This bibliography includes 215 abstracts of publications on the use of nuclear energy in the production of potable water from saline or brackish waters. The uses of nuclear reactors, radioisotopic heat sources, and nuclear explosives are covered in relation to the various desalination methods available. Literature through April 1967 has been searched for the present edition. References to the technical report literature are arranged by report number under the issuing organizations, and the journal references are arranged alphabetically by journal title. Author and report number-availability indexes are included. (Author/PR)
NUCLEAR ENERGY FOR WATER DESALINATION
A BIBLIOGRAPHY

Compiled by
Helen P. Kuhns
Henry D. Raleigh
and
Myrna L. Steele

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Cover photo by Jan Hahn
NUCLEAR ENERGY FOR WATER DESALTING

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Compiled by

Helen F. Kuhns
Oak Ridge National Laboratory

Henry D. Raleigh
Myrna L. Steel
Division of Technical Information Extension
Oak Ridge, Tennessee

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UNITED STATES ATOMIC ENERGY COMMISSION
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ABSTRACT

This bibliography includes 215 references to publications on the use of nuclear energy in the production of potable water from saline or brackish waters. The uses of nuclear reactors, radioisotopic heat sources, and nuclear explosives are covered in relation to the various possible desalination methods available. Author and report number-availability indexes are included.

INTRODUCTION

Throughout the world there are at present serious shortages in the available fresh water supplies for basic human consumption, for industrial use, and for crop irrigation. The outlook for future fresh water needs indicates that critical shortages will develop in many areas of the world unless new methods of supply are found. One of the most promising methods currently under investigation is the desalination of sea and brackish waters. In this bibliography an attempt has been made to cite the report and published literature available on the use of nuclear energy for saline water demineralization. Some work has been done on the use of radioisotopic heat sources and the heat produced by a nuclear explosion, but the major emphasis of study to date has been on the development of large-scale nuclear reactors for use in dual-purpose power-water or water-only plants.

The present edition of NUCLEAR ENERGY FOR WATER DESALTING: A BIBLIOGRAPHY brings up to date the edition of September 1965 and its predecessor, originally issued for the Water Research Program at the Oak Ridge National Laboratory in July 1964 (ORNL–TM–892). Literature through April 1967 has been searched for the present edition.

References to the technical report literature are arranged by report number under the issuing organizations, and the journal references are arranged alphabetically by journal title.
REFERENCES

REPORTS


American Machine and Foundry Co., Waterford, Conn.


The investigation of a small nuclear heat source for use in operating a newly developed, multistage, multistage (MEMS) flash-distillation plant is reported. The nuclear plant considered is of 21 megawatts thermal capacity. It is basically a upgraded research reactor using pressure-tube fuel elements containing UO2 fuel. The new MEMS flash-distillation cycle operates at considerably higher efficiencies than present-day multistage flash-distillation plants.

Atomic Energy Board, Pelindaba, Pretoria (South Africa).


A bibliography containing 297 abstracts on the factors influencing the competitiveness of nuclear reactors for electric power production is presented. A chapter is included on the economics for water desalination.

Atomic Energy Commission, Washington, D. C.


Prepared for the United Nations Third International Conference on the Peaceful Uses of Atomic Energy, 1964. The use of nuclear energy to desalinate seawater is discussed. Water shortages in the United States and around the world are reviewed. The history of desalination activities is outlined. Results of studies of the use of heat from reactors for distillation are described. Economic aspects are discussed.

Atomic Energy of Canada, Ltd., Toronto (Ontario).


The economics of applying a CANDU type reactor to the particular circumstances of the joint US/Israel study of a dual purpose plant producing 200 MW(e) and 125 million gallons per day are considered. Since the economics are attractive relative to the use of boiling or pressurized water reactors, some consideration is given to the system planning aspects of dual purpose plants, with particular reference to flexibility of operation between the two portions of the overall plant. Brief summaries of the main desalination processes and of desalination costs are given in the appendices.


The efficiencies of modern large scale evaporation plants are discussed together with their technical limitations, problems, and costs. The most urgent research problems in this field lie in the continuous distillation process at temperatures above 250°F and in improving heat transfer and boiling under conditions of small temperature differences.


From 1st International Symposium on Water Desalination, Washington, D. C.

The present and immediately planned efforts of the U.K.A.E.A. in cooperation with industry in the desalination of water are briefly summarized. Various aspects of the multistage flash distillation process as well as related or supporting fundamental research studies currently underway are discussed. Designs of large combined desalination and nuclear power plants now being prepared are mentioned. Although the main effort is being devoted to the work on flash distillation, some alternative methods that are being studied are summarized.


The development of nuclear energy is discussed with emphasis on the areas of marine applications of nuclear energy, economics of nuclear fuels, international development programs, industrial aspects of international safeguards, saline water conversion, space applications, and non-power applications of isotopes and radiation.

Atoms Internationale, Canoga Park, Calif.


From American Power Conference, Chicago.

Specific types of nuclear power plants in combination with desalting plants are examined to establish the relative economic potential of various heat sources for large-scale dual-purpose application. It was concluded that both technically and economically the dual-purpose approach has a decided advantage where a ready market exists for the power produced.

Australian Atomic Energy Commission.


Report of developments in research carried out by the AAEC on nuclear power, peaceful uses of nuclear explosives, nuclear desalination, raw materials, and radioisotopes are reported.

Battelle-Northwest, Richland, Wash.

Pacific Northwest Lab.


After a brief survey of water resources and usage in the U. S., the means for meeting water shortages are considered: water reuse, storage, redistribution, and desalination of sea or brackish waters. The factors that will decide which of these methods will be used in a locality are discussed: water quality requirements, status of desalination technologies, and water cost considerations. Seawater desalination is presently not widely competitive with other processes, but factors which may change this situation are discussed.

Battelle-Northwest, Richland, Wash.

15 (BNWL-SA-596) ENVIRONMENTAL FACTORS RELATING TO LARGE WATER PLANTS. Parker, Her-
A review of work done in marine biology, fisheries and environmental science, and the economics of desalination in connection with water production plants is presented. The site selection, man-made island design, and the economics of a particular reactor concept offering the potential of low capital and energy costs for use in a single-purpose water desalting plant were determined. In order to evaluate the economics of the system, the deep-pool reactor heat source was assumed to supply heat to a multistage flash evaporation water desalting plant. The emphasis of the study was on the reactor heat source. The design and cost estimate of the water plant itself was based on previous studies and on a computer code for optimization of multistage flash evaporation plants. The components of the water plant were identified only to the extent necessary to be compatible with the unique features of the deep-pool reactor. The reference case is a 50-million-gallon-per-day (mgd) plant. The plant description and detailed cost estimate refer specifically to this case. Adjustments were made to plants of 10-mgd and 500-mgd capacity to provide an indication of the effect of size on the cost of the water produced. Special consideration was given to the unique aspects of the reactor plant design, including material compatibility and the design requirements associated with the depth of the reactor tank. The safety advantages inherent in the essentially unpresurized, deep-pool reactor concept were utilized in the plant design and were evaluated in a preliminary accident analysis. Special consideration was given to the unique aspects of reactor design, including material compatibility and the design requirements associated with the depth of the reactor tank. The safety advantages inherent in the essentially unpresurized, deep-pool reactor concept were utilized in the plant design and were evaluated in a preliminary accident analysis.
plant for operation in southern California are presented. Results of the study are given on the effect of blinding at the Diemer plant, product conveyance, and blending facilities, conceptual designs of seawater systems, nuclear safety analysis, site selection, fossil versus nuclear fueled dual purpose plants, optimization of dual purpose plants, conceptual plant descriptions, plant capital cost estimates, and the cost of water.


A detailed analysis of the feasibility of dual-purpose plants located at Pelican Point and on Bolsa Island (a man-made island) and of the cost of water from these plants is summarized. Plants using boiling-water and pressurized-water reactors were considered. It is recommended that the Bolsa Island site be selected for the location of the plant.


The economics, plant analysis, boiling analysis, and feasibility of a concept of nuclear-desalting and power-producing plant on the California coast are reviewed and evaluated.

Brookhaven National Lab., Upton, N. Y.


The recent development of large-scale nuclear sources of low cost electrical power makes it possible to consider the coupling of nuclear power reactors with efficient electrochemical devices for large-scale production of industrial chemicals. The electrochemical nuclear system consists of the three basic building blocks: nuclear reactor, d-c generator, and electrochemical cell. The electrochemical nuclear generation of H and O is of interest for the fixation of N for fertilizer, generation of liquid and gaseous carbonaceous fuels, the production of Fe and steel, and production of liquid H and O for aircraft and rocket fuel. Based on speculation that low cost, high pressure water electric power can be obtained, studies are made of the economics of electrochemical ammonia production relative to conventional fossil-fuel-based plants are presented as a function of nuclear power costs. A desalinated water and fertilizer electrochemical nuclear plant appears attractive. A dual-cycle, high temperature radiation and electrochemical reactor offers a highly efficient N fixation system in the future. The realization of these concepts depends on a combination of low cost nuclear power, low investment electrochemical devices, and utilization of by-products.


From American Society of Civil Engineers, Structural Engineering Conference, Miami Beach, Fla.

A conceptual presentation is given of a dual-purpose desalination and nuclear power plant, with the ultimate objective of bringing forward the structural engineering aspects of a modular vessel-structure assembly that, by structural features, illustrates effectively the great new developments associated with saline-water conversion. The material selected for this presentation embraces concepts and ideas representing the outcome of many months of fruitful researches on the subject of Combined Flash Evaporators. One special concept for the Structure, the peculiarly shaped module which consists of an orthotropic plate system, is believed to be the appropriate structure for effectively conveying the idea of what can be accomplished with a traditional material conventionally limited to some specific engineering aspects. The modular concept as applied to boiler segments of limited manufacturing area and with pressurized elements independently and internally built is not new; its application, however, to evaporator stages of great magnitude is certainly an evolutionary product of the present engineering designs. This new application of the module will be of interest both to the engineers engaged in researches in the field of industrial design and the engineers dedicated to analogous structural configurations. Although no general theoretical derivations are given of the complete mathematical treatment of orthotropic plates, some general transformations of the constant coefficients of either the fourth or eighth order differential equations are given and adequate emphasis on fundamental principles associated with the use of the coefficients in the equations for pressurized orthotropic systems are discussed. In this respect, it is believed that the idea of a fictitious plate constitutes a contribution to the analysis of orthotropic plates.


The application of nuclear energy to the desalination of water is an area where there is much promise for a near-term economically competitive situation with fossil fueled heat sources. Nuclear reactors can be used in one of two ways to produce the process steam needed for desalting seawater. The possibilities are: (1) design a reactor with minimum capital and fuel costs to produce steam exclusive of power use or (2) design a reactor system that will produce electricity by a turbine generator, either backpressure or extraction, and use the backpressure or extraction steam as the heat source for the water desalination plant. The investigations concentrated on the second possibility because the first approach would have no economic advantage over a fossil-fuel-fired single-purpose water plant in the applicable power ranges. Based on steam and electrical requirements determined from studies of combined desalination and power plant installations in the Florida Keys conducted for the OSW under a parallel contract, it was established that very high power levels in the range of 150 to 600 MWt would be required. To obtain valid information for comparison of boiling- and pressurized-water reactor systems in the selected size range, proposals were requested and received from reactor manufacturers. Two of these proposals were based on the boiling-water concept and the remaining three utilized pressurized-water reactor designs. All of the proposals were evaluated on a uniform basis, as far as practicable. Where such items as auxiliary systems or steam generators for brine steam (in the case of the boiling-water designs) were not included in the quoted costs, adjustments were made accordingly. This brought each bid to the same degree of completeness and thus normalized the overall installed costs. Features considered, in addition to costs, were reliability, proven design, operability and maintainability, efficiency, and vendor experience. From a comparison of all the factors considered it was concluded that the proposals from Vendor A met the design requirements and were best suited economically for furnishing electricity and steam, in a dual-purpose reactor and water desalination plant. To verify quoted figures, detailed fuel cost calculations were made and compared with the figures given by Vendor A. Fair agreement was found; the differences shown were 24.3 cents/million Btu as compared to the Vendor A estimate of 21 cents/million Btu. Among the factors that account for the differences are the allowances for fuel processing, the estimated batch size charged to the reactor per refueling operation, and the daily separation plant charges. Since the fuel cycle data submitted by Vendor A are estimates (and most likely conservative) for proposal purposes, a more detailed and precise determination of
differences would not be warranted for this study. However, to ensure adequate margins in calculating nuclear power costs, nuclear fuel costs of 24.3 cents/million Btu were used. Using the Vendor A designs producing 412 and 706 psia steam, preliminary studies were made of the steam costs to a desalination plant producing 6,000,000 gallons per day of fresh water, which was the basis used prior to the final selection of the water plant capacity. These initial calculations showed that the 706 psia steam reactor design gave the lower power costs of the two pressures offered. Further, the incremental increase in power costs resulting from a power plant designed to meet combined needs, as compared to an unassociated power plant, were smaller for the nuclear system than for a fossil-fueled plant. It was found, after developing costs for brine heater steam extracted at pressures of 37.9, 49, and 57 psia, that the lowest-pressure steam had the least cost. While the initial studies were based on the fuel costs for the unassociated power plant were found to be lower than the corresponding costs from fossil plant. This situation, which is unusual for nuclear plants of comparably low capitalization, was largely due to four factors: (a) The compact Vendor A primary system design combined with the pressure suppression containment building arrangement results in a nuclear plant of low first cost. (b) Use of municipal financing with its lower fixed charges. (c) The lower fixed charge rate than industrial financing decreases the disadvantage of the higher nuclear plant first cost compared to fossil-fueled plants. (c) The nuclear fuel costs for the selected reactor design are comparatively low at 24.3¢/106 Btu. (d) The fuel oil cost of 42¢/106 Btu at the Florida Keys is relatively high. The analyses of electric power costs are based on normal economics, i.e., no subsidies or monies for research and development assistance or for design support were assumed for the nuclear reactor system. Further, fuel costs include fuel use charges as well as all other factors. For the nuclear reactor systems the fixed charges were based on municipal financing and were established as 7.50 percent per year for depreciable capital and 5.17 percent per year for nondepreciable capital. For fossil-fuel plants the insurance allowance was reduced to 0.38 percent, thus yielding 7.15 percent and 5.02 percent for depreciating and nondepreciating capital, respectively. The results of this study indicate an economic advantage for a dual-purpose nuclear power and water desalination plant, as compared to a fossil-fuel-fired unit with similar capitalization and functions, as well as the economic savings shown, and the anticipated advancements in the state-of-the-art attendant to the application of combined nuclear power and large-scale water desalination, the reactor was recommended as the basis for detailed engineering designs of dual-purpose plants in the Florida Keys.

**California Univ., Livermore. Lawrence Radiation Lab.**


In a proposed method for the high pressure distillation of seawater the distillation would take place in a deep underground cavity formed by the explosion of a nuclear device. The high pressure in the cavity would be maintained by the hydrostatic heads of seawater and distilled water in the piping above the cavity. A depth of over 3,000 feet has been suggested. The heat of distillation would come from the heat of the nuclear explosion stored in the material surrounding the cavity; the separated salt water would be left in the cavity. By transferring heat from the outgoing distilled water to the incoming seawater, the amount of heat necessary for the distillation can be minimized. The thermal efficiency of the process and heat requirements for the distillation are discussed. Preliminary cost estimates for the process are included.


From Water for Texas Conference, College Station, Texas, Sept. 1961.

Application of nuclear explosives to water resource conservation has been one of the areas of study included in the Plowshare Program since its inception. Several possibilities, including creation of inexpensive water diversion canals, large permeable areas for waste or brine disposal or for underground recharge, and construction of surface storage basins, continue to appear attractive. Creation of new underground storage volume and salt water conversion seem, on the basis of available information, less likely to be successful. Production of earth dams by explosive emplacement is being considered. In all of these studies, which make use of data obtained from past nuclear tests, evaluation of safety problems constitutes a major effort. In many cases there is presently insufficient information to make firm conclusions, while in a few there appear to be no insurmountable safety problems. If results of studies continue to be encouraging, nuclear explosives may make possible projects which have hitherto been too large or costly to consider. These applications may be possible within the next decade or two.

**California Univ., Los Angeles. Dept. of Engineering.**

The utilization of the heat produced in an underground nuclear explosion for the distillation of seawater to produce fresh water is discussed. It is stated that the process appears to be possible and economical. The fundamental principles of distillation are reviewed and a phase equilibrium diagram of the sodium chloride-water system is presented.

**Canadian General Electric Co., Ltd., Peterborough (Ontario).**

**Civilian Atomic Power Dept.**


The Canadian HWR was investigated for use as a dual-purpose reactor. Economics are discussed.


An analysis was made of a Canadian heavy water reactor for the purpose of evaluating its performance for electric power generation and seawater desalination. Results are discussed.

**Chance Vought Corp., Dallas, Tex.**


The use of radioisotopic power is considered as a heat source for saline water conversion. The most economical source appears to be the calcined fission product waste from processed spent reactor fuel elements. The results indicate that, for special conditions, this source of heat is competitive with conventional fuels.


The results of various studies on compatibility, thermodynamics, nuclear, and materials aspects of a full-scale heater utilizing calcined radioisotope waste products (ARTESIA) are presented. These studies have permitted the conceptual design of an ARTESIA heater capable of supplying the thermal requirements for a 1 million gallon per day saline water conversion system operating at 200 kwh/1000 gal. Based on these data, a laboratory test model (Volume III) will be designed and fabricated to investigate, by test, problems which may be expected with the full scale design.


ARTESIA proposes the use of radioisotopes as an energy source for saline water conversion. The economic and technical feasibility has been analytically established. Further work is included on the design of an experimental test model capable of producing 250 gallons per day using one megacurie of cerium-144 and a six-stage flash evaporation conversion unit. Also included is a hazards analysis of the test model.


A study was conducted of the use of radioisotope power as a heat source for saline water conversion. An economic feasibility study was made on this type of energy. The most economical source appears to be from the calcined fission product waste from processed spent reactor fuel elements. The results indicated that, for special conditions, this source of heat is competitive with conventional fuels. Results are presented of various studies on compatibility, thermodynamics, nuclear, and materials aspects of a full-scale heater utilizing calcined radioisotope waste products. The studies have permitted the conceptual design of a nuclear heater capable of supplying the thermal requirements for a one million gallon per day saline water conversion unit operating at 200 kwh/1000 gal. The design of a laboratory test model is given. The model will be capable of producing 250 gallons per day using one megacurie of cerium-144 and a six-stage flash evaporation conversion unit: A hazards analysis of the test model is included.

**Comisión Nacional de Energía Nuclear, Mexico City.**


References (956) to various methods and equipment used for the desalination of water are given to reports, journals, and books published from 1954 through 1964. A separate author index is included.

**Commissariat à l’Energie Atomique, Tunis (Tunisia).**


Water requirements of industrial and domestic purposes are increasing, and in several cases water supply of these...
regions by pipes is not the best solution; then, water conversion plants are to be considered among alternative water supply systems. Among energy sources required for water conversion plants, nuclear energy may be considered. Nuclear energy may offer advantages especially for dual-purpose plant. Many problems of course have to be solved but reactors and saline water conversion plants technology at present time has no great difficulties to be solved. Generally, it is possible to foresee types of reactors and to adapt them for dual-purpose, processes for desalination which have the great experience, and the problems of connection of energy source and desalination plant. Some situations and especially that of Tunisia will be examined.


The Department of the Interior proposes a broad-gage, accelerated program of action designed both to discover new techniques for desalting and to improve existing processes for the benefit of large and small communities. Emphasis will be given to the development of the most promising large-scale distillation processes. The Atomic Energy Commission proposes the development of large-scale nuclear energy systems for combination power-water application in coordination with the development of desalting processes by the Department of the Interior. The heavy water moderated, organic cooled reactor offers the best potential at this time for large power-water application.

Division of Reactor Development (AEC), Washington, D. C.


Capital costs, fuel cycle costs, and operating costs are reviewed for light water-moderated and -cooled pressurized reactors, and graphite- and heavy water-moderated reactors for steam production for desalination. Dual-purpose (desalination and electric power production) operations were not considered. The current status and near-term potentials, effect of scaling-up of size, and the research and development programs are reviewed. No determination was made as to the reactor concept that would be best suited to desalting plants.

Division of Technical Information Extension (AEC), Oak Ridge, Tenn.


A bibliography is presented on the developments in the production of potable water from saline or brackish water. The 372 references cover literature through September 1961. The report references are arranged alphabetically by title.

Du Pont de Nemours (E. I.) and Co., Aiken, S. C. Savannah River Lab.


Heavy-water-moderated reactors are attractive candidates for vigorous development and commercialization in the U. S. nuclear power program. By virtue of their excellent neutron economy and their ability to operate on simple, mass-produced, low-cost fuel elements, these reactors offer the potential of energy generation costs that are lower than those attainable in other converter reactors, higher conversion ratios than any other converter reactor, a self-sustaining breeding cycle with Th fuel, and low-cost steam for process heat applications such as desalination. It is concluded from consideration of estimated energy generation costs, neutron economy, present status of technology, and the extent of available development facilities that liquid D2O and an organic liquid are the best candidates for further development as coolants for D2O-moderated reactors.


Conceptual designs of reactors moderated with D2O were prepared for a study of the use of large reactors for seawater distillation. Two designs are presented: a near-term reference design producing 3500 MW thermal with pressurized liquid D2O coolant, and a more advanced design producing 8300 MW thermal with organic coolant. Steam costs are estimated for dual-purpose and -cooled steam from 11 to 16¢/million Btu for the 3500-MW(t) plant, and from 4 to 9¢/million Btu for the 8300-MW(t) plant, as the power credit changes from 3 to 11 mill/kWh.


From 1st International Symposium on Water Desalination, Washington, D. C.

The alternate sources of fresh water are discussed; and it is concluded that the rising cost of obtaining additional supplies of fresh water, it is necessary to develop methods to remove contamination from brackish water or seawater to assure that the requirements for fresh water be met. Both major and minor sources of energy available for desalting are discussed and evaluated. Charts are presented to show various aspects of the use of the major sources of energy, fuel energy required by various desalting processes, etc. It is concluded that an established electric utility can produce the lowest cost electricity or steam for desalting, and charts and discussion are presented to show what kind of plant could best carry out the process.

Fluor Corp., Ltd., Whittier, Calif.

49 (PB-161010) PRELIMINARY DESIGN STUDY OF AN OPTIMUM NUCLEAR REACTOR-SALINE WATER DISTILLATION PLANTS. Fluor Corp., Ltd., Whittier, Calif.) Research and Development Progress Report No. 34, 1959. 234p. OTS.

An engineering design study was made of a 50 × 106 gallons/day sea water conversion plant employing a multistage flash evaporator and a light water reactor. It was necessary to select the optimum 370 MW(th) reactor and to select the optimum capacity multi-stage flash evaporator that when combined with the optimum reactor system would produce 1000 gallons/day at the least total cost. A preliminary design of a 1 × 104 gallon/day pilot plant was also prepared. The cost of potable water produced from sea water moderated reactors was estimated to be $0.35 per 1000 gallons. This estimated cost includes all costs associated with the operation of the plant.

32\textsuperscript{79}U or 232\textsuperscript{Th} oxide fuels that have sufficient 240\textsuperscript{Pu} concentration will not suffer an economic disadvantage when NN is incorporated with either a combination multiple-effect and reverse osmosis, a membrane process. Process description, performance, and economics are considered.

52 (GA-6294) APPROACHES TO THE CONVERSION OF SEA WATER TO FRESH. Bray, Donald T.; and Johnston, Thomas A. (General Atomic Div., General Dynamics Corp., San Diego, Calif.). 23p. (CONF-660349-4; GA-6294).

From American Power Conference, Chicago.

Discussion is presented on two methods for the desalination of seawater: dual-purpose plants making use of the High Temperature Gas-cooled Reactor (HTGR) as the heat source and reverse osmosis, a membrane process. Process description, performance, and economics are considered.


Computer studies indicated that plutonium-enriched 238\textsuperscript{U} or 232\textsuperscript{Th} oxide fuels that have sufficient 240\textsuperscript{Pu} concentration will not suffer an economic disadvantage when NN is incorporated with either a combination multiple-effect and reverse osmosis, a membrane process. A reduced spatial concentration fuel containing 238\textsuperscript{U} and 232\textsuperscript{Th} enriched with plutonium was studied to determine fuel cycle costs and reactivity response characteristics. Costs for thermal energy supplied to a desalinization plant were determined for two reactor sizes, 3500 and 8300 Mw(e). Fuel cycle costs, reactivity, conversion ratio, and breeding ratio calculations were made for a revised 300 Mw(e) fast reactor using supercritical-pressure water as the coolant.


From American Nuclear Society 11th Annual Meeting, Gatlinburg, Tenn.

The fitting of the N reactor in the total national nuclear program is discussed. Possible power ratings and applications of the N reactor to desalination are discussed.

General Electric Company, San Jose, Calif.


From American Power Conference, Chicago.

Data are presented on the application of boiling water reactors to dual purpose plants, with emphasis placed on the costs of steam to the desalting plant for a wide range of pressures. The costs were computed on the basis of recently published information on product line boiling water reactors. The trend toward lower water desalting costs with lower steam pressures to the desalting plant is noted. This trend has been confirmed, for certain conditions, in the case of boiling water reactor applications. Further appraisal of this characteristic of dual purpose plants has been attempted in order to assess the reasons therefore and to better define the most economical plant arrangements. The water production costs for the present-day BWR to the water cost estimating methods are comparable to those computed for future nuclear reactor concepts of several times the unit size (25,000 vs. 33,000 Mw(e)). Water production costs from medium size dual purpose installations based on present-day boiling water reactor technology may well fall within the range of economic feasibility based upon a computed 1975 power credit of 3.86 mills/kwh (private ownership).


From Symposium on Water Production Using Nuclear Energy, Tucson, Ariz.

The boiling water reactor, as one of the lowest cost sources of thermal or electric energy available for desalting projects, has been the subject of numerous evaluations over the past few years. The energy cost, which can constitute 30-50% of the total cost of desalted water and can also directly influence the capital investment in the desalter, continues to show a downward trend. Boiling water reactors are now competitive with other energy sources using less than 20c/MBtu fuel. In consequence, these BWRs can supply heat at ~250°F from the turbine exhaust for less than 10c per 1000 pounds of steam. During the past year or so, the rate of BWR commitments has built up to a level of over 2,000 Mw(e) per annum. The design of BWRs required for desalting plants differs very little from these commitments for central station applications. It is concluded that the past few years of encouraging development of the various desalting plant concepts have been paralleled by a comparable gain in BWR operating experience and performance capability, thus further helping to maximize the overall promise of current desalting program efforts.

Gosudarstvennyi Komitet Po Ispol'zovaniyu Atomnoi Energii SSSR.


The general properties of dual-purpose plants are briefly discussed. Methods for determining the cost of fresh water and electric power are briefly described. An analysis was made of the prime cost of fresh water and electric power. The results are presented.
Growth Industry Shares, Inc., Chicago.


From Canaveral Council of Technical Societies, 3rd Space Congress, Cocoa Beach, Fla.

The role of electric power in seawater desalting in the U.S. during the next decade is examined considering certain conditions relating to alternative supplies, technology and scale-up, and the specific market for water. Emphasis in the cost evaluation is placed on the development of large dual-purpose power-water desalting plants.


From American Nuclear Society 11th Annual Meeting, Gatlinburg, Tenn.

The economics of small (10 to 15 Mw(0)) nuclear plants which produce electric and desalinate water were studied for the purpose of quantitatively determining the cost of electricity and water produced by small dual-purpose nuclear plants and to compare these to actual water and electricity prices for representative locations. It is concluded that there are many places where such plants are economically attractive compared to existing electric and water production units. These small dual-purpose plants are also attractive as pilot plants because of their modest capital costs.

Indiana University, Bloomington.


From Symposium on Water Production Using Nuclear Energy, Tucson, Ariz.

The various technical and economic factors which affect the supply of freshwater are examined. The economic principles for the use and development of water resources and the economics of desalting are discussed. Cost considerations are examined for the choice of desalting processes, fossil versus nuclear fuels, single purpose versus dual purpose plants, and how costs are allocated between water and power in a dual purpose facility. Some of the economic aspects of the Bechtel study of a dual-purpose nuclear plant for Southern California are reviewed.

International Atomic Energy Agency, Vienna (Austria).


A preliminary study was made of the possible use of a nuclear dual-purpose installation for the production of both electric power and desalted water. The factors likely to have a bearing on the features of the plant are discussed. It is concluded that the minimum capacity of the largest generating unit for the network is 51-58 Mw, and that the water demand will vary between 12,000 and 22,000 m³/day. Power and distilled water costs figure to be 3.5 millimes (8.5 US mills)/kwh and 45-77 millimes/m³ ($0.40-0.70/1000 gal), respectively.


A summary of highlights of the latest developments pertaining to nuclear desalination and related topics is presented. Recommendations of the conference panel on the Agency's role and future activities in nuclear desalination are discussed.


The power production and demands in Greece are briefly discussed. The use of a dual-purpose reactor is discussed.


A total of 771 references, almost all with abstracts, is given to the literature published and/or abstracted during the period 1960-1963. The references are arranged into six sections dealing with general aspects, evaluation of power reactors, nuclear propulsion, water desalination, reactor materials, and other economic aspects. An author index is included.

Joint United States-Israel Power and Desalting Team.


The economics of a dual-purpose electricity-desalination nuclear power reactor for use in Israel beginning about 1971 is analyzed. The concept studied employs flash distillation for desalination.


It is shown that a dual-purpose power-water desalting plant in Israel with a capacity of 200 megawatts salable power and 100 million gallons water per day ready for initial operation in 1971 and full commercial operation by mid-1972 is technically feasible. Based upon the conceptual design work performed, it was concluded that either a pressurized water or boiling water reactor would be technically feasible for the nuclear steam supply and that the desalting plant should be of the multi-stage flash type. Capital costs have been estimated for the dual-purpose plant and allowances have been made for the electrical power and water conveyor facilities beyond the dual-purpose plant boundaries. Water production costs have been estimated for fixed charge rates of 8 per cent, 7 per cent, and 10 per cent. Estimates were also made for fossil-fuel plants of compa-
For United States-Israel Joint Board, the study was conducted in two phases. The first phase was directed toward determining the feasibility of a dual-purpose electric power-water desalting plant for commercial operation in Israel by mid-1972 and included: (1) comparisons of various dual-purpose power and desalting plants using the multi-stage flash evaporation process and selection of one of these plants (hereinafter referred to as the reference plant) for detailed evaluation, (2) comparison of this selected plant with a comparable fossil-fuel dual-purpose plant, and (3) a recommended development program to confirm certain desalting plant components and design criteria. The second phase was directed toward preparing a detailed evaluation of the reference plant and to develop information for use in preparing an application to funding agencies. During Phase II the conceptual design was refined and new estimates of the initial cost, annual cost, and the unit cost of water were prepared. In addition, several plant alternatives and factors important in the determination of the total annual cost were examined such as: (1) differences in the desalting plant design and in the cost of water resulting from the selection of either a boiling-water or pressurized-water reactor for the nuclear steam supply, (2) differences in the cost of water resulting from the selection of a concrete instead of a steel reactor containment building, (3) differences in the cost of water resulting from the selection of concrete instead of steel evaporator chambers, (4) review of the plant operating factor, (5) determination of the effect of seasonal seawater temperature on the capital cost, and the unit cost of water, and (6) determination of the change in the cost of water which would result if potential decreases in the nuclear fuel cycle costs materialized. Included are the results of the Phase I work and the results of the above Phase II studies including the estimates of capital cost, annual cost, and the unit cost of water.


From American Society of Civil Engineers, Water Resources Engineering Conference, Denver, Colo.

The economic and technical advantages of using extraction or exhaust steam from a nuclear power steam plant as a heat source for desalting water are discussed. The dual-purpose electric power and desalting plant in Israel is described to illustrate these advantages.

Oak Ridge Gaseous Diffusion Plant, Tenn.


An engineering evaluation was made of plants for producing 1 billion gallons of product water per day by the flash evaporation process. Conceptual designs and cost estimates were prepared for three different type plants: modular plant, compact plant, and multilevel plant.

Oak Ridge National Lab., Tenn.


From American Chemical Society 14th National Meeting, Los Angeles, Calif., March—April 1963.

The economics of desalting processes for sea water using large nuclear reactors as a source of power for water distilling plants is discussed. It is pointed out that low-cost electric power could be obtained as a byproduct of the natural uranium type could be undertaken in a relatively short time and would produce water in the cost range of 20 cents/1000 gal and power for 3 million kw/hr or less, after writing off development costs. It is also suggested that breeder reactors would ultimately produce the lowest cost energy, but would need a longer time for development. Cost estimates are presented using regenerative evaporation in multiple-effect or flash type evaporators and natural uranium reactor or an advanced fast breeder reactor. The cost of water would be 9.8 cents/1000 gal or 6.1 cents/1000 gal, depending on the reactor type used.


Fuel cycle costs were evaluated for a variety of reactor stations for the production of water and possibly electricity. The base case studied was a heavy-water-moderated, light-water-cooled, natural-uranium reactor using the nested tube element. Fuel cycle throughputs ranged from 1 to 30 short tons of uranium per day. The fuel cycle costs were also determined for the same fuel element when an irradiated fuel was discarded rather than processed at 10 and 30 tons per day, and when plutonium and depleted uranium replaced the natural uranium at 1 to 30 tons per day. An attempt was made to examine on a comparable basis a partially enriched fuel of the Dresden type at 10 tons per day. These studies indicated: unit costs are rapidly reduced by increase in production requirements; natural—uranium fuels have the lowest fuel cycle costs; and bauxite and inventory are the major factors in fuel cycles for slightly enriched uranium.


Fuel fabrication costs were estimated for the very large reactors proposed for water desalination. Fabrication of 18 metric tons of uranium per day into identical elements is an insignificant part of the cost of generating heat.


Abstracts are presented of 15 papers which were given at water research and nuclear desalination. Some of the topics treated include hyperfiltration, polarization, CaSO₄ solubility in solutions, Ti corrosion, fuel cycle costs, reactor types, evaporators, and plant optimization.
AN ANALYSIS OF DUAL-PURPOSE DESALINATION PLANTS.

Efforts were divided into three general categories: calculating fuel fabrication costs, developing fabrication processes for thin titanium tubing for evaporator-condensers, and evaluating fuel performance codes for fuel fabrication costs were extended to include the coextensivc of Zircaloy cladding with thorium, thorium–uranium alloy, or uranium. Metal fuel performance was surveyed for the conventional application of metal fuel for large desalination reactors. Methods of producing flat titanium tubing by rolling forming, tube drawing, isostatic pressing, high-energy-rate forming, and press forming were evaluated.

77  (ORNL-3889) AN ECONOMIC STUDY OF THE PRODUCTION OF AMMONIA USING ELECTRICITY FROM A NUCLEAR DESALINATION REACTOR COMPLEX.


One example of the use of large blocks of low-cost nuclear power projected for the foreseeable future would be production of hydrogen and ammonia fertilizer by the electrolysis of water. The cost of ammonia production at a dual-nuclear desalination site via electrolysis was compared with the cost using the conventional steam-methane reforming process. Factors studied included power cost, natural gas cost, production rate, return on investment, type of electrolytic cell, by-product oxygen credit, and transportation cost. Using electrolytic cells that operate at very high current densities, ammonia can be produced for $38/ton with power at 2.5 to 3.0 mils/kW h. Such power costs are obtainable on an incremental basis from commercial light-water power plants. Advanced reactors of nuclear power producing power at 1.5 mils/kW h appear to be capable of producing ammonia competitive in the United States (assuming a credit for by-product oxygen) with steam-methane reforming using natural gas at 29 to 33¢ million Btu’s. The average U.S. industrial natural gas price in 1963 was 34¢ per million Btu’s. The production of hydrogen and ammonia fertilizer at a nuclear desalination site is considered sufficiently attractive to justify further study.


From IAEA Panel on Use of Nuclear Energy in Saline Water Conversion, Vienna, Apr. 1964. Analytical considerations are given of some areas of possible improvements in dual-purposes and water-only plants. The effects of product ratio (water to electricity) on the optimum turbine exhaust temperature, performance ratio, and cost of water were determined for several cases and are presented graphically. The effects of a power subsidy on the water costs were also determined. The use of a steam turbine to drive a vapor-compression evaporator in a water-only plant and the use of a single pressure vessel for both the reactor and evaporators in a dual-purpose plant are suggested.


From 5th Panel Meeting on Use of Nuclear Energy in Saline Water Conversion, Vienna.

The advent of nuclear desalting stations will make possible an important new source of water from the sea. In each situation, however, it is important to determine how the proposed plant compares with alternative methods of supplying the needed water, and to optimize the plant design to fit the local needs. Some of the analytical tools and techniques that can be applied to these tasks are discussed.

In the case of the dual-purpose plant producing power as well as water, the cost of steam must be allocated appropriately to the two products. Although this is a purely arbitrary choice, a method is presented which has the novel feature of apportioning heat cost so that neither water nor power cost is appreciably affected by changing the product ratio of the plant design. Although simple analytical models can assist in characterizing desalination plant systems, the details of design and optimization are greatly aided by computer techniques. The computer codes in use at the Oak Ridge National Laboratory for desalination studies are listed, and illustrated by examples.


From Institute of Nuclear Materials Management Meeting, Cincinnati.

It may be stated that distilled water may be economically produced by distillation in a large dual-purpose nuclear facility. Projected water costs are low enough for agricultural and cultural purposes if full advantage is taken of the favorable cost features of by-product electricity, natural uranium or breeder fuels, a large-fuel-processing industry, and large-size construction. Further reductions in water cost will undoubtedly occur as the results of research and development are applied to the nuclear desalination industry.


From Symposium on Water Production Using Nuclear Energy, Tucson, Ariz.

The nature of technical achievements that are missing in the production of agricultural water by nuclear desalination is defined, and their difficulties are outlined. The urgency of the program is discussed.


Very large reactors supplying heat to evaporators seem likely to be capable of producing fresh water from the sea which is cheaper than can be anticipated from any other presently proposed method, and possibly cheap enough for irrigation. This likelihood is especially strong if production of electric power is combined with production of water. The low cost could be achieved, however, only if quantities of water are produced which are much larger than have heretofore been considered in the saline water program. The cost of such a project and the amounts of water and power concerned tend to approach the scale of large river development projects. It is probably economically practical for municipalities to construct dual-purpose plants for production of power and city water using current technology. These moderate-size plants could be utilized. These plants might well serve as pilot plants for developing larger stations.

84  (ORNL-TM-466) PROSPECTS FOR SEA-WATER DESALINATION WITH NUCLEAR ENERGY. AN EVALUATION PROGRAM. Young, Gale; Hammond, R. Philip; Spievak, I. (Oak Ridge National Lab., Tenn.).

An evaluation and preliminary design program is proposed for the application of large nuclear reactors to the distillation of seawater. The applicable technology of evaporation processes and low-heat reactors is surveyed and applied to the projection of the cost of producing fresh water in large plants.


The effect of brine temperature on the cost of water from large municipally owned D/P reactor stations was investigated. It was found that water costs from 25,000 Mw stations varied between 11.7 and 12.6c/1000 gal in the maximum brine temperature range of 160 to 360°F. By-product electric power was sold at 1.49 mills/kwhr. The optimum size of reactors for producing combinations of 1 to 3 billion gpd and 1000 to 5000 Mw(e) was determined. From these optimums, incremental costs of producing power and water were calculated.


Cost differences between natural uranium and partially enriched uranium fuel cycles are discussed. The estimated costs for a 10 ton per day, single purpose fuel cycle for a reactor of the Dresden type using 1.5% enrichment (Core 13) are given. Bar and increment-charges were calculated for advanced pressurized-water reactors.


The purpose of this limited study was to estimate the cost of fabricating fuel elements for very large process heat reactors intended for desalination of seawater. In contrast, the reactors would be marine-cooled by light water, and fueled by natural uranium. The special case of using plutonium and depleted uranium as the fuel was also considered. The fuel elements were envisaged as being of the concentric-tube, Zircaloy-clad type, containing either vibratory compacted natural UO₂ or 99.4% depleted UO₂ spiked with 0.6% PuO₂ costs were estimated for three reactor sizes: 3500, 25,000, and 100,000 Mw(e). Fabrication plants were conceived, operational methods were established, processing times and labor were estimated, and the future cost of Zircaloy was predicted. From this analysis the cost of natural-uranium fuel fabrication, not including uranium or UO₂ costs, was estimated to be $10.5, $9.62, and $2.53 per kilogram of uranium for 3500-, 25,000-, and 100,000-Mw(e) reactors, respectively. The cost of PuO₂-UO₂ fuel fabrication, including all operations from sol-gel-oxidized oxide to finished elements but not including plutonium, uranium, or PuO₂-UO₂ costs, was estimated, per kilogram of uranium plus plutonium, to be $19.05, $12.15, and $6.30, respectively.


A survey was made to determine the feasibility of producing large amounts of nitrogen, phosphate, and potassium fertilizers with the cheap power produced from a large atomic reactor. The optimum combination was a multipurpose reactor complex for fresh water distillation and fertilizer from the sea, air, and phosphate rock. No other raw materials are required and only the three principal fertilizers containing nitrogen, phosphorus, and potassium are produced. Large amounts of by-products, required for the reaction, are also produced. The arc process is used for nitrogen fixation from air to produce nitric acid and fresh water is electrolyzed to produce hydrogen for nitrogen fixation from the air as ammonia. Ammonium nitrate and nitric acid are formed. Alternatively, nitric acid could be produced by oxidation of ammonia instead of the arc process, if cheaper. Dicalcium phosphate or triple superphosphates are produced by nitric acid leaching of phosphate rock or by treating phosphate rock in an electric furnace with coke and silica. In the furnace process, coke must be shipped in as a raw material but silica would be available at oceanside locations. Potassium is recovered from seawater by precipitation of potassium dipicrylamine. Acidification of the precipitate with nitric acid produces potassium nitrate and the dipicrylamine is freed for reuse. Potassium can also be precipitated as magnesium calcium potassium phosphate but additional caustic must be shipped in to neutralize the phosphoric acid. The effect of reducing power costs per kwh from 8 to 10 mills for private industry or from 4 mill/kwh for TVA to 1 mill at a large multipurpose reactor station was estimated. The use of electrical power to replace natural gas as a process heat source was also assumed. Reductions in ammonia or dicalcium phosphate prices of less than 5% were projected on large amounts of natural gas as process heat was lowered. However, the reduction in cost of nitrogen fixation (using ammonia) was estimated to be about 50% higher than the present method which uses natural gas as a raw material to produce hydrogen. Since these steps are modern engineering techniques, little further reduction in cost is expected. Hence, the production of nitric acid by arc fixation of air is the key item which could potentially reduce costs significantly for the whole complex but one which could not be estimated with accuracy without a detailed cost estimate and design survey. At 1 mill/kwh, the power cost alone for arc fixation of nitrogen is $0.029/lb N. Thus arc fixation nitrogen might be competitive with ammonium nitrate but not with ammonia which sells for $0.104 and $0.956/lb N, respectively. Since only 3% of the total energy of the arc process is used for nitrogen fixation, the wasted heat could be used to distill seawater and thus reduce the cost of nitrogen fixation. However, the reduction in cost of nitrogen fixation may be small since the energy is degraded before return to the distillation system. For example, if 30% of the heat is recovered at high temperature steam (worth $0.41 mill/kwh, or 120 mill/10^6 Btu) and 26% is useful as process heat (worth $0.034 mill/kwh, or 10 mill/10^6 Btu) the reduction in total cost of power for nitrogen fixation (using 1 mill/kwh) is 15%. Increasing the efficiency of the arc process (i.e., the yield of nitrogen/kwh) is considered the best means for decreasing the cost of nitric acid produced by the arc method.


A paper presented at the European Atomic Energy Society's Symposium on Fuel Cycles for Power Reactors, Baden-Baden, Germany, Sept. 1963. The lowest fuel cycle costs for converter reactors can be achieved by natural uranium or by natural uranium-water-moderated reactors of very large size. Natural uranium fuel cycles operated at cycle capacities of 10 t/d and larger offer overall fuel costs that are small, about...
0.08 mill/kwhr thermal, or 0.18 mill/kwhr electricity at 29% thermal efficiency. These costs assume 14%/yr charge on capital, a 5.5% charge on consumable inventories, burnup of 7000 Mwd/ton of uranium and 17.4% uranium credit of $6.70/g. If plutonium is not recovered but discarded, the costs are approximately 0.9 mill/kwhr electricity. Plutonium can be recovered and recycled with depleted uranium to the same extent with an additional 29% increase in fuel cycle costs over the natural uranium case. This natural uranium cycle is probably a factor of five less costly than the least expensive partially enriched uranium case if plutonium (where initial Pu is 1.5% or less) is recovered and sold; a factor of two less than the least expensive enriched case if plutonium is not recovered, particularly in fuel cycles of less than several tons per day capacity, and its attractive economically if the plutonium produced is recycled with depleted uranium.


Comparison of nuclear desalting plants with conventional water supply projects now proposed for the southwestern United States shows that the nuclear stations are at least competitive in some areas, and this competitive position will improve as water needs increase and nuclear costs come down. An independent study made for the Office of Science and Technology confirmed the Oak Ridge National Laboratory's estimates of low energy costs from very large reactors.

(ORNL-TM-758) COST STUDY OF A LARGE SODIUM COOLED FAST BREEDER REACTOR FOR A SEA WATER DESALINATION PLANT. Gall, W. R. (Oak Ridge National Lab., Tenn.). Mar. 1964. 56p. Dep. (mn): $3.00 cy, $0.50(mn)/CFSTI.

A very rough preliminary design study and cost estimate are presented for a 25,000 MWU plutonium fueled fast breeder reactor for use in a desalination plant. Designed for operation with sodium temperatures below 800 F, the primary system can be constructed of carbon or low alloy steels. The reactor vessel is 44 ft inside diameter, and with a coolant temperature rise of 250 F, four pumps circulate a 4,000,000 gpm of sodium through four 4500 MW(t) reactors. Inlet steam at 600 psia drives eight 540 MW(e) (e) turbine-generators, each unit at 25 psia to the evaporation plant. Estimated direct construction costs per thermal kW are:

| Reactor with primary coolant system | $5,672 |
| Turbine generator plant | $4,726 |
| Secondary sodium system | $2,419 |

Top charges add approximately 40 per cent to these costs.


Estimates of the cost of dual-output nuclear desalination plants are presented, based on projected costs of boiling H2O cooled heavy water reactors and multistage flash evaporators. Several combinations of private and public ownership of the facilities are shown. Plants in the size range 1060 to 26,000 MW thermal are considered.


Detailed cost estimates of a multi-state flash evaporator (MSE) and a vertical multiple-effect evaporator (LTV) were used as a basis for comparing these two types of evaporators. Although the cost estimates were both for one billion gpd plants, the steam temperatures and maximum brine temperatures specified for the two plants were different (mainly because the specifications were written at two different points in time). Hence it was necessary to modify the MSE flowsheet to the steam, maximum brine and seawater temperature conditions of the LTV to permit making a normalized cost estimate for the MSE. Comparison of the systems was made for evaporators using 240°F steam, 250°F maximum brine temperature, and 80°F seawater; the LTV had six effects, and the MSE four stages. For the assumptions of this study, the principal findings are:

1. Although the LTV requires about one-third more heat transfer surface than the MSE, its total construction cost was less than 47.5% of the MSE.

2. The LTV, having a larger fraction of its total capital cost in aluminum bracing tubing, which might have to be replaced once during the 30 or 35 year lifetime of the whole plant, requires a higher fixed charge, 6.4% for the LTV as compared to approximately 20% for the MSE.

3. The cost of water produced in the LTV of performance ratio 6 lb product/1000 Btu is about 26,100 g cheaper than the MSE.

4. The cost of water produced in the MSE is 20% cheaper than the LTV.


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surized water reactor, and a 10,000 gpd evaporator plant
operated with a 25,000 MW(e) nuclear-electric plant which
was powered by three pressure tube reactors.


Preliminary design and economic studies of a 3500-
MW(U) low-temperature sodium-cooled fast breeder reactor concept for use in desalination applications are reported. The reactor consists of an oxide-fueled core and metallic uranium radial blankets operating at a reactor inlet temperature of 500°F and a mean outlet temperature of 800°F. Four applications of the reactor design are considered:
1. Central-station power plant
2. Dual-purpose plant
3. Self-contained plant
4. Single-purpose process-heat plant

Based on proposed desalination ground rules, this system produces prime steam for less than 9 cents per million Btu. As a central station power plant, the system is capable of producing power at 1.5 mills/kwhr. If power is valued at this price, process heat in the form of steam at 500°F can be delivered to an evaporator plant for about 9.54/MBtu from the single-purpose process-heat plant, 8.34/MBtu from the self-contained plant, and less than 5e/MBtu from a dual-purpose plant producing 450 MW(e) power and above the auxiliary power requirements of the desalination complex.

was made to ascertain which processes should be given priority for further detailed study as possible components of a nuclear industrial-desalination complex. Factors studied included market potential, demand for large quantities of power or steam, shipping costs, production costs, and economics expressed as power/tonne.


Flowsheds were developed for flexibility in the product output of dual-purpose nuclear desalting plants with base load rating 500 MW(e) and 250 M gal/day. The base plant has a 3228 MW(M) pressurized water reactor, a back-pressure turbine-generator, and a multi-stage flash evaporator. The performance and cost of alternative systems for providing flexibility were evaluated by means of a computer model of the plant. Among the systems investigated were variable back pressure turbines, optional low pressure condensing turbines, pumped storage, turbine bypass de superheaters, optional evaporator modules, vapor compression and heat pumps. Some of these systems appeared to be useful for providing economical peak power, for spinning reserve, in trading power for water, or in operating at mismatched product demand.


From IAEA Panel on Costing Procedures for Nuclear Desalination, Vienna, Austria.

A procedure for the allocation of the total cost of a power-desalting plant to the separate products is described. The cost of producing the energy required by both products includes the cost of rejecting waste heat. The production cost of energy in the form of prime steam is divided between the cost of power and water according to its potential for producing electric power. Common facilities not associated with the production of energy are allocated to water and power costs according to the use or benefit that each product receives. This method has the characteristic that for an energy source with a given capacity the water-to-power production ratio may be varied over a range of values without significantly changing the cost of each product as long as the temperature of the heat supplied to the water plant is within the useful range for the process being used. The characteristic is due to the fact that: (1) since the energy cost component of power cost is constant, any increase in the unit power cost varies in the relatively minor effect of the equipment and operating unit costs of the power station as a function of size; (2) the variation in exhaust steam cost to the water plant as a function of exhaust pressure is balanced by a variation in the water plant design (if optimum) to match the water plant efficiency with the cost and condition of its heat source.


Methods were developed for predicting the dynamic behavior of a large dual-purpose plant consisting of a pressurized-water reactor (PWR), a back-pressure turbine generator plant, and a multistage flash (MSF) evaporator. A flexible digital computer code was developed which calculates the transfer functions for single-effect MSF plants. Preliminary results were obtained for a 250-megagallon reference plant and some of the major control problems were described. The water cycle consisted of a reference PWR plant, and transfer functions for a large back-pressure turbine were derived.


A Fortran IV code was designed to design a multi-stage flash desalination plant consisting of a brine heater which receives heat from an external source and transfers it to the brine, an evaporator recovery section which produces the major part of the product water and recovers heat to permit the plant to operate at performance ratios greater than one, and the evaporator reject system which rejects the heat to the coolant while producing a minor portion of the total product water. The code is used to calculate process flows and temperatures, heat transfer coefficients, plant geometry, and water cost.


An economics study was made for the nuclear production of desalinated water. Separate discussions are presented on the following: shape of the demand curves, the characteristics of supply and principles of adaptation of supply and demand.

Oak Ridge National Lab., Tenn. and Oak Ridge Gaseous Diffusion Plant, Tenn.


The costs of the chemical and metallurgical steps in the fuel cycle for large desalination reactors are estimated. Both capital and operating costs are presented at varying plant capacities for a Zircaloy-clad fuel element containing depleted uranium and recycled plutonium as the oxidizer. UO$_2$-0.5PuO$_2$. The chemical steps are reported at throughputs of 1, 10, and 30 short tons of uranium per day; and the metallurgical or fabrication step at throughputs of 1, 3, 5, and 10 tons per day, as specified by the Office of Science and Technology. The total estimated cost of all the chemical and metallurgical steps drops from $51.17 to $14.68 per kilogram of uranium as the cycle throughput is increased from 1 to 10 tons of uranium per day. All steps decrease in cost as plant capacity is increased, with the most impressive decrease in the irradiated assembly processing step, which decreases from $26.19 to $4.10 to $2.07 per kilogram of uranium as throughput is changed from 1 to 10 to 30 tons of uranium per day. The contained data in conjunction with previous studies of a natural uranium fuel cycle and reprocessing optimization study will yield complete fuel cycle costs and plutonium value in recycle.

Office of Saline Water, Washington, D. C.


The Northeast water supply situation and the drought problem are reviewed. Large dual-purpose, nuclear-fueled desalting plants of 300 MGD capacity can be built as a long-range solution to the need for additional water supply. Alternating water supplies, such as the Hudson River and small desalting plants, are discussed and found to be adequate for the present. However, additional desalting studies are needed.

111 (NP-16250) POTENTIALITIES AND POSSIBILITIES OF DESALTING FOR NORTHERN NEW JERSEY

The potentialities and possibilities of desalting are considered as a source of water supply to the area of New York City and the four northern counties of New Jersey. Desalting is explored in terms of its cost and relationship to the growing need for water and the existing surface water supply system, and proposed additions to the surface system. Various design configurations, including nuclear, fossil, and refuse-disposal fuel sources and dual-purpose power-water production, are considered.


Research progress on saline water conversion is reported under the headings of chemical physics, biosciences, chemistry, applied science, materials, distillation, membranes, special projects, engineering services, engineering analyses, and program analysis and coordination.


Potential separation processes and energy sources for demineralization of seawater are outlined and discussed. A chronological bibliography of demineralization of seawater is included.


A bibliography is presented of those monographs, scientific and technical reports, papers and periodical articles which are a result of the activities of the Office of Saline Waters or which were written by a staff member of that Office. The bibliography which is arranged by author, is divided into two parts: 1. Articles and Monographs. II. Reports, and is supplemented by author and subject indexes.

Sargent and Lundy, Chicago, Ill.


Conceptual designs and construction cost estimates of two heavy-water–moderated, natural-uranium-fueled power reactor plants are reported. Both plans use vertical pressure-tube reactors, in which heat is transferred to boiling light water, as heat sources. A part of the energy in the steam is converted to electrical energy in steam-turbine generators; the energy in the turbine exhaust steam is used to heat seawater in the turbine condensers. The seawater flows to an adjacent distillation plant for the production of fresh water. Two plant sizes are considered. One consists of a full-scale system designed to produce a power output of 25,000 million thermal megawatts. The second system is based on a reactor having a thermal power output of 3,500 MW(t) and is considered to be a prototype of the larger plant. A preliminary composite flow diagram of the 25,000 MW plant is given. Three reactors, each designed for a heat power output of 8,253 MW, are used to produce 500 psig saturated steam for nine turbine generators. The turbines exhaust to nine brine heater–surface condensers at exhaust conditions of 17.2 psia, 220°F; the heat of vaporization is removed in the seawater by heating it from 185 to 200°F. The plant outputs are about 4,000 MW(e) to the switchyard and 26,300 MW(t) as 200°F seawater. The system includes all facilities for a complete power generating system, including the switchyard, control rooms, waste disposal systems, offices and shops in addition to the structures and systems associated with the reactor–turbine complex. The general layout of the plant is shown. Each reactor is contained in a separate containment structure, and all nine turbine-generators are located in a single containment building. The reactor buildings consist of vertical pre-stressed concrete cylinders, capped with hemispherical domes, while the turbine containment building is one-half of a horizontal steel cylinder, capped on the ends with spherical quadrants. In cross section, the turbine building is semi-circular with a flat concrete floor. The reactor and turbine containment units structures form one containment volume for the expansion of reactor coolant in the event of a coolant system rupture. Based on the complete one of coolant, the critical power of the entire design is 8.5 psig. Both the reactor and turbine buildings have double outer shells, with the space between the shells connected to a waste gas compression system, allowing leakage from the inner shell to be collected, monitored, and passed through iodine filters and disposed of safely.

The study includes necessary electrical auxiliaries, heating, ventilating and air conditioning systems, and plant utilities such as fire protection systems, and sewage systems. It is assumed that the seawater for the brine heaters and that used for miscellaneous cooling purposes in the plant is pumped to the power plant by pumps at the saline water evaporation plant. Power for these pumps is transmitted to the saline water plant by three 345 kV feeders from the switchyard. Approximately 300 MW(e) is estimated to be required for this service. The 3,500 MW plant uses one pressure tube reactor to produce saturated steam at 600 psig. Two 325 MW(e) turbine generators are driven by the steam, which condenses in brine heaters at 17.2 psia, 220°F before being pumped back to the reactor inlet as condensate. The heat of vaporization of the turbine exhaust steam is used to raise the temperature of the seawater from 185 to 200°F, as in the 25,000 MW plant. This system generates a gross power output to the switchyard of 274 MW(e). The output of 200°F seawater is about 2800 MW(t) under these conditions. The plant structures differ from those of the 25,000 MW plant, in that only the reactor systems are housed in a containment structure. The turbines are located on foundations that are outdoor structures, and the turbine-generators and auxiliaries are weatherproofed for outdoor service. The containment building of this plant has only a single containment barrier, and consists of a vertical cylindrical steel building 180 feet in diameter, enclosed at the top by a hemispherical and at the bottom by a hemispherical slop. The design pressure of the containment building is 13.5 psig is based on instantaneous release of the entire reactor coolant inventory to the interior of the building. As provided for the 25,000 MW plant, the small, 325 MW system includes control, inspection, and cooling systems, and small saline water, and nuclear systems, and offices and shops necessary for a complete power plant. It is assumed that pumping facilities for the seawater for condensing purposes and miscellaneous cooling services are provided by saline water plant. The estimated capital investments for the plants are $126,955,000 for the 3,500 MW plant and $607,787,000 for the 25,000 MW plant.


Design and economic aspects of 300-, 500-, and 1000-MW(e) heavy water–moderated power reactors are illustrated and the computer codes used in the analyses are discussed. The plant concepts all use pressurized water reactors with cold heavy water as moderator and are cooled by: liquid heavy water, boiling heavy water, organic liquids, and light water for. The liquid heavy water-cooled and organic-cooled reactors are used in an indirect cycle while the boiling heavy water- and light water for-cooled reactors operate in a direct cycle. The use of large heavy water–moderated reactor systems as an energy source in desalination plants which would produce electrical power and fresh water is evaluated. Nuclear safety and defense considerations are discussed. Illustrations of the plant designs for this application are presented.

117 (SL-2158) LARGE CONDENSING AND NON-CONDENSING TURBINE PLANT STUDY. (Sargent and Lundy, Chicago). Feb. 11, 1964. For Oak Ridge National Lab., Tenn. Contract (W-7405-eng-26); Subcontract 2148. 36p. Dep.(mn); $2.00(cy), 1(mn) OTS.

Costs and performance characteristics of three large turbine generator plants, two of which are designed for ex-
haunting steam to a desalination plant and the third is
a conventional condensing unit, are discussed. Each of the
units is rated initially at 550 MW(e) and will be used in
large dual-purpose reactor power plants.

118 (SL-2317) LARGE TURBINE PERFORMANCE
AND TURBINE PLANT COST STUDY. (Sargent and Lundy,
(ORNL-TM-1641). Dep. mn. CFSTI $3.60 cy, $0.65
mn.

For Oak Ridge National Lab., Tenn.

Performance data and cost estimates are developed for
units employing large condensing and noncondensing turbine
generators applicable to large nuclear dual-purpose power
and desalination plants. The units studied have capacities
ranging from 500 to 750 MW(e) and a variety of steam con-
ditions and cycle arrangements.

Task Group on Nuclear Power and Saline Water
Conversion.

119 AN ASSESSMENT OF LARGE NUCLEAR POW-
ERED SEA WATER DISTILLATION PLANTS. (Task Group
1964. 41p. $0.35(GPO).

A memorandum summarizes the findings, conclusions,
and recommendations of the Task Group, and a report of
the interagency subcommittee is presented. The studies
indicate that water prices attainable using stations made
up of 5,500-MW(e) dual-purpose reactors are 23¢ per
1,000 gal when all the plant complex is financed at a 7%
fixed charge rate, or 28¢ per 1,000 gal when the reactor
and water plants are financed at 14 and 7% fixed char-
ge rates, respectively. The cost for irrigation appears to be
11¢ per 1,000 gal. Water conveyance costs are considered.
It is emphasized that a station analysis for a specified pro-
posed station would be required to determine the most
practical plant. The research and development program
required for dual-purpose reactor stations producing from
10 up to 620 MGD is described. The status of nuclear re-
actor technology and seawater distillation plants is exam-
nined. Desalting processes other than distillation are dis-
cussed briefly.

120 APPENDICES TO AN ASSESSMENT OF LARGE
NUCLEAR POWERED SEA WATER DISTILLATION
PLANTS. (Task Group on Nuclear Power and Saline Water

Technical design and performance data are given for
dual-purpose power plants for 1500 to 55,000 MW(e) using
bolling reactors, pressurized reactors, heavy water re-
actors, organic-cooled reactors, liquid metal–cooled re-
actors, high–conversion reactors, enriched-fuel reactors,
and fast breeder reactors. Power value estimates for
the dual-purpose desalination plants are presented. Methods
of desalination are discussed. Evaluation of potential water
markets in southern California coastal areas is considered.
Federal Reclamation financial criteria are applied in as-
sessing the large distillation plants.

Technion-Israel Inst. of Tech., Haifa.

121 (A/CONF.28/P/548) FEASIBILITY OF NU-
CLEAR REACTORS FOR SEA WATER DISTILLATION
IN ISRAEL. Aschner, F. S.; Yiftah, S.; Glueckstern, P.

Current power capabilities and future requirements in
Israel are discussed. The heating requirements, perfor-
mancc ratios, and temperature limitations of flash evapo-
ration for seawater distillation are considered. Dual-
purpose nuclear reactors for power and desalination
processes and high-heat reactors for low-pressure
steam generation in desalination are discussed technologi-
cally and economically with conventional steam generation
in Israel. Investment costs based on these alternatives and
the water prices expected are given.

Union Carbide Corp., Oak Ridge, Tenn.

Y-12 Plant.

122 (ORNL-TM-1289) SALINE: A FORTRAN
COMPUTER PROGRAM FOR THE PROCESS DESIGN OF

SALINE WATER CONVERSION PLANTS USING THE
MULTI-STAGE, FLASH–EVAPORATION PROCESS. Griff-
ith, W. L.; Keller, R. M. (Union Carbide Corp., Oak
eng-26–81P. Dep. mn. CFSTI $5.00 cy, $0.75 mn.

For Oak Ridge National Lab., Tenn.

A Fortran IV computer program that performs heat
balance, material balance, and cost calculations on saline
water conversion plants using the multi-stage, flash-
evaporation process is described. The code is a modified
revision of a program written by the Bechtel Corporation
for OSW. Under the simplifying assumptions inherent in
the mathematical model, a complete heat and material bal-
ance is calculated by a stage-to-stage numerical technique
from the design parameters supplied. Costs are calculated
from these results and the economic data supplied. Opti-
mum design parameters which minimize total cost over a
30-year period can be determined either by a series of
computer runs or by an optimization procedure supplied.

Details of the numerical procedure, program options, and
usage are presented. Results obtained with an IBM-7090
from typical design data and a complete listing of the
Fortran program are included.

United Nations. Dept. of Economic and
Social Affairs.

123 (ST/ECA/86) WATER DESALINATION: PRO-
POSALS FOR A COSTING PROCEDURE AND RELATED
TECHNICAL AND ECONOMIC CONSIDERATIONS. (United
56p.

In view of the fact that desalinated water must by its
very nature be relatively costly, both in terms of invest-
ment per installed unit of capacity and of total cost per
unit of product water, it is particularly important that a
clear and simple costing method should be devised which
would allow policy makers and administrators to establish
an approximate, but realistic, true cost for product water.

The procedure outlined provides a tool which should make
it possible to establish the cost of water from existing in-
stallations on a uniform basis, and which may thus be used
as a guide for rate setting policies. At the same time, the
method should be equally applicable to plants which are
not yet built, but for which basic data are available and for
which principal technical specifications can be provided by
manufacturers or consulting firms. If an adequate system
for costing water from conventional sources is available,
as may well be the case in many countries, the procedure
outlined should make it possible to compare the cost of de-
salinated water from a plant with given specifications with
that of water from an alternative source for which it has
been possible to establish the full cost per unit of product,
using parameters comparable to those employed for de-
salination.


124 NUCLEAR POWER–WATER DESALTING PLANT
AND THE ELECTRIC UTILITY INDUSTRY. Sinamon, W. H.;
O'Toole, J. D. (Westinghouse Electric Corp., Pittsburgh).
25p. (CONF-660429-4). ORAU. Gmelin, AED-CONF-66-
098-5.

From American Power Conference, 28th Annual Meeting,
Chicago.

The principles and status of technology of nuclear steam
supply systems are reviewed; typical ranges of energy
costs from such systems are presented; and some unique
turbine-generator configurations and their influence on
cost of energy supplied to the water desalting plant are
discussed. In addition, the potential capability of a reactor to
'stretch' utilization and need for overall optimization in dual-purpose
plants are discussed.

TRANSLATIONS

125 (AEC-tr-6733) ANALYSIS OF THE TECHNI-
CAL AND ECONOMIC INDICES OF NUCLEAR-POWERED
DESALINATION PLANTS. Logino, A. A.; Koryakin,
Yu. I.; Cherneev, V. A.; Zaikhina, I. I.; Stoyushnov,
B. A.; Sponov, A. D. Translated from Paper SWD/56

A method is described which makes possible the establishment of parameters for the optimum thermal efficiency of two-loop dual-purpose atomic stations.


Economic and technical aspects of dual-purpose desalination-power plants using several types of reactors are discussed. Fast-neutron, water-cooled and -moderated, water-graphite, and heavy water reactors are considered. It is shown that a fast reactor of 2,200 MW(t) output is the most economical for desalination of 180,000 to 220,000 m³ of seawater per day.


An evaluation of the power potentials and economic indices of reactors of the Beloyarsk type gives grounds to consider these reactors to be very promising for a combined production of electric power and desalted water, especially under the conditions when these two types of the product are equally important and necessary.


Among the versions under investigation utilizing turbines with controllable steam diversion, the most convenient seems to be the atomic energy station with fast neutron reactors producing desalinated water at a cost of 4.5 kopeks/m³. The calculations do not pretend to shed complete light on the effect of the basic parameters of the installation on the cost of fresh water. Economic indices are given for dual-purpose plants capable of providing a city of 500,000 population with electricity and fresh water.


The results of a study of desalination plants using organic-cooled reactors of 15, 30, and 70 MW(t) are presented.

The utilization of nuclear power for the distillation of sea water is considered in its economic aspects. A pressurized water reactor combined with a flash evaporator is discussed as the reactor type. The characteristics of such a reactor are tabulated. The capital costs for the installation and operation of the reactor system for flash evaporation of sea water are given.


The possibility of using heat from a nuclear reactor in distillation and solvent extraction techniques of water purification is considered. Cost data are presented for an installation with an output of 40 million gallons per day.


A cost comparison was made of nuclear and conventional power plants for the desalination of sea water. The simultaneous production of electricity and desalinated water, the efficiency of the natural uranium–graphite–gas reactor, the development of mixed nuclear power plants, and the types of reactor are considered.


Nuclear power stations in the Soviet Union are described briefly. Economic aspects of using nuclear energy as a source of electric power are discussed. The program for use of heat from nuclear reactors for desalination of seawater is reviewed.


The various phases of the state of California's interest in nuclear energy and water demineralization as initiated through the work of two legislative subcommittees are described. The history, principal demineralization techniques, present and probable future water costs, and research and development programs, both state and federal, are described and discussed. The present status and future possibilities of nuclear energy applications are reviewed and discussed. The effect of nuclear energy in the coming 10 to 15 years on the California Water Plan is considered in detail. The types and possible use of so-called "nonconventional" sources of energy are reviewed and discussed, and their use in relation to the water program in the near future is discussed. The future program of the state in the development of water demineralization and nuclear energy applications is presented. Many tables and graphs are used to elucidate the various aspects of the report.


The economics of nuclear fuel as compared with electricity and coal are discussed. Fueling costs of 7c/million Btu have been demonstrated for nuclear reactors, compared to 30–40c/million Btu that most plants must pay for coal, or natural gas. However, it isn't possible to get 7-cent steam in small units because of design considerations. The desalinization of water, paper mill process heat, light-water vs organic, and high-temperature heat are discussed.


A survey of the current status of nuclear desalination technology indicates the main areas of world demand, the state of the art in the engineering and technology of large saline-water conversion plants, as well as results of recent research in the design of multi-stage flash and tube-type evaporators. A review is made of the effects of the application of process heat from nuclear reactors to the economics of large scale desalination, with special attention to the role of heavy water moderated "high converter" reactors.


A condensation of a Fluor Corporation study to determine the best combination of reactors and distillation processes that could produce the lowest cost water is presented. Desalinated seawater is produced for approximately 63 cents per 1000 gallons by a heavy water–moderated and cooled reactor combined with a seven-stage, long tube vertical, multiple-effect evaporator.


Results of studies of dual purpose nuclear power-desalting plants and an outline of the development program for the next decade are presented. Current nuclear desalting technology and cooperative international exchanges are described which have the possibility of providing fresh water at less than 50 cents per 1000 gallons.


Project Artesia proposes to convert fission product wastes into an energy source for saline water conversion. The radioactive aqueous waste material from reactor fuel element reprocessing plants is calcined to an insoluble powder and loaded by vibrational compaction into rods. A sufficient number of rods is loaded into a pressure vessel in which the heat is transferred to a suitable liquid transfer fluid. This energy is then carried to a conventional saline water conversion system through an intermediate heat exchanger. The economic feasibility of a conceptual model has been studied, and the cost of producing 1000 gallons is estimated to be $6.79/1000 gal. The technical aspects are next considered: radioactive material, materials selection, heat transfer, and compatibility. Finally, the safety and hazards of the experimental test model are described.


During the last 6 years dozens of atomic power stations, with a total capacity of about 5000 Mw(e), were built; their operating experience offers a basis for economic evaluation of their performance. It was concluded from data on these stations that the cost of the nuclear–generated electricity and heat is becoming competitive with energy derived from conventional sources, even though government subsidies played an important role in the development of the present plants. The main factors that contributed to the increasing importance of atomic power plants include: use of large reactors, up to 600 Mw; increasing cost of conventional fuels; prolonged periods of operation of the atomic power plants, and inclusion of these plants in interconnected networks. It is forecast that by 1970 about 25,000 Mw(e) and by 1980 up to 250,000 Mw(e) atomic power capacity will be available. Desalination could be calculated to be one of the chief potential fields of application of atomic energy that will probably become completely competitive with other systems within the next two decades.


Papers at the Third Geneva Conference on specialized applications of atomic energy are discussed under three headings: desalination of sea water; atomic heating plants; and problems connected with the development of portable reactors. Economic investigations carried out in the United
States and Israel revealed that, depending on the cost of fossil fuels, fresh water may be produced competitively by reactors with a capacity between 220 and 600 MW. A 1000-MW desalination reactor is planned by the Soviet Union to be located near the Caspian Sea. Two reactors were constructed primarily for space heating: in Halden, Norway, and Stockholm, Sweden. Similar work is in progress in the Soviet Union, basing the design on that of the Boloyark power reactor. The portable reactors are designed for operation in remote areas where high fuel costs make them competitive. The United States has five such reactors in operation. These reactors are characterized by low weight, small dimensions, portability, ease of assembly, long core life, and simple operation and maintenance. Ship propulsion reactors include that of the icebreaker Lenin. Design work on maritime reactors is in progress in Holland, sponsored by Euratom and in West Germany.

149

Discussions are presented of two English desalination studies, a nuclear-powered distillation plant and an electrolysis plant, and the American nuclear-powered distillation plant at Point Loma. The Flor Corporation design study for a nuclear distillation plant of 208,000 cubic meters per day capacity is mentioned, and comments on the economic evaluation of reactors for the desalination of sea water utilizing the flash evaporation process.

150

A summary is presented of five U.S. studies on the economic evaluation of reactors for the desalination of sea water. A short review of estimated economies of single and dual purpose reactor-powered distillation plants is presented. A bibliography containing 17 references is included.

152
NUCLEAR REACTOR FOR DISTILLING SEA-WATER. Viletschuk, Isaac; Araz, Nathan. Engineering, 185: No. 4810, 228-30 (May 16, 1958).

A pressurized-water reactor producing low temperature steam for distillation of sea water is shown to have highly favorable conditions of operation in arid and semi-arid areas. The constructional and technological features of the Low Temperature Reactor (LTR) are shown to be much simpler than for a power reactor, and certain features of the LTR are compared with those of a Shipping-port-type reactor. Cost data are analyzed for distilling water by a power reactor and by the LTR and are found to compare favorably.

153

Present desalination processes and cost estimates for each are discussed. Desalination processes include electrolysis, reverse osmosis, freezing, and evaporation. The best economic prospect is the construction of large combined plants in which nuclear energy is used to produce electricity and fresh water. A large nuclear dual-purpose plant is described and nuclear fuels are compared with fossil fuels.

154

The extent to which electrolysis can be an economic means of obtaining fresh water from salt water, when nuclear reactors are used as energy sources, is examined. Comparisons between electrolysis and flash distillation as a means of obtaining large volumes of fresh water are presented. Discussions of plant components, electrical and mechanical, and comments are made on the differences in plant behavior and product.

155

Uses of nuclear reactors to produce heat for distillation of saline water are discussed. World water requirements are also considered.

156

A pressurized water reactor producing low temperature steam for desalination, multi-effect multi-stage flash distillation, scale control by distillation, multi-effect distillation, the theory of distillation, reverse osmosis, and electrolysis are considered. Use of nuclear reactors as heat sources in desalination is discussed.

157

The firmly established applications of nuclear power such as electric power generation, submarine propulsion, and space auxiliary power are reviewed. Several new areas of application including booster reactors for deep space, desalting of sea water, power packages for hardened sites, and underground explosions of nuclear devices are also discussed.

158

In an analysis of the thermodynamics of dual-purpose desalination, it is apparent that the base-loaded plant with noncondensing turbine provides the most economic approach to desalination even though new storage capacities will be required. Conveyance of water to existing reservoirs and variable operation of the water facility offer no economic advantages. Desalination of water is too expensive for agricultural applications, but it provides a promising source of fresh water for certain areas with special water problems where conventional supplies are inadequate to meet the needs of growing populations and increased industrialization. Thermodynamic comparisons of single-purpose power plants (fossil and nuclear), single-purpose water plants (fossil or nuclear); noncondensing dual-purpose (fossil and nuclear); and condensing dual-purpose (nuclear) plants are given.

159

Various purification processes for salt water using reactor and conventional heat and electrical sources are described. Flash distillation, vapor compression, and electrolysis are discussed. The relative merits of mixed installations that produced electricity as well as purified water are considered.

160

Feasible cycles for supplying low-energy-level steam to the desalting flash evaporators of dual-purpose electric-generaion and seawater conversion plants are presented and discussed. Cycles which generate electricity as the primary product and desalted water as the by-product are compared with cycles which produce water as the predominant product and electricity as the by-product. Investigations include fossil-fueled steam cycles and nuclear-fueled steam cycles at various pressures and temperatures. Determination of the most feasible cycles for various capacity ranges of water production and electrical generation are presented.

161

The development of nuclear power for desalination is discussed. The historical development of this technology, the advantages of nuclear energy, the AEC program for desalting application, and the program of technology scale-up are considered. Trends in costs of nuclear power plants, data from dual-purpose plant studies, fuel costs for light water
The program to desalt sea water by nuclear energy is considered. It was found that with large, dual-purpose nuclear plants, power and water could be produced at competitive costs in water-short coastal areas by about 1975-1978 and that such installations would be able to supplement sources of municipal and industrial water. Dual-purpose plants fired by 200- to 1500-Mw reactors were studied. The advantages of dual-purpose plants were confirmed, and there seems to be a sound basis for combining the production of these two utilities, especially with nuclear reactors as the heat source. Better use of available heat is made; economies are offered by building one large plant instead of two smaller plants to produce the two products; and savings in certain equipment are possible. A wide range of plant sizes and reactor types was investigated, and various assumptions on factors such as fixed charge rates, value of power, and plant load factor were employed. Considerable variations in the resulting predictions of the costs of water and power were found, and predicted costs, however, proved to be encouraging, and nuclear dual-purpose plants, especially those of a larger size, should be competitive with alternate methods of water supply. For example, a plant for operation in 1975, which uses a 1500-Mw water-cooled reactor, is predicted to produce 190 Mw of electricity and 170 million gal/day of water at a cost of about 32¢ per 1000 gal. For a plant built for operation in 1975, which uses an 850-Mw heavy-water reactor and produces about 1460 Mw of electricity and 620 million gal/day, the cost of water is predicted to be around 25¢ per 1000 gal. The electricity produced in a dual-purpose plant (the power value) can have a substantial effect on reducing water cost. For the plant using the 1500-Mw water-cooled reactor, the water price is lowered by about 32¢/1000 gal for every mill/kwhr of power selling price increase. In the case of the 1500-Mw water reactor plant, the cost was found to increase from -32¢/1000 gal to 40¢/1000 gal when the entire plant load factor decreased from 0.8 to 0.6. The reasons for this trend were considered most promising for large-scale power desalting use in the heavy-water, organic-cooled reactor (HWOCR). The HWOCR concept offers significant potential for producing low-cost electric power and heat, especially in large single unit sizes. Because of its specific design features, extrapolation to a large-scale unit of up to 8 to 10,000 Mw capacity is considered feasible. The reactor also has the potential for very low energy costs whether used in power only or dual-purpose plants. As an advanced converter, the HWOCR also promises a substantial improvement in nuclear fuel utilization compared to present light-water reactors. It is expected that the initial prototype would be sufficiently developed to permit its operation in 1970.

DESALTING OCEAN AND SALINE WATERS.

Emel'ianov, V. (Corresponding Member of the Acad. Sci. USSR). Nauka i Zhizn' No. 3, 20-3(March 1965). (In Russian)

Brief discussions are presented of desalination processes, and various desalting installations now in operation are mentioned. The economics of nuclear dual purpose plants are discussed. A 2,200 Mw(e) reactor in a dual-purpose plant could produce 701 Mw(e) and 180,000 cubic meters of fresh water per day at a cost of 2 to 3 kopeks per cubic meter. Reactors in the range of 10,000 to 20,000 Mw(e) would produce water cheap enough to be used for irrigation.

FRESH WATER BY NUCLEAR POWER.


Flash distillation, using steam from an AGR, as a method for desalination of sea water is discussed. An advanced gas-cooled reactor and multistage flash distillation plant were designed to yield 400 Mw of electricity and 60 million gallons of fresh water daily is described.

166 NUCLEAR ENERGY—POSSIBILITY OF DESALTING OCEAN AND SALINE WATERS.


A brief review is given of the vapor compression, flash distillation and falling film methods of desalination, and diagrams are presented of typical processes. The development of nuclear energy for sea water desalting is discussed. Topics considered include nuclear and fossil energy resources, the advantages of nuclear energy, trends in nuclear plant and operating costs, the history of desalting using nuclear power, and the AEC program for desalting application. Also discussed are engineering studies of desalting installations, scale-up of the desalting technology, and the international program. The goals of this development are to provide a nearly inexhaustible resource of energy, and large quantities of pure water from the sea at reasonable cost.

DESALINATION AND THE ROLE OF NUCLEAR POWER.


A brief review is given of the vapor compression, flash distillation and falling film methods of desalination, and diagrams are presented of typical processes. The development of nuclear energy for sea water desalting is discussed. Topics considered include nuclear and fossil energy resources, the advantages of nuclear energy, trends in nuclear plant and operating costs, the history of desalting using nuclear power, and the AEC program for desalting application. Also discussed are engineering studies of desalting installations, scale-up of the desalting technology, and the international program. The goals of this development are to provide a nearly inexhaustible resource of energy, and large quantities of pure water from the sea at reasonable cost.

APPLICATION OF NUCLEAR ENERGY TO LARGE-SCALE POWER AND DESALTING PLANTS.


There is a current widespread interest in dual-purpose nuclear plants, attributable to successful developments in both the nuclear and desalination fields. During the past eight years, it has become clear that nuclear energy may provide economically with fossil fuel power in many geographic areas. At the same time, parallel strides have been made in the technology and economics of seawater conversion, particularly in distillation varieties. The best developers meeting the energy needs for large power-water situations have opened the way for consideration of large-scale plants which can supplement both the electrical energy and fresh water needs of large metropolitan areas near the coast. Specific types of nuclear power plants in combination with desalting plants are examined to establish the relative economic potential of various heat sources for large-scale dual-purpose application.

FEASIBILITY OF OFFSHORE DUAL-PURPOSE NUCLEAR POWER AND DESALINATION PLANTS.


Discussion of the ecological and technical reasons suggests offshore locations for dual-purpose nuclear power and desalination plants to be an attractive solution to the siting problem. A study on the feasibility of offshore construction of such dual-purpose nuclear plants shows that the necessary technological experience is available from applications for other purposes such as offshore oil wells, bridges, caissons, floating dry docks, and other marine structures. Conceptual design studies for a large-scale nuclear power and desalination plant using alternatively an island caisson, a deep-water caisson, and a moored floating platform are described. Conceptual design studies for offshore dual-purpose nuclear plants are made.
The effects of large-scale reactors on the economics of nuclear power and process heat generation are considered. The cost figures for a 25,000 Mw(t) dual-purpose plant producing 5000 Mw(e) and one billion gallons per day are presented.


Tables and information are summarized from report DP-830 on the use of heavy-water reactors for both single and dual-purpose plants.


A general design approach for application of nuclear energy to desalination of sea water is discussed. A survey is presented of nuclear desalination projects and studies. Technical problems, siting criteria, and reactor types are discussed in large-scale reactor development for desalination.


The conclusions and cost data presented in the Inter Agency Task Group study of large nuclear-powered seawater desalination plants are summarized.


A summary is given of the Geneva Conference papers on the development of power reactors for desalination purposes.


Nuclear reactors in very large sizes hold out the promise of large-scale distillation of fresh water from the sea at a cost low enough for municipal, industrial, and irrigation use. According to the results of a preliminary study, water in these cost ranges can be produced by breeder-reactor distilling plants if they can be built large enough—up to 100,000 Mw(th). The cost of water depends strongly on the size of the unit; for larger plant sizes, costs below 15¢/100 gal may be possible.


A reference design for a reactor desalinization and power-generating plant (particularly, the reactor design) is presented. The facility, based on current technology, would use three 5,333-MwU heavy-water moderated, boiling-light-water-cooled reactors fueled with natural uranium oxide to provide 4,600 Mw(e) of electricity and 2 billion gallons of water per day. Cost estimates for construction and operation are also included.


Capital costs, fuel costs, and costs for operation and maintenance are discussed for power-desalination dual-purpose power plants.


A summary is given of the Geneva Conference papers on advanced reactor designs and concepts including nuclear superheated reactors, fast-breeder reactors, heavy-water reactors. Applications such as water desalination and nuclear space power units are also discussed.


The development of large single-purpose reactor-powered water plants is discussed. It was concluded that for a $10^9$-gpd plant, water would cost ~$900/1000 gal.

The disadvantages of dual-purpose plants include production of large blocks of power, limits to flexibility of plant location due to power transmission costs, lower plant efficiency under certain operating conditions, and higher costs than single-purpose plants. A reactor design is proposed in which brine temperature is limited to 100°F. The reactor can be either light-water-cooled and moderated with slightly enriched uranium fuel, or heavy-water cooled and moderated with natural or slightly enriched uranium fuel. Selected as basic design was an aluminum-clad natural UO$_2$ fuel, with D$_2$O as coolant and moderator. Multistage flash evaporator designs were studied and evaluated.


Dual-purpose nuclear desalting plants are considered in the light of fundamental and economic aspects. The effects of size and duality are discussed, and the cost of steam considered. It was concluded that in areas requiring both power and water, dual-purpose plants with ~$10^9$ gpd capacities can be designed for fixed rather than flexible product ratio and tailored to particular applications.


The role of nuclear desalination plants in solving the problem of agricultural water is discussed. Controlling factors, such as population growth, food requirements, and land and its use are discussed. The amount of water needed for food production is considered. Data on the cost of desalting are reviewed. It was concluded that, combined with improved agricultural techniques, nuclear desalting may add as little as 2.5 cents per day to the cost of man's food.

182 SEA-WATER DISTILLATION BY NUCLEAR POWER. Bethon, Henry E. Power, 194: No. 1, 82-3 (Jan. 1966).

A summary is presented on an economic study of a combined power-water desalination plant using a pressurized-water, heavy-water-cooled, breeder reactor fueled with natural-uranium dioxide. The plant capacity would be 50 Mw(e) and 6 million gallons per day.


The progress in a 50 million gallons per day nuclear desalination plant study is reviewed. Cost comparisons are made for five principal conversion processes, and fresh water production at a cost of 28 to 36 cents per 1000 gallons is predicted.


A survey is provided of reports on progress in the nuclear desalination program given at the Atomic Industrial Forum at San Francisco on Nov. 30, 1964. Major attention was paid to a large-scale nuclear desalting program that would provide regional water supply plants in the West. Such plants would produce about 500 to 700 mgd (Mgal/day) of water and have an electrical output of over 100 Mw. Best economic potential for these plants seems to reside in the heavy-water moderated organic-cooled reactor (HWOCR) and in the multi-staged flash distillation process (MSF). The first phase of this large-plant program has two objectives: to operate at least one intermediate-size prototype dual-purpose plant of about 50 Mw capacity; and to operate a prototype power-only HWOCR of about 1000 Mw capacity. These two objectives are scheduled to be achieved by 1970. In the second phase, a large-dual-purpose prototype plant would employ a nuclear-energy source. General recommendations call for expanded research and development efforts in all phases of the program, and an increase of...
$200 million in authorized expenditures through 1972. At present, the HWOCR concept is considered most promising for combination plants. Units up to 100,000 Mw are considered technically feasible at this time, and the reactor is the reactor in rotation. The heat energy from the reactor is transferred to the sea water by conduction causing the sea water to boil. The steam so produced is guided to a condenser. During the rotation of the reactor, the scraper blades remove deposits of salt resulting from the boiling of the sea water. The reactor is described for particular application to "floating fields" described in British Patent 1,038,329 and which would be maintained in an area, not necessarily far from the coastline, but at a sufficient distance not to provide any form of radiation hazard to inhabitants of the local area.


Use of nuclear and other forms of energy in desalination of seawater by various processes is examined. While fossil fuel costs vary widely from one location to another, nuclear fuel cycle costs are essentially unaffected by location. They are often somewhat lower than fossil fuel costs and will drop further as the scale of operations in the nuclear industry expands. However, nuclear steam-supply systems tend to cost more than fossil-fired units. Consequently, the most economical energy source can be selected only after thorough evaluation of the various options. Factors that apply to such an analysis include the size of the heat supply and the local cost of fuel delivered to the facility. Experience has shown that nuclear energy will tend to be economical in the larger plants and fossil fuel in smaller ones. Nuclear fuel cycle costs are heavily dependent on the size of the nuclear power industry. Future lower cost will result from increased volume of production and improved technology. It is shown that a nuclear fuel cycle cost of 144/million BTU is competitive with oil-gas fuel at 233/million BTU. A dual-purpose plant generating about 630 Mw (net) power and 150 million gal/day of desalinated water was considered.


The design, development, economic aspects, and use of nuclear reactors for desalination of seawater are reviewed. Results are summarized on reactor types used in studies of nine different electric generation-desalination cases.


The economics of dual-purpose plants are discussed, following a brief consideration of the technical feasibility of such plants.


A discussion concerning selection of the most economical method of providing desalinated water using currently demonstrated technologies is presented. It is concluded that the use of nuclear power to desalinate sea water appears to offer a feasible and potentially economic source of water for municipal areas and for agriculture where extensive transportation is not required.


**A NOTE ON A NEW METHOD OF COST ALLOCATION FOR COMBINED POWER AND WATER DESALINATION PLANTS.** Barnea, Joseph (Resources and Transport Division, United Nations, New York). Water Resources Research, 1: No. 1, p.143-8 (First Quarter 1965).

The cost allocation method described, which is for dual purposes or combined electricity water desalination plants, uses exclusively economic data. The method is based on the cost of power and water produced in single-purpose plants and on the application of the cost relationship for a given net output of water and power to the total annual cost of a combined plant.

**PATENTS**


A nuclear power station design is presented using a steam-powered system for circulating gas coolant. The steam is received at intermediate pressure from a reactor in rotation. The heat energy from the reactor is transferred to the sea water by conduction causing the sea water to boil. The steam so produced is guided to a condenser. During the rotation of the reactor, the scraper blades remove deposits of salt resulting from the boiling of the sea water. The reactor is described for particular application to "floating fields" described in British Patent 1,038,329 and which would be maintained in an area, not necessarily far from the coastline, but at a sufficient distance not to provide any form of radiation hazard to inhabitants of the local area.

**MISCELLANEOUS**


A study of the combination of reactors and distillation processes which will produce the lowest cost water is presented with emphasis on large-scale aspects of desalination. Graphite, heavy and light water heterogeneous reactors using natural or slightly enriched, aluminum-clad uranium fuel elements, combined with multiple-effect flash or evaporation distillation plants are studied. The heat combination of systems is determined to be a heavy water-moderated and cooled reactor combined with a seven-page long-tube-vertical multiple-effect evaporator. Plant costs and operating expenses and their effect on the cost of water produced are summarized.


The possibility of using the heat energy released in underground nuclear explosions for the desalination of sea water is examined. The conditions that may exist in systems where sea water is pumped into the heated zone created by an explosion and the heated water returned to the surface and then vaporized to give steam and solids...
are investigated. The economics of such systems are roughly estimated from AEC proposed charges for nuclear bombs and the costs for hot sea water delivered to the surface are found to be high.

196 **SALINE WATER DEMINERALIZATION AND NUCLEAR ENERGY IN THE CALIFORNIA WATER PLAN.** Koch, Albert A. California. Department of Water Resources. Division of Resources Planning. Bulletin 93. December 1960. Described are the various phases of the problems of nuclear energy and saline water conversion, as they apply to the water problems of the state of California. The present status of saline water conversion and its future possibilities indicate that it will cost at least two to five times more than development of natural water resources. The possible application of nuclear energy to sea water conversion and the production of electrical and mechanical power is discussed and it is indicated that nuclear energy will have a marked effect on the future development of the California Water Plan.


The economics of fresh water production based on the multistage flash evaporation of sea water is discussed for a single-purpose, 50 million gallon per day plant. The steam generator employed in a 370 Mw(t) pressurized light-water reactor. Based on current technology, the water costs are estimated at 38 to 42 cents per thousand gallons, with future costs predicted to be 24 to 31 cents per thousand gallons within the next decade.

200 **NUCLEAR APPLICATIONS TO SALINE WATER CONVERSION, ECONOMIC IMPLICATIONS.** A P A N E L D I S C U S S I O N . pp.1-16 of "Proceedings of the Tenth Anniversary Conference of the Atomic Industrial Forum," New York, Atomic Industrial Forum, 1964. The results of studies on the economics of nuclear desalination plants, particularly plants also producing electricity, are summarized, together with associated technological efforts. Cost estimates are given, including comparisons of conventional and nuclear systems.


A 21 Mw(t) reactor is studied for use in operating a multieffect, multistage flash distillation plant for the desalination of water. The nuclear plant is basically an upgraded research reactor using UO2 pressurized light-water reactor. Based on current technology, the water costs are estimated at 38 to 42 cents per thousand gallons, with future costs predicted to be 24 to 31 cents per thousand gallons within the next decade.

202 **USE OF NUCLEAR POWER FOR THE PRODUCTION OF FRESH WATER FROM SALT WATER.** HEARING BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY, CONGRESS OF THE UNITED STATES. Eighty-Eighth Congress, Second Session. August 18, 1964. $0.06(GPO).

Included in the Hearing are a year-by-year breakdown of funds appropriated to the Office of Saline Water, a compilation of plant, 147-52 of Saline Water by the Division of Resources Planning, Bulletin 93. December 1960. It is also investigated that the economics of desalination using conventional and nuclear energy, papers presented by AEC commissioner, James T. Ramsey at the Geneva Conference and the IAEA Panel Meeting on Nuclear Desalination, the report to the President on a "Program for Advancing Desalting Technology," and papers presented by the U.S.R. Delegation during its July 1964 visit to the United States.


The advantages of the reverse osmosis process are examined for the large scale purification of sea and brackish waters. Energy requirements and capital costs are compared for reverse osmosis and distillation plants, and their economy of operation using an 8300 MW(t) large, moderately, organic-cooled reactor as the heat source is examined. It is shown that the dual purpose reverse osmosis plants can yield much saleable electric power and produce a considerably greater quantity of water than can the distillation system under optimum conditions. In addition, the unit cost of water will be less for the reverse osmosis process.


Vapor at relatively low temperatures and pressures can be used in industrial plants (particularly the nuclear power industry). The economics of fresh water production based on the dual purpose, 50 million gallon per day plant. The steam generator employed in a 370 Mw(t) pressurized light-water reactor. Based on current technology, the water costs are estimated at 38 to 42 cents per thousand gallons, with future costs predicted to be 24 to 31 cents per thousand gallons within the next decade.


Needs for desalination, the systems used, the proposed utilization of nuclear reactors for this purpose, and the principles of the multi-flash evaporation system are reviewed, and the coupling of reactors and desalination is discussed. In the coupling of nuclear reactors and desalination, various problems are presented. The use of a reactor for water alone or for the simultaneous production of electrical energy and vapor and of organic reactors for production of heat at low temperatures, preliminary results in a design study of this type of reactor are presented.


An economic comparison was made of water and organic nuclear reactors for the simultaneous production of electrical energy and vapor and of organic reactors for vapor production and of water reactors for the simultaneous production of electrical energy and vapor. The water reactors considered were the PWR and the BWR. The reactor showed that the dual-purpose organic reactors could be competitive with the water reactors for powers of the order of 150 Mw(t). At 1700 Mw(t) however the two reactors would be competitive.

The reference design selected in a joint United States-Israel study of a dual-purpose power-desalination plant is described. The plant complex consists of a light water reactor, a back pressure turbine, and a multi-stage flash evaporator with capacities of 200 MW(e) and 100 million gallons of water per day. Engineering and economic aspects of the plant are discussed and a proposed development schedule is presented.


A brief review is given on various methods for desalination of saline waters. The use of hydrophobic coolants, intensification heat exchange by film formation by means of stationary column packing, removal of scum-forming salts by sorption on resins, followed by regeneration of the resins from the evaporators are described. The performance of nuclear reactors for desalination and production of electricity is also discussed.


Topical volume: AID financing of reactors, air pollution, breeder reactors, coal use, competition in nuclear industry, cost of coal-fired power, costs of nuclear power, desalination, education in the nuclear field, fast breeder reactors, fast reactor fuel tests, foreign sales, fuel cycle, fuel cycle guarantees, fuel inventory cost, reprocessing fuels, gas-cooled breeder reactors, nuclear power growth, heavy water organic reactors, design improvements in nonbreeder reactors, nuclear ships, indemnity legislation, isotope uses in industry, licensing, Long Island reactor proposal, maritime reactors, national laboratories, oceanographic programs, nuclear fuel cycles, operating contract award policy, plutonium, the plutonium recycle reactor, fabrication of pressure vessels, nuclear weapon proliferation, submarine propulsion by radioisotopes, regulatory jurisdiction, reliability of nuclear power, safeguards agreements and inspection, seed blanket reactor, siting, sodium component development, sodium pump test facility, steam-cooled breeder reactors, supercritical reactors, superheat reactors, toll enrichment, and uranium conversion to hexafluoride.


A detailed summary is presented of the 1964 desalting operations of the Department of the Interior. Research, processes, and demonstration plants are covered.


Eight papers presented at the symposium are given. Topics covered include: Application of ion exchange for conversion of saline water into fresh water, sea and brackish water desalting in Japan, developments in obtaining fresh water from seawater in Germany, British activities in desalination development and research, desalination research in Italy, the state of desalination research in Israel, evolution of the distillation process for seawater conversion, and the role of the United Nations Department of Economic and Social Affairs in the field of water desalination.


From American Chemical Society, Detroit.

It is pointed out that reverse osmosis can be used in conjunction with a nuclear reactor to yield at least as much electrical power and, at the same time, produce a considerably greater quantity of water in a desalting plant than the distillation system under optimum conditions.


From 1st International Symposium on Water Desalination, Washington, D. C.

The general conditions and reasons for which lower fresh water costs may be expected with the nuclear-dual purpose plants than fossil fueled plants are presented. A determination method is developed by means of the energy concept to allow the accomplishment of an equitable cost breakdown in a dual-purpose plant based on the design data of the plant itself, independent of cost comparisons with reference plants or market conditions. The economics of nuclear-fueled single-purpose desalting plants is discussed.


From 1st International Symposium on Water Desalination, Washington, D. C.

The principles involved in the optimization of nuclear dual-purpose power-water plants are discussed assuming only modest advances in reactor and flash distillation plant technology. Comparisons between reactor types as sources of heat and economic considerations are examined.


From 1st International Symposium on Water Desalination, Washington, D. C.

A model of a dual purpose power/desalination nuclear plant is described and used to simulate operation for a variety of control systems and disturbances in the operating conditions. A comparison of the dynamic behavior of the plant to nuclear single-purpose plants indicates the model is in working order.
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