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## Economic and Safety Aspects in Nuclear Seawater Desalination

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### Abstract

This study is a preliminary economic assessment of the coupling of nuclear reactors and desalination systems. In Algeria, the production of potable water from seawater desalination will reach in 2020 a capacity of 2.5 million m<sup>3</sup>/day. Consequently, the desalination of seawater will become in the next years an expanding industry. As this virtually unlimited water resource consumes a huge amount of energy, and because the power derives from fossil origin source, a diversification of the energy sources is foreseen for the future. For this purpose, nuclear power and renewable energies are two alternatives that are considered in the government energy policy to increase the electricity production nationwide. In this paper, we present the coupling of nuclear reactors and desalination processes. We are carrying out preliminary economic evaluation and comparison of various energy source options coupled with different seawater desalination processes. The various case studies include the cost and performance models of several types of nuclear and fossil energy sources, the levelized cost of water and power, a breakdown of cost components, energy consumption and net saleable power for each selected option[1].

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### 1. Introduction

Presently, problems raised by supplying of fresh water do not concern only dry countries but also rather well watered countries: demand for water increases by about 4% per year while natural resources remain the same. There is therefore an increasing unbalance between water needs and resources. The available volume of water on the earth is more than one billion km<sup>3</sup>, while the worldwide consumption hardly exceeds 1,000 km<sup>3</sup> per year [2]. Search a difference seems to be quite reassuring; but more than 97% of potential water supplies are found in oceans and not directly available. Under these conditions, it was logical to think of making these important reserves available, which has led, in the past decades, to rapid development of the desalination techniques.

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From a technical and economical standpoint, seawater desalination as an alternative source of potable water has become particularly attractive due to continuous innovations in the relevant technologies leading to a very significant reduction of desalination costs. Desalination is an energy-intensive process. One of the advantages of seawater desalination is the availability of manufacturing units of a water of purity sought for different uses. The other advantage is the security of water supply of constant safe quality. 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. Among the options which were chosen to allow the diversification of water resources: the desalination of seawater is the most promising. The use of this non-conventional water resource is a strategic issue because seawater is regarded as an inexhaustible resource.

Based on the estimations of only the Mediterranean region, it can be shown that around 2020, there will be additional need of water production of about 10 million m<sup>3</sup>/day. In Algeria, to avoid the inevitable water shortage expected by year 2025 [3,4], several factors militate in favor of the recovery of the alarming situation to achieve in the near future the balance between water supply and demand. This requires mobilizing the maximum surface and ground water resources, seeking new water resources, fighting against the wastes and improving the quality of the available water. The increase in water demand, in recent years in the three major categories (industry, agriculture and domestic), requires innovative planning of water resources.

Algeria which is characterized by a coastal band of 1,200 km on the Mediterranean Sea and an alarming dryness must turn to this huge inexhaustible water reserve. However, this virtually unlimited water resource consumes a huge amount of energy and diversification of the energy sources is foreseen for the future. It is considered in the government energy policy.

In the first part of this paper, we focused on the theoretical aspects of desalination processes, technical aspects of the coupling of a nuclear reactor and desalination systems, safety and its environment aspects.

Calculations are performed in the second part of this paper using the Desalination Economic Evaluation Program software DEEP-3, developed by the International Atomic Energy Agency (IAEA). We are carrying out preliminary economic evaluation and comparison of various energy source options coupled with different seawater desalination processes. The various case studies include the cost and performance models of several types of nuclear and fossil energy sources, the levelized cost of water and power, a breakdown of cost components, energy consumption and net saleable power for each selected option.

## **2. Desalination Process**

The desalination techniques which are available may be classified into two principal's categories according to their basis: processes using membranes and thermal processes.

The whole of the processes using the technique of distillation (except the process compression of vapor, VC) use thermal energy. The processes using the membranes, as well as the VC, call upon electrical energy or mechanics FIG.1.

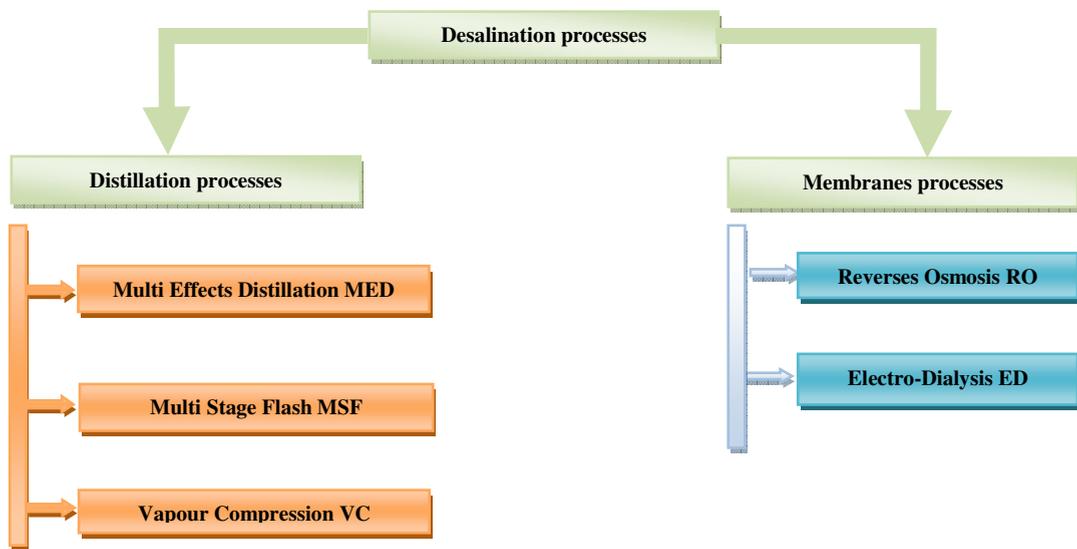


Fig. 1. Various desalination processes

### 3. Nuclear desalination

Nuclear desalination is defined as the production of potable water from sea water in an integrated facility in which both the nuclear reactor and the desalination system are located on a common site, sharing some of common systems or facilities, and the energy used for the desalination system is supplied by the nuclear reactor [6]

#### 3.1. Coupling aspect

In the case of nuclear plants that co-generate *heat* and *electric* power, the steam can be bled off at suitable points in the secondary circuit of the power plant for use by the desalination plant. However, protective barriers must be included in all cogeneration modes to prevent potential carry-over of radioactivity [7].

##### 3.1.1. Thermal coupling to Thermal Desalination Plant

Thermal energy can be supplied to the DP via an intermediate heat transfer loop. In such configuration, to transfer the thermal energy there is a direct fluid coupling between and desalination plant. These introduce the risk of radioactive contamination of the product water.

FIG. 2 gives a schematic diagram of the coupling arrangement of an MSF plant with a nuclear power reactor along with an intermediate heat exchanger as an additional isolation loop. A coupling arrangement for a nuclear power reactor with a MED plant is shown in FIG.3. It uses the flash loop as an isolation barrier.

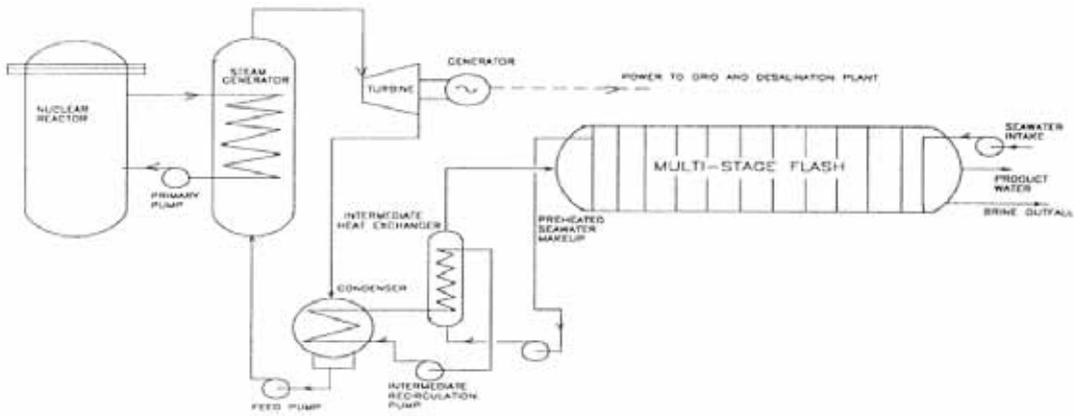


Fig. 2. Schematic diagram of a nuclear power reactor coupled to an MSF plant.

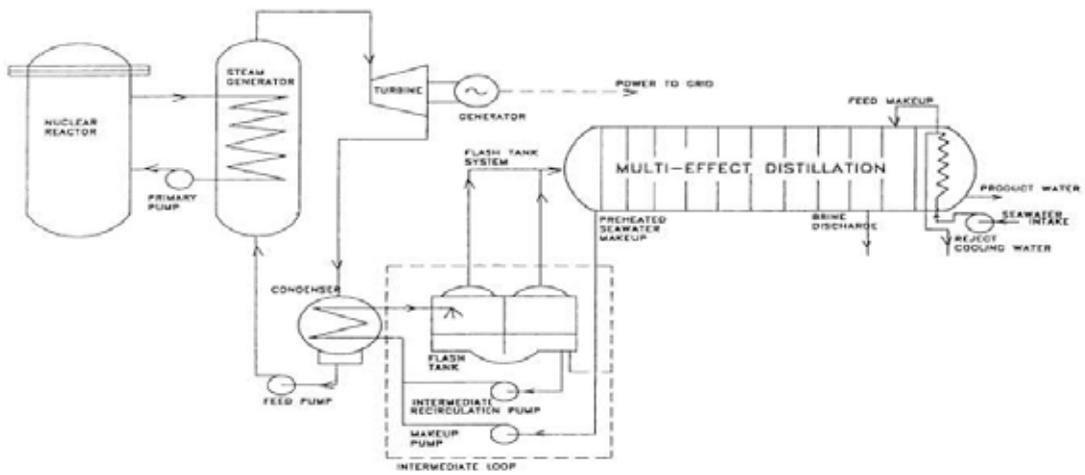


Fig. 3. Schematic diagram of a nuclear power reactor coupled to an MED plant.

### 3.1.2 Electrical coupling to Reverse Osmosis Desalination Plant

In the case of RO DP, only energy supplied by the nuclear power plant is electricity to operate the DP pumps. Since there is no thermal coupling between the reactor and the DP, there is no direct path for carryover of radioactive materials from the reactor to the product water. However as the RO plant shares common resources with nuclear power plant such as common sea water intake and outfall, the effect of this on the possible contamination of the product water must be evaluated.

### 3.1.3 Thermal and electrical coupling to hybrid Desalination Plant

Hybrid DP consists of both thermal and membrane based desalination processes. Coupling hybrid desalination plant with nuclear power plant is more complex as it involves both couplings.

It can be advantageous to use part of the electricity generated by the nuclear cogeneration plant to operate RO or MVC desalination plants in addition to thermal desalination plants. The hybrid system at the same location can play an important role in bringing down the water cost as well as making multiple product water qualities available. FIG.4. shows a schematic coupling arrangement for a hybrid MSF-RO plant [8].



- a) Any leakage in the isolation heat exchanger will be directed to the Isolation loop and not to the Desalination Plant loop.
- b) The allowed radioactive contamination for the Isolation loop is slightly higher and more easily monitored.

Disadvantage is that the operating pressure in the Desalination Plant loop is higher which is difficult to use as pressure of the Desalination Plant is dictated by the process and it is not very high.

### 3.2.2.2 Low-High-Low (L-H-L) configuration

The reactor loop pressure ( $P_1$ ) is lower than the IL pressure ( $P_2$ ); the DP loop pressure ( $P_3$ ) is lower than the IL ( $P_2$ ) (L-H-L). In this case, a pressure barrier against undesired transfer between the reactor loop and the IL.

Advantage of this configuration is that the radio activities are enclosed inside of primary loop.

Disadvantage is that is difficult to monitor the possible contamination of IL and to exclude the possibility of leakage from IL to final product.

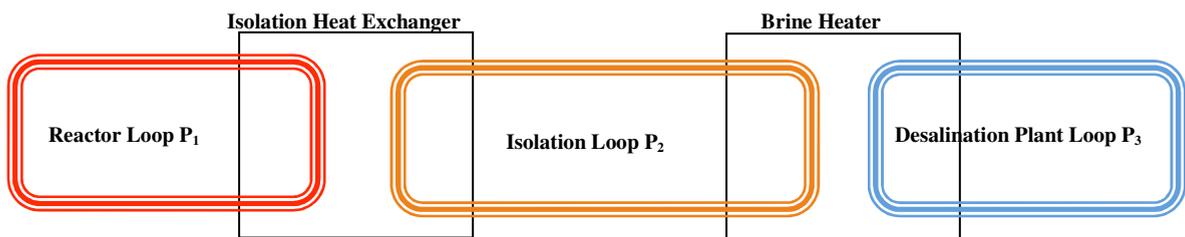


Fig. 5. Coupling of the desalination plant to nuclear reactor by an Isolation loop

## 4. Economic evaluation

Calculations are performed using the Desalination Economic Evaluation Program software DEEP-3 which has been developed originally by General Atomics under contract, and has been used in the IAEA’s feasibility studies[9,10]. This program allows the calculation of the levelised water and power cost, and gives a breakdown of costs components, energy consumption and net saleable power for each selected option. Specific power plants can be simulated by adjustment of input data including design power, power cycle parameters and costs. Also DEEP allows to perform cogeneration/desalination economic evaluation in order to analyse various desalination process and energy source options.

In this part of the present paper, we are carrying out economic evaluation and comparison of various energy source options coupled with different seawater desalination processes. The various case studies include the cost and performance models of several types of nuclear and fossil energy sources.

The desalination processes included in *DEEP* are summarised in Table 1

Table 1 Desalination processes contained in the spreadsheet

Process	Abbreviation	Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

The energy sources included in *DEEP* are steam power plants, gas turbines, combined cycle, diesel, heating plants and renewable energy, they are summarised in Table 2.

Table 2 Energy sources contained in the spreadsheet

Energy source	Abbreviation	Description	Plant type
Nuclear	PWR	Pressurised light water reactor	Co-generation plant
Nuclear	PHWR	Pressurised heavy water reactor	Co-generation plant
Nuclear	GTMHR	Gas turbine modular helium reactor	Power plant
Nuclear	SPWR	Small pressurised light water reactor	Co-generation plant
Nuclear	HR	Heat reactor (steam or hot water)	Heat-only plant
Fossil	SSB	Superheated steam boiler	Co-generation plant
Fossil	GT	Open cycle gas turbines	Co-generation plant
Fossil	CC	Combined cycle	Co-generation plant
Fossil	D	Diesel	Power plant
Fossil	B	Boiler (steam or hot water)	Heat-only plant
Renewable	RH	Renewable source of heat	Heat-only plant

### 5. Results and analysis of different combinations

The results of coupling the remaining reactors (PWR, PHWR) and CC with the desalination processes given Table 2 also give the water cost and the saleable power. This second parameter constitutes an additional argument for the selection of the economic option. Several reactors have been selected to be coupled to various desalination processes. Based on the Electricity Utility requirements the reactor’s size should not be greater than 600 MWe so its introduction into the grid could be made easily and early [11]. For all computations we assume a seawater temperature of 20°C, a TDS of 38500 ppm. Unit water costs were evaluated and presented in Fig 6 from a low cost of 0.58 \$/m<sup>3</sup> using Nuclear Steam Co-generation coupled with RO, to a high cost of 2.14 \$/m<sup>3</sup> with Combined Cycle (fossil) coupled with MSF. Furthermore, comparing the different desalination processes, one can conclude that the MSF process gives the highest cost. The normalized costs for these plants are summarized in figure 6

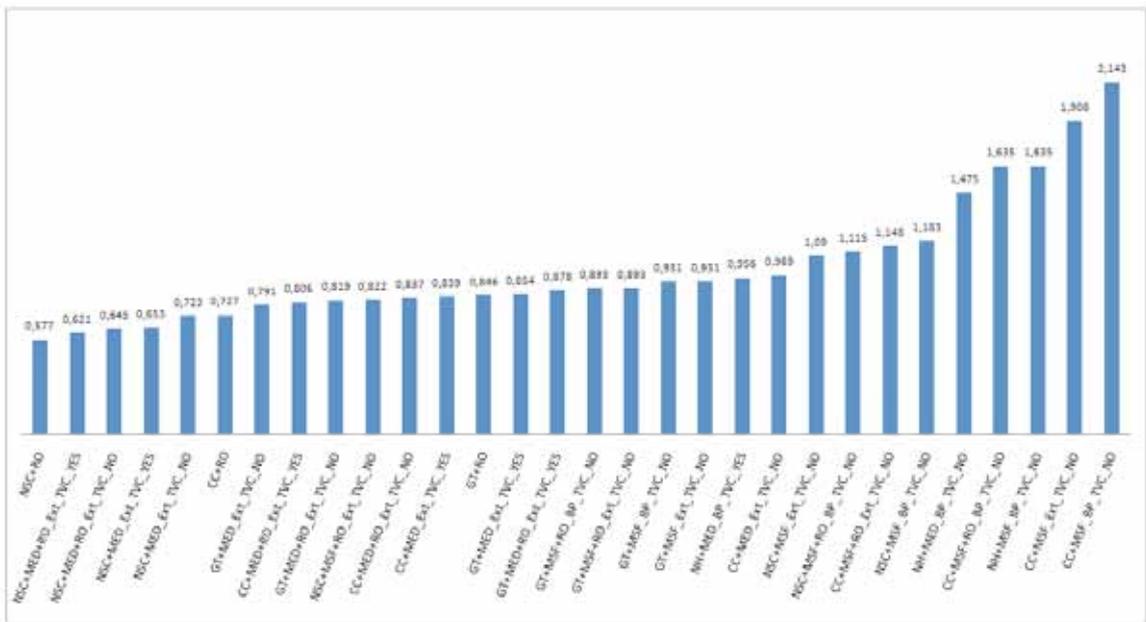


Fig. 6. The cost of water produced by various cases

### 5. Conclusions

Progress achieved in the techniques of desalination, had a very positive influence on the costs related to the fresh water production. These costs have decreased a lot during the last ten years, desalination by the nuclear reactor seems a very competitive solution, compared to the systems based on fossil energies not only for the simultaneous production of electricity and potable water, but also for the minimization of the emission of greenhouse effect gas.

The energy strategy adopted by Algeria, is allowing the diversification of the energies sources: nuclear and renewable in addition to existing fossil ones.

This strategy, in the medium and long term, will be answering the increasing demand for water by means of the nonconventional resources such as the nuclear desalination which could be a solution of substitution in the coastal areas of the country. This will meet mainly the domestic and industrial needs and sometimes even the agricultural needs in these areas.

Calculations are performed using the Desalination Economic Evaluation Program software DEEP-3 used in the IAEA’s feasibility studies. We are carrying out preliminary economic evaluation and comparison of various energy source options coupled with different seawater desalination processes. The various case studies include the cost and

performance models of several types of nuclear and fossil energy sources. It proves that nuclear desalination is more competitive compared to desalination using the fossil energy.

It may be concluded, that any cost estimate cannot replace a specific feasibility study including pilot testing, environmental aspects and transport cost.

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