IAEA
International Atomic Energy Agency

Interoffice Memorandum

To:	D. Hahn, DIR-NENP	**From:**	I.Khamis NENP/NPTDS, 22822
Through:		**Clearance:**	S. Monti SH-NPTDS
Reference:	622-I35005-CR-2	**Date:**	2015-12-04

Subject: Meeting Report of the Second 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: 1-3 December 2015

Program code: 1000155 2014.02 I35005 RBF-MP1-2015 613224-NHR-TRV-Non Staff RCS NENP-Nuclear Power Technology Development Section

Scientific Secretary: Mr Ibrahim Khamis

Chairperson: Mr. I. Pioro, UOIT, Canada

ATTENDING EXPERTS

Name	Country/Organization	Date
Ms Maria Cecilia Conti	Argentina/ Com. Nac. Energia Atomica-CNEA	1-3 Dec
Mr Igor Leonardovich Pioro	Canada/ University of Ontario Institute of Technology (UOIT))	1-3 Dec
Ms Guo Yali	China/ Dalian University of Technology	1-3 Dec
Mr Sai Kiran Kaza	India/ Bhabha Atomic Research Centre (BARC)	1-3 Dec
Mr Ahsan Ullah Khan	Pakistan/ Karachi Nuclear Power Plant (KANUPP)	1-3 Dec
Ms Grazyna Zakrzewska-Koltuniewicz	Poland/Institute of Nuclear Chemistry and Technology	1-3 Dec
Ms Anna Przybyszewska	Poland/ National Center for Nuclear Research	1-3 Dec

cc:
A. V. Bychkov
de Grosbrois
NENP All staff
ARMS

File

M-13/Rev. 6 (Sep 07)

1. 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).

2. Objectives of the meeting

The purpose of the workshop is to:

- Review and discuss the detailed overall work-plan of the CRP and expected outcome;
- Discuss progress made by the Chief Scientific Investigators (CSIs), present and future work-plans of each participant, especially newly joined members;
- Harmonize, integrate and adjust, as necessary, individual work-plans to align to overall objectives of the CRP; and
- Discuss a preliminary draft table of content for a Technical Document to be published on the results of the CRP.

3. Outcome of the meeting

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. 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…). The CRP is expected to result in the publication of an IAEA technical report summarizing and discussing the CRP's results and additional scientific publications by CRP participants.

Argentina (Ms Conti) presented on progress made in the first year. The results of the activities carried out since Oct-14 until Aug- 2015 have been presented in the 2nd RCM. The main goals of Argentina during this CRP are the: 1) design and construction of an experimental rig for testing both a MP-MEE (modular plate multi-effect evaporator) operating in a thermal mode and also a RO system alone as well as for testing a hybrid MED + RO configuration; 2) Analysis of the coupling to a SSR for production of water for both reactor and secondary circuit, removal of waste heat in different operating conditions and the provision of potable water to the NPP staff.

The main results of the MP-MEE design achieved were related with a macroscopic analysis which includes heat and mass balances and efficiency estimations (GOR and Specific heat transfer area) and with the micro scale level design (transport phenomena, up to the moment film hydrodynamics and stability). Both macroscopic and micro scale analysis were necessary to lead to a mechanical design of the device which is under development. The objectives and operative modes of the experimental rig were mentioned as well as the details of the RO system. RO plant is under purchase and includes ultrafiltration membranes as a pre-treatment and the possibility of test different chemicals in the feed-water line. RO modules are designed for testing both seawater and brackish water. The possibility of sharing the development of a Plate Heat Exchanger Evaporator with a local company is currently being explored. The coupling of the NDs plants (RO+MEE) to NPP was explored under different process configurations. The purpose is to recover heat from the secondary circuit in order to rise RO feedwater inlet temperature and minimize the specific electric consumption of the hybrid MEE+RO

system. Also for the RO energy efficiency, variables like Pressure, Permeate flow, inlet Temperature and process configuration have been investigated with ROSA Software © . The results show that the simplest and most efficient configuration is the ND-MEE coupled to SSR through an intermediate high pressure circuit and the ND-RO recovering waste heat from the main condenser of the NPP-Secondary Circuit. Also the response of connection/disconnection of intermediate loop was modelling and it was concluded that the less intrusive connection scheme is to return the condensate from the loop to the main condenser of the Secondary Circuit.
Planned activities for the 3ed year include the followings:

- Experimental Rig
  - MP-MEE: Conclusion of the theoretical and mechanical design and the commitment for the construction of the device.
  - RO System: Commitment of the experimental plant and its connections to the rig to preheat feed-water.
  - Heating source: The start –up is planned and also the setup of the control system.
- ND plants coupled to SSR
  - Conclusion with the coupling of the intermediate loop to the SSR and basic engineering (currently under study)
  - Conclusion of the water production cost assessment for the hybrid configuration in a specific country site (currently under study). In that send the use of DEEP code is planned for fixed and operative costs.
  - Study of the ND plant (MEE) as reactor heat sink in events.
  - Considerations on the release of concentrated solutions which will be analysed in the next period.

Canada (Mr. Pioro) presented on current status of nuclear power including importance of using supercritical fluids in nuclear engineering i.e. supercritical water (reactor coolant and working fluid in one concept of Generation -IV reactors), carbon dioxide (working fluid in the Brayton cycle and heat pumps), helium (reactor coolant) and refrigerants (modelling fluids instead of supercritical water). Specifics of thermophysical properties and heat transfer have been addressed. It was found that analysis of the current low-temperature non-nuclear applications of NPPs such as desalination and district heating are important for further development for cogeneration. However, in some cases (like the case of direct cycle NPPs (BWRs)), it is important to separate flows of reactor coolant from other flows such as the product water from desalination or water for district heating. This can be done by separating these flows with intermediate loop or heat pump to increase temperature. A possible working fluid can be a supercritical carbon dioxide, which corresponds by many properties for low-temperature applications (critical temperature of carbon dioxide is about 31oC). Therefore, our plans for the next year are to:

- Identify the source of heat available and type of the nuclear power plant, and the potential non-electric application to be coupled to the heat exchanger under investigation.
- Develop a heat transfer correlation for supercritical carbon dioxide at low temperatures i.e. between 40-50 ºC.
- Investigate specifics of thermophysical properties and heat transfer at such low temperatures of supercritical carbon dioxide.
- Develop a concept of a system with supercritical carbon dioxide, which will transfer heat from reactor coolant from direct cycle NPPs with BWRs, i.e., which might contain small levels radioactivity, to the intermediate heat exchanger which will be coupled to a low temperature non-electric applications such as desalination or district heating with a heat pump. One heat exchanger will be installed in the reactor coolant condenser and another one in the desalination or the district heating systems.

China (Ms Guo) presented on nuclear seawater desalination technology on ocean platform. She described an offshore nuclear power station platform with MED desalination system, which could

supply power to nearby drilling platforms economically with reduction of gas consumption and emissions, increase the efficiency of the system, balance the reactor's power output, and supply the required fresh water. Based on discussion made during this RCM, modification in the work plan will be made as recommended. In addition, the next year work plan will include the following:

- Demonstrate the desalination method in the offshore platform nuclear power plant (OPNPP);
- Determine the optimal position of steam extraction from the NPP, compare the electricity generating efficiency at different positions;
- Set up a model to calculate the thermodynamic performance of nuclear power system with different evaporator pressures, numbers and parameters of extraction steam, reheating and regeneration systems, etc.;
- Set up a model to calculate the performance of MED desalination with and without TVC for different feeding patterns, TVC positions and steam, water parameters;
- Couple the above models to simulate the performance of the dual purpose nuclear power system.

India (Mr Kaza) presented on progress made in the first year on design and development of Advanced Low Temperature Desalination (ALTD) Process coupled to Nuclear power plants. Literature survey was carried out and advanced Low Temperature Desalination (ALTD) process based on Single Stage Flashing (SSF) and Single Effect Distillation (SED) schemes were found suitable. Available waste heat sources in 220MWe Pressured Heavy Water Reactor (PHWR), 100 MW(th) Dhurva research reactor and proposed 300MWe Advanced Heavy Water Reactor (AHWR) was discussed. Case studies on both schemes of ALTD process utilizing low grade waste heat from these reactors were carried out. It was concluded that ALTD process based on SSF scheme (ALTD-SSF) using outlet cooling seawater from final condenser of PHWR is most suitable for exploiting low grade waste heat (<400C). Process flow sheet and coupling methodology were developed. Technical challenges involved in design of ALTD-SSF plant and advancements such as use of corrugated tube heat exchanger were discussed. Specifications of flash chamber, condenser and vacuum system were presented. As per work plan, modelling and simulation of ALTD-SSF will be carried out in next year.

Pakistan (Mr Khan) presented on Karachi Nuclear Power Plant. KANUPP has already gone through experience of integrating NPP with desalination system, MED type, low temperature, and low pressure (75C.0.42 bar abs) using extraction steam of turbine cycle which is operating safely since five years. In the current CRP, a brief introduction of existing nuclear desalination was made. The aims and possible outcomes of the CRP were discussed. The KANUPP's proposal aims at exploring the possibilities of utilizing low quality waste heat from NPP for producing fresh water through desalination. In the first year identification of various waste heat sources from NPP was performed. The available waste heat from NPP condenser outlet (low temperature/low pressure), process salt water, turbine lubricating oil and blow down were identified as potential sources. During analysis of these sources it was found that the temperature of water from blowdown system is high enough to be a useful source but the flow rate is quite low whereas the temperature from the condenser and other sources are quite low for a meaningful desalination with distillation processes. However, this relatively hot water can be fed to the RO process, with preheating known as the ROph process. The scheme for utilization of cooling waste water discharge from MED condensers as feed water for upcoming sea water desalination SWRO Plants, of which, the first unit of capacity 0.25 MGD has already been supplied with the preheated waste water. The advantages gained by using preheated water and blending of SWRO and MED products were also discussed in the presentation. The work plan for the next year was presented. The proposal will be modified as recommended to reflect future work in accordance with the discussion made during the RCM.

Poland (Ms Zakrzewska) presented on progress made in the first year. The presentation concerned 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 this research were as follows:

- 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 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 sea water 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.

According the revised plan of research the next-year activities will be focused on further studies on MD and its competitive characteristics in relation to other processes applied for water desalination and water decontamination. RO as well as thermal processes will be used as reference methods. The experimental studies will be supplemented with modelling and simulation work enabling more complete evaluation of the process. Development of the appropriate models of the process will enable the prediction of behaviour of the full-scale systems and help in design of future industrial units.

Poland (Ms Przybyszewska) presented her work plan in the field of innovative using a heat pump which integrates well with the overall objective of CRP. The presentation concerned application of heat pump system for district heating. A low temperature waste heat flow can be upgraded to useful high temperature heat with the use of a heat pump. She proposed the possibility of utilizing low quality waste heat (40-50°C) from Maria Research Reactor as a heat source for its system. She explained that motivation of researches, preliminary technical feasibility, coupling aspects, calculation and proposed schemes. One of the main objectives is to prepare a case study "using heat from the Maria Reactor as a heat source for heat pump". The results will predict the reasonableness of this project as well as assess feasibility of similar projects on a larger scale. Partial deliveries of heat to the

district heating can help to significantly reduce the costs associated with maintaining of current infrastructure based on small heat sources burning conventional fuel - oil.

The project is one of the strategic activities in nuclear cogeneration field at National Centre for Nuclear Research. Participation in this CRP has built strong nuclear cogeneration team in Poland. Experience from projects: European NC2I-R and national HTR-PL can help to conduct this project. The major expected outcomes from this research are: feasibility report on nuclear district heating based on heat pump utilizing low quality waste heat, design basis report of a system for NCBJ- Świerk site, techno-economic recommendation for future applications.
Plan for the next year includes:

- Collect data about operation of the reactor in the past 5 years, including the daily power levels.
- Collect data about the needs of heat in the past 5 years, including the power capacity or fuels consumption for each day.
- Review of literature about advances in heat pump technology.
- Review of literature about advances in district heating coupled with low temperature sources.
- Review of commercial technology of heat pumps.
- Collect data about economic and environmental factors for case study.
- Analysis of use heat from the Maria Reactor as a heat source for heat pump.
- Collect data about circuit in nuclear power plants, focusing on parameters of waste heat i.e. temperature, flow etc.
- Feasibility study of implementation of low waste heat from nuclear power plant as heat source for district heating based on heat pump system.

4. Agenda

Annex 1 attached.

5. Conclusions

6. Fruitful discussion has resulted in consolidating work plans by participating CSIs.
7. It was agreed that all proposed modifications on the workplan should reach IAEA by end of 31 Jan 2016.

8. Recommendations

It was recommended by participants that:

- Future presentations by CSIs should discuss only activities related to progress made by CSIs as part of the CRP.
- All modified work plan be harmonized to fall under the overall objectives of the CRP. The following CSIs agreed to modify workplan as follows:

Canada	• Identify the source of heat available and type of the nuclear power plant, and the potential non-electric application to be coupled to the heat exchanger under investigation. • Develop a heat transfer correlation for supercritical carbon dioxide at low temperatures i.e. between 40-50 ^{o}C. • Investigate specifics of thermophysical properties and heat transfer at such low temperatures of supercritical carbon dioxide. • Develop a concept of a system with supercritical carbon dioxide, which will transfer heat from reactor coolant from direct cycle NPPs with

	BWRs, i.e., which might contain small levels radioactivity, to the intermediate heat exchanger which will be coupled to a low temperature non-electric applications such as desalination or district heating with a heat pump. One heat exchanger will be installed in the reactor coolant condenser and another one in the desalination or the district heating systems.
China	• The scope of the research should be more precisely defined in order to avoid duplication with other activities carried out by the same CSI and his group
India	• In later stage of the CRP, the scope of work should be extended to cover PWR technologies to avoid limiting it to PHWR.
Pakistan	• The scope of analysis should be extended to: identifying available and characteristics of waste heat and its reuse in various NPPs in the country, optimization of potential low quality steam extraction from NPPs, and economic assessment to show the benefits.
Poland (Ms Zakrzewska)	• In later stage of the CRP, may wish to consider modelling of hybrid systems (RO and MD), and simulate upscaling of the system to meet large scale radioactive decontamination
Poland (Ms Przybyszewska)	• Assessment of the overall benefits of waste heat re-use (substitute for the cooling towers, estimate No of houses, inhabitant, and economics)

- The foreseen TECDOC shall cover the following Table of content:
  - **Ch 1:** Introduction, highlight of CRP, Objectives of the report/study, overview of the subject
  - **Ch 2:** Potential of low-temperature non-electric applications suitable for cogeneration with NPPs. (Countries:)
  - **Ch 3:** Techno-economic evaluation of various types of nuclear power reactors suitable for low-temperature cogeneration (Countries:)
  - **Ch 4:** Assessment of potential re-use of waste heat and efficiency improvement in NPPs (Countries:)
  - **Ch 5:** Challenges for the coupling of low temperature non-electric applications to NPPs (Countries:)
  - **Ch 6:** Advances in low-temperature non-electric application technologies
  - **Ch 7:** Develop recommendations on the application of advanced low-temperature desalination systems to supply nuclear power plants with water of required quality and quantity (All).
  - **Ch 8:** Summary and Conclusions (All)
  - References (All)
  - **Annexes (All)**
- Next RCM meeting: to be planned in Vienna, during 1st week of Dec 2016.

ANNEX 1

2nd RCM on CRP Application of Advanced Low Temperature Desalination Systems to Support Nuclear Power Plants and Non-electric Applications"

01-03 December 2015

Vienna, Austria

Room C0737

Meeting Agenda

Tuesday, 01 December 2015

Welcoming and opening remarks		
09:30	Overall status of the CRP & Objectives of this meeting	Mr Khamis, IAEA
10:15	Presentation 1: Current Situation on design and construction of a modular MED desalination system and a hybrid (thermal and RO) testing rig	Ms Conti Argentina
11:00	*Coffee Break*	
11:15	Presentation 2: Application of advanced low temperature desalination systems to support NPPs and other energy technologies	Ms Guo, China
12:00	*Lunch Break*	
13:30		
14:15	Presentation 4: Situation on Nuclear desalination in Iran	Mr Haji-Hosseini, Iran, Islamic Rep of
15:00	*Coffee Break*	
15:15		
16:00	Presentation 6: Application of advanced membrane systems in nuclear desalination	Mr Khan, Pakistan
16:45	Open Discussion	
17:30	Wrap up of Day 1	

Wednesday, 02 December 2015

Opening Session		
09:30	Presentation 1: Application of advanced membrane systems in nuclear desalination	Ms Zakrzewska, Poland
10:15	Presentation 2: Current situation of nuclear desalination in Poland	Ms Przybyszewska, Poland
11:00	*Coffee Break*	
11:30	Presentation 3: Nuclear power for non-electric applications in Canada	Mr Pioro, Canada
12:15	*Lunch Break*	
14:00		
14:45	*Coffee Break*	
15:15	Presentation 5: Development of advanced low temperature desalination process coupled to NPPs	Mr Shivayyanamath, India
16:00	Open Discussion	
17:00	Wrap up of Day 2	

Thursday, 03 December 2015

09:30	Discussion on: (1) Plan for next year: common issues (2) Specific work plans of each CSI (3) Modifications to work plans (4) Foreseen table of content for the final report of the CRP	All participants
10:30	*Coffee Break*	
11:00	Discussion on: - Conclusion and recommendations - Future RCM	All participants
11:30	Discussion on: Finalization of RCM report	All participants
12:00	***Closing Remarks & End of the Meeting***	