PERSPECTIVES OF NUCLEAR ENERGY FOR SEAWATER DESALINATION

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1. Introduction

The worldwide availability of potable water greatly exceeds the amounts needed and used, but resources are not evenly distributed. The importance of having adequate supplies of potable water for growing populations and the complex problems of satisfying this need have been globally recognized (World Meteorological Organization (WMO) 1997).

There are regions where water is scarce and where the population is already at the mercy of inadequate supplies. Figure 1 shows the countries which are projected to experience water stress or water scarcity in the coming decades.

Among the various approaches to solving the water shortage problem is seawater desalination, a very promising method of securing abundant fresh water. When desalted, seawater can contribute to the solution of growing water problems wherever the sea is accessible. The basic principle of seawater desalination is to remove salt from seawater and bring down the dissolved solids to an acceptable level. In desalting seawater, energy for the desalination process is generally supplied in the form of either steam or electricity. To date, conventional fossil fuels have mostly been utilized as energy sources for existing desalination plants.

However, fossil energy resources are limited and their increasingly intensive use raises environmental concerns, including the threat of a gradual climate change with far-reaching consequences.

At the same time, worldwide demand for energy is steadily growing and adequate solutions are needed. Nuclear energy contributes significantly to the world's existing supply of energy and it has the potential to do even more.

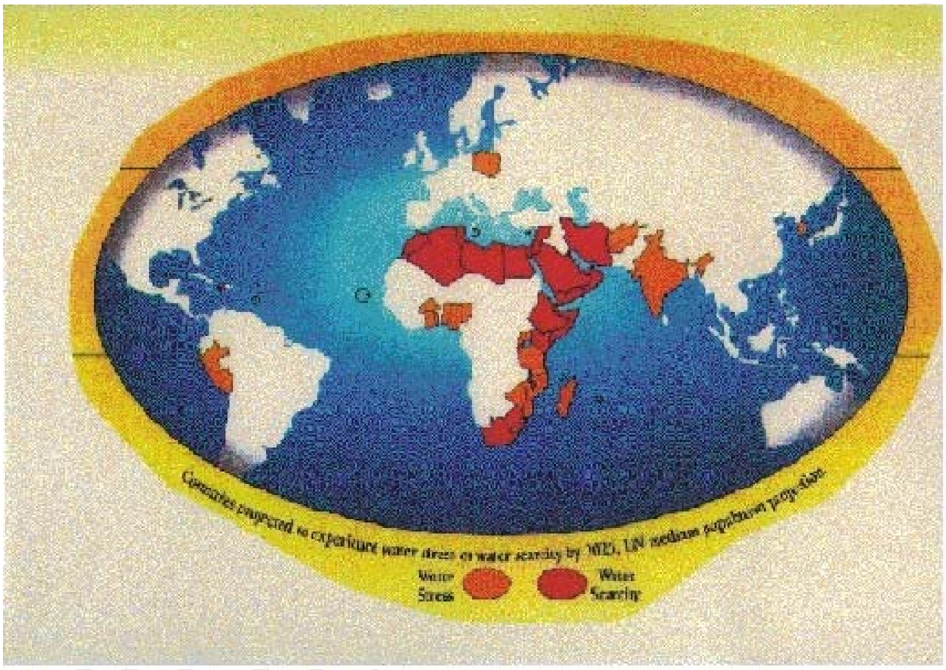

Figure 1. Countries projected to experience water stress or water scarcity by 2025, United Nations (UN) medium population projection (Engelman and LeRoy 1993)

2. The Early Years

Combining the use of nuclear energy with the industrial process of supplying potable water by seawater desalination was considered as far back as the 1960s. Indeed, at that time great optimism prevailed regarding the use of nuclear energy.

Several studies were undertaken by individual countries, organizations, and nuclear industries. At the request of its member states, the International Atomic Energy Agency (IAEA) performed several technical and economic studies between 1964 and 1967, which were issued in a technical reports series (IAEA 1964, 1966a, b, 1967).

The design and construction of the Shevchenko complex (now Aktau in Kazakhstan) for seawater desalination was launched by the former Soviet Union. The BN-350, a liquid metal-cooled fast reactor, went into operation in 1973 and since then has provided both electricity and heat for the production of potable water (Boranov et al. 1965; Muralev et al. 1997).

Developments in the nuclear field focused on large power reactors for electricity generation and the BN-350 in Kazakhstan is still the only power reactor in the world supplying heat for industrial-scale desalination, producing approximately 80 000 m^3 day^{-1} of potable water for municipal use (Figure 2).

Several nuclear power plants in Japan have been desalting a few thousand cubic meters per day each for feedwater make-up as well as for household use in the plants (Figure 3). In Ashdod, Israel, an integrated plant was operated continuously for over a year in the early 1980s which was designed to simulate the coupling of a multieffect distillation (MED) plant with a nuclear reactor.

A low-temperature, horizontal tube, multi-effect (LT-HTME) unit having a production rate of 17 400 m^3 day^{-1} was coupled to a 50 MW(e) oil-fired power plant. The heat to the desalination unit was supplied under conditions similar to those characteristic for a nuclear power plant, i.e. flashing cooling water used in the back pressure turbine condenser.

Major developments, however, have taken place in both nuclear power and in desalination. No further projects have been undertaken regarding the combination of nuclear energy and seawater technologies.

Figure 2. Evaporators for the nuclear desalination plant (Liquid Metal-cooled Fast Breeder Reactor (LMFBR) connecting an Multi-Effect Distillation (MED) Facility) in Aktau, Kazakhstan.

Figure 3. Nuclear desalination plant (Pressurized Water Reactor (PWR) connecting an Multi-Stage Flash (MSF) Distillation Facility) in Ohi, Japan.

3. Renewed Interest

At the 1989 IAEA general conference, a resolution was adopted to assess the technical and economic potential of nuclear desalination in the light of experience gained in recent years: desalination, which during the 1960s constituted an emerging technology with a status comparable to nuclear reactors for electric power at that time, has become an established commercially available process (Wangnick 1995), with further potential for improvements. Nuclear reactors for electric power have also matured.

Even though nuclear reactors have become a technically proven and economically competitive source of energy, which in 1998 supplied approximately 16 per cent of worldwide electricity consumption, they have been plagued by problems of public and political acceptance in many countries. While prospects for further penetration into the electricity supply market are now lower than expected earlier, interest in other applications, in particular seawater desalination, has reappeared.

A number of factors are contributing to the promotion of nuclear desalination technology. They include growing concerns about the environmental effects of burning fossil fuels, recognition of the benefits of diversification of energy sources, and the development of new advanced reactor concepts in the small- and medium-power range.

Since the renewal of the IAEA's activities concerning nuclear desalination, a growing number of countries and international organizations have expressed interest, participated in meetings, and provided information and support.

Following the 1989 general conference, the IAEA took steps to update its review of available information on desalination technologies and the coupling of nuclear reactors with desalination plants. The results were reported in an IAEA (1990) technical document. After the status review, the IAEA (1992) prepared and issued a report which contained an assessment of the economic viability of seawater desalination by using nuclear energy in comparison with fossil fuels. The study encompassed a broad range of both nuclear and fossil plant sizes and technologies in combination with various desalination processes. Other aspects, such as environmental and institutional issues, were also discussed. In 1991, in response to a request for technical assistance submitted by five North African States (Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, and Tunisia) a regional feasibility study on nuclear desalination was launched. The study was completed in 1995 with a technical document (IAEA 1996c).

Other work is being carried out in response to a resolution of the 1993 general conference concerning demonstration facilities of nuclear desalination. A study was performed to identify, define, and characterize a practical set of options for a demonstration of nuclear desalination. Work on this "options identification program" started in 1994 and was completed in 1996 with the publication of a technical document (IAEA 1996b).

A key outcome of the studies was the development of a convenient methodology for rapidly calculating the performance and costs of power and water production for various power and desalination plant couplings. The methodology is imbedded in a spreadsheet routine containing simplified sizing and cost algorithms which are easy to implement, generally applicable to a wide variety of equipment, and representative of state of the art technologies. The spreadsheet methodology was published in a computer manual (IAEA 1997a) and is available to interested users from the IAEA's section of Nuclear Power Technology Development. The methodology is reviewed further in section 7.

Furthermore, the IAEA carried out a study to establish a methodology for economic ranking of different co-generation plants for electricity and potable water as well as a cost allocation method for costing electricity and potable water based on exergy pro-rating. An IAEA (1997b) technical document was published which describes both methodologies and illustrates them for a representative site on the Arabian Peninsula. These activities, studies, and reports are not isolated efforts. Rather, they have been performed in the context of a multiyear effort, following a logical sequence and complementing each other.

4. Seawater Desalination Technologies

Seawater desalination is the processing of seawater, through the separation of dissolved saline components, to obtain fresh water with low salinity, adequate for drinking. In general, large-scale, commercially available, desalination processes can be classified into two categories: (a) processes that require mainly heat and some electricity for ancillary equipment (distillation processes) and (b) processes that require only electricity (membrane processes). Every desalination process requires energy, either heat and electrical energy (mainly for pumping) or electrical energy only (the use of mechanical energy instead of electrical energy is also possible). The lowest energy consumption including that for seawater pumps and water pre-treatment is currently obtained with reverse osmosis (RO) plants. After more than 40 years of intensive research and development in seawater desalination technology, only distillation processes and the RO process have achieved commercial, large-scale application (Wangnick 1996).

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