[1.] Ahmed Abdel Hamid A. ABDALLAH

MODERN TECHNOLOGY AND ECONOMICAL DEVELOPMENTS IN DESALINATION ON EMPHASIS OF NUCLEAR METHODOLOGY

[1.] Faculty of Engineering at the Civil Engineering Department, Giza Higher Institute of Engineering and Technology, Giza, EGYPT

Abstract: Fresh water resources are rapidly being exhausted in many regions in the world. The worst-affected areas are the arid and semiarid regions of Middle East and North Africa. It is estimated that about 20-25% of the world's population are suffering from adequate and safe water supply. This proportion will increase due to population growth relative to water resources. During past decades, more interests are paid to the desalination of sea and brackish water resources. Desalination technologies have been now well established, and the total world capacity in mid-2012 was 80 million m^3/day of potable water, in some 15,000 plants, majority of these are in the Middle East and North Africa. Nowadays using nuclear energy for fresh water production from seawater (nuclear desalination) has been drawing broad interests in many countries. These interests are driven by the expanding global demand for fresh water, by concern about global heating emissions and pollutions from fossil fuels and developments in small and medium sized reactors that might be more suitable than large power reactors. Several international organizations, like the IAEA, adopted cooperative active programs for supporting the activities on demonstration of nuclear seawater desalination worldwide. These include optimization of the coupling of nuclear reactors with desalination systems, economic research and assessment of nuclear desalination projects, development of software and training for the economic evaluation of nuclear desalination as well as fossil fuel based plants. In this paper, recent technical and economic developments in nuclear desalination and its future prospects have been reviewed and evaluated.

Keywords: Nuclear desalination; Potable water needs; Water resources scarce areas

INTRODUCTION

The purpose of this paper is to provide an overview of various nuclear desalination plant design concepts, which are being proposed, evaluated, or constructed in countries with the aim of demonstrating the feasibility of using nuclear energy for desalination applications under specific conditions. Recent technical and economic developments in nuclear desalination and its future prospects have been reviewed and evaluated. Future potential applications of a variety of nuclear reactor designs in nuclear desalination are being proposed for examination. These include: high- temperature gas reactors (HTGRs), liquid metal cooled reactors (LMRs) such as lead-bismuth cooled or sodium cooled reactors, and other innovative reactor design concepts. The paper also focuses on advanced designs in the small category, i.e. those now being built for the first time or still on the drawing board, and some larger ones which are outside the mainstream categories. Many of the designs described here are not yet actually taking shape. Three main options are being pursued: light water reactors, fast neutron reactors and also graphite-moderated high temperature reactors. The first has the lowest technological risk, but the second (FNR) can be smaller, simpler and with longer operation before refueling.

DESALINATION TECHNIQUES

Seawater desalination is the process to obtain "pure" water through the separation of the seawater feed stream into:

» a product stream that is relatively free of dissolved substances, and
» a concentrate brine discharge stream.

As depicted in Figure 1, desalination processes can be broadly categorized into two main types: processes using heat and process using electricity. The first types of processes are mainly the distillation processes, multi-stage flash (MSF) or multi effect distillation (MED). Vapour compression (VC) is a distillation process but it uses electricity, just as the membrane based processes like the reverse osmosis (RO) and the electro- dialysis (ED). Of these, the most commonly used processes are MSF, MED and RO. VC is often combined with MED.

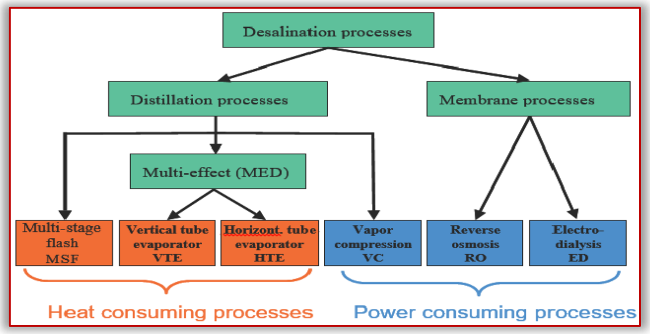

Figure 1. Types of desalination techniques

In distillation processes, (MSF or MED) seawater is heated to evaporate pure vapour that is subsequently condensed. The heat energy required for distillation is usually supplied as low pressure saturated steam, which may be extracted from the exhaust of a back pressure turbine, from a crossover steam duct or from a dedicated, heat only plant.

The amount and quality of steam, required to produce the desired amount of pure water, depends on the seawater temperature, the maximum brine temperature and the type, design and performance of the distillation plant. Usually, the efficiency of distillation plant is expressed in kg of pure water produced per kg of steam used in the first effect: this ratio is called the gain output ratio (GOR).

Desalination is an energy intensive process. For the MED and MSF plants, the principal energy is in the form of heat but some electrical energy is required for the pumps and auxiliaries. RO uses only electrical energy to create the required pressure. The total energy consumption of these two processes is a function of many variables: heating fluid temperature and flow rate, seawater temperature and salinity, desalination plant capacity etc. Indicative values are given in Table 1. Desalination processes are described from technical point of view in many literatures. [1-3]

STATUS AND DEVELOPMENTS IN NON-NUCLEAR DESALINATION.

— Technical Status and Developments

In mid-2012, the total world capacity of potable water was 80 million m^3/day (29,200 GL/yr), in some 15,000 plants. A majority of these are in the Middle East and North Africa. The largest plant – Jubail 2 in Saudi Arabia - has 948,000 m^3/day (346 GL/yr) capacity, operated by Saudi Water Conversion Corporation. Two thirds of the world capacity is processing seawater, and one third uses brackish artesian water. The major technology in use and being built today is reverse osmosis (RO) driven by electric pumps which pressurize water and force it through a membrane against its osmotic pressure. (About 27 Bar, 2700 kPa. Therefore RO needs compression of much more than this).

This accounted for 60% of 2011 world capacity. A thermal process, multi-stage flash (MSF) distillation process using steam, was earlier prominent and it is capable of using waste heat from power plants. It accounted for 26% of capacity in 2011. With brackish water, RO is much more cost-effective, though MSF gives purer water than RO. A minority of plants use multi-effect distillation (MED - 8% of world capacity) or Multi-effect Vapour Compression (MVC) or a combination of these. MSF-RO hybrid plants exploit the best features of each technology for different quality products.

In Israel, some 10% of Israel's water is desalinated, and one large RO plant provides water at 50 cents per cubic meter. Malta gets two thirds of its potable water from RO. Singapore in 2005 commissioned a large RO plant supplying 136,000 m^3/day - 10% of needs, at 49 cents US per cubic meter. Malta gets two thirds of its potable water from RO, and this takes 4% of its electricity supply. Singapore in 2005 commissioned a large RO seawater desal plant supplying 136,000 m^3/day - 10% of needs, at 49 cents US per cubic meter, and has contracted for a 318,500 m^3/d RO plant on a build-own-operate basis, costing US$ 700 million, to provide water at US 36 c/m^3. The same company is building a 500,000 m^3/d seawater desal plant in Algeria [4].

The UAE operates the 820,000 m3/day Jebel Ali MSF plant in Dubai, Fujairah producing 492,000 m^3/day, Umm Al Nar 394,000 m^3/day, and Taweelah A1 power and desal plant producing 385,000 m^3/day. In February 2012 China's State Council announced that it aimed to have 2.2 to 2.6 million m^3/day seawater desalination capacity operating by 2015[5].

The Kwinana desalination plant near Perth, Western Australia, has been running since early 2007 and produces about 140,000 m^3/day (45 GL/yr) of potable water, requiring 24 MWe of power for this, hence 576,000 kWh/day, hence 4.1 kWh/m^3 overall, and about 3.7 kWh/m^3 across the membranes. The plant has pre-treatment, then 12 seawater RO trains with capacity of 160,000 m^3/day which feed six secondary trains producing 144,000 m^3/day of water with 50 mg/L total dissolved solids. The cost is estimated at a $ 1.20/m^3. Discharge flow is about 7% salt. Future WA desalination plants will have more sophisticated pre-treatment to increase efficiency. In August 2011 the state government decided to double the size of its new Southern Water Desal Plant at Binning up plant near Perth to 100 GL/yr, taking the cost to about $1.45 billion. Stage 1 of 50 GL/yr was within the A$ 955 million budget. At the April 2010 Global Water Summit in Paris, the prospect of desalination plants being co-located with nuclear power plants was supported by leading international water experts.

— Energy Consumption and Economics

Desalination is energy-intensive process. As seen from Table 1, Reverse Osmosis (RO), needs up to 6 kWh of electricity per cubic meter of water (depending on its original salt content), hence 1 MWe will produce about 4000 to 6000 m^3 per day from seawater. MSF and MED require heat at 70-130°C and use 25-200 kWh/m^3, though a newer version of MED (MED-MVC) is reported at 10 kWh/m^3 and competitive with RO. A variety of low-temperature and waste heat sources may be used, including solar energy, so the above kilowatt-hour figures are not properly comparable.

Table 1. Average energy consumption and water cost in desalination processes (modified after Ref. [2])

Process	World installed capacity (%)	Specific Heat Consumption (kWth.h/m^3)	Specific Electricity Consumption (kWth.h/m^3)	Water Cost ($ / m^3)
MSF	44	50-110	4-6*	0.8-1.86
MED	4	60-110	1.5-2.5*	0.27-1.49
RO	42	none	3-5.5	0.45-1.62
ED	6	none	-	0.58
VC	4	-	-	0,46-1.21

* Some electricity is required to run the pumps and other auxiliary systems in MSF and MED

For brackish water and reclamation of municipal wastewater RO requires only about 1 kWh/m^3. The choice of process generally depends on the relative economic values of fresh water and particular fuels, and whether cogeneration is a possibility. Approximately, it could be concluded that, in order to produce about 300 000 m^3/day, MED process would require about 550 MW (th) and 15 MW (e). To produce the same amount of water, RO would require only about 60 MW (e). The thermal energy requirements for MSF could be twice as much as those for the MED plant.

NUCLEAR DESALINATION

— Economical and Environmental Incentives

Nuclear desalination is defined to be the production of potable water from seawater in a facility in which a nuclear reactor is used as the source of energy for the desalination process. Electrical and/or thermal energy may be used in the desalination process. The facility may be dedicated solely to the production of potable water, or may be used for the generation of electricity and production of potable water, in which case only a portion of the total energy output of the reactor is used for water production. Nuclear power is a proven technology, which has provided more than 16% of world electricity supply in over 30 countries. More than ten thousand reactor-years of operating experience have been accumulated over the past 5 decades. In recent years, the option of combining nuclear power with seawater desalination has been explored to tackle water shortage problem. Over 175 reactor-years of operating experience on nuclear desalination have been accumulated worldwide. Several demonstration programs of nuclear desalination are also in progress to confirm its technical and economical viability under country-specific conditions, with technical co-ordination or support of IAEA.

In this context, nuclear desalination now appears to be the only technically feasible, economically viable and sustainable solution to meet the future water demands, requiring large scale seawater desalination:

» Nuclear desalination is economically competitive, as compared to desalination by the fossil energy sources,
» Nuclear reactors provide heat in a large range of temperatures, which allows easy adaptation for any desalination process.
» Some nuclear reactors furnish waste heat (normally evacuated to the heat sink) at ideal temperatures for desalination.
» Desalination is an energy intensive process. Over the long term, desalination with fossil energy sources would not be compatible with sustainable development: fossil fuels reserves are finite and must be conserved for other essential uses whereas demands for desalted water would continue to increase.

Furthermore, the combustion of fossil fuels would produce large amounts of greenhouse gases and toxic emissions. Basing the estimations to only the Mediterranean region, it can be shown that around 2020, there will be additional need of water production of about 10 million m^3/day. If nuclear instead of fossil fueled option is chosen, then one could avoid about:

» 200 000 000 t/year of CO2,
» 200 000 t/year of SO2,
» 60 000 t/year of NOx, and
» 16 000 t/year of other hydrocarbons.

These extrapolated to the world desalination capacities would lead to more than double the amounts given above [6].

— Current Experience and Developments in Nuclear Desalination

Table 2 summarizes past experience as well as current developments and plans for nuclear-powered desalination based on different nuclear reactor types.

Japan now has over 150 reactor-years of nuclear powered desalination experience. Kazakhstan had accumulated 26 reactor-years before shutting down the Aktau fast reactor at the end of its lifetime in 1999. The experience gained with the Aktau reactor is unique as its desalination capacity was orders of magnitude higher than other facilities.

Most of the technologies in Table 2 are land-based, but the Table also includes a Russian initiative for barge-mounted floating desalination plants. Floating desalination plants could be especially attractive for responding to temporary demands for potable water [7].

Table 2. Current nuclear reactor types and adopted desalination processes

Reactor type	Location	Desalination process	Status
LMFR	Kazakhstan (Aktau)	MED, MSF	In service till 1999
PWRs	Japan (Ohi, Takahama, Ikata, Genkai)	MED, MSF, RO	In service with operating experience of over 125 reactor-years.
	Rep. of Korea, Argentina, etc.	MED	Under design
	Russian Federation	MED, RO	Under consideration (floating unit)
BWR	Japan (Kashiwazaki-Kariva)	MSF	Never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999.
HWR	India (Kalpakkam)	MSF/RO	Under commissioning
	Pakistan (KANUPP)	MED	Under construction
NHR-200	China	MED	Under design
HTRs	France, The Netherlands, South Africa, USA	MED, RO	Under development and design

LMFR: liquid metal fast reactor; PWR: pressurized water reactor; BWR: boiling water reactor; HWR: heavy water reactor, NHR: nuclear heat producing reactor; HTR: high temperature reactor MED: multi-effect distillation; MSF: multi stage flash distillation; RO: reverse osmosis

— Technical and Economic Feasibility of Nuclear Desalination

The following sections provide additional details on the new developments listed in Table 3.

» Argentina has identified a site for its small reactor (CAREM), which could be used for desalination. A related initiative on safety aspects of nuclear desalination addresses practical improvements and implementation and shares advances around the world.
» China is proceeding with several conceptual designs of nuclear desalination using NHR type heating reactor for coastal Chinese cities. A test system is being set up at INET (Institute of Nuclear Energy Technology, Tsinghua University, and Beijing) for validating the thermal-hydraulic parameters of a multi-effect distillation process.

- Egypt has completed a feasibility study for a nuclear co-generation plant (electricity and water) at El-Dabaa. Construction of a pre-heat RO test facility at El Dabaa is nearing completion. The data generated will be shared with interested Member States.
- France has recently concluded several international collaborations: one with Libya designed to undertake a techno-economic feasibility study for a specific Libyan site and the adaptation of the Libyan experimental reactor at Tajoura into a nuclear desalination demonstration plant using both MED and RO processes in a hybrid combination. The other collaboration is with Morocco (The AMANE project) for a techno-economic feasibility study of Agadir and Laayoun sites. Under a bilateral collaboration signed between India and France, it has also been agreed that the two partners will collaborate on the development of advanced calculation models, which will then be validated at Indian nuclear installations (the experimental reactor CIRUS and the Kalpakkam plant, with hybrid MSF-RO systems).
- Israel continues to regularly provide technical and economic information on low cost desalination technologies and their application to large-scale desalination plants.
- Japan continues with its operation of nuclear desalination facilities co-located inside many nuclear power plants.
- The Republic of Korea is proceeding with its SMART (System-integrated Modular Advanced Reactor) concept. The project is designed to produce 40 000 m^3/day of potable water.
- Morocco continues the process of establishing an adequate legal and institutional legislative and regulatory nuclear framework while staying abreast of technical developments in general and nuclear desalination.
- Tunisia has completed its techno-economic feasibility study, in collaboration with France, for the la Skhira site in the southeast part of the country. The final report, presented in March 2005 was very favorably received by the Tunisian authorities who have already announced their willingness to go for the nuclear desalination option.
- USA will include in its Generation IV roadmap initiative a detailed discussion of potential nuclear energy products in recognition of the important role that future nuclear energy systems can play in producing fresh water.
- Further R&D activities are also underway in Indonesia and Saudi Arabia. In addition, interest has been expressed by Algeria, Brazil, Islamic Republic of Iran, Iraq, Italy, Jordan, Lebanon, Philippines, Syrian Arab Republic and United Arab Emirates in the potential for nuclear desalination in their countries or regions.
- India is building a demonstration plant at Kalpakkam using a 6300 m^3/day hybrid desalination system (MSF-RO) connected to an existing PHWR. The RO plant, with a production capacity of 1800 m /day, was set up in 2004 and is since operating. The MSF plant (4500 m^3 /day) is to be commissioned in 2006.
- Libyan Arab Jamahiriya is considering, in collaboration with France, to adapt the Tajoura experimental reactor for nuclear desalination demonstration plant with a hybrid MED-RO system. The MED plant, of about 1000 m^3/day production capacity, will be manufactured locally.
- Pakistan is constructing a 4800 m^3/day MED thermal desalination plant coupled to a PHWR at Karachi. It is expected to be commissioned towards the end of 2006.
- The Republic of Korea is exploring a possibility of using a co-generating integral type reactor SMART combined with a multi-effect distillation (MED) plant producing 40000 m^3/day of fresh water. The basic design of 330 MW (th) SMART is completed. In parallel with out-pile tests, a one-fifth scale pilot plant SMART-P is being planned to construct along with a MED unit by 2008.
- The Russian Federation continues its R&D activities in the use of small reactors for nuclear desalination and has invited partners to participate in an international nuclear desalination project based on a nuclear floating power unit (FPU) equipped with two KLT-40s reactors. The co-generation plant, foreseen for construction in 2006, will be sited at the shipyard in Severodvinsk, Arkhangelsk region in the western North Sea area where the FPU is being manufactured [8].

ADVANCES IN REACTOR DESIGN FOR NUCLEAR DESALINATION

There are no specific nuclear reactors for desalination. Any reactors, capable of providing electrical and/or thermal energy can be coupled to an appropriate desalination process. These reactors can operate as dedicated systems (producing only the desalted water) or as co-generation systems producing both water and electricity.

Dedicated nuclear systems are considered more suitable for remote, isolated regions. Many developing countries may face both power and water shortages. In this case, IAEA studies have shown that the small and medium sized reactors (SMRs), operating in the cogeneration mode, could be the most appropriate nuclear desalination systems for several reasons:

- SMRs have lower investment costs.
- Almost all SMR concepts appear to show increased availability (≥ 90%).
- Because of inherent safety features, most SMRS have a larger potential for being located near population centers, hence lowering the water transport costs.

This section is thus mainly devoted to a very brief description of SMRS. These reactors have been discussed in detail in [3]. For the purposes of updating the information, two innovative, generation-4 SMRs (IRIS and ANTARES) are also described. CAREM-D, The NHR-200 and The AP-600 are the most important advanced reactor systems used for modern nuclear desalination plants as described in Table 3.

Table 3. Some technical characteristics of different nuclear reactors proposed for desalination [9]

	CAREM	NHR-200	AP-600	GT-MHR*	PBMR*
Net thermal/ electrical power (MW(th)/MW(e))	100/27	200/NA	610/1932	600/286	266/115
Fuel	Enriched UO2	Enriched UO2	Enriched UO2	Enriched UO2 particles	Enriched UO2 particles
Coolant	Water	Water	Water	He	He
Moderator	Water	Water	Water	Graphite	Graphite
Coolant circuit pressure (MPa)	12.25	2.5	15.5	71.5	69.6
Coolant circuit in/out temperature (°C)	284/386	153/210	288/322	493.2/854.6	525/892
Secondary circuit feed water pressure (MPa)	4.7		57.5	-	-
Secondary circuit feed water (fluid) temperature (°C)	200			-	-
Intermediate (or tertiary) circuit pressure (MPa)		3.0		7	7
Intermediate (or tertiary) circuit in/ out temperature (°C)		135/170		100	100
Plant life time (years)		40	40	60	60
Net thermal/ electrical power (MW(th)/MW(e))	743/240	330/90	2 X 150/35	335/1002	600/280
Fuel	Nt. UO2	Enriched UO2	Enriched UO2	Enriched UO2	Enriched UO2 particles
Coolant	D2O	Water	Water		He
Moderator	D2O	Water	Water		Graphite
Coolant circuit pressure (MPa)	10.3	15	12.7	15.5	5.5
	PHWR	SMART	KLT-40C	IRIS	ANTARES
Coolant circuit in/out temperature (°C)	249/293.4	270/310		292/328.4	395/850
Secondary circuit feed water pressure (MPa)	4.2	5.2		6.4	(N2/He) 5.5
Secondary circuit feed water (fluid) temperature (°C)	170	180		224	(350/800)
Intermediate (or tertiary) circuit pressure (MPa)					
Intermediate (or tertiary) circuit in/ out temperature (°C)			130		30/550
Plant life time (years)	40	60	40	60	60

* Calculated characteristics for MED couplings based on waste heat utilization

TECHNICAL AND ECONOMIC DEVELOPMENTS

Considerable advances have been recently made in several countries on the development of improved or innovative nuclear reactors. These include:

- Advanced PWRs such as CAREM (integral PWR, Argentina), SMART (integral PWR, Republic of Korea), NHR-200 (dedicated heat only reactor, being developed by INET, China), AP-600 (Westinghouse, USA and ANSALDO, Italy) and the barge-mounted KLT-40 class of reactors, derived from Russian Ice-breakers[10].
- HWRs, being modified for nuclear desalination in India and Pakistan. HTRs such as the GT-MHR (developed by an international consortium, led by General Atomics) and the PBMR (planned to be constructed soon in South Africa by the PBMR Company).
- Other advanced reactors such as the integral PWR, IRIS (being developed by an international consortium, led by Westinghouse) and the innovative HTR, ANTARES (under development by Framatome, ANP, France)[11,12].

Desalination technologies have, in parallel, also known considerable technological innovations:

- an almost exponential increase in production capacity of the plants: thus, for example, between the years 980 and 2005, multi-effect distillation (MED) unit plant capacities have increased from 1 000 to 31 000 m^3/day and multi-stage flash (MSF) unit sizes have increased from 31 000 to 80 000 m^3/day.
- choice of high performance materials, (e.g. carbon-steel in place of simple, painted steel), development of high heat transfer alloys for the tubes, increasing use of non-metallic evaporator materials.
- improvement in corrosion resistance (e.g. utilization of anti-scaling organic products in place of conventional acid treatment).
- improvements in availability and thermodynamic efficiencies, due to the incorporation of on- line cleaning procedures.
- modular construction, with improvements in fabrication procedures, reducing construction lead times.
- development of efficient and more precise process control systems and procedures.

The most rapid and significant advances have been reported in membrane based processes, in particular reverse osmosis (RO):

- increase of salt rejection efficiency (from 98 to 99.8 %).
- increase in permeate flux (86 %).
- enhanced chlorine tolerance.
- reduction of the costs of cleaning and pre-treatment due to ever increasing resistance against fouling.
- development of longer life membranes.

Many countries have undertaken nuclear desalination studies in their specific conditions. Analysis of the results leads to the following conclusions: Whatever the nuclear reactor, the desalting capacity and the site-specific conditions, nuclear desalination is by far economically the most interesting option as compared to the gas turbine, combined cycle plant as long as gas prices remain higher than about 21 $/bbl, if nuclear can achieve capital costs at or below the 1500 $/kWth range. In this context, the IAEA has received 8 reports summarizing site- studies from Argentina (CAREM + RO), China (NHR-200 + MED), Egypt (PWR-1000 + RO, PWR- 1000 + MED), France (PWR-900 and AP-600, coupled to RO and MED, GT-MHR and PBMR, coupled to MED, with waste heat utilization), India (PHWR + MED, PHWR + RO and PHWR + hybrid MSF-RO), Republic of Korea (SMART + MED), Pakistan (CANDU + MED) and Syrian Arab Republic (PBMR coupled to MED, MED/VC and RO) [13].

Because of very diverse site conditions, production capacities, economic hypotheses, variety of nuclear reactors and even calculation methods, it is very difficult to arrive at specific conclusions regarding different nuclear desalination systems. One may however, obtain a range of values for different combinations:

» For the RO based systems, desalination costs vary from 0.6 to 0.94 $/m^3.
» In all cases where the nuclear desalination costs are compared with those from the combined cycle plant, it is observed that the nuclear desalination costs are much lower.
» For the MED based systems, the nuclear desalination costs vary from 0.7 to 0.96 $/m^3.
» In one study, the MED /VC, coupled to a PWR leads to a cost of 0.5 $/m^3.
» As for RO, wherever comparisons have been made, the desalination cost of nuclear reactors coupled to MED are systematically more than 20% lower than the corresponding cost by the combined cycle MED systems.
» In a hybrid MSF-RO system, the desalination cost of MSF, coupled to a PHWR is 1.18 $/m^3, compared to 0.95 $/m^3 for RO but that of the hybrid MSF-RO system is 1.1 $/m^3. This cost is likely to be further reduced as hybrid system capacity is increased [14].

With identical economic hypotheses, used for three cases, DEEP-3 results show that nuclear reactors, coupled to RO would lead to a desalination cost of 0.6 to 0.74 $/m^3. Corresponding cost for MED would be about 0.89 $/m^3.

Nuclear desalination costs can still be further reduced by adopting certain cost reduction strategies involving the use of waste heat from nuclear reactors and normally evacuated to the sea or river, the launching of optimized hybrid systems and the extraction of strategic and costly minerals from the brine rejected by desalination plants, accompanied by zero brine discharge to the sea.

The most crucial problem for the launching of full-fledged nuclear desalination systems remains the financing of projects. However, studies have shown that the project financing method (in which instead of financing the local utility, an independent structure for project financing is created and which seeks to reduce the risks through multiple government and/or international credits) coupled to the leasing (instead of buying all the project equipment, a part is leased) would be a very suitable approach for most developing countries [14].

CONCLUSIONS

This paper provides information and recalls some of the advances made both in the nuclear reactor and desalination technologies. It is expected that the information contained in this report would be of use to decision makers in the Member States considering nuclear desalination options. Desalination technologies are mainly of two types:

» thermal processes, based on the utilization of heat energy for distillation (also requiring some electrical energy for the pumps and other auxiliary systems) and
» membrane based processes using only electrical (or mechanical) energy.

Among the thermal processes, the most commonly used are MSF and MED Vapour compression (VC) is a distillation process which uses electrical energy. Reverse Osmosis (RO) and Electro-dialysis (ED) are membrane based processes. There are no specific nuclear reactors for desalination. Any reactors capable of providing electrical and/or thermal energy can be coupled to an appropriate desalination process. These reactors can operate as dedicated systems (producing only the desalted water) or as co-generation systems producing both water and electricity. Dedicated nuclear systems are considered more suitable for remote, isolated regions. Many developing countries may face both power and water shortages. In this case, many studies have shown that the small and medium sized reactors (SMRs), operating in the cogeneration mode, could be the most appropriate nuclear desalination systems.

References

[1] T.Younos, Economics of desalination, Journal of Contemporary Water Resources & Education, 132, (2015) 39-45
[2] IAEA, Use of Nuclear Reactors for Seawater Desalination, IAEA-TECDOC-574, IAEA, Vienna (2012)
[3] IAEA, Optimization of the Coupling of Nuclear Reactors and Desalination Systems, IAEA-TECDOC-1444, IAEA, Vienna (2015)
[4] S. Nisan, S. Dardour, Y. Dumont, N. Reguigui, Inter-regional collaborative nuclear desalination studies by France and Tunisia, Int. J. Nuclear desalination, 1, 3, 308–324 (2014).
[5] T.M. Pankratz, Advances in desalination technologies. Nuclear desalination: Challenges and options, International Conference Marrakech, Morocco (2011).
[6] IAEA, Desalination Economic Evaluation Program (DEEP 3.0) User's Manual, Computer Manual Series 19, Vienna (2016).
[7] M.Methnanp, Recent model developments for the Desalination Economic Evaluation Program DEEP, International Desalination Association Congress, Singapore (2015).
[8] S. Nisan, B. Commercon, S. Dardour, A new method for the treatment of a reverse osmosis process with preheating of the feed water, Desalination, 182, 485–49 (2005).
[9] S. Dardour, S. Nisan, F. Charbit, Utilisation of waste heat from GT-MHR and PBMR type of reactors for nuclear desalination, EUROMED 2006 Conference, Montpellier, France (2006).
[10] GT-MHR CONSORTIUM, International GT-MHR Project Design Review, St Germain-en- Laye, France (1999).
[11] J.R. Humphries, K. Davies, J. Ackert, An advanced reverse osmosis technology for applications in nuclear installations, ICAPP Meeting, Hollywood, Florida, USA (2002)
[12] J.Le Dirach, S.Nisan, C. Poletiko, Extraction of strategic materials from the concentrated brine rejected by integrated nuclear desalination systems, Desalination, 182, (2005), 451–462
[13] Massachusetts Institute Of Technology, MIT Report, The future of nuclear energy (2003)
[14] N.Bozgiemda, S. Nisan, M. Albouy, Financing of nuclear desalination projects in developing countries, EUROMED 2006 Conference, Montpellier, France (2006)