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PLAN FOR PRODUCING POTABLE WATER ECONOMICALLY

1. In September 1990, in resolution GC(XXXIV)/RES/540, the General Conference requested the Director General: "to contact appropriate United Nations agencies and internatonal and national organizations and institutions with a view to assessing all available information on the future need for potable water relevant to nuclear desalination"; "to assess in detail - within his competence and with the assistance of international and other organizations concerned and also making use of cost-free experts whenever possible - 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"; "to include nuclear desalination as one of the activities in future programmes of the Agency in the process of preparing the Agency's programme and budget"; and to present to the General Conference at its thirty-fifth regular session "a report on progress in implementing the relevant recommendations contained in the Attachment to document GC(XXXIV)/928".

2. Subsequent to the adoption of the above-mentioned resolution, Algeria, Egypt, the Libyan Arab Jamahiriya, Morocco and Tunisia submitted a request to the Agency for assistance in conducting a feasibility study on nuclear desalination for selected sites in North Africa. The Secretariat decided to proceed simultaneously with the economic assessment requested in the General Conference resolution and with the regional feasibility study requested by these five Member States.

3. The initial activities, undertaken as part of the economic assessment, consisted of reviewing and analysing the relevant information and data available within the Secretariat (mainly information and data resulting from earlier studies on nuclear desalination and on small and medium power reactors) and of obtaining - through questionnaires - complementary, up-to-date technical and economic information and data from potential suppliers of nuclear reactors suitable for coupling to desalination plants. Also, the availability and the characteristics of desalination processes were looked into. These activities were followed by comparative economic assessments carried out with the assistance of interested potential suppliers and of consultants.

4. A report on progress, containing a summary of a preliminary economic assessment, was presented to the General Conference in September 1991 (GC(XXXV)/INF/298). The Conference requested the Director General to report again in 1992 (GC(XXXV)/RES/563).

5. Subsequently, activities were carried out within the framework of the regional feasibility study. A Phase 1 - or prefeasibility study - was defined as the period in which data and information would be gathered. Emphasis was placed on analysing the electricity and potable water demand and the available energy and water resources in the participating countries, and on reviewing desalination processes and relevant experience. Included within the scope of the prefeasibility study were also the selection of representative sites, the analysis of the supply conditions for electricity and potable water, site specific economics, financing aspects, local participation, infrastructure requirements, institutional and environmental aspects and launching conditions. These activities were performed jointly with relevant institutions in the participating countries, and a report on the prefeasibility study is expected at the end of 1992. It shows that North Africa has an immediate shortage of 3 million m^3/d of potable water - and

will have a 9 million m^3/d shortage by the year 2000. The need for seawater desalination at 15 potential sites is expected to range between 50 to 720 thousand m^3/d in the year 2000. Three sites with a common size of about 120 thousand m^3/d are being investigated under Phase 1. The necessary investment for covering water needs through desalination by the year 2000 amounts to about US $30 billion. During several regional meetings, the North African country representatives recommended:

- the creation of a joint regional organization for potable water;
- the establishment of a joint R&D and training facility;
- the provision of a joint special fund for activities in the event of a water shortage in the region;
- that international organizations provide more favourable financial conditions; and
- that special technical assistance programmes be carried out.

Phase 2 will consist of the in-depth feasibility study as originally requested; several countries have submitted new requests for incorporation in the 1993/94 regular Technical Co-operation Programme.

6. In response to the wishes of the General Conference a report has been prepared. It contains an assessment of the need for desalination and information on the most promising desalination processes and energy sources and on nuclear reactor systems proposed by potential suppliers worldwide. The main part of the report is devoted to evaluating the economic viability of seawater desalination using nuclear energy, in comparison with fossil fuels. This evaluation encompasses a broad range of both nuclear and fossil plant sizes and technologies and of combinations with desalination processes. Finally, relevant safety and institutional aspects are briefly discussed. The Attachment to this document contains the executive summary of the report (this material constitutes chapter 1 of the report). The Secretariat will issue the full text of the report in the IAEA-TECDOC series in September 1992.

ATTACHMENT

TECHNICAL AND ECONOMIC EVALUATION OF POTABLE WATER PRODUCTION THROUGH DESALINATION OF SEAWATER BY USING NUCLEAR ENERGY AND OTHER MEANS

1. EXECUTIVE SUMMARY

1.1 NEED FOR DESALINATION

Worldwide availability of potable water exceeds substantially the amounts of water being used. However, water resources are not evenly distributed. It is estimated that about three quarters of the world's population lack safe drinking water. Population growth, increased pollution and reduction of existing ground and surface water resources are expected to increase water supply problems, in particular in arid regions. In addition to potable water, which is essential to sustain life, water is required by households to ensure an adequate quality of life, by industry as an essential input to industrial production, and by agriculture, where irrigation may be needed to complement precipitation.

There is no worldwide inventory of requirements for seawater desalination. Nevertheless, the extent and distribution of current desalination capacity (by the end of 1991, 15.6 million m^3/d capacity had been contracted in 30 countries) provides an indication of the regions and countries which have already exhausted other less expensive potable water supply options, and which are expected to continue to expand their desalination capacities in the future. The most important users are the Middle East (about 70% of the worldwide capacity), mainly Saudi Arabia, Kuwait, the United Arab Emirates, Qatar and Bahrain and North Africa (6%), mainly the Libyan Arab Jamahiriya and Algeria. Among industrialized countries, the USA (6.5%) is an important user (California and parts of Florida). Other countries taken together have less than 1% of worldwide capacity. Statistics show a rapid increase of the installed desalination capacity during the last decade.

Assuming that the growth rates of the capacity for seawater desalination production prevalent during the last decade will be approximately maintained during the 1990s, there might be about 20 million m^3/d capacity in operation worldwide by the year 2000. Medium and long term forecasts beyond the year 2000 are highly speculative. A doubling of installed capacity each decade seems to be a reasonable expectation, assuming that current trends are maintained. Should major cost reductions be achieved, growth rates could be substantially higher.

1.2 AVAILABLE DESALINATION PROCESSES

Seawater desalination is not new, and was already used in ancient times to produce drinking water. In this respect, it is similar to windpower. The current desalination technology, however, involving large scale application, has a history comparable to nuclear power, i.e., it spans about three decades. Desalination is an established and proven commercially available technology, with further potential for improvement. Experience shows that desalination plants can be operated with high availability, if high quality standards are applied and maintenance is given due attention.

For the purposes of the present report, the scope of a "desalination plant" encompasses a complete installation which is capable of producing desalted seawater, including water intake and outlet structures, the processing plant which may include several desalination units, and all on-site auxiliary installations needed for proper operation and maintenance, except the energy source. The limits of this scope are the input connections for the supply of energy and the outlet for the potable water produced. Water storage, transport and distribution facilities are not included. The reason why the energy source has been excluded from the scope is to facilitate a comparative evaluation of the economics of using different energy supply options.

Among the various existing desalination processes, described in IAEA-TECDOC-574 "Use of Nuclear Reactors for Seawater Desalination", the following have been selected for the present study as the most interesting for large scale water production: reverse osmosis (RO), multieffect distillation with vapour compression (MED/VC), multieffect distillation (MED), and multistage flash distillation (MSF). All are proven by experience and all are commercially available from a variety of suppliers. For the detailed economic assessment, the RO and MED processes have been selected as representative, but costs have also been calculated for MED/VC and MSF.

To desalinate water, energy is required. The form and amount of the energy input depends on the process used. RO and MED/VC require only mechanical energy which in this report is in the form of electricity. Respectively, 5-7 and 7-9 kW.h of electricity is required for producing one m^3 of potable water, depending on the design, unit size and site conditions. These amounts do not include energy consumed for water transport and distribution, which would again be provided by electricity (pumping power) and would be the same for any desalination process at the same site and with the same production volume.

For the distillation processes (MED and MSF) the energy input is mainly in the form of low temperature heat (hot water or steam) and some electricity, which for MED is about 2-2.5 kW.h/m^3 and for MSF about 4-6 kW.h/m^3. The heat consumption depends on the design, in particular the number of effects and the "gain-output ratio" (GOR), which in turn is related to the temperature of the heat source. For MED, the specific heat consumption is in the range of 30-120 kW(th).h/m^3 for heat source inlet temperatures of 120°C to 70°C and for MSF about 55-120 kW(th).h/m^3.

All energy requirements of the current worldwide desalination capacity could be supplied by a generating capacity of about 4000-5000 MW(e), which is equivalent to around 1% of the total nuclear power in operation and under construction in the world.

1.3 ENERGY SOURCES AVAILABLE FOR COUPLING TO DESALINATION PLANTS

The energy required for seawater desalination can be supplied either by conventional or nuclear sources; there are no technical impediments to the use of electricity or heat (or both) produced by a nuclear reactor. In principle, nuclear power reactors could accommodate any size of desalination plant.

When desalination plants are supplied with electricity from an electric grid system which contains nuclear power generating capacity, a corresponding part of their energy demand is effectively supplied by nuclear power. Of course, this applies to any type of industrial installation supplied with electricity from such a grid.

When an electric grid is available (grid concept), the electricity generating plant can be integrated into the grid and optimized to satisfy the combined energy demand of both the electricity market and of the desalination plant, thus benefiting from the size effect. When no electric grid connection is available, the generating plant would have to be dedicated to supplying energy to the desalination plant only, and the size of the plant would then be determined by the energy demand of the desalination plant.

The generating plant could be land-based or floating, and could be used for heat production only, for cogeneration of electricity and heat (coupled with the MED or MSF processes), or for electricity production only (coupled with the RO or MED/VC processes). When coupled with the MED or MSF process, the power plant would have to be located adjacent to the desalination plant; when coupled with the RO or MED/VC processes, it would not need to be near the desalination site.

With the grid concept, depending on the size of the interconnected electric system and on the energy demand of the desalination plant, any size of nuclear reactor could be employed, either for the cogeneration of electricity and heat or for electricity generation only. Without a grid connection, only small reactors would be suitable.

Regarding available reactor systems, information and data have been provided to the Agency in response to a questionnaire, including some twenty different concepts covering a wide range of sizes and types of reactor, as well as fields of application (production of electricity, heat, or cogeneration). All concepts are based on known technology, incorporating advanced features intended to increase safety levels, achieve simplifications, and improve performance. According to the potential suppliers, some systems are commercially available now, while others are expected to become available in the future. None, however, have been built or committed to date.

In addition to the received information on reactors, various current designs of large size nuclear power plants are known to be commercially available at present. Regarding additional advanced concepts which are under development, no detailed information has been received in response to the enquiry. It should be noted that because of the high cost of development for advanced reactors, especially the innovative concepts, Member States with have ongoing programmes in advanced reactor development may find it attractive to cooperate internationally in technology development.

For the purposes of the present study, fossil fuelled plants have been taken as the available alternative energy supply source, against which nuclear plants have to compete. Fossil fuelled plants include diesel engines, gas turbines, combined cycle or coal fired electrical plants, or boilers for the supply of heat only.

1.4 ECONOMIC ASSESSMENT

Experience shows that most nuclear power plants currently operated in electrical systems provide electricity at competitive costs. The cost of electricity produced by nuclear plants may exceed the cost of fossil alternatives in cases where very low cost coal or gas is available, but in most cases, nuclear power plants constitute the cheapest source of electricity, often by substantial margins. According to the operators of nuclear cogeneration plants in several countries, the heat generated by these plants is competitive with alternative fossil fuelled supply options. In all existing nuclear cogeneration plants, electricity is the main product (more than 90%). There is no commercial experience yet in single purpose nuclear plants for heat production.

Economic assessments of current medium or large size power reactors can be performed with reasonable accuracy and confidence, as there is substantial information available, including cost information on such reactors operating in the cogeneration mode. Such reactors could readily provide energy to desalination plants without substantial design modifications. Owing to their size, they would have to be integrated into electrical grids and would supply primarily electricity to the interconnected system, and in addition, energy to the desalination plants (electricity, or cogenerated heat and electricity). In most locations, the cost of energy produced would compare favourably with equivalent fossil sources, considering fuel costs prevalent on the international market.

For new designs of reactors, in particular in the lower size ranges, detailed and reliable economic assessments are much more difficult to perform, as there is less information available. Nevertheless, the cost estimates provided to the Agency by prospective suppliers indicate that such reactors should be economically competitive.

Economic assessment of fossil fuelled plants can also be performed with reasonable accuracy and confidence, as there is much experience available. Fossil energy production costs depend heavily on fuel prices, which are expected to increase in the future. In addition, discussions have been initiated in a number of countries to charge fossil fuelled plants with a special tax because of their CO_2 emissions. It is to be noted that the influence of fuel costs on nuclear energy costs is much less. It is also expected that nuclear fuel cycle costs will remain more stable than fossil fuel costs in the future.

For any desalination process, specific water production costs would be lower with larger desalination units (economics of scale). Site related factors also have a substantial influence on production costs, in particular seawater composition and temperature, and water intake and outlet structures. Costs for RO desalination plants are strongly influenced by the required quality of the water produced. None of the processes selected for the study show a clear general economic advantage with respect to the others, though recent contracting experience indicates preference for the RO process. In 1991, RO accounted for about half of the desalination capacity ordered, in particular for desalination of brackish water.

The method considered appropriate for deriving average water costs for seawater desalination is the constant money levelized cost method. In the assessment all costs are expressed in the January 1991 US dollar currency unit.

For assessing the final cost of potable water provided to the consumer, there are three principal cost components, with the first two corresponding to the water production cost:

- the cost of desalination resulting from capital charges and from operation and maintenance of the desalination plant, not including costs related to energy supply;

- the cost of energy supplied to the desalination plant; and

- the cost related to water storage, transport and distribution to the consumer (including capital charges of the relevant installations, operation, maintenance, energy consumption and losses).

The share of these components in the final water cost depends on many factors, such as production capacity, process used, site characteristics, energy source, transport route and distance. A rough estimate of the order of magnitude indicates that the sum of the first two components (water production cost) represent about half of the final water cost.

The energy source (nuclear or fossil fuelled alternatives) with its corresponding energy cost affects the water production costs in proportion to its share in the overall water production. Therefore, specific cost uncertainties of the energy source are of minor influence. Each cost component, however, has its importance, and any cost reductions which can be achieved, will contribute to the overall aim of providing potable water economically.

In the comparative economic assessment which has been performed, the costs of water storage, transport and distribution were not considered. This cost component is fundamentally site dependant and can only be analysed on a case by case basis. The cost of electricity, which depends on the energy source chosen, will effect the water transport and distribution costs (pumping), but this will be relatively minor. A more important effect on the cost of transport may come from siting constraints, if the energy source and the desalination plant have to be located adjacent to each other, as compared to independent siting conditions applicable to the processes which require electricity only.

The desalination cost component (excluding energy input) has been evaluated using cost information available from the desalination market. It has been found that desalination plants (excluding the energy sources) are in general capital intensive, investment requirements being on the order of $1000 to 2000 per m^3 of production per day, for large units. Plants using the RO process are at the lower end of capital investment, but they have higher operation and maintenance costs.

The choice of the energy source has little influence on the two production cost components of the desalination plants, corresponding to capital charges and operation and maintenance costs. The influence of the choice of the energy source is practically limited to the energy cost component.

Among fossil fuelled plants, it has been found that low speed diesel engines are the most economical choice for small electricity generation capacities, up to about 50 MW(e); gas turbines for up to about 100 MW(e); combined cycle gas and steam turbines or fuel oil or gas fired plants for the largest sizes available for these options (500 MW(e)); and coal plants for sizes above 500 MW(e). All fossil fuelled plants are less capital intensive than the equivalent nuclear options, but have a larger fuel cost component.

The economic assessment of the nuclear option has been based on cost information available in general, and in particular on information provided to the IAEA in response to the questionnaire. To cover a wide range, representative sizes of 50, 300, 600 and 900 MW(e) were selected for single purpose electricity or dual purpose (cogeneration of electricity and heat) plants, and 50, 100, 200, and 500 MW(th) for single purpose heat only units. The economics of units in the very small size range have not been analysed in detail. For single purpose electricity and dual purpose nuclear plants (electricity being the main product), the estimated specific construction costs were between $1600 and 2800 per kW(e). Heat only single purpose plants were estimated to cost between $650 and 1700 per kW(th).

In all power plant construction costs (nuclear as well as fossil fuelled) an increase of 10% was included, to take into account a cost differential applicable to an assumed location on the North African coast compared to base costs estimated for locations in supplier countries. A comprehensive set of economic and performance parameters has been adopted, and levelized energy costs as well as water costs have been calculated, and constituted the basis for comparison. For dual purpose (cogeneration of electricity and heat) plants in particular, the "power credit" method has been used.

Calculations were performed for the following cases:

- real interest rates of 5, 8 and 10%;
- coupling of nuclear and fossil fuelled plants with desalination plants using the various representative processes selected;
- EEC and WHO drinking water standards;
- different load factor assumptions;
- increased or reduced construction costs;
- escalated and higher or lower fossil fuel costs.

These parameters were considered to be those which have a large influence on the economics.

1.5 SAFETY, REGULATORY, ENVIRONMENTAL AND INSTITUTIONAL ASPECTS

To complement the comparative economic assessment of seawater desalination, other relevant aspects have also been considered.

Practically all factors, conditions, requirements and arguments which apply to the consideration of nuclear versus fossil energy supply systems are in general equally valid and relevant when these energy sources are used for seawater desalination. This is to be expected, because in principle it makes no difference to the desalination plant if the energy (electricity or both electricity and heat) it receives is produced by nuclear fission or by burning fossil fuels.

In addition, however, there are some aspects which are unique to the coupling of nuclear reactors with desalination plants, such as: the need to avoid any conceivable radioactive contamination of the potable water which is the end product of the desalination plants; the need for joint long term planning of both water and energy supply; and the coordinated implementation of related projects.

These additional aspects have to be taken into account, but it appears that none of them present unsurmountable impediments to the practical application of nuclear power for supplying energy to desalination plants.

It is to be noted that financing may constitute a major constraint for those countries which need desalination but have scarce financial resources. Desalination plants, water transport and distribution systems as well as nuclear power plants are all capital-intensive installations. For these countries, innovative financing approaches, preferential financing terms and international support would be needed to facilitate their access to clean and safe potable water.

1.6 MAIN CONCLUSIONS

The following are main conclusions of the results of the study.

- Demand for seawater desalination

By the end of 1991, about 15.6 million m^3/d desalination capacity was contracted worldwide. Demand is expected to increase, as less expensive alternative options gradually become exhausted. Assuming that past trends prevail, about 20 million m^3/d capacity is expected to be in operation by the year 2000, which could be doubled in the following decade.

- Available desalination systems

Seawater desalination is an established and commercially available technology. Among the various processes, RO, MED/VC, MED and MSF appear to be those with the best near-term prospects. RO and MED have been selected as representative processes for the detailed economic analysis, but cost calculations have also been performed for MED/VC and MSF. The energy input required by RO and MED/VC is mechanical energy (e.g. electricity), while for MED and MSF low temperature heat (steam or hot water) and electricity are needed.

- Available energy sources

Nuclear power and fossil fuelled plants are considered to be the available options to provide electricity, heat, or both electricity and heat to desalination plants. There are no technical impediments to the use of either option. Fossil fuelled plants include diesel engines, gas turbines, combined cycle units, and oil, gas or coal fired steam/power plants or boilers.

- Available nuclear reactors

In response to an IAEA questionnaire, information and data were provided by potential suppliers on about twenty advanced reactor concepts, covering a broad range of sizes, types of reactor, fields of application and development status. In addition, various current designs of large size reactors are known to be commercially available at present. There are also several other advanced concepts under development, which include reactors in the small and very small power range, and which could become available in the future.

- Coupling of energy sources with desalination systems

Desalination processes which require electricity only (RO or MED/VC) are coupled with electricity generating plants or with a grid. Energy is transmitted through electrical connections. Processes which require heat and electricity (MED or MSF) are coupled with dual purpose (cogeneration of electricity and heat) plants, or with single purpose (heat only) plants and an additional electricity supply source (grid or dedicated generating unit). Energy is provided through a heat transfer system (steam supply or hot water circuit) and through electrical connections.

- Grid connection

Connecting desalination plants to a suitable electrical grid presents major benefits, as it permits taking advantage of economics of scale for the integrated power plants and offers high reliability of supply. The use of medium or large size electricity or dual purpose plants is possible only if they are integrated into such a grid; otherwise only small size units are feasible.

- Siting

Processes using heat imply the need for adjacent siting of the energy source and the desalination plant, while separate siting is admissible for processes using electricity only. For transmission of electricity, distance is practically no constraint. Separate siting offers the benefit of individual and independent site optimization of both the desalination plant and of the energy source, in particular regarding the desirable distance from population centers. Under special conditions and regional circumstances, desalination plants with very small-sized nuclear reactors could be attractive.

- Comparative energy costs

With the methodology applied and the assumptions adopted, the economic analysis shows that levelized electricity costs of nuclear and fossil fuelled options are in general in the same range. Competitivity depends very much on unit size and interest rates. For large units (900 MW(e)), nuclear power shows cost advantage versus fossil plants, for medium sizes (300 to 600 MW(e)), costs are similar, while for small sizes (50 MW(e)), fossil power (diesel engine) is favoured. Lower real interest rates tend to favour the nuclear options, due to their larger capital charge component. For single purpose plants for heat (thermal), energy costs are also in the same range for both alternatives.

- Comparative water production costs

Analysis of water production costs shows generally results and trends similar to the energy cost analysis, of the use of nuclear and fossil energy sources. Water costs are in the same range for both energy sources in combination with any desalination process for similar water production capabilities. The nuclear alternative is in general favoured for larger sizes and lower interest rates, while fossil is less expensive for smaller sizes and higher interest rates. About one-quarter to one-half of the water production cost comes from the energy cost component, the remainder corresponding to capital charges and operation and maintenance costs of the desalination plant, which are practically unaffected by the choice of energy supply option.

- Overall water costs

Water production costs are in general between \$0.7 and 1.1 per m^3, for desalination plants combined with dual purpose (cogeneration of electricity and heat) or electricity (only) generating plants. Combinations with heat only plants result in considerably higher (\$1.2-2.0 per m^3) water production costs. When water storage, transport and distribution costs are added and losses included, the final cost of water (to the consumer) will be significantly higher.

- Investments

Construction costs of nuclear plants are in all cases higher than those of fossil fuelled units. Investment requirements of desalination plants are higher than the investment required for the energy source (usually by a factor of 2 to 3), considering only the portion attributable to the energy supply required for the desalination plant. Grid connected dual purpose (electricity and heat) plants which simultaneously supply the electricity market and the desalination plant, provide about 80 to 90% of their production capability to the grid, and the investment corresponding to this portion is attributable to the electricity sector. Overall specific investment requirements of desalination plants, including the attributable portion of the energy supply systems, are typically around \$1500 to 2500 per m^3/d capacity. In combination with single purpose heat only units, specific investments can be higher and may reach up to \$5000 per m^3/d capacity for the smallest sizes considered in the economic analysis.

- Overall conclusion

The use of nuclear energy as an alternative option to the use of fossil fuelled plants for supplying energy for seawater desalination is technically feasible, and in general economically competitive for medium to large size units integrated into the electric grid system.

Large electricity generating nuclear power plants, which are integrated into the electricity supply grid system, and which supply electricity to separately located desalination plants using the reverse osmosis process, offer the most cost advantageous option.