International Atomic Energy Agency
GENERAL CONFERENCE

GC

GC(XXXVIII)/8
8 August 1994

GENERAL Distr.
Original: ENGLISH

Thirty-eighth regular session
Item 16 of the provisional agenda
(GC(XXXVIII)/1)

PLAN FOR PRODUCING POTABLE WATER ECONOMICALLY

1. Last year, in resolution GC(XXXVII)/RES/617 entitled "Plan for producing potable water economically", the General Conference requested the Director General - inter alia - to submit to the Conference in 1994 a document on which discussion could be based. This document has been prepared in response to that request.

2. Between 1964 and 1967, the Agency issued a series of technical reports on the subject of seawater desalination using nuclear energy. At that time, the interest in the subject was not high owing to cost uncertainties, potential safety issues connected with the siting of nuclear plants and the apparent mismatch between the power output of nuclear plants then being constructed and the power requirements of any reasonably sized desalination plant. Nuclear power was of interest primarily for electricity production.

3. At the 1989 session of the General Conference, renewed interest in the potential of nuclear reactors for seawater desalination was expressed by some Member States, and in resolution GC(XXXIII)/RES/515 the Conference requested the Director General to assess the technical and economic potential of nuclear reactors for seawater desalination in the light of experience gained during the previous decade.

4. In response to that resolution, the Agency, under the Regular Budget and with the help of outside experts, initiated the preparation of a technical document (IAEA-TECDOC-574) entitled "Use of Nuclear Reactors for Seawater Desalination" which was issued in September 1990 (a summary of its contents was presented to the General Conference in document GC(XXXIV)/928). The technical document contained an up-to-date review of seawater desalination technologies and summaries of various studies on the coupling of nuclear reactors with desalination plants. Also, it described the experience gained with the only operating complex using a nuclear reactor directly for desalination - the Aktau complex (previously known as the Shevchenko complex) in Kazakhstan. Problems of site-specific economic competitiveness and institutional issues associated with the introduction of nuclear power were generally identified as obstacles to the use of nuclear reactors for desalination.

94-02927

5. At its 1990 regular session, having considered the conclusions and recommendations put forward in document GC(XXXIV)/928, the General Conference, in resolution GC(XXXIV)/RES/540, requested the Director General - inter alia - to assess "all available information on the future need for potable water relevant to nuclear desalination" and the "costs of potable water production with various sizes of nuclear desalination plant at selected promising sites, with a comparison of the costs of desalination by nuclear and other means".

6. Subsequent to the 1990 General Conference session, Algeria, Egypt, the Libyan Arab Jamahiriya, Morocco and Tunisia submitted a request to the Agency for assistance in conducting a regional feasibility study on nuclear desalination for selected sites in North Africa. The Secretariat decided to proceed simultaneously with this study and the assessments requested in resolution GC(XXXIV)/RES/540.

7. In 1991, the General Conference had before it, in document GC(XXXV)/INF/298, a progress report on actions taken in response to resolution GC(XXXIV)/RES/540 and on the North African regional feasibility study. In the report it was stated that a preliminary evaluation indicated that nuclear desalination could be competitive, depending on the capacity of the nuclear reactor coupled to the desalination plant and the costs of the fossil fuel which would be required in order to fuel an alternative, fossil-fired energy source similarly coupled to the desalination plant. Also, with regard to the North African regional feasibility study, it was stated that data on the demand for and supply of potable water and electricity had been collected for all five of the participating countries and that the data indicated a current potable water deficit in North Africa of 3 million m^3/day, growing to about 9 million m^3/day around the turn of the century.

8. At its 1991 session, the General Conference, in resolution GC(XXXV)/RES/563, requested the Director General to report to it again in 1992.

9. In 1992, the General Conference had before it, in the Attachment to document GC(XXXVI)/1013, an executive summary of a technical document (IAEA-TECDOC-666 entitled "Technical and economic evaluation of potable water production through desalination of seawater by using nuclear energy and other means" issued in September 1992.[1/] Regarding the competitiveness of nuclear vis à vis fossil-fired plants, the economic evaluation indicated that much depended on the required plant size: if large plants were required, the competitive edge would be with nuclear power; if small plants were required, it would be with fossil fuels; and if medium-size plants (300-600 MW(e)) were required, the costs would be similar. Overall water costs (exclusive of storage and distribution costs) would be in the range US$ 0.7 - 1.1/m^3 for desalination units coupled either with dual-purpose plants (i.e. plants cogenerating electricity and heat) or with plants generating electricity only; coupling with plants that generated heat only would result in considerably higher water costs (in the range US$ 1.2 - 2.0/m^3).[2/]

1/ IAEA-TECDOC-666 has been translated into Arabic.

2/ Additional information from IAEA-TECDOC-666 is presented in Annex I to the present document.

10. Regarding the North African regional feasibility study, it was reported in document GC(XXXVI)/1013 that several potential sites for desalination plants had been identified (with water demand expected to range from 50 000 to 720 000 m^3/day by the year 2000). Work on the study is now close to completion, with two more regional meetings planned - one for finalizing the economic evaluations and one for reviewing the final report; this will involve approximately five man-months of national effort, one man-month of outside expert assistance and three man-months of Agency support.[3/]

11. In the light of the information presented to it at its 1992 regular session, the General Conference, in resolution GC(XXXVI)/RES/592, requested the Director General - inter alia - to convey to the relevant organizations of the United Nations family and to other relevant international organizations the main conclusions of the "Technical and economic evaluation of potable water production through desalination of seawater by using nuclear energy or other means" and called upon Member States in a position "to provide expert services and extrabudgetary resources in support of the activities relating to seawater desalination using nuclear energy which are foreseen in the draft Agency programme for 1993-94 to make such services and resources available".

12. In response to resolution GC(XXXVI)/RES/592, the Secretariat submitted document GC(XXXVII)/INF/323 to the General Conference in 1993. The document provided a summary of the actions taken in distributing information to other organizations and to Member States and of their responses.[4/]

13. In document GC(XXXVII)/INF/323 it was reported that Saudi Arabia had requested technical assistance for a feasibility study on the application of nuclear energy for seawater desalination. Work on this study has started; there have been two advisory missions (in April 1993 and May 1994), and Saudi Arabia has set up an internal organizational structure for co-ordinating the study. A meeting in Saudi Arabia to initiate the collection of necessary data is planned for late in 1994; it will involve the services of about six outside experts for two man-months and three man-months of Agency support.[5/]

14. Also available at the time of the General Conference's 1993 session was document GOV/INF/708 on the Agency's contributions to "Agenda 21", which had been adopted at the United Nations Conference on Environment and Development in June 1992 and covered a wide range of issues under the broad concept of "sustainable development". In the Agency's contribution to "Agenda 21" it was stated that more work could be done to assess the

---

3/ Additional information concerning the North African regional feasibility study is also presented in Annex I to the present document.

4/ An up-to-date report on the interest displayed in and the extrabudgetary resources provided for the work plan described in document GC(XXXVII)/INF/323 is contained in Annex II to the present document.

5/ Additional information is provided in Annex I to the present document .

viability of specific desalination projects in Member States if funding was made available for expert services in support of national efforts.

15. In resolution GC(XXXVII)/RES/617 (referred to in paragraph 1 above), the General Conference also requested the Director General to consult with interested States, the relevant organizations of the United Nations family and other relevant international organizations concerning the implementation of demonstration facilities and the main conclusions of the "Technical and economic evaluation of potable water production through the desalination of seawater by using nuclear energy or other means".

16. In response to that request, the Secretariat wrote to all Member States and to relevant organizations concerning their interest in a possible demonstration facility for seawater desalination using nuclear power. The replies indicated a significant level of interest in such a demonstration facility (see Annex II to the present document). As a result, the Secretariat convened consultants in March and June 1994 and an Advisory Group in June 1994 (the meetings in question were funded through the Agency's Regular Budget); the report of the Advisory Group is provided in Annex III to the present document.

17. The main conclusion of the Advisory Group was that there is a need to establish a programme for identifying a practical set of options from which one or more demonstration facilities with well-defined objectives might be chosen. It was estimated that a period of approximately two years and about ten man-years of effort would be required in order to complete the programme. For implementation of this options identification programme, which has not been foreseen in the Agency's regular programme for 1995-96, additional extrabudgetary funds would be needed.

18. Lastly, in resolution GC(XXXVII)/RES/617 the General Conference again called upon Member States in a position to provide expert services and extrabudgetary resources in support of the activities relating to seawater desalination using nuclear energy to make such services and resources available. So far, approximately US$ 570 000 and the services of two cost-free experts, one partly cost-free expert and one associate junior professional have been provided (see Annex II to the present document).

SUMMARY OF IAEA ACTIVITIES ON THE

DESALINATION OF SEAWATER

USING NUCLEAR ENERGY

SUMMARY OF IAEA ACTIVITIES ON THE DESALINATION OF SEAWATER USING NUCLEAR ENERGY

1. GENERAL

Following the renewed interest in the use of nuclear energy for seawater desalination at the IAEA General Conference in 1989, the IAEA has actively pursued this topic in accordance with requests from Member States. Two IAEA TECDOCs were published, namely IAEA-TECDOC-574 "Use of Nuclear Reactors for Seawater Desalination and IAEA-TECDOC-666 "Technical and economic evaluation of potable water production through desalination of seawater by using nuclear energy and other means". These reports contained a review and analysis of prior information available within the Secretariat, an assessment of the need for desalination based on recent analyses of the world's potable water resources and information on the most promising desalination processes and energy sources, as well as on nuclear reactor systems proposed by potential suppliers worldwide. The economic viability of seawater desalination by using nuclear energy in comparison with fossil fuels was evaluated. The evaluation encompassed a broad range of both nuclear and fossil plant sizes and technologies in combination with various desalination processes. Several other aspects relevant to the subject such as potential environmental and institutional issues were also discussed.

In the North African Regional feasibility study which was initiated in 1991, emphasis was placed on analysing the electricity and potable water demand and the available energy and water resources in the participating countries. Included within the scope of the feasibility study were the selection of representative sites, the analysis of site specific economics for various combinations of energy source and desalination process appropriate for each site, financing aspects, local participation, infrastructure requirements and institutional and environmental aspects. These activities were performed by the relevant institutions in the participating countries with assistance provided by the Agency. Work on the feasibility study is still in progress and is expected to be completed by the end of 1994.

In the feasibility study for Saudi Arabia, for which assistance from the IAEA was requested, two advisory missions to Saudi Arabia have been made and work on a survey of existing potable water resources and present and future demand was started in 1993.

This Annex contains a summary of significant technical and economic data from the two Agency documents, TECDOC-574 and TECDOC-666, and two other documents, the International Desalination Association's Worldwide Desalting Plants Inventory and the Population Action International publication on worldwide water resources. This Annex also contains an interim summary of the results from the North African Regional feasibility study and a brief summary of some technical information pertaining to the study for Saudi Arabia.

2. SUMMARY OF SIGNIFICANT TECHNICAL AND ECONOMIC DATA FROM THE REFERENCE DOCUMENTS

1. Potable water demand for domestic purposes, averaging 100 m^3 per person per year, accounts for only a small portion of total demand in most countries. As standards of living rise, not only does the demand for domestic use increase but also the demand for potable water for the associated higher degree of industrialization. Depending on the standard of living, the degree of industrialization and the extent of agricultural irrigation, the equivalent of 1000 m^3 per person per year appears to be almost a minimum requirement to sustain development.

2. The shortage of potable water from available natural resources is already evident in many areas of the world and will become more so in the future as the population grows and industrialization expands. Using a potable fresh water availability of less than 1000 m^3 per person per year as an indicator of chronic water scarcity, approximately 35 countries are either presently experiencing potable water scarcity or are expected to do so by the year 2025.

3. Desalination of seawater is a proven technology for producing potable water. As of 1990, a worldwide total of 7500 desalination units in 100 countries with a total capacity of 13 million m^3/day were installed or under construction. Extrapolation to the year 2000 at recent contracting rates, would indicate an installed capacity of around 20 million m^3/day by that date.

4. Among the various processes available for the desalination of seawater, the Multi Effect Distillation (MED), Multistage Flash Distillation (MSF), Reverse Osmosis (RO) and Multi Effect Distillation with Vapour Compression (MED/VC) processes are commercially available and appear to have the best near-term prospects for expanded application.

5. All of the desalination processes require input energy. For MED and MSF the energy requirement is primarily as heat, hence requiring same site, or nearby siting of the energy source and the desalination process. For RO and MED/VC, the energy requirement is primarily as electricity, hence permitting separate siting of the energy source and the desalination process.

6. The cost of the energy is a significant contributor, presently between 35% and 55%, of the water production costs. Providing the energy requirement, heat or electricity, from a nuclear power plant has the potential of reducing the water costs if the nuclear plant can produce energy at a lower cost than an alternate energy source.

7. The lesser environmental impact of a nuclear energy source compared to a fossil-fired energy source is a recognized, but presently intangible, advantage for nuclear energy. Having to overcome several special institutional issues is a recognized, and also intangible, disadvantage for nuclear energy. The most significant of these issues involves the assurance of the safety of the nuclear plant by having an adequately trained and experienced organizational infrastructure.

8. A nuclear plant has been coupled to a desalination plant at the Aktau complex in Kazakhstan. A prototype liquid sodium-cooled fast reactor (BN-350) in the complex has been operating in the dual purpose (cogeneration of electricity and heat) mode for over 20 years. The heat has been supplied to different types of distillation processes (MED and MSF) during this period and has reliably supplied all of the drinking, household and industrial water requirements of the region. In 1993, the nuclear plant, with a power output of 520 MW(t), provided the heat to produce 80 MW(e) and 80,000 m^3/day of desalinated water. Water production costs are reported to be competitive within the specific conditions of the region.

9. The coupling of a nuclear plant to a separately-sited electricity-only desalination process (RO and MED/VC) would not involve any technical issues. Overcoming the institutional issues associated with nuclear would be the only barrier. However, if the same site is contemplated for the nuclear plant and the desalination plant due to either the nuclear reactor being required to not only provide the electricity but also the possible minimal heat requirements of the associated process or for a hybrid process involving electricity and heat, then some technical issues and perhaps even more institutional issues may arise.

10. A distinct mismatch is evident between the power output of present commercially-available nuclear plants and the power requirements for reasonably-sized desalination plants. A large, distillation process desalination plant producing 500,000 m^3/day requires only about 500 MWth; a similarly-sized electricity-only reverse osmosis plant requires only about 100 MWe. For countries or areas within a country with an available grid system these mismatches can be overcome by the sale of excess electricity from the electricity-only plant and, similarly, the electricity produced by a larger dual purpose plant built to provide the heat for the distillation process. Without such a grid system, only plants with small power output would be required.

11. From information and data provided to the Agency in response to a questionnaire, over twenty advanced nuclear reactor concepts of smaller power output and hence, closely matching the energy requirements of desalination plants are under development. Information concerning the design and the design status of these concepts has been reviewed by an Advisory Group in 1994 and will be published in the Agency's report on Small and Medium Reactors (SMR).

12. An economic analysis concluded that competitiveness between nuclear and fossil-fired sources for providing the energy requirements for any type of desalination plant was primarily dependent on the unit size (output capacity) of the energy source. For large unit sizes (equivalent to 900 MWe or greater), nuclear power would show a cost advantage; for medium unit sizes (equivalent to the range of 300 MW(e) to 600 Mw(e)), energy costs are similar; for small unit sizes (equivalent to around 50 MW(e)) or less) fossil-fired power would show a cost advantage.

13. The capital cost and the operation and maintenance costs of the desalination plant are practically unaffected by the choice of the type of plant providing the energy. Hence, the cost of water (exclusive of storage, transportation and distribution costs) trends similar to the cost of the energy. In general, the cost of water ranges between US$

0.7 and 1.1 /m^3 for dual purpose (cogeneration of electricity and heat) or electricity-only energy sources and between US$ 1.2 and 2.0 /m^3 for heat-only energy sources. Large electricity generating nuclear power plants, integrated into an electric grid system, supplying electricity to separately-located, reverse osmosis (RO) desalination plants, offer the largest cost advantage for nuclear.

3. SUMMARY OF INTERIM RESULTS FROM THE FEASIBILITY STUDIES

1. In the past 40 years, the population of the five North African countries has increased from 42.5 millions in 1950 to 117.8 millions in 1990 with an average annual growth rate of 2.55%. It is expected that the population of these countries will continue to increase with high growth rate. The increasing population coupled with the ongoing significant expansion in industry will increase the demand on the already strained potable water supply. Therefore, alternative sources of water supply, such as desalination, have to be considered.

2. The only significant energy resources in the region are oil, gas, and limited hydraulic energy. Oil and gas will be depleted in the next century unless new discoveries are made. Hydro power is nearly fully utilized. Solar and wind power have potential but electricity production from these sources is not yet competitive. The only alternatives for electric power production in the future appear to be imported fossil fuels or nuclear power.

3. The largest source of surface water in the region is the River Nile, but the Nile represents a significant source of surface water only for Egypt. The whole North African region lies, for the most part, within the temperate zone and the bioclimate varies from arid to extremely arid. Surface water in the region includes rivers and rain water intercepted by dams or connected cisterns. Several smaller rivers exist in Algeria, Morocco, and Tunisia. Groundwater resources have played an important role in providing potable water in the region, particularly in places where surface water resources are limited, such as in the Libyan Arab Jamahiriya. In the northern areas, however, large extractions have led to a sharp decline in water levels followed by seawater intrusion. The study estimates that, by the year 2025, the overall regional water deficit could be as high as 40 million m^3/day. It would appear, therefore, that seawater desalination must play an increasing role in mitigating the present and future deficit.

4. Desalination plants were first introduced into the region in 1926 when a desalination plant was built in the Ras-Gharib oil field in Egypt. Various plant sizes and technologies have since been employed to satisfy the regions' increasing demand for fresh water for both municipal and industrial purposes. The present regional desalination plant inventory has about a 900,000 m^3/day capacity.

5. Eleven sites for desalination plants were identified by the five participating countries. The potable water-shortage requirements by the year 2005 for the region adjacent to

these sites represent a range of desalination capacities from 24,000 to 720,000 m^3/day. Five sites, one in each of the participating countries, were chosen for the cost evaluations. The complete range of required capacities were covered by these choices.

6. At each of the five sites, various energy sources were considered for the coupled desalination plant. Single purpose plants generating only one form of energy, electricity for a RO or MED/VC desalination plant or heat for a MED or MSF desalination plant were considered. Dual purpose plants cogenerating electricity (for sale) and heat to a coupled MED or MSF desalination plant or electricity and heat for a hybrid RO/MED desalination plant were also considered. A limitation that any electricity generation could not exceed 10% of each country's electric grid capacity was applied. The nuclear plants considered in the study were those for which technical information and cost estimates were provided to the Agency by the vendors of the various concepts.

7. The costs of alternative energy supply options to be coupled to the various desalination processes depended on the capacity of the desalination plant. The costs for each combination of desalination process and an energy source varied with different locations and countries. The economic assessment followed the same procedure and methodology adopted in TECDOC-666.

8. Since the last General Conference, one regional meeting to review the overall status of the study has taken place and, in addition, there have been several expert missions on specific aspects, particularly to assist in economic evaluations.

9. The preliminary results of the North African Regional feasibility study follow the same pattern as in the generic study, TECDOC-666, and indicate that:

a) For all coupling schemes, the cost of water produced from MSF is substantially higher than that from other considered desalination processes.
b) The cost of water produced from single purpose heating plants (US$ 1.25 - 3.0/m^3) is higher than that produced from electricity-only or dual purpose plants (US$ 0.7 - 1.0/m^3).
c) The larger the nuclear plant power output, the smaller the specific water costs.
d) The difference between water costs produced from MED and RO Plants is very small, without any particular trend favoring either of the two processes.

10. As a general conclusion, the North African Regional feasibility study indicates that the use of nuclear plants as an alternative option to the use of fossil-fuelled plants for supplying energy for seawater desalination is technically feasible, and is, in general, economically competitive for medium to large size units integrated into the electric grid system.

11. For the feasibility study for Saudi Arabia, two advisory missions to Saudi Arabia have been made and an outline of the study has been made. In addition, Saudi Arabia has set up several internal organizations to coordinate the study.

12. From published information on available water resources and on potable water demand for Saudi Arabia[1/], it is evident that Saudi Arabia continues to draw large quantities of water from non-renewable (deep aquifer) resources to meet demands. A significant expansion of the country's already large seawater desalination industry appears to be absolutely necessary.

1/ "Desalination in Saudi Arabia, Status, Options and Issues", Ibrahim I. Kutbi and Abdul Matin, Nuclear Engineering Department, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia, (1992)

SUMMARY OF COUNTRIES'

SUPPORT TO THE AGENCY ACTIVITIES ON

SEAWATER DESALINATION USING

NUCLEAR ENERGY

1. GENERAL

In 1990, the North African countries Algeria, Egypt, Morocco, Libyan Arab Jamahiriya and Tunisia requested assistance in performing a regional feasibility study on the use of nuclear energy for seawater desalination. This study is close to completion.

Since 1991, Libyan Arab Jamahiriya has contributed extrabudgetary funds and cost-free expert services towards the activities.

In 1992, Saudi Arabia requested assistance for a feasibility study on the use of nuclear energy for desalination. The initial phase of this study is underway.

In 1992, the Russian Federation offered to construct, under the IAEA auspices, a floating desalination plant with a nuclear energy source for training and demonstration purposes.

In the course of the meetings held on the topic of seawater desalination using nuclear energy the following countries participated: Algeria, Argentina, Belgium, Canada, China, Cyprus, Egypt, France, Germany, Greece, India, Indonesia, Israel, Japan, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Morocco, Qatar, Russian Federation, Saudi Arabia, Switzerland, Syria, Tunisia, United Arab Emirates, United Kingdom and United States of America. The following organizations also participated: the Arab Atomic Energy Agency, the Food and Agriculture Organization and the World Meteorological Organization.

2. GENERAL CONFERENCE RESOLUTIONS REQUESTING SUPPORT

There have been three resolutions requesting support:

1990 General Conference - Resolution GC(XXXIV)/RES/540

- requested the Director General to make use of cost-free experts whenever possible.

Several countries were approached in the course of the ongoing activities.

1992 General Conference - Resolution GC(XXXVI/RES/592)

- requested the Director General to call upon Member States in a position to provide expert services and extrabudgetary resources in support of the activities relating to seawater desalination using nuclear energy which are foreseen in the Agency programme for 1993-1994 to make such services and resources available.

The Secretariat contacted potentially interested countries and international organizations.

1993 General Conference - Resolution GC(XXXVII/RES/617)

- calls upon Member States in a position to provide expert services and extrabudgetary resources in support of the activities relating to seawater desalination using nuclear energy to make such services and resources available.

- requested the Director General consult with interested states, the relevant organizations of the United Nations family and other relevant international organizations concerning the implementation of demonstration facilities.

All Member States and about 60 relevant organizations were approached by the Secretariat.

3. SUMMARY OF RESPONSES TO PROVIDE EXPERT SERVICES AND EXTRA BUDGETARY RESOURCES

Argentina, Canada, Jordan, the United States of America and the Arab Atomic Energy Agency (AAEA) have provided extrabudgetary funds; the People's Republic of China, Egypt, India and Saudi Arabia offered the services of experts, in some cases partly cost-free; the Philippines considered support in 1993, but withdrew in 1994. As already noted, the Libyan Arab Jamahiriya contributed extrabudgetary funds and cost-free expert services which were not specifically in response to the resolutions.

The following countries and organizations replied that they were not in a position to support: Australia, Denmark, Finland, Germany, Israel, the Netherlands, New Zealand, Norway, Russian Federation, Switzerland, Syrian Arab Republic, Turkey, OPEC Fund and the African Development Bank.

4. SUMMARY OF RESPONSES TO EXPRESS INTEREST CONCERNING THE IMPLEMENTATION OF DEMONSTRATION FACILITIES

Canada, China, Cuba, India, Indonesia, Mauritius, Peru, Turkey and the United States replied favorably on an official basis. Informal, favorable replies were received from institutions in the following countries: Germany, Israel, Japan, and Libyan Arab Jamahiriya.

Australia, Bolivia, Brazil, Finland, Germany, the Netherlands, New Zealand, the Philippines, the ICRP and the OECD Nuclear Energy Agency replied that they were not in a position to support.

5. SUMMARY OF EXTRABUDGETARY FUNDS RECEIVED AND OF EXPRESSIONS OF INTEREST

Table 1 shows the extrabudgetary funds received from Member states and Table 2 gives an overview of the Member States supporting the Agency activities.

Table 1: Extrabudgetary Funds for Activities on Seawater Desalination Using Nuclear Energy US$

	1991	1992	1993	1994	TOTAL
Libyan Arab Jamahiriya	100000	53100		50000	203100
Argentina			10000	5000	15000
Jordan			2800		2800
Canada				18657[1/]	18657
Arab Atomic Energy Agency				6000	6000
USA				325000[2/]	325000
TOTAL	100000	53100	12800	404657	570557

[1/] Canadian $ 25000 converted to US$

[2/] Support for Saudi Arabian feasibility study

Table 2: Support to the IAEA plan for producing potable water economically

	Response to	Nature of response	Type of support
Algeria	general	official, user	participates in feasibility study
Argentina	RES/592	official, vendor	provided funds for overall activity
Canada	RES/592-617	official, vendor	provided funds for overall activity
China	RES/592-617	official, vendor/user	provided partly cost-free expert, offered nuclear island
Cuba	RES/617	official, user	has interest
Egypt	general RES/592	official, user informal	participates in feasibility study, offered partly cost-free experts
Germany	RES/617	informal, vendor	offered floating desalination facility
India	RES/592-617	official, vendor/user	offered partly cost-free experts
Indonesia	RES/617	official, user	has interest
Israel	general	informal, vendor	offered desalination facility
Japan	RES/617	informal, vendor	offered nuclear equipment
Jordan	RES/592	official, user	provided funds for overall activity
Libyan Arab Jamahiriya	general	official, user	participates in feasibility study, provided funds and cost-free experts for overall activity,
	RES/617	informal	offered financing for project
Mauritius	RES/617	official, user	has interest
Morocco	general	official, user	participates in feasibility study
Peru	RES/617	official, vendor	offered site
Russia	general	official, vendor	offered floating nuclear desalination plant
Saudi Arabia	general RES/592	official, user official	participates in feasibility study offered experts
Tunisia	general	official, user	participates in feasibility study
Turkey	RES/617	official, user	has interest
United States of America	RES/592-617	official, vendor	has interest, provided funds for Saudi Arabian feasibility study
Arab Atomic Energy Agency	RES/592	official	provided funds for overall activity

DEMONSTRATION FACILITIES FOR

SEAWATER DESALINATION USING

NUCLEAR ENERGY

-A Recommended Options Identification Programme-

1. INTRODUCTION

In order to meet the growing need for water, many coastal countries are exploring the economic viability of seawater desalination. Seawater desalting is a particularly energy intensive process, and many of the water short countries have low indigenous fossil energy reserves. Even countries with sufficient fossil energy reserves recognize that such fuels could have more valuable applications than water production. Moreover, since the need for water will last as long as mankind, the solution for energy supply should be long term. Thus, nuclear energy is an appropriate energy source for desalination for all countries regardless of indigenous fossil fuel reserves. A noteworthy example of seawater desalination using nuclear energy is the supply of potable water for the city of Aktau, (Kazakhstan)[1/] over the last twenty years.

The IAEA has been studying the feasibility of desalination using nuclear energy since the 1960s and has published a series of reports [1-5] as part of its programme on this technology. The programme was terminated in 1977, because the interest in desalination appeared to be less strong than in other applications of nuclear energy. The reasons were uncertainty in costs, mismatch between the size of nuclear power plants being constructed and desalination plants, and the safety issues related to location of nuclear power plants close to large consumers of desalted water.

Following a hiatus in this early activity, interest from Member States was once again raised in 1989. Since that time, the Agency has undertaken several activities on seawater desalination using nuclear energy. These activities were requested through adoption of resolutions by the General Conference under the heading "A plan for producing potable water economically". The Agency has organized a number of meetings and prepared two technical documents, one on the status and one on the technical and economic evaluations of seawater desalination [6,7]. In addition, the Agency is assisting North African Countries and Saudi Arabia in performing feasibility studies on the use of nuclear energy for seawater desalination. The former is expected to be finished by the end of 1994 and the latter by 1995/96.

An increasing level of interest is being shown in the subject of seawater desalination using nuclear energy. At the 1993 General Conference, Member States passed Resolution GC(XXXVII)/RES/617 which "Requests the Director General to consult with interested States ..... concerning the implementation of demonstration facilities...". In response to that Resolution, the Agency has distributed letters to all Member States asking them to provide information about their interest in a possible demonstration facility for seawater desalination using nuclear energy.

The responses to that request to Member States show a growing level of interest in both seawater desalination using nuclear energy and in a demonstration of that capability. Given the level of interest, the Agency convened a Consultancy in March 1994 to put in place the groundwork for an Advisory Group Meeting (AGM) in June 1994. The task of the AGM was to advise the Agency with respect to the question of moving ahead with a demonstration facility.

1/ The experience providing potable water at Aktau is described briefly in [6,7].

In summary, it was the conclusion of the AGM that to effectively advance the use of nuclear energy for seawater desalination, any demonstration facility must be part of a well-defined demonstration programme supported by the Agency's other activities in this field. Within the framework of such a programme, one or more demonstrations are considered to be appropriate, so long as they contribute in a coherent, integrated fashion to the overall objectives of the programme. However, additional work was considered necessary to adequately identify, define and characterize a practical set of options for demonstration.

It is the purpose of this report to present to the Agency the conclusions and recommendations of the June 1994 AGM as a result of its deliberations with respect to the issue of demonstration of the capability for seawater desalination using nuclear energy.

2. OBJECTIVE OF A DEMONSTRATION PROGRAMME

The AGM identified that the programme objective would be to demonstrate and to build confidence, through the design, construction, operation and maintenance of an appropriate facility or facilities, that seawater desalination using nuclear energy can be successfully accomplished as one of the elements of a Member State's national development programme in an economically competitive manner while meeting established safety and reliability criteria.

3. APPROACH TO ACHIEVING THE OBJECTIVE

The intent of the AGM was that the demonstration programme objective be achieved through the definition and implementation of an integrated programme of activities leading to the identification of a set of practical options for proceeding with appropriate demonstration(s). Although a considerable body of valuable information and experience is already available, it is not sufficiently well characterized at this stage to allow an informed decision to be made on the merits of specific demonstration(s) which might be proposed. Accordingly, it was considered that as a first step the Agency should undertake an "Options Identification Programme" with the purpose of identification and definition of a set of practical options as a basis for deciding whether and how to proceed with the subsequent implementation of one or more demonstration projects (facilities).

The Options Identification Programme would develop practical options for proceeding with a desalination facility using a nuclear reactor as an energy source. These practical options would be presented to the General Conference by the Agency. The Programme would not in itself include implementation of any demonstration projects. It would, however, identify the required investment, infrastructure, regulatory, technical and licensing requirements to proceed with the actual implementation of demonstration projects for specific cases, as applicable.

As an integral part of the overall demonstration programme, the detailed investigations and recommendations arising from the Options Identification Programme should serve as a basis for any decisions to be taken regarding implementation of demonstration projects. However, some limited or full scope demonstration projects carried out by Member States during the course of the Options Identification Programme could be considered to fall within the framework of the Agency's overall demonstration programme. For this to be the case, such demonstrations would need to clearly meet the guidelines being developed under the Options Identification Programme for practical demonstration projects and would need to contribute in some significant manner to the overall objectives of an integrated demonstration programme as it evolves.

4. OPTIONS IDENTIFICATION PROGRAMME

There currently exists, as a result of the field experience and studies available to date, a wide range of possible choices in terms of desalination technologies, reactor types, coupling schemes, and sites for demonstration projects. There is also a wide range of aspects which either limited or full scope demonstration projects could address. These range from very narrow and specific technical aspects to much broader ones. At the one extreme, for example, would be the details of a coupling scheme and the ability to model its behavior. At the other extreme would be broader aspects involving the introduction of an integrated water and electricity production facility into the national water and energy supply planning framework, where questions of systems interaction, operational reliability, maintenance and economics become the focus of interest.

4.1 Purpose

The purpose of the Options Identification Programme would be to narrow down this very broad range of possibilities to a much more limited set of practical demonstration projects. This limited set of options would be ones which would be well defined, in which all the aspects necessary to ensure success would be fully investigated, which had an applicability much broader than the specific country and site at which they were carried out, and which could practically be developed on a time scale commensurate with the needs of that specific option being identified. As this programme is not intended to serve as either a reactor or a desalination process development programme, any demonstration options identified would be based on reactor and desalination technologies which were themselves readily available without further development being required at the time of the demonstration.

4.2 Process

The process to be followed in carrying out the Options Identification Programme is intended to be similar to that used for the development of IAEA-TECDOC-666. A small Working Group would be established to carry out the work. This group could consist of representatives from interested Member States and Agency staff. The group, under the coordination of the Agency, would be charged with the responsibility for definition and performance of all activities necessary to identify and fully characterize a set of practical demonstration options.

The Working Group would carry out its activities through a combination of periodic structured meetings and individual work assignments. The group would be expected to call upon the services of a variety of specialists, including Agency in-house expertise, as required to address specific technical issues. Throughout the duration of the programme, occasional peer review meetings would be convened by the Agency, possibly through the mechanism of Advisory Group Meetings or Technical Committee Meetings.

4.3 Programme Elements

In order to fully develop a path towards the overall objective of the demonstration programme, a set of specific elements would be identified which need to be addressed in order to fully characterize and ensure the success of any proposed demonstration project (i.e., in more detail than in IAEA-TECDOC-666). Each of these elements, if properly addressed through the mechanism of a demonstration (either limited or full scope), would enhance the level of confidence in the desalination of seawater using nuclear energy.

The definition and detailed investigation/evaluation of these elements is considered to be one of the first activities to be undertaken by the Working Group, as that will form the basis for the development of a practical set of demonstration options. Starting from the current results of the accumulated experience and the studies, the aim is to address the elements in sufficient detail to establish applicable criteria and characteristics for selection of a limited number of demonstration projects which can be recommended for subsequent decision making. Some of the typical elements to be considered could include items such as:

- **General Considerations**
  This category would typically include the early selection of several candidate site locations, preferably with varied characteristics and requirements; identification of programme requirements, including criteria, ground rules, timing/schedule; organizational requirements; etc.

- **User Requirements**
  This category would typically include items such as water and energy supply/need, constructability, operability and maintainability, expected reliability, competitiveness, etc.

- **International Aspects**
  This category would typically include items such as interest and willingness to participate of prospective owner/sponsor, non-proliferation aspects, long term market prospects/demand, applicability to other locations, international support, participation, etc.

- **Local and National Infrastructure**
  This category would typically include items such as availability of a sound regulatory structure to analyze licensability and monitor compliance, suitability of site, public and political acceptability, local infrastructure readiness/availability, organizational structure, etc.

- **Technical Aspects**
  This category would typically include items such as applicable nuclear plant designs and sizes, desalination processes and capacities, development and licensability status of concept/design, etc.

- **Economic Aspects**
  This category would typically include items such as cost/benefit considerations; capital requirements; operating, maintenance and fuel costs; design and management costs; financing prospects, supplier credibility, etc.

4.4 Identification of Practical Options

Having carried out the detailed investigation/evaluation described above, the next step would be to select a set of practical candidate demonstrations which could be recommended for implementation. In addition to the full scope facilities evaluated in the feasibility studies, there might be many combinations of limited scope demonstrations that could also contribute to addressing the aspects that arise in considering desalination using a nuclear energy source.

The Working Group would narrow down the possibly large, initial set of candidate demonstrations to a smaller set which would have the broadest general applicability, and would most significantly contribute to achieving the overall objective.

This smaller set of candidate demonstrations would then be the subject of a further detailed evaluation of suitability according to applicable criteria/characteristics developed as described above. The degree of investigation required in each particular case would depend on the specific nature of the aspects being addressed, the applicable criteria and the proposed demonstration(s). An even smaller set of candidate demonstrations would evolve.

The next step would then be to possibly further characterize the even smaller set of options in terms of a timescale of near term, medium term and longer term options. The time scale on which various options are deemed to be practical and recommended for implementation may vary, depending on the nature of the aspect to be addressed, the complexity of the evaluation required, and the nature of the demonstration to be recommended for implementation. Note that this flexibility in time scale has the advantage of allowing for early identification and implementation of demonstrations.

4.5 Relevant Experience

As previously stated there is already in existence a significant body of relevant experience which can be drawn upon as a starting point for moving forward with future work. It is intended that this experience be considered in detail by the Working Group so that existing work is not duplicated, and so that those aspects which can be addressed on the basis of current experience are appropriately accounted for in developing demonstrations which add to the overall body of knowledge required to build the level of confidence in desalination using nuclear energy sources. The current experience can generally be categorized as field experience, generic studies, and specific feasibility studies. A summary of this experience is provided in [6], supplemented by information contained in [7-10].

5. IMPLEMENTATION OF DEMONSTRATION PROJECTS

As a result of the Options Identification Programme a small number of practical options will have emerged that have the potential for practical implementation. The decision to proceed to an implementation programme for any of these options is outside the scope of the Options Identification Programme; however, the Working Group may well recommend that one or more of these options should be implemented.

Should a user decide to proceed with a project implementation programme based on one of the recommended options, the work that contributed to the selection will have considered aspects of project planning that would provide a sound basis for the project implementation itself. These aspects include the items presented in Section 4.3, but project planning will require these items to be pursued to a greater depth in accordance with standard project implementation practices.

The final decision to proceed with a project should not occur until a user is satisfied that the detailed planning and assessment phases of the project have been satisfactorily completed and that the project is fully viable. The user will have satisfied himself on aspects such as the QA programme, the fuel cycle concept and the degree of national participation; on the existence of an adequate regulatory structure for licensing and compliance; on project implementation and timescale aspects such as project and engineering management, project risk management, project phasing and overall timescales; on equipment procurement, manufacture and installation, etc.; on the economic viability of the project within a defined market and with the financing and contractual basis of the total project.

6. ESTIMATED TIME FRAME AND EFFORT

It is estimated that the Options Identification Programme can be carried out over a period of approximately two years from the time it is initiated. Such a period should be adequate to narrow down and provide detailed characterization of an appropriately limited number of practical demonstrations. This time frame should also be sufficient to allow completion of the feasibility studies currently underway and to incorporate the results of those studies.

Based on the experience in preparing IAEA-TECDOC-666, an estimated level of effort of approximately 10 man-years, with associated expenses, would be required to complete the Options Identification Programme.

7. EXAMPLES OF POTENTIAL DEMONSTRATION PROGRAMMES

Appendix I provides several examples of potential demonstration projects which might be considered for eventual implementation. These examples have been provided by individual organizations in Member States, and have not been reviewed by the AGM nor the Agency. They do, however, constitute representative examples of the type of candidate demonstrations which might be recommended by the Working Group for implementation.

8. CONCLUSIONS AND RECOMMENDATIONS

There is evidence of a growing level of interest in both desalination using nuclear energy and in a demonstration of that capability. However, the AGM concluded that the question is much larger than simply one of a "demonstration facility." In order to effectively progress the state of knowledge and build confidence in the use of nuclear energy for desalination, any demonstration facility must be part of a well-defined demonstration programme supported by the Agency's other activities in this field. Such a programme will provide additional stimulus to the use of nuclear energy for desalination.

As a first step in moving forward with a demonstration programme, the Options Identification Programme to adequately identify, define and characterize the most practical set of options for demonstration is recommended. It is further recommended that this be initiated as soon as possible, and executed in a timely manner. The Agency should pursue a proactive role, supporting and guiding the effort and further stimulate interest amongst Member States.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Desalination of Water Using Conventional and Nuclear Energy, Technical Reports Series No. 24, IAEA, Vienna (1964).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy for Water Desalination, Technical Reports Series No. 51, IAEA, Vienna (1966).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Costing Methods for Nuclear Desalination, Technical Reports Series No. 69, IAEA, Vienna (1966).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Guide to the Costing of Water from Nuclear Desalination Plants, Technical Reports Series No. 80, IAEA, Vienna (1967).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Guide to the Costing of Water from Nuclear Desalination Plants, Technical Reports Series No. 151, IAEA, Vienna (1973).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of Nuclear Reactors for Seawater Desalination, IAEA-TECDOC-574, Vienna (1990).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical and economic evaluation of potable water production through desalination of seawater by using nuclear energy and other means, IAEA-TECDOC-666, Vienna (1992).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on Small and Medium Reactors, IAEA-TECDOC (under preparation).

[9] Nuclear Desalination as a Source of Low cost potable water in North Africa, Report of Feasibility Study, (under preparation).

[10] Prospects of Nuclear Desalination in Saudi Arabia, Report of Feasibility Study, (under preparation).

Appendix I: EXAMPLES OF DEMONSTRATION PROGRAMMES

Descriptions of potential demonstration projects were provided by individual organizations in Member States. This Appendix contains only a brief description of each of the potential demonstration projects.

The proposed projects were not reviewed by the Consultants, the Advisory Group Meeting, nor the Secretariat. They are included solely to illustrate a range of possible demonstrations that could be considered.

- **A CANDESAL Nuclear Desalination System Demonstration Programme**

  The Canadian developed CANDESAL Nuclear Desalination System couples two proven technologies, reverse osmosis (RO) seawater desalination and CANDU nuclear power generation, into an facility for the cogeneration of fresh water and electricity. In addition to the traditional electrical coupling, the CANDESAL system employs a unique thermal coupling between the reactor and the desalination plant through the use of the reactor's condenser cooling water as pre-heated feedwater to the RO desalination plant.

  The objective of a CANDESAL demonstration programme would be to build confidence, through the design, construction, operation and maintenance of an appropriate facility or facilities, that seawater desalination system using both electrical and thermal energy from either a CANDU 6 (670 MW(e)) or a CANDU 3 (450 MW(e)) reactor can be successfully accomplished. The proposed programme consists of two limited scope demonstrations which serve as logical steps leading eventually to a full scope demonstration facility.

- **Advanced Nuclear Heating Reactor Desalination Demonstration Programme**

  The advanced nuclear heating reactors HR-5 (5 MW(t)), HR-10 (10 MW(t)), and HR-200 (200 MW(t)), developed in China, coupled to the Multi-Effect Distillation (MED) desalination process, are proposed as possible systems for a Desalination Demonstration Facility using nuclear energy. The HR-5 has been successfully operated in China since 1989 and cogeneration of heat and electricity using nuclear energy was demonstrated successfully in 1991 to 1992.

  The objective of the nuclear desalination demonstration programme would be to prove that a seawater desalination plant closely coupled to a heating reactor as the energy source can be successfully accomplished.

  The proposed demonstration programme consists of three possible full scope facility options, option 1 (HR-200 land-based desalination plant), option 2 (HR-10 floating desalination plant), and option 3 (HR-5 floating desalination plant), and one limited scope demonstration using the present HR-5 reactor to demonstrate coupling technology.

- **The Floating Nuclear Desalination Plant APWS-80 as a Short-term Full Scope Demonstration Facility**

  The Russian Federation proposes to build and operate an APWS-80 floating nuclear desalination plant (NDP) with a KLT-40 type nuclear plant (80MW(t)) coupled to a MED desalination plant as a short-term full scope and full scale nuclear desalination demonstration facility.

  The principal objectives of this facility would be to obtain the actual construction cost of a nuclear desalination plant, to demonstrate the principal operational technical-economic characteristics of the NDP and hence, substantiate the estimated cost of desalinated water.

- **TRIGA Research Reactor Facility with Optional Desalination Demonstration**

  The US-developed TRIGA research reactor with the option of converting the reactor to a heating reactor, coupled to a MED desalination plant is proposed as a full scope demonstration facility. The reactor would normally be operated as a low power, pool-type research reactor for nuclear, reactor and materials research. With the addition of minimal equipment to permit forced circulation, the reactor would be converted to a 50 MW(t) heating reactor with a coolant outlet temperature as needed for the coupling.

- **Nuclear Desalination Demonstration Project using the Gas-Turbine Modular Helium Reactor**

  A single module of the US-developed GH-MHR (286 Mw(e)) coupled to a RO desalination plant with preheated feedwater is proposed as a full scope demonstration facility. The objective would be to demonstrate the cogeneration of electricity for coupling to the RO plant and the heat for preheating the feedwater for the RO plant.