IAEA
International Atomic Energy Agency

INDAG Newsletter

News from the International Nuclear Desalination Advisory Group
No. 7, September 2007 ISSN 1011-XXXX

http:/www.iaea.org/nucleardesalination

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A Word from the Deputy Director General

Nuclear Desalination is an important option for the production of potable water while caring about the environment and sustainability in many Member States. With the support of the IAEA, several Member States have assessed, or are currently assessing feasibility of nuclear desalination projects. Among them are Algeria, Jordan, Libya and United Arab Emirates who have ongoing national technical cooperation projects with the IAEA. The IAEA continues to provide guidebooks, technical documents, and computer programs as well as technical assistance through the framework of the technical cooperation programme.

In the framework of the Coordinated Research Programme (CRP) on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies, a fourth and final Research Coordination Meeting (RCM) was held in October 2006. The final results of this CRP were published as IAEA-TECDOC-1561 entitled Economics of Nuclear Desalination – New Developments and Site-specific Studies – Final Report of a coordinated research project 2002-2006. The updated version of the IAEA Desalination Economic Evaluation Program (DEEP), DEEP 3.1 was released in September 2006. The IAEA International Conference on Non-Electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications, was organized with OECD/NEA and the International Desalination Association (IDA), and hosted by the Japan Atomic Energy Agency on 16-19 April 2007 at Oarai, Japan.

During the last meeting of INDAG held in February 2006, information was exchanged on the progress of national and interregional activities on nuclear desalination. Emphasis was placed on enhancing the IAEA support in facilitating nuclear desalination activities in Member States.

I am pleased with the release of the seventh issue of the INDAG newsletter highlighting the current activities of the IAEA and from Member States.

Y.A. Sokolov
Deputy Director General
Department of Nuclear Energy, IAEA

A Word from the Chairman

INDAG, as an international IAEA advisory group on nuclear desalination, has clearly demonstrated its successful role in meeting its terms of reference by providing advice and guidance on the IAEA's Agency's activities in nuclear desalination and reviewing progress, identifying important topics for and contributing to status reports, coordinated research projects, technical meetings in the field of nuclear desalination, providing forum for exchange of information on the progress of national and international programmes in this field, providing advice on preparatory action by Member States for implementing nuclear desalination demonstration projects, guiding technology development & innovations and facilitating deployment of nuclear desalination in interested member states.

The successful completion of several TC supported projects and other national nuclear desalination projects have demonstrated the technoeconomic interest and viability of nuclear desalination. The LTE nuclear desalination plant which was integrated to CIRUS nuclear research reactor in India for demonstrating utilization of waste heat and coupling aspects for seawater desalination has completed three years of successful operation. SWRO section of Nuclear Desalination Demonstration Project at Kalpakkam has completed five years of successful operation. Japan has continuously operated nuclear desalination facilities to use desalinated water inside the plants. A Nuclear Desalination Demonstration Project is being established in Pakistan utilising heat from the Karachi Nuclear Power Plant (KANUPP). The Federal Energy for Atomic Agency (ROSATOM) has started the construction of a small floating barge mounted heat and power cogeneration nuclear plant based on KLT-40C in North West of Russia. The construction of E1-Dabaa Experimental RO Desalination Facility in Egypt was completed. The construction project of the SMART pilot plant for performance verification of SMART reactor and desalination technology is actively in progress. Nuclear Desalination Studies at CEA, France are increasingly becoming interregional, including the latest deal with Libya for cooperation on nuclear desalination. Morocco is considering to introduce nuclear desalination. US expertise in the areas of membrane technologies are utilised in demonstration projects.

INDAG has consistently supported and emphasised the need for the deployment of the nuclear desalination in the interested member states and enhanced synergy among the actively-involved countries. The IAEA has been very effective in promoting the exchange of information, cooperative research and technical cooperation among its member states. It has a very important future role to play as water scarcity is a global issue, and every year new countries are affected by growing water problems.

P. K. Tewari
Chairman, INDA

Recent Activities in Nuclear Desalination in Member States

Argentina

There has been a continuous support by Argentina to theIAEA's programs on nuclear desalination since the early nineties. Two institutions have been involved in this support: the Argentine CNEA (Comisión Nacional de Energía Atómica) and the main Argentine Nuclear Vendor INVAP S.E. (State owned Company). During the last years INVAP has contributed on developing specific engineering and project management findings out of the well-settled IAEA's Safety Approach of Nuclear Desalination focused on Safety issues. This work includes backgrounds on the SAR content survey, detailed safety approach for Nuclear Desalination coupling, the development of the conceptual engineering of Coupling Systems with alternative Safety Features, deriving design requirements from safety objectives. These alternative designs are the Product Water Radiation Monitoring and the use of Pressure Reversal in the thermal coupling, and were assessed in terms of viability and cost. For the latter the process impact on the efficiency of the NPP for the ND coupling was also assessed.

Recently a comprehensive overview of the work performed on this field has been elaborated and presented in the frame of the International Conference on Non-Electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications, Oarai, Japan, April 2007, starting with the basis on which a safety analysis must be performed including recommendations on the way to report it following IAEA Standards, finally reaching a comparison of engineered safety features considered in the coupling analysis and the rationale to select one for a specific project.

This approach is intended to complement the design assessment of a NDP coupling in the early stages of the project and to give support to the Regulatory Bodies on the licensing process. Simultaneously and during the last year, the CRP on Economic Research on, and Assessment of Selected Nuclear Desalination Projects and Case Studies, in which the CNEA has been participating, was completed including the IAEA-TECDOC which summarises the work performed. The conclusion shows that after diverse economical assessments (DEEP and IPEE methodologies) and a sensitivity study on the product cost with the fossil fuel price (for a combined cycle gas turbine plant), the interest rate and the plant capacity, the use of a CAREM NPP coupled to an RO plant provides an attractive, economic and feasible option for electricity and freshwater production in the selected site of Puerto Deseado, Argentina.

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China

Seawater desalination has already been classified as one of priority developing technology in the Chinese National Marine Economic Development Planning Outline and the Chinese National Sub-plan for Seawater Utilization issued on Aug.2005. Based on the R&D over more than forty years, for the capacity more than 500 m^3/d each unit, 12 seawater desalting plants have been established in China with a total capacity of 40,000 m^3/d, and the capacity under construction has exceeded 50,000 m^3/d. Desalination should become an important part of water supply safety system in coastal areas and China should become one of the countries with the most powerful desalination industry by laying a solid foundation for that.Studies for nuclear power desalination and large-scale desalination plant, include the special materials and technology for the nuclear power desalination process, building a demo project with a daily treatment volume of 100,000-200,000 tons and the single unit should be able to treat 10,000-40,000 tons each day; the optimizing and safety guarantee of the nuclear power station and low temperature pile desalination system.

Egypt

The Nuclear Power Plants Authority of Egypt (NPPA) has been developing a nuclear desalination model with technical assistance from the IAEA through technical cooperation project: EGY/ 04/046 Simulation of Nuclear Desalination Plant with an objective of utilizing simulation tools to develop nuclear desalination simulator. FORTUM Nuclear Services Ltd. of Finland supplied NPPA with the Advanced PROcess Simulation (APROS) software simulation tool.

The model considers a generic PWR 1000 MWe nuclear power plant, coupled thermally with an MED desalination process through a pressurized water/flash intermediate loop. Six effects MED plant having 25000 m^3/day capacity of a simple design architecture using the Falling Film Horizontal Tube Evaporators (FF-HTE) were selected. A low pressure saturated steam, supplied from the intermediate loop flash box, was used as a heat source.

The main objective of this model is to study the coupling effects between the nuclear power plant and the coupled desalination plant under different operating regimes and scenarios, hence, demonstrate the feasibility of safe operation of nuclear desalination system for the production of potable water. The evaluation of the simulation model for the steady state and transient conditions was carried out by applying different scenarios involoving changes of the operating variables of the nuclear desalination plant. Schematic diagrams for the MED plant simulation and details of MED effect using APROS are shown in figures 1 and 2.

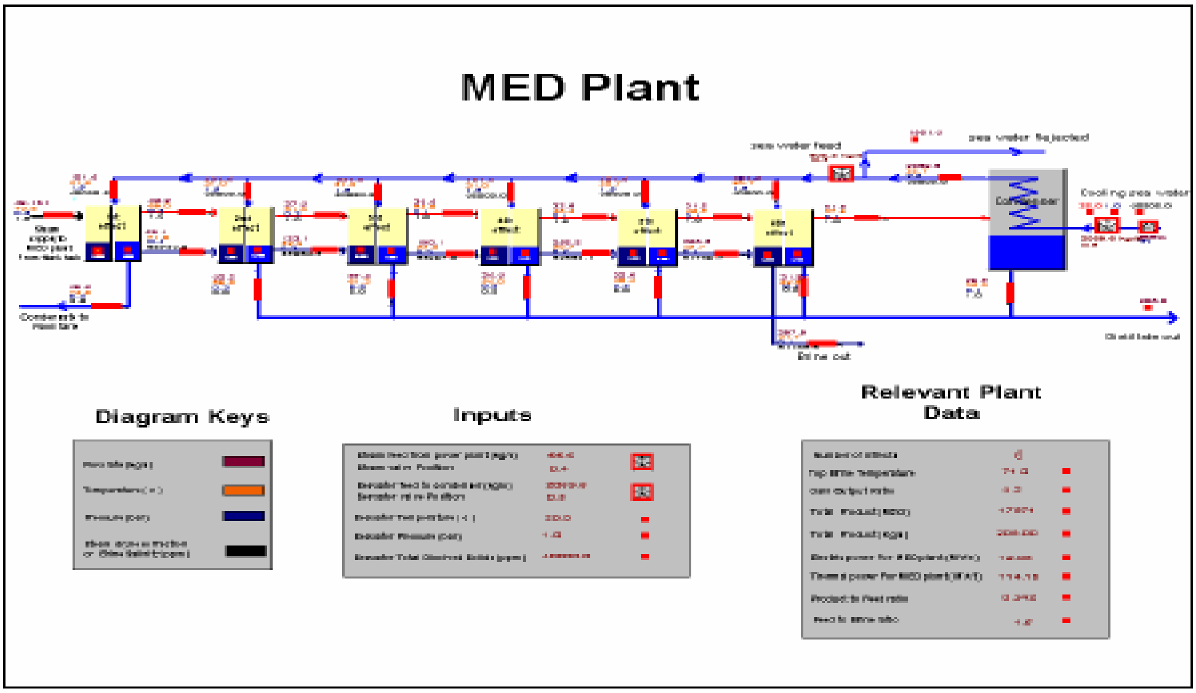

Fig.1 Schematic diagram of APROS GUI MED plant simulation

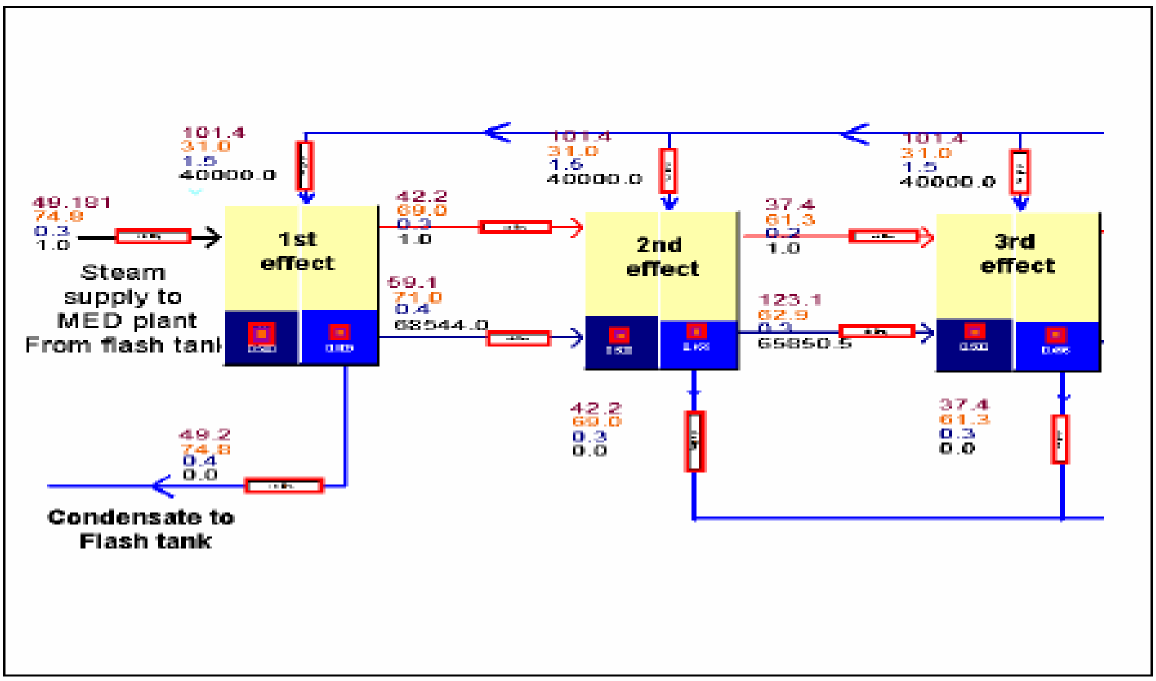

Fig. 2 A schematic representation of the APROS GUI MED effecs

France

CEA investigations have recently been focused, and will continue to do so over the next years, on the economic evaluation of selected power and desalination costs of integrated nuclear desalination systems based on the utilisation of existing as well as GEN IV nuclear reactors and three fossil fuelled plants (the circulating, fluidized bed coal fired plant CFB-900, the oil-fired plant OIL-500 and the Gas turbine combined cycle plant CC-900), all coupled to MED and/or RO desalination plants. Detailed comparisons will also be made with renewable energy based desalination systems. The study aims at evaluating real costs of the integrated systems with and without the environmental impact costs (externalities).

In the contxt of a bilateral collaboration between CEA and BARC (India) a MED/mechanical VC simulator has been developed during a two month visit of a BARC scientist to CEA, Cadarache. This simulator will be validated on an existing Indian installation at BARC. It will be extended to include thermal VC, MSF and RO modules. Another Indian scientist, working with the Cadarache team, has completed preliminary studies on the extraction of Uraniaum from the rejected brine. The bilateral collaboration with REWDRC of the Libyan Arab Jamahiria is in progress. Preparations are underway to elaborate the advanced project report to utilize the Libyan experimental reactor at Tajoura as a demonstration plant for nuclear desalination.

India

Desalination of water is one of the key drivers under non-power applications of Atomic Energy Programme in India. Bhabha Atomic Research Centre (BARC) has been pursuing development of a variety of desalination technologies and has deployed a large number of desalination plants in water scarcity areas of the country. BARC is also engaged in coordinating nationwide activities on desalination and water purification which includes nuclear desalination.

The first-of-its-kind Nuclear Desalination Plant based on Low Temperature Evaporation (LTE) utilising waste heat of nuclear research reactor CIRUS was demonstrated at Trombay. It has completed three years of successful operation and fulfils the entire makeup water need of the CIRUS. The successful demonstration has opened up the possibility of setting up large size nuclear desalination plants using low grade/waste heat of nuclear reactor for seawater desalination. It is proposed to integrate 500,000 litres/day nuclear desalination plant with an advanced heavy water reactor (AHWR) for seawater desalination.

The seawater reverse osmosis (SWRO) plant, with a 1.8 million litres per day (MLD) capacity of Nuclear desalination demonstration project (NDDP) at Kalpakkam is completing five years of successful operation since its commissioning in 2002. Potable water produced is supplied to reservoir for distribution to DAE facilities in Kalpakkam. Based on the successful experience, it is planned to set up a SWRO plant (2.0 MLD capacity) in New BARC Centre at Vizag in the southern part of India. It is proposed to set up an advanced hybrid MED-RO desalination plant (400,000 litres/day capacity) at Trombay. Experimental studies on recovery of valuables from reject brine/seawater are also planned. BARC is providing consultancy to Bharat Heavy Electricals Limited (BHEL) for large size desalination plants.

BARC has actively participated in a CRP entitled Economic Research on, and Assessment of Selected Nuclear Desalination Projects and Case Studies which has been successfully completed recently. As per bilateral agreement, BARC (India) and CEA (France) are working on integrated nuclear desalination systems which include waste heat utilsation, hybrid systems and socio-economic aspects.

Israel

Since October 2005, Israel has been producing high quality desalinated seawater on a large scale. The Ashkelon RO (reverse osmosis) seawater desalination facility is the world's largest of its kind and produces today water over 100 MCM/a (million cubic meters per year) of a quality significantly better than 300 ppm TDS, Clorides less then 20 ppm and Boron less then 0.4 ppm. In May 2007, a second large scale seawater desalination unit, in Palmachim (central Israel along the coast), started to produce 30 MCM/a.

A third Desalination plant (Hadera site, 100 MCM/a) started construction on June 2007 and is planned to start its water supply to the national grid at the end of 2009. Two additional large scale units are planned with capacities of 45 and 150 MCM/a to start production by the end of 2012. Also, a total capacity of another 80 MCM/a will be added in the next years by upgrading existing units.

All together, Israel plans (backed up with a governmental statement dated July 1st 2007) to produce about 505 MCM/a of desalinated seawater by 2013, which will be about half the consumption of drinking water (municipal use) in the country. The projects are financed by the private sector and all but one are BOT (build operate transfer) projects, having the facilities transferred to governmental ownership after 25 years. Two northern seawater desalination projects were recently cancelled due to non-profitability forecasts and inability to assure the investments (Shomrat and Haifa bay).

The typical time to erect and operate a 100 MCM/a seawater desalination facility in Israel is 5-7 years (from the governmental decision to water supply) and the cost is around 250 million US dollars.

Typically, the cost forecast of the desalinated water in the large scale RO facilities is around 60 US cents per cubic meter in July 2007 currency levels. The power for the desalination facilities is basically taken from the national grid, with the exception of the Ashkelon plant that has a self operated NG (natural gas) power station.

Among the benefits expected from large scale water desalination in Israel are :

- Lowering the water total salinity, thus improving agricultural crops (10%-15% more crops with water of less than 200 ppm salinity).
- Improvement of the water quality in the municipal grid.
- Less problems in heating and cooling systems nationwide.
- Less pumping energy required to deliver water to the southern part of the country.
- Lowering the underground water salinity.
- Better water supply reliability.
- More flexibility in electrical energy consumption, since part of the water can be desalinated in electrical low-demand hours.

Japan

At the present time, Japan has no new national projects, international projects and inter-regional projects on the nuclear desalination. Japan, however, has continuously operated some nuclear desalination facilities to use the water inside the plants without any serious troubles. Although there is not any exclusive nuclear desalination for supplying potable water to residents, potential needs exist especially in the western parts of Japan and non-nuclear seawater desalination systems have been working: The potable water of 50,000 m^3/day is supplied in Fukuoka district and 40,000 m^3/day in Okinawa City.

R&D on innovative nuclear technologies is conducted under the contract with MITI. Concept design studies on small light water reactors generating an electric power of 350 to 450 MW such as an Integrated modular reactor (IMR) by Mitsubishi Heavy Industries (MHI) and the copmact containment reactor (CCR) by Toshiba have been continuing, which can be used also as energy source for desalination, if necessary.

Developments of the high temperature engineering test reactor or high temperature test reactor (HTTR) together with the hydrogen production technology of IS process have been conducting in Japan Atomic Energy Agency (JAEA). The HTTR reactor outlet coolant temperature of 950℃ has been attained in April, 2004 and a test of one week continuous hydrogen production by the Iodine-Sulfur (IS) process has been completed in June, 2004. These developments have been pushing a concept design study of the high temperature gas-cooled reactor cogeneration system, which generates electricity, hydrogen and fresh water by Multi-Stage Flash (MSF) desalination process, e.g., gas-turbine high temperature reactor (GTHTR)300C with reactor thermal power of 600 MW for co-generation in heat utilization rate of 80%.

Korea, Rep. of

The objectives of the Korean programme are mainly to develop an integrated desalination plant with SMART (system-integrated modular advanced reactor) for generation of electricity and water production. The SMART reactor, an integral type pressurized water cooled reactor is coupled with the multi-effect distillation thermal vapor compression (MED-TVC) process. The programme is being carried out by the Korea Atomic Energy Research Institute (KAERI) as the leading organization with the support of Government and participation of industries.

The concept of the SMART desalination plant aims to supply 40,000 tons of fresh water per day and 90 MW of electricity to an area with approximately hundred thousand populations or an industrialized complex. The SMART reactor which is an integral type pressurized water cooled reactor with rated thermal power of 330MWt is coupled with MED-TVC process. Both the conceptual design and basic design of SMART with a desalination system were successfully completed in March of 1999 and in March of 2002, respectively. Major components such as steam generator, main coolant pump, and control element drive mechanism are being developed and currently performance tests are underway. A series of performance tests and safety tests for SMART reactor systems has been performed at high-temperature high pressure thermal hydraulic test facility.

A one year feasibility study has been carried out to expedite commercialization of SMART and improve power generating cost and water production cost. In this study, technical aspects, safety aspects and economic aspects were evaluated for a new SMART desalination plant with increased reactor power, optimized reactor system and safety system. Currently, the next phase project plan to obtain the design certificate of SMART is being reviewed by the steering committee.

Libyan Arab Jamahiriya

The Libyan Nuclear Desalination Project (LIBND-P1) is being proposed in the context of the Memorandum of Understanding (MOU) for collaboration in the field of peaceful uses of atomic energy, which has been made between CEA (France) and the National Bureau of Research and Development (NBRD) of the Libyan Arab Jamahiria. The project is mainly concerned with:
- A techno-economical feasibility study of an integrated nuclear desalination system at the selected site in the Libyaa Arab Jamahiria.
- Exploration of the possibility to use the Tajoura research reactor as a tool to demonstrate nuclear desalination, based on the utilisation of hot water provided by the reactor.
- Major objectives of the project are:
- Coherent demonstration of the technical feasibility of nuclear desalination with optimal cogeneration of electricity and water, using selected nuclear reactor concepts and desalination processes.
- Economic analysis of the diverse desalination scenarios with the possible combinations of above nuclear reactors and desalination systems. Assessment of the competitiveness and sustainability of these systems as against fossil and renewable energy based systems in the Libyan Arab Jamahiriyan conditions.
- Use of the Tajoura reactor to demonstrate nuclear desalination.
- Safety studies of the above systems.

The expected end result of the project is to furnish the complete technical specifications of a nuclear desalination plant, providing electricity to the Libyan Arab Jamahiriyan grid and producing desalted water in a cogeneration mode.

Morocco

Studies have shown that water resources are limited, unevenly distributed, and vulnerable. The desalinization of brackish and seawater can be a competitive solution in terms of cost and environmental impact. Lower costs stem from the contribution of several direct and indirect factors: technological progress, equipment performance, project scale effects, and substantial reduction of energy consumption, energy recycling, and market liberalization.

Morocco undertook conventional desalinisation feasibility studies using grid electricity, wind and solar energy to compare the findings with those of the Pilot Project on nuclear desalinisation, which was implemented through an IAEA TC programme. Moreover, with the help of IAEA experts, an adequate and sound legal and institutional legislative and regulatory nuclear framework was established and is on its way for approval and consequent ratification. Morocco is still involved in bilateral nuclear desalination activity, and confirms its choice for embarking on nuclear power as an important component of the energy mix which will diversify its energy supply sources while enabling seawater desalination where the deficit is critical.

Pakistan

The KANUPP nuclear desalination plant was originaly scheduled to be commissioned by November 2007. However due to some re-organization of the contractor's company, procurement of raw material for fabrication of equipment, and other related issues, commissioning was delayed considerably. All the work activities have therefore been rescheduled and now Pakistan is confident that the schedule will be strictly adhered to. The present progress of work is as follows;
- Fabrication of all MED equipment has been started at our works and presently nearly
- 40% of the fabrication work for the main MED equipment has been completed.
- Equipment fabrication of MED plant is scheduled to be completed by April 2008.

Regarding the isolation loop fabrication and installation, all the required raw material has been procured. Design engineering has been completed and drawings have been released for construction. Construction work is scheduled to start by September 2007 and shall be completed by February 2008. Similarly, procurement of the seawater intake system material and equipment is in progress and is expected to be completed by September 2007. Installation work shall start soon and is scheduled to be completed by November 2007. All the installation and erection activities for all systems are scheduled to be completed by June 2008 and startup of the plant in July 2008.

Russian Federation

The Russian Federal Agency for Atomic Energy (ROSATOM) has continued construction of a floating barge-mounted heat and power co-generation nuclear plant equipped with two KLT-40C reactors. This small floating NPP is designed to produce up to 70 MW of electric power and about 150 Gkal/h of heat for district heating.

Decision has been made to enlarge the scope of the project and construct a series of floating nuclear power plant (NPP) of the same type (see Fig. 3). First-of-a-kind floating power unit was founded at the navy yard «PO-Sevmash» (Severodvinsk-city, Arkhangelsk Region) on April 14, 2007. It was named "Academician M.V. Lomonosov". Planning commissioning year of the plant in Severodvinsk-city is 2010.

Feasibility studies for several more sites in the North and Far-East regions of Russia (Pevek at Chukot Peninsular and Veluchinsk at Kamchatka Peninsular in particular) are now under way. Also the possibility to apply the floating NPP for energy supply to minerals mining at shoreland and crude oil recovery at continental shelf in the Arctic Ocean area is investigated. In parallel to the current floating NPP Project the R&D aimed at broadening the model-line of nuclear floating power units is carried on. Long-time planning comprises construction of floating power units of 12 to 300 MWe which will supply power and heat to municipal consumers and industries including nuclear desalination in the remotely isolated areas of Russia and other countries.

Fig. 3 Floating Nuclear Power and Desalination Complex

Saudi Arabia

As a member of the gulf cooperation council (GCC), Saudi Arabia and other members of the GCC have initiated a joint study regarding the uses of the nuclear technology for peaceful purposes according to the international criteria. Recently, the GCC sought the assistance and expertise of the Agency on a proposed study which would cover both the feasibility of introducing nuclear power for electricity generation and seawater desalination, and also the development of other non-power nuclear applications for peaceful purposes, and to ensure that all steps and procedures were conducted in full transparency.

United States of America

The USA is continuing to support INDAG's activities through active participation in related IAEA Coordinated Research Projects (CRPs), meetings, and conferences. US experts recently participated in the IAEA international conference on non-electrical applications of nuclear energy (i.e., hydrogen production and desalination). Argonne National Lab (ANL) has also contributed to two very recent IAEA technical documents (IAEA-TECDOCs) on status of nuclear desalination in IAEA member states (IAEA-TECDOC-1524) and a soon to be published IAEA-TECDOC on the results of a CRP on economics of site-specific nuclear desalination projects (also known as CRP-2). The USA, with the leadership of ANL, will continue to do its best to contribute to INDAG's mission in highlighting and further examining the benefits and future applications of nuclear desalination around the world.

Current Members of INDAG, Term III (2005-2008)

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BARC

Development of a joint MED/VC simulator

S. Nisan, (CEA, France) and P.K. Tewari (BARC, India)

1. Introduction

The French Atomic Energy Commission (CEA, France) and the Bhabha Atomic Research Centre (BARC, India) signed a specific agreement in the field of nuclear desalination on November 10, 2005. This agreement included a technical annex, outlining the various tasks that the two parties could realise conjointly in the field of nuclear desalination

The kick-off meeting of the project was held at BARC premises on March 23-24, 2006. In this meeting, the technical annexe presenting the research programme to be pursued by the two partners was discussed in detail and the implementation programme finalised.

During the same meeting, the two parties decided, among other actions, to extend the MED simulator developed by CEA, to include vapour compression models so that the ensemble could be tested and validated around the 50 m^3/day MED/VC installation at BARC.

A Scientist from BARC was invited to the CEA desalination team at Cadarache for a period of two months in order to acquire the simulators working principles and to introduce a new vapour compression model in the simulator, now known as **INFMED** (**In**do-**F**rench **MED** simulator).

The results of this work were partially presented at the Trombay Symposium on Desalination and Water Reuse in March 2007. The full joint paper is accepted for publication in the internationally well known journal, **Desalination**, [1].

2. Process Description

In the MED evaporative process, the feed seawater is heated in the product and brine blow down pre-heaters. It is then fed in parallel to the evaporator stages where it is sprayed on the tube bundle.

The steam condensing inside the first effect tube bundle gives up its latent heat and generates an almost equal amount of vapour from the feed. The concentrated brine is sent to the next effect maintained at a slightly lower pressure. The vapour produced in the first effect condenses on the inside of the heat transfer tubes in the second effect, giving up its latent heat and generating an almost equal amount of vapour from the feed brine. The vapour generated in the last effect is taken to a Vapour Compressor (VC) where it is compressed to a higher temperature and used as heating steam in the first stage. Here thin film evaporation of brine occurs on the outside of horizontal tubes and condensation of vapour occurs on the inside of the horizontal tubes in the evaporator resulting in high heat transfer coefficients. In the vapour compression process the compressor provides the driving force for this heat transfer and provides the energy required in separating the solution and overcoming the dynamic pressure losses and other irreversibilities. A schematic diagram of two effect MED-VC desalination plant is shown in the Figure 1.

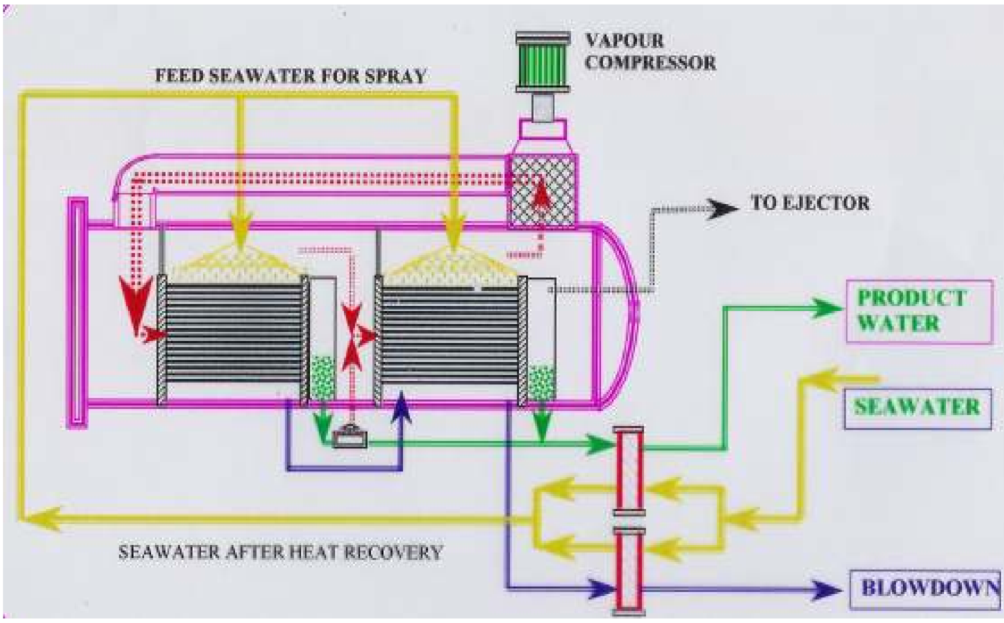

Figure 1: Schematic diagram of an MED-VC system

1. Software package description

INFMED includes models for MED and the MED-VC process (Figure 1). This software runs under the Windows 9x/Me/2000/XP operating system.

The Software has a modular architecture (Figure 2). It consists of a graphical user interface (developed under Microsoft Visual Basic) for simulating and viewing the results of both steady and unsteady states of MED-VC desalination system. The models considered in the simulator are analytical; they derive from basic mass, momentum and energy principles applied to process subsystems. They also include correlations for heat transfer coefficients and thermo-physical properties of pure and saline water. These models are described in detail in [1] for all relevant components (evaporators, heat exchangers etc) both for steady state and transient conditions.

2. Case Study

A case study was undertaken simulating a two and three effects 50 m^3/day MED-VC of an existing Indian installation.

For the purposes of illustration, we present the results of a transient state calculation.

A disturbance of change in feed flow rate of 10% change in magnitude and 10 sec duration is given to the system. The program is asked to calculate the response in temperature, level and salinity as a function of time (no of iterations x time step). The maximum number of iterations fixed is 100 and the time step used is 1 sec. A value of 0.5 for epsilon (integration limits between 0 &1) was chosen to do the implicit Euler integration.

Results are shown in Figure 3.

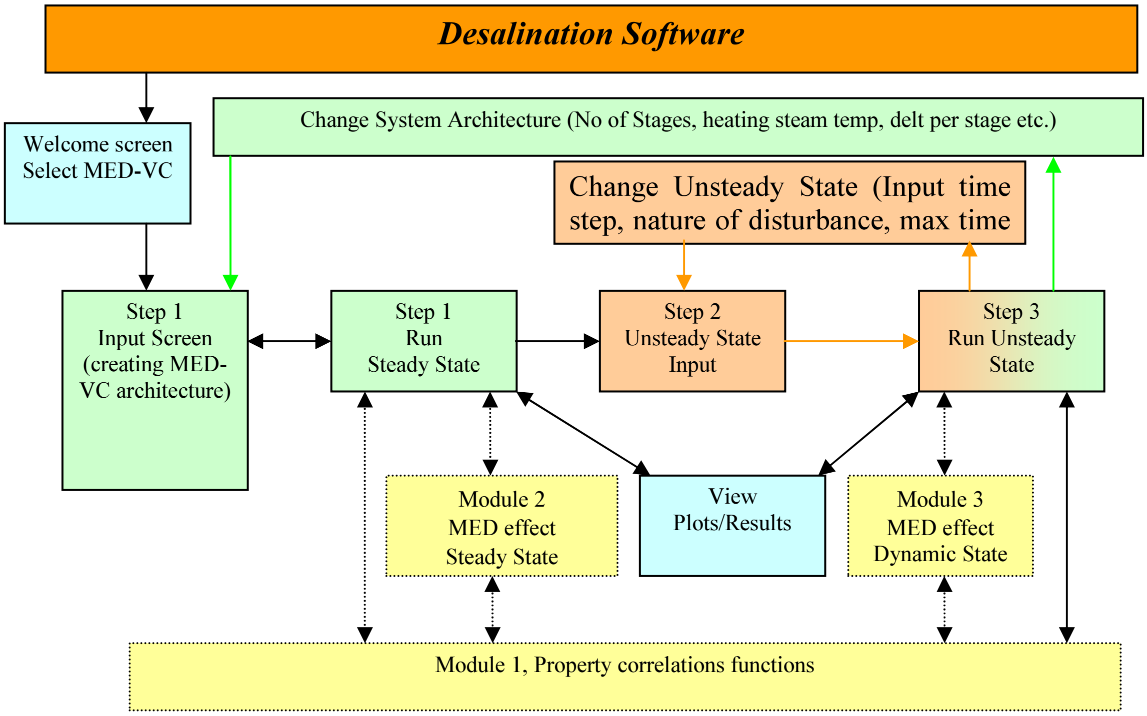

Figure 2. General system architecture

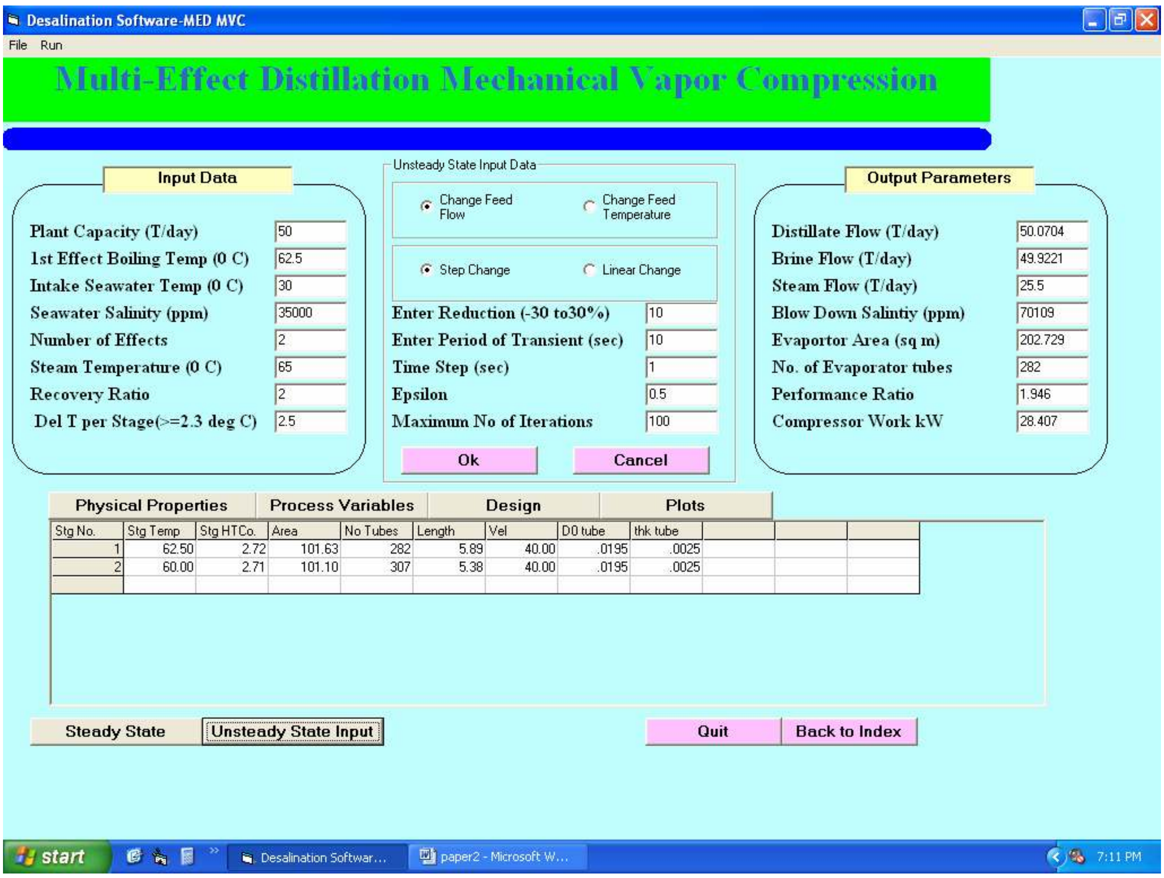

Figure 3: Unsteady state disturbance input

Variation of Temperature, Level and Salinity in each stage for 10% step reduction in feed flow rate of a 50 m^3/day, 2 stage MED-VC plant is shown in the Figure 4. The plots show changes with respect to their steady state values. The reduction of feed flow has caused the temperature in each stage to increase slightly. The level in each stage has fallen owing to reduced blow down brine flow. The salinity has therefore shown an increase. After the disturbance has been withdrawn the level and salinity both return to their new steady state values.

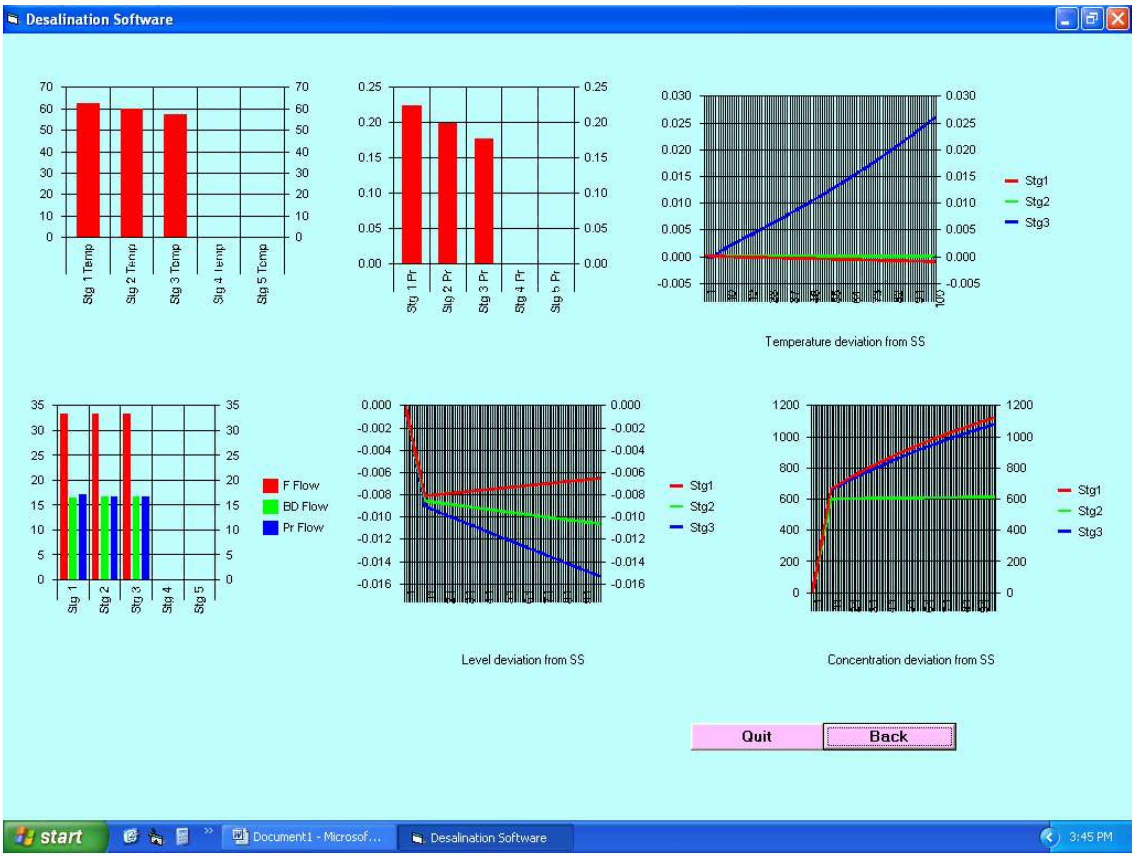

Figure 4:Three stage steady and unsteady state outputs

3. Conclusions

First test indicate that the MED/VC simulator developed conjointly by CEA and BARC indeed shows very good results as the errors on the test case do not exceed 5 to 10% in the transient conditions. It is planned to extend the simulator to include other desalination processes such as the MSF , RO and ROph (RO with preheating of the feed-water).

The simulator is expected to be validated on the Indian MED/VC installation, which has been commissioned recently.

G Kishore[a] S. Nisan[b] S. Dardour[b], A.K. Adak[a], V.K. Srivastava[a], P.K. Tewari[a], A dynamic simulator (INFMED) for the MED/VC plant, **Desalination** (2007).

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DEEP UPDATE
WITH NEW WATER TRANSPORT COST MODEL

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1. Introduction

Following the recommendations made by participants of the recently completed coordinated research project (CRP) on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies, and because water transport cost is an essential part of the overall water production cost, an update of DEEP through a detailed model for water transport cost produced by desalination plants and transported to populated centers is suggested. Technical, economic evaluation and assessment of the water transport are made in the new version of DEEP3.11 using some parameters as input data. The new version calculates the water transport cost per m^3. Three generic comparative case studies were preformed using three different methods of calculation (DEEP3.11, EES and the hand calculations). Results were in excellent agreement.

The DEEP3.11 now includes economic evaluation and hydraulic models of water transport system solved using EXCEL software program. Both models were integrated into the original structure of DEEP program through the water plant capacity, purchased electricity price, discount and interest rates in all 38 different template files. The main DEEP.XLs has been modified to allow the user to edit the input data and show results. Figure 1 illustrates the schematic diagram of the water transport system flow starting from point (1) which represents the water production point and point (2) representing populated center (consumer point). Between the two points, there are pipes, pumping stations, storage tanks …etc.

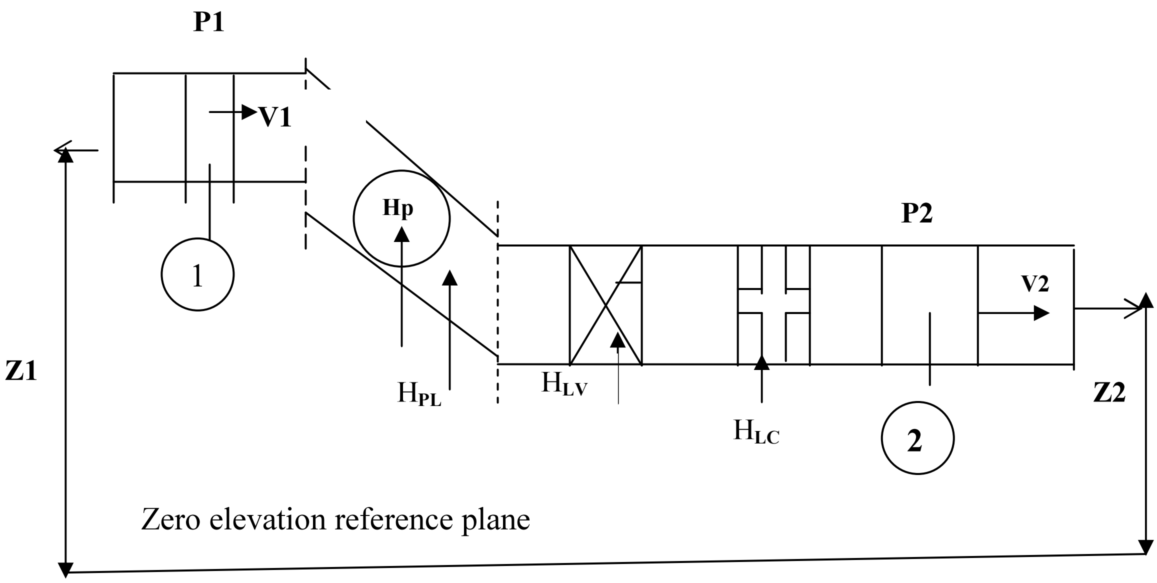

Fig.1 Schematic representation of water transport system

The economic evaluation is determined using two main parameters: capital cost and variable costs. The capital cost is the sum of pipe and pump cost (taxes, interest during construction and installation cost which include the pipe excavation and laying). Such cost could be made either as an input data (if available) or be obtained from curve-fitted formula[1]. The variable costs consist of electricity consumption and O&M for pipes and pumps. Whereas the water transport cost per m3 is determined using the annuity cost (the annuity cost can be defined as the water cost times the charge rate) divided on the annuity water production. Figure 2 shows the flow chart of cost analysis of water transport cost.

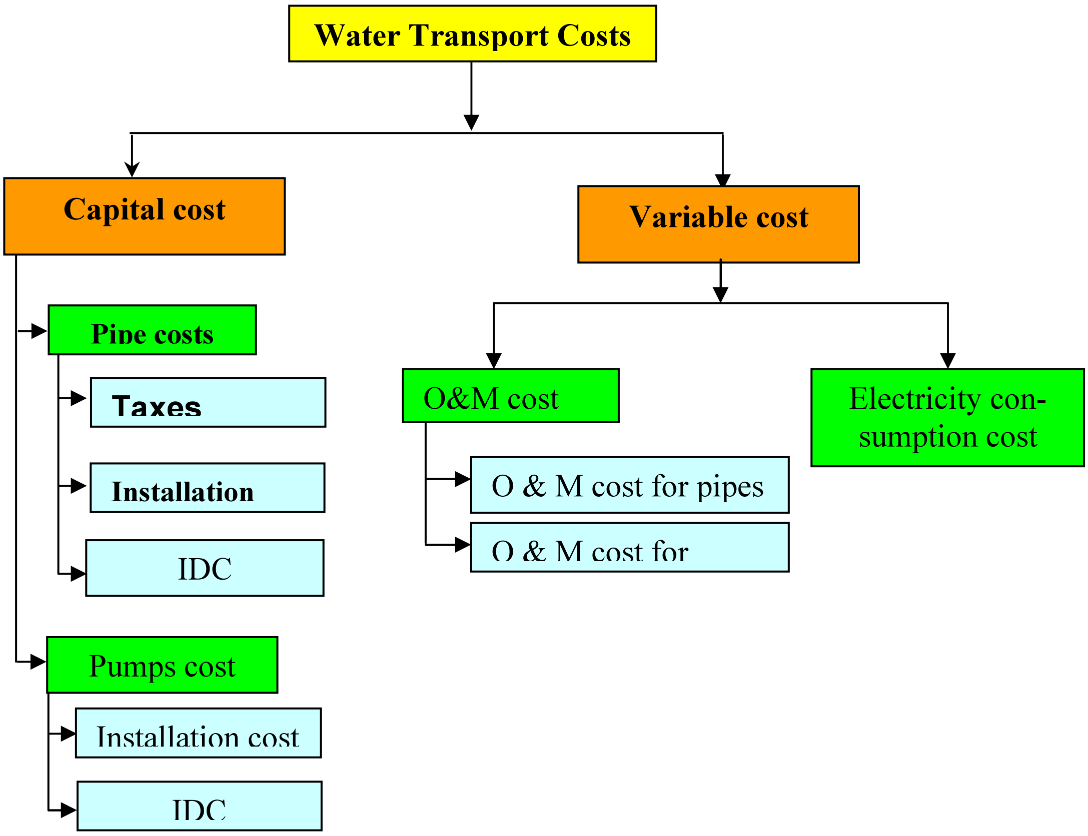

Figure 2. Water transport cost analysis

[1] The construction cost is divided into two main parts: construction cost of the pipes and tanks and the construction cost of the pumping station. The construction cost of pipes is usually calculated according to the diameter of the pipe using the following equation:

$$spcc = 10.82 \cdot (Dn)^4 + 115.34 \cdot (Dn)^3 - 417.07 \cdot (Dn)^2 + 1944.5 \cdot (Dn)$$

Where Dn is the diameter given in mm, and the construction cost of the pumping station is directly related to the power of the pumping station and is given as:

$$pump\,cost = 0.00001 \cdot (N)^3 + 0.0024 \cdot (N)^2 + 0.7459 \cdot (N) + 36.702$$

Table 1 shows the software spreadsheet which includes many parameters was taken as input.

Table 1. Water transport spread sheet

WATER TRANSPORTATION MODULE DEFINITION			
INPUT			
Technical Description	-	-	
Total flow rate	(m^3/day)	Q_d	140000
Actual length of the pipe	(m)	L	30000
Velocity of fluid at inlet	(m/sec)	V_1	1
Velocity of fluid at outlet	(m/sec)	V_2	1
Pipe roughness	m	epsilon	0
Number of pipes line		C_3	2
Number of pumps including basic pumps& aux. pumps		C_4	4
Number of basic pumps		C_5	2
Elevation at inlet from datum	(m)	Z_1	0
Elevation at outlet from datum	(m)	Z_2	0
Pressure at inlet	(Pa)	P_1	1
Pressure at outlet	(Pa)	P_2	1
Number of elbows for pipe line		C_1	6
Loss coefficient for elbow		K_e	0.42
Number of valves for pipes line		C_2	6
Loss coefficient for valve		K_v	1
Number of coupling		n	5000
Loss coefficient for coupling		K_c	0.2
PI (π)		PI	3.14
Gravity acceleration		g	9.814
Dynamic viscosity (μ)	(kg/m.sec)	mu	0.00114
Water density	(kg/m^3)	rho_w	1000
Specific gravity for water		gamma_w	9797
Economic Description			
The interest rate	%	i_r	8
The discount rate	%	d_r	8
Construction lead time	months	Con_p	0
Pipeline operational availability factor	%	F_av	100
Energy price	($/Kw.h)	A_9	0.06
Pipe price per unit length	($/m)	A_1	308
Installation price for basic lines	($/m)	A_2	160
life time for pipes	(Year)	X_1	30
Specific pump price	($/Mwe)	Fp	110000
Pumps installation & building cost	($)	A_12	100000
life time for pumps	(Year)	X_2	15
sales tax factor		Fs	0.15
Annual O&M cost factor for pipes	(%/year)	Fo_1	0.03
Annual O&M cost factor for pumps	(%/year)	Fo_2	0.04
Performance Calculation			
Total flow rate per line	m^3/s	Q	0.810185185
Total flow rate	m^3/s	Qtot_1	1.62037037
Total annual water transported	m^3/year	Qtot_2	51100000
Cross section area of pipe	(m^2)	A_c	0.810185185

Inside Diameter of the pipe	(m)	d	1.015914878
Head losses due to entrance of the pipe	(m)	H_i	0.025473813
Head loss due to elbows	(m)	H_e	0.128388017
Head loss due to couplings	(m)	H_c	50.94762584
Reynolds number		R_e	891153.4014
friction factor get from moody diagram for smooth pipe		F	0.011814781
Head losses due to friction in the pipe	(m)	H_f	17.77516106
Head losses in the valves	(m)	H_v	0.305685755
Total head loss	(m)	H_loss	69.18233448
Required pump head	(m)	H_p	69.18233448
Pump power	W	P	549126.7727
Cost Calculation			
1- capital cost			
Pipe price including sales tax	($/m)	A_s	354.2
Pipe cost per unit length	($/m)	A_3	514.2
Pipe cost for single line	($)	A_4	15426000
Interest during construction for pipe line	($)	IDC_l	0
Total pipe cost	($)	A_5	30852000
Annual total pipe cost	($/year)	A_6	2740503.975
Pumps price	($)	A_11	241615.78
Interest during construction for pumps	($)	IDC_p	0
Total pumps cost	($)	A_13	341615.78
Annual total pumps cost	($/year)	A_14	39910.81612
Annual capital cost	($/year)	A_23	2780414.791
Capital cost	($/$m^3$)	A_24	0.054411248
2- Consumed Energy Cost			
Annual consumed energy	(kwh/year)	A_8	4810350.529
Annual consumed energy cost	($/year)	A_10	577242.0635
Consumed energy cost	($/$m^3$)	A_28	0.011296322
3- O&M Cost			
Annual O & M cost for pipes	($/year)	A_15	925560
Basic operating pumps price	($)	A_16	120807.89
Total basic operating pumps cost	($)	A_17	220807.89
Annual O&M cost for pumps	($/year)	A_18	8832.3156
Annual O&M cost for pipes & pumps	($/year)	A_19	934392.3156
O&M cost	($/$m^3$)	A_26	0.018285564
Annual total cost	($/year)	A_20	4292049.17
Water transport cost per m^3	**($/$m^3$)**	**A_22**	**0.083993134**
Water transport cost per m^3 and km	**($/$m^3$/km)**	**A_29**	**0.002799771**

2. Case studies

For validation purposes, three generic case studies were made. Table 2 shows the input data for all three generic case studies using DEEP3.11. Results obtained are compared against both the Engineering Equation Solver (EES) software and hand calculations. Table 3 illustrates the comparison of the three cases using the three different methods of calculations.

Table 2. Input Data of the Generic Case Studies

Items \ Case	Case 1	Case 2	Case 3
Total flow rate [m3/day]	140000	300000	600000
Actual length of the pipe [m]	30000	320000	2000000
Velocity of fluid at inlet [m/sec]	1	2.3	2.3
Velocity of fluid at outlet [m/sec]	1	2.3	2.3
Pipe roughness [m]	0	0.007	0.007
Number of pipes line	2	1	1
Number of pumps including basic pumps& aux. pumps	4	2	2
Number of basic pumps	2	1	1
Elevation at inlet from datum [m]	0	0	0
Elevation at outlet from datum [m]	0	860	500
Pressure at inlet [pa]	1	1	1
Pressure at outlet [pa]	1	1	1
Number of elbows for pipe line	6	10	10
Loss coefficient for elbow	0.42	0.42	0.42
Number of valves for pipes line	6	100	100
Loss coefficient for valve	0.02	0.02	0.02
Number of coupling	5000	55000	55000
Loss coefficient for coupling	0.02	0.02	0.02
PI (π)	3.14	3.14	3.14
Gravity acceleration [m/sec2]	9.814	9.814	9.814
Dynamic viscosity (μ) [kg/m.sec]	0.00114	0.00114	0.00114
Water density [kg/m3]	1000	1000	1000
Specific gravity for water [m]	9797	9797	9797
The interest rate [%]	8	8	8
The discount rate [%]	8	8	8
Construction lead time [months]	0	25	25
Pipeline operational availability factor [%]	100	90	90
Energy price [$/kw.h]	0.06	0.04	0.04
Pipe price per unit length [$/m]	308	308	308
Installation price for basic lines [$/m]	160	160	160
Life time for pipes [years]	30	30	30
Specific pump price [$/MWe]	110000	130000	130000
Pumps installation & building cost [$]	100000	100000	100000
Life time for pumps [years]	15	15	15
Sales tax factor [%]	0.15	0.15	0.15
Annual O&M cost factor for pipes [%/year]	0.03	0.03	0.03
Annual O&M cost factor for pumps [%/year]	0.04	0.04	0.04

Table 3. Comparison of Generic Case Studies for DEEP3.11

Case \ Items		Water transport cost per m3	Water transport cost per m3/km
Case 1	DEEP	0.0760256	0.002534
	ESS	0.07603	0.002534
	Hand Calc.	0.07603	0.0025337
Case 2	DEEP	0.588239	0.001838
	ESS	0.58819	0.001838
	Hand Calc.	0.5882	0.001840
Case 3	DEEP	1.69389	0.0008469
	ESS	1.6940	0.0008469
	Hand Calc.	1.69388	0.000847

3. Conclusion

DEEP 3.11 is a new version of DEEP which is capable to calculate the water transport cost in any place, with acceptable accuracy. The user needs only to specify water flow or the capacity, pipeline length and elevation of sites against sea level or difference in elevation of the beginning and end of the pipeline routs.

Highlights of ongoing and future activities at the IAEA (2006/2007)

A consultancy to prepare a Status Report on Nuclear Desalination Systems was held in Vienna, 9-10 February 2006.

A new CRP on Advanced Process Heat Applications has been launched in 2007. The CRP will address in part the use of waste heat from HTGR for seawater desalination.

Validation of DEEP as well as update to include water cost transport economics are currently underway and expected to be completed in 2007.

A Technical Meeting/Workshop on Nuclear Desalination: Opportunity for safe and secure water is to be held in one of the Gulf Countries Council in late 2007.

A Training Course on Desalination System Modelling - Technology and Economics, was held at ICTP Trieste, Italy, 24-28 April 2006.

The Technical Meeting to Foster Information Exchange on Socio-economic and Environmental Aspects of Nuclear Desalination, was held in Vienna 12-14 June 2006. Various aspects of thermal, membrane and hybrid desalination technologies were discussed in detail for reducing water costs and improving environmental impacts. Sustainability aspects and the comparative economics of fossil, renewable nuclear energy received particular attention in view of a potentially much larger role of nuclear energy in the future. The meeting concluded that more emphasis should be given to collateral issues such as infrastructure development, socio-economic and environmental aspects and public perception, as these are essential for the implementation of large-scale nuclear desalination projects.

The Technical Meeting on Integrated Nuclear Desalination Systems, was held in Vienna11-14 December 2006. Representatives from participating Member States agreed that nuclear desalination will most likely be accepted in countries where nuclear power production is acceptable, and the existence of a nuclear power program in a country should considerably facilitate the deployment of nuclear desalination where needed. In many Member States there is still a need for more public information and education about nuclear power in general and nuclear desalination in particular. Emphasis was made on the appropriate infrastructures and manpower development as a prerequisite for nuclear energy deployment. Small and medium power reactors are preferred by some Member States for several reasons, especially their better match to smaller grids and relatively lower investment costs. In addition, hybrid nuclear desalination systems may have additional economic advantages due to their considerable flexibility.

In 2006, expert missions under TC Projects were made to Algeria, Egypt, Jordan, the Libyan Arab Jamahiria, and United Arab Emirates. Their objectives of such meetings varied from revisiting original work plans to reviewing progress on feasibility studies and in some cases conducting national training courses on DEEP and APROS software. In addition, two fact-finding-missions consisting of seven IAEA experts were made in 2007.to Jordan and the Gulf Countries Council (GCC) to discuss the feasibility of nuclear power and desalination in such countries. The objective in both cases has been to assess the needs of Member States and advise on the best approach for launching a nuclear power programme. Implementation of TC projects on feasibility of nuclear desalination in Member States such as Algeria, Jordan and United Arab Emirates were continued.

INDAG met in February 2006 and presentations of the status of activities in the Member States were made by the members. INDAG reviewed the IAEA's current and future activities and made several recommendations. The follow-up actions are being taken up.

IAEA presence at International Conferences

1. Hybrid Desalination Systems and Economic Evaluation Using IAEA's DEEP, IDA International Water Forum, Dubai, March 2006
2. Seawater Desalination Using Nuclear Heat/Electricity- Prospects and Challenges, Euromed 2006, Montpellier, May 2006
3. Effects of recent fossil fuel price hikes on seawater desalination costs: A comparision of fossil and nuclear options using DEEP-3, Euromed 2006, Montpellier, May 2006.
4. Towards Innovative Desalination and Energy Production in Kuwait, Dec. 9-11, 2007

Recent IAEA publications relevant to nuclear desalination[1]

- Optimization of the Coupling of Nuclear Reactors and Desalination Systems, IAEA-TECDOC-1444, Vienna (2005)
- The Power Reactor Information System- PRIS and its Extension to Non-electrical Application, Decommissioning and Delayed Projects Information, Technical Reports Series No. 428, Vienna (2005)
- Innovative Small and Medium Sized Reactors: Design Features, Safety Approaches and R&D Trends, IAEA-TECDOC-1451, Vienna (2005)
- Desalination Economic Evaluation Program (DEEP 3.0), Computer Manual Series No. 19 (2005)
- The results of the CRP on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies were published as IAEA-TECDOC-1561 (2007)
- A Status Report on Nuclear Desalination Activities in the Member States was published as IAEA-TECDOC-1524 (2007)
- The IAEA organized an International Conference on Non-Electric Applications of Nuclear Power: Seawater Desalination, Hydrogen Production and other Industrial Applications, 16-19 April 2007, held in Oarai, Japan
- The new version DEEP 3.1 was released in September 2006. It is now available on download under a licence agreement
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[1] **How to get IAEA publications**: Orders and requests for information may be addressed directly to:
Sales and Promotion Unit, International Atomic Energy Agency, Wagramerstrasse 5, P.O. Box 100, A-1400, Vienna/Austria
E-mail: sales.publications@iaea.org, Web site: http://www.iaea.org.wordatom/Books

Printed by the IAEA in Austria, September 2007

IAEA
International Atomic Energy Agency

INDAG Newsletter
No. 7, September 2007

07-29711

Wagramer Strasse 5, P.O. Box 100,
A-1400 Vienna, Austria

The INDAG Newsletter is prepared yearly by the Division of Nuclear Power, Department of Nuclear Energy.
Printed by the IAEA in Austria, September 2007