united nations educational, scientific and cultural organization

international atomic energy agency

the
abdus salam
international centre for theoretical physics

ICTP 40th Anniversary

SMR.1555 - 6

**Workshop on
Nuclear Reaction Data and Nuclear Reactors:
Physics, Design and Safety**

16 February - 12 March 2004

Status and Prospects for Nuclear Desalination

**Braj M. MISRA
International Atomic Energy Agency
Division of Nuclear Power
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna
AUSTRIA**

These are preliminary lecture notes, intended only for distribution to participants

Status and Prospects of Nuclear Desalination

B.M. Misra

Division of Nuclear Power

International Atomic Energy Agency (IAEA)

Vienna, Austria

Global Water Availability and Demand

Water, energy and environment are essential inputs for the sustainable development of society in the coming years and are therefore aptly mentioned as life support systems. These are therefore current issues of deliberations at national and international fora. Seventy percent of the planet is covered with water, but only 2.5% of that is fresh water. Nearly 70% of this fresh water is frozen in the icecaps of Antarctica and Greenland. Most of the rest is in the form of soil moisture or in deep inaccessible aquifers, or comes in the form of monsoons and floods that are difficult to contain and exploit. Less than 0.08% of the world's water is thus readily accessible for direct human use, and even that is very unevenly distributed[1].

Recent statistics show that currently 2.3 billion people live in water-stressed areas and among them 1.7 billion live in water-scarce areas, where the water availability per person is less than 1000 m^3/year. In fact, the situation is going to worsen further, statistics[2] show that by 2025 the number of people suffering from water stress or scarcity could swell to 3.5 billion and 2.4 billion of them are expected to live in water-scarce regions (see Figure 1). Water scarcity is a global issue, and every year new countries are affected by growing water problems

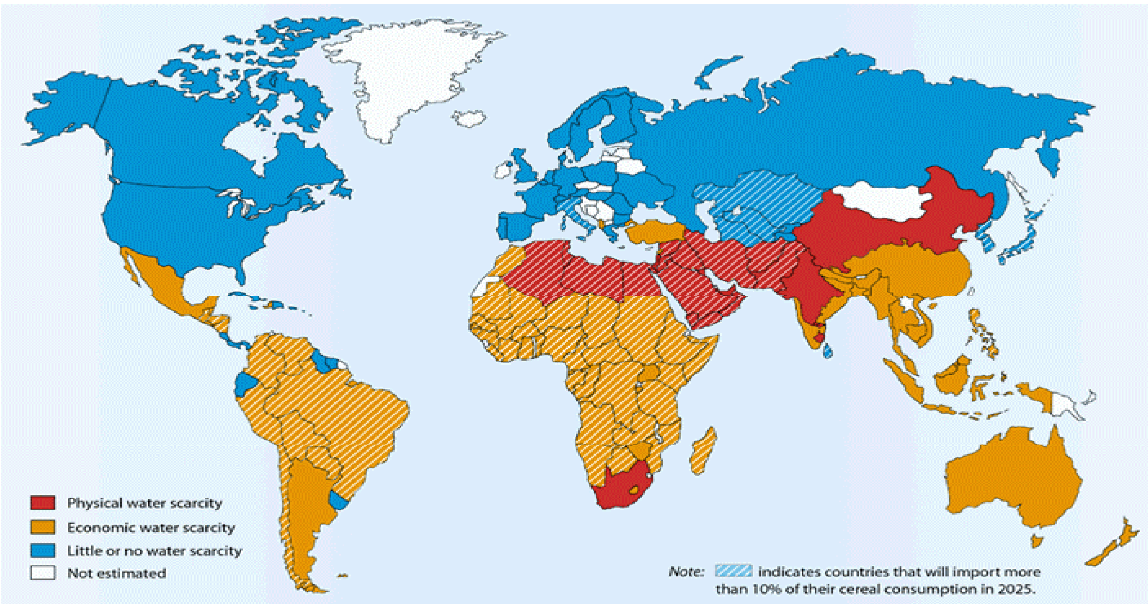

Fig. 1. Areas projected to experience economic and physical water scarcity by 2025 Data Source: International Water Management Institute (2000).

Desalination as an Alternate Source of Fresh Water

Better water conservation, water management, pollution control and water reclamation are all part of the solution to projected water stress. So too are new sources of fresh water, including the desalination of seawater. Desalination technologies have been well established since the mid-20th century and widely deployed in the Middle East and North Africa. The contracted capacity of desalination plants has increased steadily since 1965 and is now about 32.4 million m^3/d worldwide[3], as shown in Figure 2 (Wangnik, 2002). This corresponds to approximately 15,233 units with an average capacity of 2000 m^3/d.

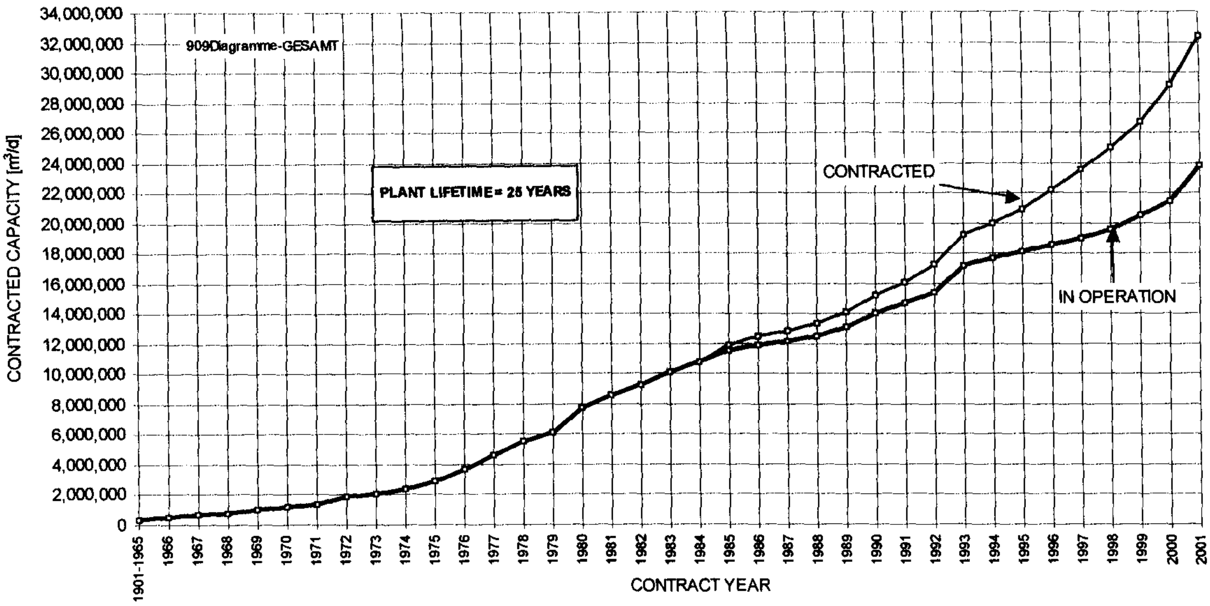

Fig. 2. Cumulative worldwide desalination capacity. The top line in the top figure shows total operating and contracted capacity. The bottom line in the top figure shows just operating capacity.

Large-scale commercially available desalination processes can generally be classified into two categories: (a) distillation processes that require mainly heat plus some electricity for ancillary equipment, and (b) membrane processes that require only electricity. In the first category (distillation) there are two major processes: multi-stage flash (MSF) and multi-effect distillation (MED). In both seawater is heated; the steam that evaporates is condensed and collected as freshwater; and the residual brine is discharged. In the second category (membranes) is the reverse osmosis process (RO), in which pure water passes from the high-pressure seawater side of a semi-permeable membrane to the low-pressure freshwater permeate side. The pressure differential must be high enough to overcome the natural tendency for water to move from the low concentration freshwater side of a membrane to the high concentration seawater side in order to balance osmotic pressures.

The reverse osmosis and few other membrane processes commercialised in recent years have also demonstrated the feasibility of effluent water treatment on large scale for water reuse for domestic, industrial and agricultural purposes. This also contributes to environmental protection.

The Role of Nuclear Power in Desalination

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. The desalination of seawater using nuclear energy is a feasible option to meet the growing demand for potable water. Over 150 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.

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

There are many reasons which favour a possible revival of the nuclear power production in the years to come: the development of innovative reactor concepts and fuel cycles with enhanced safety features which are expected to improve public acceptance, the production of less expensive energy as compared to other options, the need for prudent use of fossil energy sources, and the increasing requirements to curtail the production of greenhouse gases (GHG), toxic gases, particulates and acid rain, which are all associated with the combustion of fossil fuels.

It is thus expected that this revival would also lead to an increased role of nuclear energy in non-electrical energy services, which, at the moment, are almost entirely dominated by fossil energy sources. Among various utilization of nuclear energy for non-electrical products, using it for the production of freshwater from seawater (nuclear desalination) has been drawing broad interest in IAEA Member States as a result of acute water shortage issues in many arid and semi-arid zones worldwide.

Past Experience and Current Developments in Nuclear Desalination

Table 1 summarizes past experience as well as current developments and plans for nuclear-powered desalination based on different nuclear reactor types.

Japan now has over 125 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 1 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.

Table 1. Reactor Types and 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, RO	under design
	Russia	MED, RO	under design (floating unit)
BWR	Japan (Kashiwazaki)	MSF	never in service following testing in 1980s, due to alternative freshwater sources; dismantled in 1999.
PHWR	India (Kalpakkam)	MSF/RO	under commissioning
	Canada	RO (preheat)	under design
	Pakistan (KANUPP)	MED	under design
NHR	China	MED	under design
HTGR	South Africa, France, The Netherlands	MED, MSF, RO	under consideration

Figures 3, 4, and 5&6 show some view of nuclear desalination plants at Aktau (Kazakhstan), Ohi (Japan) and Kalpakkam (India)

Fig. 3. Evaporators at Aktau, Kazakhstan

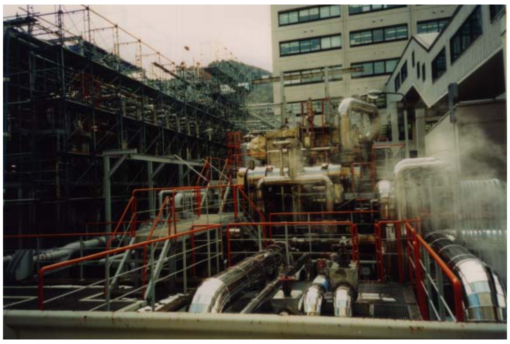

Fig. 4. Operating plant: Ohi, Japan

Fig. 5. Hybrid (MSF+RO) plant, Kalpakkam, India

Fig.6 View of SWRO membrane modules at Kalpakkam

The following paragraphs provide additional detail on the new developments listed in Table 1 and some others:

- Argentina has identified a site for its small reactor (CAREM), which could be used for desalination. Depending on financing, construction could begin in the near future.

- Canada has embarked on a three-year project to validate its innovative reverse osmosis (RO) system design concepts.

- China is proceeding with several conceptual designs of nuclear desalination using NHR type heating reactor for coastal Chinese cities.

- France has begun feasibility and economic studies on nuclear desalination as part of CEA's own innovation programme and as part of a proposed joint European study (the EURODESAL Project, Ecowater).

- Egypt is working on a two-year feasibility study for a nuclear co-generation plant (electricity and water) at El-Dabaa. Based on the results, government approval to proceed towards implementing the project will be sought.

- India is building a demonstration plant at Kalpakkam using a 6,300 m^3/d hybrid desalination system (MSF-RO) connected to an existing PHWR. Civil engineering and electrical work is completed, and India expects to commission the plant in 2004.

- The Republic of Korea is proceeding with its SMART (System-integrated Modular Advanced Reactor) concept. Work is into the basic design phase. The project is designed to produce 40,000 m^3/d of potable water.

- Morocco, in June 2000, halted a demonstration project at Tan-Tan originally intended to produce 8000 m^3/d of potable water using an NHR-10 of Chinese design. Possible next steps are being studied.

- Pakistan is considering coupling of a MED thermal desalination plant of 4,800 m^3/d capacity with existing PHWR at KANUPP.

- Russia is progressing with the design and licensing of a floating co-generation plant, based on a Nuclear Floating Power Unit (NFPU) with KLT-40C reactors, for the Arctic Sea coast area. Manufacturing of major components started in 2000.

- Tunisia has undertaken several studies to select a suitable desalination process and to identify what process could be coupled to a nuclear reactor. La Skhira site has been identified in the southeast part of the country for further study.

- 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 Brazil, Iran, Iraq, Italy, Jordan, Lebanon, Libya, Philippines, and Syria in the potential for nuclear desalination in their countries or regions.

New Developments

There has been many improvements and innovations in the desalination technology in recent years These include operation of RO plants at elevated temperatures using the seawater from condenser cooling water return enhancing the product output, operation of MED plants using low temperature steam resulting in savings in energy cost and possibility of waste heat utilization for vacuum evaporation of seawater. Various nuclear reactor types are being investigated for such studies.

The nuclear desalination project, KANUPP, Karachi envisages design studies for a 4800 m^3 /d MED plant utilising low grade heat from the PHWR reactor resulting in low cost of fresh water produced. The coupling scheme of the reactor and desalination system is shown in Fig.7.

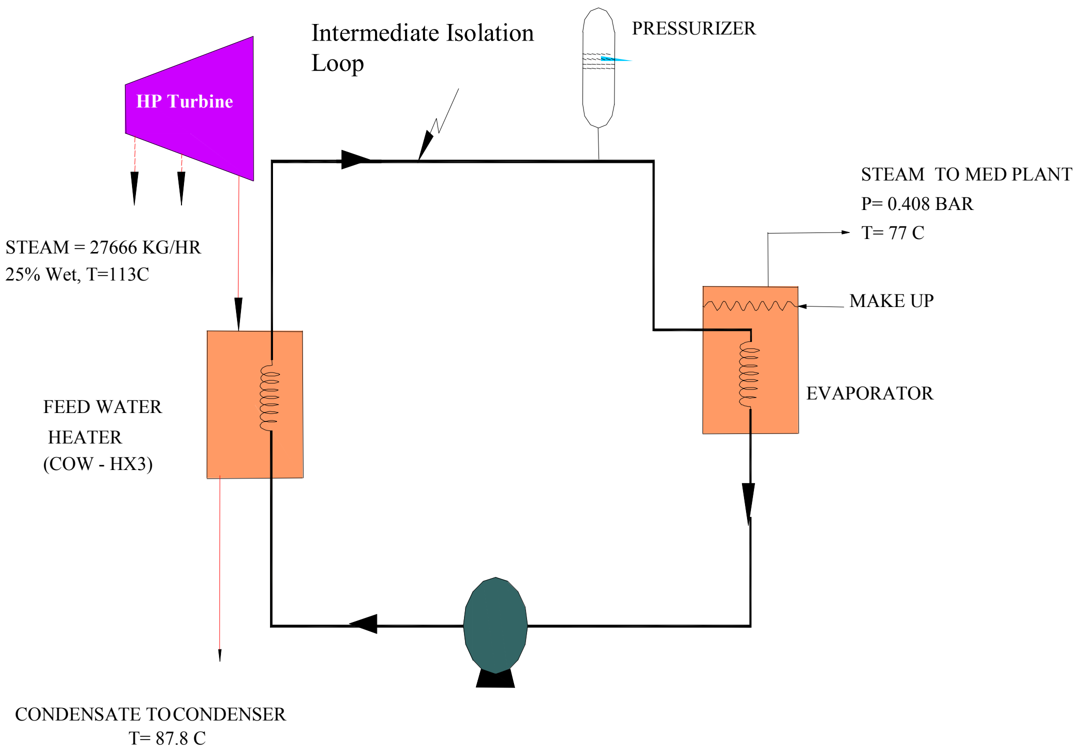

Fig.7 Schematic diagram of coupling of MED plant with KANUPP

The High-Temperature Gas-cooled Reactor (HTGR) design, one of the leading reactor concepts currently under consideration for future nuclear power plant deployment, is one of the candidate reactor designs well suited for seawater desalination applications. While traditionally, emphasis has been on HTGR suitability for high-temperature applications such as hydrogen production, the potential of this plant design for low-temperature applications such as nuclear desalination, is increasingly attracting interest with the provision of virtually cost-free waste heat. Since a good portion of the total production cost of seawater desalination, in the range of 30 to 50 %, is attributed to energy cost, the potential exists for a significant reduction in the cost of fresh water production using an HTGR in co-generation mode.

IAEA Recent Activities on Nuclear Desalination[4]

IAEA has been providing its Member States with the publication of guidebooks technical documents, and computer programmes on nuclear desalination as well as the provision of technical assistance through the framework of technical co-operation programmes.

A number of technical co-operation projects have assessed the feasibility of particular projects. In 1999 the IAEA launched an interregional technical co-operation project “Integrated Nuclear Power and Desalination System Design”. The project is designed to facilitate international collaboration between technology holders and potential end-users for the joint development of integrated nuclear desalination concepts, aiming at the demonstration of the viability of nuclear desalination at a specific site or sites. Under the IAEA regional technical co-operation framework, several international collaboration activities are underway, for example, between the Republic of Korea and Indonesia; and France and Tunisia.

A CRP on “Optimization of the Coupling of Nuclear Reactors and Desalination Systems”, which started in 1998, covers a review of reactor designs suitable for coupling with desalination systems, the optimization of this coupling, possible performance improvements and advanced technologies of desalination systems for nuclear desalination. The CRP is identifying optimum coupling conditions for a wide variety of nuclear system and desalination processes.

A new CRP on “Economic Research on, and Assessment of, Selected Nuclear Desalination Projects and Case Studies” has started early 2002 with the participation of 11 institutions from 11 Member States. It will deepen the economic aspects of nuclear desalination plants and give more confidence in this option.

IAEA’s DEEP computer code has been widely used by engineers and researchers from the interested Member States for preliminary economic evaluation of desalination by a wide range of fossil and nuclear energy sources, coupled to selected desalination technologies. This tool is under constant upgrade based on the inputs received by the users.

Economics

Economic comparisons indicate that water costs (and associated electricity generation costs) from nuclear seawater desalination are generally in the same range as costs associated with fossil-fuelled desalination. A detailed economic analysis by the IAEA looks at three representative water shortage regions distinguished by their seawater and economic characteristics relevant to desalination. The three regions are Southern Europe (South of France, Italy, Greece, Turkey and Spain); the North Africa, Red Sea and South East Asian region; and the Arabian Gulf region. Given the conclusion that nuclear and fossil-fuelled desalination are broadly competitive with each other, any particular future investment decision will depend on site-specific cost factors and on the values of key parameters (fuel price, interest rate, construction time, etc.) at the time of investment. Higher fossil fuel prices would of course favour nuclear desalination; higher interest rates would favour less capital-intensive fossil-fuelled options.

The broader picture however, is that the worldwide use of desalination is still negligible compared to the demand for fresh water. To become a noticeable (and quantifiable) market for nuclear energy, desalination needs to compete successfully with alternative means of increasing fresh water supply. For nuclear desalination to be attractive in any given country, two factors must be in place simultaneously: a lack of water and the ability to use nuclear energy for desalination. In most regions, only one of the two is present. Both are present for example in China, the Republic of Korea and, even more so, in India and Pakistan. These regions already account for almost half the world’s population, and thus represent a potential long-term market for nuclear desalination. The market will expand further to the extent that regions with high projected water needs, such as the Middle East and North Africa, increase their nuclear expertise and capabilities.

Recent feasibility studies on the economic evaluation of coupling NHR-200 with VTE-MED process has been carried out in China. The analysis was based on the site-specific case study of Shandong nuclear desalination project, domestic market price in China and innovative technical design. As a result the specific desalted water cost for a 160,000 m^3/d plant was estimated to be 0.61 US$/$m^3$. Similar economic evaluation of the integrated SMART desalination plant of 40,000 m^3/d capacity was carried out using IAEA's DEEP. The water cost range from 0.70 to 0.90 US$/$m^3$. The projected cost of water from Russian KLT-40 floating reactor based nuclear desalination plants is also in the above ranges. These studies indicate the possibility of safe and economic production of potable water from nuclear desalination plants in the future.

For the case of HTGRs, assuming an MED plant life of 25 years, an availability factor of 90% and an interest rate of 5%, a total production cost of water around US$ 0.50/m^3 has been estimated which is competitive with the current desalted water prices. Introduction of an RO unit is also possible utilizing the electrical power from the reactor in off-peak periods.

References:

1. Helmer R., International Symposium on Seawater Desalination with Nuclear Energy, Taejon, Republic of Korea (1997)

2. Sommariva C. and M. McDonald, Desalination & Water Reuse Quarterly, Vol. 13/2, p. 13 (2003)

3. Wangnik K., IDA Worldwide Desalting Plants Inventory Report No. 17 (2002)

4. IAEA Web page on Nuclear Desalination