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Interoffice Memorandum

To:	D. Hahn DIR-NENP	**From:**	I. Khamis NPTDS
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Reference:	I35005-CR-3	**Date:**	2016-12-12

Subject: Meeting Report of the 3rd Research Coordination Meeting on Application of Advanced Low Temperature Desalination Systems to Support Nuclear Power Plants and Non-electric Applications

Place of Meeting:	IAEA Headquarters, Vienna
Date of Meeting:	28-30 November 2016
PTAEO Code:	1000155.2016.02.RBF-MP1-2016.613222.NENP-Nuclear Power Technology Development Section
Scientific Secretary:	Mr Ibrahim Khamis
Chairperson:	Mr Igor L. Pioro, UOIT, Canada

1. Participants

Name	Country/Organization	E-mail Address
Mr M. Chocrón	Argentina/ CNEA	chocron@cnea.gov.ar
Mr I. L. Pioro	Canada/ UOIT	igor.pioro@uoit.ca
Mr Saurabh	India/ BARC	saurabhk@barc.gov.in
Mr A. Khan	Pakistan/ KANUPP	msnahsan@gmail.com
Ms G. Zakrzewska-Koltuniewicz	Poland/ INCT	g.zakrzewska@ichtj.waw.pl
Mr M. Lipka	Poland/ NCNR	maciej.lipka@ncbj.gov.pl.

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ARMS

2. Background

Seawater desalination using nuclear energy could be seen as an attractive, non-conventional water resource to meet the rising water demands. This CRP focuses on the introduction of innovative low temperature technologies to support NPPs and non-electric applications. Additional dimensions of the CRP are to analyse the economics of cogeneration systems (i.e. for electricity and water coproduction).

3. Objectives of the meeting

The purpose of the RCM is to:

- Review progress made by the participating CSIs towards reaching the CRP objectives.
- Discuss potential contributions to the foreseen IAEA TECDOC documenting results achieved by participants.
- Discuss details of the Draft Table of content of the expected TECDOC, and assign Leads to chapters of the TECDOC chapters.
- Discuss workplan and schedule for the finalization of both the CRP and the TECDOC.

4. Outcome of the meeting

The IAEA (Mr Khamis, Scientific Secretary) Drivers for the CRP include the quest for advances in technologies which may lead to more efficient and economical desalination systems, promoting R&D on new technologies to enable nuclear desalination systems to be a viable option, coordinate efforts of Member States (MSs) on ND, establish platform for information exchange between MSs, and compliment other CRP on nuclear desalination (Coupling Optimization… & Economic Assessment…), hence the 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 emphasized to participants to the CRP that the results obtained by them in their final reports will determine if a technical document could be compiled and published. This publication could summarize and present the CRP's results as well as any additional scientific publications made by the CRP participants. Otherwise, the results of the CRP and other related useful information presented in previous technical meeting could be compiled together in a TECDOC.

Argentina (Mr Chocrón) presented the progress achieved and the related activities that were conducted within the project. This includes:

- Ultrafiltration and Reverse Osmosis (UF+RO) hybrid water experimental system is purchased and on-site, next to the Heat Source Rig. Now in process of connection.
- Design of the MP-MEE device is complete in the following aspects: micro design (heat and mass transfer balances at the micro level), mechanical design at the basic level, selection of material for the plates and testing against localized corrosion in advanced development, and purchase order for the mechanical design of the MP-MEE device at the detailed engineering level.
- Coupling the RO+MEE to the Small Size Reactor (SSR) is analyzed as follows: production of water and energy consumption calculations were conducted for the hybrid scheme, designed and main equipment dimensioned at a basic engineering level (input for cost) are concluded for the intermediate circuit.

Canada (Mr Pioro) presented results of the evaluation of thermal efficiencies of various NPPs using subcritical-pressure Rankine steam-turbine power cycle and one supercritical-pressure thermal power plant also with the Rankine cycle has been performed using the IAEA software DE-TOP. In order to

use DE-TOP, they have tried to validate it by simulating thermal efficiencies of different existing power plants and comparing these results with actual industry values from literature. The power plants used for validation were: VVER-1000 (PWR), Pickering CANDU-6, BN-600 (SFR), Advanced Gas-cooled Reactor (AGR) Torness, RBMK-1000 (Light-water Graphite-moderated Reactor (LGR)), and the Tom'-Usinsk supercritical-pressure thermal power plant. The results of this comparison showed that: calculated vs. industry-based thermal efficiencies have uncertainty of about ±3%; and due to simplifications and unaccounted irreversibilities, the software overestimates the industry-based values of thermal efficiencies by about 6%. Therefore, the correction factor of 0.94 was introduced to improve the accuracy of thermal-efficiencies calculations. This research resulted in 3 papers presented and published in the proceedings of the largest in the world international nuclear-engineering conference.
It is worth mentioning that the CSI has tried to introduce the IAEA software DE-TOP to his university students as part of his thermodynamics-cycle analysis dedicated mainly for class of about 80 junior students, and to the design-group students (4^{th}-year, 3 students), who used this program for their research and papers' preparation.

India (Mr Saurabh) presented on the carried out R&D on design and development of Advanced Low Temperature Desalination (ALTD) process coupled to Nuclear Power Plants. Feasibility studies on utilisation of low grade waste heat from outlet cooling seawater from the NPP condenser (~40°C) or Low Pressure (LP) turbine exhaust steam (~45°C) for the purpose of desalination are carried out. It was concluded that ALTD process based on Single Stage Flash (SSF) scheme using outlet cooling seawater from NPP condenser is most suitable for utilisation of low grade waste heat. A design basis report containing the flow sheet, process calculation and equipment design of 450 m3/d ALTD-SSF coupled to 220 MWe PHWR has been prepared. Modelling and simulation of ALTD-SSF plant coupled to NPP has been carried out. A dynamic model based on the mass, energy and component balance equation is developed. Set of ordinary differential equations are solved numerically by Runge Kutta method of 4th order. The model predicts the response of the plant for a step change in one or more manipulated variables. Effects of variation of feed seawater temperature, feed seawater flow and inlet cooling seawater temperature to the condenser, on the performance of the plant have been discussed. Developed model will be useful in identifying the safe operating conditions of the plant and development of suitable control system for smooth operation of the plant.

Pakistan (Mr Khan) Karachi Nuclear Power Plant (KANUPP, 137 MWe plant) has already gone through a valuable experience of integrating NPP with the desalination system, MED type, Low temperature Low pressure plant using extraction steam of turbine cycle which has been operating safely since last seven years. The main areas on which the work was done regarding the objectives of the ongoing CRP with reference to Pakistan context include: conducting a feasibility study for optimization of potential low quality steam extraction from various stages of KANUPP turbine applying the IAEA toolkit DE-TOP, identification of available waste heat sources, quantitative and qualitative assessment of the available waste heat, and the development and implementation of scheme for utilization of waste water from existing 1600 m^3/day MED plant as preheated feed to the upcoming four (4 Nos.) Sea Water Reverse Osmosis (SWRO) plants to be installed in the same vicinity. In that context the progress of work performed in the year 2015-2016 was presented. During the meeting, analysis performed on the quantity and quality of bleed steam available from various stages of High Pressure Low Pressure KANUPP turbine was discussed (6 options analysed). The results showed that utilizing 100 % bleed steam from Low Pressure Second stage was found to be the most feasible option with respect to KANUPP context in a way that with the given condition, it imposes minimal power

loss and producing more water, whereas due to low pressure and temperature steam, it is expected that the material construction cost of the Intermediate Coupling Loop (ICL) will be relatively lower. Thus ultimate outcome of the work performed in CRP may provide reliable data for design of a possible low temperature desalination plant to be coupled with forthcoming NPP in Pakistan and MSs thereby ensuring the availability of necessary amount of fresh water enhancing the safety of the plant.

Poland (Ms Zakrzewska) presented on the development of low-temperature systems for nuclear desalination, based on application of membranes. Among different membrane processes potentially useful for these purpose reverse osmosis (RO), mature process, and membrane distillation (MD), which has not found application yet, were selected. Poland has not faced water shortages so far. The country does not have nuclear power plants yet; however, the reasonable way to increase the safety of future nuclear power plants, planned for construction within the Program of Polish Nuclear Energy, is to furnish the NPPs with effective desalination systems. These systems could clean water needed within NPP in normal operation conditions and in emergency situations, when large amount of polluted wastewater should undergo decontamination. The objectives of research were to: review the possible low-temperature systems based on membrane processes, which are useful for desalination of water; make assessment of membrane processes: reverse osmosis (RO) and membrane distillation (MD) as possible processes to be applied in water desalination: separately or as components of hybrid processes; assess the possibility of the use of desalination membrane technologies as a measure for decontamination in case of an event in NPP; consider the possibility of nuclear cogeneration in Poland. The presented research was related mainly to membrane distillation; the performed literature review and the own studies of INCT showed great potential of this process for desalination of water. The experiments were performed with laboratory set-ups; the influence of the main process parameters like the type of the medium treated, operating temperature difference, and the average temperature in the system, feed flow rate, and total salt concentration were evaluated. The important part of the work was the experiments with radioactive solutions that allow the assessment of MD for multiple applications within NPP. The main idea of the project is to use the membrane units not only for seawater desalination, but also to produce water for NPP purposes at every stage of development and operation. In that way such systems could be used for:

- cleaning the coolant, recycling of water with recovery of boric acid, preparation of water for decontamination;
- treatment of low-level radioactivity effluents during regular, every-day operation (waste from laboratories, floor drains, boron recycling water, wastes contaminated with transuranic elements, waste from decontamination);
- decontamination of wastewater in case of accident.

Poland (Mr Lipka) During the National Centre for Nuclear Research presentation the activities connected to the Idea of using heat from the Maria reactor as a heat source for heat pump was presented. The concept assumes the installation of the heat pump on the secondary cooling system of MARIA research reactor. The heat pump working on the water having a temperature of c.a. 25 ®C will be able to reuse the waste heat for district heating and possibly also district cooling of MARIA reactor facility. The available thermal power provided by MARIA and heat needed for the building were presented. Because the power is ~20 times greater than the needs (20 MWth vs 1 MWth respectively), also the idea of using the big enough heat pump for the whole Institute was presented, however this concept still has to be carefully examined. This kind of installation, if ever constructed, would be the first of a kind, the literature studies has not revealed using a heat pump to reuse the low-temperature waste heat from research reactor anywhere in the World. It might me also economically

competitive with current way of heating the National Centre for Nuclear Research (heavy oil – mazut), however detailed economic analysis is yet to be conducted after the selection of heat pump type.

5. Agenda

Annex 1 attached.

6. Conclusions

- The CRP will be terminated after this 3rd RCM.
- The TOC of the TECDOC has been finalized, leads to each chapter and sub-chapters have been assigned.
- Participants agreed to submit their final reports by March 31st, 2017, and contributions to the foreseen IAEA TECDOC by May 30th, 2017. By June 15th, the IAEA will distribute the preliminary draft of the TECDOC to all chapter leads and main editor of the TECDOC. Main editor will deliver back the first draft of the TECDOC to IAEA by July 30th 2017.
- As a result of this CRP, some achievements have been reported by few participants such as:
  - 17 publications/conference papers.
  - 13 students/graduate students received training by working on the topic.
- The foreseen TECDOC shall cover the following Table of Content (the chapter leads are indicated beside the chapter titles as well as the contributors to each chapter):

1. **INTRODUCTION** *(Main Editor)*
   - Highlight of the CRP *[Mr Khamis &Mr El-Emam]*
   - Objectives of the Report *[Mr Khamis &Mr El-Emam, Main Editor]*
   - Scope of the report *[Mr Khamis &Mr El-Emam, Main Editor]*
2. **LOW-TEMPERATURE TECHNOLOGIES FOR NUCLEAR COGENERATION** *(India-CSI)*
   - Desalination *[Thermal desalination: Mr Saurabh (India). Membrane/hybrid: Ms Zakrzewska (Poland)]*
   - District heating/cooling *[Mr Lipka - Poland]*
   - Other LT Industrial applications *[Mr Saurabh]*
3. **CHALLENGES FOR LOW-TEMPERATURE NUCLEAR COGENERATION** *(Pakistan-CSI)*
   - Safety *[Mr Khan (Pakistan)]*
   - Reliability and Availability *[Mr Chocron (Argentina)]*
   - Implementation *[Mr Chocron (Argentina)]*
   - Market *[Mr Khamis &Mr El-Emam]*
   - cost *[Mr Khan (Pakistan)]*
   - Public acceptance *[Ms Zakrzewska (Poland)]*
   - Environmental impact *[Ms Zakrzewska (Poland)]*
4. **ASSESSMENT OF WASTE HEAT RE-USE IN NUCLEAR COGENERATION** *(Argentina-CSI)*
   - Benefits of nuclear cogeneration *[Mr Chocron (Argentina)]*
   - Support to NPPs *[Mr Chocron (Argentina)]*
   - Support to Non-electric applications *[Mr Igor (Canada)]*
5. **CASE STUDIES ON NUCLEAR COGENERATION** *(Main Editor)*

   A. Demonstration projects in Member States *[All]*
      - Argentina
      - China
      - India
      - Pakistan
      - Poland
      - Slovenia
      - Hungary
      - Switzerland

7. Recommendations

- Based on the assessment of the final reports to be submitted to the IAEA by the CSIs, a Consultants Meeting could be planned during the 3rd quarter of 2017 to discuss the first draft of the TECDOC.

- DE-TOP should be updated to include Brayton cycle based reactors, incorporate properties of different fluids for other types of reactors like SCWR and GCR and verify DE-TOP trough benchmarking.

ANNEX 1

3rd RCM on CRP Application of Advanced Low Temperature Desalination Systems to Support Nuclear Power Plants and Non-electric Applications"

28-30 November 2016

Room M0E16, VIC, Vienna, Austria

Meeting Agenda

	DAY 1 Monday, 28 November 2016	
09:30	**Welcoming and opening remarks**	Khamis, IAEA
09:40	Overall status of the CRP & Objectives of this meeting	Khamis, IAEA
10:00	***Presentation 1***: Discussion of the results, work progress & contribution to the TECDOC	Mr. Chocron, Argentina
11:00	***Coffee Break***	
11:15	***Presentation 2***: Discussion of the results, work progress & contribution to the TECDOC	Mr. Pioro, Canada
12:00	***Lunch Break***	
13:30	***Presentation 3***: Discussion of the results, work progress & contribution to the TECDOC	Mr. Saurabh, India
14:15	***Presentation 4***: Discussion of the results, work progress & contribution to the TECDOC	Mr. Khan, Pakistan
15:00	***Coffee Break***	
15:15	***Presentation 5***: Discussion of the results, work progress & contribution to the TECDOC	Ms. Zakrzewska, Poland
16:00	***Presentation 6***: Discussion of the results, work progress & contribution to the TECDOC	Mr. Lipka Poland
16:45	Open Discussion	
17:30	***Wrap up of Day 1***	
	DAY 2 Tuesday, 29 November 2016	
09:00	Discussion on the potential contributions to the foreseen IAEA TECDOC.	All participants
11:00	***Coffee Break***	
11:30	Continue the discussion on the potential contributions to the TECDOC & Assign Leads to chapters of the TECDOC chapters	All participants
12:30	***Lunch Break***	
14:00	Discuss details of the Draft Table of Contents of the expected TECDOC	All participants
14:45	***Coffee Break***	
15:15	Finalize the Table of Contents of the expected TECDOC	All participants
16:00	Open Discussion	
17:00	***Wrap up of Day 2***	
	DAY 3 Wednesday, 30 November 2016	
09:00	Specific workplans of each CSI	All participants
10:30	***Coffee Break***	
11:00	Conclusion and recommendations	All participants
11:30	Finalization of RCM report	All participants
12:30	***Closing Remarks & End of the Meeting***	