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A Word from the Deputy Director General

Having more than 200 reactor-years of operating experience worldwide, nuclear desalination is posed to play a major role in near future where as many as 50 Member States are considering nuclear power not only for electricity generation but also for cogeneration for seawater desalination in many cases. Nuclear desalination could provide a sustainable water resource at a reasonable cost and help overcome water shortages as climate change and oil price continue to be of major concern. Further merits of nuclear desalination could well be established if small and medium size nuclear reactors are made available soon, and different approaches utilizing waste heat from nuclear reactors succeed to further reduce cost of nuclear desalination. Nuclear desalination will thus be an important option for safe, economic and sustainable supply of large amounts of fresh water.

Several nuclear desalination projects are ongoing around the world, mostly in developing countries as end-users. Indeed, expanded nuclear desalination operations will soon be a reality in India and Pakistan. Other countries like Algeria, China, Egypt, Jordan, Indonesia, Libyan Arab Jamahiriya, the Gulf Cooperation Council, and the United Arab Emirates are following suit. The support of the IAEA to Member

States on nuclear desalination continues through facilitating research into demonstration projects, providing experts, technical assistance and publications, providing software, as well as facilitating technology transfer and information exchange.
The IAEA has also launched several Coordinated Research Projects (CRP). One CRP was on Optimization of the Coupling of Nuclear Reactors and Desalination Systems and completed in 2004. Another CRP on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies was completed in 2006. Yet another CRP on Advances in Nuclear Power for Process Heat Applications has been launched in 2007. This CRP focuses mainly on the use of waste heat produced in high temperature reactors for seawater desalination.

During the last meeting of INDAG (will soon be replaced by the Technical Working Group on Nuclear Desalination TWG-ND) held in January 2008, information was exchanged on the progress of national and interregional activities on nuclear desalination. The meeting discussed also the need to establish an IAEA roadmap to promote the implementation of integrated nuclear desalination systems in Member States.

I am pleased with the release of the eighth issue of the TWG-ND Newsletter highlighting the current activities of the Agency and from the Member States.

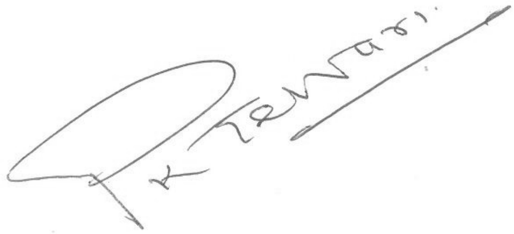
Y.A. Sokolov
Deputy Director General
Department of Nuclear Energy, IAEA

A Word from the Chairman

Water scarcity is one of the most pressing crises affecting our planet. It is a global issue. Nuclear desalination is an inevitable option as the increase in water shortage, climate change and oil prices would have a greater impact. There would be need for small, medium and large size nuclear desalination plants in the coastal areas which would be governed by the demand with respect to quantity and quality of the desalinated water.
The International Nuclear Desalination Advisory Group (INDAG) continues to provide guidance on the Agency's activities in nuclear desalination. During the year, it has successfully demonstrated its role in technical meetings, coordinated research projects (CRPs) and conferences including the International Conference on 'Non-Electric Applications of Nuclear Energy: Nuclear Desalination, Hydrogen Production and Other Industrial Applications' held in Oarai, Japan (16-19 April 2007); the initiation of a CRP on Advanced Heat Process Applications and the update & release of DEEP with new water transport cost model. Technical meeting on Advances in Integrated Nuclear Desalination Systems was held during 3-5 Dec. 2007 at Cadarache, France. The results of the CRP on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies were published as IAEA-TECDOCs. The IAEA website for nuclear desalination was updated. It is planned to launch a new CRP on specific advances in nuclear desalination technologies.
Seawater desalination has been classified as one of the priority developing technology in the Chinese National Marine Economic Development Planning Outline and National Sub-Plan for Seawater Utilization. Activities in Egypt related to use of nuclear energy for seawater desalination involve experimental investigation of feed water preheating on the performance of RO membranes. CEA (France) focused on the economic evaluation and development of MED/VC simulator (in collaboration with BARC, India). CEA is also engaged in theoretical and experimental studies aiming to use the Tajoura experimental reactor in Libyan Arab Jamahiriya as nuclear desalination demonstration program (in collaboration with REWDRC, Libyan Arab Jamahiriya). BARC (India) has been engaged in development and deployment of desalination technologies for a wide range of water related applications. The 30,000 litres/day (LPD) desalination plant based on Low Temperature Evaporation (LTE) integrated with nuclear research reactor for the utilization of waste heat (first-of its-kind) has been operating successfully since last four years. RO section (1.8 million litres/day (MLD) capacity) of Nuclear Desalination Demonstration Project (NDDP) Kalpakkam has completed five years of operation. In Japan, ten nuclear reactors are integrated with desalination facilities (1.0–2.6 MLD capacity) for producing desalinated water from seawater. The Korean nuclear desalination program includes development of an integrated desalination plant with SMART for electricity generation and sea water desalination. Morocco has constantly shown its interest in nuclear

desalination. PAEC, Pakistan is establishing a MED (1.6 MLD capacity) type nuclear desalination demonstration plant at Karachi nuclear power plant (KANUPP). The Russian Federal Agency for Atomic Energy (ROSATOM) is constructing a floating barge mounted heat and power cogeneration nuclear plant based on state-of-the-art ship propulsion reactor KLT-40s of PWR type. The rising demand for energy and water has prompted the GCC countries to consider exploring the nuclear option for power generation and seawater desalination. The production of water using nuclear power is one of the proposed missions of US DOE's newly launched Global Nuclear Energy Partnership (GNEP)'s Grid Appropriate Reactor (GAR) campaign. The need still exists for assessment of immediate and near-term country specific requirements for water and power co-generation. The IAEA may adopt a road map on its nuclear desalination activities and create a 'nuclear desalination tool kit' containing DEEP and a set of documents providing guidelines for launching a nuclear desalination program.

Excellent prospects are foreseen as in next 10-20 years as long as the interested Member States will be able to safely and economically generate nuclear power. The IAEA and INDAG will continue to play an important role in facilitating and providing advice on nuclear desalination activities in Member States.



P. K. Tewari
Chairman, INDIA

Recent Activities in Nuclear Desalination in Member States

China	With four nuclear desalination projects, China is expected to become one of the leading countries on desalination industry. The Liaoning Hongyanhe NPP project will have a total of six PWR units of 1000 MW(e) class are planned for the site. Nuclear desalination will be adopted in this project to provide water for the requirement of NPP operation in phase I. The other four nuclear units in phase I will share one desalination plant type-SWRO having a capacity of 15,000m3/d in phase I and 100,000m3/d will be reached in phase II, supplying water to the Dalian city. The second project is the Sandong Nuclear Desalination Plant (SNDP) in Yatai city, Shandong Province. The feasibility study of SNDP project has be finished in 2005. Further study is being carried out for the selection of the design characteristics of the selected reactor: NHR-II, the coupling scheme with hybrid RO/MED and optimum capacity. Another project focuses on nuclear desalination complex consisting of NHR-II as a new pool-vessel type reactor coupled with a LT-MED facility. The pre-feasibility study has already been completed which includes several options of capacities: 80,000 m^3/day, 100,000m^3/day to 120,000 m^3/day. The fourth project will be constructed near by Daya Bay NPP. The aim of project is to act as an emergency water source of Shenzhen city and be the secondary water source of Shenzhen city. The suggested capacity is 330,000 m^3/day.

Egypt

Egypt has been considering for sometime the various options for satisfying the increasing demand for electricity, including nuclear energy. Motives for nuclear desalination include the increase of population and the constant depletion of fresh water resources. Therefore, seawater desalination is expected to play an increasing role in mitigating fresh water deficit. In this regard, a nuclear reactor providing electricity to the grid can in principle provide also electricity and/or heat to a desalination plant. Egypt continued to operate the RO-pilot plant (see fig. 1)

Fig. 1. RO testing Desalination Demonstartion Plant in Egypt

France

Over the last years, CEA has concentrated on activities as: feasibility studies in collaborations with other countries, specific studies on the environmental impact of desalination, analysis of economic of desalination including environmental costs, scoping the recovery of waste hear from HTR, development of an MED/VC simulator in collaboration with India, development of models for Reverse Osmosis, research on zero brine discharge strategy for nuclear desalination systems and extraction of valuable materials from the rejected brine, elaboration of specific chemical protocols for the extraction of Rubidium and uranium in collaboration with India, and engaging in studies for the Libyan demonstration project in collaboration with the Libyan Arab Jamahiriya.

India

India has been engaged in the development and deployment of desalination and water purification technologies for a wide range of water related applications. It includes sea water reverse osmosis (RO) plant for coastal areas, brackish water RO plant in villages for producing safe drinking water, multistage flash (MSF) plant for seawater desalination using low grade steam, low temperature evaporation (LTE) plant using waste heat for seawater desalination, membrane (ultra-filtration) based water purification technologies for domestic and community use, waste water recycle and reuse using membrane processes. RO technology and domestic water purifier have been transferred to various parties. India has successfully developed and commissioned next generation seawater desalination technologies for producing ultra-pure water (> 10 mega-ohm-cm) based on multi effect distillation-vapour compression (MED-VC) and low temperature evaporation with cooling tower (LTE-CT).

Among the salient projects on nuclear desalination in India are: the 30,000 Litres/Day (LPD) nuclear desalination plant based on low temperature evaporation (LTE) integrated with CIRUS and utilizating nuclear waste heat (first-of-its-kind) which has been operating well as per design intent since last four years. Preliminary studies have been taken up. RO section (1.8 Million Litres/ Day (MLD) capacity) of Nuclear Desalination Demonstration Project (NDDP) of 6.3 MLD capacity has been operating on regular basis since last five years. MSF section (4.5 MLD capacity) of NDDP is nearing completion.

Fig. 2 Nuclear Desalination Demonstartion Plant in India

Japan	Despite that Japan has currently no new national projects, international projects and inter-regional projects on nuclear desalination, its 10 nuclear reactors have been continuously operating the desalination facilities with capacity of 1000 to 2600 m3/d to use the water inside the plants without any serious troubles since 1973 (Ohi-1, the oldest one). However, the potential needs for supplying potable water to residents exist especially in the west parts of Japan where non-nuclear seawater desalination systems are operating: The potable water of 50,000m^3/day is supplied in Fukuoka district and 40,000m^3/day in Okinawa City. The new RO system developed by Toyobo and Toray is adopted in the plant of Fukuoka, in which the recovery ratio is improved to 60 %.
Korea, Rep. of	The objectives of the Korean nuclear desalination program is mainly intended to the development of an integrated desalination plant with SMART (System-integrated Modular Advanced Reactor; thermal power of 330MWt) both for electricity generation and for seawater desalination. The SMART reactor, an integral type pressurized water cooled reactor, is coupled with the Multi-Effect Distillation Thermal Vapour Compression (MED-TVC) process. In 2006, one year SMART design optimization study has been carried out to expedite realization of SMART and to improve the economical efficiency, licensability, manufacturability and maintainability. Power up-rating was considered to raise the economical efficiency. Steam generator cassette design was modified to accommodate the in-service inspection of tube elements. Passive/active hybrid safety system was adopted instead of full passive safety system symbolized by the safeguard vessel.
Libyan Arab Jamahiriya	In view of sever water shortage problem the Libyan Arab Jamahiriya has retained the desalination of seawater to be one of the major option to augment national efforts for the supply of potable water and decided to conduct certain activities toward capacity building and cost optimization in this field. In the frame of national strategy for energy mix to sustain socio-economic development and recognizing the possible role of nuclear energy in seawater desalination the Libyan Arab Jamahiriya decided to pursue nuclear desalination.
Morocco	As part of its infrastructure continuous improvement, Morocco adopted specific law covering all water management aspects. Nuclear desalinisation is considered an important option among other options. Morocco has demonstrated its commitments to further promote the introduction of nuclear power for electricity production and desalination.

Pakistan

Pakistan has primarily focused on installation of a 1600 cu-m/day capacity MED type nuclear desalination demonstration plant (NDDP), as shown, at Karachi nuclear power plant (KANUPP). The commissioning of the NDDP project is now scheduled by mid of year 2008. The demonstration plant at KANUPP will help PAEC to evaluate the most feasible options for developing future nuclear desalination facilities along the coastal areas of Pakistan thus contributing to the socio-economic development of these areas.

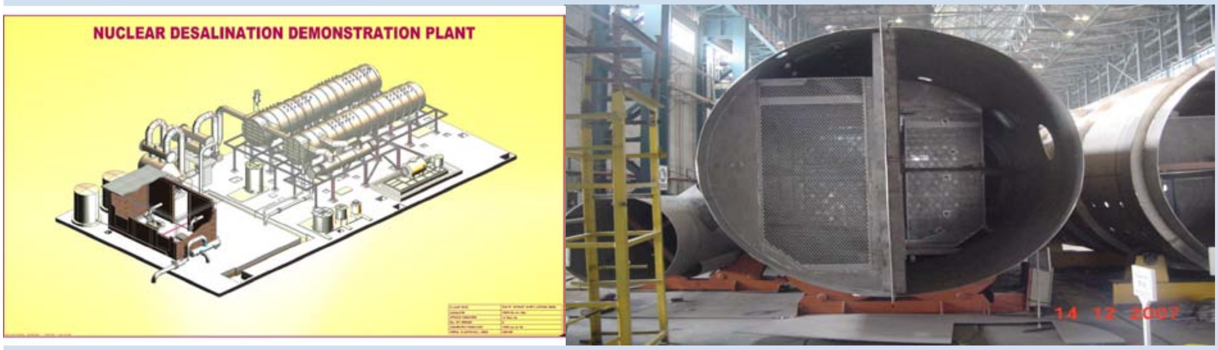


Fig. 3 Nuclear Desalination Demonstartion Plant in Pakistan

Russian Federation

Small reactors development and implementation programme is in progress in the Russian Federation. Motivation for the programme is very high electricity and heat cost produced by of conventional power stations in decentralised power supply areas of the country. Prospects for non-electric application of nuclear energy, including nuclear desalination, broaden the area for small reactor at the future internal and international market.

The Russian Federation continues the construction of a floating barge-mounted heat and power co-generation nuclear plant based on state-of-the-art ship propulsion reactor KLT-40S of PWR-type. The basic construction contract was signed on June 14, 2006 and the announced construction cost amounts to 9.1 billion Russian Rub. It is planned to put the plant into operation in 2010. The floating NPP can produce up to 70 MWt of electric power and about 150Gkal/h of heat for district heating. Life time of the plant is 40 years, continuous operation period before dockyard repair is 12 years. Total operating staff numbers 69 persons

Saudi Arabia

The rising demand for energy and water has prompted the GCC countries to consider exploring the nuclear option for power generation. Saudi Arabia and other GCC Countries namely: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates, have decided to carry out a joint study by the GCC members with the help of IAEA to forge a joint programme in the field of nuclear technology for peaceful purposes according to international criteria and systems.

United States of America

The USA has engaged the IAEA on nuclear desalination issues through INDAG and other IAEA related activities for several years now. Production of water using nuclear power is one of the proposed missions of US DOE's newly launched Global Nuclear Energy Partnership (GNEP)'s Grid Appropriate Reactor (GAR) campaign.

The overall view is that the IAEA can and should play a leading role in any future possible plans for large scale deployment of nuclear-based power and water cogeneration systems around the world. Argonne National Laboratory as the official US representative to the INDAG will do its best to assist in these activities as necessary and within the available resources to do so.

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Benchmarking and validation of the Desalination Economic Evaluation Code DEEP/V3.1

S. Nisan, I. Khamis, S. Suleiman

1. Introduction

The IAEA Desalination Economic Evaluation Programme (DEEP) was issued as a user-friendly version towards the end of 1998. DEEP is the modified version of the desalination cost evaluation package developed in the eighties by General Atomics and named Co-generation and Desalination Economic Evaluation Spreadsheet, CDEE. Although, initially developed for a quick, order of magnitude, assessment of a nuclear or fossil energy based desalination system, over the years DEEP has truly become an international reference code for the techno-economic evaluation of integrated desalination systems.

DEEP software has been under continuous evolution. and consistent development for the last ten years. The earlier concepts of nuclear energy systems have been modified considerably. New concepts have been proposed and analyzed. Similarly, fossil fuelled systems have also undergone important changes due to the integration of various innovations made. Desalination systems have also undergone an asymptotic development in their design.

During the initial development of DEEP, the input data on power costs of electricity producing systems was hastily collected from the analysis of a series of questionnaires sent from the IAEA to Member States which were involved at that time in the feasibility studies of nuclear and fossil energy based power production systems. This input cost data has remained more or less unchanged in the subsequent versions of DEEP. Therefore, modifications and updates have been recognized by DEEP users and were the subject of various IAEA activities. Indeed, such modifications inspired consecutive updates of DEEP itself.

Through the previous years, DEEP was updated constantly within DEEP-1 family (versions 1.0, 1.1, 1.2 and working version 1.7). Both the user interface and model structure were further developed and in 2000 a new upgrade – first version from the DEEP-2 family was released. Its salient feature was the complete modularization of various cases. As the user group enlarged, new ideas as well as criticisms of the DEEP models appeared. Some of them were implemented gradually in different working versions (versions 2.0, 2.1, 2.2, 2.3, 2.4, 2.6). The four year period of continuous development culminated in the development of DEEP 3.0, released in August 2005. Following further development, the latest version of DEEP 3.11 was released in 2007. In fact, most of the of the suggested modifications focused on DEEP models and not much on input data.

It is for such reasons that the IAEA continues to take steps to improve DEEP performance. In its last meeting, the IAEA International Nuclear Desalination Advisory Group (INDAG) strongly recommended that a new activity on DEEP benchmarking and validation be undertaken. The basic motivations for this activity were:

- To harmonize DEEP utilisation, through the exchange of information on DEEP results by as large a group of DEEP users as possible.
- To define, calculate, and analyse few reference DEEP cases by selected experts and compare with results of other benchmark participants.
- To suggest correction or modifications to models in DEEP based on the above analyses.
- Finally, to validate DEEP with known and reliable results or measurements in operating desalination systems.

During the first consultancy meeting held in 2007, a reference benchmark problem was elaborated by experts from Egypt, France, India, Syrian Arab Republic and the USA. A road map was subsequently discussed. This road map is shown in figure 1. A second consultancy meeting was held in 2008. The DEEP benchmarking is now proposed to all interested Member States.

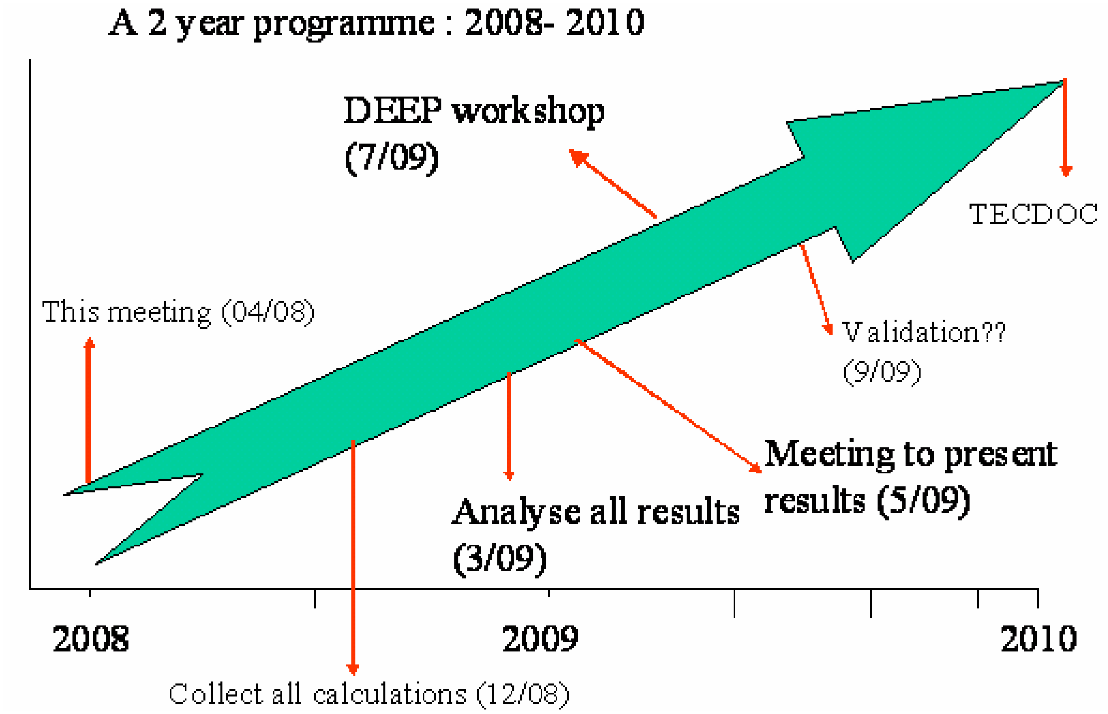

Figure 1: Road map for DEEP benchmarking and validation

2 Corrections to some DEEP models

It was felt that before opening DEEP to a large number of users for Benchmarking, some of the observed errors should first be corrected so as not to mask the effect of other options. The experts made a list of corrections for the immediate, medium term and long term actions. The first correction proposed and implemented in DEEP is the calculation of the net thermal power transferred to the distillation plant (Qcrm).

DEEP first calculates the parameter Qcr (the heat rejected via the condenser) as

While at first sight it may seem that in the expression of Qcr, one is substracting quantities in two different

$$Q_{cr} = Q_{tp} - Peg$$

$$Q_{tp} = Total\ base\ plant\ \ thermal\ \ power,\ (MWt)$$

$$Peg = Pen + Pal$$

$$Pen = total\ plant\ net\ elctrical\ power\ (MWe)$$

$$Pal = \ plant\ auxiliary\ load\ (MWe)$$

units (MW(e) and MW(th),) in fact the reject heat to the condenser is the difference of the powers produced in the reactor and the electrical power. In both cases, the units are MW and thus, contrary to what was anounced in the Consultancy, the expression for Qcr is correct. Qcr is then used to calculate Qcrm in the following way in DEEP3.1:

PWRs and PHWRs :

*Qcrm=IF(OR(EnPlt="NH";EnPlt="FH";EnPlt="RH"); Qtp*Ebl;*
SI(TurType="BackPr";Qcr;MIN(Wdrc/Gor/24/3600(598-0,6*Tcm)*4,1868;(Qtp-Pen)/(1-h))))*

Coal fired plants :

=SI(OU(EnPlt="NH";EnPlt="FH";EnPlt="RH"); Qtp*Ebl;
SI(TurType="BackPr";Qcr;MIN(Wdrc/Gor/24/3600*(598-0,6*Tcm)*4,1868;(Qtp-Pen)/(1-h))))

Gas turbine, combined cycle plants CC :

=SI(OU(EnPlt="NH";EnPlt="FH";EnPlt="RH"); Qtp*Ebl;
SI(TurType="BackPr";Qcr;MIN(Wdrc/Gor/24/3600*(598-0,6*Tcm)*4,1868;(Qtp-Pen)/(1-h))))

If the option is the "extraction turbine" then in DEEP3.1, one verifies the test and selects the minimum between two expressions

(Wdrc/Gor/24/3600(598-0,6*Tcm)*4,1868), or, (Qtp-Pen)/(1-h))))*

We have verified that the second expression is dimensionally correct but comes into play only when the required desalting capacity Wdrc is >280 000 m^3/day. If the user inputs a capacity greater than this value he gets a warning that the production required is higher than what is achievable! It is not yet clear what is the basis for this. Neither do we know from where the empirical formula for the first term was derived. In the interest of its simplicity, and its more physical nature, we would recommend that only the first expression be used in future calculations. The expression for Qcrm would thus read

Qcrm = (Wdrc/Gor/24/3600*(598-0,6*Tcm)*4,1868),

where

Tcm = Maximum brine temperature + temperature drop in the first effect.

It has been tested that using this formula, the required capacity is equal to the theoretical production. These include the correction for GOR (Gain Output Ratio), which at the moment is calculated by an empirical relation. The proposed correction aims to calculate physically the value of this very important parameter. DEEP calculate the GOR for MED using an experimental equation:

$$\text{GOR}=0.8*\text{Nemed} \qquad (1)$$

This very simple equation might not really be a sufficient expression for GOR, which should be thermodynamically calculated as

$$\text{GOR}=\frac{\sum_{j=1}^{n}D_j+\sum_{j=2}^{n}d_j}{M_S}=\frac{M_D}{(M_f\times C_{Pf}(T_1-t_2)+D_1\times\lambda_1)/\lambda_s} \qquad (2)$$

Where λ is the latent heat of vapour, determined by the following experimental equation [1][1]:

$$\lambda=2589.583+0.9156\times T-4.8343\times10^{-2}\times T^2 \qquad (3)$$

And C_{Pf} is the specific heat of the feed water, also determined using following experimental equation[1]:

$$C_{Pf}=\left(A+BT+CT^2+DT^3\right)\times10^{-3} \qquad (4)$$

Where the parameters A,B,C and D are defined according to the S=TDS of the feed water by the following experimental equation:

$$\begin{aligned} A&=4206.8-6.6197\times S+1.2288\times10^{-8}\times S^2\\ B&=-1.1262+5.4178\times10^{-2}\times S-2.2719\times10^{-6}\times S^2\\ C&=1.12026\times10^{-2}-5.3566\times10^{-4}\times S=1.8906\times10^{-6}\times S^2\\ D&=6.877\times10^{-7}+1.517\times10^{-6}\times S-4.4628\times10^{-9}\times S^2 \end{aligned} \qquad (5)$$

As is well known, the GOR is mainly related to both heating steam temperature and number of effects Thus a range of heating steam temperature were chosen from 45 up to 125 Co .
Table 1 show the difference of GOR calculated by the two methods:

Table 1. Comparison of GOR values

Heating steam Temperature (C^o)	Number of effect	GOR (DEEP)	GOR (calculated)
125	34	27.2	22.24

[1] [1] Ed. Frank Kreith, Mechanical Engineering Handbook, Boca Raton: CRC Press LLC, 1999

115	30	24	20.52
105	26	20.8	18.61
95	22	17.6	16.5
85	18	14.4	14.13
75	14	11.2	11.54
65	10	8	8.67
55	6	4.8	5.49
45	2	1.6	1.9

Yet another proposal to be implemented in the near future is that so far DEEP calculates the thermodynamic parameters using the Carnot cycle, where as in practice it is the Rankine cycle that is used.

3 First Results of the benchmark reference calculations

Using the standard benchmark problem, the experts proceeded to calculate the reference cases for two PWRs (the 900 MW(e) French PWR and the AP-600 proposed by Westinghouse) and a 900 MW(e) gas turbine combined cycle plant. All these power plants were coupled to MED, MSF and RO systems. Hybrid MSF/RO and MED/RO have also been calculated.

Some of the main results are summarised in Figures 2 to 4.

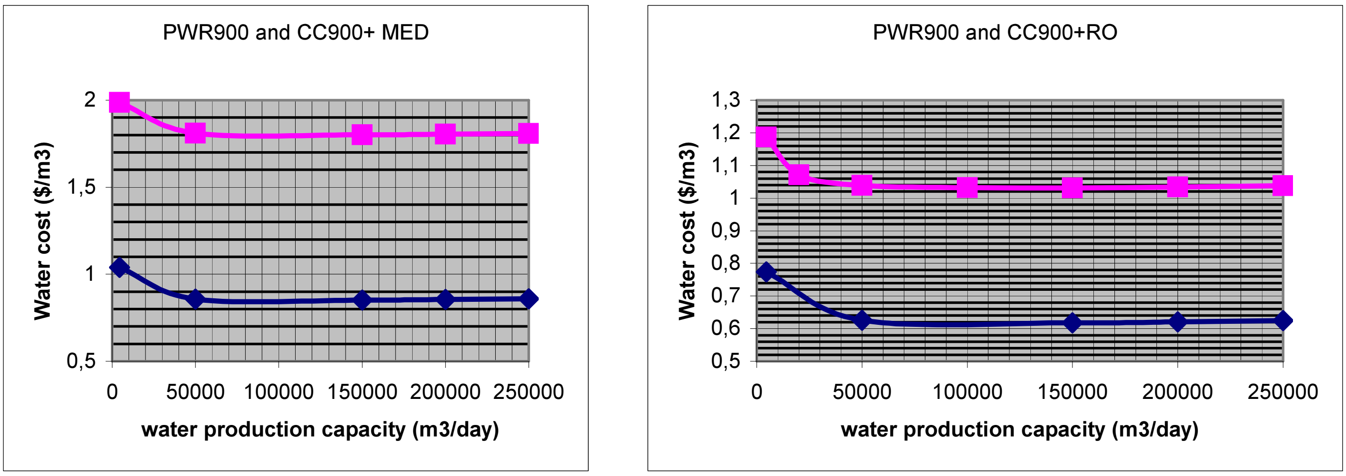

Figure 2: PWR900 (blue curve) and CC-900 water costs when coupled to MED and RO systems

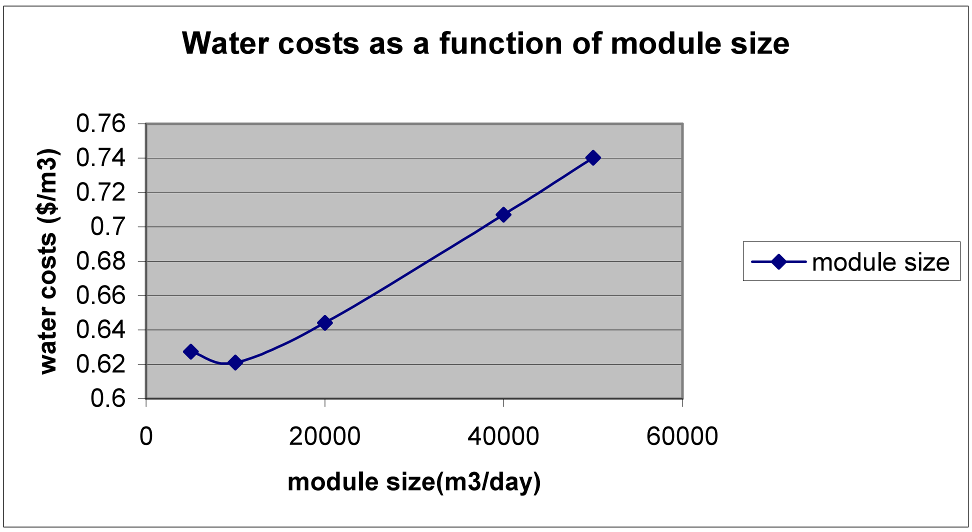

Figure 3: Influence of module size (RO plant) on the water cost

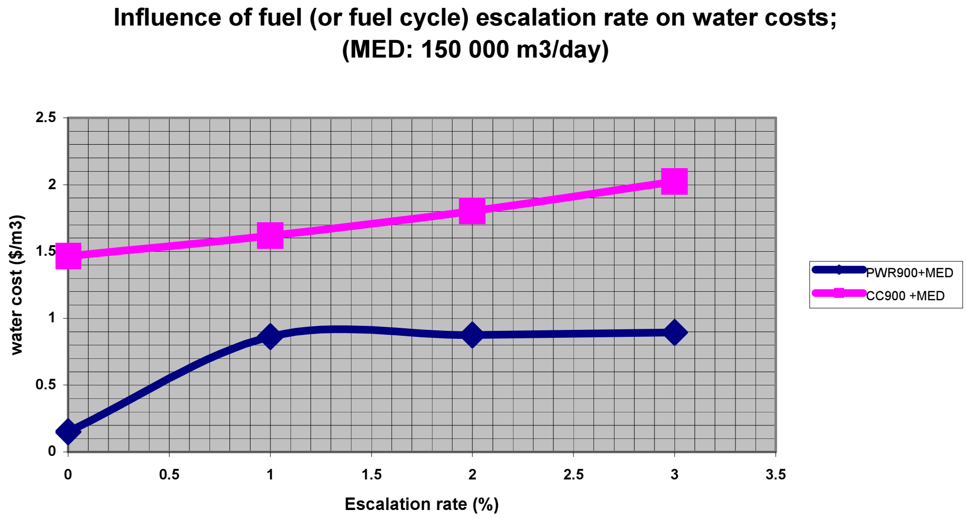

Figure 4: Influence of fuel (or fuel cycle) cost escalation on water costs

4 IMPROVING UTILIZATION OF DEEP

Yet another aspect of this rather intensive utilisation of DEEP is the fact that there are always new users of DEEP. Such newcomers either do not spend enough time to review the background behind the DEEP models or in some cases pay no attention to some of the important parameters whose values are site and case dependent or can not be taken as default values. For example, changing the value of the maximum brine temperature from 65°C (default value for nuclear reactors) to 120°C (default value for a gas turbine, combined cycle plant) may result in a 30% error on the water costs! Similarly, choosing a very low or very high module size can affect the water costs in a substantial manner.

5 Conclusions

The DEEP benchmark is now well on the way. It is to be shortly proposed to a large number of interested Member States. First results from reference calculations have confirmed the following observations:

- Nuclear systems have much lower water and electricity costs as compared to fossil fuelled systems.
- Escalation in fuel cycle costs do not significantly affect the water costs for nuclear systems. On the contrary fuel cost escalation very significantly increase the water costs for fossil energy based systems.

Although not shown here, results from hybrid system calculations also show the same tendencies. A more detailed analysis, based on all the results, will be made in the near future.

Highlights of ongoing and future activities at the IAEA (2007/2008)

The IAEA activities on nuclear desalination include: coordination of research projects between interested research institutes; development and application of a nuclear desalination economic evaluation software (DEEP); coordination of joint development of integrated nuclear desalination plants by technology holders and potential end-users; and providing a platform for information exchange through international meetings and publications.

Several nuclear desalination projects are ongoing around the world, mostly in developing countries as end-users. Indeed, expanded nuclear desalination operations will soon be a reality in India and its neighbour Pakistan. Other countries are following suit. The IAEA facilitates research into such projects and, through expert missions and technical cooperation agreements between Member States, new and promising design concepts for future nuclear desalination options have in fact materialized over recent years and their technical and economic feasibility demonstrated.

The IAEA has established in 1997, the International Nuclear Desalination Advisory Group (INDAG) which provided a comprehensive and regular forum for the exchange of information on nuclear desalination technologies and programs. INDAG also provided technical guidance for facilitating development of viable coupling configurations of nuclear and desalination systems. Recently, the IAEA is about to re-establish a technical working group instead of INDAG in order to expand the mandate of this group onto technical issues related to nuclear desalination.

The IAEA has also launched several Coordinated Research Projects (CRP). One CRP was on Optimization of the Coupling of Nuclear Reactors and Desalination Systems and completed in 2004. This CRP covered a review of reactor designs suitable for coupling with desalination systems, the optimization of this coupling, possible performance improvements and advanced desalination technologies for nuclear desalination. The main goal of this CRP was to identify optimum coupling conditions (configuration, process parameters, etc.) for nuclear and desalination systems. Reactor types evaluated in the optimization include a PHWR, PWRs and dedicated heat reactors. The CRP also evaluated safety aspects and some economic considerations. Another CRP on Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies was completed in 2006. This CRP deepened the understanding of various economic aspects of nuclear desalination plants, yielded an upgraded version of the Agency's software DEEP, and provided a uniform approach to the economic assessment of future possible nuclear desalination projects. The final Technical Document from this CRP was published sometime in 2007. Yet another CRP on Advances in Nuclear Power for Process Heat Applications has been launched in 2007. This CRP focuses mainly on the use of waste heat produced in high temperature reactors for seawater desalination.

A number of technical cooperation projects have assessed the feasibility of specific nuclear desalination options. In 1999, the IAEA launched an interregional technical co-operation project known as Integrated Nuclear Power and Desalination System Design. The project is designed to facilitate international collaboration between technology holders and potential end-users for the joint development of integrated nuclear desalination concepts, aiming at the demonstration of the viability of nuclear desalination for a specific site or sites. Several bilateral or multilateral collaboration programs are currently being facilitated through this framework.

The Technical Meeting of the **DEEP Users Group** was held in VIC, Vienna, 8-9 April 2008. The technical meeting was aimed at: re-examining all thermal and RO plant models in DEEP, correcting any necessary formula or panel related to DEEP code, and discussing preliminary draft of quality assurance document for DEEP development. Seven experts from seven Member States attended the meeting and at the closing of the meeting recommended to distribute benchmark problem and data to as many DEEP users as possible (including Industrial companies and other R&D research Institutes), once received, analyse results of benchmarking calculations with respect to the references cases prepared. (To be done by a designated expert), and discuss results of analysis in one or more consultancies. It was also recommended that three immediate corrections are made before starting DEEP validation. They include correction of the formula for the calculation of IDC in fossil fuelled systems with fossil fuel price escalation, revision of the basic data for the power plants and the desalination plants, and performing calculations using DEEP with Rankine and other cycles. The complete roadmap for the validation and benchmarking could be as follows:

INDAG as a Technical Working Group

In line with the efforts to unify and update the Terms of Reference for the Technical Working Groups in the Department of Nuclear Energy, it is suggested to rename INDAG to the Technical Working Group on Nuclear Desalination (TWG-ND). The new name is also reflected in the following Terms of Reference. The TWG-ND, is currently being established.
The functions of the TWG -ND are:

a) To provide advice and guidance, and to marshal support in their countries for implementation of the IAEA's programmatic activities in the area of nuclear seawater desalination;

b) To provide a forum for information and knowledge sharing on national and international programmes development in the area of nuclear desalination;

c) To act as a link between the IAEA's activities in specific areas and national scientific communities, delivering information from and to national communities;

d) To provide advice on preparatory actions in Member States and the IAEA's activities in planning and implementing coordinated research programmes, collaborative assessments and other activities as well as the review of the results on nuclear desalination demonstration projects;

e) To develop and/or review selected documents from the Nuclear Energy Series, assess existing gaps and advise on preparation of new ones, in the scope of their field of activity;

f) To identify important topics for discussion at SAGNE and contribute to status reports, technical meetings and topical conferences in the field of nuclear desalination;

g) To encourage participation of young professionals, as appropriate, in IAEA activities.

Members of the TWG on Nuclear Desalination shall be appointed by the Deputy Director General, Department of Nuclear Energy, following consultation with the respective national authorities or organizations. Members of the TWG on Nuclear Desalination:

- Shall be recognized experts in nuclear seawater desalination having extensive links with national technical communities;
- Are to serve for a standard length of four years;
- Shall participate in the Group in their personal capacity and shall provide as appropriate views on national policies and strategies in the technical field;
- May as appropriate bring experts to provide additional information and share experience in the meetings of the TWG.

INDAG met in Jan 2008 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.

Meeting on Advances in Nuclear Power Process Heat Applications

This coordinated research project (CRP) aims to evaluate the potential of advanced reactor designs in some process heat applications, such as hydrogen production and seawater desalination. High Temperature gas cooled reactors (HTGRs) are posed to play a potential role due to their high temperature output of 850-950 ºC, which improves hydrogen production efficiency and their available and free waste heat, which lowers the cost of thermal desalination. Therefore, challenges to be addressed by this CRP are related to process technologies, coupling safety, high temperature material technology and the economic merits of centralized vs distributed production units.

Meeting on Integrated Nuclear Desalination Systems

Nuclear desalination is expected to play a major role in future as it provides a sustainable water resource at a reasonable cost. The demonstration of integrated nuclear desalination systems, where nuclear power plants are coupled to desalination plants, has received much attention for the past years. An integrated use of technology can compensate the impact on rising cost. As desalination and water reuse expansion in the world continues at a rapid pace, these innovations must be integrated into the next generation of water facilities. The meeting is intended to provide an opportunity for the participants from Member States to exchange information and share experience on nuclear desalination activities in their respective countries, which are actively involved in the nuclear desalination activities or considering the introduction of nuclear desalination.

EA 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
5. The 8th Gulf Water Conference on Water in the GCC… Towards an optimal Planning and Economic Perspective Manama, Kingdom of Bahrain, March 3-6, 2008.

6. The International Desalination Association (IDA) and Global Water Intelligence Conference (GWI) on Water, Finance & Sustainability 2008: New directions for a thirsty planet London, 21 &22 April 2008.

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 new version DEEP 3.11 was released in September 2007. It is now available on download under a licence agreement
- Proceedings of 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, under printing 2008.

How to get IAEA publications: Orders and requests for information may be addressed directly to:
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