# SAFETY ASPECTS AND ECONOMIC EVALUATION OF NUCLEAR-FUELLED DESALINATION PLANTS

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## ABSTRACT

Interests in adopting nuclear power plants as dual-purpose for power generation and producing fresh water have been growing worldwide during the past decades, due to the economic and environmental competitiveness of nuclear power versus oil-fired generation plants. With the decision to introduce nuclear power plants for electricity generation in Egypt, and in view of the increasing demand for fresh water in the country due to social, economic and industrial developments, investigation for the potential of nuclear power for desalination in Egypt is of great interest. The main objective of this paper is to review, analyze and evaluate the recent status of nuclear desalination technologies. It provides a review of various fissile (nuclear) desalination plants design concepts which are being constructed, proposed and evaluated. Coupling of nuclear power and water desalination plants as well as various safety features implemented in nuclear distillation plants have been reviewed and discussed. Economic assessment for various desalination technologies with the applications of PWR and PHWR nuclear reactor designs for desalination industry are proposed, discussed and evaluated. The paper proposed a competitive desalination concept for Egypt supported by technical aspects and economical feasibility.

## 1. INTRODUCTION

Recently, it is estimated that one fifth of world population, or more than one billion persons worldwide, do not have access to safe potable water. This situation, because of increasing world population, is likely to deteriorate in the future. Moreover, by the year 2025, it is anticipated that 33% of the world population, or more than 1.8 billion people, will live in region or countries without adequate water supplies, unless new desalination plants become operational [1-3]. Currently, nuclear reactors have already been used for desalination plants on relatively small scale projects whereas more than 150 reactor-years of operating experience with nuclear desalination. Seawater desalination is the processing of seawater to produce pure or potable water through the separation of the seawater feed stream into a product stream that is relatively free of dissolved substances and a concentrated brine discharge stream. Nuclear desalination is the production of potable, industrial, and/or high purity water from seawater (or brackish water) in a facility in which a nuclear reactor is used as the source of energy for the desalination process.

Egypt like many other countries is also experiencing serious fresh water shortages and has participated in an earlier regional project for evaluating the feasibility of nuclear seawater desalination. The country has assessed the introduction of nuclear power and has approved the El-Dabaa site as the location for the first plant. Also, Egypt is now studying the feasibility studies of a nuclear desalination plant under specific site conditions at El-Dabaa location. These studies are carrying out with the assistance of IAEA. The main objective of this study is to review, analyze and evaluate the recent status of nuclear desalination technologies. It provides a review of various fissile (nuclear) desalination plants which are being constructed, proposed and evaluated. Economic assessment for various desalination technologies with the applications of PWR and PHWR nuclear reactor designs for desalination industry are proposed, discussed and evaluated. The paper proposed an optimum desalination concept for Egypt supported by technical, economical feasibility as well as safety features.

## 2. REVIEW

### 2. 1. Desalination process techniques

There are many proven desalination technologies available. However, after more than 40 years of intensive research and development in seawater desalination technology, only the multi-stage flash (MSF), multi-effect distillation (MED) processes and the reverse osmosis (RO) membrane process have achieved commercial large-scale application. In recent years, the hybrid process consisting of combinations of distillation and RO processes is gaining interest. Distillation and RO are expected to continue to be the leading desalination processes in the near future (1). Recently, there are many proven desalination techniques available and adopted in different countries. In the distillation processes, seawater is heated to evaporate pure water that is subsequently condensed. Distillation processes are driven by low-temperature fluid (below 130°C) (1), this fluid is generally steam, which may be taken from a power plant after partial utilization. From the beginning, distillation processes have been implemented in heat recovery chambers placed in series as a result of the high specific heat required to evaporate water. The performance of distillation processes increases with increasing number of chambers. However, the overall temperature difference between the heat source and the cooling water sink as well as economic considerations limit the number of chambers. Typical temperature differences for commercial distillation plants are 2-6°C per heat recovery chamber (1,2). Table (1) depicts different techniques for desalination processes which are fully proven and widely utilized for seawater desalination all over the world.

**Table1. Different technologies for desalination processes**

| Process technique | Description and abbreviation |
|---|---|
| 1. Distillation | Multi-effect distillation **(MED)**<br>Multi-stage flash **(MSF)** |
| 2. Membrane | Stand-alone reverse osmosis **(SA-RO)**<br>Contiguous reverse osmosis **(C-RO)** |
| 3. Hybrid | Multi-effect distillation with reverse osmosis **(MED/RO)**<br>Multi-stage flash with reverse osmosis **(MSF/RO)** |

In multi-stage flash (MSF) process, seawater feed passes through tubes in each evaporation stage where it is progressively heated. Final seawater heating occurs in the brine heater by the heat source. Subsequently, the heated brine flows through nozzles into the first stage, which is maintained at a pressure slightly lower than the saturation pressure of the incoming stream. As a result, a small fraction of the brine flashes forming pure steam. The heat to flash the vapour comes from cooling of the remaining brine flow, which lowers the brine temperature. Subsequently, the produced vapour passes through a mesh demister in the upper chamber of the evaporation stage where it condenses on the outside of the condensing brine tubes and is collected in a distillate tray. The heat transferred by the condensation warms the incoming seawater feed as it passes through that stage. The remaining brine passes successively through all the stages at progressively lower pressures, where the process is repeated. The hot distillate flows as well from stage to stage and cools itself by flashing a portion into steam which is re-condensed on the outside of the tube bundles.

Multi-effect distillation process (MED) is a distillation process with the oldest large-scale applications. In each effect, heat is transferred from the condensing water vapour on one side of the tube bundles to the evaporating brine on the other side of the tubes. This process is repeated successively in each of the effects at progressively lower pressure and temperature, driven by the water vapour from the preceding effect. In the last effect at the lowest pressure and temperature the water vapour condenses in the heat rejection heat exchanger, which is cooled by incoming seawater. The condensed distillate is collected from each effect. MED plants have a much more efficient evaporation heat transfer process than MSF plants. Due to the thin film evaporation of brine on one side of the tubes and the condensation of vapour on the other side, high heat transfer coefficients are achieved.

The reverse osmosis (RO) process is a membrane separation process in which pure water passes from the high-pressure seawater side of a semi-permeable membrane to the low pressure permeate, or "pure" water, side of the membrane. In order to overcome the natural osmotic process (migration of pure water from a solution of low concentration into a solution of higher concentration in order to balance the osmotic pressures), the seawater side of the system has to be pressurized to create a sufficiently high net driving pressure across the membrane. In practice, the seawater can be pressurized to pressures as high as 70-80 bar [2].

Distillation processes MSF and MED plants as well as RO process need intensive pre-treatment of the seawater to avoid scaling by adding acid or advanced scale inhibiting chemicals. The pre-treatment of seawater for MED plants is similar to that in MSF plants. In general, polyphosphate is introduced into the seawater feed to prevent calcium carbonate scale formation on the heat transfer tubes. Today, corrosion resistant materials are available at reasonable costs as well as high temperature, cost effective antiscalants. A steam jet-ejector vacuum system is used to remove vent gases from the deaerator and non-condensable gases evolving during evaporation from the system. Although distillation processes MSF and MED, are widely used for seawater desalination, the RO process has become especially reliable and economical in recent years. In the RO process, energy is consumed to compress the saline feed up to 7 or 8 MPa in order to overcome the osmotic pressure of the saline solution of about 6 MPa. RO needs about 4-6 kWh of electricity per cubic meter of water depending on its salt content, while distillation process require heat at 70-130 $^{o}$C and consume about 30-200 kWh/m$^3$. The choice of desalination process technique depends on the relative economic values of fresh water and fuel cost [(2,3)].

## 2.2. Nuclear reactors for desalination

It is well known that desalination is an intensive energy consumption process. Although the technologies described above are very different, they all have a common feature; they require a significant consumption of energy. There are many proven energy sources available. Four combinations of energy source and power level were chosen for this assessment; with the intent that they represent a range of nuclear power plant sizes and that they include existing power generation options as well as promising power supply concepts currently being developed.

Water-cooled reactors have been widely used in nuclear systems and have good operating performance as a commercial energy supply systems. Boiling water reactors (BWRs) in particular are known for their simple direct cycle configuration, in which steam generated in the reactor directly flows and expands in the steam turbine without large steam generators between the reactor and the turbine. The pressurized water reactor (PWR) is the most common reactor type in operation today in the world. Many different design configurations of PWRs exits, but they are common in the use of light water as both coolant and moderator in the reactor core. The vertically oriented core of the PWR consists of a large number of close-packed fuel channels mounted in a large, heavy walled pressure vessel containing the primary coolant. Heat is removed from the PWR core by circulation of the primary coolant through steam generators producing saturated steam in the secondary side. The steam is circulated through high pressure and low-pressure turbine stages and is then condensed back into liquid in the condenser and returned as feedwater to the steam generators. Seawater is circulated through the condenser cooling system to remove waste heat from the energy generation process. (PWRs typically have an overall efficiency of about 32-34%, so that only about a third of the energy released in the reactor core is converted to electricity - the rest is discharged as waste heat). Power levels for operating PWRs range up to as much as 1400 MW(e). For power levels at or below 900 MW(e) the plants become more truly dual-purpose plants, producing significant quantities of both water and electricity [4,5].

The Ap 600, is an advanced passive PWR configuration of 600 MWe power, designed to be simple, inherently safe and relatively inexpensive. It is a modular construction configuration in which components will be built and assembled off-site, which reduces construction time. When compared to standard PWRs, of similar size, the design simplifications reduce the requirements for valves (≈50%), pipes (≈80%) and for cables (≈ 70%). Among the significant improvements is a digitized control and instrumentation system and sealed pumps. All of this is intended to provide reliable and economical operation. Concerning safety aspects of AP 600 compared to standard PWR, it has passive systems to cope with accidents. The Ap 600 reactor pressure vessel, steam generator, emergency core cooling system are all built in within the containment building; a large steel tank with a 130 feet diameter and is surrounded by a concrete shield building [4].

The pressurized heavy water reactor (PHWR) is characterized by a horizontally oriented core, with the fuel channels housed in individual small diameter pressure tubes through which heavy water ($D_2O$) circulates as the primary coolant. The pressure tubes are mounted in a large diameter horizontal tank (Calandria) containing low temperature, low pressure heavy water as the moderator. Heat produced by the fission process in the reactor core is removed by circulation of primary coolant through a steam generator, which produces steam on its secondary (light water) side. As with the PWR, the secondary system circulates steam through a turbine and then a condenser, where it is condensed back into water and returned to the steam generator. Conversion efficiencies are very similar to those for the PWR, and so about two thirds of the energy released by fission is discharged as waste heat via the condenser cooling system. With the PHWR there is also a small amount of heat produced in the moderator, and this is removed via a separate moderator heat removal system.

Although PHWRs in excess of 800 MW (e) are currently in operation, the 900 MW(e) considered for this study was the PHWR 9 currently under development. None are currently in operation or under construction. This design is an evolutionary advance from the existing 600 MW(e) PHWR 6, incorporating typical features of innovative reactors: a number of technological advances intended to further enhance safety, reliability and economics. PHWR 6 (700 MWe class) reactors have consistently ranked amongst the top 10 in the world for lifetime performance. Canada has operated Units successfully, as well as the Republic of Korea, and Argentina for more than 17 years. PHWR 6 units have the highest lifetime capacity factor within their class. The design of the PHWR makes it a safe and natural choice for coupling with potable water production as its inherent safety assures the quality of the product water for public consumption or industrial or agricultural use [5].

## 3. SAFETY FEATURES

The task of coupling nuclear power and water desalination plants is very important, especially when coupling with distillation plants. Coupling designs should take into considerations, firstly, any possibility of radioactive contamination of the desalted water secondly, the possibility of penetration of salt water into the turbine circuit and, thirdly it should not be expensive. To achieve higher level of safety, a couple of features are added in the BWR+RO. One of them is the use of gas turbine generators (GTGs) as an emergency power source. Together with the conventional diesel generator (DG), the use of GTG enhances the diversity of emergency power sources. GTGs are widely used in many industries and the reliability of GTGs is as high as that of DGs. The other feature involves design for preventing a severe accident. For overpressure protection of the PCV, passive containment cooling system (PCCS) is included. The PCCS is composed of three independent trains in which shell-and-tube type heat exchangers condense steam in the PCV and water condensed in the PCC flows back to the RPV by gravity.

The main criteria used in the design of safety systems are simplicity, reliability, redundancy and passivity. Special emphasis has been placed on minimizing dependency on active components and operator's actions. The following are features of these systems:

1- First shutdown system (FSS): Consist of Ag-In-Cd alloy rods.
2- Second shutdown system: It is a gravity driven injection system of borated water at high pressure.
3- Residual heat removal system: This reduce the pressure on the primary system and removes the decay heat in case of a lost of heat sink.
4- Emergency injection system: This system prevents the core exposure in case of Lost of Coolant Accidents (LOCA).
5- Containment system: This is a pressure – suppression type with two major compartments, (a dry well and wet well).
6- Pressure relief system: This is aimed at protecting the integrity of the reactor's pressure vessel against over pressure in the event of an imbalance between the core power generated and the power removed by the systems.

***Plant Response to Accidents***

1- Blackout: It is one of the events with a major contribution to core meltdown probability in a conventional light water reactor. In the CAREM NPP, the feedback coefficients will produce the self-shutdown of the nuclear reaction. The extinction and cooling of the core and the decay heat removal are guaranteed without electricity by the passive features of the safety systems. Loss of power produces the interruption of the feed water to the hydraulically driven CRDs, and thus produces the insertion of the absorbing elements into the core. The residual heat removal system removes the decay heat.
2- Loss of coolant accident (LOCA): Since only small LOCAs are possible, and due to the large water inventory in the RPV, there is a long time span between the iniation of The LOCA and core exposure in comparison with conventional

PWRs. The largest break allows some minutes of depressurization before triggering the emergency injection system with the RPV at 15 bar and the core fully covered.

3- Main steam pipe break: It produces a transient that can be easily handled by the safety systems due to the small water inventory of the steam generators in the secondary side and the large water inventory of the primary system [6-8].

# 4. ECONOMIC ASSESSMENT

## 4.1. Calculation procedure and input parameters

The nuclear plant total annual production cost $C_t$ is defined as [9]

$$\mathbf{C_t = C_e + C_w} \qquad \textbf{(1)}$$

In terms of water and electricity unit cost, equation (1) is rewritten as

$$\mathbf{C_t = c_e}\,E + \mathbf{c_w\ W} \qquad \textbf{(2)}$$

Where: $\mathbf{c_e}$ = unit cost of electricity
$\mathbf{c_w}$ = unit cost of water production
**E** = annual electricity production
**W** = annual water production

$$\mathbf{c_w\ W = C_t - C_e}\,E \qquad \textbf{(3)}$$

Unit water production cost of the plant in terms of total cost and unit electric cost is given by:

$$\mathbf{c_w = [C_t - C_e E] / W} \qquad \textbf{(4)}$$

and

$$\mathbf{W = P_r \times 24 \times PF \times 365} \qquad \textbf{(5)}$$

Where: $\mathbf{P_r}$ = net water – production rate ($m^3$/day),
**PF** = plant factor

From Equation (4) and (5), water production unit cost could be represented as:

$$\mathbf{c_w = [C_t - C_e E] / [P_r \times 24 \times 365 \times PF]} \qquad \textbf{(6)}$$

A computer model DEASP (Desalination Economic Assessment Program) has been developed and used for the economic calculations. In this economic assessment, the impact of inflation on increasing some economic parameters was taken into consideration. Input parameters, nuclear power plants and power levels applied in desalination technologies and assumed plant cost for economic assessment are identified in Table (2). As shown from the Table, value of interest rate considered was chosen to be 10 % to account for the impact of inflation rate. Fuel cycle costs as well as construction costs were also increased by the same rate. Similar considerations apply to related items of construction lead time, lifetime, and decommissioning cost. All figures are to some extent based on specifications obtained from reactor designers or suppliers, but were harmonized to allow better interpretation of the results obtained. The desalination processes considered and their main characteristics are shown in Table 1. Values of: 50 000, 100 000, 240 000, 400 000 for NWPR were considered in the calculations.

Of the various power plant options considered, three nuclear plant types with different capacities are considered as described in section 2.2. Input data for these plants is based on "design expectations" for performance and economic characteristics, and not on actual operating experience. Accordingly, when comparing the analysis results for these plants with those from the other power plant options, different value for the plant specific parameter must be considered. While absolute comparisons in the cost of water production may not be appropriate, the changes in these costs under the varying conditions considered should be indicative of the trends to be expected.

**Table 2: Input parameters and assumed plant cost for economic comparison.**

| **Input parameter** | **PWR 60** | **PWR 900** | **PHWR 600** | **PHWR 900** | **HR 200** |
|---|---|---|---|---|---|
| Reference Power Plant Unit Net Output ($MW_e$) | 600 | 900 | 676 | 875 | 200 MW(th) |
| Reference Condensing Temperature (°C) | 42 | 42 | 42 | 42 | 42 |
| Technical status | Being developed | Existing | Being developed | Existing | Existing |
| Reference Net Thermal Efficiency (%) | 31.5 | 33 | 32.8 | 32.2 | N/A |
| Assumed Overnight Cost ($\$/kW_e$) | 1937 | 1600 | 1677 | 1552 | 486 |
| Availability (%) | 85 | 85 | 95 | 95 | 80 |
| Construction Lead Time (months) | 60 | 72 | 52 | 50 | 40 |
| Specific O&M Cost ($/MW-h) | 11 | 9 | 6.8 | 6.3 | 2.2 |
| Fuel (Cycle) Cost ($/MW-h) | 5 | 8.5 | 2.4 | 2.3 | 2.6 |
| Specific Decommissioning Cost ($\$/kW_e$) | 200 | 200 | 253 | 236 | 67 |
| Economic and Technical Life Time (Year) | 40 | 40 | 40 | 60 | 40 |
| Interest rate (SF/SN) (%) | 10 | 10 | 10 | 10 | 10 |
| Construction cost ($\$/MW_e$) | 1650000 | 1400000 | 1450000 | 1300000 | 40000 |

Desalination plant availability is typically much higher than that of power plants. The calculations carried out for this analysis assume the presence of a backup heat source for nuclear power plants, so that distillation processes can continue to operate when the power plant is not available.

In the comparative economic assessment performed, the cost of water storage, transport and distribution are not considered. These cost components are fundamentally site dependent and can only be analyzed on a case-by-case basis. These costs are intentionally not included in the calculations as they are not factors in the cost of water production.

## 4.2 Model Verification

Verification of the present model compared to DEEP code has been performed considering a sample calculations for 900MWe, water production cost using the three desalination techniques MSF, RO and MED. It could be seen from this figure that the present model exhibits conservative behavior with respect to DEEP calculations. The result of verification the present model verification with respect to DEEP code is shown in Fig. (1). A sample of DEEP model calculation has been chosen using RO technique coupled with 900 MW PHWR. As shown from this figure, the present model gives a conservative economic assessment calculation with respect to DEEP code. The results of DEASP showed about 2% increase in water production cost. This increase could be attributed to the variation of DEASP mathematical model in some parameters with respect to DEEP model.

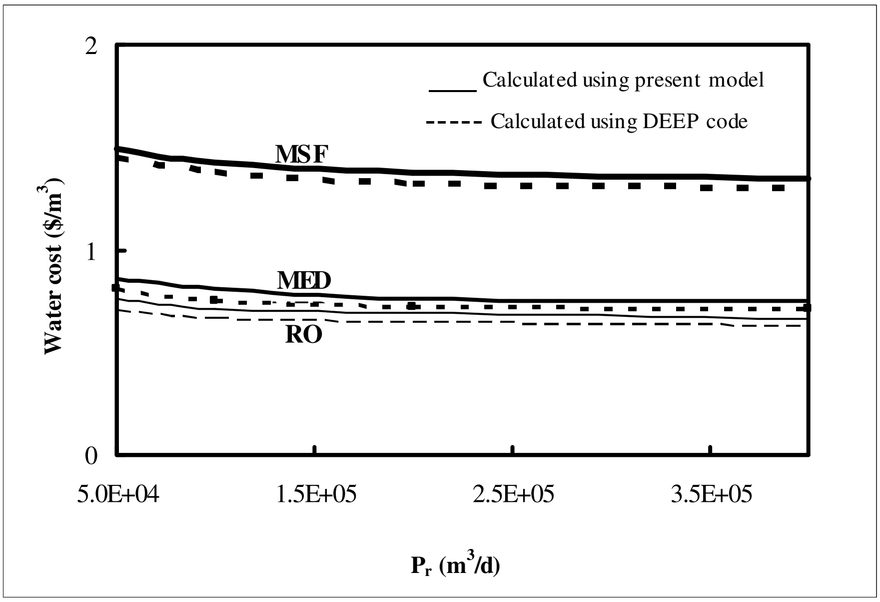


**Fig. 1: Verification of the present model with respect to DEEP code for PHWR type reactor of 900 MWe capacity.**

## 5. RESULTS AND DISCUSSION

Figures 2 and 3, illustrate the variation of water cost for different reactor types and different desalination techniques at net water production rate ($P_r$): 50,000 and 400,000 $m^3$/d respectively, while Figures 4 through 7 depict the variation of water cost as a function of $P_r$ rate for different desalination techniques and reactor types. From these Figures, analyses of the results are provided in the following sections. Water production costs are highly dependent on site-specific input data and assumptions, particularly electricity costs and economic assumptions.
Nevertheless, some general observations can be made, as discussed below:

Desalination prices range from 0.33 $/m³ to about 1.89 $/m³ depending upon the water plant type and size, energy source, specific region and economic scenarios. Over a wide range of power sources, the differences between the water production costs by RO and MED tend to be small as compared to the large differences introduced by changes in discount rate. Independent of the energy sources and regions considered, in all investigated eases water production costs from MSF appear to be systematically higher than those from RO or MED. If a relatively less stringent drinking water standard, such as WHO rather than EU, is adopted then whatever the energy source, the required desalination capacity or the region, water costs from RO are systematically lower than from other desalination processes. Water production costs with small reactors dedicated to heat production only are higher compared to larger dual-purpose nuclear reactors. Thus for example, for the MED process the water production costs from the heat-only reactor are about 30-40% higher than those from the dual-purpose reactor with the highest water costs, mainly because energy costs are higher roughly by a factor of two [(10)].

Water costs from RO systems are typically lower than those from MED systems (varying mostly from 10 to 30% in favour of RO). This gives RO an economic advantage even though its product water has a higher TDS content than that from MED. Water prices from RO are underestimated, due to the assumption of equivalence between the price of grid electricity used during unavailability periods of power production plants and the production cost calculated by DEEP for the specific power plant. Water prices from MSF systems are significantly higher than those from MED systems (by as much as 0.45-0.90 $/m³). The difference between MSF and RO is even greater. This appears to be a relatively significant economy of scale as plant capacities increase. This effect is more pronounced for lower sized plants. For higher capacities, the economics of scale are only a few percent of the water production costs [(11)].

For the production of desalted water, a nuclear power plant can be coupled with all types of desalination plants, i.e. with reverse osmosis (RO) plants, with distillation plants and their various combinations. Nuclear desalination combined with an RO plant has the following advantages: a) Maximum level of safety from the view point of preventing radioactive contamination of fresh water, since these two plants would be connected only by electrical cables; b) Connection of NSSS and the desalination plant via electrical cables only will facilitate the transient conditions for the nuclear plant in case of disconnection of the desalination plant, and c) As was precisely established, fresh water cost will be minimum if the reverse osmosis technology is adopted [12,13].

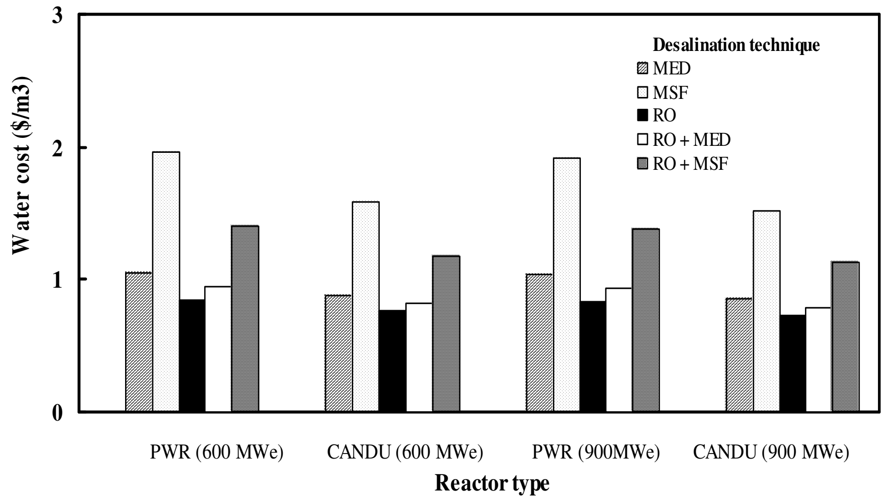


**Fig. 2: Variation of water cost with reactor type (at $P_r$ 50000 $m^3$/day).**

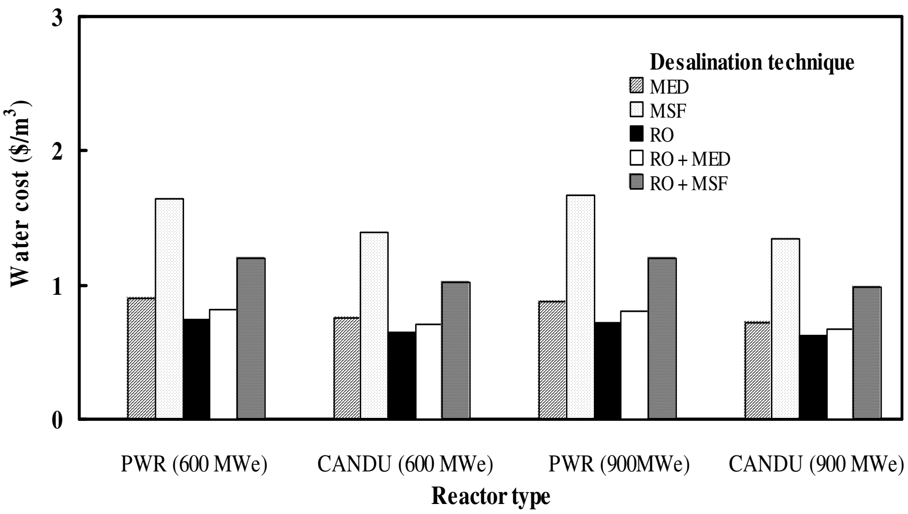


**Fig. 3: Variation of water cost with reactor type (at $P_r$ 400000 $m^3$/day).**

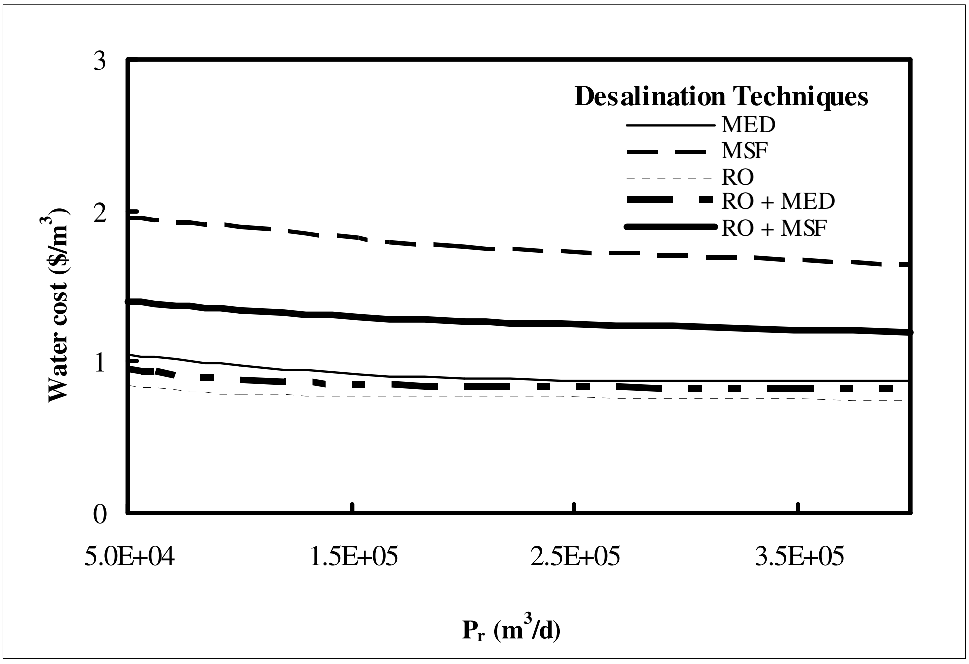


**Fig. 4: Variation of water cost with $P_r$ for PWR type reactor of 600 MWe capacity.**

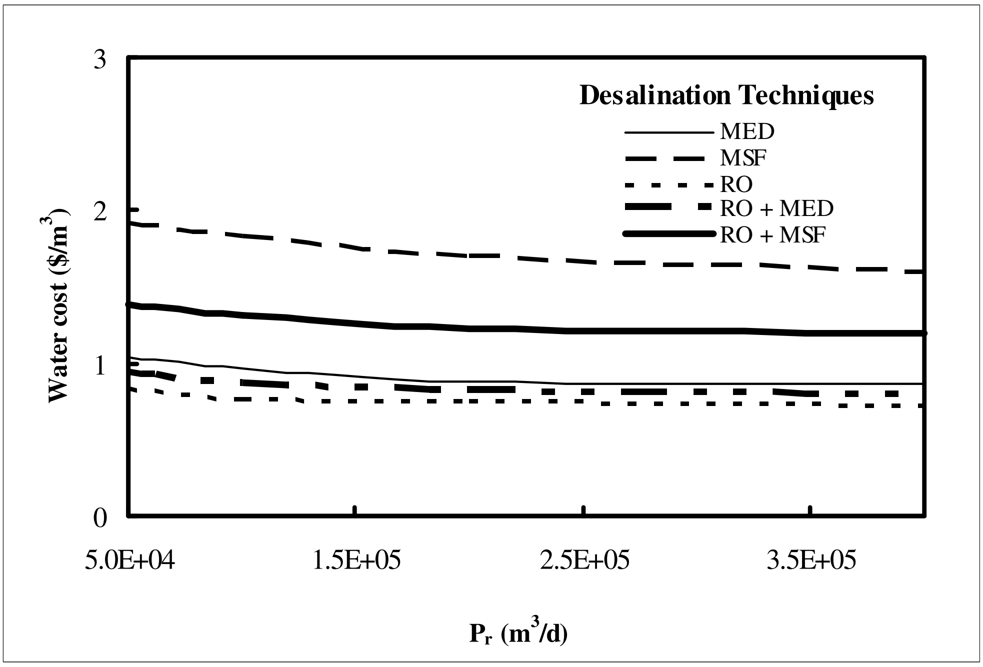


**Fig. 5: Variation of water cost with $P_r$ for PWR type reactor of 900 MWe capacity.**

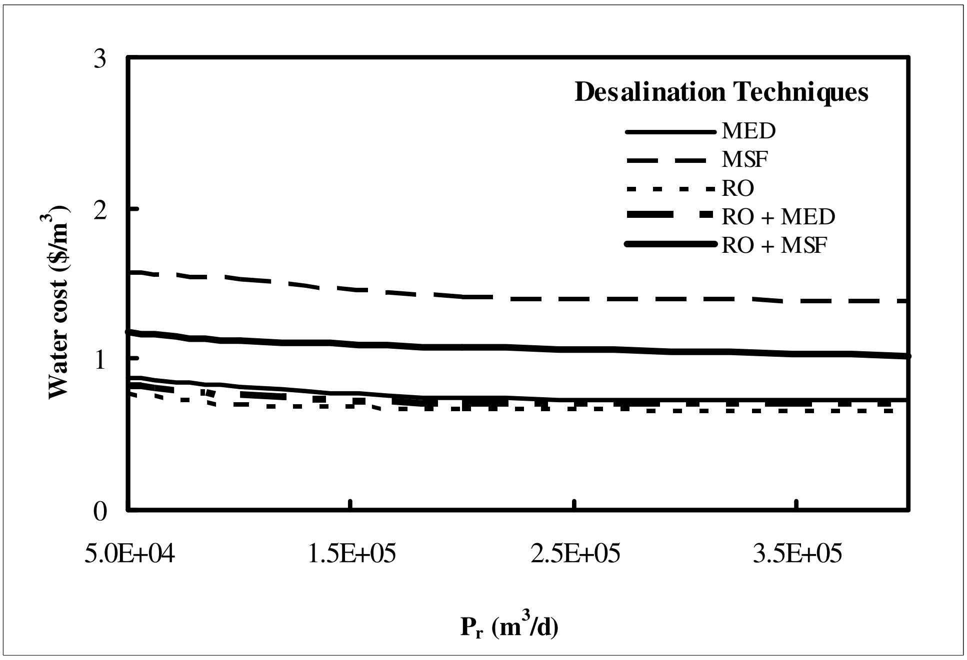


**Fig. 6: Variation of water cost with $P_r$ for PHWR type reactor of 600 MWe capacity.**

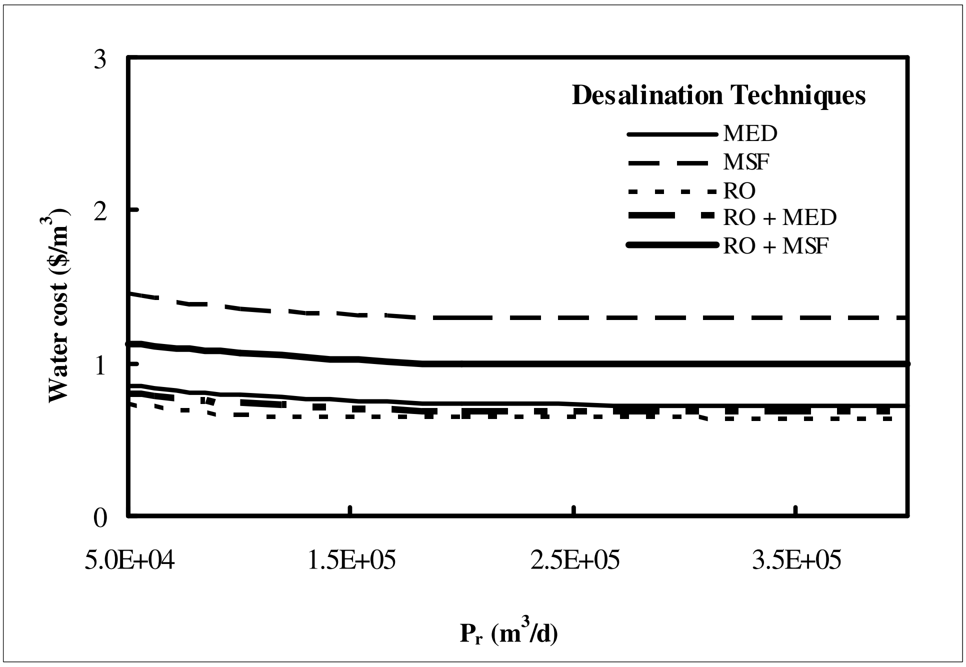


**Fig. 7: Variation of water cost with $P_r$ for PHWR type reactor of 900 MWe capacity.**

The disadvantages of membrane desalination are as follows:

- The need for significant pre-treatment of water so as to protect membranes from bacteria, free chlorine and oxygen;

- Low resistance of membranes to possible operational departures of the desalination plant resulting in failure of membrane and their costly replacement;
- A limited service life of membrane elements (require replacement over several years);

For the above reasons it is recommended that the RO facilities could be used to produce the cheapest desalted water (though not of premium quality). As opposed to RO plants, distillation plants have some advantages (they are capable of producing desalinated water of higher quality and have higher reliability and longer life cycle).The MED water plants are up-to-date facilities characterized by high cost efficiency and productivity of desalination process, quality and stability of produced distillate, low consumption of energy resources, low need in metal and occupied area, enhanced reliability and flexibility, simplicity of control, maintenance and repair. As an additional benefit, the cost of these plants is not very high and rather competitive in the international market (14). Combined (hybrid) distillation plants consisting of RO and distillation plants can be of special interest for consumers. In this case one can obtains very pure fresh water from the distillation plant, as well as fresh water from the membrane water plant with a higher level of salt but at a lower cost. The consumer has a choice for the optimal ratio of the distillation and RO product water (15).

Analysis of the results obtained indicated that the competitiveness of the desalination plant option would be significantly increased if the capital cost could be reduced, as currently envisaged for innovative reactors under development. Desalination costs range from 0.33 $\$/m^3$ to about 1.89 $\$/m^3$ depending upon the nuclear reactor (as an energy source), water plant types and sizes, and economic parameters. Over a wide range of power sources and regional conditions, the differences between the water production costs by RO and MED tend to be small. Independent of the energy sources and regions considered, in all investigated cases water production costs from MSF appear to be systematically higher than those from RO or MED, the nuclear option appears to be particularly advantageous with both RO and MED. Water production costs with small reactors dedicated to heat production only are systematically higher compared to larger dual-purpose nuclear reactors.

## 6. CONCLUSIONS

From the previous results and discussions, the following findings could be concluded:

1) For all types of selected nuclear reactor types and desalination techniques, water production cost at higher $P_r$ is lower than water cost at lower values of $P_r$.
2) Water production cost decreases slightly with the increase of $P_r$.
3) The MED desalination technique has the highest cost, while the RO technique has the lost value at all values of $P_r$.
4) The hybrid configurations RO + MED and RO + MSF give moderate water production costs.

5) The hybrid configuration RO + MED gives the lower production cost, and slightly higher than RO technique.
6) PHWR system with 900 MWe power rating gives the lowest water production cost with all techniques especially RO and RO + MED configuration.
7) It is recommended that reverse osmosis facilities be used to produce the cheapest desalted water (though not of premium quality).
8) For the production of desalted water, a nuclear power plant can be coupled with all types of desalination plants, i.e. with reverse osmosis (RO) plants, with distillation plants and their various combinations.
9) The use of nuclear energy for electricity and potable water production is an attractive, technically feasible and safe alternative to fossil energy options. In general, the economics of nuclear desalination are driven by the same factors as those for the economics of nuclear electricity generation. Lower power generation costs, with enhanced safety, coupled to the increased importance of environmental considerations would lead to a better competitive position for nuclear energy in comparison with fossil powered plants. Nuclear desalination, in consequence, would also be a competitive option.
10) In dual-purpose plants, designed for the production of both water and electricity, the cost of electrical power production is an important parameter both because of its contribution to the cost of water production and its potential for revenue generation as a separate commodity. Generally, regarding the levelized cost of water production, the PHWR yields the lowest costs.

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