NUCLEAR POWER FOR SALT WATER CONVERSION

Pressure on water resources is resulting in many countries from population growth, rising living standards, and the increasing demands of industrialization; there is, in consequence, a corresponding interest in the possibilities of large-scale desalting of water. The application of nuclear energy to desalting is being studied by IAEA, with special reference to the needs of developing countries.

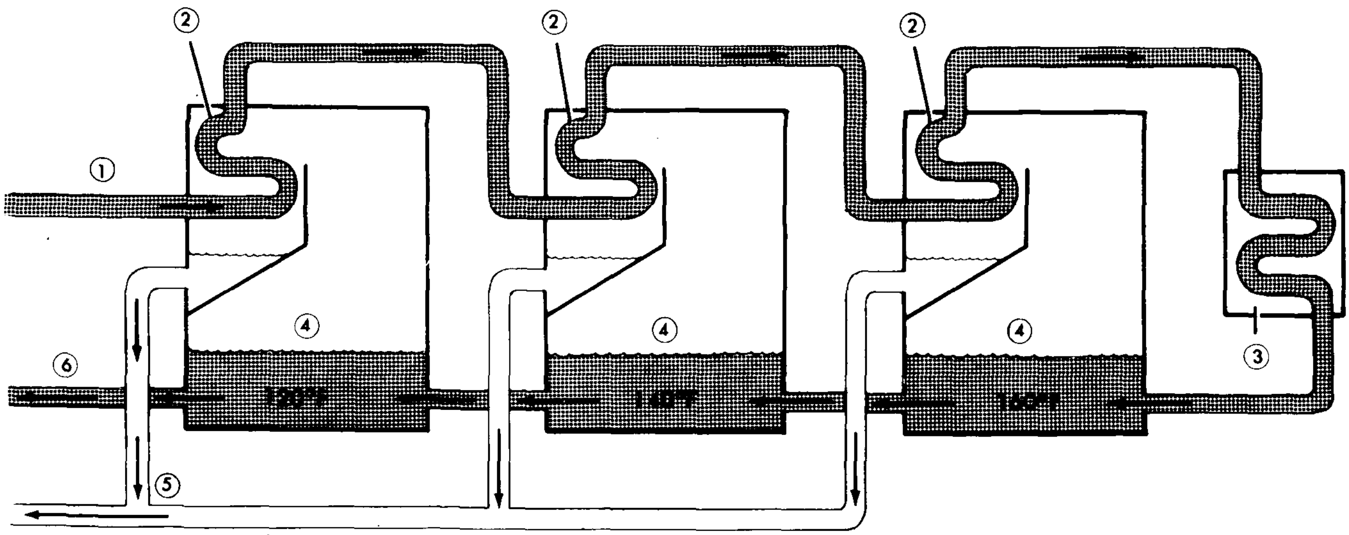
President Johnson recently expressed the interest of the USA in co-operating with other countries anxious to cure water shortages. "This would be a part of a general programme for pooling experience and knowledge in this important field," he said. "The International Atomic Energy Agency is a focal point in this programme."

A number of technical and economic studies have been undertaken by other organizations in several countries. The desalting of salt water by distillation or other processes has long been familiar, but usually only on a small scale and at relatively high cost. The principal question today is whether much more economical results can be obtained by a great increase in the scale of operations, and by enlisting the most modern techniques.

The matter is of most immediate interest to the arid regions. It was as a result of a request from Tunisia, following the 1962 General Conference, that the Agency undertook a series of studies. In March 1963 a group of experts met in Vienna under the chairmanship of Mr. J. K. Carr, Under-Secretary, US Department of the Interior, to discuss how the Agency could best help developing countries to use nuclear energy for desalting. This was followed by the visit of an Agency staff member to Tunisia with a UN mission and by the convening of a further expert panel in September 1963. This meeting was under the chairmanship of Mr. Carr and of Mr. J. T. Ramey, Commissioner, US Atomic Energy Commission. Eleven countries were represented, as well as the United Nations and the Food and Agriculture Organization. The panel examined the technical situation, including conversion methods and reactor systems.

Purification Process

Nuclear energy is, of course, only one of several possible sources of heat or electricity for the operation of desalting plants; which is to be used is mainly a question of economics. As for the desalting plant proper, this may be one of several systems, some of which employ heat and some electricity.



FLASH DISTILLATION

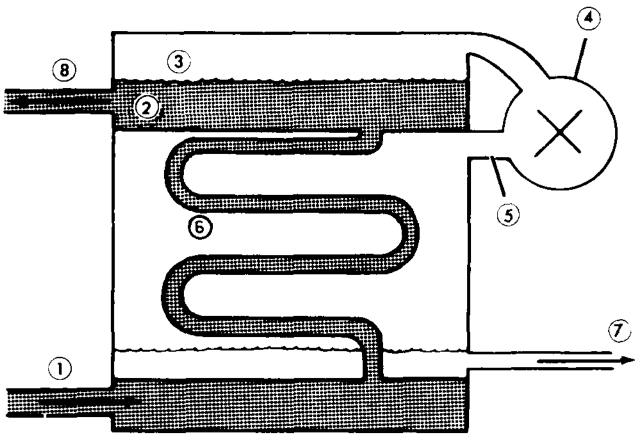
1. Salt water inlet; 2. Condenser; 3. Heater; 4. Flash vapour; 5. Fresh water; 6. Brine outlet.

Water at a given temperature and pressure is released into a chamber of slightly lower pressure where it flashes into vapour and is condensed. A vacuum multiple-stage plant is based on the progressive heating of salt water to a temperature of approximately 180° F and the subsequent flashing of a portion in successive chambers, each operating under slightly higher vacuum. The flash vapour from each stage is condensed on tubes containing the incoming cooler salt water, and constitutes the fresh-water product.

The most familiar is distillation, using heat. Two processes have already been used in large commercial installations, but considerable technical improvements are being made, which will reduce the cost of the water produced. Distillation yields water containing several tens of parts per thousand of salt, and this is suitable for industrial use without further processing. Taking as an example a plant using the "flash" evaporation system to produce 5 million gallons a day, estimated capital expenditure at present is 80 cents per gallon of daily capacity; if the fuel costs 35 cents per million British Thermal Units (BTU) the water would cost about 65 cents per 1000 gallons.

The other principal evaporation process is multiple effect distillation, using long vertical tubes. Installations using this process are more likely to suffer from corrosion; this limits efficient working temperatures and hence productive capacity.

The vapour compression process begins with the boiling of salt water. The resultant vapour is compressed, slightly raising its temperature, and in condensing this steam gives up heat which is used to evaporate more salt water. The process has promise, but it will be some time before its possibilities can be fully assessed. The same is true of the freezing process, which has been tried with good results in numerous pilot plants and will be further tested in a demonstration plant now being built (in North Carolina).



VAPOUR COMPRESSION

1. Salt water intake; 2. Boiling salt water; 3. Steam at 212° F; 4. Compressor; 5. Compressed steam at 222° F; 6. Condensing steam; 7. Fresh water; 8. Brine outlet.

Salt water is boiled on one side of a heat-transfer barrier such as a boiler tube. The vapour is compressed, raising its pressure about 3 psi and temperature about 9° F. The heated steam is returned to the outer side of the boiler tube, where its latent heat of condensation evaporates additional water in the tube. The condensed vapour is removed through a heat exchanger as distilled water.

The principal process using electricity is electrodialysis, whereby salts under the influence of an electric current are separated out by means of semi-permeable membranes. This process has already proved its worth, but since as yet there is only a small demand for membranes, they are expensive. Cost of the process depends on the quantity of the contained salts to be removed, and their nature. The conductivity of salt water becomes very low for salt contents of less than 500 parts per million so that it would be very expensive to use this process for obtaining water of lower salt content; nor does it eliminate organic matter often contained in water. It has the advantage that it can be used at currents of varying intensity, which makes for flexible operation.

Use of Reactors

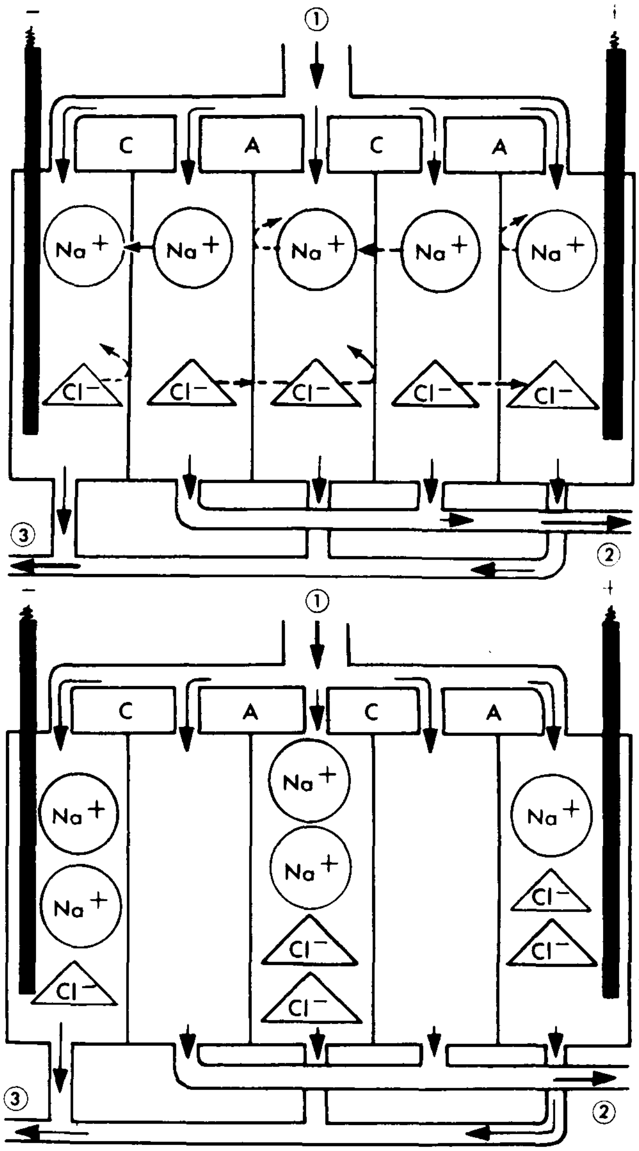
Of these processes, flash evaporation has been more fully developed than the others and at present gives the best results. With this process, too, an important economic advantage can be gained from the large capacities involved where nuclear reactors are employed. Nuclear power becomes cheaper as the scale of operations increases, and the trend is towards large desalting units.

Power reactors of the types already in use today for generation of electricity could be applied to the desalting processes described above, but experience up to the present has shown these reactors to be too expensive. Distillation processes (which are the most suitable for sea-water conversion) require only low-pressure steam. Reactors could be designed with a more economical technology especially to supply such low-grade steam, but this would involve heat exchange difficulties. The economics of developing such reactors does not appear to justify the expense, particularly within the power range which is of interest to the developing countries.

The most economical low-pressure steam is obtained by expanding high-pressure steam in a turbine - hence the advantage of combined installations producing electricity and fresh water. For example, the United States Atomic Energy Commission has prepared some estimates of the cost of heat supplied to a desalting plant by a light-water, enriched-uranium reactor. For a reactor of 1500 MW(t) used for desalting only, the cost is estimated at 33 cents per million BTU. Where electricity also is generated, the cost would probably be about 20 cents.

Any condenser turbine can be linked to a saline conversion plant using low-pressure steam. A certain amount of desalted water can be produced in this way without greatly altering the original characteristics of the plant, and this water is obtained at the best possible price since the energy can be regarded as provided free. The amount of water is limited, however, depending on the inlet temperature of the steam into the turbine.

For a mixed installation using the flash evaporation process, the optimum ratio of products is about one gallon of water to one kilowatt-hour of electricity. The capital cost of the original power station is increased by only eight per cent for a capacity of several million gallons a day.



ELECTRODIALYSIS

1. Salt water intake; 2. Fresh water; 3. Brine outlet.

When an electric current is transmitted through a saline solution, the cations in the solution migrate towards the cathods and the anions towards the anode. Membranes in sheets of cation- or anion-exchange material permit the passage of either cations or anions, respectively, in the solution. If a series of alternate cation- and anion-permeable membranes is placed between the electrodes, the anions pass through the anion-permeable membrane towards the anode, but are stopped at the next membrane, which is permeable only to cations. Similarly the cations moving in the opposite direction will pass the cation membrane but not the next. Thus, as anions and cations collect and combine in alternate compartments, the water there is enriched with salt while that in the other compartments is depleted. (This and the two foregoing from McGraw-Hill *Encyclopedia of Science and Technology.* Copyright 1960 McGraw-Hill Book Co. Used by permission).

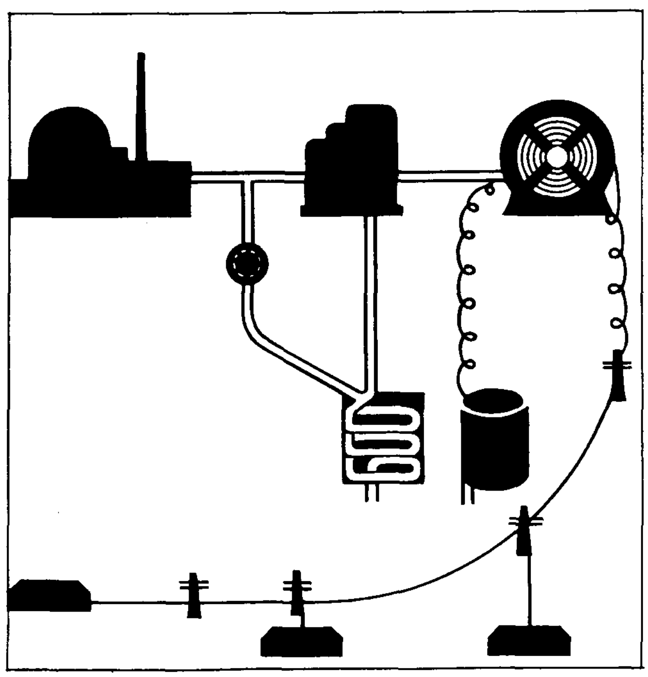
Mixed Installations

When the amounts of water and electricity produced are independent of seasonal and daily variations in demand, optimization of a mixed installation is relatively easy. Since high load factors and large production capacities are to the advantage of nuclear reactors, use of reactors in mixed installations will depend largely on the flexibility of these installations - i. e. the extent to which the various desalting processes can be brought in to balance fluctuations in the electricity demand and to maintain or increase the load on the steam-raising plant. Different desalination processes, each using different forms of energy, can be combined in many ways. The number of possible combinations is increased if the possibility of storing water and transmitting electrical energy is taken into account.

In order to gain flexibility, capital expenditure has to be increased, some of the plant being in operation at full load for only part of the time. For such installations, therefore, those processes involving the least capital expenditure must be considered. Even mixed installations employing only one type of process possess a certain flexibility; the aim is to ensure a continuous demand for steam or for electricity, depending on the type of process.

The accompanying sketch shows a scheme employing the flash evaporation process. When the demand for electricity falls, part of the high-pressure

1 REACTOR OR BOILER
2 TURBINE
3 ALTERNATOR
4 EXPANSION VALVE
5 ELECTRODIALYSIS OR VAPOUR COMPRESSION
6 SUPPLY NETWORK
7 DISTILLATION PLANT
8 FRESH WATER
9 WATER DESALTING PLANTS



steam can be delivered direct to the desalting plant through an expansion valve. With suitable design, the daily output of water could be adapted to the demand, and fluctuations in the load on the source of heat reduced.

Where electrodialysis is used, the desalting plant can be brought into operation very quickly, and since the process can be used under varying conditions of electric current (current densities), it affords a highly flexible utilization of the available power. Furthermore, since it operates from electricity and not heat, and since electricity is easily transmitted, the desalting plant could be situated geographically at the most economical point for the distribution of water. It would be possible to have several desalting plants dispersed according to regional needs; but this would mean forgoing the benefits of large capacity installations.

Other processes offer a variety of possible arrangements for achieving flexibility in mixed installations, but a highly flexible system involves additional capital expenditure and somewhat less efficient utilization of parts of the plant. Each case must be studied individually.

Reactor Types

In mixed installations, power reactors of some proven type would be used. At present the choice would be made from the following systems: light-water/enriched-uranium, heavy-water/natural-uranium, and gas-graphite/natural-uranium. Studies carried out by organizations in several countries indicate that, at present, light-water reactors are the only ones which can compete with conventional thermal power stations in the power range of about 100 MW(t). Two other types - the heavy-water/natural-uranium system and the gas-graphite/natural-uranium system - are worth considering only for installations of much higher capacity.

The moderator of the heavy-water type is usually cooled by circulation in an exchanger, and the energy thus removed is not normally recovered. By subjecting the moderator to slight pressurization, its temperature can be raised sufficiently to enable it to serve as a source of energy in a distillation plant. It is a considerable advantage to recover several per cent of the reactor's thermal power in this way.

Studies on gas-graphite/natural-uranium reactors suggest that a mixed installation employing a reactor of 1000 MW(t) could provide a net electric power of 200 MW, and daily water output of 80 million gallons, at an electricity cost of 6.4 mills per kWh, and cost of desalted water of 41 cents per 1000 gallons.

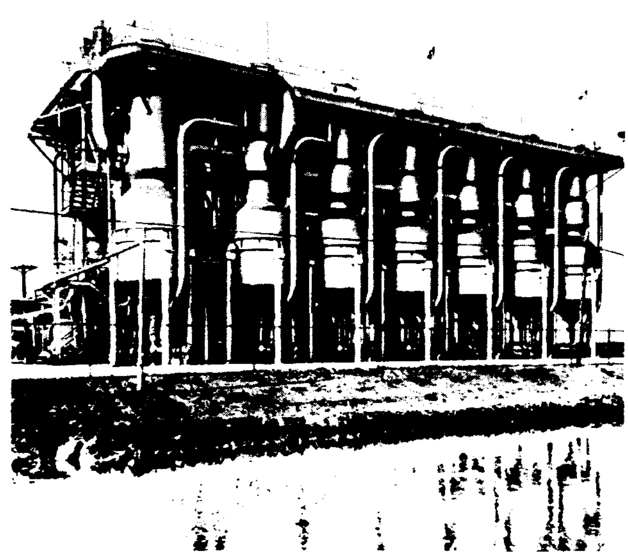
The largest power reactor under construction at present is of 3000 MW(t), and such a plant would be capable of producing water for domestic and industrial purposes at a price competitive with new sources of supply in areas which are already short of water, such as California, Paris or Manchester. By a process of extrapolation promising cost estimates have been made for much larger reactors, but, until these estimates have some more substantial basis of experience, they must be regarded as speculative. In any case, it is reactors in the range 200-1000 MW(t) which interest the developing countries today.

Studies Needed

The reactors mentioned are well-established systems. Within every system, however, the thermal power, the thermodynamic characteristics, the technological design and the fuel elements vary from one reactor to another. There will be a considerable saving when a certain degree of reactor and fuel standardization makes it possible to spread the cost of studies and of equipment.

Technical and economic studies need to be made on combined water and power schemes, to establish a range of preferred arrangements and operating schedules. In particular, there should be a complete study of mixed installations, conventional and nuclear; it should relate to the thermodynamic balance-sheet for these installations and to their flexibility and their economic optimization. This should be followed by construction of demonstration plants of medium size, which is the only way of establishing a sound economic basis for the future. A demonstration mixed installation on a larger scale might be envisaged as an international project.

A demonstration plant converts sea-water to fresh, at the rate of a million gallons a day, at Freeport, Texas, USA. This plant - using conventional power - employs multiple-effect distillation. It is one of several demonstration plants using different systems; built as part of a long-range salt-water conversion programme sponsored by the U.S. Government. (Photo. U.S. Information Service)



In considering the possibilities of desalting plants for arid or semi-arid regions, there are evident advantages in planning not for single isolated centres, but for the region concerned as a whole. Where such regions belong to several countries, it would be greatly to the mutual benefit of the States involved to co-ordinate the solution of their power and water problems.

The Agency's preliminary investigations of possible applications in the arid regions in developing territories suggest that the present method of providing electricity from diesel stations produces electricity at a fairly high price, and that combined power and water schemes should produce cheaper electricity. It seems reasonable to assume that the electricity price could be reduced sufficiently far below the present diesel price to be attractive for power development and still contain a margin which could subsidize the water. Further, since such a power/water scheme would produce cheaper water, it would enable governments to distribute more water for the same subsidy.

Future Uses

The immediate prospects for large-scale agricultural use, however, are not encouraging. Most irrigation networks at present are subsidized; capital cost is often borne by the State, while the price paid by the cultivator hardly covers the cost of operation. The Food and Agriculture Organization, after studying numerous cases throughout the world, and on the assumption that governments could subsidize irrigation water up to 40 per cent, came to the following conclusion:

> "Except in very specific cases, it will not be possible to consider the economic use of desalted water for irrigation as long as its production cost without subsidy is above 10 cents per 1000 US gallons. Only when this cost is of the order of 3 cents per 1000 US gallons will the use of desalted water for agriculture develop on a large scale."

The demand for energy is very small in the agricultural regions and irrigation alone requires about 1 kWh per 1000 gallons of water supplied to the consumer. Moreover, the use of desalted water in agriculture calls for special methods, which will require a long time to develop. One useful approach would be to prepare pilot sectors of 10-20 hectares near the first mixed installations. Later, a larger pilot sector of about 1000 hectares would be essential, before larger-scale projects were undertaken.

The information gathered by the Agency on Southern Tunisia indicates that desalting of sea-water could be undertaken there with present technology, and that a substantial saving could be made by combining this with power production; the energy source could probably be a nuclear reactor.

On present indications, desalting processes are not likely to be used for irrigation, save in unusual circumstances - e.g. where there is a large demand for electricity at a price sufficiently high to subsidize water production. On the other hand, with further development the possibilities for industrial and domestic use appear considerable, especially where there is considerable scope for expansion of electricity supply. The future development of larger units should favour nuclear energy, but very large nuclear generating stations can be introduced into the electricity supply grid only as the base load becomes sufficient to justify them. The long-term trend towards ever larger demands for electricity, along with technological progress in the nuclear field, does suggest that nuclear energy will eventually play an important part in water supply.