on Industrial Applications

Wednesday, 21 Dec 2011

Session 4: Breakout session		
09:00	Review organization of the session	Mr. Khamis, IAEA
Room B-0513 ***Technical and Economic Aspects of Using Nuclear Energy for Cogeneration Options*** 9:30 – 10:30 Draft of TECDOC on Cogeneration		**Room B-0482** ***Economic and Safety Issues of Industrial Applications of Nuclear Energy*** 9:30 – 10:30 Draft of TECDOC on Industrial Applications
10:30	***Coffee Break***	
11:00 – 12:30 Draft of TECDOC on Cogeneration		11:00 – 12:30 Draft of TECDOC on Industrial Applications
14:00	***Lunch Break***	
14:00 – 15:30 Draft of TECDOC on Cogeneration		14:00 – 15:30 Draft of TECDOC on Industrial Applications
15:30	***Coffee Break***	
16:00 – 17:00 Assigning Leads for Chapters & Discuss future workplan		16:00 – 17:00 Assigning Leads for Chapters & Discuss future workplan

Thursday, 22 Dec 2011

Session 4:		
09:00 10:30	Summary of Chairpersons	All Participants
10:30	***Coffee Break***	
10:45	Conclusion &Recommendations	
12:30	***Closing Remarks***	All Participants
13:00	***End of the meeting***	

ANNEX II

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OPPORTUNITIES FOR COGENERATION WITH NUCLEAR ENERGY

1. INTRODUCTION
    - Importance
    - Background
    - Objectives
2. FUNDAMENTAL ASPECTS OF COGENERATION
    - Definition of cogeneration (thermal and electrical options)
    - User's requirements
    - System configurations and couplings
    - Potential benefits
        - Conventional vs. cogeneration
    - Assessment of cogeneration
        - Economic assessment
        - Thermodynamic assessment
        - Environmental impact assessment
        - Sustainability assessment
    - Operational considerations and implications vs. conventional plants
    - Concluding remarks
3. COGENERATION WITH NUCLEAR POWER
    - Types of NPPs suitable for cogeneration
    - Technology description and system designs
        - System configurations and couplings
        - Technical requirements and constraints
    - Examples of existing retrofits
    - Potential of cogeneration in existing NPP fleets
    - Closing remarks
4. COGENERATION APPLICATIONS
    - Overview of cogeneration (non-electric) applications
    - Desalination
    - District Heating and Cooling
    - Hydrogen production
    - Petrochemical products
    - Other industrial applications
    - Niche applications
    - Concluding remarks
5. SAFETY CONSIDERATIONS SPECIFIC TO COGENERATION
    - Site consideration
    - System coupling (isolation loop, pressure reversal, monitoring, tritium, etc.)
    - Control and operating strategies (part load operation, possibility to start/stop NEA etc.)
    - Risk assessment considerations
    - Concluding remarks
6. ECONOMIC EVALUATION
    - Costing methodology

        - Existing methodologies for allocating the cost of cogenerated products
        - Cost components (capital costs, O&M costs, IR, etc.)
        - Economic performance criteria
    - Estimation of project's viability
        - Plant profitability analysis: (cost/benefit assessment: cost/energy savings vs investment costs, cash flow, etc.)
        - Sensitivity analysis
        - Other related market parameters
    - Project contracting and financing options
    - Economic consideration of environmental impact
    - Concluding remarks
7. FEASIBILITY CONSIDERATIONS
    - Cogeneration vs. multi-generation
    - Cogeneration with SMR vs. large nuclear power plants
    - Cogeneration with new NPPs vs. retrofitting existing NPPs
    - Concluding remarks
8. CASE STUDIES
9. CONCLUSIONS AND RECOMMENDATIONS (ID)
10. APPENDICES

ANNEX III

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INDUSTRIAL APPLICATIONS OF NUCLEAR ENERGY

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2. ENERGY USE IN INDUSTRY
    - Energy consumption by industry
    - Potential market analysis
    - Concluding remarks
3. NUCLEAR REACTORS FOR INDUSTRIAL APPLICATIONS
    - Main types and features of reactors
        - Existing reactors
        - New reactors and time frames for deployment
        - Role of reactor size
    - Availability and reliability aspects
    - Mapping reactors and applications
    - Cogeneration applications
    - Safety aspects
    - Concluding remarks
4. NUCLEAR HYDROGEN PRODUCTION FOR INDUSTRY
    - Current practices for hydrogen production
    - Review of nuclear hydrogen production methods
    - Comparative economic and environmental impact assessment
    - Concluding remarks
5. NUCLEAR ENERGY FOR PETROLEUM INDUSTRIES
    - Current practices in petroleum industry
    - Review of applications
        - Oil and gas extraction
        - Oil upgrading and refinery
        - Coal gasification and liquefaction
        - Synthetic fuels
        - etc.
    - Estimation of market size for nuclear energy
    - Comparative economic and environmental impact assessment
    - Concluding remarks
6. NUCLEAR ENERGY FOR PETROCHEMICAL INDUSTRIES
    - Current practices in petrochemical industry
    - Review of applications
        - Fertilizer
        - Plastics and polymers
        - Paints and dyes
        - Pharmaceutical

        - etc.
    - Estimation of market size for nuclear energy
    - Comparative economic and environmental impact assessment
    - Concluding remarks
7. NUCLEAR ENERGY FOR OTHER INDUSTRIES
    - Review of major applications
        - Metal industries (steel, aluminium, etc.)
        - Ceramics
        - Paper and textile
        - Food processing industry
        - Cement industry
        - etc.
    - Estimation of market size for nuclear energy
    - Comparative economic and environmental impact assessment
    - Concluding remarks
8. CONCLUSIONS AND RECOMMENDATIONS
9. APPENDIX