Desalination of Sea Water Using Nuclear Heat

by Nenad Raisić

Fresh water, at low cost, is in increasingly short supply in many parts of the world. Aside from the chronic water shortage problems in arid regions, the difficulties are particularly acute in large metropolitan areas which expand faster than the water supply from nearby natural water resources can be expanded. In fact, for a number of large metropolitan areas, the alternative to costly transportation of fresh water over long distances from remote natural sources is the desalination of sea water.

At present, desalination is the only major unconventional source of water supply of economic significance. It is the only alternative that is technically feasible with respect to large-scale operation. The total world desalination capacity is about 2.1 million cubic metres per day, which is indeed a marginal addition to conventional water supplies. The rate of expansion of desalination capacity during the past 10 years has been 18% per year, and it is almost certain that the future rate of expansion will be much higher. Table 1 shows the locations

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Table 1: Distribution of Desalination Plants around the World

Region	Number of Plants	Capacity (cubic metres per day)
USA and US Territories	372	352 000
Other North America	41	48 000
Caribbean	39	128 000
South America	24	24 000
Great Britain and Ireland	69	64 000
Europe	149	272 000
Africa	104	228 000
Middle East	153	584 000
Asia	68	272 000
Australia and the Pacific	10	8 000
USSR	7	120 000
All Locations	1036	2100 000

Source: Reference [1].

of existing desalination plants. The world's only nuclear desalination plant is at Shevchenko in the USSR. Using steam from a nuclear power plant, it produces 120,000 cubic metres of desalted water per day.

Noteworthy is the desalination project which the government of Saudi Arabia is launching for the next six years, with a total capacity of 2 million cubic metres of fresh water per day. Other desalination projects are also being planned in the Middle East.

The major limitation of desalted water is its high cost. Desalination is not able to compete with conventional fresh water supplies except in those cases where water must be transported over long distances. In fact, transportation of water up to several hundred kilometres is generally less expensive than desalination.

Not all users of water can afford high-cost water. This is particularly true with respect to the use of water in agriculture and industry, where consumers can hardly pay more for water than their competitors in the world market. Therefore, the major market for desalination plants has been limited to municipal use, where the cost of water is less important than in agriculture or industry. Municipal users have found that high-cost water is preferable to water shortages or water-use limitations. Up to 80% of the present world desalination capacity supplies urban areas, and the remaining 20% is for military and industrial use. Figure 1 shows the use of desalination plants sold between 1951 and 1974.

A major portion of the cost of desalted water is the cost of the energy required in the process. At present, oil is used almost exclusively as the energy source for desalination plants, and with current oil prices, the fractional contribution of oil to the total cost of desalted water approaches 70%. Few other industrial processes are so energy intensive.

Consequently, one can assume that desalination can be a long-term solution to water supply problems of large metropolitan areas only if the expensive fossil fuel might be replaced by a readily available and cheaper source of energy. This requirement can potentially be satisfied by nuclear energy.

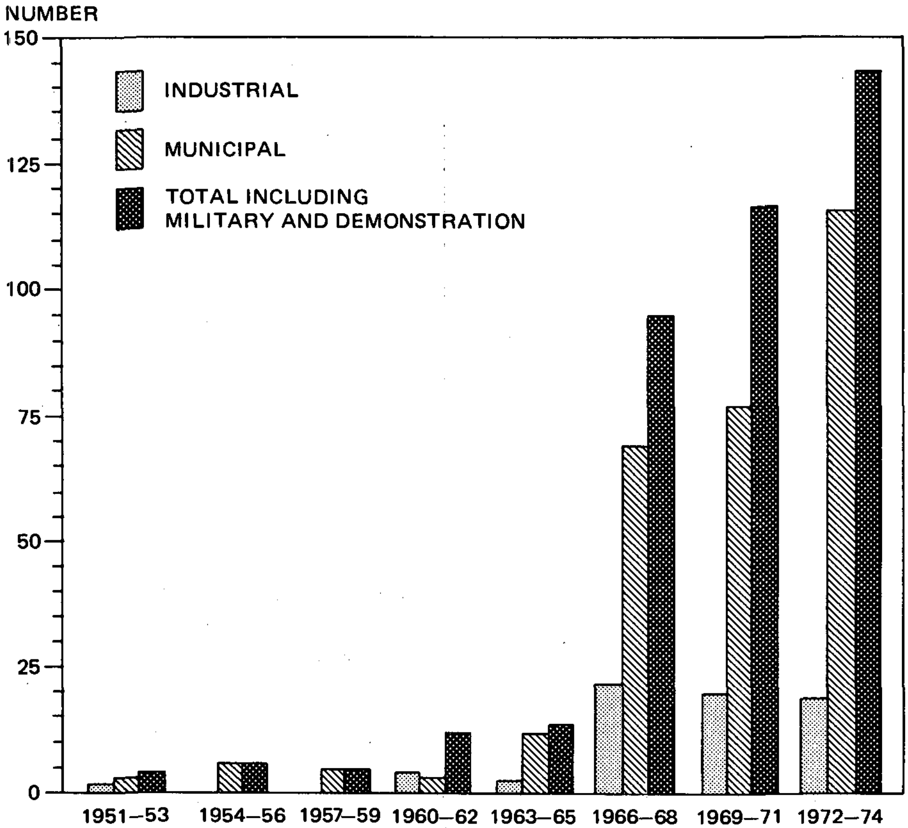
Nuclear desalination had been considered in the past; however, before the abrupt increase in oil prices, nuclear power was not competitive with low-cost oil. Despite a number of studies, no commitments other than the plant in the USSR were made in favour of nuclear desalination.

NUCLEAR REACTORS AS HEAT SOURCES

The heat produced by nuclear reactors can be used either for the production of electricity or it can be applied directly in industrial processes. Depending on the type of reactor, heat can be extracted at various temperatures in the form of hot gas, steam or hot water. The application of low pressure and low temperature steam in industrial processes is particularly promising because commercially available nuclear reactors can produce large quantities of such steam at relatively low cost.

Distillation is the process most frequently used in desalination plants. Up to 90% of all desalted water is produced at present by distillation and the rest is produced by membrane processes, namely, electro-dialysis and reverse osmosis. For the distillation process, the heat requirements in the form of low pressure and low temperature steam are 45 to 65 kWh per cubic metre (160 to 240 kJ per kilogram) of product water.

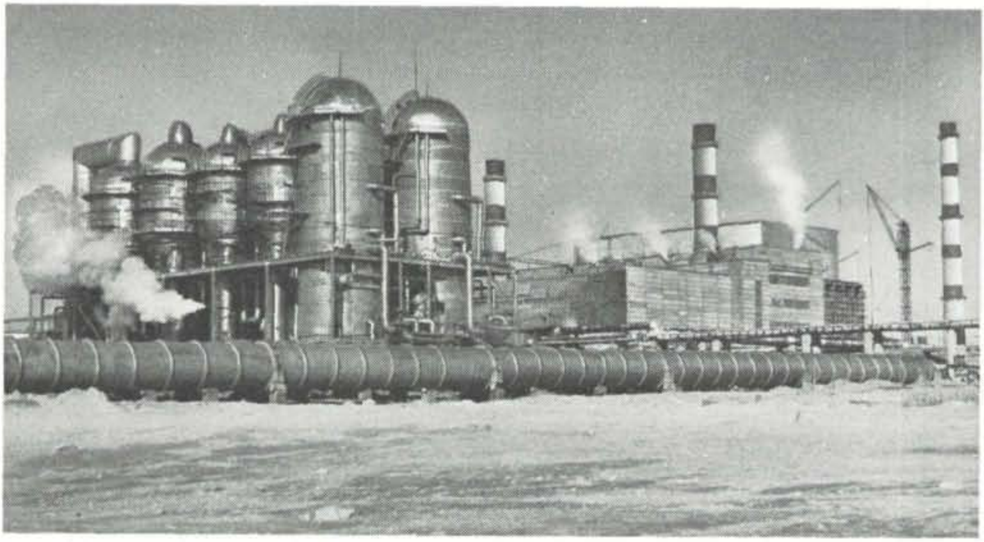
Figure 1: World-wide Sales of Land-based Desalting Plants with Capacities of One Million Gallons per Day or More



Source: Reference [1]

There are two approaches to the use of nuclear reactors in desalination: they can be used for a single purpose (i.e. heat production) or for dual purpose (generating electricity and heat production). For either application, the nuclear reactor must meet several requirements: (1) it should be available in sizes of practical interest for dual power/desalination or for desalination only; (2) the technology of the particular reactor type should be well developed to guarantee safe and reliable operation; (3) the economics of heat production should be attractive and competitive with other available energy sources.

The size of the nuclear power plants to be used for desalination is of particular importance. The smallest nuclear power plant commercially available at present is 600 MWe, or 1900 MWth. If used for the single purpose of desalination, this plant size could satisfy the heat requirements of a desalination plant with a capacity of 700,000 to 800,000 cubic



Distillation plant at the Shevchenko Atomic Power Station, USSR.

metres per day of desalted water, sufficient for a city of 1.5 million inhabitants. However, the desalination plants that are presently available are not large enough to handle all of the heat output from a 1900 MWth reactor. Therefore, nuclear reactors with 135 MWth, 260 MWth or 1100 MWth outputs are being considered as potentially more suitable for desalination plants with production capacities of, respectively, 50,000 100,000 or 400,000 cubic metres of desalted water per day.

Another solution to the problem of plant size mismatch is to use commercially available nuclear power plants for dual purpose operation. In a dual purpose power plant, the steam is normally extracted from the turbine after being expanded to some degree. In principle, one can select the ratio of water/electricity production by deciding at what temperature and pressure the process steam should be extracted. Typical production ratio may vary from 120 litres/kWh down to 20 litres/kWh. In all cases, a reduction in the amount of electricity that is produced cannot be avoided. This reduction varies from 56% for the 120 l/kWh ratio to 10–20% for the 20 l/kWh ratio [2].

Dual purpose nuclear power plants might be an adequate solution for the water supply problems of some rapidly expanding metropolitan or arid industrial areas. The size of the desalination plant can be tailored to the existing demand and the excess capacity of the nuclear plant can by used to generate electricity.

For other metropolitan areas, however, it may be preferable that the first desalination plants use smaller power plant units that can satisfy the short and medium term needs for water and provide at the same time sufficient experience for future, larger desalination operations.

Small nuclear reactors in the size range 300 to 1000 MWth [3] might be best suited to situations where water production capabilities have to be added to the existing water supply system at regular intervals. Construction of desalination plants in smaller sizes may be justified because the scaling factor in desalination installations does not play a significant role in the capital cost of water production. Water production is proportional to the heat transfer area of the evaporator installation, and operation of the small power plants may have advantages with respect to safety and availability.

Aside from the aspect of size, safety and high availability are the next most important factors in considering nuclear reactors for desalination. Higher than usual safety is required so that the plant can be located close to a metropolitan area in order to keep water transport to a minimum. High availability means that the reactor should be capable of operating continuously for long periods without forced outages.

ECONOMICS OF NUCLEAR DESALINATION

The evaluation of the cost of water from nuclear desalination plants is hindered by several difficulties. First, as in any dual purpose plant, the sharing of cost between two or more products is rather arbitrary, and second, in the present period of escalation of both raw material and industrial product prices, any estimate of water production cost quickly becomes obsolete.

Nevertheless, because energy is the primary cost in producing desalted water, a comparison can be made between conventional and nuclear desalination.

Industrial steam production costs in single and dual purpose nuclear reactors have been studied recently by the Oak Ridge National Laboratory in the USA [4, 5]. On the basis of this data, a comparison of steam production costs from conventional and nuclear sources is made in Table 2. It should be pointed out that the costs are expressed in early 1976 US $, assuming a 13.9% fixed charge rate for utility financing of nuclear power plant capital costs.

The lowest cost steam is from a large dual purpose nuclear plant. If steam is extracted from the back end of the turbine for heating the brine, the costs could be even less, perhaps as much as 50% lower.

The International Atomic Energy Agency has been studying the feasibility of nuclear desalination since the 1960's and has published a guide for evaluating both the capital and energy cost of water from nuclear desalination plants [6].

Table 2: Expected Prime Steam Production Costs from Nuclear and Conventional Plants

	US $ per million kJ
Residual oil-fired plant, oil at US $ 11–14/bbl	2.51–3.20
Low-sulphur vs. western coal, US ¢ 74-183/10^6 BTU delivered to Houston	1.89–3.13
3750 MWth dual-purpose nuclear plant PWR, 2 units	1.71
313 MWth single-purpose plant, single unit	2.84

Table 3: Estimated Energy Cost of Water from Desalination Plants

	US $ per cubic metre distilled water
Conventional boiler with residual oil at US $ 11–14/bbl	0.56–0.71
Single-purpose nuclear plant (313 MWth), one unit	0.63
Dual-purpose nuclear power plant 3 750 MWth, 2 units (prime steam)	0.38
Dual-purpose nuclear power plant 3 750 MWth, 2 units (exhaust steam saturated at 115°C)	0.25

The energy cost of water from desalination for different energy sources is shown in Table 3. It was assumed that the desalination plant performance ratio would be 4.5 kg water/1000 kJ of heat output. This estimate shows the obvious advantage of using nuclear heat for desalination purposes. The lowest cost is from a dual purpose nuclear power plant using exhaust steam.

A number of IAEA Member States have expressed their interest in nuclear desalination. The governments of Egypt, Iran, Israel and Kuwait are considering the construction of nuclear desalination demonstration or production plants and other countries are closely following developments in this field.

References

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