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PLAN FOR PRODUCING POTABLE WATER ECONOMICALLY

1. Last year, in resolution GC(XXXIII)/RES/515, the General Conference requested the Director General "to assess the technical and economic potential for using nuclear heat reactors in sea water desalination in the light of the relevant experience gained during the past decade, to assess the interest of potential beneficiaries and technology holders, and to report - through the Board of Governors - to the Conference at its thirty-fourth (1990) regular session".

2. The Secretariat decided that the best way of responding to this resolution was to prepare a status report. Accordingly, a group of consultants from countries which are continuing with efforts in the field of interest met in December 1989 and prepared a draft report. In May 1990, the draft report was reviewed by an advisory group consisting of 15 experts from nine countries, whose comments and suggestions were incorporated into the draft report by a consultants' group. The report was finalized by a further consultants' group, which completed its task on 1 August 1990.

3. The report reviews current technologies for sea water desalination, recent experience in this field, options for coupling nuclear plants with desalination processes, and institutional issues related to nuclear desalination. The Attachment to this document contains a synopsis of the report, with conclusions and recommendations for future activities (this material constitutes sections 1 and 2 of the report). The Secretariat intends to issue the full text of the report in the "IAEA-TECDOC" series later during the current month.

4. On 12 September the Board of Governors requested the Director General to transmit the material in the Attachment to this document to the General Conference together with the summary record of the Board's discussion relating to it.*/

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*/ The summary record will be transmitted to the Conference in an Addendum to this document.

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USE OF NUCLEAR REACTORS FOR SEAWATER DESALINATION

S Y N O P S I S

1. INTRODUCTION

1.1. Objectives of the report

The last International Atomic Energy Agency (IAEA) status report on desalination, including Nuclear Desalination, was issued nearly 2 decades ago. The impending water crisis in many parts of the world, and especially in the Middle East, makes it appropriate to provide an updated report as a basis for consideration of future activities.

This report provides a state-of-the-art review of desalination and pertinent nuclear reactor technology. Information is included on fresh water needs and costs, environmental risks associated with alternatives for water production, and data regarding the technical and economic characteristics of immediately available desalination systems, as well as compatible nuclear technology. It is intended to provide a basis for identifying and implementing safe and economic short-term solutions that could secure water for locations with an urgent need. Additionally, the report indicates worthwhile areas for future R&D and possible Agency sponsorship and coordination of activities.

1.2. Need for Nuclear Desalination

1.2.1. Need for Water

Large quantities of water are required in many parts of the world for agricultural, industrial and residential uses. The world is becoming more and more aware of its shortage of fresh water. A United Nations Populations Fund (UNFPA) report, published in May 1990, predicts a dramatic increase in world population. For example, the population in Africa is expected to increase from about the 650 million people at present to over 1,580 million by the year 2050. Another report, published in December 1987 by the Center for Strategic and International Studies (CSIS) and titled "US Foreign Policy on Water Resources in the Middle East", also supports this data. The CSIS report notes recent population growth rates in excess of 3% in several countries in the

Middle East. It further predicts that the population growth rate will remain at the current level in the near term.

It is understood, from experience, that a growth rate above 1% creates a difficult situation for an existing infrastructure, and especially for the fresh water situation. The population growth rate of more than 3% in the water-short Middle East is a clear indication of a coming water catastrophy. This point cannot be overemphasised. The problem is compounded by increasing pollution, and increasing salinity of the rapidly disappearing natural fresh water resources. It also has to be emphasized that existing natural water resources must be conserved for future generations and for the prevention of desertification.

Conservative predictions for the year 2000 indicate a shortage of water in the Mediterranean Area alone of some 10 million m^3/day. Other locations where water is becoming scarce include most of the Arab countries, regions in India, Pakistan, China, South and Middle America, and on some South Pacific Islands. The shortage of water in these areas is expected to be not less than 10 million m^3/day.

The extent of the shortage noted above implies that water may become a question of life or death in those areas, not just one of convenience. Other locations will experience a decline in the quality of life, due to the fact that the specific daily water consumption will have to be reduced considerably, as a result of the exhaustion and/or pollution of natural fresh water resources. Some examples are; Europe (Greece, France, Spain, Italy, UK), America (California, Florida), Mexico, Chile, Brazil, Australia, Africa and Asia (USSR, Bali, Tahiti).

1.2.2. Reasons for Seawater Desalination

Seawater is the largest water source available. Compared with existing fresh water natural resources, its availability is essentially unlimited in the foreseeable future. It is still relatively unpolluted compared with natural fresh water sources. If we want to conserve the existing natural water resources, and avoid further desertification, then SEAWATER DESALINATION is the only water source available. If we want to reverse the decline in natural water resources or counteract desertification by reforesting, (and use the trees as a CO_2-sink as well), SEAWATER DESALINATION is the only logical way.

1.2.3. Reasons for Nuclear Energy

Worldwide concern with the negative aspects of the "Greenhouse Effect" is intensifying, and has led to an understanding that CO_2 emissions must be limited to at least their present level if not curtailed. This concern makes it necessary to target the most significant CO_2 sources, with a view to affecting reductions. In addition to energy conservation measures especially with the expected growth in population, it is expected that changes in the key energy and transportation sectors will be required. A related concern is acid rain and it's negative effect on forests (an important CO_2-sink). Taking these factors into account, any new production of energy should be based on non-CO_2 and SO_2 emitting sources. Equally important is conserving our limited oil resources for future generations. Oil is too valuable a material to simply be burned, rather, it should be conserved as an essential raw material for the petrochemical industry, and lubrication.

The foregoing leaves us in the near term, with only one industrially proven, large scale, non-fossil energy resource: nuclear energy. Further, in addition to the environmental aspects discussed above, nuclear energy may also have a positive impact on water cost, as it has had on electricity cost in many countries. For those countries with a need for water, but with few or no fossil energy resources, nuclear fuel is the cheapest form of imported energy.

1.3. Cost as a Barrier to be Overcome

The specific cost of the water produced (cost/m^3), as well as capital investment cost, are the main barriers to the implementation of any large scale desalination programme to counteract the impending water crisis.

Drinking water needs to be considered as a fundamental need, and be subsidised such that water cost is no longer a huge fraction of income as it is for many people. Such considerations indicate a target production cost for potable water of less than 1 US$/$m^3$.

The real cost of not providing sufficient water, or providing water at unacceptable cost, is very difficult to predict. It can be said that the major effect will be a decline in economic growth, but the unavailability of water at an acceptable cost is predicted by some to lead to uncontrollable action by the population and interstate conflict. It is not unreasonable to assume that the cost of "Not Doing It" is far higher than "Doing It" even with large subsidies.

1.4. Environmental Incentives

The environmental incentives for nuclear desalination are quite convincing. Assuming an increase in the daily water production of 10 million m^3 up to the year 2000, using nuclear instead of fossil powered energy production and using advanced desalination technologies, emission of about:

20, 000, 000	t/year	CO_2
200, 000	t/year	SO_2
60, 000	t/year	NO_x
16, 000	t/year	HC

can be avoided in the Mediterranean area alone. The potential worldwide reduction in emissions would be more than double these figures.

1.5. Outline of Report

This report includes two major sections addressing the technical and economic aspects of Nuclear Desalination. Section 3 provides a detailed discussion of desalination technologies and identifies those with significant near-term potential. Section 4 addresses the practical and theoretical experience of coupling nuclear plants with desalination processes.

Section 5 identifies data on the water situation from various sources and summarizes the various data into global shortage figures for the next decade. The shortages are compared with the potential availability from the various sources. Using the summarized data, the positive and negative aspects of nuclear and fossil desalination are presented. Section 6 summarizes the institutional issues.

Section 2 is a summary of Sections 3 through 6. In particular, Subsections 2.3 and 2.4 provide important conclusions regarding our understanding of the incentives and problems related to Nuclear Desalination and recommendations for future action.

2. SUMMARY AND CONCLUSIONS

This section highlights the principal conclusions of the IAEA review of desalination using nuclear energy. Desalination technologies are summarised in Section 2.1, nuclear technology in 2.2, while major considerations affecting the potential for Nuclear Desalination are summarized in Section 2.3, and finally, the conclusions and recommendations arising from the study are given in Section 2.4.

2.1. Desalination Technologies

Many desalination technologies have been suggested based on different principles of separation. Some of them have been successfully developed, and these are discussed in detail in Section 3 of this report. For near term application, the most useful are summarised below.

2.1.1. Distillation Processes

Multi-Stage-Flash (MSF) Distillation. This process is the most widespread (capacity-wise) at present. The technology is well proven and mature, but seems to be approaching the limit of its technical potential.

Multi-Effect-Distillation (MED). Experience with several generations of this old process have led to two advanced types of evaporators - one with vertical tubes as heat transfer elements, the other with horizontal tubes. The latter has shown good results, especially at temperatures below 75°C, where low cost materials are used. Such evaporators have proven to be easy to operate and maintain. They also demonstrate relatively good economy, both when external steam is used as a heat source or when mechanically driven Vapor Compression (VC) is applied. Both these methods seem to have the best potential for low cost water of all the distillation processes, and may prove to be the best among all desalination processes.

An additional improvement in the economy of distillation processes may come from combining two of the above processes into a hybrid system (e.g. MSF preheater for MED or VC).

2.1.2. Membrane Processes

Reverse Osmosis (RO): This process has more recently shown the most remarkable improvement among existing desalination processes, owing to advancement in membrane technology. With a proper post-treatment, drinking water of adequate quality to meet World Health Organization (WHO) standards can now be obtained with a single-stage. Both investment and operating costs of this process are estimated to have a potential of being lower than MSF and MED. The RO process is considered as one of the most promising for the next generation of desalination plants.

Other Processes: Electrodialysis (ED) has been successfully applied to seawater desalination, but implementation in actual applications has so far been limited to small capacities. Meanwhile improvements to RO have overtaken those of ED, and so it is questionable whether this process can survive in the near future. Another membrane process, membrane distillation, also attracts attention. Although this process has many advantages, the energy consumption can not be reduced drastically, and hence this process is expected to be only applied where cheap waste heat exists. Vacuum freezing vapour compression (VFVC) is a very promising process as well, and its' potential to reduce capital and operating costs justifies further R & D.

Combination with Distillation Processes: Combining distillation processes with membrane processes into hybrid systems has certain merits where the specific advantages and disadvantages of each of the processes enable mutual compensation.

2.2. Nuclear Technologies

Current experience with Nuclear Desalination is limited, however, continuing interest is reflected in several recent studies.

2.2.1. Current Experience

The only reactor currently being used for seawater desalination is a Liquid Metal Cooled Reactor, the BN-350, which was put into operation in July 1973 at the town of Shevchenko (USSR). This dual purpose plant can produce 125 MW of electric power and 100000 m^3/d of potable water.

The thermal output of the reactor to the desalination process is 75 MW. The BN-350 reactor is also being used for experiments in nuclear physics, physical metallurgy and sodium engineering.

The development and improvement of different desalination processes such as the 5-effect Long Tube Vertical (LTV), 10-effect LTV and 34 stage MSF are being pursued at the Mangyshlak peninsula complex in the town of Shevchenko (USSR). The total operating capacity of this complex is 140,000 m^3/d.

In general, the BN-350 reactor has operated satisfactorily with the only large defect being in the steam generators of the third reactor loop. This was due to defects during the manufacturing and welding of the lower ends of the heat transfer tubes. In addition, two small leaks in the sampling and oxide indication sub-systems were detected and repaired.

The prolonged operating experience of the BN-350, which couples the Liquid Metal Reactor with Multi-Effect Vertical Tube Evaporators has proven the reliability of Nuclear Desalination. On the basis of this experience, the development of different desalination processes is planned in the USSR, such as Low-Temperature Horizontal Tube Multi-Effect Distillation (LT-HTMED) and Horizontal-Tube Thin-Film Evaporators (HT-TFE) to be coupled with thermal reactors providing distillate production to several hundred of thousand m^3/d.

2.2.2. Recent Studies and Related Experience

The use of nuclear energy for seawater desalination has been both directly and indirectly addressed in a series of recent studies. These studies have included the three main reactor types: Water Cooled Reactors, Gas Cooled Reactors and Liquid Metal Reactors.

In the case of Water-Cooled Reactors (WCRs), no explicit recent study of Nuclear Desalination was identified. However, considerable recent work has been done on the generalized application of such reactors for process steam and heated water, and considerable experience in such applications has been accumulated in Canada, Czechoslovakia, East Germany, Poland and the Soviet Union.

In these latter cases, where operational experience has been obtained, the primary product of the nuclear station has usually been electricity production and the reactor systems are correspondingly large. Energy for process steam and/or heating is taken mostly as a byproduct, using steam extraction or, alternatively, utilizing the otherwise wasted heat that is rejected through the condenser. In areas of significant electricity demand, such approaches could also be employed for desalination. Specific additional issues that must be addressed are the location of such large reactors in close proximity to water production facilities, and possibly large population centers, and the additional safety measures that are required when coupling WCRs (particularly those of the boiling water reactor type) to the desalination process.

Of further interest, when considering desalination applications, is the recent work toward developing relatively small, specialized WCR types for process steam and district heating. Examples of such reactors ranging in capacities from 10–500 MWt are being developed in Canada, France, Germany and the Soviet Union. Additional WCR designs primarily intended for shipboard applications could also be considered for desalination purposes.

Examples of small WCRs in current operation include a prototype of the SLOWPOKE reactor in Canada and a number of small reactors at Bilibino in the USSR. Energy outputs from existing and proposed small reactor types range from heated water at 80°C to steam at pressures normally associated with electricity generation (7–8 MPa). Obviously the specific means of coupling the various small reactor types with a variety of desalination technologies is a key factor to be addressed. With respect to this latter point, a degree of experience was obtained through an experimental programme at Ashdod, Israel in 1983. In those tests, a large LT-HTMED prototype was coupled with an existing fossil facility in a manner that closely simulated coupling with a nuclear heat source. The heat supply system, unit size, and mode of operation were designed as close as possible to nuclear steam supply. Positive results were attained from the one year operation period.

Before specific conclusions regarding desalination with WCRs can be made, one or more specific studies would be required. The following should be addressed for each case:

- Identification of appropriate siting and economic groundrules as a basis for the evaluation
- Selection of an appropriate combination of reactor type and desalination process
- Development of the coupling interface. If this is in the form of thermal energy, particular attention should be paid to special safety requirements related to the potential for water supply contamination with radionuclides
- Technical and economic evaluations of the resulting concept.

It would be particularly useful to accomplish the above for a typical dual purpose cogeneration application as well as a typical single purpose application in which the reactor energy is exclusively used for the desalination process.

In a recent study sponsored by the Metropolitan Water District of Southern California (MWD), in cooperation with the U.S. Department of Energy(DOE), the Modular High Temperature Gas Cooled Reactor was evaluated for seawater desalination. The study was based on a modified version of the reference 4x350 MWt Modular/HTGR, operating in a series cogeneration mode with a Low Temperature Horizontal Tube, Multi-Effect Distillation (LT-HTMED) process. The combined facility would provide approximately 466 MW of electrical generation capacity and 401,000 m^3/day of desalted water at 40 ppm Total Dissolved Solids (TDS) content. Additional product water at a higher, but acceptable, TDS content could be produced by blending with locally available brackish water.

The particular combination of the MHTGR with the LT-HTMED process was found to result in significantly reduced product costs, when compared with prior evaluations. An additional key parameter was found to be the assigned value of the electricity which, in the MWD/DOE study, tended to minimize the cost of heat energy to the desalination process. While the resulting costs ($ .34/m^3 - $ .49/m^3) were not quite competitive with existing sources of water in the California region, they gave encouragement that competitive costs could be achieved in the foreseeable future.

Further, while care must be taken in extrapolating the results from one region to another, the costs predicted in this MWD/DOE study are already extremely competitive with current alternatives in the Middle

East. Further they are dramatically lower than prices projected until now for Conventional Desalination processes.

Another study of the use of Gas-Cooled Reactors for Nuclear Desalination was carried out in the Federal Republic of Germany (FRG). This study considered integral barge mounted power and desalination plants in two sizes, corresponding to the use of two and four reactors respectively, to produce 100,000 m^3/day or 200,000 m^3/day of desalted water at 450 ppm TDS. The reactors considered were the HTR-Module type with a thermal rating of 200 MWt each. The desalination plant is of the Reverse Osmosis (RO) type with numerous parallel trains arranged in two stages. Energy input to the RO process is both in the form of electricity and heat. For each two reactors, 164 MWe is generated, with 30 MWe required for the RO process and 12 MWe for internal uses. The remaining 122 MWe is available for sale. Thermal energy input is provided by preheating seawater feed in the condenser, thus using waste heat from the turbine generator exhaust.

The barge mounting concept is expected to have a number of advantages relative to the fixed land based type. First, construction at a central shipyard type facility is expected to reduce cost and improve quality. Secondly, the plant may be towed to any location with sea or river access where it would be fixed upon a foundation prior to operation. If required, the plant could be relocated after appropriate preparation for transport, and refloating of the barge.

While on first consideration, the costs of water from the FRG study are somewhat higher than predicted from the US study, taking account of the technical progress in RO technology since 1985 and currently lower nuclear fuel costs would tend to bring the results closer together.

The only recent example in which a Liquid Metal Reactor (LMR) is being considered for future Nuclear Desalination is found in Japan. The Central Research Institute of the Electric Power Industry (CRIEPI) of Japan initiated a conceptual design effort in 1989 to consider a group of small (125 MWt each) LMR modules to provide input power to a desalination process. The purpose of the study is the prevention of desertification of the world. This focus on agriculture is unique among recent desalination study efforts.

The LMR modules are described as being simple in concept and having largely passive safety characteristics. Hence, the name "4S" (Super-Safe, Small and Simple). The core consists of U-Pu-10%Zr based metal fuel pins, and its life is forecasted to be 10 years without refueling.

For the desalination process, Reverse Osmosis was selected because of low energy consumption, simplicity in operation, and low maintenance. Energy output from the reactor modules is in the form of steam, and both mechanical and electrical coupling of the steam turbines to the RO pumps is being considered. The total range of water production to be addressed is up to 3 million m^3/day.

The CRIEPI study of the 4S LMR is at an early stage relative to the HTR studies in the US and Federal Republic of Germany, and results are not yet available regarding possible water costs.

2.3. Major Considerations

The following important issues are of special significance for Nuclear Desalination.

2.3.1. Size Compatibility

The relative scale of nuclear power and desalination facilities must be taken into account when considering a combination of these two technologies. As an indication of the current differences in scale, consider the energy requirements of a modern Reverse Osmosis process which, including an allowance for product pumping and unrelated auxiliaries of 2.5 kW_eh/m^3, might typically be on the order of 9 kW_eh/m^3. For an average size desalination plant of 25,000 m^3/day, this would imply an electrical capacity of some 9.4 MWe. Clearly this is small compared to present electricity generation plants where 1000 MWe is typical. Even with the few very large desalination plants that have been deployed or are being discussed, the mismatch in scale is significant.

The relative scale of the nuclear energy source and the desalination plant may be more or less important depending upon the following factors:

- If there is a large market for electricity in the region with an integrated electrical grid, the mis-match in size may be relatively unimportant. This is because the energy input to desalination plant (either electricity or waste thermal energy) can be provided as a co-product or by-product of electricity production for the grid.

- In the case of single purpose nuclear plants directly coupled to the desalination process, the need for very small nuclear plants would be indicated. This is typical of some middle-eastern areas without well developed electrical grids.

2.3.2. Cost and Finance

The cost of a scheme to overcome the problems of the envisaged worldwide drought and to counteract the drought by conventional and Nuclear Desalination schemes will be in the range of 120 billion US $ (in 1990 dollars). This amount needs to be spent within the next ten years and does not include the investment required in the developed countries. In order to find proper ways to finance the above amount, to assess the exact needs and best technical solutions, and to initiate significant international technological R & D cooperation, a specialized UN entity may need to be set up to win the fight against worldwide drought. Action is urgently needed to coordinate the technical and financial study, and resolution of this serious problem in a short period of time.

2.3.3. Safety Considerations

In addition to the current detailed safety requirements for all nuclear installation, and the trend to develop even simpler and more inherently safe designs, some specific precautions against possible minute leakage from the nuclear system into the desalination-systems are needed. Various types of reactors need various precautions, but no insuperable difficulties are foreseen.

2.3.4. Environmental Considerations

The environmentally negative aspects of Nuclear Desalination concern the potential for harmful effluent in an accident. Conversely, desalination could improve the environment considerably, e.g., if the water is used for irrigation purposes in arid regions providing food and trees and thereby an important CO_2 sink. The availability of fresh water in itself is a very important positive environmental factor.

Fossil powered desalination plants release at least carbon dioxide and sulfur dioxide and some other environmentally harmful substances. The deterioration of air quality on a global basis has become a subject of intense discussion around the world. In addition to the acidification effects of nitrogen and sulfur oxides (acid rain), the long term effects of increasing carbon dioxide levels in the air (global greenhouse warming) is causing concern.

The degree to which Nuclear Desalination can contribute to reduced environmental pollution depends on the future development of nuclear desalting capacity and on the specific types of fossil fuel replaced by nuclear.

This situation is similar to that in the field of electricity generation although energy consumption for seawater desalination is orders of magnitude lower. When compared to the combustion of coal (sulfur content 2%, without flue gas cleaning) each MW of nuclear thermal power avoids a corresponding CO_2 emission of about 3200 t per year and a SO_2 emission of up to about 50 t per year. Compared to oil or natural gas, the avoidable CO_2 emission is lower (about 2000-2900 t CO_2 per year). SO_2 emissions may reach almost zero if desulfurized natural gas is used as fuel.

Thus, if the worldwide desalting capacity in 1990 (see Figs. 60-a to e) (about 13 million m^3/day for plant sizes > 400 m^3/day installed out of which about 10 million are in operation) could be powered by nuclear instead of fossil fuel, an emission of 32 million tons of CO_2 and about 0.2 million tons of sulfur and nitrogen oxides would be avoided.

This is not much compared to emissions from total worldwide electricity generation capacity, particularly if one takes into account that a 100% market penetration by Nuclear Desalination plants is unrealistic.

None-the-less significant environmental improvement can be achieved by Nuclear Desalination in those regions where a large desalination capacity is concentrated. A global effect will be noticeable if desalination capacity increases as drastically as is predicted in the future.

2.3.5. Other Institutional Barriers

A number of institutional barriers must be overcome in addition to the separate issues of finance, safety and environmental inputs which have been discussed above. Important among these are public acceptance and the organizational aspects of facilities that combine nuclear energy, desalinated water, and perhaps, electricity production.

The lack of public acceptance has been a significant barrier to the further use of nuclear energy in many countries. This lack of public acceptance may be attributed to concerns with the possibility of nuclear accidents, higher than expected costs experienced in some projects (notably in the USA) and the tendency of the public to associate nuclear power plants with nuclear weapons.

A general trend toward improved public acceptance is beginning to become evident. This improving trend is associated with the following factors:

- The general recognition that additional energy resources will be needed,
- Increasing concern with environmental issues associated with the use of fossil fuels,
- The emergence of a new class of smaller nuclear reactors with improved, and in some cases passive safety characteristics.

Organizational aspects must also be addressed. With the notable exception of the USSR experience in Shevchenko, nuclear energy and water production have traditionally existed as separate functions. Nuclear energy, in particular, has been more commonly associated with electricity production, rather than water supply and distribution. When combining these technologies, a number of additional organizational considerations arise of which the following are examples:

. Will the combined plant be owned by the electric utility, water utility, both utilities or an independent organization?
. Will the plant be operated as an integrated entity or will the nuclear plant be operated separately from the water plant?
. How will the income, costs and risks be shared among the parties involved?

While such questions do not constitute insuperable barriers, they do indicate the importance of the principle that, before project commitment, all involved parties must clearly understand and agree on the allocation of risk, reward and responsibility for the financing, construction and operation of the plant.

2.4. Conclusions and Recommendations for Future Actions

On the basis of the USSR experience and the above mentioned recent studies, conclusions and recommendations for future actions were discussed and agreed upon by all the participants of the Advisory Group Meeting convened by the Agency on 16-18 May 1990 in the Vienna International Center. These conclusions and recommendations are provided below.

2.4.1. Conclusions

1. The fresh water shortage is becoming a question of life in many areas of the world, such as the Middle East and the southern part of the Mediterranean Sea. In other areas such as certain parts in USA, Spain, Italy and France water shortage may have an increasing impact on the quality of life.

2. About 70 - 80% of all conventional desalination plants of about 10 million m^3/day are in operation in the Mediterranean area and the Middle East.

3. There is a strong need to build additional seawater desalination plants, in particular in the Mediterranean area and the Middle East. A rough estimate indicates that by the year 2000, there will be a shortage of about 12 million m^3/day.

4. Beneficiaries and desalination technology holders in different countries have shown their high interest in solving the water shortage problem and have performed feasibility studies for some selected areas, such as "Southern California Desalination Study" (USA), "Super-Safe, Small and Simple Liquid Metal-Cooled Reactor" (Japan) and "HTR-Module for Seawater Desalination" (Federal Republic of Germany).

5. The expected increasing shortage of water in the near term future in many parts of the world makes it necessary to consider more advanced/more economic production schemes than are available today.

6. Energy has been found to be a significant contributor, about 35 to 55 % in recent plants and 25 to 40 % in future modern plants to the total cost of desalination. Nuclear energy has the potential to reduce that cost.

7. Nuclear Desalination is technically feasible based on currently available technology and the USSR experience at Shevchenko bears it out. Currently available technology includes various thermal distillation processes using low temperature heat and electrically-coupled processes using Reverse Osmosis techniques.

8. The economic feasibility of Nuclear Desalination has been demonstrated in the USSR. Recent studies have indicated possible feasibility in other areas but these results must be confirmed on a site specific basis. Capital costs are a still major concern.

9 The use of nuclear energy for large scale desalination would have less environmental impact than fossil-fired thermal energy sources.

10. There is a mismatch in the power output of nuclear plants and power requirements from present desalination plants, a typical plant producing 500,000 m^3/day may require about 500 MW_{th} (140 bar; 530 ^oC).

   o In areas with a developed infrastructure and large populations this mismatch can be overcome by sale of excess electricity (electrically coupled desalination technologies) or by dual purpose (cogeneration of electricity and low temperature heat) plants.

- In areas without an established infrastructure or large population concentrations, such as occurs in many middle-east countries, smaller reactors would be required.

- For single purpose coupling of reactors to the desalination process, very small reactors would be required. This could pose the problem of spreading out thinly the skilled operating personnel required.

11. Large nuclear reactors for electrical generation are available on a commercial basis but commercial experience with modern smaller reactors is limited.

12. Institutional barriers (e.g. regulatory issues, financing and public acceptance) comprise additional barriers to Nuclear Desalination.

13. The current state of technology indicates that production of desalted water solely for agricultural purposes is not economic.

14. Further development of technologies such as advanced membranes and hybrid processes are expected to further reduce costs.

2.4.2 Recommendations

1. Establishment of data base containing current potable water consumption and prospective future demands for concerned areas of the world. This should be coordinated by IAEA or another appropriate UN Organization.

2. The technical and economic feasibility of Nuclear Desalination for specific sites should be clarified through more detailed studies.

3. A comparative technical and economic evaluation should be made for a limited number of desalination technologies and reactor types in one or more representative middle-east sites. The output should cover a range of 4,000 m^3/d to 500,000 m^3/d. The following should be included:

a) Desalination Technologies

- o Reverse Osmosis (RO)
- o Multi-Effect Distillation/Vapour Compression (MED/VC)
- o Multi-Effect Distillation (MED) (Thermal Coupling)

b) Reactor Types

- o Light Water-cooled Reactor
- o High Temperature Gas-cooled Reactor

This study should be coordinated by the IAEA.

4. Based upon results of Item 2 above, necessary R & D and/or demonstration needs should be identified and an appropriate working programme should be established if possible under the auspices of the IAEA (with extra budgetary resources if required) to address the following issues:

- o Establish the needs for potable water including quantity and distribution means
- o Evaluate possible options for the use of nuclear energy
- o Identify technical and economic requirements which must be met
- o Identify possible solutions to institutional issues, particularly financing for developing countries, e.g. through the establishment of an international fund.
- o Continue to monitor and assess other promising reactor developments and desalination technologies.

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