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Desalination Economic Evaluation Program (DEEP)

User's Manual

INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 2000

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DESALINATION ECONOMIC EVALUATION PROGRAM (DEEP)
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FOREWORD

The scarcity of fresh water, and especially potable water, is jeopardizing life in many regions of the world. Seawater desalination offers a promising option for the supply of potable water. Seawater desalination is an energy intensive process and nuclear energy is a promising candidate as an energy source.

The increasingly severe worldwide problems in water shortage have given a new momentum to nuclear desalination studies. In this context, the IAEA has been carrying out since 1989 an active programme in the investigation of nuclear desalination.

The software DEEP (formerly called "Cogeneration and Desalination Economic Evaluation" Spreadsheet, CDEE) has originally been developed under contract by General Atomics (USA), and has been used in several studies published by the IAEA. For further confidence in the software, it was validated in March 1998. After that, a user friendly version was issued under the name of DEEP 1.0 in 1998. In March 2000, a new, updated version of DEEP was issued as Version 2.0, for which the present manual was compiled.

Until March 2000, DEEP has been distributed to some 30 Member States of the IAEA. DEEP is available upon request as a CD-ROM version from the IAEA. In order to use the software, a license agreement with the IAEA needs to be established.

The manual was compiled by K. Wagner (Sections 1, 2, 4, 7 and Annex) and by G. Woite (Sections 3, 5 and 6). The IAEA officer responsible for the manual is P. Gowin of the Division of Nuclear Power.

EDITORIAL NOTE

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1. GENERAL DESCRIPTION OF DEEP

DEEP (formerly named "Co-generation and Desalination Economic Evaluation" Spreadsheet, CDEE) has been developed originally by General Atomics under contract, and has been used in the IAEA's feasibility studies. For further confidence in the software, it was validated in March 1998. After that, a user friendly version has been issued under the name of DEEP at the end of 1998.

DEEP output includes the levelised cost of water and power, a breakdown of cost components, energy consumption and net saleable power for each selected option. Specific power plants can be modelled by adjustment of input data including design power, power cycle parameters and costs.

1.1. PURPOSE AND USE OF THE SPREADSHEET METHODOLOGY

The Spreadsheet Methodology for Co-generation/Desalination Economic Evaluation is suitable for economic evaluations and screening analyses of various desalination and energy source options for several reasons.

First, using spreadsheets is a commonly adopted way to cope with quite large calculations. These calculations include in the case of DEEP simplified models of several types of nuclear/fossil power plants, nuclear/fossil heat sources, and both distillation and membrane desalination plants. Current cost and performance data have already been incorporated so that the spreadsheet can be quickly adapted to analyse a large variety of options with very little new input data required. The spreadsheet output includes the levelised cost of water and power, breakdowns of cost components, energy consumption and net saleable power for each selected option. Specific power plants can be modelled by adjustment of input data including design power, power cycle parameters and costs.

Second, spreadsheet programs are widespread and they run on every modern personal computer. For user interface, implementation of the VBA for Excel was used (VBA means Visual Basic for Applications and it is incorporated into the Excel environment). Excel is one of the most frequent spreadsheet programs used all over the world.

Last but not least, the spreadsheet enables to annotate the calculations in place and create self-explaining tables so that methodology used in DEEP may be commented directly in the spreadsheet.

DEEP serves three important goals:

1. It enables side-by-side comparison of a large number of design alternatives on a consistent basis with common assumptions.
2. It enables identification of the lowest cost options for providing specified quantities of desalinated water and/or power at a given location.
3. It gives an approximate cost of desalinated water and power as a function of quantity and site specific parameters including temperatures and salinity.

However, the user is cautioned that the spreadsheet is based on simplified models. For planning an actual project, final assessment of project costs should be assessed more accurately based on sub-stantive information including project design and specific vendor data.

1.2. SOFTWARE AND PLATFORM REQUIREMENTS

DEEP is built around standard Excel files and it needs the PC with Windows with installed Excel program. DEEP was developed for these versions of software:

Operating system:	**Microsoft Windows 95/98** or **Microsoft Windows NT 4.0**
Application:	**Microsoft Excel 97**

With respect to present common PC configurations, the HW requirements are not critical. Everything with Windows 98 conforms. Typical configurations for office works should be sufficient.

During the testing of the DEEP, one installation was also made on a 486/66 MHz machine. It has been observed that the responses to some commands were rather slow in this case.

1.3. DEEP HISTORY

Since 1989, the IAEA has re-established activities on seawater desalination, which it had abandoned for more than a decade. It has been engaged in a number of separate investigations on the use of nuclear and fossil energy for the desalination of seawater. In 1990, the IAEA published a report [1], which assessed the need for desalination based on analyses performed in the late eighties of the world's potable water resources and information published during the last decade on the most promising desalination processes and energy sources, including nuclear systems proposed by potential suppliers. During 1991/1992, a generic investigation was conducted on the technical approach and the comparative cost for utilising nuclear energy with various state-of-the-art desalination technologies. Findings from this investigation are presented in [2]. An essential outcome was the development of a convenient methodology for rapidly calculating performance and costs of power and water production for various power and desalination plant couplings. The methodology has been imbedded in a spreadsheet routine. It contained simplified sizing and cost algorithms that were easy to implement, generally applicable to a variety of equipment and representative of state-of-the-art technologies.

Between 1992 and 1994, the IAEA provided assistance to North African countries (Algeria, Egypt, the Libyan Arab Jamahiriya, Morocco and Tunisia) to investigate site specific applications of nuclear energy for desalination. During this investigation, the spreadsheet methodology was substantially improved to include the capability to model many types of nuclear/fossil electric power and heat sources of varying sizes depending on site specific demands. The methodology was unique in that it was a collaborative effort by international experts in the fields of nuclear energy and desalination. It embodied the basic technical and economic principles of power and desalination plant performance and could quickly be adapted to any site condition. The results of this study were released by the IAEA in the form of a report [3] in November 1996. This report contains an assessment of the regional specific aspects, the available technical options with respect to desalination processes and energy sources, the cost evaluation of various technical option for the production of desalted water, as well as the financial constraints and options, and finally the necessary steps to ensure the successful implementation of a nuclear desalination programme.

With endorsements at the general Conference in its 1994 session, an options identification programme of two years duration was initiated to identify and define a set of practical options for demonstration of seawater desalination, in which the methodology was used to estimated the cost of power and water for nuclear desalination. Some improvements and additional features were implemented to consider site specific conditions and to widen the field of application. The results were presented in Ref. [4] in August 1996.

Consequently, the methodology was envisioned as a useful tool for any institution, which desires to investigate the feasibility of desalination at specific sites, with energy supplied as either heat or electric power from a nuclear, fossil or renewable energy source or from the power grid.

An essential outcome of the IAEA’s studies was the development of a methodology for preliminary economic evaluation and comparison of various energy source options to be coupled with different seawater desalination processes [5]. The methodology, which includes cost and performance models of several types of nuclear and fossil energy sources as well as seawater desalination processes, was imbedded in a spreadsheet routine and published by the IAEA in April 1997. Since that time many changes and improvements have been made in the Excel code and this new updated version of the CDEE/DEEP manual became a necessity.

1.4. IMPROVEMENTS OF CDEE INCORPORATED IN DEEP

The improvements of the old CDEE spreadsheet incorporated in DEEP are the following:

- **MSF Performance Model:** A new equation has been derived and implemented in DEEP to calculate the GOR as a function of the overall water plant working temperature of the MSF plant.
- **MED Performance Model:** The technical development of commercially available MED plants, especially high temperature vertical tube evaporators (HT-VTE), was tremendous within the last years. The main reasons are found in the improvements in heat transfer coefficients, the use of cheaper tube and shell materials — especially in the upper temperature effects — and the increasing unit size. Higher thermodynamic efficiencies at lower investment costs have been the consequences. To cover this technical development, a new model to estimate the GOR of MED plants has been incorporated in DEEP.
- **RO Performance Models:** The membrane performance of RO modules such as salt rejection, permeate product flow and membrane compaction resistance could be improved tremendously within the last years, so that the performance models incorporated in old CDEE are not representing the state-of-the-art. To cover the improvements, new performance models have been established covering both the effect of seawater salinity and the effect of seawater temperature. The new models are based on sample calculations performed with original simulation programs of membrane manufactures.
- **Extraction/Condensing Turbine Model:** In the old CDEE version, only a backpressure turbine model was included for the coupling of distillation plants with steam power plants. For this coupling arrangement, the GOR of the distillation plant is already fixed by the required water production capacity and the type and size of the power plant chosen. To allow DEEP the coupling of distillation plants with different GORs for an identical water plant capacity, a steam extraction/condensing turbine model has been added.
- **Gas Turbine Model:** The old version of CDEE did not comprise a technical performance model for gas turbines. The user had to specify the required input data such as gross power output, gross thermal efficiency and exhaust gas temperature himself. The specification of the input data, in particular the adjustment to site specific conditions, required detailed experience in gas turbine technology which could not be expected by the user of CDEE. To facilitate the use of the spreadsheet, a model was added which includes the large influence of the air inlet temperature on the gas turbine performance. In the new version, the extrapolated equation of the gas turbine design was incorporated. To calculate the site specific performance data, the user has to specify merely the site specific air inlet temperature. DEEP calculates then the site specific gross output and the site specific exhaust gas temperature. If the size of the gas turbine does not fulfil the site specific energy requirements, the user can alternatively increase the number of gas turbine units or change the reference gross output of the gas turbine. DEEP adjusts the site specific gross output to the new input data.
- **Combined Cycle Model:** The combined cycle model of the old CDEE version has been reconstructed. The steam cycle comprises a dual pressure cycle with single-flow HP and single-flow LP section. The user can specify a reference gross output. The gross outputs of gas turbine and steam turbine are then calculated according to the output ratio of the reference combined cycle. In this way, the size of the steam turbine always fits to the size of the gas turbine. Furthermore, the user can specify the site specific air inlet temperature as well as the site specific condensing temperature. DEEP adjusts the technical performance data to the site specific conditions in applying both the gas turbine model and the condensing steam turbine model. The heat recovered in the HRSG and transferred to the steam cycle is adjusted to the site specific exhaust gas temperature and exhaust mass flow rate of the gas turbine. The coupling of distillation plant units with the combined cycle plant is performed by the steam extraction/condensing turbine.
- **Others:** The new performance models introduced above have been incorporated in DEEP, causing some minor changes in the remaining models. For the energy options ‘Nuclear Heat Reactor’ and ‘Fossil Boiler’, a new macro was developed and incorporated in DEEP to calculate the minimal maximum brine temperature. That means, for no energy option users

have to iterate the required maximum brine temperature of the distillation plant on their own as it was in the old CDEE version; instead, they are guided by DEEP suggesting suitable values. For the energy options ‘Diesel’ and ‘GTMHR’, only RO desalination options are foreseen for the time being.

1.5. DEEP VALIDATION PROCESS

As already mentioned, the user is cautioned that the DEEP spreadsheet is based on simplified models. The production costs achieved are approximated values which should give decision makers contemplating a nuclear desalination project a first indication to start a more thoroughly examination. For planning an actual project, final assessment of project costs should be assessed more accurately based on substantive information including project design and specific vendor data.

Nevertheless, the results of DEEP should be as accurate as possible. To get better confidence about the quality of the output data, a programme was implemented in 1997 by the IAEA to validate CDEE[1], which includes the following three steps:

(a) to perform a survey of computer codes for the evaluation of energy sources, desalination plants and coupling devices which could be used for validation,

(b) to perform a survey of design, cost and operational data of seawater desalination plants in operation or in study, and

(c) to perform benchmark calculations to compare the results obtained in (a) and (b) with the results of sample calculations achieved with CDEE taken the same plants and input data as a basis.

However, neither computer codes nor data of projects covering the same diversified scope of evaluation options as CDEE do and applying the same economic comparison methodology could be identified. Therefore, CDEE was divided in separate subroutines, which have to be analysed individually. For each subroutine, computer codes as well as performance and cost data have been collected. Another outcome of the surveys was that some improvements and modifications in CDEE should be performed before initiating benchmark calculations. These improvements should cover new performance models which consider the tremendous technical development in desalination technology within the last few years and which allows CDEE to cover a broader range of evaluation options.

1.6. SCOPE OF DEEP AND OF THE USER’S MANUAL

This manual is designed to facilitate workshops and provide the user with clear instructions for proper use and interpretation of the spreadsheet methodology and to provide documentation of the methodology and calculation algorithms. It is a new version of a previous manual [5] updated with respect to changes made both in the performance and cost calculation and in the user friendly interface.

The use of the manual is limited to the types of power or heating plants, desalination processes and coupling models described. These coupling combinations are modelled for meeting the World Health Organization drinking water standards. The methodology focuses on plants larger than 100 000 m^3/d. However, modifications and changes can be easily made using the description contained in Section 7 of this manual.

The DEEP main calculation sheet supports both nuclear and fossil power options, it considers heating and power plants as well as heat-only plants, distillation processes of MSF and MED and membrane process of reverse osmosis. A part of the DEEP installation is a couple of validated reference cases. In these reference cases (RC) the following power options are used:

[1] The validation procedure was performed before CDEE was made more user friendly and renamed DEEP.

RC	Energy source	Abbreviation	Description	Plant type
1	Nuclear	PWR	Pressurised light water reactor	Co-generation plant
2	Nuclear	PHWR	Pressurised heavy water reactor	Co-generation plant
3	Fossil–coal	SSBC	Superheated steam boiler	Co-generation plant
5	Fossil–oil/gas	SSBOG	Superheated steam boiler	Co-generation plant
6	Fossil	GT	Open cycle gas turbine	Co-generation plant
7	Fossil	CC	Combined cycle	Co-generation plant
8	Nuclear	HR	Heat reactor (steam or hot water)	Heat-only plant
9	Fossil	B	Boiler (steam or hot water)	Heat-only plant
10	Nuclear	GTMHR	Gas turbine modular helium reactor	Power plant
11	Fossil	D	Diesel	Power plant
12	Nuclear	SPWR	Small PWR	Co-generation plant

For each of above listed cases the performance and economic evaluation is made automatically for four desalination technology combinations if applicable. These options are:

Process	Abbreviation	Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

1.7. GENERAL SOFTWARE STRUCTURE

From the general point of view, DEEP is a software tool built on the basis of Visual Basic for Excel. This tool separates the performance and cost calculations called "case" on one side and the support for data input and change and output presentation on the other side. As a by-product, the interface between these two parts is defined so that the future development of the whole package may be performed by independent developers and new cases might be easily incorporated into DEEP.

DEEP supports the user when working with a single case, changing input data and browsing in the output sheets as well as when comparing variations with different input parameters. DEEP is focused on the typical user without much knowledge on technical features of the model used for evaluation.

DEEP package consists of several parts, which are implemented as EXCEL files.

Case file:

The desalination technology performance and economic evaluation calculations are made inside a case EXCEL file that is completely taken from previous versions of CDEE.

The "Sample Case.xls" is provided for the user's convenience and is placed in the directory of C:\My DEEP Documents\Cases. In this directory a subdirectory Reference Cases does exist where several reference cases developed in the past and validated by the IAEA are stored. In this directory of C:\ My DEEP Documents\Cases user defined (generated) cases will be stored later (default option). The user can group cases into projects. The names of these projects may be identical with names of directories, e.g.
C:\My DEEP Documents\Project Name 1

Comparative Presentation (CP) file:

The user is offered a new feature — Comparative Presentation. The user can select several cases and a comparison table is made automatically based on the selected cases. This table is then stored as a usual EXCEL file with one worksheet. This sheet is named "CP" and it contains a table with certain values from selected cases. The file "Sample CP.xls" is provided for the user's convenience and is placed in the directory of C:\My DEEP Documents\CPs. Here will be other user defined (generated) Comparative Presentations stored later.

Control file:

The third type of EXCEL files used in DEEP package is a single copy of "Deep.xls" stored in the directory of C:\Program Files\Deep20 (where 20 means the DEEP Version 2.0). This file contains the user friendly interface, which helps the user to work more comfortably. It helps the user to create and maintain Comparative Presentations. Both user types of EXCEL files — "Calc" and "CP" sheets — are inside Deep.xls provided with set of predefined graphs, which are updated, according values in the selected cases. There are several menu items in the "DEEP" menu bar offering plenty of printing possibilities. More details on commands, which make easy to the user to work with DEEP, are given in Section 4 below.

New cases are generated using the knowledge basis stored in two directories of C:\Program Files\Deep20\Energy and C:\Program Files\Deep20\Desalination, where are placed parts of the Reference Cases relevant either to different energy plant sources or to different desalination options. Using the **New case** command the user first creates (composes) coupling of the selected energy source and the selected desalination plant. Then a first case of such a desalination plant is generated. After that the user can easily generate many cases based on one of the reference cases, which differs only in input data values simply by using the **New case by modification** command.

The main design principle used for developing DEEP was to keep all EXCEL functions available for the user and to leave the basic calculation spreadsheet open for user changes. Despite of this freedom the user has to follow some rules to work effectively with DEEP. User friendliness for most of the users poses a certain burden on the Excel advanced user who has to make his (model) changes within a predefined Excel environment.

2. INSTALLATION OF DEEP

The installation is a very simple and straightforward procedure. The DEEP package is distributed on the CD-ROM. The basic prerequisites are as described in Section 1.2:

Operating system: **Microsoft Windows 95/98** or **Microsoft Windows NT 4.0**
Application: **Microsoft Excel 97**

There is another requirement for the printer driver to be already installed in the Windows environment before the DEEP installation starts (which is the usual case, the printer has not be connected to the personal computer physically).

Then the installation may be performed manually by copying the two directories mentioned in Section 1.7:

D:\My DEEP Documents

and

D:\Program Files

from the CD-ROM to the computer on drive ***C:*** (there is no rule against installation on another drive; in such a case only a simple change of drive letter suffices inside the DEEP.xls has to be made on certain places). It is recommended to use *File Manager* or *File Explorer* to drag the directory '***Program Files'*** from the CD-ROM into the '***C:***' (root) directory in the computer. After that, files from the CD-ROM are copied to the directory of ***C:\Program Files\Deep***. You can also drag the above mentioned directories from an open root directory of the CD-ROM to the C drive icon or to the open root directory of the C drive. With this copying done the DEEP is ready to be used.

Users can naturally enjoy the advantage of automatic installation procedure. Then they have to run the file Setup. This may be done very easily by double clicking on this file's icon. Then all the copying is made automatically.

After installation the user can make a shortcut for DEEP on his screen simply by dragging the file DEEP.XLS from directory ***C:\Program Files\Deep*** into the free surface of the screen. You can drag this file DEEP.XLS or the shortcut icon into Start button to have DEEP in the Start menu. With this last step the installation process is finished and DEEP is ready to be used.

Note: If the user's Excel application prompts for making macros enabled or disabled, the user has to enable macros both for DEEP.XLS and Setup.XLS, otherwise the code of both files will not be executed and both the DEEP installation and application will not run.

Possible installation problems:

The appearance of the DEEP logo might look strange. The cause is probably in insufficiency of colour capacity of screen graphic of the user's PC. The logo image is stored in 16 bit h*igh colour* system. This misbehaviour has no impact on other DEEP functions, especially the calculations are not damaged. Microsoft Excel is widely used for solving many tasks. In a few cases, it was observed that the settings of certain constants inside the DEEP were insufficient to cope with settings of the actual Excel installation. In such a case, users are kindly requested to report this problem to the person they have received DEEP from. The detailed description of all circumstances (especially the information about other applications that use Excel and/or change Excel settings) is needed as a prerequisite for the successful solution.

3. TECHNOLOGIES COVERED BY DEEP

3.1. GENERAL

Every desalination process requires energy. The heat energy required for distillation can be extracted from the steam cycle of a fossil fired or nuclear power plant, from a heating plant or from suitable waste heat sources. Electricity, which is required for all desalination processes, can be taken from a power plant or from the electrical grid. DEEP is designed to calculate these energy inputs and the water (and electricity, if applicable) production costs (Fig. 1).

The energy conversion and water desalination technologies are described here as far as necessary for the user for preparing input data, basically understanding the calculations, and interpreting the results of DEEP. Reference is made to [6] for more extensive descriptions.

Technologies

- Desalination processes
- Power plants, in particular the low pressure (LP) turbine cycle
- Heating plants
- Coupling devices and arrangements.

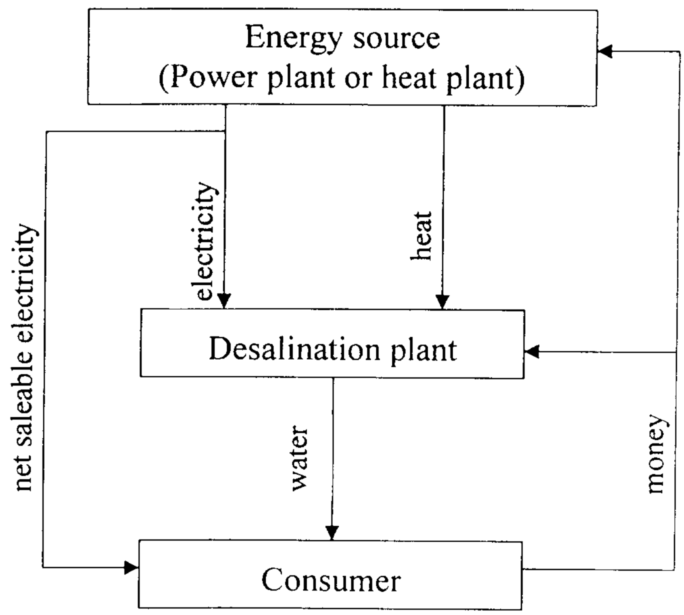


Fig. 1. Energy, water and money flow scheme.

3.2. DESALINATION PROCESSES

The desalination processes included in DEEP are summarised in Table I.

TABLE I. DESALINATION PROCESSES CONTAINED IN THE SPREADSHEET

Process	Abbreviation	Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

Distillation

In distillation processes, seawater is heated to evaporate pure vapour that is subsequently condensed. The heat energy required for distillation is usually supplied as low pressure saturated steam, which may be extracted from the exhaust of a back pressure turbine, from a crossover steam duct or from a heating plant (boiler or heat reactor).

It is important which amount and quality of low grade steam is required and available to produce the required amount of water. The amount and quality of steam required depends on the sea water temperature, the maximum brine temperature and the type, design and performance of the distillation plant. Usually, the thermodynamic efficiency of distillation plants is expressed in kg of water produced per kg of steam used. This ratio is called the gain–output ratio (GOR), which is in the range of 6 to 10 for current commercial multi-stage flash (MSF) distillation plants and up to 20 for multi-effect distillation (MED) plants. However, the GOR does not account for the steam temperature and therefore does not assign a thermodynamic value to the steam. Thus, comparing different distillation plants by means of the GOR is only useful if the temperature difference between the heating steam and the seawater is the same. A distillation plant with a GOR of 8 requiring steam of 70°C, for instance, is thermodynamically superior to a distillation plant with the same GOR but requiring steam of 120°C.

3.2.1. Multi-stage flash (MSF) distillation

Figure 2 shows the schematic flow diagram of an MSF system.

Seawater feed passes through tubes in each evaporation stage where it is progressively heated. Final seawater heating occurs in the brine heater by the heat source. Subsequently, the heated brine flows through nozzles into the first stage, which is maintained at a pressure slightly lower than the saturation pressure of the incoming stream. As a result, a small fraction of the brine flashes forming pure steam. The heat to flash the vapour comes from cooling of the remaining brine flow, which lowers the brine temperature. Subsequently, the produced vapour passes through a mesh demister in the upper chamber of the evaporation stage where it condenses on the outside of the condensing brine tubes and is collected in a distillate tray. The heat transferred by the condensation warms the incoming seawater feed as it passes through that stage. The remaining brine passes successively through all the stages at progressively lower pressures, where the process is repeated. The hot distillate flows as well from stage to stage and cools itself by flashing a portion into steam which is re-condensed on the outside of the tube bundles.

MSF plants need pre-treatment of the seawater to avoid scaling by adding acid or advanced scale inhibiting chemicals. If low cost materials are used for construction of the evaporators, a separate deaerator is to be installed. The vent gases from the deaeration together with any non-condensable gases released during the flashing process are removed by steam–jet ejectors and discharged to the atmosphere.

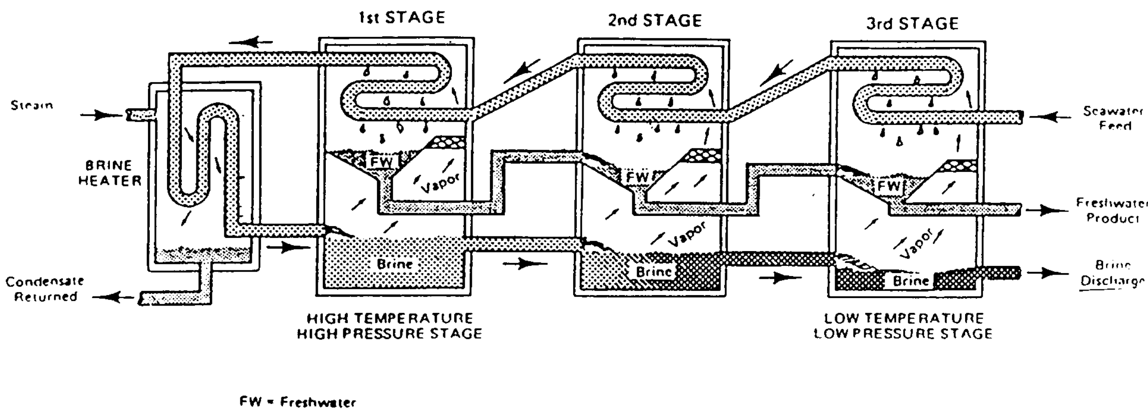


Fig. 2. Schematic flow diagram of an MSF system.

In each evaporation stage, there are temperature losses, which reduce the temperature difference between incoming seawater feed and brine to an effective temperature difference $\Delta\vartheta_i$, resulting in higher thermal energy consumption. The temperature losses consist of three components:

- boiling point elevation (BPE) of saline water in contrast to pure water, $\Delta\vartheta_{BPE}$ (0.5–1.2°C according to the operating point of the MSF plant and seawater salinity),
- non-equilibrium temperature loss (NEL) $\Delta\vartheta_{NEL}$, which is caused by thermal and hydrodynamic effects like insufficient time for the superheated brine to evaporate completely, or a greater total static head (vapour plus liquid) on the brine near the bottom of the stage in contrast to the surface (0.2–1.0°C),
- temperature losses as a result of pressure losses of vapour while streaming across the demister and around the tube bundles, $\Delta\vartheta_{RV}$ (<0.2°C).

There are to two principal arrangements used in MSF systems: the brine recycle mode (MSF-BR), and the once-through mode (MSF-OT). The majority of the MSF plants built use the brine recycle mode. The brine recycle mode was invented in the early years of desalination when seawater corrosion resistant materials and advanced additives were not available or too expensive. In brine recycle systems, the heat of condensation of vapour, produced in the last stages (heat rejection section) is taken by cooling water, a major part of which is rejected back to the sea. Only a small part (about 2.5 times the amount of the product water) is deaerated and chemically treated against scaling, and is fed as make-up water to the subsequent stages. The required amount of feedwater to produce a certain amount of potable water is recirculated and kept below a maximum salinity by constantly removing a certain amount of brine blowdown and adding make-up water. In this way, the amount of acid chemicals against scaling can be reduced, and carbon steel with a high corrosion allowance can be used due to the absence of oxygen in the make-up water.

Today, corrosion resistant materials are available at reasonable costs as well as high temperature, cost effective antiscalants. Therefore, MSF-OT systems, in which the feedwater is directly taken from the sea without brine recycling, have already successfully been applied. In MSF systems, the deaeration of the feedwater occurs in the first stage, and additives are injected before the feedwater enters the plant.

The main advantages of MSF-OT systems over MSF-BR systems are:

- savings of equipment (pumps, valves and other armatures) and of pumping energy because of leaving out the brine recycle loop and the heat rejection section,

- savings in heat transfer area and/or thermal energy consumption because of the lower boiling point elevation in each stage (lower salinity of the flashing brine),
- reduced risk of calcium sulphate scaling due to the lower salt concentration levels, which also permits a higher maximum brine temperature.

Today, MSF plants have reached a mature and reliable stage of development. Unit sizes up to 60 000 m^3/d have been built. The thermal heat and electricity consumption is in the range of 45 to 120 kW(th)·h/m^3 and 3.0 to 6.0 kW(e)·h/m^3 respectively. Expressed in exergy units (kW·h/m^3), the total consumption is in the range of 15 to 24 kW·h/m^3. Using polymeric anti-scaling additives, the maximum brine temperature is limited to 120°C for MSF-BR systems and 135°C for MSF-OT systems due to scaling problems.

3.2.2. Multi-effect distillation (MED)

The MED process is the oldest large scale distillation process. From the thermodynamic point of view, MED processes are superior to MSF processes since they can achieve a higher GOR than MSF processes with identical heat transfer area and the same temperature difference between heat source and cooling water sink. In spite of this superiority, the MED process could not compete with the MSF process in the past. The main reasons for this may be traced to the components and materials used, as well as the lack of experience in large scale MED plant operation.

Figure 3 shows the schematic flow diagram of MED process using horizontal tube evaporators. In each effect, heat is transferred from the condensing water vapour on one side of the tube bundles to the evaporating brine on the other side of the tubes. This process is repeated successively in each of the effects at progressively lower pressure and temperature, driven by the water vapour from the preceding effect. In the last effect at the lowest pressure and temperature the water vapour condenses in the heat rejection heat exchanger, which is cooled by incoming seawater. The condensed distillate is collected from each effect. Some of the heat in the distillate may be recovered by flash evaporation to a lower pressure. As a heat source, low pressure saturated steam is used, which is supplied by steam boilers or dual purpose plants (co-generation of electricity and steam).

According to the direction of vapour and brine flow, there are “forward feed” and “backward feed” arrangements. In forward feed MED plants, vapour and brine move through the evaporators as parallel flows from the first high pressure evaporator to the last low pressure one (see Figure 3). The pre-heating of feedwater occurs in separate heat exchangers. In backward feed MED plants, vapour and brine move through the evaporators in opposite directions, whereby separate feedwater preheating is eliminated.

Currently, MED processes with the highest technical and economic potential are the low temperature horizontal tube multi-effect process (LT-HTME) and the vertical tube evaporation process (VTE).

The main differences between LT-HTME plants and VTE plants are in the arrangement of the evaporation tubes, the side of the tube where the evaporation takes place and the evaporation tube materials used. In LT-HTME plants, evaporation tubes are arranged horizontally and evaporation occurs by spraying the brine over the outside of the horizontal tubes creating a thin film from which steam evaporates. In VTE plants, evaporation takes place inside vertical tubes. Furthermore, in LT-HTME plants the maximum brine temperature is limited to 70°C, since low cost materials such as aluminium for heat exchanger and carbon steel as shell material are used.

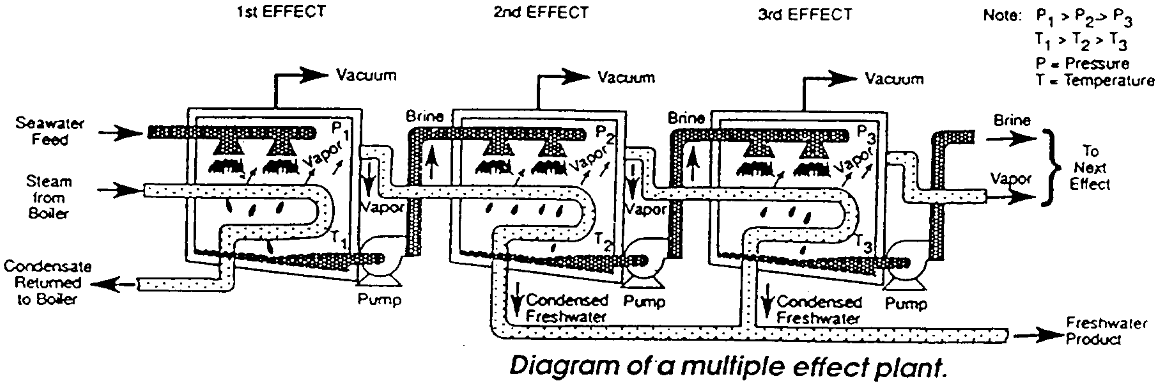


Fig. 3. Schematic flow diagram of an LT-HTME plant.

MED plants have a much more efficient evaporation heat transfer process than MSF plants. Due to the thin film evaporation of brine on one side of the tubes and the condensation of vapour on the other side, high heat transfer coefficients are achieved. Consequently, the number of effects for a certain temperature difference between heat source and cooling water sink can be increased in comparison to MSF plants, thus decreasing the specific heat consumption.

The pre-treatment of seawater for MED plants is similar to that in MSF plants. In general, polyphosphate is introduced into the seawater feed to prevent calcium carbonate scale formation on the heat transfer tubes. A steam jet-ejector vacuum system is used to remove vent gases from the deaerator and non-condensable gases evolving during evaporation from the system. Some LT-HTME designs need a more stringent filtration of the seawater feed, as a result of the small nominal diameters of the brine distribution devices, which do not permit the presence of relatively large suspended particles in seawater.

Table II shows some technical data of typical commercial MED plants.

TABLE II. TECHNICAL DATA OF MED PLANTS (WITHOUT VAPOUR COMPRESSION)

Physical quantity	Unit	LT-HTME	VTE
Maximum brine temperature	°C	70*	135
GOR	1	4–13.5	4–21
Number of effects	1	5–18	5–28
Thermal heat consumption	kW(th)·h/m^3	48–160	25–160
Electricity consumption	kW(e)·h/m^3	1.2–3.5	0.9–4.5
Total exergy consumption**	kW·h/m^3	9–14	9–14

*since low cost materials are used.
**supplied with low pressure saturated steam of power plants.

MED plants with vapour compression (VC)

In some MED designs, a part of the vapour produced in the last effect is compressed to a higher temperature level so that the energy efficiency of the MED plant can be improved (vapour compression). To compress the vapour, mechanical compressors (isentropic efficiency: about 80%) or steam-jet ejectors (isentropic efficiency: less than 20%) are employed. These designs, however, are usually applied in some stand-alone plants but not in integrated plants for electricity and potable water production.

3.2.3. Reverse osmosis (RO)

Reverse osmosis is a membrane separation process in which pure water is "forced" out of a concentrated saline solution by flowing through a membrane at a high static transmembrane pressure difference. This pressure difference must be higher than the osmotic pressure between the solution and the pure water. In practice, seawater has to be compressed up to 70–80 bar since its osmotic pressure is about 60 bar, whereas the osmotic pressure of the permeate is negligible.

The saline feed is pumped into a closed vessel where it is pressurised against the membrane. As a portion of the water passes through the membrane, the salt content in the remaining brine increases. At the same time, a portion of this brine is discharged without passing through the membrane.

RO membranes are made in a variety of modular configurations. Two of the commercially successful configurations are spiral-wound modules and hollow fibre modules. In both of these configurations, module elements are serially connected in pressure vessels (up to 7 in spiral wound modules and up to 2 in hollow fibre modules).

A spiral wound module element consists of two membrane sheets supported by a grooved or porous support sheet. The support sheet provides the pressure support for the membrane sheets as well as providing the flow path for the product water. Each sheet is sealed along three of its edges, and the fourth edge is attached to a central product discharge tube. A plastic spacer sheet is located on each side of the membrane assembly sheets, and the spacer sheets provide the flow channels for the feed flow. The entire assembly is then spirally wrapped around the central discharge tube forming a compact RO module element.

The recovery ratio (permeate flow rate divided by the feed flow rate) of spiral wound module elements is very low so that up to 7 elements are arranged in one module to get a higher overall recovery ratio. Spiral wound membranes have a simple design (reasonable production costs) with a relatively high resistance to fouling. Spiral wound membranes are currently operated at pressures as high as 69 bar and recovery ratios up to 45%. Hollow fibre membranes are made of hair-like fibres, which are united in bundles and arranged in pressure vessels. Typical configurations of hollow fibre modules are U-tube bundles, similar to shell and tube heat exchangers. The feed is introduced along a central tube and flows radially outward on the outside of the fibres. The pure water permeates the fibre membranes and flows axially along the inside of the fibres to a "header" at the end of the bundle. Typical outside diameters of hollow fibres are somewhere in the order of 85 μm to 200 μm. Hollow fibres can withstand pressures as high as 82.7 bar and have high recovery ratios up to 55%.

The following membrane materials are currently used for seawater RO membranes:

- cellulose acetate membranes
- polyamide membranes
- thin film composite membranes.

The choice of a suitable membrane material is particularly influenced by its resistance to free chlorine, free oxygen, temperature, bacteria and to the index of pH of the saline solution.

Cellulose acetate membranes have been playing an important part in seawater desalination. Although strongly limited in index of pH, the advantages are low material costs and the resistance to chlorine, which is used in feedwater to inhibit biological fouling. Cellulose acetate membranes have a relatively short operating life and suffer pressure compaction (deterioration of permeate water flow because of creep buckling of the membrane material at high pressure and high temperature).

Polyamide and thin film composite membranes have, in general, higher water fluxes and higher salt rejections than cellulose acetate membranes. However, these types of membranes are subject to chlorine attack. If chlorine is added to feedwater to control biological growth, the feedwater must be dechlorinated before entering the membrane modules.

Thin film composite membranes consist of two layers of different polymers: one relatively thick and porous layer (e.g. polysulfone) which provides the membrane support, and one relatively thin (about 0.05–0.1 μm) and dense layer (e.g. polyamine) which provides the semipermeable characteristics. The different materials of the layers make it possible to optimise each layer separately which results in higher water fluxes and higher salt rejections at high mechanical strength in contrast to membranes consisting of only one material.

The membrane performance of RO modules such as salt rejection, permeate product flow and membrane compaction resistance were improved tremendously in the last years. The DEEP performance models cover both the effect of seawater salinity and the effect of seawater temperature on recovery ratio and required feedwater pressure.

As drinking water standards, the World Health Organization (WHO) guidelines, which recommend 1000 ppm for TDS and 250 ppm for chlorides as the highest desirable level, were applied. System parameters such as operation pressure, maximum element recovery and element permeate flow were assumed to be in compliance with the design guidelines of the manufactures not expecting problems in operation (compaction, fouling, scaling, etc.).

A key criterion for the RO layout is the specific electricity consumption, which should be as low as possible. That means, the recovery ratio has to be kept as high as possible and the accompanying feedwater pressure as low as possible fulfilling the drinking water standards as well as the design guidelines of the manufactures.

A disadvantage of RO is the need for significant pre-conditioning of the feedwater to protect the membranes. The extent of pre-treatment requirements depends on a variety of factors, such as seawater composition and temperature, seawater intake, membrane materials and recovery ratio. RO pre-treatment includes the following steps:

- chlorine disinfection to prevent biological growth in feedwater,
- coagulation followed by one of the mechanical separation methods (sedimentation, filtration, flotation) to remove colloidal and suspended matter from the feedwater,
- conditioning with acids to adjust the pH index for carbonate scale suppression and with inhibitors (polyphosphates) to prevent sulphate scale formation.

For chlorine sensitive membranes, in addition, feed de-chlorination through activated carbon filters and/or sodium bisulphate dosage is required.

Since the overall recovery ratios of current seawater RO plants are only 30 to 50%, and since the pressure of the discharge brine is only slightly less than the feed stream pressure, all large scale seawater RO plants as well as many smaller plants are equipped with energy recovery turbines, usually Pelton turbines, which recover a part of the pumping energy.

High salt rejection and good high pressure operation qualities of current membranes permit the economical operation of seawater RO plants in single stage systems, even on the high salt content waters found in the Middle East while producing drinking water in accordance to WHO standards.

In recent years, seawater RO has become a reliable and commercial process applicable on a large scale. A weak point in RO operation is the low tolerance of membranes to operational errors, which has led in the past to high membrane replacement costs in some cases.

Typical electricity consumption of RO plants is in the range of 4 to 7 $kW(e)\cdot h/m^3$ dependent on the seawater salinity, recovery ratio, required permeate quality, plant configuration and energy recovery in the brine blowdown.

3.2.4. Hybrid desalination plant

A hybrid desalination plant is composed of a distillation plant (MSF or MED) and a RO plant. Such a combination can be appropriate in a number of situations, and user requirements, e.g.:

- To enhance the water production capacity at a given power plant site.
- When more than one water quality is required.
- Optimal production of water with salinity lower than RO permeate but higher than distillation product.

DEEP calculates first the performance of the distillation plant and then the RO plant to match the required total production capacity.

3.3. ENERGY SOURCES

The energy sources included in DEEP are steam power plants, gas turbines, combined cycle, diesel and heating plants. They are summarised in Table III.

TABLE III. ENERGY SOURCES CONTAINED IN THE SPREADSHEET

Energy source	Abbreviation	Description	Plant type
Nuclear	PWR	Pressurised light water reactor	Co-generation plant
Nuclear	PHWR	Pressurised heavy water reactor	Co-generation plant
Nuclear	GTMHR	Gas turbine modular helium reactor	Power plant
Nuclear	SPWR	Small pressurised light water reactor	Co-generation plant
Nuclear	HR	Heat reactor (steam or hot water)	Heat-only plant
Fossil	SSB	Superheated steam boiler	Co-generation plant
Fossil	GT	Open cycle gas turbine	Co-generation plant
Fossil	CC	Combined cycle	Co-generation plant
Fossil	D	Diesel	Power plant
Fossil	B	Boiler (steam or hot water)	Heat-only plant

3.3.1. Steam power plants

DEEP includes simplified models of the nuclear and fossil fired steam power plants summarised in Table III. The turbines of steam power plants may work in the condensing, backpressure or extraction/condensing mode.

The condensing mode is usual for single purpose steam-electric plants, in particular for base load plants. It does usually not allow the extraction of heat, except from the cooling water (e.g. for preheating RO feedwater).

The backpressure mode is preferably applied for a fixed ratio of electricity and heat output, which may be used for a distillation process.

The operating flexibility of a power plant/distillation complex is enhanced by using extraction/condensing turbines that allow to vary the ratio of electricity and water production at reasonable efficiency. The steam for distillation may be extracted from the crossover pipe between the high pressure (HP) and low pressure (LP) turbine sections. Since the LP section is mechanically coupled to the HP section, at least around 5% of the full steam amount must always flow through the LP section for sufficient cooling of the turbine blades [7]. If the distillation plant is shut down, the full electric output can be generated.

DEEP includes models of one fossil fired and three nuclear steam power plants.

Pressurised water reactor (PWR) power plant

To cover the energy demand for producing the reference quantities of potable water and electricity, a medium size pressurised water reactor with a thermal power of 1870 MW(th) was chosen. The schematic flow diagram of the reference PWR and relevant technical parameters are given in Fig. 4 and Table IV respectively.

TABLE IV. TECHNICAL PARAMETERS OF THE REFERENCE PWR POWER PLANT

Core power	MW(th)	1870
Net output	MW(e)	about 600
Net efficiency	%	about 32.0
Auxiliary Loads	MW(e)	38
Primary system:		
Coolant/moderator		H_2O
Coolant cycle		Indirect
Pressure boundary		Pressure vessel
Pressure	Bar	155
Temperature (out/in)	°C	312.4/276.1
Loops		2
Steam generators		2
Pumps		4
Fuel reload:		
Fuel		UO_2
Initial enrichment range	%	2.0-3.0
Reload enrichment at the equilibrium	%	3.55
Refuelling frequency	Months	18 or 24
Type of refuelling		off power
Number of fuel assemblies		145
Number of fuel rods per assembly		264
Average core power density	kW/litre	78.82
Average discharge burnup	MW·d/t	40 000
Secondary system:		
Pressure	Bar	53.6
Temperature (out/in)	°C	268.3/223.9

The reactor is cooled by two 155 bar pressurised water cooling loops, where the thermal energy released during nuclear fission is transmitted to a steam power cycle in two steam generators. In the steam power cycle, there are high and low pressure turbine stages with two moisture separator reheater units and six stages of feedwater heating. The steam generators produce steam at a pressure of 53.6 bar, yielding a net electrical output of approximately 600 MW(e) at condensing pressure of 0.077 bar (40°C). The turbine unit consists of a double flow, high pressure turbine and two low pressure double flow turbines that exhaust to individual condensers.

Water at 223.9°C enters the steam generators of the cooling loops. After evaporating and superheating, the steam leaves the steam generators as slightly superheated steam of 268.3°C and 53.6 bar. This steam flows into the high-pressure turbine, expanding to a pressure near 26 bar. The steam then enters the two moisture separators and flows through two reheating stages (only one moisture separator reheater is shown in Figure 12 for clarity), entering the low-pressure turbines, ultimately expanding to the condenser pressure of 0.077 bar. The condensate is pumped through a series of six feedwater heaters back to the steam generators.

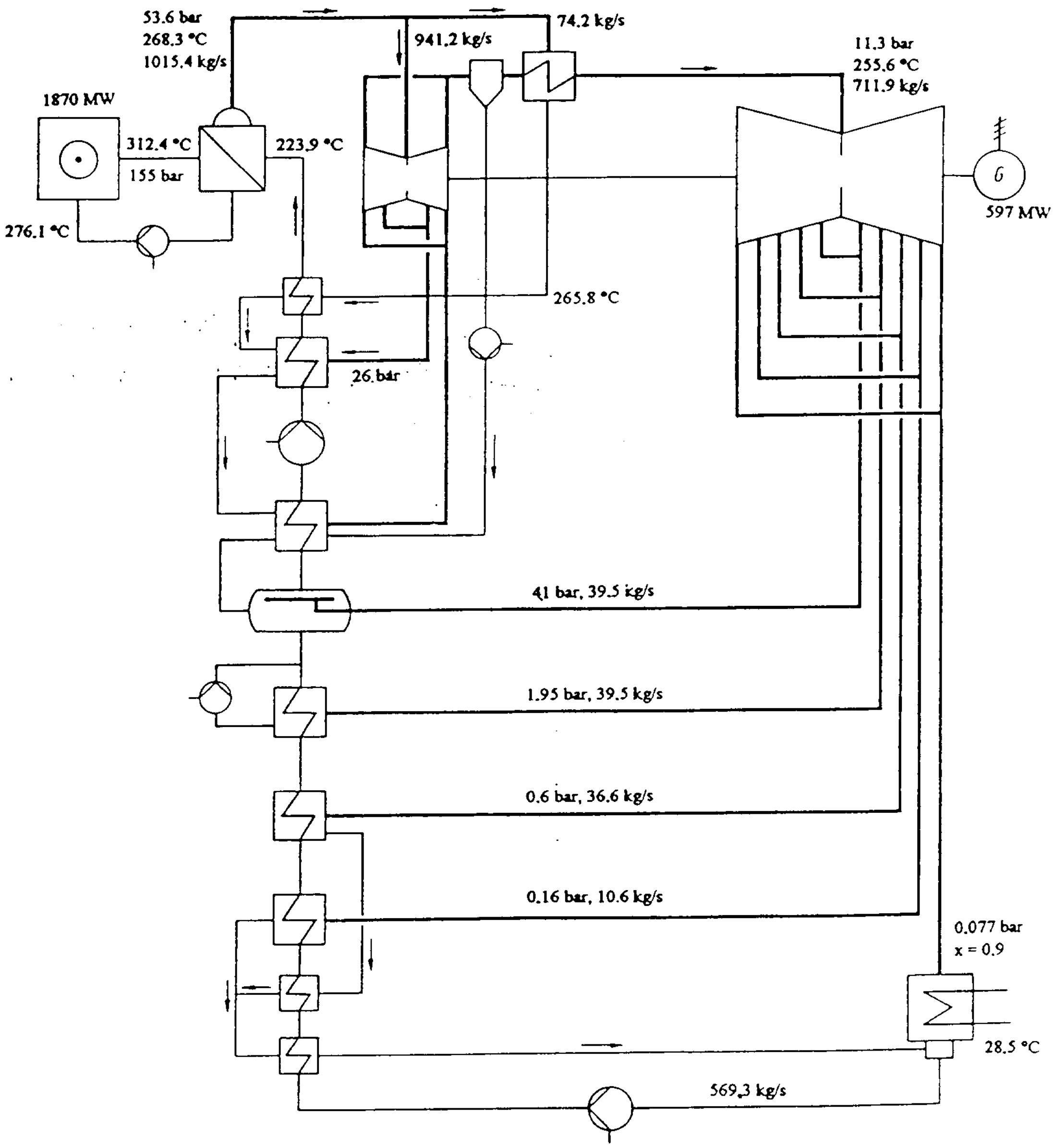


Fig. 4. Schematic flow diagram of the reference PWR power plant.

Pressurised heavy water reactor (PHWR)

The PHWR model of DEEP is based on a CANDU design of 450 MW(e). Technical parameters of the PHWR plant are given in Table V.

TABLE V. TECHNICAL PARAMETERS OF THE PHWR PLANT

Parameter	Value	Unit
Thermal power	1515	MW(th)
Electric power	450	MW(e)
Thermal efficiency	29.7	%

Small pressurised water reactor (SPWR)

The SPWR model of DEEP is based on a design developed for Russian nuclear powered icebreakers. Technical parameters of the SPWR plant are given in Table VI.

TABLE VI. TECHNICAL PARAMETERS OF THE SPWR PLANT

Parameter	Value	Unit
Thermal power	160	MW(th)
Electric power	35	MW(e)
Thermal efficiency	21.9	%

Fossil fired superheated steam power plant

The fossil fired superheated steam power plant (SSB) model is based on modern oil or gas fired design with 92% boiler efficiency and 40% net thermal efficiency.

3.3.2. Gas turbine plant

DEEP includes models of two gas turbines. The first one, the GE MS 9001E with a gross output of 123.6 MW(e), represents a conservative design with a gross thermal efficiency of 33.6% at ISO conditions (15°C, 60% humidity). The second one, the GE PG 9331(FA) with a gross output of 226.5 MW(e), represents a more advanced design with a gross thermal efficiency of 35.6% at ISO conditions. The performance models of the gas turbines (gross power, gross efficiency and exhaust temperature as a function of inlet air temperature) are included in Section 5.

Combined cycle power plant (combined cycle)

The reference combined cycle consists of 3 natural gas fuelled gas turbines with unfired heat recovery steam generators (HRSGs) and a dual pressure reheat steam cycle. The gas turbines are rated at 145 MW(e) net output each and the steam turbines at 205 MW(e) net output taking the average annual ambient conditions (air: 28.5°C, 1 bar, 60%, seawater: 28.5°C) as a basis. The overall net electrical output of the combined cycle is about 640 MW(e) with a net thermal efficiency of 49.7%. Table VII

TABLE VII. TECHNICAL PARAMETERS OF THE REFERENCE COMBINED CYCLE POWER PLANT AT AVERAGE ANNUAL AMBIENT CONDITIONS

Gas turbines:		
Net electrical output	MW(e)	3 · 145
Net thermal efficiency	%	33.8
Thermal power	MW(th)	3 · 428.9
Fuel		natural gas
Frequency	Hz	50
Compressor pressure ratio		15:1
ISO turbine inlet temperature	°C	1100
Exhaust gas flow	kg/s	3 · 494
Exhaust gas temperature	°C	541
Steam turbines:		
Net electrical output	MW(e)	204.7
Auxiliary loads	MW(e)	10.8
Steam parameter	bar/°C	80/500
Generator and mechanical efficiency	%	98.5
Condensing pressure	Bar	0.077
Isentropic efficiency of high-pressure (low-pressure) turbines	%	85 (75)
Overall combined cycle:		
Gross electrical output	MW(e)	654.9
Auxiliary loads	MW(e)	15.2
Net electrical output	MW(e)	639.7
Net thermal efficiency	%	49.7

Average annual air conditions: 28.5°C, 1 bar, 60% relative humidity.

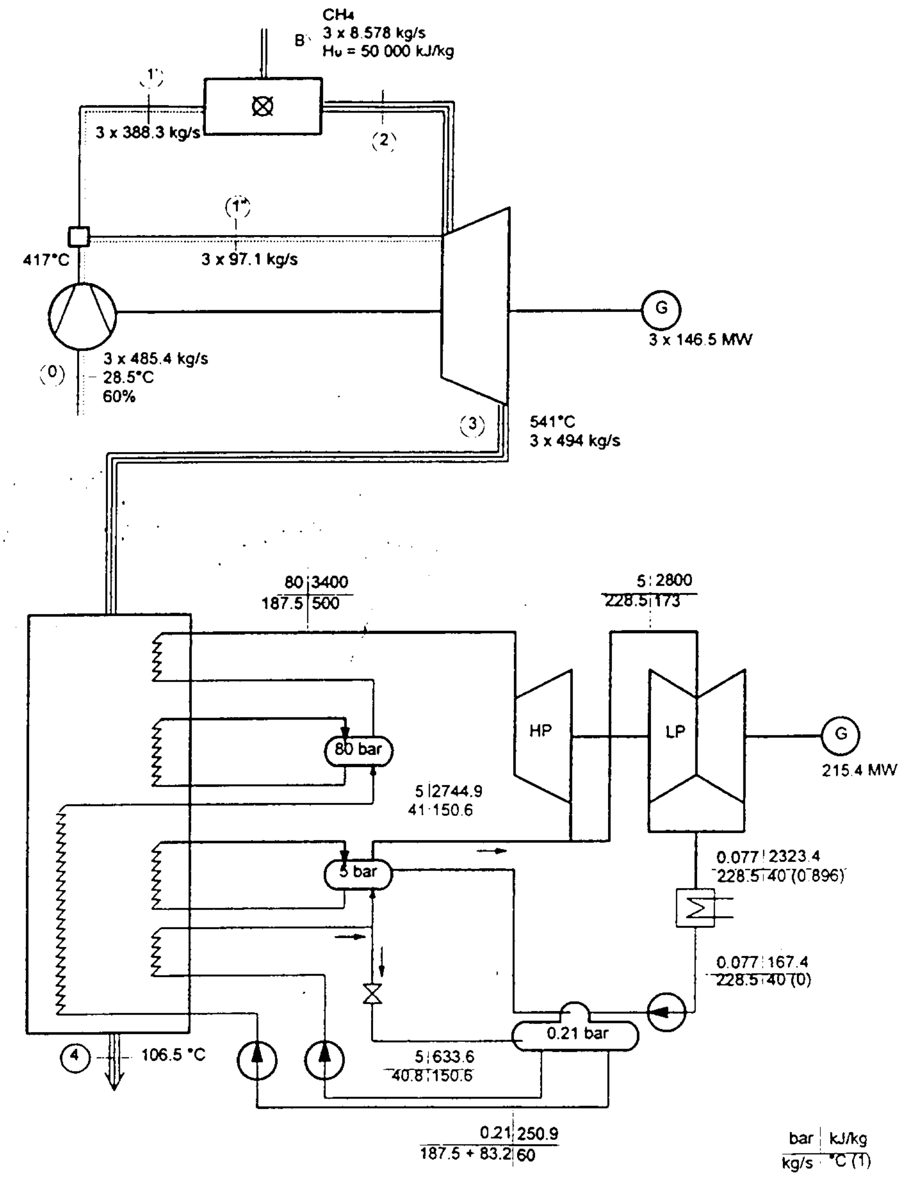


Fig. 5. Schematic flow diagram of the reference combined cycle.

contains relevant technical parameters of the reference combined cycle based on detailed calculations by a manufacturer [3]. Figures 5 and 6 show the schematic flow diagram of the combined cycle and the temperature/heat recovery diagram of the HRSGs respectively. To simplify matters, only one HRSG is shown in Fig. 5.

The steam parameters of the dual pressure steam cycle are 80 bar/500°C and 5 bar/151°C. Feedwater pre-heating occurs exclusively in the economiser section of the HRSGs. The steam turbine unit consists of a single flow high pressure turbine and a double flow low pressure condensing turbine serially placed on one shaft.

Nuclear gas turbine plant

The model for a nuclear gas turbine plant is based on a design by General Atomics, referred to as GT-MHR. The plant would be coupled to a RO plant.

Diesel

The diesel plant model is based on a modern design with 50% thermal efficiency. The electric output is fed to a RO plant.

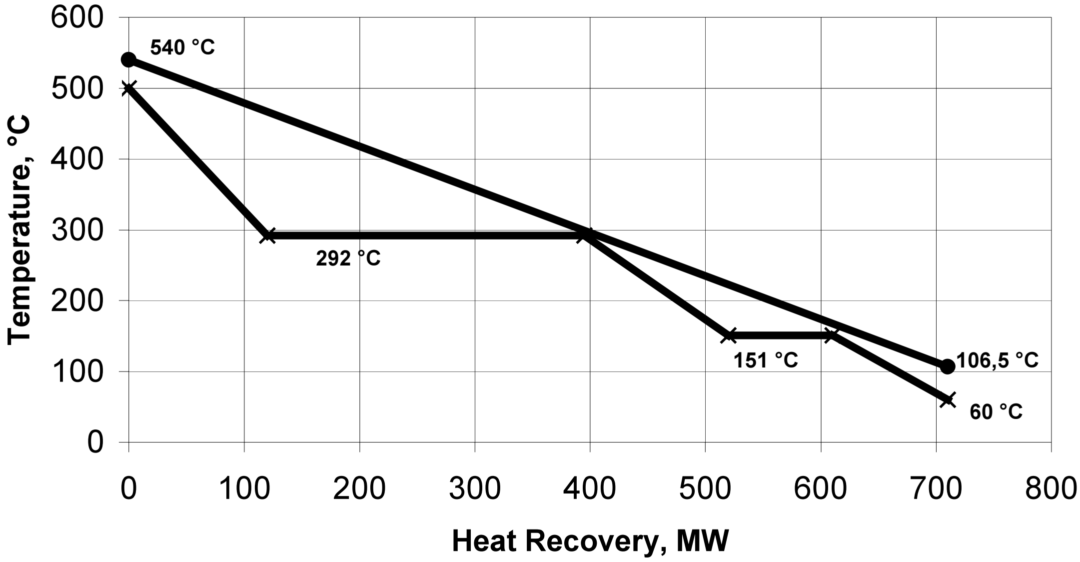


Fig. 6. Temperature/heat recovery diagram of the HRSGs.

3.4. HEATING PLANTS

Fossil fired boiler

The boiler model is based on a conventional oil or gas fired boiler with 90% boiler efficiency. The boiler model can only be coupled to a distillation process.

Heat reactor

The heat reactor model is based on a Chinese design of 200 MW(th). The heat reactor model can only be coupled to a distillation process.

Backup heat source

A backup heat source will be installed if a distillation plant shall continue producing water also at downtimes of the main heat source. A backup heat source may be a fossil fired boiler or a vapour compression unit. To keep the backup heat costs low, a backup heat source will often be designed only for part of the distillation plant capacity, or may be replaced by another water source or demand management measure (e.g. by temporarily pumping more water from a reservoir, or by providing less water to some consumers).

3.5. COUPLING ARRANGEMENTS

The power plants described above can be coupled to MSF, MED or RO plants, except the GTMHR and diesel plant, which can only be coupled to RO plants. An overview of coupling options is presented in Fig. 7, where N/A means not applicable; the number means that the coupling may be solved by DEEP and the number corresponds to the number of the coupling diagram presented in the Annex.

Coupling of a power plant to a stand alone RO plant requires only an electrical connection. There is no need for co-location. A contiguous RO plant, using waste heat from the power plant for feed preheating, must be co-located. DEEP includes models of both stand alone and contiguous RO plants.

ENERGY SOURCE	MED	MSF	SA-RO	C-RO	HYBRID MED/RO	HYBRID MSF/RO
PWR	1	2	3	4	5	6
PHWR	1	2	3	4	5	6
Fossil power	8	9	10	11	12	13
GT	14	15	16	N / A	17	18
CC	19	20	21	22	23	24
GTMHR	N / A	N / A	7	N / A	N / A	N / A
Small PWR	1	2	3	4	5	6
Diesel	N / A	N / A	25	N / A	N / A	N / A
Heat reactor	26	27	N / A	N / A	N / A	N / A
Fossil boiler	28	29	N / A	N / A	N / A	N / A

Fig. 7. Matrix of energy sources and desalination plants.

Coupling devices are important for distillation processes. They are designed to prevent both the ingress of brine or seawater into the turbine cycle of the power plant (or into the heat transfer cycle of a heating plant) and the ingress of contaminants (e.g. radionuclides) from the power or heating plant into the product water. A NPP will be coupled to a distillation plant by an intermediate loop, which could either be a hot water loop (usual for MSF) or a flash loop (usual for MED). DEEP calculates the performance and cost impacts of intermediate loops. Examples of coupling PWRs and distillation processes are given below.

For MED and MSF processes, joint siting of the PWR and the distillation plant is necessary because transport of heat over long distances is expensive and involves substantial losses.

The turbine system in the PWR power plant has to satisfy simultaneously the requirements of electricity generation and those of providing low temperature steam for the seawater distillation system. The latter in turn determines the specific volume of the steam, the volumetric flow rate, the average steam velocity, the cross-section areas and the steam velocity vectors of the turbine(s) supplying heat to the seawater distillation plant.

Using the reference PWR as energy source for the reference seawater distillation plants, the following solutions for providing low temperature steam could be envisaged:

- using low temperature extraction steam from the low pressure condensing turbines;
- diverting steam from the crossover pipe at the inlet of the low pressure turbines;
- using two backpressure turbines instead of two low pressure condensing turbines;
- replacing low pressure turbines by extraction/condensing turbines with crossover pipes;
- using a backpressure turbine and a low-pressure condensing turbine in parallel (not necessarily of the same size) instead of two low pressure condensing turbines.

Extracting steam from the lowest extraction points of low pressure condensing turbines has a limitation. The amount of steam extractable is relatively small, not sufficient to produce the reference amount of 290 000 m^3/d.

From the exergetic point of view, diverting steam from the crossover pipe at the inlet of low pressure turbines is not a good solution. Steam with a relatively high exergy content, synonymous with a relatively high potential to produce electricity, would be used just for low-temperature heating purposes, resulting in unnecessarily high electricity generation losses.

Solution 3 could be applied, either by operating the two low pressure condensing turbines at higher exhaust pressure (in general limited to less than 0.2 bar), or in exchanging the low pressure condensing turbines for backpressure turbines. For this solution, the leeway in optimising the seawater distillation plant is very low. Taking into account, that the GOR of distillation plants for a certain temperature difference between heating steam and cooling water sink can only be slightly varied for economic reasons, the GOR is nearly determined by the water demand required.

In solution 4, low pressure steam, which is adjusted to the heating steam requirements of the distillation plant, is taken from the crossover pipes between the two sections of the extraction/condensing turbine. As a result, the full electrical output could come back on line if the distillation plant was shut down. Furthermore, the turbine arrangement has a high flexibility against variable water–electricity ratios, but would lead to higher investment cost.

In solution 5, the reference distillation plant is coupled with the PWR using a backpressure turbine and a low pressure condensing turbine in parallel (see Fig. 8). The exhaust steam condition (mass flow rate, temperature, pressure) of the backpressure turbine is also adjusted to the heating steam requirements of the distillation plant. Increasing the GOR will decrease the size of the backpressure turbine, while the size of the low pressure condensing turbine increases. This turbine arrangement enables the coupling of all reference distillation plants with the PWR power plant, and therefore, an economic ranking (optimisation) of the distillation plants while keeping the water output constant.

The question whether solution 4 or solution 5 is better, can only be answered by a detailed and specific case study.

When coupling seawater desalination plants with nuclear power plants, the risk of possible radioactive contamination of potable water produced must be made as low as achievable. Thus, at least two "barriers" between the reactor and the saline water are required, and the so-called "pressure reversal" principle should be utilised. For PWR power plants, the steam generators are the first barrier against the transport of radioactive isotopes into the distillation plant.

When coupling the reference MSF plants with the reference PWR power plant, the brine heaters of the MSF units serve as the second barrier. In order to have the pressure reversal, the brine at the brine heaters is maintained at a pressure sufficiently higher than the pressure of the heating fluid, so that the direction of a potential leakage in the brine heaters will be away from the MSF units, into the steam power cycle. In such a case, controlling devices that monitor the salinity of the steam power cycle of the PWR power plant would shut it down. Due to the two barriers and the pressure reversal, the probability of radioactive contamination of the desalted water is very low. Nevertheless, should it happen, there are further instrumentation devices that monitor radioactivity in the MSF plant, and actuate systems to divert the effluents away from the mains, notify the operators and stop the process.

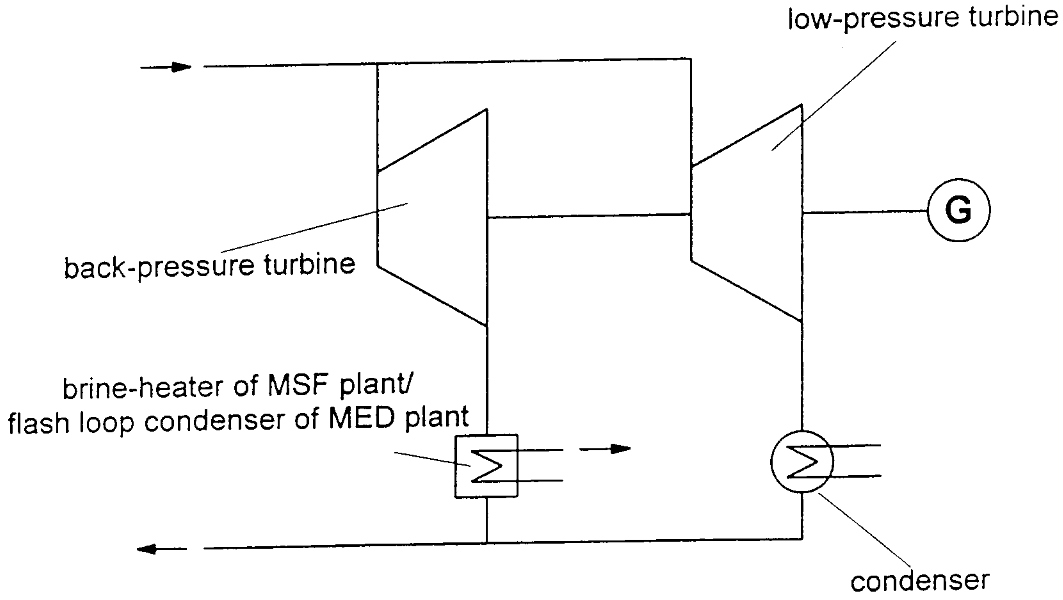


Fig. 8. Coupling of the distillation plant with the PWR power plant (backpressure turbine and low pressure condensing turbine in parallel).

A more stringent provision against radioactive contamination, which helps also against salination of the steam power cycle of the PWR power station, is a “pressurised water isolation loop” between the condenser of the backpressure turbine and the brine heaters of the MSF units (see Fig. 9). The pressure in this loop would be lower than the brine pressure, but higher than that of the backpressure steam. This results in an additional barrier and an additional pressure reversal to prevent radioactive contamination of potable water.

The above described kind of pressurised water isolation loop results in an additional investment cost for the MSF plant, higher energy demand for pumping, and in an additional loss in electricity generation because of the higher exhaust temperature of the backpressure turbine. Furthermore, provisions for direct seawater (cooling water) supply to and discharge from the backpressure condenser to allow operation of the PWR power plant when MSF units are out of service are required.

For MED plants, the thermal coupling with the PWR power station is implemented by open “flash-loops” (see Fig. 10). Backpressure turbine exhaust steam is condensed in the flash-loop condensers of the MED units. The latent heat of condensation is transferred to a circulating saline water stream, which is heated by approximately 5°C. A portion of it flashes in the flash chambers, thereby forming low temperature steam for the first MED effect. The condensate of the steam delivered to the first MED effect is already pure distillate and adds to the produced water. Cooled saline water from the flash chambers is recycled to the flash-loop condensers. A portion of the circulated water is continuously drawn off as brine blowdown to prevent salinity build-up. Makeup saline water is supplied from the feed stream to the circulating water to replace the losses through flashing and brine blowdown. When MED units are not in operation, the flash-loop condensers are supplied with cooling water through a bypass line to allow continuation of power plant operation.

When a distillation plant is coupled to a fossil fired power plant, the isolation loops are usually omitted. Otherwise, the coupling is implemented in the same way as coupling to a NPP.

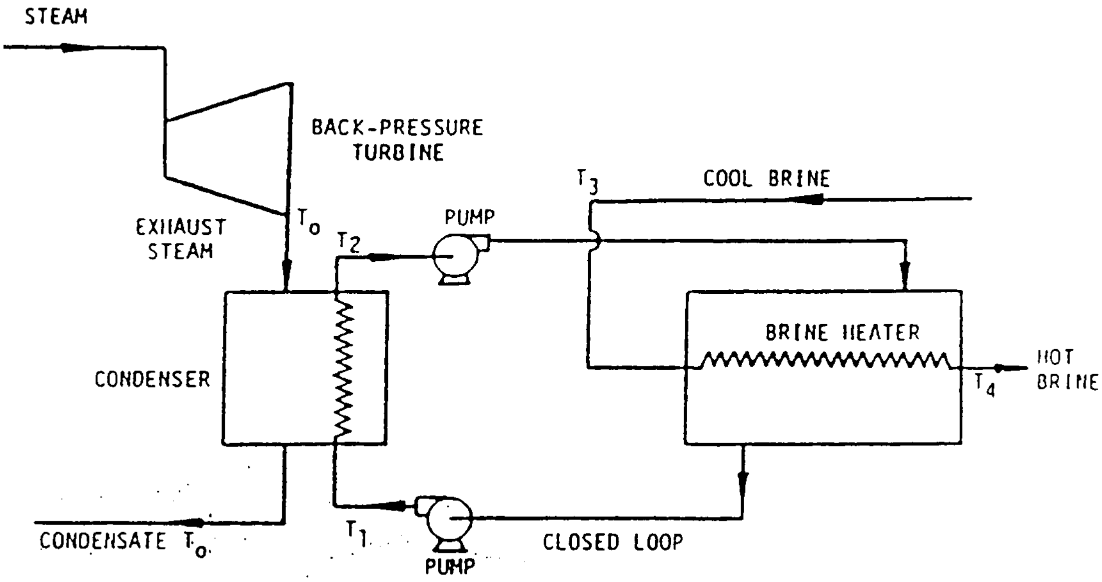


Fig. 9. Pressurised water isolation loop between backpressure condenser and MSF plant (just one MSF brine heater is shown for clarity).

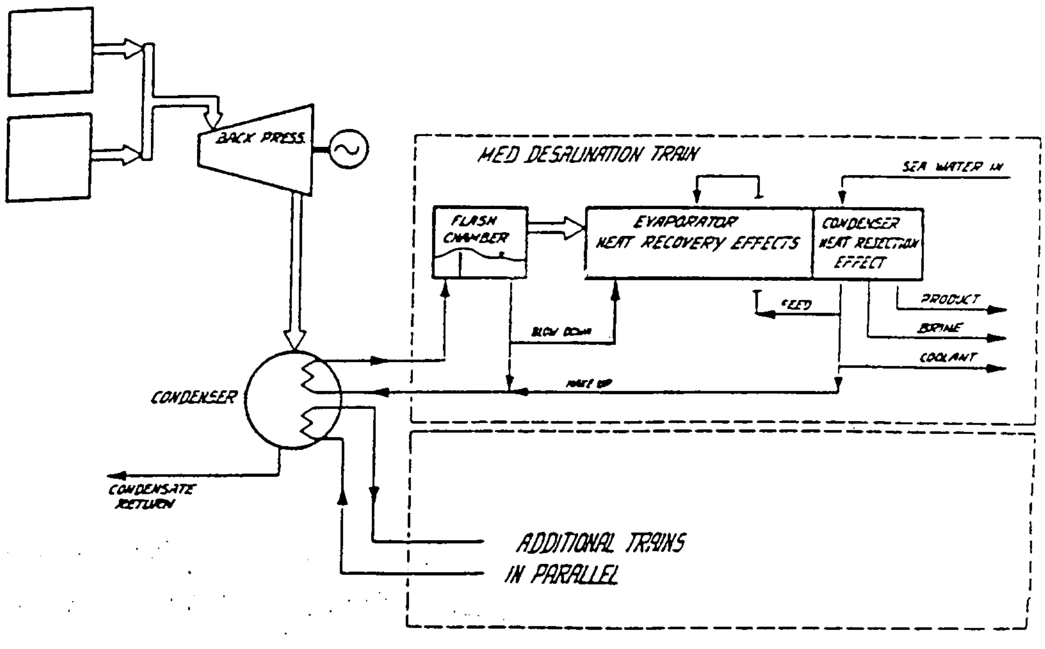


Fig. 10. Flash loop between backpressure condenser and MED units.

4. DEEP SOFTWARE

4.1. STARTING WITH DEEP

The program DEEP is implemented as an Excel file with worksheets, Visual Basic for Application (VBA) modules and user forms. To start DEEP means to open the *DEEP.xls* file (when double clicking on the DEEP icon to invoke the Excel program and then open the *DEEP.xls* file automatically) and by this way to start executing the VBA code from inside of *DEEP.xls*. This might be done by one of following actions:

- double click on the DEEP icon on the screen
- select a menu item DEEP from the Start/Program menu (if you have copied the icon here)
- double click on the file *DEEP.xls* in the ***C:\Program Files\DEEP*** directory window
- open *DEEP.xls* from running *Excel* application.

At the beginning DEEP preserves some Excel settings, closes all other files except *DEEP.xls*, creates the pull down menu bars of **CASE** and **PRESENTATION** and makes some checking. All these things need time. At last the usual EXCEL cursor appears quietly over the "***Main***" sheet. Then the user can start the work with DEEP. The user can select menu items from the pull down menu bars of **CASE** and **PRESENTATION**. The DEEP session ends with the closing the "*DEEP.xls*" file or with exiting Excel. Before that the cleaning procedure makes Cases or CPs closed and recovers some EXCEL settings to the previous state automatically.

4.1.1. Working with a single case

This section describes how to use sheets "***Input***", "***Full Input***", "***Summar**y*" and "***Full Report***" and how to manipulate graph sheets with names starting with # character ("***#P-I***", "***#W-I***" and "***#TRR***").

First, a single case must be opened. The user selects one of the menu items: **New case**, **New case by modification** or **View case** from the **CASE** menu bar. Then a dialogue sequence appears to identify the case to open. Details to particular dialogues follow later. Then the case is opened and the "***Main***" sheet contains the file name where the case is stored.

The "***Input***" sheet is normally locked for input. To allow changes of values in the "***Input***" sheet the user selects menu item **Enable edit** from the **CASE** menu bar. Then DEEP switches to the "***Input***" sheet and enables edit. To change a particular value of a variable the user has to **DOUBLE CLICK** on the corresponding cell. Some input values are formatted over two neighbouring cells. The user should position the cursor carefully to the left side of the value intended to change. After that a message or input box will appear. The input box shows the value to change, the original text and the abbreviated name of this variable taken from the "***Calc***" sheet of an opened case. The user may use this possibility when making changes in the case file to prompt other users or himself about the changes. The same is valid for the more detailed "***Full Input***" sheet, which is placed just below the menu item **Enable edit** from the **CASE** menu bar.

The **Enable edit** mode is automatically switched off when the user selects another sheet.

Both "***Input***" and "***Full Input***" sheets contain the input data organised into several groups. Each group is placed into a box with rounded edges. Input data are grouped by the technology main parts and by their use for performance and cost calculations.

From the point of view of possible changes, DEEP classifies the input variables into three classes. These classes are marked with different colour in the "***Input***" sheet as follows:

- **green**
  Input variables, which are often changed by the user while generating cases, are marked by the green colour. A message "Welcome input" appears in the input box when a user double clicks on the green cell. If the changed value is a result of formula in original sheet, a warning is issued and the formula is not destroyed.

- **blue**
  The normal text colour within the user sheets in DEEP is blue (dark blue). This colour refers to the normal input. Users should change this input data only when they understand the calculation model well. Users usually do not change these values while generating cases. A message "Part of the model" appears in the input box when a user double clicks on the blue cell. These parameters are indicated in Ref. [5] with a small hand (with a few exceptions).

- **red**
  Input variables, which are result of some precalculations or switches, should not be changed at all by the user while generating cases. These input variables are given their value during the development process of the respective case. That is why the changes of these variables by DEEP users are not allowed. Such variables are marked by the red colour.

When the case is opened (**New case**, **New case by modification** and **View case** commands) the case data are directed to tables and graphs mentioned above and the user can enjoy ready-made reports and graphs.

The sheet "**Summary**" shows concise report on one A4 page. The sheet "***Full Report***" offers the more detailed report to the user.

For the single case, there are several graph sheets available. Their names start with # character ("**#P-I**", "**#W-I**", "**#TRR**").

Before creating new case or before viewing the next case, current case has to be closed.

4.1.2. Working with comparative presentation

This section describes how to work with sheets "**CP**" and "***CPDef***" and with graph sheets with names starting with @ character: "***@P-I***", "***@W-I***", "***@NSP+WC***" and "***@TTR***". It is possible to compare up to nine cases in one *Comparative Presentation* (CP).

To create a new comparative presentation (CP) or to change selected cases in the existing (just viewed) CP the user selects the "**New CP/Change links**" menu item. Then the ***Editing*** mode is switched on and the user can see the "***CPDef***" sheet. This sheet contains nine boxes for nine compared cases. Not all the cases must be filled out. There are two buttons in each box. The button on the left side has label **Select** and the button on the right side has label **Deselect**.

Selecting compared case

The user selects the "DEEP" menu bar item **New CP/Change links** and the sheet "***CPDef***" is made visible to the user. The case is selected by pressing one of the **Select** buttons. Then the standard *Open File dialogue* starts. The opened file full name (path and name) is transferred to the corresponding column of the opened CP file and the case file is closed without change. The DEEP takes care that the reference to the particular cell inside the "***CP***" sheet is preserved. The graphs point to the "***CP***" sheet, so the graphs are linked as well in that moment.

Deselecting compared case

The user selects the "DEEP" menu bar item **New CP/Change links** and the sheet "***CPDef***" is made visible to the user. The case is deselected by pressing one of the **Deselect** buttons. Then case is deselected and the "***CP***" sheet shows again values of empty cells in the corresponding column.

4.1.3. Printing output sheets

In the DEEP package there are following print commands available:

Print Input Sheets, Print Summary Report, Print Full Report   in the "CASE",

and

Print CP and Print CP Graphs   in the "PRESENTATION" menu bars.

These print commands make the same steps for each sheet to be printed. The sheet is selected automatically, the headers and footers are set with values corresponding to the CASE or CP opened and then the standard Excel Print Preview command is invoked. Users can look at the sheets they want to print and they can choose whether to print or not.

In the case of printing graphs, all graphs are printed within one printing command. The Print Preview is invoked automatically for each graph. If users want to cancel all printing after the first sheet, they have to be patient and cancel all subsequent graphs preview one after another.

Note: *The implementation of* DEEP *keeps all Excel functionality available to the user. The user has a possibility to invoke standard Excel printing command (selecting a menu item File|Print or File|Preview|Print or by touching the Print or Print Preview icons placed on standard toolbar).*

Before creating new CP or before viewing the next CP, current CP has to be closed.

4.2. NEW FEATURES OF DEEP

An important step on the road to establish good user friendliness for CDEE (the predecessor of DEEP) was made by issuing this version of DEEP. Main changes from previous version are:

- the reference cases previously contained in one file were separated into their own files,
- the reference cases were restructured substantially in order to put the spreadsheet parts corresponding to particular technology pieces so close each other as possible,
- the input and calculation sheets were put together into one sheet in order to use the advantage of the Excel build-in debugging tool,
- the calculations were separated from presentations,
- the VBA functions for calculation of Tmbmin and some membrane characteristics were made more robust and safe,
- the modularization enabled to separate modules of different energy plants and desalination plant options, so that the user can compose cases with required couplings,
- the inside calculations within the "Calc" sheet use the names of physical variables instead of row and column identificators usually used in spreadsheet programs,
- the user is provided with more comfort for generating cases,
- the two input sheets have been added for the user to hint what cells are recommended, allowed and prohibited to change. and
- the user may use predefined graphs and tables.

The main advantage of this DEEP architecture is the possibility to develop calculation cases by several experts on various places separately and simultaneously as well as to maintain the graphical capabilities and the user friendly support for all users centrally.

4.3. THE “MAIN” SHEET DESCRIPTION

In the upper part of the “Main” sheet the DEEP name and the current version are placed. Below that there is a *User frame* with some information. Starting with the DEEP Version 2.0 the user is allowed to open both one case and one comparative presentation simultaneously.

User name:
Here is the text, which the DEEP print commands place into the right footer on all printouts. Its contents is derived automatically from the system information on the user’s PC during the starting phase of DEEP.

Case names:
For the opened case its case name and assumed site location are displayed on the Main sheet.

File names:
Both the name of the case file with a “***Calc***” sheet and the name of the CP file with a “***CP***” sheet are displays on the Main sheet.

4.4. SINGLE CASE PRESENTATION SHEETS

The DEEP output sheets serve for presenting data calculated in separate cases.

Tables

“Input”	contains the main input variables used in calculations
“Full Input”	contains more detailed list of input variables
“Summary”	contains the most important results presented on one page
“Full Report”	contains the “Summary” sheet information and more details

Graphs

“#P-I”	contains graphs ***Power Plant Investment*** *(Total and Specific)*
“#W-I”	contains graph ***Water Plant Investment*** *(Total and Specific)*
“#TRR”	contains graph ***Total Required Revenue*** *(for one case)*

Names of the graph sheets start with # for case files and with @ for CP files to indicate the affiliation of these graphs with the respective type of file. The first letters of the graph’s title are then used to derive the abbreviated name for the sheet.

4.5. COMPARATIVE PRESENTATION OUTPUT SHEETS

The output sheets available in DEEP for presenting data from comparative presentations are following:

Tables

“CP”	Sheet with comparison of selected cases — presents selected variables important for comparison
“CPDef”	Sheet with links to compared cases and with Select & Deselect buttons — contains full path names to selected cases

Graphs

“@P-I”	contains graphs ***Power Plant Investment*** *(Total and Specific)*
“@W-I”	contains graphs ***Water Plant Investment*** *(Total and Specific)*
“@NSP+ WC”	contains graphs ***Net Saleable Power and Water Cost***
“@TRR”	contains graph ***Total Required Revenue*** *(for comparing more cases)*

When the CP is opened (**New CP/Change links** and **View CP** commands) the CP data are directed to table and graphs mentioned above and the links to separate compared cases are copied to theirs respective places on the **"CPDef**" sheet.

4.6. DEEP PULL DOWN MENU BARS DESCRIPTION

The "DEEP" menu is arranged into two bars, which contain two sets of menu items. The last "**About DEEP**" menu item shows short information about DEEP provider. One set of menu items deals with ***Cases*** (with calculations), the other with ***CPs*** (comparative presentations). The names of the menu items are expressing the respective actions called by them.

4.6.1. Open and save Single Case

New cases are generated using the knowledge basis stored in the *Reference Cases* and DEEP package uses their slightly modified copies in the *Templates* directory. Using the **New case** and **New case by modification** commands the user can easily generate new cases.

New case menu item

It opens the *New Case Dialogue* where the user can fill in the information needed for the case composition. Based on this information DEEP selects the proper templates, composes these templates in one sheet, and stores it under the new name given by the user. Then DEEP switches to the "***Input***" sheet and enables changes in the input data. The default values in the input data cells are taken from the template files.

New case by modification menu item

It opens the *Open File Dialogue* where the user can select a case, which should serve as a template. Then the DEEP makes a copy of this opened file and stores it under another name given by the user. Then DEEP switches to the "***Input***" sheet and enables changes in the input data.

Close case menu item

It closes opened CASE file and prepares the DEEP for opening another case. When closing the CASE file the user can decide whether the changes are saved or not.

View case menu item

It opens the *Open File Dialogue* where userd can select a case, which they want to see. The DEEP checks whether user selected CASE or CP. Then the proper routines are called to handle the file opened. The file is opened in view mode where no changes to input data are allowed.

4.6.2. Editing Single Case

Enable edit menu item

If the user starts with **New case** or **New case by modification** the DEEP is put in the mode where changes in the "***Input***" sheet are enabled. This is not allowed after the **View case** command until the user presses **Enable edit.** Then DEEP switches to the "***Input***" sheet and enables changes in the input data. The experienced user can use the more detailed "Full Input" sheet.

Save case menu item

The opened file is saved and the edit mode is not changed. Except saving the file nothing else happens.

Discard Changes menu item

If users made some changes and are not happy with these changes, they can discard them by this command. Then DEEP reads old values recorded during last save command (or at the beginning when the case was created) and switches back to the editing mode.

4.6.3. Printing Single Case

Print Input Sheet menu item	prints the "***Input***" and "Full Input" sheets
Print Summary menu item	prints the "***Summary***" sheet
Print Full Report menu item	prints the "***Full Report***" " sheet
Print Case Graphs menu item	prints several sheets with graphs

To see the illustration of the above mentioned printouts please start the DEEP program, open the *Sample Case.xls* file provided by the developer for your convenience and look at desired sheets.

4.6.4. Open and save Comparative Presentation

The CPs (Comparative Presentations) **Menu Items**

New CP/Change links menu item

If there is no CP opened it creates a new CP file and stores it under a new name given by the user. Then it shows the sheet "***CPDef***" and enables to establish links to compared cases using the standard *Open File Dialogue.*

If there is already CP opened (see the next menu item description below) it shows the sheet "***CPDef***" and enables changes to established links.

View CP menu item

It opens the CP file and after that it connects the table and graphs to the data contained in the opened CP file.

Close CP menu item

This command closes the opened CP file and prepares DEEP for opening another CP. When closing the CP file the user can decide whether the changes are saved or not.

Save CP menu item

The opened file is saved and the edit mode is changed to view mode. Nothing else happens.

Save AS CP menu item

The same as the **Save CP** command except it enables to store the file under another name.

4.6.5. Printing Comparative Presentation

Print CP menu item	prints the "***CP***" sheet – tabulated comparison
Print CP Graphs menu item	prints several sheets with graphs

To see the illustration of the above mentioned printouts please start the DEEP program, open the *Sample CP.xls* file provided by the developer for your convenience and look at desired sheets.

4.7. HOW DEEP WORKS

The development of the user friendly spreadsheet is built upon an idea of linked Excel files. The linking procedure enables redirection of links to different Excel files with separate cases. Inside DEEP there are sheets reserved for links to case files and comparative presentation files. Formally these sheets look like Calc sheet from case files or CP sheet from comparative presentation files and they contains no direct values or formulas but links. All printable tables and graphs are then linked to these sheets.

The DEEP package consists of several parts, which are implemented as EXCEL files.

Case file:

The desalination technology and its economic evaluation are made inside a case EXCEL file with following sheets:

"***Calc***"	is a worksheet with formulas (derived from the formulas of CDEE 8.3).
"***VBA_Calc***"	is module sheet with some functions used in formulas. This module sheet is normally hidden to the user.

The "*Sample Case.xls*" is provided for the user's convenience and is placed in the directory of ***C:\My DEEP Documents\Cases.*** In this directory of ***C:\My DEEP Documents\Cases*** user defined (generated) cases will be stored later (default option).

Comparative Presentation (CP):

The user is offered a new feature — *Comparative Presentation*. The user can select several cases and a comparison table is made automatically based on the selected cases. This table is then stored as a usual EXCEL file with one worksheet. This sheet is named "***CP***" and it contains a table with certain values from selected cases.

The file "*Sample CP.xls*" is provided for the user's convenience and is placed in the directory of ***C:\My DEEP Documents\CPs.*** Here will be other user defined (generated) *Comparative Presentations* stored later.

Reference Cases:

In the directory of ***C:\My DEEP Documents*** a subdirectory Reference Cases does exist where several reference cases developed in the past and validated are stored.

Control files:

The third type of EXCEL files used in DEEP package is a single copy of "*Deep.xls*" stored in the directory of ***C:\Program Files\Deep20***. This file contains the user friendly interface, which helps the user to work more comfortably. It helps the user to create and maintain *Comparative Presentations*. Both user types of EXCEL files – "***Calc***" and "***CP***" sheets are inside *Deep.xls* provided with set of predefined graphs which are updated according values in the selected cases.

There are other files in the directory of ***C:\Program Files\Deep20***, which are needed for DEEP to work. A substantial part of DEEP 2.0 are Excel files with the definition of separate technology modules. These files are the core of the DEEP 2.0 subsystem for composition cases from modules.

Note: All these control files are part of the licensed IAEA's software property and are not recommended to be browsed by common DEEP users and has not to be changed in any case.

5. DEEP CALCULATION STRUCTURE

5.1. OVERVIEW

An overview of the DEEP calculation structure is presented in Fig. 11. Basically, DEEP consists of the sections

- Input,
- Performance calculation of energy source,
- Performance calculation of water plant,
- Cost calculation and economic evaluation,
- Output.

Each section has several modules, which are shown as bold text in rounded frames. They are illustrated in more detail in Figs 12 to 33. Relevant calculation steps are shown as rectangles and are described below. The symbols in the figures and formulas correspond to those in the DEEP spreadsheets. Data transfers from and to other modules are indicated as arrows.

The input is grouped into

- User's input (same as 'Welcome input' in Section 7),
- Default data (which may be changed by an experienced user), and
- Model parameters (which should normally not be changed).

The 'User's input' refers to data for which the user is prompted to either provide data for his specific case or to use data from a sample case.

Default data are some kind of standard data, which will often apply, but may be changed by an experienced user if this user has different information on the subject.

Model parameters are internal to the DEEP model, and are thus not subject to input by the user. However, an experienced user may in some cases vary some model parameters, e.g. to evaluate an innovative technology with different model parameters.

The input data are the basis for calculations of energy source and desalination plant performance, costs and economic evaluation. The input requirements are discussed in more detail in Section 6, and the output definitions and options in Section 6.9.

5.2. BASE POWER PLANT PERFORMANCE CALCULATION (ELECTRICITY ONLY)

5.2.1. Steam power plant

A scheme of the base steam power plant performance calculation is presented in Fig. 12.

Relevant steps are the calculation of the site specific average condensing temperature, the site specific net electric power and the condenser reject heat load.

If the site specific average condensing temperature Tc differs from the reference condensing temperature Tcr, the site specific net unit power output Pen is recalculated using the low pressure turbine stage model described under 5.3. The site specific plant net power output is then calculated by multiplying the site specific net unit power output by the number of units.

The condenser reject heat load Qcr from the thermal power Qtp and the gross electric power Peg. The gross electric power Peg, condenser reject heat load Qcr and site specific average condensing temperature Tc are relevant inputs to the dual purpose power plant performance calculation.

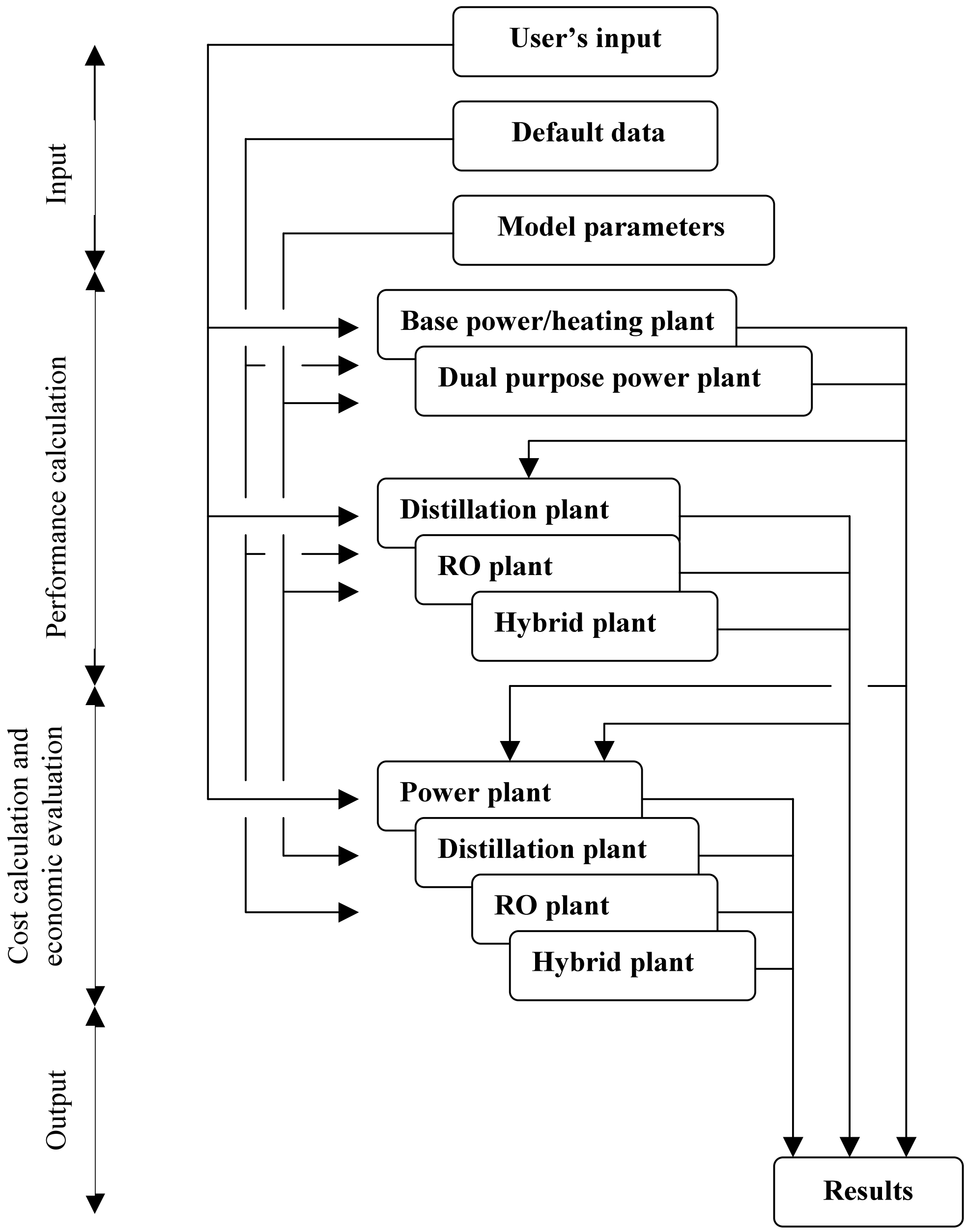


Fig 11. DEEP flow chart overview.

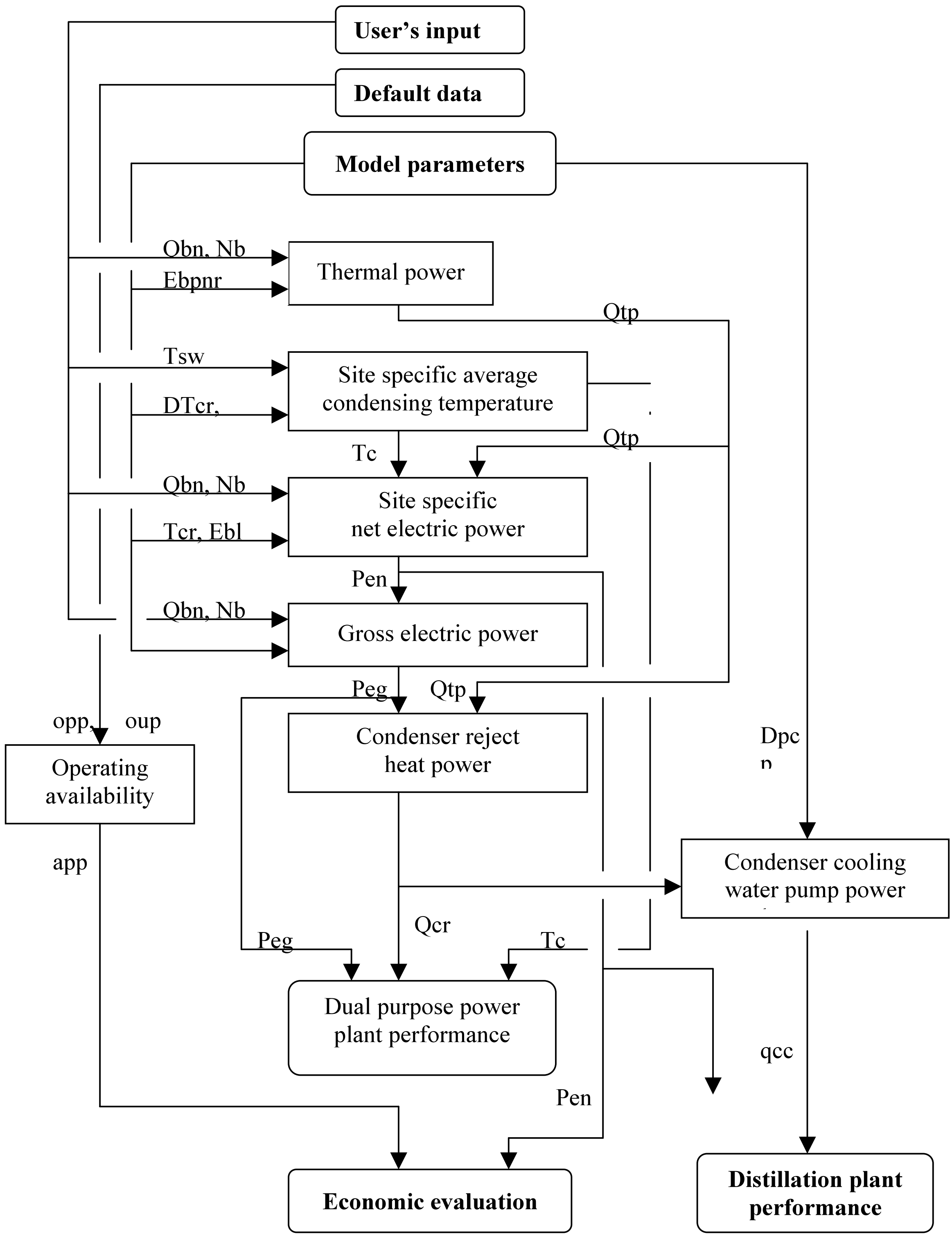


Fig 12. Performance calculation for base steam power plant.

5.2.2. Gas turbine plant

DEEP includes models of two gas turbines (GT). The first one, the GE MS 9001E with a gross output of 123.6 MW(e), represents a conservative design with a gross thermal efficiency of 33.6% at ISO conditions (15C, 60% humidity). The second one, the GE PG 9331(FA) with a gross output of 226.5 MW(e), represents a more advanced design with a gross thermal efficiency of 35.6% at ISO conditions. The performance models of the gas turbines (gross power, gross efficiency and exhaust temperature as a function of inlet air temperature) are presented in Figs 13 and 14. As the graphs show, the gross power, exhaust temperature and gross efficiency vary with the inlet air temperature. The gross power and gross efficiency are therefore recalculated for the site specific air temperature.

5.3. MODIFIED (DUAL PURPOSE) POWER PLANT PERFORMANCE CALCULATION

This calculation is required for steam or CC power plants coupled to a distillation process (MED or MSF) in order to determine the amount of low pressure (LP) steam available for a distillation process, and the lost electricity production. The net power output of the dual purpose power plant is of course less than the output of the base power plant if LP steam is extracted for heating the brine to the maximum brine temperature. The calculation procedure is illustrated in Fig. 15. No such calculation is done for GT plants since waste heat can be used to raise steam for a distillation process.

DEEP calculates the lower limit of the maximum brine temperature, i. e. the temperature required to attain the specified water production capacity of the distillation plant with the full amount of exhaust (backpressure) steam of the power plant. The upper limit of the maximum brine temperature is determined by corrosion and scaling limits of the distillation process (120C for MED, 135C for MSF). For extraction/condensing turbines, the user can specify a maximum brine temperature between the lower and upper limit, in line with the turbine design. A logic flow diagram of the extraction/condensing turbine model is presented in Fig. 16.

The procedure to calculate the minimum required maximum brine temperature is illustrated in Fig. 17 for a MSF plant. The procedure is similar for a MED plant but differs in the following way:

- The overall working temperature (difference of the maximum brine temperature Tmb and the seawater temperature Tsw minus the temperature difference between brine and seawater temperature in the last stage (effect)) is first used to calculate the number of effects from an empirical relationship and then the GOR from another empirical relationship.
- The upper limit for the maximum brine temperature is 120°C (135°C for MSF).

The procedure varies also slightly among different energy sources, but the main logic remains as in Fig. 17.

The modified condensing temperature is calculated from the maximum brine temperature plus the effective first stage temperature drop (condenser approach plus intermediate loop temperature drop, if applicable).

The lost shaftwork qls is then calculated as the mechanical work that would result from extracted steam expansion from the modified condensing temperature to the site specific average condensing temperature. This is approximated by:

qls = Qcr*Et*etac/(1-Et*etac)

Qcr = condenser reject heat load of the extracted steam

Et = isentropic expansion efficiency 0.6 for nuclear LP turbine stages
0.85 for fossil LP turbine stages

etac = Carnot efficiency = (Tcm – Tc) / (Tcm + 273)

Tcm = modified condensing temperature

Tc = site specific average condensing temperature of base power plant.

Text cont. on p. 41.

GE (MS 9001E)

Site and Gas Turbine Conditions:

Ambient Pressure:	1013 mbar
Relative Humidity:	60 %
Inlet Loss:	102 mm H_2O
Exhaust Loss:	254 mm H_2O
Fuel:	Standard Natural Gas (CH_4)
Fuel Temperature:	27 °C
Fuel LHV:	50.044 kJ/kg
NOX Suppression:	no injection
Turbine Speed:	3000 RPM

Power Output: **gross at generator terminals**

Base Load Operation

GE (MS 9001E)

Air Inlet Temperature	°C	12	20	28	36	44	15(ISO)
Power	MW	125	118.8	112.5	106.1	99.8	123
Gross Efficiency	%	33.8	33.5	33.0	32.5	31.8	33.8
Airflow	kg/s	407.9	394.3	380.4	365.9	351.3	
Pressure Ratio		12.5	12.1	11.7	11.2	10.8	12.3
Exhaust Flow	kg/s	414.6	400.7	386.5	371.8	356.9	410
Exhaust Temperature	°C	538	543	549	555	561	539
Fuel Flow	kg/s	7.38	7.09	6.81	6.53	6.27	

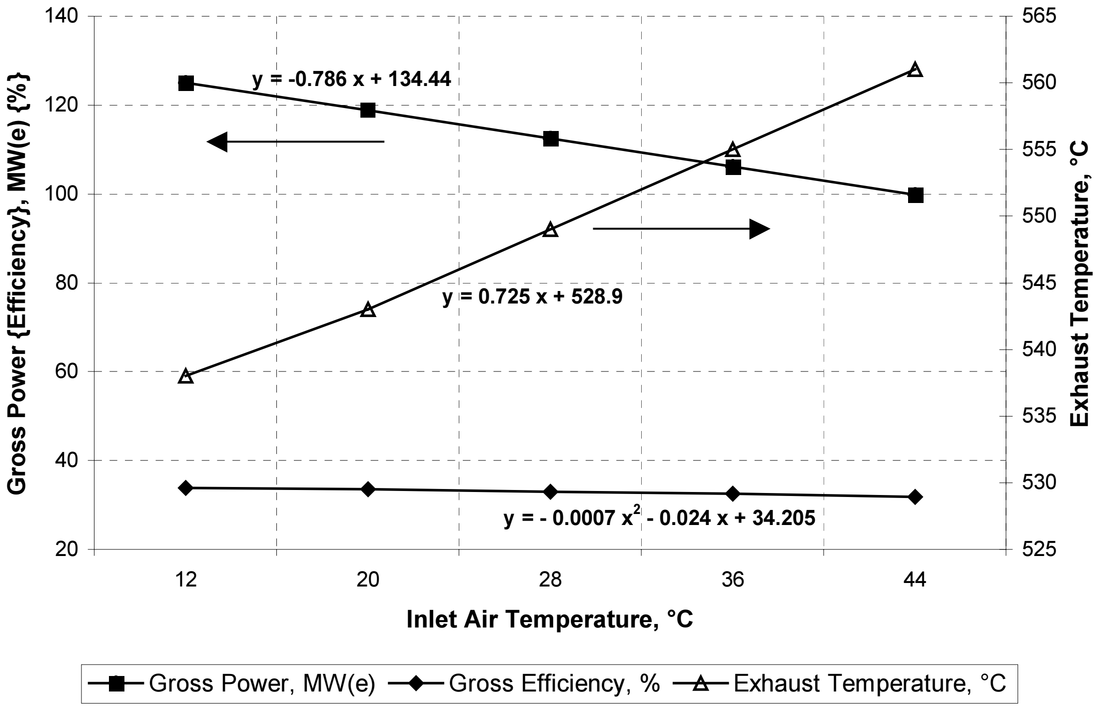


Fig 13. Performance characteristics of the conservative GT plant.

PG 9331 (FA)
Site and Gas Turbine Conditions:

Ambient Pressure:	1013 mbar
Relative Humidity:	60 %
Inlet Loss:	102 mm H_2O
Exhaust Loss:	254 mm H_2O
Fuel:	Standard Natural Gas (CH_4)
Fuel Temperature:	27 °C
Fuel LHV:	50.044 kJ/kg
NOX Suppression:	no injection
Turbine Speed:	3000 RPM

Power Output: **gross at generator terminals**

Base Load Operation

GE PG 9331 (FA)

Air Inlet Temperature	°C	12	20	28	36	44	15(ISO)
Power	MW	222.7	215.9	204.0	192.0	180.8	226.5
Gross Efficiency	%	35.5	34.9	34.4	33.7	32.9	35.6
Airflow	kg/s	610	589	571	556	535	
Pressure Ratio							15
Exhaust Flow	kg/s	623	602	583	568	546	613
Exhaust Temperature	°C	591	598	605	612	618	589
Fuel Flow	kg/s	12.8	12.4	11.9	11.4	11	

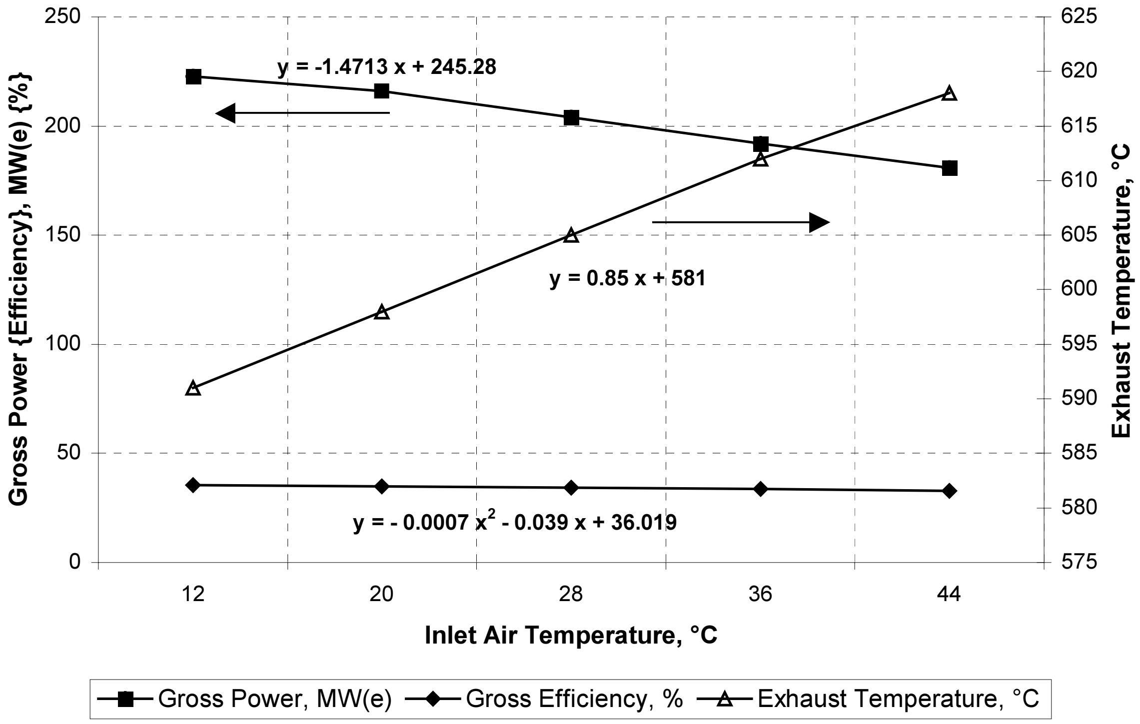


Fig 14. Performance characteristics of the advanced GT plant.

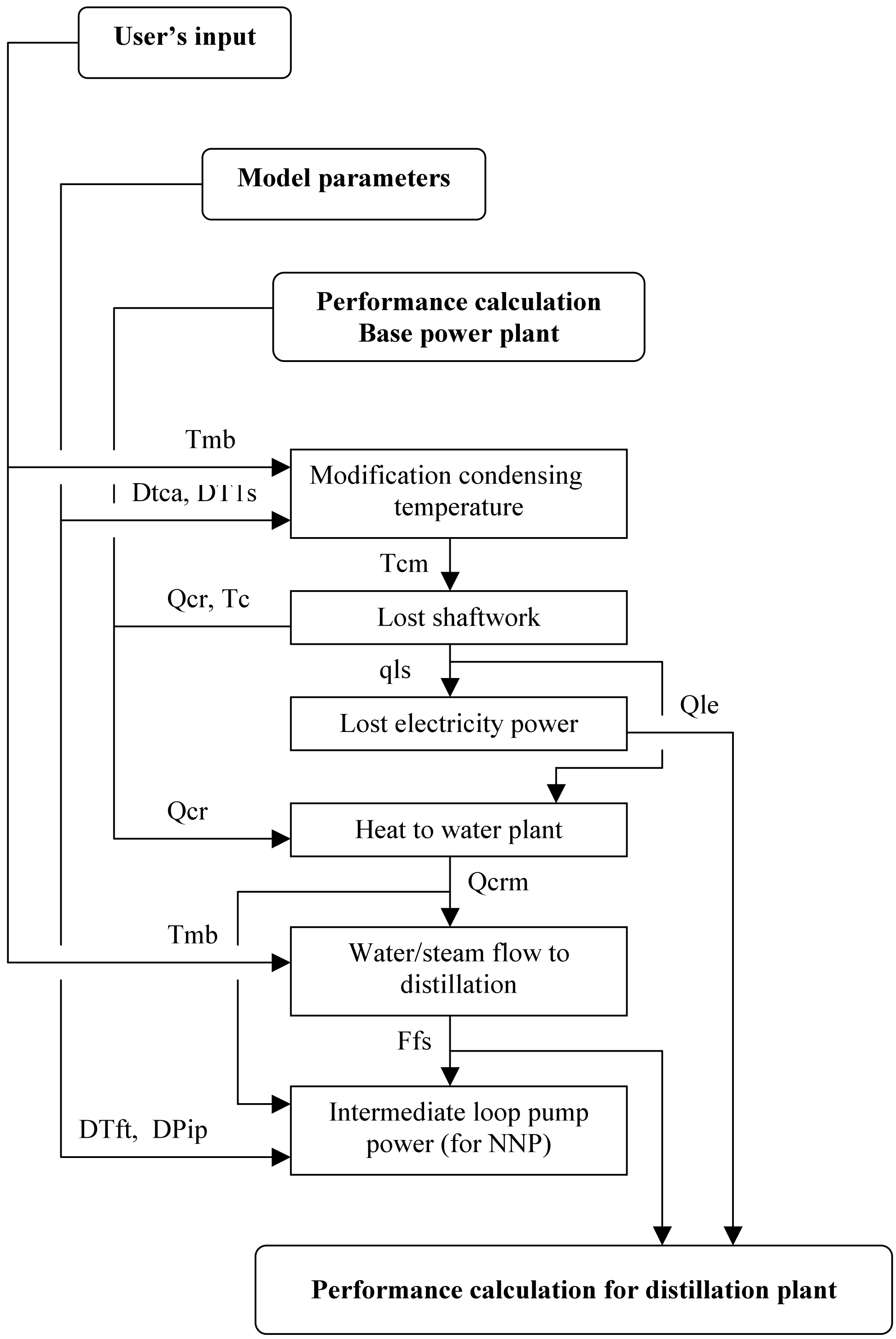
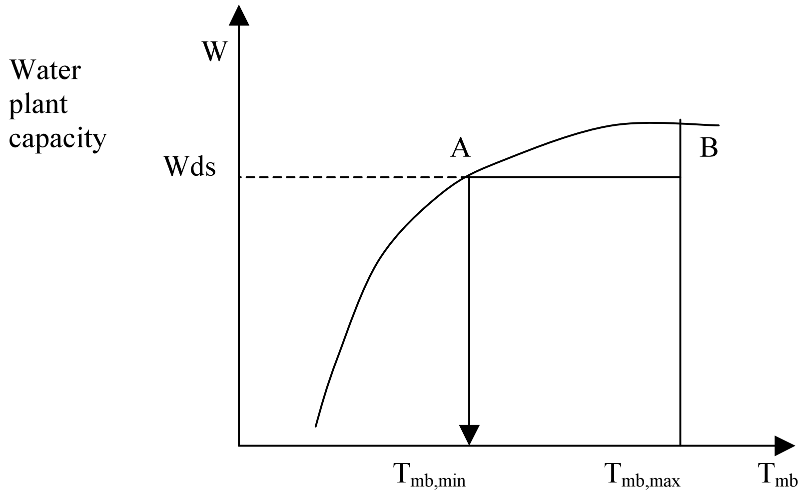


Fig 15. Performance calculation – Dual purpose power plant.



Wds: Requires distillation plant capacity, m^3/d
T_{mb}: Maximum brine temperature, °C
AB: Temperature range of T_{mb} °C to produce Wds with an extraction/condensing turbine,
$T_{mb,min}$: Lowest maximum brine temperature required to produce Wds, °C
$T_{mb,max}$: Technical limit of maximum brine temperature of distillation plant, °C (135 °C for MSF, 120 °C for MED)

Input: Wds, Power plant type, Number of power plant units, Distillation plant type

↓ (Macro, T_{mbf}) for fossil plant; T_{mbn} for nuclear plant

$T_{mb.\ min}$

Output: ↓ Range of T_{mb} ($T_{mb.\ min} \leq T_{mb} \leq T_{mb.\ max}$)

The user is informed on $T_{mb.\ min}$, and has the choice to specify $T_{mb.}$ According to the allowed range. The performance calculation continues as follows:

Input: T_{mb} (specified by the user)

↓ GOR GOR of MSF/MED plant

↓ Qcrm Total heat to MSF/MED plant

↓ qls Lost shaft work

Output: ↓ Qle Lost electricity production MW(e)

Fig 16. Logic flow diagram of the extraction/condensing turbine model in DEEP.

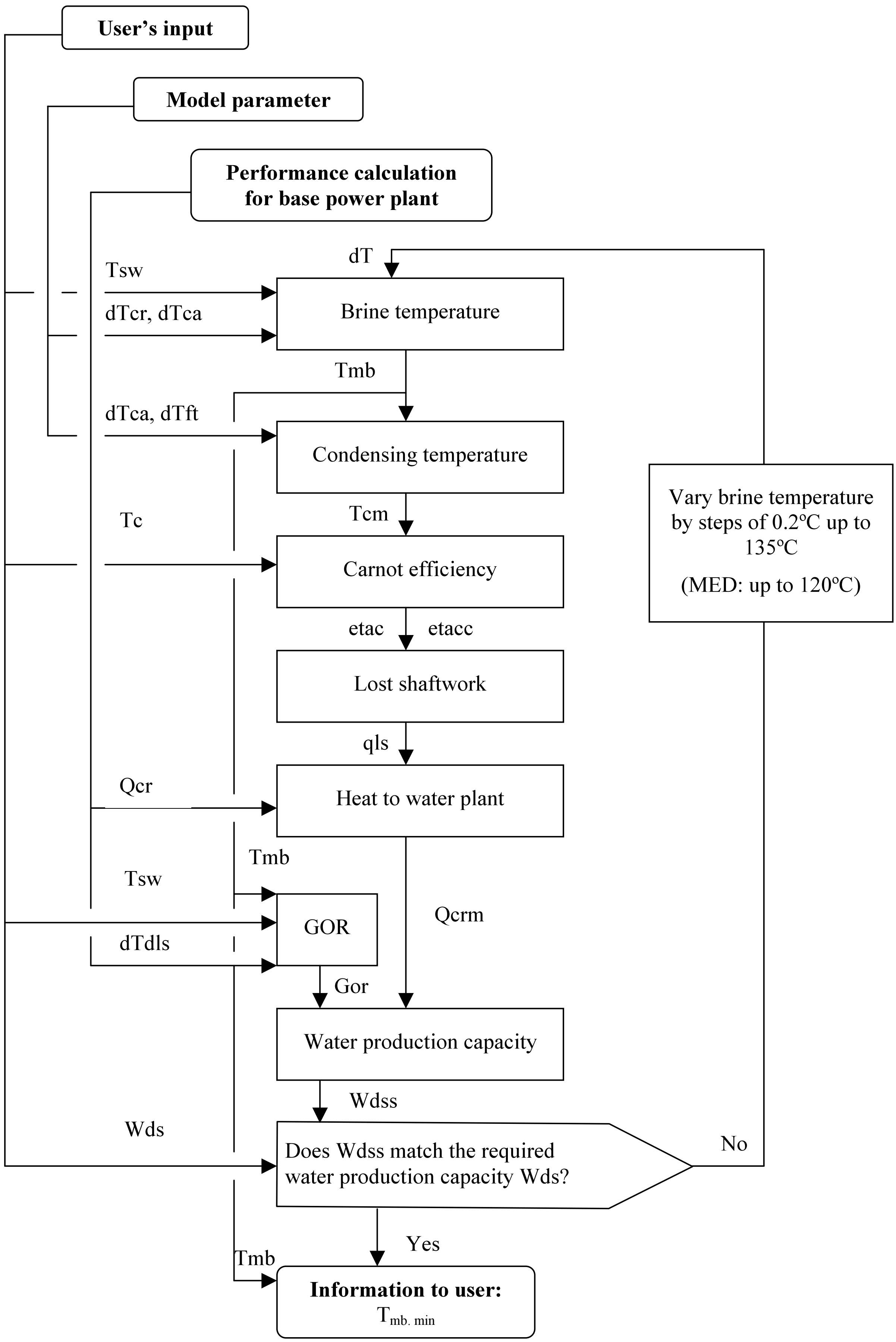


Fig 17. Calculation of the minimum required maximum brine temperature for a MSF plant.

The isentropic expansion efficiency of nuclear LP turbine stages is lower than for fossil LP turbine stages mainly because nuclear LP turbines use saturated steam whereas LP turbines of fossil fired plants use superheated steam.

The lost electric power Qle is calculated from

Qle = qls*(turbine mechanical efficiency)*(generator efficiency) [MW(e)]

turbine mechanical efficiency:	0.988 (typical value)
generator efficiency:	0.985

The total heat Qcrm delivered to the water plant is

Qcrm = Qcr+qls [MW(th)]

Qcr = condenser reject heat load

The water production capacity Wdss is then calculated from the GOR, the heat to water plant Qcrm and the maximum brine temperature Tmb. Wdss is compared to the required water production capacity Wds (user's input). If Wdss and Wds don't match, the procedure is repeated with a 0.2°C higher maximum brine temperature until Wdss and Wds will match.

As a result of the procedure, the user is informed on the minimum required maximum brine temperature Tmbmin to attain the specified water production capacity with the given capacity of the energy source (backpressure turbine).

The user may put in this or a higher temperature Tmb, but must stay within the techno-economic limits of about 70–120°C for MED and 70–135°C for MSF (once-through).

Specifying a higher temperature Tmb would mean that steam would be extracted at a higher temperature and pressure from an extraction/condensing turbine. This lower amount of steam would be sufficient to attain the specified water production capacity, but would have a higher energy content.

The heat is delivered from the dual purpose power plant as hot water to a MSF plant or as steam to a MED plant. The steam flow Ffs is the total heat to the water plant divided by the latent heat of evaporation/condensation:

Ffs = Qcrm/(598–0.6*Tmb)/4.1868*1000 [kg/s]

When a nuclear plant is coupled to a MED or MSF plant, an intermediate loop is required as a barrier against possible contamination of the product water. The intermediate loop water flow rate Fil is the total heat to water plant Qcrm divided by the specific heat cp of water and the modified condenser range Tmcr:

Fil = Qcrm/cp/Tmcr*1000 [kg/s]

cp is 4.1875 J/g/°C and about 4.0 J/g/°C for saline water.

The intermediate loop water flow rate Fil is then used to calculate the pumping power qil. The modified condenser range Tmcr is the difference of the modified condensing temperature and the condenser inlet temperature.

5.4. DISTILLATION PLANT PERFORMANCE CALCULATION

5.4.1. Distillation plant performance I

The distillation plant performance I calculation is illustrated in Fig. 18. Relevant steps are the calculation of:

- Overall working temperature DTao,
- Gained output ratio (GOR),
- Maximum production capacity Wcd and installed capacity Wacd,
- Net saleable power Qdsp.

The overall working temperature DTao is calculated from the maximum brine temperature Tmb, the last stage temperature DTdls (heat reject temperature) and some small temperature differences.

The gained output ratio GOR of a MSF plant is calculated from the relationship presented in Fig. 20:

GOR = Qr,h/cH/dTdls*(1-exp(-cV,m*dTao/Qr,m))

Qr,h, etc. are defined in Fig. 20.

In numeric terms,

GOR = (598–0.6 * Tmb) * 4.1868 / 4.019 / DTdls *
* (1 – exp(–3.936 * (Tmb-Tsd-DTdls) / (598 – 0.3 * (Tmb+Tsd+DTdls)) / 4.1868)))

The gained output ratio GOR for a MED plant is calculated from the relationship presented in Fig. 21.

The maximum production capacity is calculated by multiplying the GOR and the water (MSF) or steam (MED) flow from the power plant to the distillation plant. This is used to determine the unit size Wdu and to calculate the number of units Ndu and the installed water plant capacity Wacd.

(Note: If the amount and quality of low grade steam required does not fit the amount and quality of steam available from the power plant or heating plant, recalculation with modified input data is required until the water plant requirements and heat source characteristics correspond to each other.)

The net saleable power Qdsp is calculated from the net electric power Pen of the base power plant, the lost electric power Qle and the total power use Qdp of the water plant. The latter includes the seawater pumping power qis.

The maximum production capacity Wcd is transferred to Distillation plant performance II, GOR, Wdu and Ndu to the cost calculation and the net saleable power Qdsp and total power use Qdp are transferred to the economic evaluation.

5.4.2. Distillation plant performance II

A flowsheet for the calculation of distillation plant performance II is presented in Fig. 19.

User's input, default data, model parameters and the results of distillation plant performance I calculation and of energy source performance calculation are used to calculate

- the water plant availability,
- combined power/water plant load factor,
- backup heat source load factor (if applicable),
- and the average daily water production.

The water production by the backup heat source will only be calculated if the user has set the backup heat source flag BK to Y (yes). In general, the user is advised not to use the backup heat source option since the backup heat source will usually have a low utilisation factor (could be about 15%), and will raise the levelised water production cost.

Text cont. on p. 47.

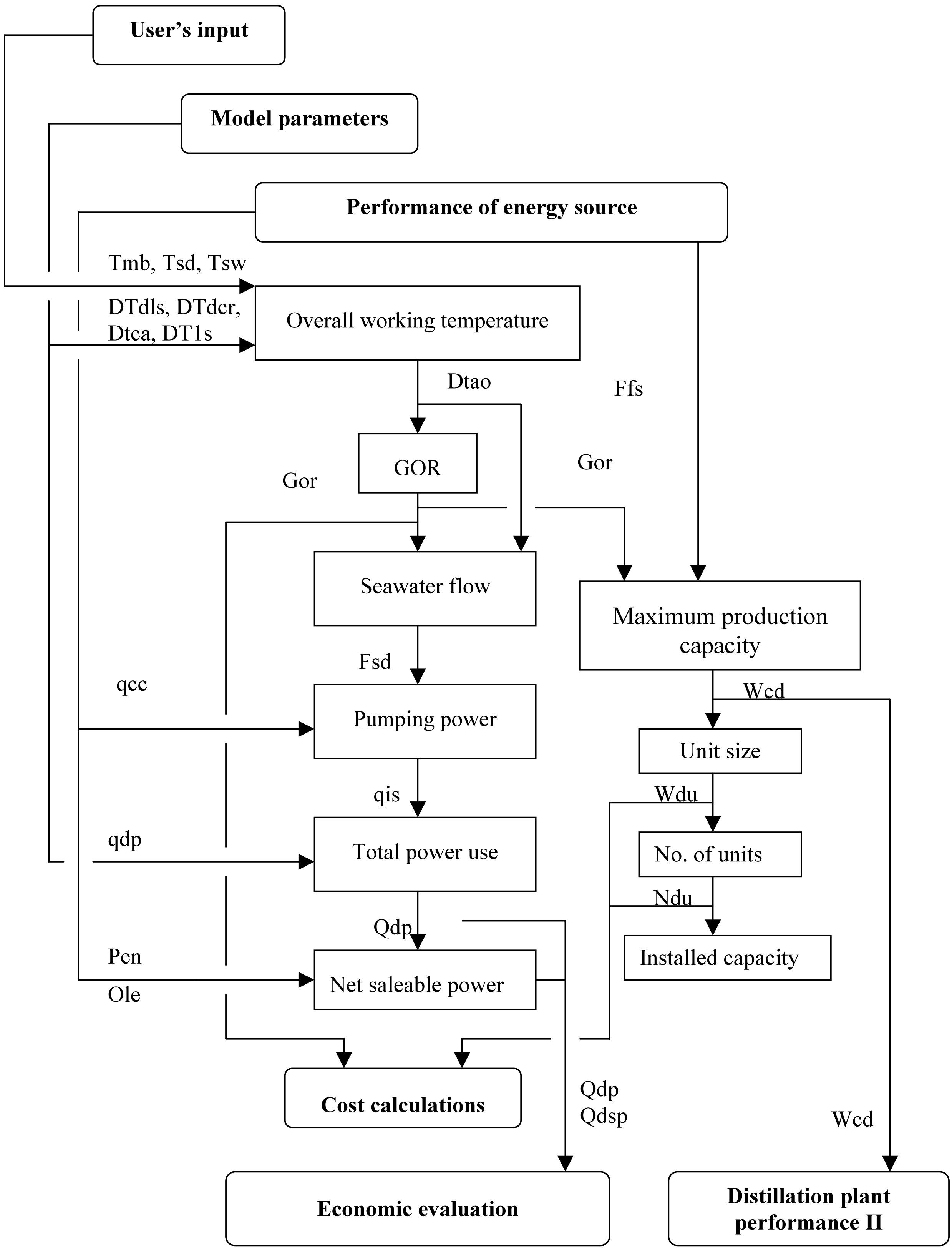


Fig 18. Distillation plant performance I – Calculation of water production capacity.

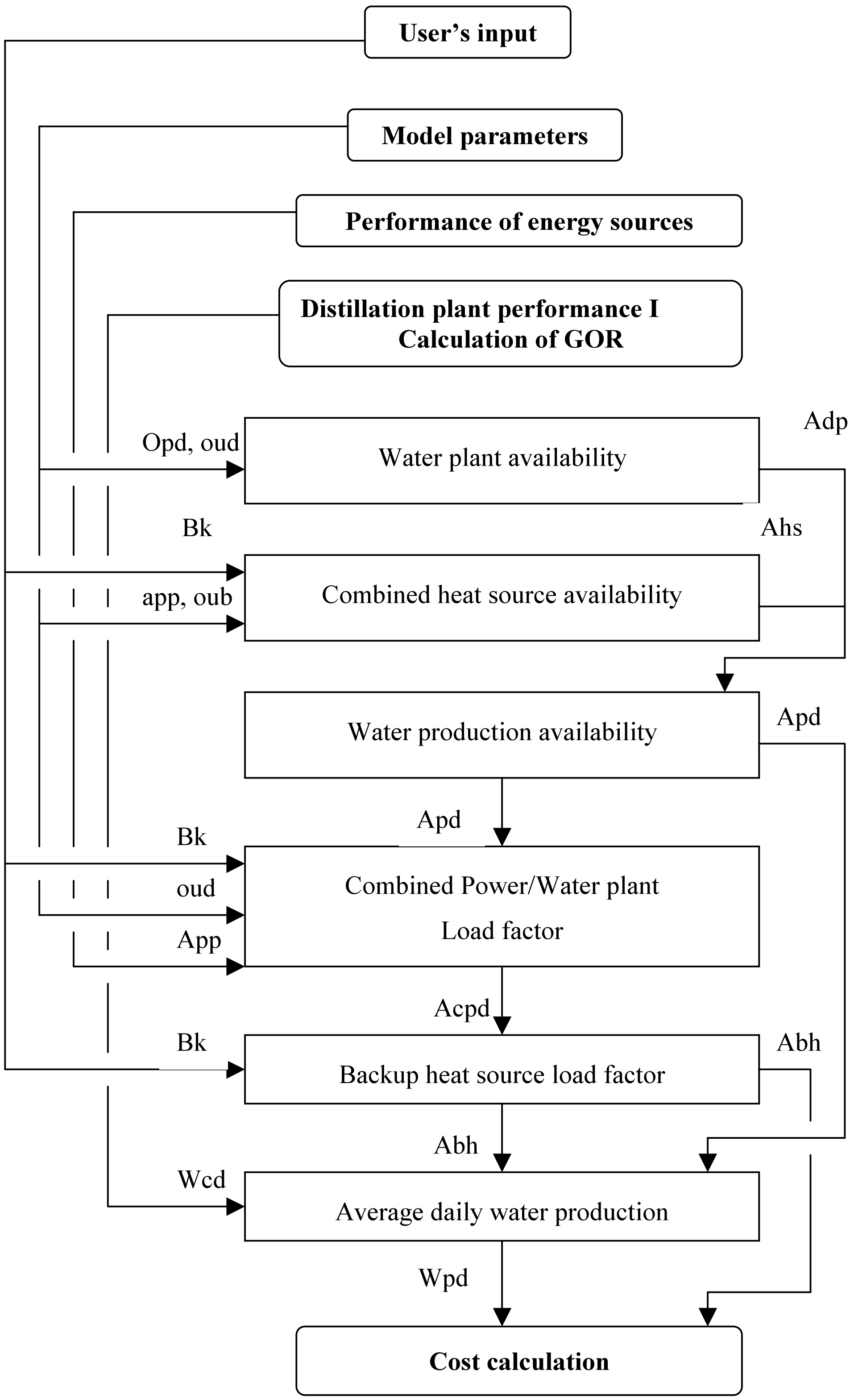


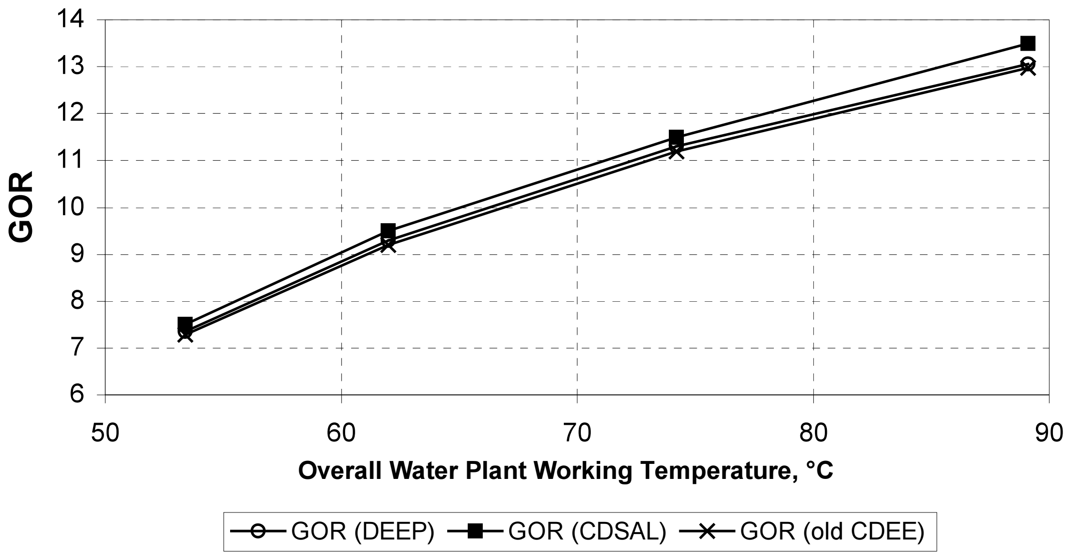
Fig 19. Distillation plant performance II – Calculation of water production.

Tsw	seawater temperature, °C
Tmb	maximum brine temperature, °C
dTdls	brine to seawater temperature in last stage, °C
dTao	= Tmb – Tsw – dTdls, overall working temperature, °C
GOR (DEEP)	GOR calculated with DEEP
GOR (CDSAL)	GOR calculated with simulation code CDSAL
GOR (old CDEE)	GOR calculated in old CDEE version

Sample Calculations for Validation

Tsw	30	30	30	30
Tmb	125	110	98	90
dTdls	5.9	5.8	6	6.6
dTao	89.1	74.2	62	53.4
GOR (DEEP)	13.05	11.30	9.29	7.36
GOR (CDSAL)	13.50	11.50	9.50	7.50
GOR (old CDEE)	12.97	11.20	9.20	7.28
Deviation CDSAL/DEEP, %	+ 3.3	+ 1.7	+ 2.2	+ 1.9
Deviation CDSAL/CDEE, %	+ 3.9	+ 2.6	+ 3.2	+ 2.9

GOR(new) = Qr,h / cH / dTdls * (1 – EXP(–cV,m * dTao / Qr,m))



Note: dTdls varies from case to case

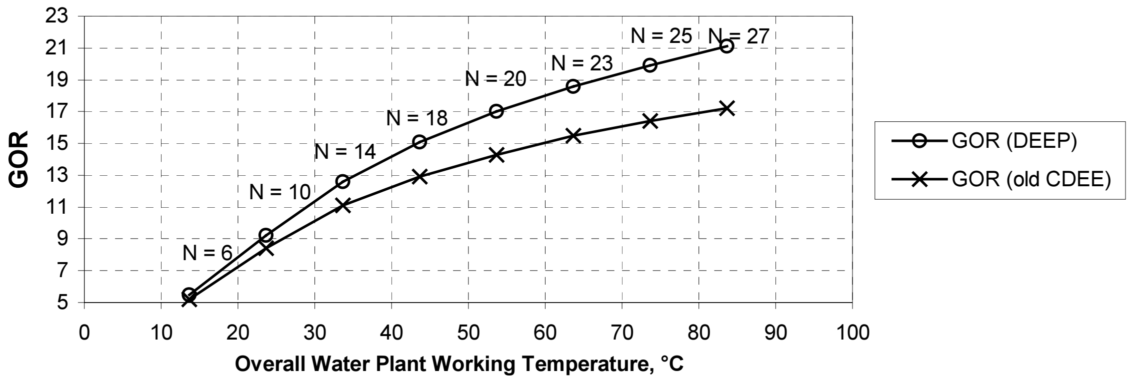
GOR(new)	=	Gained Output Ratio, simplified equation taken from Fichner hadbook of seawater desalination, valid for large No. of stages
Qr,h	=	(598 – 0.6 * Tmb) * 4.1868 , latent heat of heating vapour, kJ/kg
Qr,m	=	(598 – 0.6 * (Tmb+Tsw+dTdls)) * 4.1868 , average latent heat of water vapour in MSF stages, kJ/kg
cH	=	average specific heat capacity of feedwater in brine heater, 4.019 kJ/kg/K
cV,m	=	average specific heat capacity of brine in MSF plant, 3.965 kJ/kg/K

Fig 20. MSF-OT performance model – Validation of the new model.

Tsw	seawater temperature, °C
dTdca	condenser temperature approach, °C
dTdcr	condenser temperature range, °C
Tmb	maximum brine temperature, °C
Tdc	last effect steam temperature, °C
dTae	average temperature drop in effects, °C
dTdo	overall working temperature, °C
dTbe	average boiling point elevation, °C
Nmed	number of effects
GOR (DEEP)	GOR calculated with a new equation
GOR (old CDEE)	GOR calculated in old CDEE version

Sample Calculations for Validation

Tsw	30	30	30	30	30	30	30	30
dTdca	2	2	2	2	2	2	2	2
dTdcr	5	5	5	5	5	5	5	5
Tmb	50	60	70	80	90	100	110	120
Tdc	37	37	37	37	37	37	37	37
dTae	2.4	2.4	2.4	2.5	2.6	2.8	3.0	3.1
dTdo	13.7	23.7	33.7	43.7	53.7	63.7	73.7	83.7
dTbe	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Nmed	6	10	14	18	20	23	25	27
GOR (DEEP)	5.5	9.2	12.6	15.1	17.0	18.6	19.9	21.1
GOR (old CDEE)	5.2	8.4	11.1	12.9	14.3	15.5	16.4	17.2



GOR(new) = Qr,h / (Qr,m * dTae / dTdo + 4.019 * (dTph + dTbe))

Rautenbach R., Progress in Distillation, Desalination, 93 (1993) 1–13

Qr,h	=	latent heat of heating vapour, kJ/kg
Qr,m	=	average latent heat of vapour in MED effects, kJ/kg
dTph	=	temperature increase in feedwater pre-heater, 4°C

Notes:

– average temperature drop in effects dTae is estimated by the following equation [5]:
 dTae = 1.65 + (0.0185 * dTdo)^0.85; > 2.3
– deviations from dTae are not considered
– concentration factor CF = 2

Fig 21. MED performance model – Comparison of the new and old model.

In practice, a backup heat source will often not be required since:

- Water storage or other water resources can be temporarily over-exploited,
- The planned power plant outage is used for scheduled maintenance of the water plant,
- Demand management measures may lower the demand by some consumers.

In some situations, a small backup heat source or VC unit may be installed.

5.5. RO PLANT PERFORMANCE CALCULATION

The RO plant performance calculation procedure is illustrated in Fig. 22.

The main input parameters are:

- Sea water characteristics (salinity TDS, temperature Tsm),
- RO membrane characteristics (hollow fibre or spiral wound membrane),
- Required water plant capacity Wcst [m^3/d].

The feedwater salinity is abbreviated below as TDS(in) (TDS = total dissolved solids). Relevant results of RO plant performance calculation include the inlet and outlet osmotic pressure, the recovery ratio, plant installed capacity and water production, power use and factors for cost adjustments due to membrane area and other equipment, including piping and feed water pre-treatment. The flow diagram of the calculation procedure is shown in Fig. 22.

The inlet osmotic pressure Pio is calculated approximately from

$$\text{Pio} = 0.0000348*(\text{feed inlet temperature} + 273)*\text{TDS(in)}/14.7 \quad [\text{bar}]$$

The performance relations were derived from the simulation programs. To produce water of the required quality at low cost, the recovery ratio (ratio of product water to seawater feed amount), the required feedwater pressure and number of membrane elements/permeators depend on feedwater temperature and salinity.

In Figs 23 and 24, recovery ratio and feedwater pressure for spiral wound membranes are given. The recovery ratio is reduced with increasing salinity and increasing feedwater temperature. In the temperature range of 15 to 25°C, the feedwater pressure has to be raised with increasing temperature not exceeding the maximum element recovery[2]. In the temperature range of 25 to 40°C, the feedwater pressure can be reduced if the TDS of the feedwater is low. For high TDS feedwater, the feedwater pressure has to be raised to keep the chloride ions below the required level of 250 ppm. In Fig. 25, the number of pressure vessels as a function of feedwater salinity and temperature is shown resulting from the respective recovery ratio and feedwater pressure.

In Figs 26 and 27, recovery ratio and feedwater pressure for hollow fibre membranes are given. The recovery ratio is reduced with increasing salinity from 50% at 35 000 ppm TDS to 40% at 45 000 ppm TDS, independently of the temperature. For temperatures below 29°C, the feedwater pressure is raised with increasing temperature from 70 bar at 35 000 ppm TDS to 83 bar at 45 000 ppm TDS. For feedwater temperatures higher than 29°C, the feedwater pressure has to be reduced with increasing temperature to prevent membrane compaction. The number of permeators resulting from the respective recovery ratio and feedwater pressure is given in Fig. 28. For temperatures above 30°C, the number of permeators is increasing tremendously.

Algorithms of Figs 23 to 28 were extrapolated and incorporated in DEEP. To adjust the equation of the number of pressure vessels/permeators to the *membrane area factor* used in CDEE, the equation was divided by the number of pressure vessels/permeators achieved at reference conditions (25°C, 35 000 ppm). It should be mentioned that the layout of the membrane systems is based on system design guidelines of manufactures. These guidelines are only recommendations, which could be by-passed in some cases. However, such a thorough evaluation should be performed by RO experts using RO design programs rather than DEEP.

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[2] The element permeate flow is increasing with increasing feedwater pressure, however, the element feedwater flow is increasing, too.

The outlet TDS concentration is calculated from

$$TDS(out) = TDS(in)/(1–Rro)$$

The outlet osmotic pressure Poo is calculated approximately from

$$Poo = 0.0000348*(\text{feed inlet temperature} + 273)*TDS(out)/14.7$$

The factors for adjustment of membrane area, piping and pre-treatment are calculated from empirical approximations.

The unit size Wmu (usually 12 000 or 24 000 m^3/d) is selected (user's input or default value) and the number Nms of RO units calculated from the required production capacity Wcst [m^3/d] by

$$Nms = \text{integer } (Wcst/Wmu) +1$$

In this way, the number of RO units will be sufficient to meet at least the required water production capacity, and will provide some reserve in most cases.

The installed RO plant capacity Wacs is then calculated from

$$Wacs = Nms*Wmu \quad [m^3/d]$$

and the annual water production Wpms is

$$Wpms = Wacs*Apm*365 \quad [m^3/a]$$

Apm = RO plant availability (input or default value)

The seawater flow Fsms is then calculated from the installed RO plant capacity Wacs and the recovery ratio Rro by

$$Fsms = Wacs/Rro*1000/24/3600 \quad [kg/s]$$

The seawater pumping power Qsp is calculated from the sea water flow Fsms, the sea water pump head Psm and the efficiencies of the pump Esm and of the electric motor (assumed as 0.96):

$$Qsp = Fsms*Psm/(Esm*1000*0.96) \quad [MW(e)]$$

The booster pump power Qbp and high head pump power Qhp are calculated in the same way. The high head pump will require most of the electric power since it has to pressurise the seawater to 67 or 81 bar for spiral wound membranes and hollow fibre RO units, respectively. A fraction of this power is recovered by the energy recovery device. This is a hydro turbine (or reverse running pump) with the efficiency Eer, recovering energy from the pressurised reject brine. It is mechanically coupled to the high head pump shaft. The recovered power Qer is calculated from

$$Qer = Fsms*Psm*(1–Rro)*Eer/1000 \quad [MW(e)]$$

The recovered power will usually be less than 50% of the high head pump power.

The total RO power use Qms is then

$$Qms = Qsp+Qbp+Qhp–Qer+Qom$$

Qom = other power use of the plant (incl. lighting, etc.)

and the net saleable power Qssp is

$$Qssp = Pen–Qms$$

Pen = net power output of the base power plant.

The installed RO plant capacity, annual water production, total RO power use and the net saleable power are transferred to the cost calculation and economic evaluation modules.

The same procedure is applied for contiguous RO plants, which will use the condenser cooling water of the power plant, and will thus work at elevated feedwater temperature. The elevated feedwater temperature either can be specified by the user or will be calculated from the average seawater temperature and the condenser temperature range.

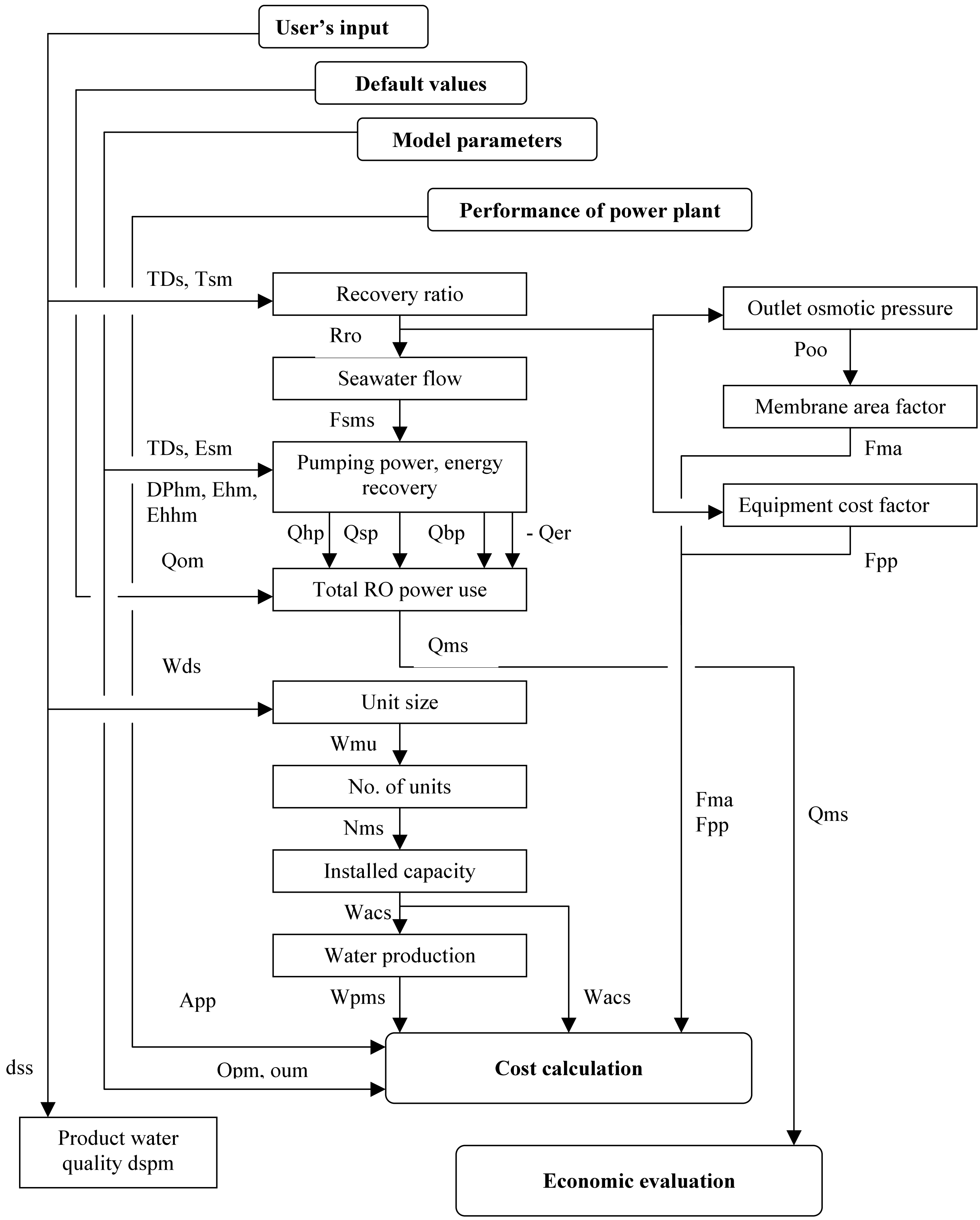


Fig 22. RO plant performance calculation.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
15°C	0.411	0.401	0.383	0.374
20°C	0.411	0.401	0.383	0.374
25°C	0.411	0.401	0.383	0.374
30°C	0.401	0.391	0.383	0.374
35°C	0.390	0.382	0.372	0.363
40°C	0.378	0.372	0.361	0.353

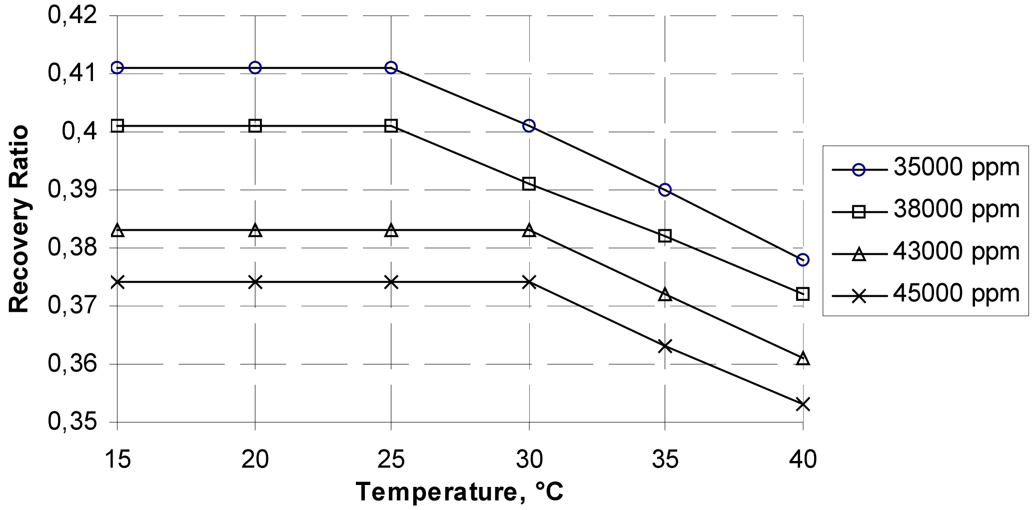


Fig 23. Recovery ratio of spiral wound membranes.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
15°C	62.7	65.3	67.7	68.4
20°C	64.1	66.4	68.3	68.8
25°C	65.9	68.0	68.8	69.2
30°C	62.2	65.3	66.4	68.5
35°C	58.2	62.4	67.8	68.8
40°C	55.0	59.1	69.0	69.2

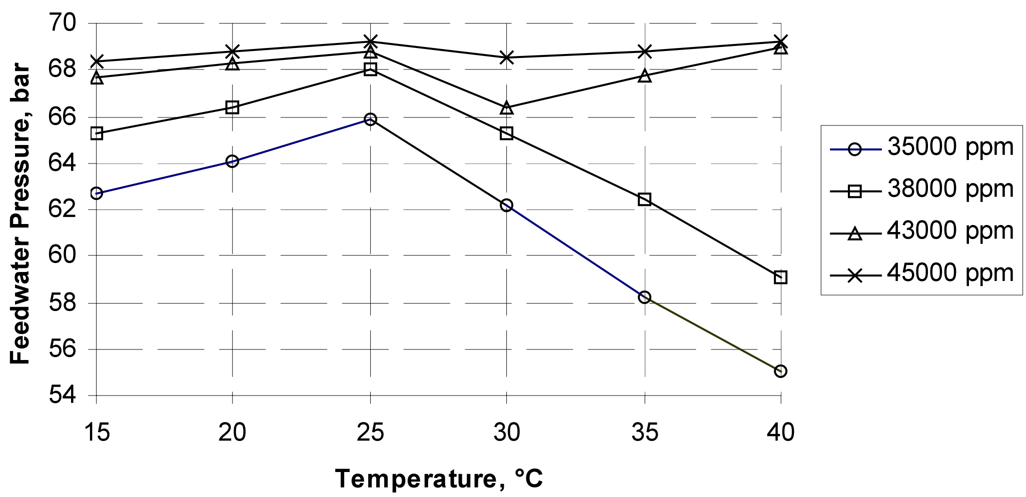
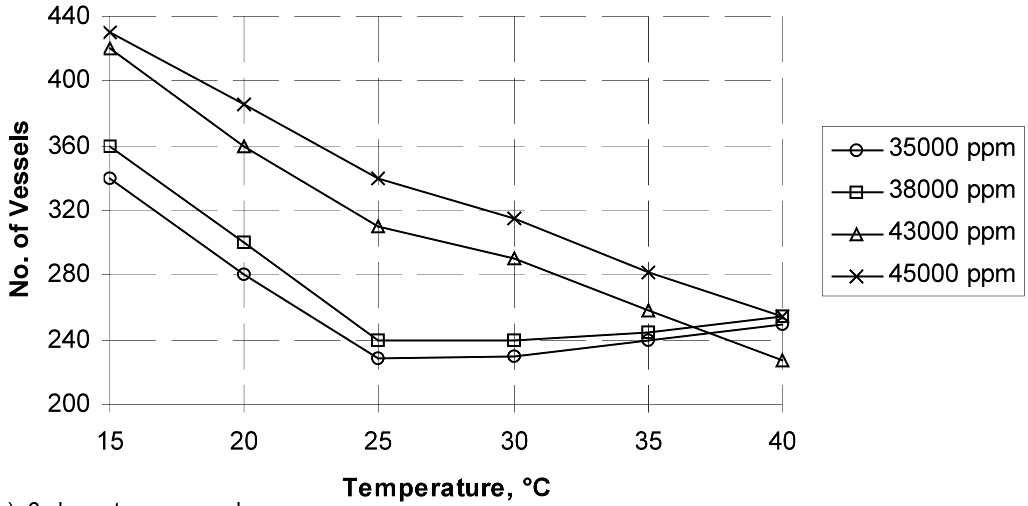


Fig 24. Feedwater pressure of spiral wound membranes.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
15°C	340	360	420	430
20°C	280	300	360	385
25°C	228	240	310	340
30°C	230	240	290	315
35°C	240	245	258	282
40°C	250	255	227	255



a) 6 elements per vessel

Fig 25. No. of membrane elements[a)] of spiral wound membranes.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
20°C	0.5	0.5	0.45	0.4
25°C	0.5	0.5	0.45	0.4
30°C	0.5	0.5	0.45	0.4
35°C	0.5	0.5	0.45	0.4

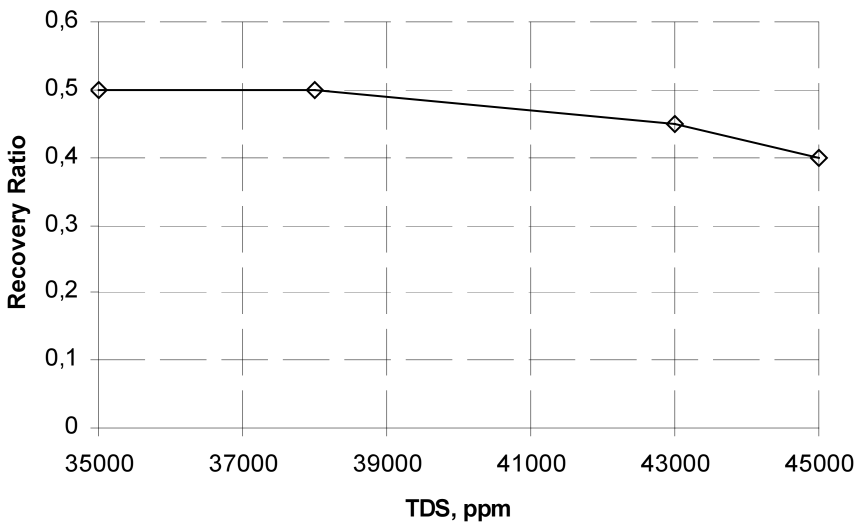


Fig 26. Recovery ratio of hollow fibre membranes.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
20°C	70.0	70.0	70.0	67.0
25°C	70.0	70.0	70.0	67.0
30°C	82.7	82.7	78.0	67.0
35°C	82.7	82.7	78.0	67.0

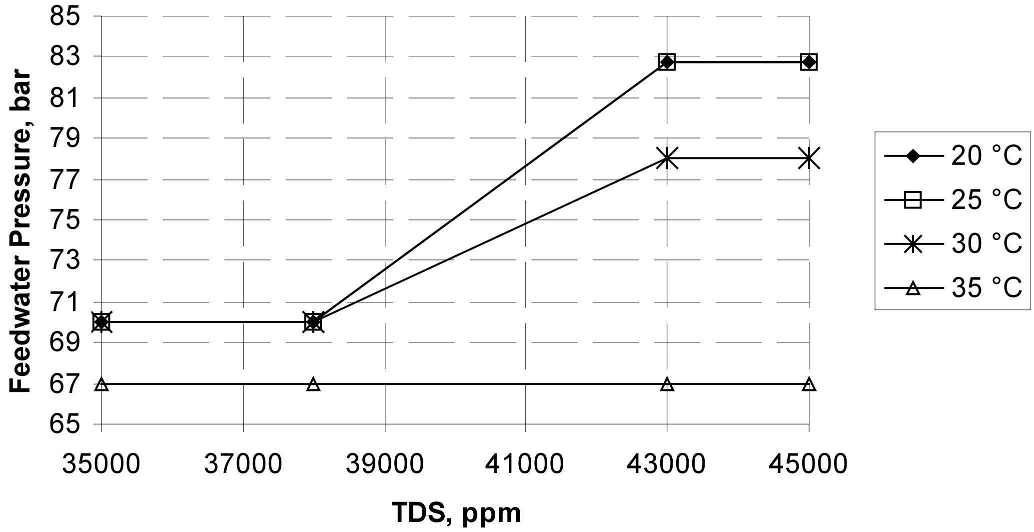


Fig 27. Feedwater pressure of hollow fibre membranes.

	35,000 ppm	38,000 ppm	43,000 ppm	45,000 ppm
20°C	358	405	375	371
25°C	345	392	377	373
30°C	344	394	410	405
35°C	431	506	590	577

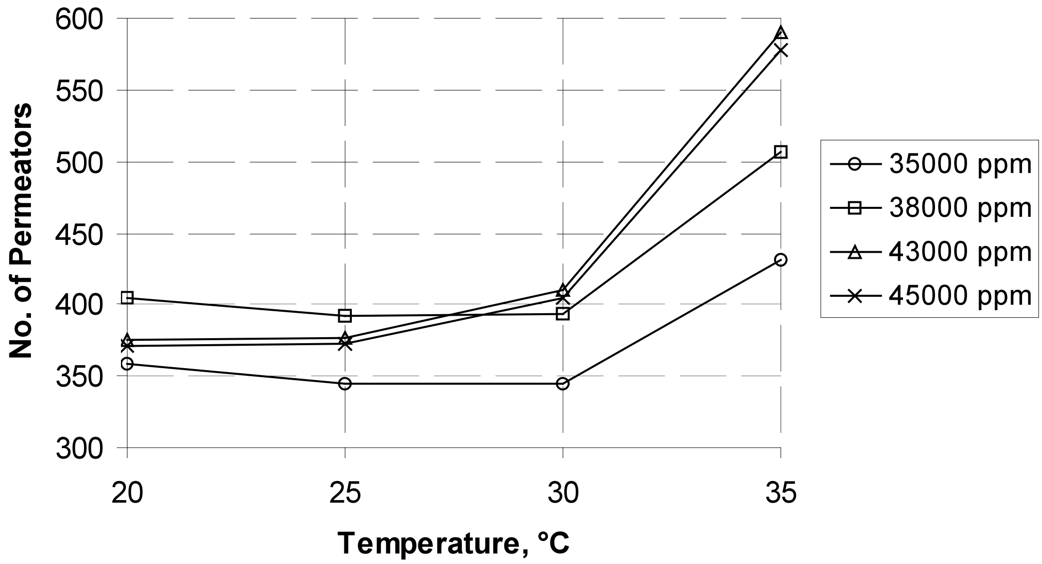


Fig 28. Number of permeators of hollow fibre membranes.

5.6. HYBRID PLANT PERFORMANCE CALCULATION

The hybrid plant consists of a distillation section with a water production capacity less than the one required by the user and an RO section to produce the balance. The capacity of the distillation section is calculated as described in Section 5.4.

The capacity of the RO section is the difference of the water production capacity required by the user, Wds, and the capacity of the distillation section, Wcd. This difference is used to calculate the RO unit size, Number of units, water production, power use, membrane area and equipment cost factors in the same way as for a stand alone RO plant (Fig. 22). The water production and power use is added to the results of the distillation plant performance calculation and transferred to the cost calculation and economic evaluation modules. The calculation procedure is illustrated in Fig. 29.

5.7. CALCULATION OF WATER PLANT CONSTRUCTION AND O&M COSTS

Cost calculations and economic evaluation are performed in constant money, i.e. excluding general inflation. However, for fuels projected to escalate faster or slower than general inflation, the appropriate real escalation rate can be put in by the user and is accounted for appropriately.

Flow charts of the calculation of water plant construction and O&M costs of distillation plants are presented in Figs 30 and 31. The water plant specific base cost (in US $/m^3.d) is calculated from empirical relations, taking into account factors for unit size, GOR/No. of effects, No. of units and model parameters. The specific costs are multiplied by the installed water plant capacity to obtain the costs in US $ millions. Costs for intake/outfall, intermediate loop and backup heat source (if applicable) are also calculated from empirical relations, and are added to obtain the plant base cost (in M$). The intake/outfall costs are calculated assuming common intake/outfall of power and water plant unless the user has specified incremental intake/outfall costs of the water plant.

Owner's costs and contingencies are added to the plant base cost to obtain the total construction cost (cdcon). Interest during construction (IDC) is assumed to be included in the empirical relations above.

The O&M costs are calculated from the user's input for salaries and wages and on empirical relationships for the number of management and labour personnel, materials cost and insurance cost. The number of management and labour personnel is multiplied by the respective wages/salaries, and the result added to materials cost and insurance cost to obtain the total O&M cost.

The calculation of RO plant construction and O&M costs follows the same logic as the procedure for distillation plants. The membrane replacement costs are levelised and included in the O&M cost.

5.8. ECONOMIC EVALUATION

5.8.1. Economic evaluation of the energy source

The economic evaluation of the energy source is illustrated in Fig. 32.

First, the construction cost Cecon (in M$) is calculated from the given specific construction cost (in $/kW(e), site related cost, unit net output and number of units. Then, the interest during construction (IDC) is calculated with the approximative formula

IDC = Cecon ((1+ idc/100)^ (Le/24) – 1

Cecon	M$	Total construction cost
idc	%	Interest rate during construction (user's input or default value)
Le	months	Construction lead time (user's input or default value)

For the approximation, it is assumed that the total construction costs are spent at mid-time of the construction period. Since the construction period Le is put in in months, and the interest rate on an annual basis, Le is divided by 24 in the above formula.

The IDC is then added to the total construction cost for obtaining the total plant investment Ceinv.

The fixed charge rate lfc is calculated from the interest/discount rate i and the plant economic life Lep. This fixed charge rate is multiplied by the total plant investment to obtain the annual levelised capital cost alcc.

The fuel cost levelisation factor is defined as the ratio of the present values of the lifetime fuel costs, including real escalation, and the unescalated lifetime fuel costs. It is calculated from the real escalation rate of the fuel price, the real interest rate i, the initial year of operation and the economic life of the power plant.

The levelised electricity cost is calculated on an annual basis by summing up the levelised capital cost, levelised decommissioning cost (if applicable), levelised fuel and O&M cost. The total of these costs, i.e. the (levelised) annual required revenue (in M$/a), is divided by the annual electricity generation (lpc, in kWh(e)) of the base power plant. The levelised electricity cost is subsequently taken to calculate the energy cost of the distillation plant (see Section 5.8.2).

The levelised heat cost of a heating plant is calculated accordingly, i.e. by summing up the levelised capital cost, levelised decommissioning cost (if applicable), fuel and O&M cost of the heating plant. The total cost is divided by the annual heat generation of the heating plant.

5.8.2. Economic evaluation of the distillation plant

Economic evaluation of a distillation plant is illustrated in Fig. 33. For dual purpose power plants, the levelised electricity cost (lpc, as calculated above) is used to calculate the energy cost adhc of the water plant by multiplying the sum of lost electricity generation Qle and the water plant electricity use by the electricity generation cost of the base power plant. This method is also referred to as power credit method by which full credit is given to the electricity generation cost, and the thermodynamic and cost benefit of combined production is given to the water production.

At heating plants, the energy cost of the water plant is the levelised heat cost as defined above.

If a backup heat source was specified, the backup heat cost is calculated from the levelised fuel cost (fuel price times levelisation factor, which accounts for real escalation), the backup heat source capacity and the backup heat source load factor.

The water production costs are then calculated by dividing the annual required revenue attributable to water production by the annual water production. The annual required revenue consists of the levelised annual capital cost and O&M cost of the water plant as well as the energy cost of the water plant including the backup heat cost, as defined above.

5.8.3. Economic evaluation of the RO plant

The economic evaluation of the RO plant is similar to the procedure for the distillation plant. It is less complex since there is no heat cost and there is no backup heat source, but the electricity consumption and cost are higher than those of distillation plants are.

The annual required revenue of the RO plant is calculated by summing up the levelised annual capital cost and O&M cost of the water plant as well as the electricity cost, which is calculated from the electricity use of the RO plant (Qms, see 5.5) and the levelised electricity cost (lpc, as calculated in Section 5.8.1). The water production cost is then calculated by dividing the annual required revenue by the annual water production.

Note to water production costs of both distillation plant and RO plant: these costs include all costs attributable to water production, but exclude costs of

- water storage,
- transportation,
- distribution.

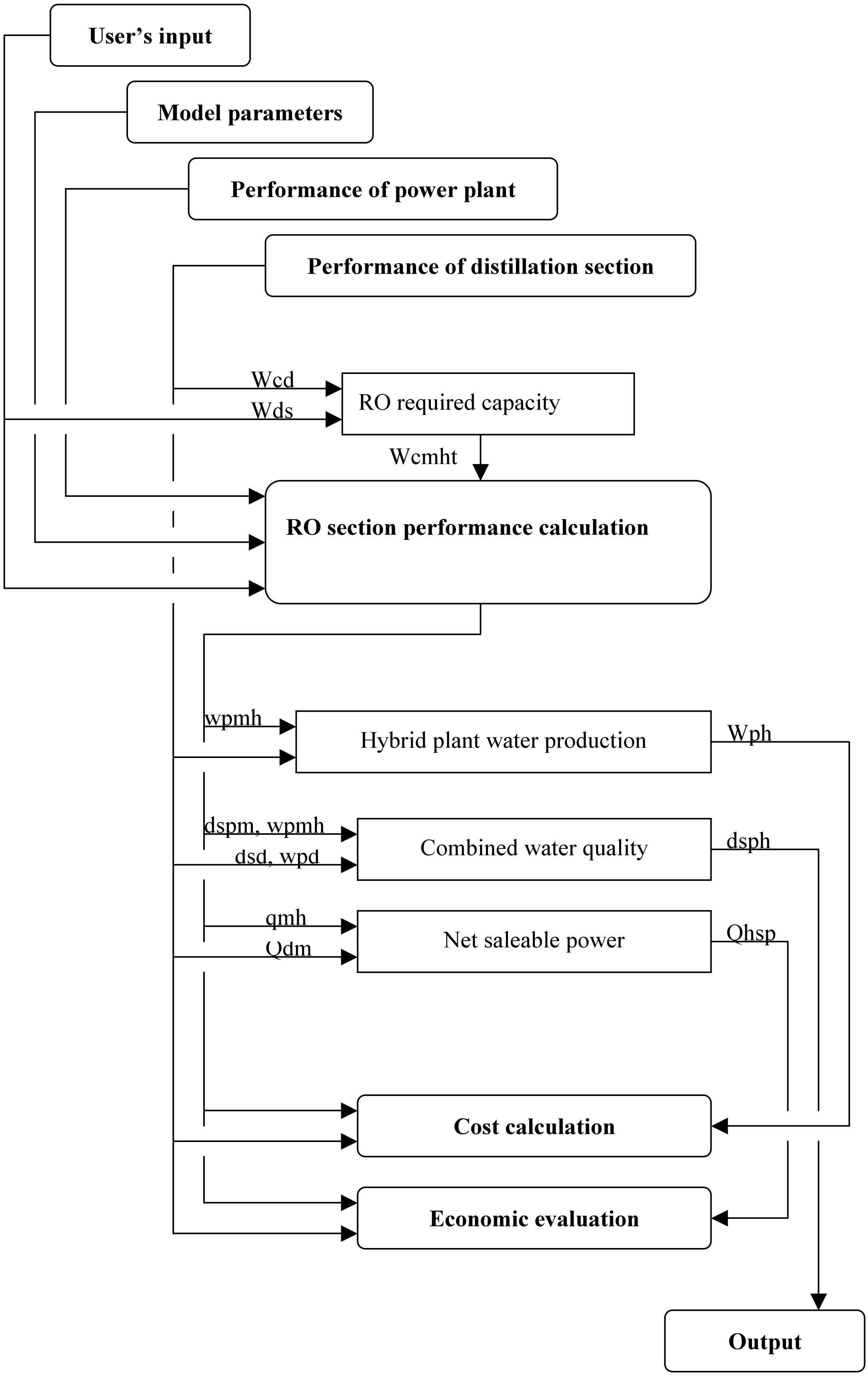


Fig 29. Hybrid plant performance calculation.

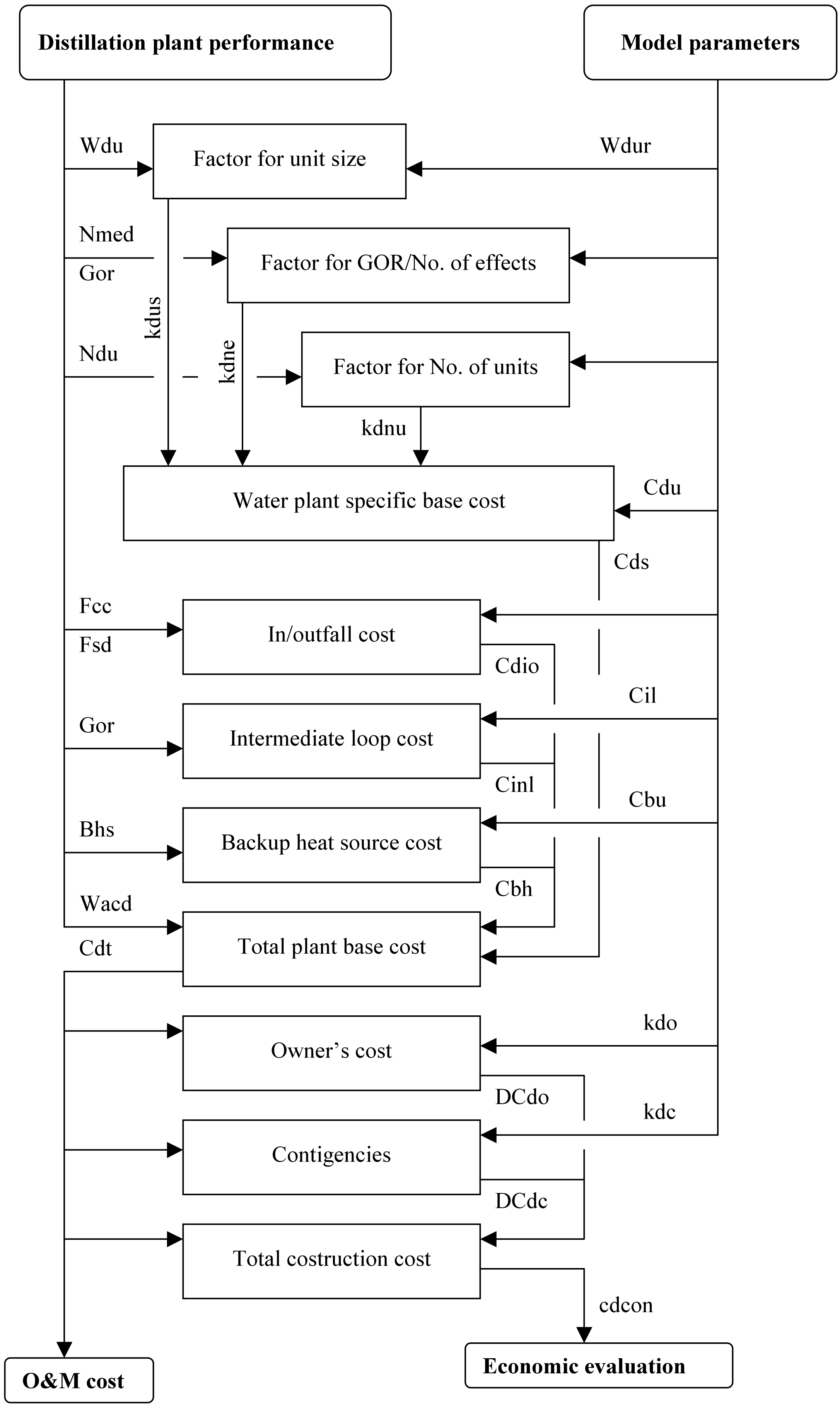


Fig 30. Distillation plant construction cost.

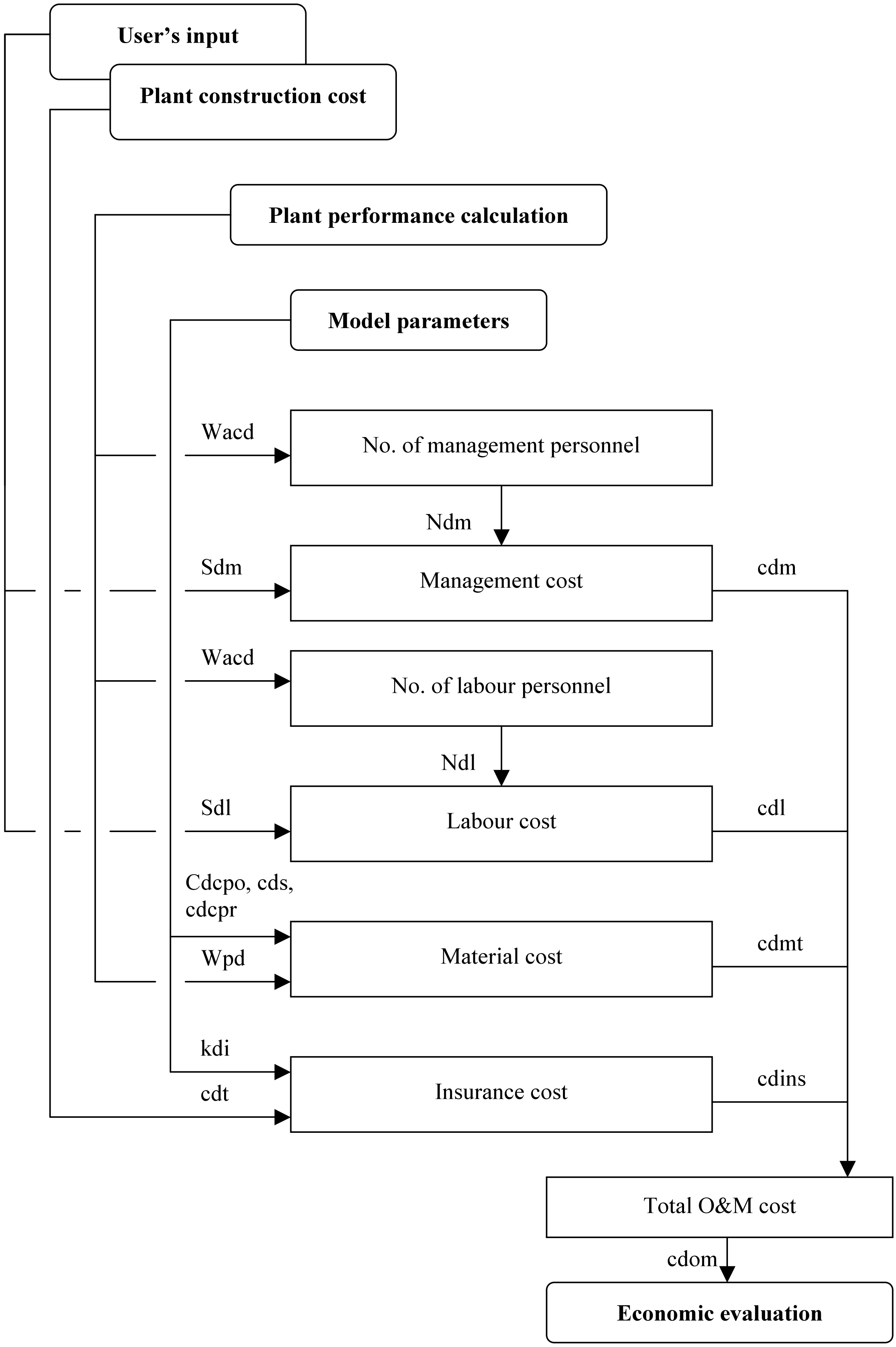


Fig 31. Cost calculation – O&M cost of distillation plant.

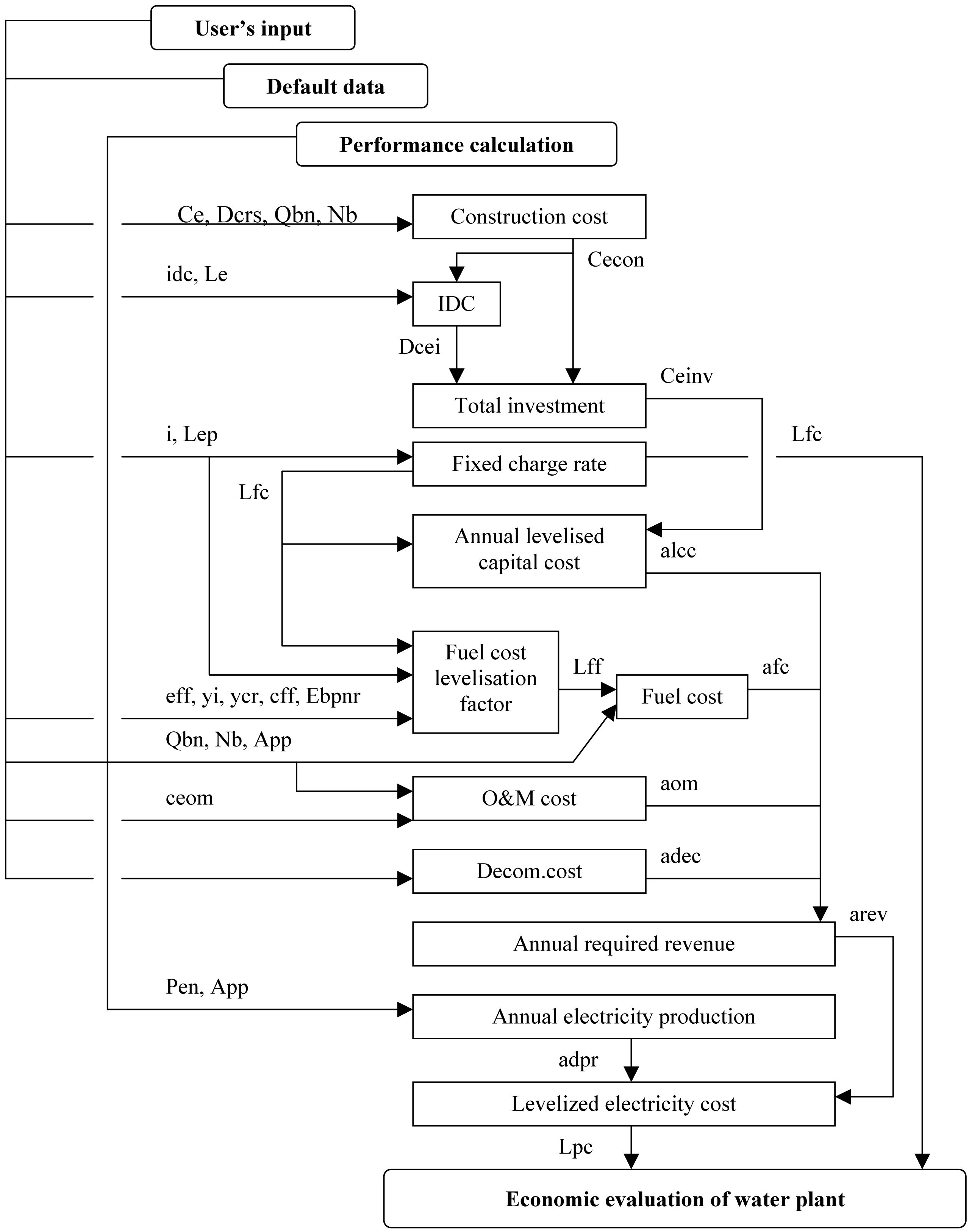


Fig 32. Economic evaluation of power plant.

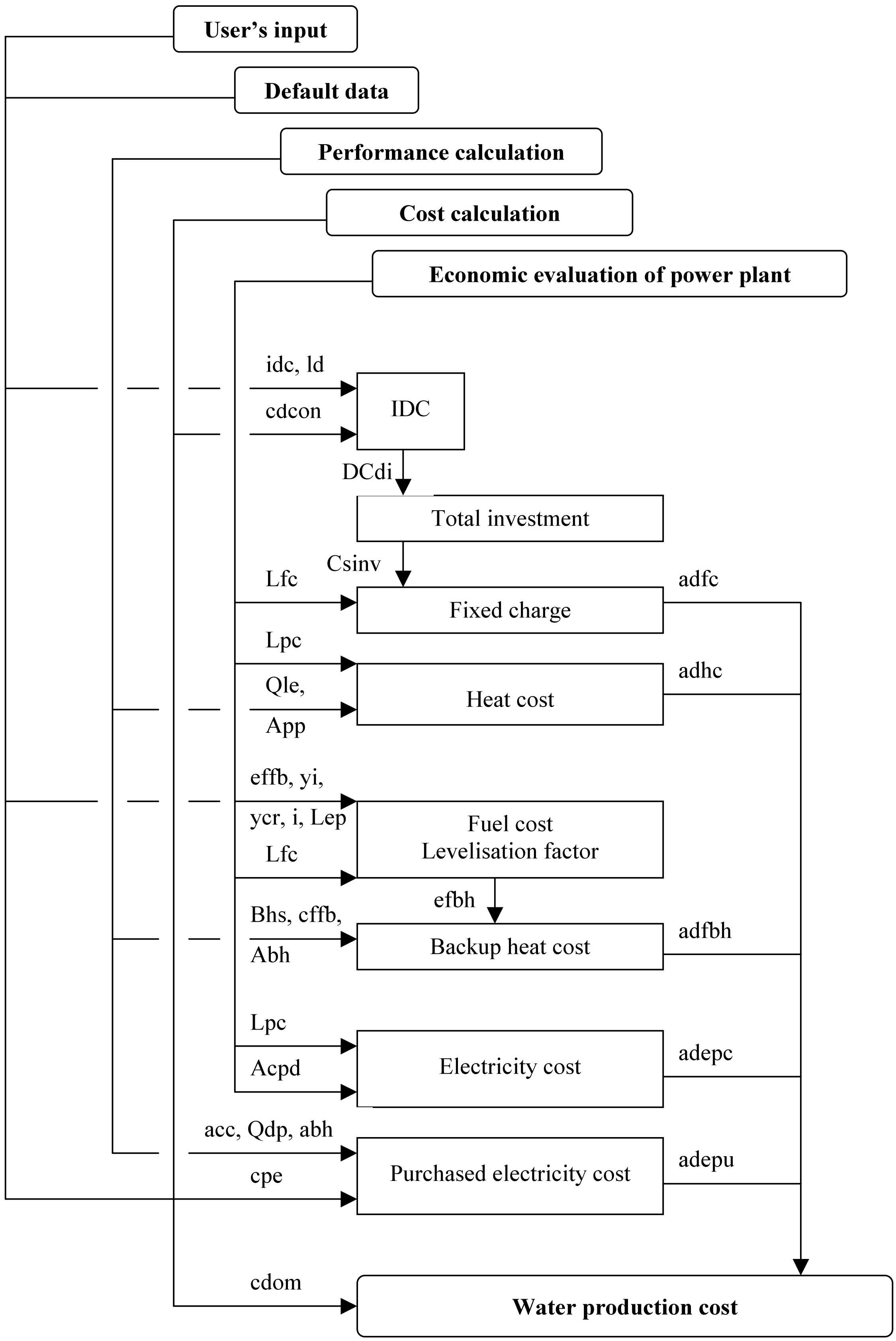


Fig 33. Economic evaluation of distillation plant.

6. INPUT DATA AND OUTPUT DESCRIPTION

Preparation of meaningful and consistent input is essential for obtaining meaningful results with DEEP. As can be seen from Section 7, the variables which are used in DEEP are either ‘welcome input’ by the user or ‘default data’ not foreseen for input via the INPUT SHEET (but may be changed by an experienced user) or ‘part of the model’ data which should not be changed. The ‘welcome input’ by the user and relevant default data are described below. DEEP includes both generally applicable default data (e.g. for economic parameters and electric motor efficiency) and default data which are specific for certain energy sources and desalination technologies. The user can change the category of each input parameter by changing its colour, and can then change default or ‘part of the model’ data.

DEEP can be used both for generic studies, in order to analyse the performance and costs of a range of combinations of power and/or heating plants and coupled desalination plants, and for site specific studies.

For generic studies, it is assumed that the user will often refer to default data contained in DEEP and provide only some other input data from other sources.

For site specific studies, it is assumed that the user has at least indicative data for specific projects. The user would then base the input data on construction and operating experience as well as on statistics and on studies performed in the context of national, regional or site specific energy and water demand and supply planning. The user will thus have information on the existing regional energy and water supply system, on energy and water demand projections, available energy and water resources, and on possible sites for future desalination plants to close existing or foreseeable areas with insufficient water supply.

An experienced user will also usually have information on performance and cost experience with existing plants and on the performance and costs of energy sources and/or desalination technologies which are considered for future projects. The user may have an idea which energy sources and which desalination technologies would be suitable for a specific site, e.g. a distillation process if the seawater has a high salt content, is polluted and/or the product water should be very clean, or a RO process if the feedwater is rather clean and/or if the required quality of the product water shall be according to WHO standards. This information will be used to prepare site specific input.

The user should have in mind that the DEEP empirical performance and cost models are valid for certain ranges of input parameters (in particular unit sizes of power and desalination plants, RO feedwater temperature and salinity), usually for 10–20% up or down. Analyses with input data outside these ranges are doubtful.

DEEP is also not designed for the design or technical and economic evaluation of specific projects. Indicative design and other project specific data can be obtained from potential suppliers or from experience with similar projects. For firm project specific information, bids from potential suppliers should be sought.

The most relevant user’s input data are described below. They are denominated as ‘welcome input’ and ‘default data’ in Section 7. In Figs 11 to 33, they are denominated as ‘user’s input’. A complete list of all input data, including welcome user’s input, default data (which cannot be put in via the input sheet), and model parameters is included in Section 7.

6.1. GENERAL

6.1.1. Case identification and site characteristics

Relevant input data include:

- Required water plant capacity,
- Distillation plant type,
- RO membrane type.

The required water plant capacity will determine the minimum required base power plant capacity, the lost electric power, and the construction cost and O&M cost of the water plant. It will also influence the preferable choice of the water plant type (e.g. RO for small plants).

The distillation plant type (MED or MSF) will determine the GOR, i.e. how much water can be produced with a certain amount of steam. It will also determine the construction cost and energy cost of the water plant. The empirical relations for the construction cost and energy consumption differ; they are included in the DEEP model parameters and in spreadsheet equations.

The RO membrane type (spiral wound or hollow fibre) will determine the performance (and thus the energy consumption and energy cost) as well as the construction cost of the RO plant.

6.1.2. Technical parameters

Relevant input data include:

- Average cooling water temperature,
- Seawater total dissolved solids (TDS).

The average cooling water temperature is important for the power plant net electric capacity. The net electric capacity is recalculated if the average cooling water temperature differs from the reference condensing temperature of the power plant.

The seawater total dissolved solids (TDS) are important for the RO plant performance. The higher the TDS, the higher the energy consumption of the RO plant, and the higher the TDS in the product water (ceteris paribus).

Relevant default technical parameters include:

- Electric motor efficiency,
- Factor for auxiliary load,
- Turbine mechanical efficiency,
- Generator efficiency.

The user should have specific knowledge about the processes to change one or more default values.

6.2. ENERGY PLANT PERFORMANCE DATA

6.2.1. Base power/heating plant

Relevant energy plant performance input data include:

- Reference base power plant (or heating plant) unit net output,
- Number of units at site,

and for power plants:

- Reference net thermal efficiency,
- Option for calculation with or without intermediate loop for heat transfer to the water plant.

The required reference base power plant unit net electric output will in many cases be determined by the electricity supply plan, and may be much higher than required for the desalination plant. The unit net electrical output will have to be in line with commercially offered unit sizes. These unit sizes will usually refer to proven plant designs (in particular to proven major components, e.g. the turbogenerator) and to defined site conditions. Some commercially offered unit sizes may also refer to advanced plants, which have been designed in detail and the design of which is certified/approved by licensing authorities. The performance characteristics and cost models of DEEP refer to these unit sizes. The steps from one unit size to the next are often quite large, but. extrapolations to other unit sizes are of questionable accuracy.

Alternatively, the heating plant capacity will usually be tailored to the heat required by the distillation plant. The reference base power plant (or heating plant) unit net output, together with the number of units at site, is used in the energy source performance calculations and cost calculations.

The reference net thermal efficiency is used to calculate the thermal power of the base power plant. This is important for the recalculation of the net electric output at site conditions with different condensing temperature than the reference condensing temperature.

Relevant default technical parameters include:

- Site specific air inlet temperature (for GT),
- Reference condensing temperature of base power plant,
- Planned outage rate,
- Unplanned outage rate.

Typical values of both the planned and unplanned outage rates are 0.1 for power plants and 0.05 for heating plants. There are important cost incentives to reduce both the planned and unplanned outage rates, and considerable improvements have been achieved at some plants. However, average lifetime experience of most plant types suggests to use conservative values not lower than the default values.

6.3. DISTILLATION PLANT PERFORMANCE DATA

Relevant distillation plant performance input data include:

- **Design cooling water temperature:** If = 0, the value will be set to the seawater temperature.
- **Unit size specification (optional):** If = 0, the unit size will be set by the code.
- Maximum brine temperature.

This value, i.e. the maximum temperature to which the brine (or the seawater feed is heated) is very important for the design and thermodynamic performance of the dual purpose power plant and of the desalination process, and will affect the water cost. The minimum required maximum brine temperature Tmbmin to attain the required water plant capacity is calculated by a subroutine (function Tmbn, Tmbf or Tmbgt) and displayed. The user can then chose a value between Tmbmin and 125°C for MED or 135°C for MSF.

Optional unit size specification:

In general, the capacity of desalination plants can be well adapted to the demand by installing a sizeable number of identical units (modules). The user should therefore usually take the default unit sizes to which the performance and cost models refer rather than specifying a different unit size. The currently offered maximum unit capacities are about 24 000 m^3/d for MED and 48 000 m^3/d for MSF. However, in some cases the user may either wish to more exactly match the required desalination plant capacity or to refer to a distillation plant/unit design which has not been modelled in DEEP. In these cases, the user may wish to specify a different unit size, but should be aware that the DEEP models refer to the default unit sizes.

6.4. RO PLANT PERFORMANCE DATA

Relevant RO plant performance input data include:

- **Contiguous RO design feedwater temperature:** This value is important for the RO plant performance calculation. A higher feedwater temperature will lead to a higher recovery ratio and thus to higher water production. However, care must be taken to observe technical limits (e.g. about 45°C for many commercial membranes) and to adjust other input values for optimal operating conditions. Inter alia, the pre-treatment requirements will change and the high head pump pressure must be raised for maintaining the quality of the product water.

- **Optional unit size specification:** This defines the unit size to which the construction cost and O&M cost refer (both in $\$/m^3/d$). In general, the capacity of desalination plants can be well adapted to the demand by installing a sizeable number of identical units (modules). The maximum capacity of RO modules is determined by the maximum capacity of currently commercially offered high pressure pumps (about 10 000 m^3/d). The user should therefore usually take the default unit size (to which the performance and cost models refer) rather than specifying a different unit size. However, in some cases the user may either wish to more exactly match the required desalination plant capacity, or he may refer to a RO plant/unit design which has not been modelled in DEEP. In these cases, he may wish to specify a different RO unit size, but he should be aware that the DEEP models refer to the default unit size.

Another relevant parameter, which is part of the model, is the

- **High head pump pressure rise:** This value is important for the electricity consumption of the RO plant. DEEP calculates the value from seawater temperature and TDS (see Figs 24 and 27); they will range from 67–83 bar for hollow fibre and 55–69 bar for spiral wound membranes. A knowledgeable user may also specify a different value.

6.5. ECONOMIC PARAMETERS

Relevant economic parameters input data include:

- Discount rate (real),
- Interest rate (real),
- Currency reference year,
- Initial year of operation,
- Plant economic life,
- Purchased electricity cost.

The real discount rate is the rate at which the lifetime costs and revenues (in constant money) of the plants are discounted to the reference date, which is here the initial year of operation. The discount rate is important for the economics of both the energy source and the water plant. DEEP includes a default value of 8%. A higher discount rate (which may be justified e.g. in countries with investment capital scarcity) will penalise capital intensive projects, and will lead to higher water cost.

The interest rate is applied to plant construction costs (which will be largely covered by loans) to calculate the interest during construction.

The currency reference year is the year to which the cost data refer.

The initial year of operation is the year to which the lifetime costs and revenues of the plants are discounted.

The plant economic life is usually assumed equal to or somewhat shorter than the technical design life. An important reason for a shorter economic life is that after a number of years the costs of continued operation might rise substantially, e.g. when the plant may have to be refurbished. The technical design life of water plants and fossil fired power or heating plants may be about 30 years. The main systems and components of nuclear plants are usually designed for 40 or more years. However, a default value of 30 years is assumed for all plant types.

The purchased electricity cost is applicable in all situations in which the electricity is supplied by the grid. This applies to distillation plants when the heat is supplied by a heating plant or by a backup heat source.

6.6. ENERGY PLANT COST DATA

Relevant energy plant cost input data include:

- **The specific plant construction cost:** excluding site related cost, contingencies, escalation and interest during construction. This cost is also referred to as overnight construction cost. The cost is put in in US \$/kW(e) for power plants and US \$/kW(th) for heating plants. For NPPs, this cost is the main contributor to the electricity generation cost.

Relevant default input data are:

- **Additional site related construction cost:** This may include additional estimated costs for site levelling, foundations, cooling water intake/outfall, special provisions for plant safety and environmental protection.
- **Contingency factor:** This factor reflects uncertainties of the construction cost estimate which are not known at the time of the estimate, including provisions for additional regulatory requirements and/or cost impacts from an extended construction period. The default contingency factor of 10% would apply to a proven power plant type and size to be constructed at a qualified site. It will have to be chosen considerably higher for innovative technologies and/or sites, which were not investigated in detail.
- **Construction lead-time:** The time period between the first pouring of concrete and the start of commercial operation. This time period depends strongly on the plant type, net output and site specific conditions. It could be about 12 months for a gas turbine plant and about 60 months for a medium or large size NPP. DEEP includes default data for the different energy sources. The construction lead-time is used to calculate the interest during construction (IDC) and the real escalation of the fuel price.
- **Specific O&M cost:** This is the non-fuel operating and maintenance cost of the energy source, including staff cost, spare parts, external assistance, insurance cost, in \$/MW(e)·h (or \$/MW(th)·h for heating plants). DEEP includes default data for the different energy sources.
- **Nuclear fuel cost:** This includes all nuclear fuel cycle costs, comprising uranium supply, enrichment, fuel fabrication and spent fuel management and disposal, in \$/MW(e)·h (or \$/MW(th)·h for heating plants). DEEP includes default data for the different nuclear plant types.
- **Decommissioning cost:** This includes all costs for the dismantling of a nuclear plant and for management and disposal of the decommissioning waste.

6.7. DISTILLATION PLANT COST DATA

Relevant distillation plant cost input data include:

- Base unit cost,
- Intake/outfall specific base cost.

Default reference values for the base unit cost are:

- 900 US \$/m^3/d for MED and
- 1800 US \$/m^3/d for MSF.

The unit cost of MED and MSF units will be calculated from empirical relations (see Section 5).

The user can specify incremental intake/outfall specific base cost. If he does not specify them (input has to be set to 0), they will be calculated from empirical relations for the cost of common intake/outfall of power plant and water plant (Section 5).

An experienced user can also specify data for:

- Intermediate loop cost,
- Contingency factor,

- Owner’s cost factor,
- Water plant lead time,
- Average management salary,
- Average labour salary.

different from the default values for distillation plants.

6.8. RO PLANT COST DATA

Relevant RO plant cost input data include:

- Base unit cost
- Intake/outfall specific base cost.

A default value for the base unit cost is 1000 US \$/m^3/d for 24000 m^3/d unit size. This value is conservative; information on recent projects indicates up to 20% lower cost. The unit cost of RO units with other size and/or performance data will be calculated from empirical relations (see Section 5).

The user can specify incremental intake/outfall specific base cost. If he does not specify them (0 input), they will be calculated from empirical relations for the cost of common intake/outfall of power plant and water plant (Section 5).

6.9. OUTPUT DESCRIPTION

The output repeats relevant input data and provides a summary of plant performance and cost calculations for

- Power (or heat) plant,
- Distillation plant,
- Stand-alone and contiguous RO plant,
- Distillation plus RO (hybrid) water plant.

Most relevant results include

- Levelised electricity cost of the base power plant,
- Levelised water cost of the specific desalination plants,
- Water production capacities of the specific desalination plants.

At the first view, the levelised water cost will be the yardstick for the economically preferable combination of power (or heat) and desalination technology. However, the user will also have to take into account:

- **Levelised electricity cost:** The plant combination with the lowest levelised water cost may have higher electricity cost than other combinations. For instance, a GT plant may yield the lowest levelised water cost (since waste heat is used for distillation) but will usually have higher electricity cost than other combinations. For an overall optimum, the electricity cost will be more important than the water cost since the revenue from electricity sales will be much higher than the revenue from water sales.
- **Product water quality:** RO plants will often produce water at lower cost than distillation plants, but the water will have higher TDS. The user has to check if the product water quality is within specified limits (e.g. WHO standard) or if a higher quality is required and a distillation process should be selected. Another situation, which may favour a distillation process, is when brackish water is available for mixing with the product water. In this case, more brackish water could be mixed with the distilled product than with RO permeate.
- **Water production capacity:** The user has to check if the water production capacity is sufficiently close to the value, he specified. If it is too low, he will have the following choices:

- Raising the maximum brine temperature (but not exceeding technical limits; see Section 6.3)
- Choosing a different power plant technology (e.g. a NPP could provide more heat for desalination than a CC plant of the same capacity)
- Choosing an energy source with higher capacity
- Choosing a hybrid process.

The user will then have to repeat the calculation until the water production capacity is sufficiently close to the value he specified.

7. DESCRIPTION OF VARIABLES USED IN DEEP SHEET CALC

(DEEP LINE BY LINE)

Legend:

	Parameter	Unit	Variable name
10	**Required water plant capacity at site**	**m^3/d**	**Wds**

Row: *Number of the row where parameter data resides in CALC sheet of the case. (This number is valid only for DEEP 1.x versions; in DEEP 2.0 it has no meaning, because the variables are named.)*

Parameter: *Description of the parameter by words.*

Variable name: *Excel name of the cell containing the parameter value. It is used in formulas.*

Unit: *Physical dimensions of the parameter.*

Input Status: *Information on the input category of the parameter*
(Welcome input
This value is prohibited to input from the INPUT SHEET.
Parameter is part of the model.)

Explanation: *Short explanation of the parameter general function. The label* <Explanation:> *is usually not used.*

Typical values: *Values, which are typical or usual for this input parameter.*

Used in: *List of variables where the parameter is used and/or presentation of formulas where the parameter is used in reference cases (for some input variables only).*

Formula: *Calculation formulas used for the parameter.*

IMPORTANT: New fundamental variable in DEEP 2.0

Parameter	Unit	Variable name
Desalinatin plant type	**text**	**DslpType**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The type of selected desalination option. It follows from plant selection made during the new case dialogue.Then is the value kept on worksheet for user identification.The variable is complemental to the variable **Energy source (EnSrc)**.

Permissible values: *MED, MSF, SA-RO, C-RO, MED-RO, MSF-RO*

Used for composition process control when creating new cases from separate technology modules.

7.1. VARIABLES USED IN THE INPUT SHEET

7.1.1. Case identification and site characteristics box

Row	Parameter	Unit	Variable name
8	**Case**	**text**	**Case**

Input Status: **Welcome Input**

Explanation: *Text or a sequential number, for user identification.*

Used in: *This parameter is never used in any other formulas.*

Row	Parameter	Unit	Variable name
9	**Assumed site location**	**text**	**Site**

Input Status: **Welcome Input**

Explanation: *The name of the site, for user identification.*

Used in: *This parameter is never used in any other formulas.*

Row	Parameter	Unit	Variable name
10	**Required water plant capacity at site**	**m^3/d**	**Wds**

Input Status: **Welcome Input**

The required water demand at the site, which is the desired water production capacity. For distillation plants, other parameters must be set to achieve this value, e.g., number of energy units, maximum brine temperature, etc.

Used in:
Row 69: Minimum required maximum brine temperature
Tmbmin = Tmbn (DpltType; Tsd; DTdcr; DTdca; DTdls; DTca; DTft; Tc; Qcr; Wds)

Row 147: Water plant lead-time
Lm = if ((INT(Wds/8/24000)+1)*12<36; (INT(Wds/8/24000)+1)*12; 36)
Row 183: Total heat to water plant
Qcrm = Wds/Gor/24/3600*(598–0,6*Tmb1)*4,1868

The water plant rated capacity of stand-alone RO and contiguous RO are defined by this value:

Row219: Required water plant production capacity Wcst = Wds
Row247: Required water plant production capacity Wcct = Wds

Row	Parameter	Unit	Variable name
11	**Required hybrid water plant capacity at site**	**m^3/d**	**Wdhs**

Input Status: **Welcome Input**

The required water demand at the site, which is the desired hybrid plant water production capacity. In fact, the RO part of hybrid plant capacity is defined indirectly this way — see Row 273, Wcmht.

Used in: *Row 270*: Required hybrid water plant production capacity Wcht = Wdhs

Row	Parameter	Unit	Variable name
12	**Energy source**	**text**	**EnSrc**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The energy source selected, e.g. nuclear, fossil or other, for user identification. It follows from plant selection made during the new case dialogue.

Row	Parameter	Unit	Variable name
13	**Energy plant type**	**text**	**EnPlt**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The name or the abbreviation of the reactor/plant type, for user identification. It follows from plant selection made during the new case dialogue.

Row	Parameter	Unit	Variable name
14	**Energy product form**	**text**	**Enprf**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The energy product form selected, e.g. co-generation, power or heat, for user identification. It follows from plant selection made during the new case dialogue.

Row	Parameter	Unit	Variable name
15	**Fuel Type**	**text**	**FuelType**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The fuel type used, for user identification. It follows from plant selection made during the new case dialogue.

Row	Parameter	Unit	Variable name
16	**Distillation water plant type**	**text**	**DpltType**

Input Status: **Welcome Input**

Type text "MED" or "MSF", for calculation of the desired distillation process in this column; no other options are available; two columns must be used if both types of distillation plants are to be investigated; not applicable if only RO is investigated.

Row	Parameter	Unit	Variable name
17	**RO membrane type**	**text**	**MemType**

Input Status: **Welcome Input**

Type text "SW" or "HF" (full name strings "SPIRAL WOUND" or "HOLLOW FIBER" were used in DEEP 1.x), for calculation of the desired membrane type in this column; no other options are available; two columns must be used if both types of membranes are to be investigated; not applicable if only distillation is investigated.

Row	Parameter	Unit	Variable name
18	**Reference coupling diagrams**	**text**	**RefDiag**

Input Status: **This value is prohibited to input from the INPUT SHEET.**
It follows from plant selection made during the new case dialogue.

Reference to relevant diagrams, for user identification.

7.1.2. Technical parameters input data

Row	Parameter	Unit	Variable name
25	**Average annual cooling water temperature**	**°C**	**Tsw**

Input Status: **Welcome Input**

Annual average seawater temperature at site intake.

Row	Parameter	Unit	Variable name
26	**Seawater total dissolved solids**	**ppm**	**TDS**

Input Status: **Welcome Input**

Seawater salinity at site intake.

Row	Parameter	Unit	Variable name
27	**Electric motor efficiency**		**Eem**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Electric motor efficiency is mostly used in calculations of pumping power.

Row	Parameter	Unit	Variable name
28	**Temperature difference for heat transfer**	**°C**	**DTht**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This value is used only in case of GT energy plant for calculation of the Boiler/HRSG efficiency.
Not used in case of CC energy plant.
Not applicable for following energy plants: PWR, PHWR, SSB, HR, B, GTMHR, D and SPWR.

Row	Parameter	Unit	Variable name
29	**Outlet temperature of gas turbine**	**°C**	**Togt**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This value is prepared for the future. Now it is not used in any of energy plants in DEEP modules.

Row	Parameter	Unit	Variable name
30	**Factor auxiliary load**		**Fal**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This value is used in calculation of total plant auxiliary loads.

Typical input values:

Auxiliary load as portion of gross output of GT, HR, B energy plant, usually 0.01.
Auxiliary load as portion of gross output of CC energy plant, usually 0.02.
Auxiliary load as portion of gross output of PWR, PHWR, SSBOG, GTMHR, D and SPWR energy plant, usually 0,05.
Auxiliary load as portion of gross output of SSBC energy plant, usually 0,08.

Used for calculation of:

Total plant auxiliary loads **Pal**, *MW(e)*
Site specific net thermal efficiency **Ebpn**
Total base plant thermal power MW(t) **Qtp**

Row	Parameter	Unit	Variable name
31	**Turbine mechanical efficiency**		**Etm**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This value is used for calculation of total site specific base power plant net output and lost electricity production.
Applicable only for steam power plants PWR,PHWR, SSB, CC and SPWR.

Row	Parameter	Unit	Variable name
32	**Generator efficiency**		**Eg**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This value is used for calculation of total site specific base power plant net output and lost electricity production.

Applicable only for steam power plants PWR, PHWR, SSB, CC and SPWR.

7.1.3. Base power plant performance data

Row	Parameter	Unit	Variable name
35	**Reference power plant unit net output (except CC, GT)**	**MW(e) {MW(t)}**	**Qbn**

Input Status: **Welcome Input**

The net electrical power (at reference condensing temperature) or net thermal heat production for a single unit. ***Used for all energy sources except CC or GT***.

Row	Parameter	Unit	Variable name
36	**Reference power plant unit net output (only GT, CC)**	**MW(e)**	**Qbg**

Input Status: **Welcome Input**

The net electrical power (at reference condensing temperature) or net thermal heat production for a single unit. ***Used only for energy sources of CC or GT****.*

Gross power of gas turbine at ISO conditions for a single unit (air temperature of 15 °C, relative humidity of 60 %). Gross output for a single combined cycle unit at ISO conditions (air temperature of 15 °C, rel. humidity of 60%) and reference condensing temperature Tcr.

Note: This parameter can be specified by the user.

However, the ratio between gross output of gas turbine and steam turbine is fixed. The ratio is based on a reference GE combined cycle with 70.8 MW(e) gross output for the steam turbine and 123.4 MW(e) for the gas turbine.

Row	Parameter	Unit	Variable name
37	**Gross output of steam turbine (only CC)**	**MW(e)**	**Qbgsc**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Used only for energy source of CC.

Portion of steam turbine gross output in reference base power plant unit gross output.
Note: no input data, CDEE adapts value according to reference output ratio of 70.8/194.2

Qbgsc = Qbg × 70.8 / 194.2

Row	Parameter	Unit	Variable name
38	**Gross output of gas turbine (only CC)**	**MW(e)**	**Qbggc**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Used only for energy source of CC.

Portion of gas turbine gross output in reference base power plant unit gross output.
Note: no input data, CDEE adapts value according to reference output ratio of 123.4/194.2

Qbggc = Qbg × 123.4 /194.2

Row	Parameter	Unit	Variable name
39	**Number of power plant units at site**		**Nb**

Input Status: **Welcome Input**

The desired number of units to meet the site power demand and/or the energy demand of the distillation water plant.

Row	Parameter	Unit	Variable name
40	**Reference net thermal efficiency (except CC, GT)**	**%**	**Ebpnr**

Input Status: **Welcome Input**

The fraction of thermal energy transferred to electrical power (at reference; condensing temperature) applies to dual purpose and power only plants and is not applicable to heat only plants.

Row	Parameter	Unit	Variable name
41	**Reference gross thermal efficiency (only CC, GT)**	**%**	**Ebpgr**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

For energy plant of GT:

Gross thermal efficiency at ISO conditions;
Note: no input data, 33.8 % is assumed as default data for conservative gas turbine design.

For energy plant of CC:

Gross thermal efficiency at ISO conditions and reference condensing temperature of base power plant.
Note: no input data, 53.3% is assumed as default data.

Row	Parameter	Unit	Variable name
42	**Gross efficiency of gas turbine (only CC)**	**%**	**Ebpgrc**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Gross efficiency of gas turbine in reference base power combined cycle plant at ISO conditions.
Note: no input data, 33.8% is assumed as default data.

Row	Parameter	Unit	Variable name
43	**Site specific inlet air temperature (only for GT and CC)**	**°C**	**Tair**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

For Gas Turbine Model:

Air temperature, which is used in DEEP to calculate the site specific gross efficiency, the site specific gross output and the site specific exhaust gas temperature of the gas turbine.

Range of input data: 12°C ≤ Tair ≤ 44°C

For Combined Cycle:

Air temperature, which is used in DEEP to calculate the site specific gross efficiency, the site specific gross output and the site specific exhaust gas temperature of the gas turbine inside the combined cycle.

Range of input data: 12°C <= Tair <= 44°C

Row	Parameter	Unit	Variable name
44	**Boiler/HSRG efficiency**		**Ebl**

Input Status: **Parameter is part of the model.**

The fraction of thermal energy transferred to the steam system (usually 0.85–0.94) for fossil steam plants and fossil boilers; for combined cycle plants and gas turbines with low pressure boiler, this value is the heat recovery steam generator efficiency.

For GT energy plant:

Heat recovered in heat recovery steam generator (HRSG).

Assumptions:– exhaust gas temperature of HRSG should be ≥ 130°C
– temperature approach in HRSG (DTht) = 25°C
– specific heat capacity of exhaust gas in HRSG is constant over temperature

For Tmb + DTht ≤ 130°C
Ebl = (Texgt – 130)/(Texgt – Tair)

For Tmb + DTht > 130°C
Ebl = (Texgt – Tmb – DTht)/(Texgt – Tair)

For CC energy plant:

Heat recovered in heat recovery steam generator (HRSG).

Assumptions:– exhaust gas temperature of HRSG should be ≥ 130°C
– temperature approach in HRSG (DTht) = 25°C
– specific heat capacity of exhaust gas in HRSG is constant over temperature

Ebl = (Texgt – 130)/(Texgt – Tair)

Row	Parameter	Unit	Variable name
45	**Main steam temperature**	**°C**	**Tms**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Main steam temperature at turbine inlet for dual purpose plants, not applicable to gas turbines. This variable is never used in other formulas.

Row	Parameter	Unit	Variable name
46	**Condenser range**	**°C**	**DTcr**

Input Status: **Parameter is part of the model.**

The difference in the inlet and outlet temperature of the condensing cooling water (usually 7–10°C for steam plants); not applicable for heat only plants and gas turbines.

Row	Parameter	Unit	Variable name
47	**Condenser approach temperature**	**°C**	**Tca**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The parameter is used for calculation of site specific average condensing temperature **Tc** *at row 161.*

Row	Parameter	Unit	Variable name
48	**Condenser cooling water pump head**	**bar**	**DPcp**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The pressure difference across the pump, typically 1.7 bar; not applicable for heat only plants and gas turbines.

Row	Parameter	Unit	Variable name
49	**Condenser cooling water pump efficiency**		**Ecp**

Input Status: **Parameter is part of the model.**

Pump efficiency, not including the motor efficiency (usually 0.70–0.85); not applicable for heat only plants and gas turbines.

Row	Parameter	Unit	Variable name
50	**Reference condensing temp. of base power plant**	**°C**	**Tcr**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Steam plant condensing temperature for operation at reference condition given by the manufacturer (usually corresponding to 6.4 cm Hg), but can vary; not applicable for heat only plants and gas turbines.

Row	Parameter	Unit	Variable name
51	**Planned outage rate**		**opp**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average planned down time in days divided by 365, typically 0.1 for power plants and 0.05 heat only plants.

Row	Parameter	Unit	Variable name
52	**Unplanned outage rate**		**oup**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average unplanned down time in days divided by 365, typically 0.11 for power and 0.05 for heat only plants.

7.1.4. Dual purpose plant performance data (not applicable for power only plants)

Row	Parameter	Unit	Variable name
55	Condenser approach temp./steam temp. drop	**°C**	**DTca**

Input Status: **Parameter is part of the model.**

For nuclear MED, nuclear MSF and fossil MSF, this is the temperature difference between the steam temperature in the backpressure turbine condenser and the brine/water temperature in the condenser outlet, typically 2.5°C.

For fossil MED, this parameter is the steam temperature drop due to pressure losses in the long steam lines to the MED plant, typically 2.5°C.

Row	Parameter	Unit	Variable name
56	**Calculation with intermediate loop for MSF option (Y/N)**		**CILMSF**

Input Status: **Welcome Input**

This parameter is a switch in formulas for calculation of intermediate loop.
It is used in rows 57, 181, 188 and 312 for calculation of DTft, Tilcr, Fil and Cinl .

Row	Parameter	Unit	Variable name
57	**Intermediate loop temperature drop**	**°C**	**DTft**

Input Status: **Parameter is part of the model.**

For nuclear/MED, the temperature difference between the hot water inlet of the flash tank/steam drum and the steam outlet of the flash tank/steam drum, typically 4 °C.

For nuclear/MSF, the intermediate loop heat exchanger approach, typically 2.5 °C.

For fossil, this parameter is not applicable.

Row	Parameter	Unit	Variable name
58	**Difference between feed steam temp. and max brine temp.**	**°C**	**DT1s**

Input Status: **Parameter is part of the model.**

For MED, this is the temperature drop for condensation in first effect typically is 0.4 °C.

For MSF, this parameter is not applicable.

Row	Parameter	Unit	Variable name
59	**Intermediate loop pressure loss**	**bar**	**DPip**

Input Status: **Parameter is part of the model.**

The pressure difference across the intermediate loop pump(s), typically 1.0 bar. This parameter is used only in case of nuclear power source for calculation of intermediate loop pumping power, **qil***, together with following parameter of* **Eip**.

Row	Parameter	Unit	Variable name
60	**Intermediate loop pump efficiency**		**Eip**

Input Status: **Parameter is part of the model.**

Pump efficiency, not including the motor efficiency (usually 0.70–0.85). This parameter is used only in case of nuclear power source for calculation of intermediate loop pumping power, **qil***, together with previous parameter of* **DPip**.

7.1.5. Distillation water plant performance data (not applicable for power only plants)

Row	Parameter	Unit	Variable name
63	**Distillation plant design cooling water temperature**	**°C**	**Tsd**

Input Status: **Welcome input**

If not specified or 0, the value will be set to the seawater temperature at the site intake.
(See row 25: Average annual cooling water temperature – Tsw).

Row	Parameter	Unit	Variable name
64	**Product water TDS**	**ppm**	**dsd**

Input Status: **Parameter is part of the model.**

The quality of the product water in total dissolved solids before post treatment, usually 25 ppm.

Row	Parameter	Unit	Variable name
65	**Optional unit size specification**	**m^3/d**	**Wduo**

Input Status: **Welcome input**

Optional unit size of the distillation plant to get more sophisticated unit size to match the required water plant capacity at site; if not specified or 0 , the unit size will be set by the code (see the explanation for rows 193 and 194 for more details).

Row	Parameter	Unit	Variable name
66	**MED plant condenser range**	**°C**	**DTdcr**

Input Status: **Parameter is part of the model.**

For MED, the difference in the inlet and outlet temperature of water plant condenser (typically 5°C).

For MSF, this parameter is not applicable.

Row	Parameter	Unit	Variable name
67	**Brine to seawater temp. diff. in last MSF stage**	**°C**	**DTdls**

Input Status: **Parameter is part of the model.**

For MSF, the difference in the feedwater inlet and brine temperature of last stage (typically 6.2°C).

For MED, not applicable.

Row	Parameter	Unit	Variable name
68	**MED plant condenser approach**	**°C**	**DTdca**

Input Status: **Parameter is part of the model.**

For MED, the difference between the condensing steam temperature in the final condenser and the condenser hot seawater outlet (typically 2°C).

For MSF, this parameter is not applicable.

Row	Parameter	Unit	Variable name
69	**Minimum required maximum brine temperature**	**°C**	**Tmbmin**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Minimum required brine temperature to get 'required water plant capacity at site' Wds.

For PWR, PHWR, SPWR, function Tmbn is used to calculate Tmbmin.
(Tmbn requires the following arguments for calculation:
distillation plant type, Tsw, DTdcr, DTdca, DTdls, DTca, DTft, Tc, Qcr, Wds)

For SSB, (both SSBC and SSBOG) and CC, function Tmbf is used to calculate Tmbmin.
(Tmbf requires the following arguments for calculation:
distillation plant type, Tsw, DTdcr, DTdca, DTdls, DTca, Tc, Qcr, Wds)

For GT, function Tmbgt is used to calculate Tmbmin;
(Tmbgt requires the following arguments for calculation:
distillation plant type, Tsw, DTdls, DTdcr, DTdca, Qtp, Peg, Texgt, Tair, Wds)

For heat only plants HR and B, function Tmbh is used to calculate Tmbmin.
(Tmbh requires the following arguments for calculation:
distillation plant type, energy source type, Tsw, DTdcr, DTdca, DTdls, Pen, Wds)

For high temperature MSF/MED plants and large 'required water plant capacity',the lowest temperature in the steam cycle of the combined cycle could be as high that theHRSG exhaust gas temperature of 130°C will be exceeded.This would lead to additional heat losses in the HRSG not covered by DEEP.

Row	Parameter	Unit	Variable name
70	**Maximum brine temperature**	**°C**	**Tmb**

Input Status: **Welcome input**

Maximum brine temperature to be entered by the user; Tmb has to be larger than Tmbmin, but lower in scale than 125 °C for MED and 135 °C for MSF (scaling and corrosion reasons).

This parameter adjusts distillation plant output and affects water costs.

For the economic reason it should be higher than 50 °C for MED and 70 °C for MSF.

In reference cases (all MED), following values of this parameter were used: Tmb=70 °C for PWR, PHWR, SSBC; Tmb=120 °C for SSBOG, CC, GT, HR, B and Tmb=100 °C for SPWR.

Row	Parameter	Unit	Variable name
71	**Seawater pump head**	**bar**	**DPsd**

Input Status: **Parameter is part of the model.**

The pressure difference across the seawater pump(s), typically 1.7 bar.

Row	Parameter	Unit	Variable name
72	**Seawater pump efficiency**		**Esd**

Input Status: **Parameter is part of the model.**

The pump efficiency, not including the motor efficiency (usually 0.70–0.85).

Row	Parameter	Unit	Variable name
73	**Water plant specific power use**	**$kW(e)h/m^3$**	**Qsdp**

Input Status: **Parameter is part of the model.**

The specific electric power use in the distillation plant, typically 2 for MED and 3 kW(e)h/m3 for MSF.

For MED,	*when GOR < 7.5*	*1.6 $kW(e)h/m^3$*
	when GOR ≥ 7.5	*$0.0034 * GOR^2 – 0.1469 * GOR + 2.5088$*
		(min value for GOR=21.6029)
For MSF	*3 $kW(e)h/m^3$*	

Formula:

For MED: = IF (Gor1 < 7.5; 1.6 ; 0.0034*Gor^2–0.1469*Gor+2.5088)

For MSF: *= 3*

Row	Parameter	Unit	Variable name
74	**Water plant planned outage rate**		**opd**

Input Status: **Parameter is part of the model.**

The average planned down time per year in days divided by 365,
typically 0.03 for distillation plants.

Row	Parameter	Unit	Variable name
75	**Water plant unplanned outage rate**		**oud**

Input Status: **Parameter is part of the model.**

The average unplanned down time per year in days divided by 365,
typically 0.065 for distillation plants.

Row	Parameter	Unit	Variable name
76	**Calculation with backup heat source**		**BK**

Input Status: **Parameter is part of the model.**

Used values: *BK = Y, calculation with backup heat source.*
BK = N, without backup heat source.

Row	Parameter	Unit	Variable name
77	**Backup heat planned outage rate**		**opb**

Input Status: **Parameter is part of the model.**

Used values:
= with backup heat source, the average planned down time per year in days divided by 365, typically 0.05;
= N/A, without backup heat source, not applicable.

Row	Parameter	Unit	Variable name
78	**Backup heat unplanned outage rate**		**oub**

Input Status: **Parameter is part of the model.**

Used values:
= with backup heat source, the average unplanned down time per year in days divided by 365, typically 0.05;
= N/A, without backup heat source, not applicable.

7.1.6. Membrane water plant performance data (not applicable for heat only plants)

Row	Parameter	Unit	Variable name
81	**Stand-alone RO design cooling water temperature**	**°C**	**Tsm**

Input Status: **Welcome input**

If not specified, the value has to be set to 0. In such a case the annual average seawater temperature at site intake **Tsw** *will substitute the value.*

If specified (> 0), it defines the stand-alone RO feedwater inlet temperature **Tim** *at row 220.*

Row	Parameter	Unit	Variable name
82	**Contiguous RO design feedwater temperature**	**°C**	**Tfm**

Input Status: **Welcome input**

If not specified, the value has to be set to 0. In such a case the annual average seawater temperature at site intake **Tsw** *and* the condenser range **DTcr** *will be used to calculate the value.*

If specified (> 0), it defines the contiguous RO feedwater inlet temperature **Timc** *at row 248.*

Row	Parameter	Unit	Variable name
83	**Optional unit size specification**	**m^3/d**	**Wmuo**

Input Status: **Welcome input**

If not specified, the value has to be set to 0. In such a case the selected unit size **Whu** *at row 229,* **Wmuc** *at row 254 and* **Wmuh** *at row 275 will be set to theirs respective default unit sizes.*

If specified (> 0), it defines the above mentioned unit sizes **Whu, Wmuc** *and* **Wmuh** *at theirs rows***.**

Row	Parameter	Unit	Variable name
84	**Seawater pump head**	**bar**	**DPsm**

Input Status: **Parameter is part of the model.**

The pressure difference across the seawater pump(s), typically 1.7 bar.

Row	Parameter	Unit	Variable name
85	**Seawater pump efficiency**		**Esm**

Input Status: **Parameter is part of the model.**

The pump efficiency, not including the motor efficiency (usually 0.70–0.85 .

Row	Parameter	Unit	Variable name
86	**Contiguous/hybrid RO transfer pump head**	**bar**	**DPtm**

Input Status: **Parameter is part of the model.**

The pressure difference across the contiguous / hybrid RO transfer pump(s), typically 1.4 bar.

Row	Parameter	Unit	Variable name
87	**Contiguous/hybrid RO transfer pump efficiency**		**Etpm**

Input Status: **Parameter is part of the model.**

The contiguous/hybrid RO transfer pump efficiency, not including the motor efficiency (usually 0.70 – 0.85).

Row	Parameter	Unit	Variable name
88	**Booster pump head**	**bar**	**DPbm**

Input Status: **Parameter is part of the model.**

The pressure difference across the booster pump(s), typically 3.3 bar.

Row	Parameter	Unit	Variable name
89	**Booster pump efficiency**		**Ebm**

Input Status: **Parameter is part of the model.**

The booster pump efficiency, not including the motor efficiency (usually 0.70 – 0.85).

Row	Parameter	Unit	Variable name
90	**High head pump pressure rise**	**bar**	**DPhm**

Input Status: **Parameter is part of the model.**

The pressure difference across the high head pump(s), typically 81 bar for hollow fibre and 67 bar for spiral wound.

This required feedwater pressure depends on membrane type, salinity and feedwater temperature. In DEEP, this value is calculated by approximating formula, which is implemented as VBA function. The VBA function uses as input data value sets presented in figures in Section 3. Separate parts of code deal with Spiral wound and Hollow fibre membrane types.

DPhm = *mempres(MemType;TDS;Tim)–1,*

where

MemType is RO membrane type (Spiral wound or Hollow fibre),
TDS is seawater total dissolved solids,
Tim is RO feed inlet temperature.

Row	Parameter	Unit	Variable name
91	**High head pump efficiency**		**Ehm**

Input Status: **Parameter is part of the model.**

The high head pump efficiency, not including the motor efficiency (usually 0.70–0.85).

Row	Parameter	Unit	Variable name
92	**Hydraulic pump hydraulic coupling efficiency**		**Ehhm**

Input Status: **Parameter is part of the model.**

The hydraulic pump hydraulic coupling efficiency, which is typically 0.97.

Row	Parameter	Unit	Variable name
93	**Energy recovery efficiency**		**Eer**

Input Status: **Parameter is part of the model.**

The energy recovery ratio of a RO plant, usually 0.7 – 0.9.

Row	Parameter	Unit	Variable name
94	**Other specific power use**	**kW(e)h/m^3**	**Qsom**

Input Status: **Parameter is part of the model.**

The remaining specific electric power use of a RO plant, typically 0.0408 or 0.98 kW(e)h/m^3 .

Row	Parameter	Unit	Variable name
95	**Planned outage rate**		**opm**

Input Status: **Parameter is part of the model.**

The average planned down time in days divided by 365, typically 0.032 for membrane plants.

Row	Parameter	Unit	Variable name
96	**Unplanned outage rate**		**oum**

Input Status: **Parameter is part of the model.**

The average unplanned down time in days divided by 365, typically 0.06 for membrane plants.

7.1.7. Economic parameters input data

Row	Parameter	Unit	Variable name
103	**Discount rate**	**%/a**	**i**

Input Status: **Welcome input**

The real discount rate, typical 8% for developing countries.

Row	Parameter	Unit	Variable name
104	**Interest rate**	**%/a**	**ir**

Input Status: **Welcome input**

The real interest rate (depends on country construction where costs are incurred), typically 8 %.

Row	Parameter	Unit	Variable name
105	**Currency reference year**		**Ycr**

Input Status: **Welcome input**

The year for which the costs should be calculated. Costs are expressed in US $ as of 1 January of the reference year.

Row	Parameter	Unit	Variable name
106	**Initial year of operation**		**Yi**

Input Status: **Welcome input**

The scheduled first year of operation; assume adequate lead-time for nuclear plants; in the calculations operation is assumed as of 1 January.

Row	Parameter	Unit	Variable name
107	**Plant economic life**	**a**	**Lep**

Input Status: **Welcome input**

The power/water plant lifetime used in the cost calculations.

Row	Parameter	Unit	Variable name
108	**Purchased electricity cost**	**$/kW(e)·h**	**Cpe**

Input Status: **Welcome input**

The relevant costs in kW(e)×h, for electricity supply to heat only plants and for backup electricity source of RO and distillation plants.

7.1.8. Energy plant cost input data

Row	Parameter	Unit	Variable name
111	**Specific construction cost**	**$/kW(e) { $/kW(t) }**	**Ce**

Input Status: **Welcome input**

The overnight cost of the energy plant (excluding site related cost, contingencies, escalation and interest during construction).

Row	Parameter	Unit	Variable name
112	**Additional site related construction cost**	**\$/kW(e) { \$/kW(t) }**	**DCrs**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The additional cost occurring in user country, typically 10% of the specific construction cost. This may include additional estimated costs for site levelling, foundations, cooling water intake/outfall, special provisions for plant safety and environmental protection.

Formula: = Ce * 0.1

Row	Parameter	Unit	Variable name
113	**Energy plant contingency factor**		**kec**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This factor reflects uncertainties of the construction cost estimate, which are not known at the time of the estimate, including provisions for additional regulatory requirements and/or cost impacts from an extended construction period. The default contingency factor of 10% would apply to a proven power plant type and size to be constructed at a qualified site. It will have to be chosen considerably higher for innovative technologies and/or sites, which were not investigated in detail.

Typical value: 0.1

Row	Parameter	Unit	Variable name
114	**Construction lead time**	**m**	**Le**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The time between the first pouring of concrete and the start of operation, usually 12–60 months. This time period depends strongly on the plant type, net output and site specific conditions. The construction lead-time is used to calculate the interest during construction (IDC) and the real escalation of the fuel price.

Row	Parameter	Unit	Variable name
115	**Specific O&M cost**	**\$/MW(e)·h { \$/MW(t)·h }**	**Ceom**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This is the non-fuel operating and maintenance cost of the energy source, including staff cost, spare parts, external assistance, insurance cost.

Row	Parameter	Unit	Variable name
116	**Specific nuclear fuel cost**	**\$/MW(e)·h { \$/MW(t)·h }**	**Csnf**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

This includes all nuclear fuel cycle costs, comprising uranium supply, enrichment, fuel fabrication and spent fuel management and disposal.

Row	Parameter	Unit	Variable name
117	**Specific decommissioning cost**	**\$/MW(e)·h { \$/MW(t)·h }**	**Csde**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

For SSB, CC, GT, B and D energy plants not applicable.

For PWR, PHWR, HR, GTMHR and SPWR energy plants:

This includes all costs for the dismantling of a nuclear plant and for management and disposal of the decommissioning waste. The value is used at row 401 for calculation of annual levelised decommissioning cost **adec**.

Row	Parameter	Unit	Variable name
118	**Fossil fuel price at start-up**	**\$/bbl (\$/t)**	**Cff**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The delivered price of crude oil at the time of reference year. It is assumed that the fossil fuel cost will be governed by the world market crude oil price based on the equivalent in heating value.

For nuclear energy plants not applicable.

Row	Parameter	Unit	Variable name
119	**Nuclear fuel annual real escalation**	**%/ a**	**efn**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The escalation rate of nuclear fuel in real terms.

Row	Parameter	Unit	Variable name
120	**Fossil fuel annual real escalation**	**%/a**	**eff**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The escalation rate of fossil fuel in real terms.

7.1.9. Distillation plant cost input data

Row	Parameter	Unit	Variable name
123	**Reference unit size for cost**	**m^3/d**	**Wdur**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The reference unit size to which the cost data apply :

For MED, typically 24,000 m^3/d.
For MSF, typically 48,000 m^3/d.

Row	Parameter	Unit	Variable name
124	**Base unit cost**	**$/($m^3$/d)**	**Cdu**

Input Status: **Welcome input**

The specific overnight unit costs of the water plant.

For MED, typically 900 $ / (m^3/d);
For MSF, typically 1800 $ / (m3/d).

Row	Parameter	Unit	Variable name
125	**Optional (incremental) in/outfall specific base cost**	**$/($m^3$/d)**	**Csdo**

Input Status: **Welcome input**

If not specified, the value has to be set to 0. In such a case a formula in row 311 is used for calculation of the value of (incremental) in / outfall specific base cost **Cdio**.

If specified (> 0) this value is supplied as the (incremental) in / outfall specific base cost **Cdio**.

Row	Parameter	Unit	Variable name
126	**Optional intermediate loop specific cost**	**$/(m3/d)**	**Cil**

Input Status: **Parameter is part of the model.**

The cost of the intermediate loop.

If not specified, the value has to be set to 0. In such a case the value will be calculated in row 312.

A typical value is 100 $ / (m^3 /d) for a plant with GOR of 11).

Row	Parameter	Unit	Variable name
127	**Water plant cost contingency factor**		**kdc**

Input Status: **Parameter is part of the model.**

The contingency factor is typically 0.1–0.2 .

Row	Parameter	Unit	Variable name
128	**Water plant owners cost factor**		**kdo**

Input Status: **Parameter is part of the model.**

The owners cost factor is typically 0.05 .

Row	Parameter	Unit	Variable name
129	**Water plant lead time**	**m**	**Ld**

Input Status: **Parameter is part of the model.**

The construction time of the water plant, 12–36 months (an algorithm is used to calculate the construction time that gives 2 years per cca 200,000 m^3/d, with a minimum of 1 year and maximum of 3 years).

Formula: = IF ((INT(Wacd/8/24000) + 1) * 12 < 36 ; (INT(Wacd/8/24000) + 1)*12 ; 36)

Row	Parameter	Unit	Variable name
130	**Average management salary**	**$/a**	**Sdm**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average management salary is typically 66,000 $/a; including indirect costs. This value strongly depends on the regional conditions. The user is advised to adjust this parameter before he starts systematic study related to certain site.

Row	Parameter	Unit	Variable name
131	**Average labour salary**	**$/a**	**Sdl**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average labour salary is typically 29,700 $/a; including indirect costs. This value strongly depends on the regional conditions. The user is advised to adjust this parameter before he starts systematic study related to certain site.

Row	Parameter	Unit	Variable name
132	**Specific O&M spare parts cost**	**$/m^3**	**csds**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

For MED, typically 0.03 $/m3.
For MSF, typically 0.035 $/m3.

Row	Parameter	Unit	Variable name
133	**Tubing replacement cost (only low temperature MED)**	**$/m^3**	**cdtr**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0,01 (for MED and **Tmb** *less or equal than 70).*
This value is used for calculation of water plant annual materials cost, **Cdmt** *in row 324.*

Row	Parameter	Unit	Variable name
134	**Specific O&M chemicals cost for pre-treatment**	**$/m^3**	**cdcpr**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.02 $/m3 for both MED and MSF.

Row	Parameter	Unit	Variable name
135	**Specific O&M chemicals cost for post-treatment**	**$/m^3**	**cdcpo**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.02 $/m3 for both MED and MSF.

Row	Parameter	Unit	Variable name
136	**Water plant O&M insurance cost**	**%**	**kdi**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.5% of the base capital cost.

Row	Parameter	Unit	Variable name
137	**Backup heat source unit cost**	**\$/MW(t)**	**Cbu**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 55,000 \$/MW(t).

= 0, without backup heat source.

Row	Parameter	Unit	Variable name
138	**Fossil fuel price for backup heat source at start-up**	**\$/bbl**	**Cffb**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

For fossil energy plants this and the following parameters have usually different values than parameters **Cff** *and* **eff** *in rows 118 and 120, respectively.*

Row	Parameter	Unit	Variable name
139	**Fossil fuel real escala. for backup heat source**	**%/a**	**effb**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The escalation rate of fossil fuel for back escalation heat source in real term. For fossil energy plants this and the following parameters have usually different values than parameters **Cff** *and* **eff** *in rows 118 and 120, respectively.*

7.1.10. RO plant cost input data (not applicable for heat only plants)

Row	Parameter	Unit	Variable name
142	**Base unit cost**	**\$/(m^3/d)**	**Cmu**

Input Status: **Welcome input**

The specific overnight unit costs of the membrane plant is typically 800 \$/(m3/d) for 24 000 m^3/d unit size.

Row	Parameter	Unit	Variable name
143	**Optional in/outfall specific base cost**	**\$/(m3/d)**	**Csmo**

Input Status: **Welcome input**

If not specified, the value has to be set to 0. In such a case a formula in row 334 is used for calculation of the value of (incremental) in / outfall specific base cost **Cmio**.

If specified (> 0) this value is supplied as the (incremental) in / outfall specific base cost **Cmio**.

Row	Parameter	Unit	Variable name
144	**Ratio membrane eq. cost to total cost**		**kme**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.20 .

Row	Parameter	Unit	Variable name
145	**Water plant cost contingency factor**		**kmc**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.1–0.2 .

Row	Parameter	Unit	Variable name
146	**Water plant owners cost factor**		**kmo**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.05 .

Row	Parameter	Unit	Variable name
147	**Water plant lead time**	**m**	**Lm**

Input Status: **Parameter is part of the model.**

The construction time of the water plant, 12–36 months (an algorithm is used to calculate the construction time that gives 2 years per cca 200,000 m^3/d, with a minimum of 1 year and maximum of 3 years).

Formula: = IF ((INT(Wds/8/24000) + 1) * 12 < 36 ; (INT(Wds/8/24000) + 1)*12 ; 36)

Row	Parameter	Unit	Variable name
148	**Average management salary**	**$/a**	**Smm**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average management salary is typically 66,000 $/a; including indirect costs. This value strongly depends on the regional conditions. The user is advised to adjust this parameter before he starts systematic study related to certain site.

Row	Parameter	Unit	Variable name
149	**Average labour salary**	**$/a**	**Sml**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

The average labour salary is typically 29,700 $/a; including indirect costs. This value strongly depends on the regional conditions. The user is advised to adjust this parameter before he starts systematic study related to certain site.

Row	Parameter	Unit	Variable name
150	**O&M membrane replacement cost**	**$/m^3**	**cmm**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.06 $/m^3.

Row	Parameter	Unit	Variable name
151	**O&M spare parts cost**	**$/m^3**	**cmsp**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.04 $/m^3.

Row	Parameter	Unit	Variable name
152	**Specific chemicals cost for pre-treatment**	**$/m^3**	**cmcpr**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.03 $/m^3.

Row	Parameter	Unit	Variable name
153	**Specific chemicals cost for post-treatment**	**$/m^3**	**cmcpo**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.03 $/m^3.

Row	Parameter	Unit	Variable name
154	**Water plant O&M insurance cost**	**%**	**kmi**

Input Status: **This value is prohibited to input from the INPUT SHEET.**

Typically 0.5% of the base capital costs.

7.2. PERFORMANCE CALCULATIONS

7.2.1. Single purpose plant performance

Row	Parameter	Unit	Variable name
161	**Site specific average condensing temperature**	**°C**	**Tc**

The average annual seawater temperature at site intake plus condenser range plus condenser approach temperature drop.

Applicable for PWR, PHWR, SBB, CC and SPWR energy plants.
Not applicable for GT, HR, B, GTMHR and D energy plants.

Formula: = Tsw + DTcr + DTca

Row	Parameter	Unit	Variable name
162	**Total base plant thermal power**	**MW(t)**	**Qtp**

The base power unit net output times number of power units at site divided by net thermal efficiency times 100.

Formulas:

For PWR, PHWR, SSB, GTMHR, D and SPWR energy plants: = Nb * Qbn / Ebpnr * 100
For CC energy plants: = Pegg / Ebpgg * 100
For GT energy plants: = Pen / Ebpn
For HR energy plants: = Qbn * Nb / (1–Fal)
For B energy plants: = Qbn * Nb / (1–Fal) / Ebl

Row	Parameter	Unit	Variable name
163	**Total site specific base power plant net output**	**MW(e) { MW(t) }**	**Pen**

For steam power plants, the number of power units times the site specific base power net output. The site specific base power net output is calculated using the turbine model described in 7.1.2 (Lost electricity production, Qle) with reference condensing temperature Tcr as reference value.

Formulas:

For PWR, PHWR and SPWR energy plants:

= Qbn * Nb – Etm * Eg * (Qtp – Qbn*Nb*(1+0,05/0,95)) *
* **0,6** * (Tc–Tcr) / (Tc+273) / (1 – 0,6*(Tc–Tcr) / (Tc+273))

For SSB energy plants:

= Qbn * Nb – Etm * Eg * (Qtp *** Ebl** – Qbn * Nb*(1+0,05/0,95)) *
* **0,85** * (Tc–Tcr) / (Tc+273) / (1–0,85 * (Tc–Tcr) / (Tc+273))

Note: The differences among nuclear and fossil steam power plants are in bold characters.

For CC and GT energy plants: = Peg – Pal

For HR, B, GTMHR and D energy plants: = Qbn * Nb

Row	Parameter	Unit	Variable name
164	**Site specific net thermal efficiency**		**Ebpn**

For steam power plants, the site specific base power plant net output divided by total base plant thermal power. For the other power plants, equal to reference net thermal efficiency.

Formulas:

For PWR, PHWR, SSB, CC and SPWR energy plants: = Pen / Qtp
For GT energy plants: = (34,205 – 0,024*Tair – 0,0007*Tair^2) * (1–Fal) / 100
For GTMHR and D energy plants: = Ebpnr / 100
For HR and B energy plants: *Not applicable*

Row	Parameter	Unit	Variable name
165	**Total plant auxiliary loads**	**MW(e)**	**Pal**

For power plants, the base power plant net output is typically about 5% of the gross power plant output. For heat only plants, about 1% of total thermal net output.

Formulas:

For energy plants of PWR, PHWR, SPWR, SSB, HR, GTMHR, D: *= Qbn * Nb * Fal*
For energy plant of B: *= Qbn * Nb / (1–Fal) / Ebl*
For energy plants of CC, GT: *=Qbg * Nb * Fal*

Row	Parameter	Unit	Variable name
166	**Site specific gross output of steam turbines (CC only)**	**MW(e)**	**Pegs**

Gross output of steam turbine(s) considering site specific conditions.

Formula: *Only for CC energy plants*

*= (Nb*Qbgsc – 0,988*0,85 * (1–(Tcr+273)/(Tc+273))*
** (Nb*Qbggc/Ebpgrc*100*(1–(1–Ebpgrc/100)*(1–Ebl))–Qbg*Nb))*
** Pegg/Qbggc/Nb*Ebpgrc/Ebpgg*

Not applicable for other energy plants except CC.

Row	Parameter	Unit	Variable name
167	**Site specific gross output of gas turbines**	**MW(e)**	**Pegg**

For number of gas turbine units multiplied by the site specific gross output of the gas turbine units. The site specific gross output of the gas turbine units is calculated by the extrapolated equation of the conservative gas turbine design as a function of Tair.

Formulas:

For CC energy plants: = (134,44 – 0,786*Tair) / 123,4 * Qbggc * Nb
For GT energy plants: = (134,44 – 0,786*Tair) / 123,4 * Qbg * Nb

Row	Parameter	Unit	Variable name
168	**Total site specific plant gross output**	**MW(e)**	**Peg**

For steam turbine plant only, this value is the sum of the total site specific base power plant net output and the plant auxiliary loads. For GT energy plant, this value is equal to Pegg (see above site specific gross output of gas turbines). For combined cycle this value is the sum of steam turbines gross output and gas turbines gross output. For heat only plants of HR and B this parameter is not applicable.

Formulas:
For PWR, PHWR, SSB, GTMHR, D, and SPWR energy plants: = Pen + Pal
For CC energy plants: = Pegg + Pegs
For GT energy plants: = Pegg

Row	Parameter	Unit	Variable name
169	**Site specific gross efficiency of gas turbines**	**%**	**Ebpgg**

Applicable only for CC and GT energy plants.

Formula: = 34,205 – 0,024*Tair – 0,0007*Tair^2

Row	Parameter	Unit	Variable name
170	**Site specific exhaust gas temperature of gas turbines**	**°C**	**Texg**

Applicable only for CC and GT energy plants.

Formula: = 528,9 + 0,725*Tair

Row	Parameter	Unit	Variable name
171	**Condenser reject heat load**	**MW(t)**	**Qcr**

For nuclear power, this is the total base plant thermal power minus the plant gross output.

For fossil steam boiler, this is the total heat load of the steam (coming from the steam boiler) to the steam turbine minus the plant gross output

For combined cycle plants, this is the bottoming condenser heat load, times the heat power to the turbine minus the plant gross output.

For GT, HR, B, GTMHR and D energy plants this parameter is not applicable.

Formulas:

For PWR, PHRW and SPWR energy plants: = Qtp – Peg
For SSB energy plants: = Qtp * Ebl – Peg
For CC energy plants: = Qtp * (1–(1–Ebpgg/100) * (1–Ebl)) – Peg

Row	Parameter	Unit	Variable name
172	**Condenser cooling water flow**	**kg/s**	**Fcc**

The power plant condenser reject heat load divided by the specific heat of water and the condenser range.

For combined cycle plants, it is the bottoming condenser heat load divided by the specific heat of water and the condenser range.

For GT, HR, B, GTMHR and D energy plants this parameter is not applicable.

The average specific heat of water (Cp) between 0°C–100°C at 1 atmosphere pressure is 4.1875 J/g/°C.

For calculational simplicity, the specific heat of seawater and fresh water was assumed to be equal.

Dimension check: [MWt] / {[J/(g x °C)] x [°C]} = [kg/s] x 1000
= Qcr / (Cp x DTcr) = [Qcr / (4.1875 x DTcr)] x 1000;

Formula: = Qcr*1000 / 4.1875 / DTcr

Row	Parameter	Unit	Variable name
173	**Condenser cooling water pump power**	**MW(e)**	**qcc**

Condenser cooling water volumetric flow multiplied by the condenser cooling water pump head divided by the condenser cooling water pump efficiency and the electric motor efficiency (assumed to be 0.96).

For GT, HR, B, GTMHR and D energy plants this parameter is not applicable.

Dimension check: [kg/s] x [bar] x 101,325[N/m^2.bar] 1000 [kg/m3] x 10^6[Nm/s.MWe]
= (Fcc x DPcp) / (Ecp x 0.96 x 9869);

Formula: = Fcc * DPcp / Ecp / Eem / 9866

Row	Parameter	Unit	Variable name
174	**Turbine exhaust flow**	**kg/s**	**Fte**

The condenser reject heat divided by the latent heat of evaporation.

For GT, HR, B, GTMHR and D energy plants this parameter is not applicable.

Dimension check: (he = 2300 J/g) [MW(t)] x 1000 / [kJ / kg] = [kg/s] = Qcr x 1000 /2300

Formula: = Qcr * 1000 / 2300

Row	Parameter	Unit	Variable name
175	**Operating availability**		**App**

The product of (1 – the planned outage rate) and (1 – the unplanned outage rate).

Formula: = (1–opp) * (1–oup)

7.2.2. Dual purpose power plant performance

Row	Parameter	Unit	Variable name
178	**Maximum brine temperature**	**°C**	**Tmb1**

Another representation of the maximum brine temperature as assumed in 7.1.5 Starting DEEP 2.0 this representation of Tmb is not used. The usual name of Tmb is used instead.

Row	Parameter	Unit	Variable name
179	**Modified condensing temperature**	**°C**	**Tcm**

The sum of the temperature in the power plant condenser outlet and the power plant condenser approach, which results in the sum of the maximum brine temperature and the effective first stage temperature drop (see detailed description under distillation plant, 7.2.3)

= Tmb + DTe1 for MED DTe1 = DTca +DTft +DT1s
for MSF DTe1 = DTca + DTft

Not applicable for GT, GTMHR and D energy plants.

Formulas:
For PWR, PHWR, HR and SPWR energy plants:
For MED: = Tmb1+DTca+DTft+DT1s
For MSF: = Tmb1+DTca+DTft

In DEEP 2.0 *the above formula*
= Tmb + DTe1
is used for both MED and MSF for all eligible energy plants!

For SSB, CC and B energy plants:
For MED: = Tmb1+DTca+DT1s
For MSF: = Tmb1+DTca

Row	Parameter	Unit	Variable name
180	**Modified condenser range**	**°C**	**DTmcr**

The temperature difference between the (nuclear) power plant condenser outlet and inlet (see 7.2.3).

Not applicable for SSB, CC, GT, B, GTMHR and D energy plants.

Formula:
For PWR, PHWR, HR and SPWR energy plants: = DTft

Row	Parameter	Unit	Variable name
181	**Intermediate loop condenser return temperature**	**°C**	**Tilcr**

The parameter is equal to the modified condensing temperature minus the condensing approach temperature minus the intermediate loop temperature drop.

Tilc = Tcm – DTca – DTft

Not applicable for SSB, CC, GT, B, GTMHR and D energy plants.

Formula:
For PWR, PHWR and SPWR energy plants:
=IF(AND(DpltType="MSF",CILMSF="N"),0,Tcm-DTca-DTft)

Row	Parameter	Unit	Variable name
182	**Gained output ratio (kg product/kg steam)**		**Gor**

Gained output ratio **Gor** *is the amount of desalted water to amount of steam supplied to distillation plant The calculation is made principally by dividing amount [kg] of water produced to steam used [kg]. This ratio is usually in the range of 6 to 10 for current commercial multi-stage flash (MSF) distillation plants and up to 20 for multi-effect distillation (MED) plants. In* DEEP *this ratio is calculated for different energy plants and different desalination plants by approximating expressions presented below.*

This parameter is not applicable for GTMHR and D energy plants, where no distillation plant may be connected.

Formulas:

For MED there are two energy plant groups:

For PWR, PHWR, HR and SPWR energy plants:
= 1.0603+0.3747*(DTao+DTao/Nemed)–0.0017*(DTao+DTao/Nemed)^2

For SSB, CC, GT and B energy plants:
= 1.0603+0.3747*(DTao)–0.0017*(DTao)^2

For MSF there is only one expression for both energy plant groups:

For [PWR, PHWR, HR and SPWR] & [SSB, CC, GT and B] energy plants:
= (598–0.6*Tmb1)*4.1868/4.019/DTdls*
(1–EXP(–3.936*(Tmb1–IF(Tsd>0,Tsd,Tsw)–DTdls)/(598–0.3*(Tmb1+IF(Tsd>0,Tsd,Tsw)+DTdls))/4.1868))

Row	Parameter	Unit	Variable name
183	**Total heat to water plant**	**MW(t)**	**Qcrm**

For heat only plants is this parameter equal to the total base plant thermal power; for fossil heat only boiler with respect to the fraction of thermal energy transferred to the steam system. For power plants, this parameter is calculated from value of gained output ratio, required water plant capacity at site and maximum brine temperature.

Formulas:

For HR energy plants: = Qtp

For B energy plants: = Qtp * Ebl

For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wds / Gor / 24 / 3600 * (598 – 0.6*Tmb1) * 4.1868

184 Lost shaftwork – this is text from the old manual. For the actual version please see next box.

The power generation that comes from steam expansion from the elevated back pressure temperature to site specific average condensing temperature Tc*;*
this is approximated by the relation Q_{mcr} x η_T x η_C*, where* Q_{mcr} *is the modified condenser heat load,* η_T *is the isentropic expansion efficiency of the turbine and* η_C *the Carnot efficiency. For backpressure turbines with condensing temperature higher than the base turbine crossover temperature, the lost shaft work is calculated in two steps.*

(The turbine model assumes that the base power plant turbine consists of 2 stages, i.e. a high and a low pressure stage. The high pressure stage is primarily a dry steam expansion and has an isentropic efficiency of 85% for nuclear and 89% for fossil, respectively. The low pressure stage has high moisture content with an effective isentropic efficiency of 60% for nuclear and 85% for fossil, respectively. The crossover temperature is 60°C for nuclear and 88°C for fossil, respectively. For both nuclear and fossil, the normal condensing temperature is assumed to be Tc*).*

Row	Parameter	Unit	Variable name
184	**Lost shaftwork**	**MW(s)**	**qls**

The shaftwork that could be generated when the extracted heating steam for seawater distillation is expanded in the low pressure section of the turbogenerator from the elevated extraction steam temperature Tcm to the site specific average condensing temperature Tc; this is approximated by the relation Qcrm x ηT x ηC, where Qcrm is the total heat supplied to the distillation plant, ηT is the isentropic expansion efficiency of the low pressure turbine section and ηC is the Carnot efficiency.

The turbine model assumes that the isentropic expansion efficiency of the extraction/condensing turbine is dependent on the actual steam temperature. For steam expansion above 60°C for nuclear and 88°C for fossil steam turbine options, a dry steam expansion is considered and the isentropic efficiency is assumed to be 60% and 85% respectively. For steam temperatures below 60°C and 88°C, high moisture content with an isentropic efficiency of 85% for nuclear and 89% for fossil steam turbine options is assumed.

For nuclear and Tcm < 60°C:

qls = qls = Qcr x η_T x η_C / (1 – η_T x η_C)
with η_T = 0.6 and η_C = (Tcm–Tc)/(Tcm+273);

For nuclear and Tcm ≥60°C:

qls = Qcr x [η_{Th} x η_C / (1 - η_{Th} x η_C) + η_{Tl} x η_{Cc} / (1 – η_{Tl} x η_{Cc}) – η_{Th} x η_{Cc} / (1 – η_{Th} x η_{Cc})]
with η_{Th} = 0.85, η_{Tl} = 0.6, η_C = (Tcm–Tc)/(Tcm+273) and
η_{Cc} = (60 – Tc) / (60 + 273);

For fossil and Tcm <88°C:

qls = Qcr x η_T x η_C / (1 – η_T x η_C) with η_T = 0.85 and η_C = (Tcm–Tc)/(Tcm+273);

For fossil and Tcm ≥88°C:

qls = Qcr x [η_{Th} x η_C / (1 – η_{Th} x η_C) + η_{Tl} x η_{Cc} / (1 – η_{Tl} x η_{Cc}) – η_{Th} x η_{Cc} / (1 – η_{Th} x η_{Cc})]
with η_{Th} = 0.89, η_{Tl} = 0.85, η_C = (Tcm–Tc)/(Tcm+273) and
η_{Cc} = (88 – Tc) / (88 + 273);

For GT, HR, B, GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR and SPWR energy plants:
= IF (Tcm<60;
Qcrm*0,6*(1–(Tc+273)/(Tcm+273));
Qcrm*0,85*[1–(Tc+273)/(Tcm+273)]+0,6*[1–(Tc+273)/(60+273)]–0,85*[1–(Tc+273)/(60+273)]

For SSB and CC energy plants:
= IF (Tcm<88;
Qcrm*0,85*(1–(Tc+273)/(Tcm+273));
Qcrm*0,89*[1–(Tc+273)/(Tcm+273)]+0,85*[1–(Tc+273)/(88+273)]–0,89*[1–(Tc+273)/(88+273)]

Row	Parameter	Unit	Variable name
185	**Lost electricity production**	**MW(e)**	**Qle**

The lost shaft work multiplied by the turbine mechanical efficiency (typically 0.988) and the generator efficiency (typically 0.97).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= qls * Etm * Eg

Row	Parameter	Unit	Variable name
186	**Net electricity produced**	**MW(e)**	**Qnep**

The plant gross output minus the plant auxiliary loads minus the lost electricity production.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Peg – Pal – Qle

For GT energy plants:
= Peg – Pal

Row	Parameter	Unit	Variable name
187	**Flash steam flow to MED (water to MSF)**	**kg/s**	**Ffs**

The total heat to water plant divided by the latent heat of evaporation, where heat of evaporation
he = (598 – 0.6 x Tmb) / 4.1868) J/g.

Dimension check: [MW(t)] = [MJ/s] x [g/J] = [kg/s] x 1000 = Qcrm / he

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Qcrm / (598–0,6*Tmb1) / 4,1868 * 1000
(Tmb1 is used instead of Tmb for formal reasons: the nearest presentation of Tmb to Ffs is used.)

Row	Parameter	Unit	Variable name
188	**Intermediate loop flow rate**	**kg/s**	**Fil**

The total heat to water plant divided by the specific heat of water and the modified condenser range.

The average specific heat of water (Cp) between 0°–100°C at 1 atmosphere pressure is 4.1875 J/g/°C for MSF (pure water) and about 4.0 J/g/°C for MED (saline water).

Dimension check: [MWt] / {[J/(g x °C)] x [°C]} = [kg/s] x 1000 = [Qcrm / (Cp x DTmcr)] x 1000

For SSB, CC, GT, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, HR and SPWR energy plants:
= IF (AND(DpltType="MSF";CILMSF="N"); 0; Qcrm*1000/4,1875/DTmcr)

Row	Parameter	Unit	Variable name
189	**Intermediate loop pumping power**	**MW(e)**	**qil**

The intermediate flow rate multiplied by the intermediate loop pressure loss divided by the condenser cooling water pump efficiency, the electric motor efficiency (assumed to be 0.96), and the density of condenser cooling water.

qil = Fil x ΔPip / (Eip x 0.96 x 1000 x ρ)   ρ = 10.1 for MED
ρ = 9.869 for MSF

Dimension check: [kg/s] x [bar] = [MWe] / (1000 x ρ)

For SSB, CC, GT, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, HR, SPWR energy plants
For MSF: = Fil * Dpip / 9869 / Eip / 0,96
For MED: = Fil * Dpip / 10100 / Eip / 0,96

7.2.3. Distillation plant performance

Definitions used in the calculations (or useful for understanding)

First effect /stage:

For MED:

The hot steam temperature is equal to the sum of the maximum brine temperature and the temperature drop for condensation in first MED effect:

Th =Tmb + DT1s

For MSF:

The hot water temperature is equal to the maximum brine temperature:

Th = Tmb

Final condenser:

For MED:

The temperature of the seawater in the water plant condenser outlet is equal to the sum of the seawater inlet temperature and the water plant condenser range:

Thsw = Tsw + DTdcr

The condensing temperature of the final condenser is equal to the temperature of the seawater in the water plant condenser outlet and the water plant condenser approach:

Tdc = Thsw + Dtdca = Tsw + DTdcr + DTdca

For MSF:

The brine temperature in the last MSF stage is equal to the sum of the seawater inlet temperature and the brine to seawater temperature difference in the last MSF stage:

Tdc = Tsw + DTdls

Middle effects/stages:

The effective overall water plant working temperature is the difference between the first effect/stage hot steam/water temperature and the final condenser condensing temperature/last stage temperature

DTdo = Th – Tdc
= Tmb + DT1s – Tdc for MED
= Tmb – Tdc for MSF

For MED

The overall working temperature is also equal to the sum of the temperature differences over all effects (or is equal to the product of the number of effects and the average temperature difference per effect):

DTdo = Nemed x DTae

The average temperature difference per effect, DTae, is a function of the overall working temperature DTdo

DTae = 1.65 + (0.0185 x DTdo) 0.85
if DTae _ 2.3, then DTae = 2.3;

The number of effects for the MED plant is therefore:

Nemed = integer (DTdo / DTae) + 1

The gain output ratio, GOR, is calculated by the following expression:

GOR = 28.4 x (1 – 0.966Nemed) for fossil
GOR = 28.4 x (1 – 0.966(Nemed+1)) for nuclear
(For nuclear sources, the intermediate flash loop is one additional effect)

The GOR and the amount of steam to the MED plant define the water plant production.

For MSF

The gain output ratio (GOR) is calculated by the following expression:

GOR= (0.97 / DTdls) x (DTdo / (1 + 0.77 x DTdo / 530))

Intermediate loop:

For MED, the temperature of the water in the power plant condenser outlet is equal to the sum of the flash tank steam temperature (which is equal to Th) and the intermediate flash tank steam temperature drop:

Tilh = Tfs + DTft = Tmb + DT1s + DTft

For MSF, the temperature of the water in the power plant condenser outlet is equal to the sum of the maximum brine temperature and the intermediate loop temperature drop:

Tilh = Tmb + DTft

The modified condensing temperature in the power plant condenser is equal to the sum of the temperature in the power plant condenser outlet and the power plant condenser approach:

Tcm = Tilh + DTca , hence
= Tmb + DTft + DT1s + DTca for MED
= Tmb + DTft + DTca for MSF

The temperature drop, condenser to maximum brine temperature is defined as the difference between the modified condensing temperature in the power plant condenser and the maximum brine temperature:

DTe1 = Tcm – Tmb
= DTft + DTca + DT1s for MED
= DTft + DTca for MSF

The temperature difference in the power plant condenser between the cooling water inlet and outlet was approximately set to the temperature drop in the intermediate loop.

Row	Parameter	Unit	Variable name
192	**Maximum water production capacity**	**m^3/d**	**Wcd**

The flash steam/water flow times the GOR.

Dimension check: [kg/s] x 3600[s/h] x 24[h/d] / 1000[kg/m^3]

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Ffs * Gor * 3600 * 24 / 1000

(It may happen that Gor1 is used instead of Gor for formal reasons. Gor1 is another representation of the same value as Gor. The nearest presentation of Gor to this formula is used.)

Row	Parameter	Unit	Variable name
193	**Default unit size**	**m^3/d**	**Wdud**

In this row there is a formula used for the selection of the water plant unit size according following rules (all values and parameters are in m^3/d).

Wdud = 12 000	for	0 <= Wcd < 85 000
Wdud = 24 000	for	85 000 <= Wcd < 170 000
Wdud = 36 000	for	170 000 <= Wcd < 250 000
Wdud = 48 000	for	250 000 <= Wcd

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= IF (Wcd<250000 ; (INT(Wcd/85000)+1) * 12000 ; 48000)

Row	Parameter	Unit	Variable name
194	**Selected unit size**	**m^3/d**	**Wdu**

If optional unit size, Wduo *is not specified (see the row 65), the default unit size* Wdud *is taken.*

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= IF (Wduo>0 ; Wduo ; Wdud)

Row	Parameter	Unit	Variable name
195	**Number of units**		**Ndu**

The integer of the ratio of the maximum water plant capacity and the selected unit size plus 1.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= INT (Wcd / Wdu) + 1

Row	Parameter	Unit	Variable name
196	**Installed water plant capacity**	**m^3/d**	**Wacd**

The product of the unit size times the number of units.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Wdu * Ndu

Row	Parameter	Unit	Variable name
197	**Temp drop – condenser to max brine**	**°C**	**DTe1**

Temperature drop – condenser to maximum brine temperature.

The temperature difference between the power plant condenser and the maximum brine temperature (including the intermediate loop for nuclear energy plants – DTft*).*

DTel = DTca (+ DTft) + DT1s for MED
DTel = DTca (+ DTft) for MSF

Formulas:

For PWR, PHWR, HR and SPWR:
For MED: = DTca+DTft+DT1s
For MSF: = DTca+DTft

For SSB, CC, GT and B:
For MED: = DTca+DT1s
For MSF: = DTca

Row	Parameter	Unit	Variable name
198	**Last stage/effect brine/steam temperature**	**°C**	**Tdc**

For MED:
The last effect condensing temperature is equal to the sum of the distillation water plant design cooling temperature (or the seawater temperature), the water plant condenser range and the water plant condenser approach. Note that if distillation water plant design cooling temperature (Tsd) *is not specified in the input data, it (*Tsd) *will be equal to the seawater temperature* (Tsw)*!*

Tdc = Tsd + DTdcr + Dtdca for MED

For MSF:
Temperature is equal to the sum of the water plant design cooling water temperature and the brine to seawater temperature difference in the last stage

Tdc =Tsd + DTdls for MSF

For GTMHR and D energy plants not applicable.

Formulas:

For PWR, PHWR, SSB, CC, GT, HR, B and SPWR:
For MED: = IF(Tsd>0;Tsd;Tsw) + DTdcr + Dtdca
For MSF: = IF(Tsd>0;Tsd;Tsw) + DTdls

Row	Parameter	Unit	Variable name
199	**Overall water plant working temperature**	**°C**	**DTao**

For MED
The maximum brine temperature plus DT1s minus the condensing temperature of the final condenser.

DTao = Tmb +DT1s – Tdc for MED

For MSF
The maximum brine temperature minus the brine temperature in the last stage.

DTao = Tmb –Tdc for MSF

For GTMHR and D energy plants not applicable.

Formulas:

For PWR, PHWR, SSB, CC, GT, HR, B and SPWR:
For MED: = Tmb1+DT1s–Tdc
For MSF: = Tmb1–Tdc

Row	Parameter	Unit	Variable name
200	**Average temperature drop between MED effects**	**°C**	**DTae**

Calculated by the following typical design expression for approximating the surface area of MED.

$DTae = 1.65 + (0.0185 \times DTdo)^{0.85}$ *for MED*
if DTae <= 2.3, then DTae = 2.3

For GTMHR and D energy plants not applicable. For MSF naturally not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR:
For MED: = IF (1,65+(0,0185*DTao)^0,85 < 2,3 ; 2,3; 1,65+(0,0185*DTao)^0,85)

Row	Parameter	Unit	Variable name
201	**Number of MED effects**		**Nemed**

For MED:
The integer of the ratio of the overall water plant working temperature and the average temperature drop between effects plus 1.

Nemed = integer (DTdo / DTae) + 1 for MED

For GTMHR and D energy plants not applicable. For MSF naturally not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR:
For MED: = INT(DTao/DTae)+1

Row	Parameter	Unit	Variable name
202	**GOR (kg product/kg steam)**		**Gor1**

Another representation of GOR–Gain Output Ratio is the ratio of kg water produced per kg of steam consumed, taken from row 182. Starting DEEP 2.0 this representation of GOR is not used. The usual name of Gor *is used instead.*

Row	Parameter	Unit	Variable name
203	**Seawater/product flow ratio**		**fsp**

The ratio between the seawater flow and product flow

fsp = 549.254 / DTdcr / Gor for MED
fsp = 2300 / 4 / (Tmb – Tdc) + 0.5 for MSF

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR:
For MED: = 549.254 / DTdcr / Gor
For MSF: = 2300 / 4 / (Tmb–Tdc) + 0,5

Row	Parameter	Unit	Variable name
204	**Seawater flow**	**kg/s**	**Fsd**

The seawater/product flow ratio times the maximum water production capacity.

For GTMHR and D energy plants not applicable.

Formula:
= fsp * Wcd / 24 / 3600 * 1000

Row	Parameter	Unit	Variable name
205	**Incremental seawater pumping power**	**MW(e)**	**qis**

For the nuclear steam power plants, fossil steam boiler and fossil combined cycle:
*The difference between the required seawater pumping power (*qsw*) for the water plant and for the base power plant (*qcc*)* [qsw = Fsd x DPsd / 9869 / Esd / 0.96 x 3 / 2]

qis = qsw – qcc, if qsw > qcc;
qis = 0 if qcc > qsw

qis = [(qsw – qcc) + ABS (qsw – qcc)] / 2

For heat only plants and fossil gas turbine:
qis = qsw

For GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (Fsd * DPsd / 9869 / Esd / Eem – qcc + ABS (Fsd * DPsd / 9869 / Esd / Eem – qcc)) / 2

For GT, HR and B energy plants:
= Fsd * DPsd / 9869 / Esd / Eem * 3/2

Row	Parameter	Unit	Variable name
206	**Water plant internal power use**	**MW(e)**	**qdi**

The installed water plant production capacity multiplied by the water plant specific power use.

Dimension check: [m3/d] x [kW(e).h/m3] x 1000 x 24

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Wacd * Qsdp / 24 / 1000

Row	Parameter	Unit	Variable name
207	**Total dist. water plant power use (incl. interm. loop)**	**MW(e)**	**Qdp**

Total distillation water plant power use (including intermediate loop)

The sum of the incremental seawater pumping power and the water plant internal power use and the intermediate loop pumping power.

For GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR, HR and SPWR energy plants:
= qis + qdi + qil

For SSB, CC, GT and B energy plants:
= qis + qdi

Row	Parameter	Unit	Variable name
208	**Water plant operating availability**		**Adp**

The water plant planned availability times the water plant unplanned availability.

For GTMHR and D energy plants not applicable.

Formula: = (1 – opd) x (1 – oud)

Row	Parameter	Unit	Variable name
209	**Backup heat source size**	**MW(t)**	**Bhs**

The total heat of the power plant to the water plant.

Bhs = Qcrm	for *BK = Y*	*calculation with backup heat source*
Bhs = 0	for *BK = N*	*calculation without backup heat source*

For GTMHR and D energy plants not applicable.

Formula: = IF (BK = "Y"; Qcrm; 0)

Row	Parameter	Unit	Variable name
210	**(Combined) Heat source availability**		**Ahs**

With backup heat source, one minus the product of the single purpose plant operating unavailability and the backup heat source unplanned outage rate.

Ahs = 1 – (1 – App) x oub	for *BK = Y*	*calculation with backup heat source*
Ahs = App	for *BK = N*	*calculation without backup heat source*

For GTMHR and D energy plants not applicable.

Formula: = IF (BK="Y"; 1–(1–App)*oub; App)

Row	Parameter	Unit	Variable name
211	**Total water production availability**		**Apd**

The (combined) heat source availability multiplied by the water plant availability.

For GTMHR and D energy plants not applicable.

Formula: = Adp * Ahs

Row	Parameter	Unit	Variable name
212	**Combined power/water plant load factor**		**Acpd**

With backup heat source, operating availability of the single purpose power plant times one minus water plant unplanned outage rate.

Acpd = App x (1– oud) for *BK = Y* *calculation with backup heat source*
Acpd =Apd, for *BK = N* *calculation without backup heat source*

For GTMHR and D energy plants not applicable.

Formula: = IF (BK= "Y"; App*(1–oud); Apd)

Row	Parameter	Unit	Variable name
213	**Backup heat source load factor**		**Abh**

With backup heat source, the total water production availability minus the combined power/water plant load factor.

Abh = Apd – Acpd; for *BK = Y* *calculation with backup heat source*
Abh = N/A (not applicable) for *BK = N* *calculation without backup heat source*

For GTMHR and D energy plants not applicable.

Formula: = IF (BK= "Y"; Apd–Acpd; 0)

Row	Parameter	Unit	Variable name
214	**Annual water production**	**m^3/a**	**Wpd**

The maximum water production capacity times the total water production availability times number of days per year.

For GTMHR and D energy plants not applicable.

Formula: = Wcd * Apd * 365

Row	Parameter	Unit	Variable name
215	**Average daily water production**	**m^3/d**	**Wpdad**

The maximum water production capacity times the total water production availability.

For GTMHR and D energy plants not applicable.

Formula: = Wcd * Apd

Row	Parameter	Unit	Variable name
216	**Net saleable power**	**MW(e)**	**Qdsp**

The total base power plant net output minus the lost electricity production minus the total distillation water plant power use.

For HR, B, GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Pen – Qle – Qdp

For GT energy plants:
=Pen–Qdp

7.2.4. Stand-alone RO water plant performance

Row	Parameter	Unit	Variable name
219	**Required water plant production capacity**	**m^3/d**	**Wcst**

The value of required water plant capacity at site (Wds) *is simply transferred to this cell.*

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wds

Row	Parameter	Unit	Variable name
220	**RO feed inlet temperature**	**°C**	**Tim**

The membrane water plant design cooling water temperature (Tsm) *if specified, else the seawater temperature* (Tsw).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= IF (Tsm>0; Tsm; Tsw)

Row	Parameter	Unit	Variable name
221	**Approximate inlet osmotic pressure**	**bar**	**Pio**

The parameter is calculated by the approximate expression for seawater osmotic pressure. The result is proportional to the product of RO feed inlet temperature in °K (Tim+273) *and seawater total dissolved solids* (TDS).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= 0,0000348 * (Tim+273) * TDS / 14,7

Row	Parameter	Unit	Variable name
222	**Recovery ratio**		**Rro**

The recovery ratio will be reduced when salinity increases; if the recovery ratio were held constant, the membrane surface would increase and scaling tendency would increase; the algorithm maintains constant reject brine salinity as seawater salinity increases; hollow fibre membranes are assumed to have an maximum allowed feed temperature of 40 °C, spiral wound membranes have a maximum allowed feed temperature of 45 °C; hollow fibre systems have a possible higher recovery ratio (up to 55%) and a higher operating pressure (82 bar) than spiral wound systems (maximum recovery ratio is 45% and maximum pressure is 68 bar)

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= memrec(MemType;TDS;Tim) *This function is stored in module in the calculation file.*

Row	Parameter	Unit	Variable name
223	**Outlet dissolved solids concentration**	**ppm**	**dso**

The seawater total dissolved solids concentration (TDS) *divided by the ratio of reject brine flow to seawater feed flow, which is 1 – recovery ratio* (Rro).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= TDS / (1–Rro)

Row	Parameter	Unit	Variable name
224	**Approximate outlet osmotic pressure**	**bar**	**Poo**

Calculated by the approximate expression for seawater osmotic pressure. The result is proportional to the product of RO feed inlet temperature in °K (Tim+273) *and outlet dissolved solids concentration* (dso).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= 0,0000348 * (Tim+273) * dso / 14,7

Row	Parameter	Unit	Variable name
225	**Membrane area factor**		**Fma**

The number of pressure vessels/permeators as a function of seawater salinity and temperature compared with the number of pressure vessels/permeators achieved at reference conditions (25 °C, 35,000 ppm). It should be mentioned that the layout of the membrane systems is based on system design guidelines of manufactures. These guidelines are only recommendations, which could be by-passed in some cases. However, such a thorough evaluation should be performed by RO experts using RO design programs rather than DEEP.

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:

= memareaw(MemType;TDS;Tim)

= memarea(MemType;TDS;Tim)/345 for hollow fibre
= memarea(MemType;TDS;Tim)/228 for spiral wound

The functions memarea(w) *are stored in one of normally hidden module Modul1 or VBA_Calc.*

Row	Parameter	Unit	Variable name
226	**Pretreatment, pump and piping size increase factor**		**Fpp**

Typical algorithm used in economic analysis, with 0.5 as a typical equipment scaling factor.

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= IF (MemType = "HOLLOW FIBER" ; (0,5/Rro)^0,5 ; (0,411/Rro)^0,5)

Row	Parameter	Unit	Variable name
227	**Product water quality before posttreatment**	**ppm**	**dspms**

Simplification of a more detailed code.

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= TDS * 0,0078

Row	Parameter	Unit	Variable name
228	**Default unit size**	**m^3/d**	**Wmud**

In this row there is a formula used for the selection of the water plant unit size according following rules (all values and parameters are in m^3/d).

Wmud = 12 000 for 0 <= Wcst < 99 000
Wmud = 24 000 for 100 000 <= Wcst

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= IF (Wcst<100000 ; (INT(Wcst/99000)+1) * 12000 ; 24000)

Row	Parameter	Unit	Variable name
229	**Selected unit size**	**m^3/d**	**Wmu**

If optional unit size (Wmuo) *is not specified (see the row 83), the default unit size* (Wmud) *is taken.*

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= IF (Wmuo>0 ; Wmuo ; Wmud)

Row	Parameter	Unit	Variable name
230	**Number of RO units**		**Nms**

The number of RO units necessary to provide the required water plant production capacity (Wcst) *with respect to selected unit size* (Wmu).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= INT(Wcst/Wmu) + 1

Row	Parameter	Unit	Variable name
231	**Installed stand-alone RO capacity**	**m^3/d**	**Wacs**

The product of the unit size (Wmu) *times plant the number of RO units* (Nms).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wmu * Nms

Row	Parameter	Unit	Variable name
232	**Seawater flow**	**kg/s**	**Fsms**

The installed water plant production capacity (Wacs) *divided by the recovery ratio* (Rro).

For B and HR energy plants not applicable.

Dimension check: [m^3/d] x 1000 [kg/m^3] / (24 [h/d] x 3600 [s/h])

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs / Rro * 1000 / 24 / 3600

Row	Parameter	Unit	Variable name
233	**Stand-alone seawater pumping power**	**MW(e)**	**Qsp**

The seawater volumetric flow (Fsms) *multiplied by the seawater pump head* (DPsm) *divided by the seawater pump efficiency* (Esm) *and the electric motor efficiency* (Eem).

For B and HR energy plants not applicable.

Dimension check: [kg/s]x[bar]x101,325[N/m^2.bar] 1000 [kg/m^3]x10^6[Nm/s.MW(e)]

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= DPsm * Fsms / 10000 / Esm / Eem

Row	Parameter	Unit	Variable name
234	**Booster pump power**	**MW(e)**	**Qbp**

The seawater volumetric flow (Fsms) *multiplied by the booster pump head* (DPbm) *divided by the booster pump efficiency* (Ebm) *and the electric motor efficiency* (Eem).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Fsms * DPbm / 10000 / Ebm / Eem

Row	Parameter	Unit	Variable name
235	**High head pump power**	**MW(e)**	**Qhp**

The seawater volumetric flow (Fsms) *multiplied by the high head pump pressure rise* (DPhm) *divided by the product of the high head pump efficiency* (Ehm)*, the hydraulic pump hydraulic coupling efficiency* (Ehhm) *and the electric motor efficiency* (Eem)*.*

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Fsms * DPhm / 10000 / Ehm / Eem / Ehhm

Row	Parameter	Unit	Variable name
236	**Energy recovery**	**MW(e)**	**Qer**

Energy recovery is modelled as a reverse running pump, mechanically coupled to the shaft of the high head pump. The calculation formula is minus the seawater volumetric flow (Fsms) *times the high head pump pressure rise* (DPhm) *times the ratio of reject brine flow to seawater flow times the energy recovery efficiency* (Eer). *[ratio of reject brine* = (1–the recovery ratio Rro)]

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= – Fsms * (1–Rro) / 10000 * Eer * DPhm

Row	Parameter	Unit	Variable name
237	**Other power**	**MW(e)**	**Qom**

The installed water plant production capacity (Wacs) *times the other specific power use* (Qsom).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs * Qsom / 24 / 1000

Row	Parameter	Unit	Variable name
238	**Total stand-alone RO power use**	**MW(e)**	**Qms**

The sum of the stand-alone seawater pumping (Qsp), the booster pump power (Qbp), the high head power (Qhp), the energy recovery (Qer) and the other power (Qom).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Qsp + Qbp + Qhp + Qer + Qom

Row	Parameter	Unit	Variable name
239	**Membrane water plant availability**		**Apm**

The product of (1 – the RO plant planned outage rate) *and* (1 – the RO plant unplanned outage rate).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (1–opm) * (1–oum)

Row	Parameter	Unit	Variable name
240	**Combined power/water plant load factor**		**Acpm**

The load factor of the power plant as electricity source for the RO plant is calculated like operating availability (App) *times one minus the RO plant unplanned outage rate* (oum).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= App * (1–oum)

Row	Parameter	Unit	Variable name
241	**Annual water production**	**m^3/a**	**Wpms**

The installed water production capacity (Wacs) *times the RO plant availability* (Apm) *times number of days per year.*

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs * Apm * 365

Row	Parameter	Unit	Variable name
242	**Average daily water production**	**m^3/d**	**Wpmsad**

The installed water plant production capacity (Wacs) *times the RO plant availability* (Apm).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs * Apm

Row	Parameter	Unit	Variable name
243	**Specific stand-alone power consumption**	**kW(e)·h/m^3**	**Qcms**

The total stand-alone power use (Qms) *times the number of hours per day divided by the installed water plant production capacity* (Wacs).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Qms * 24 / Wacs * 1000

Row	Parameter	Unit	Variable name
244	**Net stand-alone saleable power**	**MWe**	**Qssp**

The total base power plant net output (Pen) *minus the total stand-alone power use* (Qms).

For B and HR energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Pen – Qms

7.2.5. Contiguous RO water plant performance

Row	Parameter	Unit	Variable name
247	**Required water plant production capacity**	**m^3/d**	**Wcct**

The value of required water plant capacity at site (Wds) *is simply transferred to this cell.*

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wds

Row	Parameter	Unit	Variable name
248	**RO feedwater inlet temperature**	**°C**	**Timc**

The membrane water plant design feedwater temperature (Tfm) *if specified, else the seawater temperature* (Tsw) *plus condenser range* (DTcr).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (Tfm>0; Tfm; Tsw + DTcr)

Row	Parameter	Unit	Variable name
249	**Recovery ratio**		**Rrc**

See the row 222.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= memrec (MemType; TDS; Timc)

The function memrec *is stored in a normally hidden module in the calculation file.*

Row	Parameter	Unit	Variable name
250	**High head pump pressure rise**	**bar**	**DPhmc**

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= mempres (MemType ;   TDS ;   Timc   ) – 1

The function mempres *is stored in a normally hidden module in the calculation file.*

Row	Parameter	Unit	Variable name
251	**Membrane area factor**		**Fmac**

See Row 225 for Fma and Row 279 for Fmah.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (MemType = "SPIRAL WOUND" ;   memarea(MemType; TDS; Timc) / 228;
memarea(MemType; TDS; Timc) / 345)

The function memarea is stored in a normally hidden module in the calculation file.

Row	Parameter	Unit	Variable name
252	**Pretreatment, pump and piping size increase factor**		**Fppc**

Typical algorithm used in economic analysis, with 0.5 as a typical equipment scaling factor.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (MemType = "HOLLOW FIBER" ;   (0,5/Rrc)^0,5 ;   (0,411/Rrc)^0,5   )

Row	Parameter	Unit	Variable name
253	**Default unit size**	**m^3/d**	**Wmudc**

In this row there is a formula used for the selection of the water plant unit size according following rules (all values and parameters are in m^3/d).

Wmudc = 12 000   for   0 <= Wcct < 99 000
Wmudc = 24 000   for   100 000 <= Wcct

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (Wcct<100000 ;   (INT(Wcct/99000)+1) * 12000 ;   24000   )

Row	Parameter	Unit	Variable name
254	**Selected unit size**	**m^3/d**	**Wmuc**

If optional unit size, (Wmuo) *is not specified (see the row 83), the default unit size* (Wmudc) *is taken.*

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (Wmuo>0 ; Wmuo ; Wmudc)

Row	Parameter	Unit	Variable name
255	**Number of RO units**		**Nmc**

The number of RO units necessary to provide the required water plant production capacity (Wcct) *with respect to selected unit size* (Wmuc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= INT(Wcct/Wmuc) + 1

Row name	Parameter	Unit	Variable
256	**Installed contiguous RO capacity**	**m^3/d**	**Wacc**

The product of the unit size (Wmuc) *times plant the number of RO units* (Nmc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wmuc * Nmc

Row	Parameter	Unit	Variable name
257	**Seawater flow**	**kg/s**	**Fsmc**

The installed water plant production capacity (Wacc) *divided by the recovery ratio* (Rrc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wacc / Rrc * 1000 / 24 / 3600

Row	Parameter	Unit	Variable name
258	**Contiguous seawater transfer pumping power**	**MW(e)**	**Qcpc**

The seawater volumetric flow (Fsmc) *multiplied by the contiguous/hybrid RO transfer pump head* (DPtm) *divided by the contiguous/hybrid RO transfer pump efficiency* (Etpm) *and the electric motor efficiency* (Eem).

Dimension check: [kg/s]x[bar]x101,325[N/m^2.bar]   1000 [kg/m^3]x10^6[Nm/s.MW(e)]

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= DPtm * Fsmc / Etpm / 10000 / Eem

Row	Parameter	Unit	Variable name
259	**Booster pump power**	**MW(e)**	**Qbpc**

The seawater volumetric flow (Fsmc) *multiplied by the booster pump head* (DPbm) *divided by the booster pump efficiency* (Ebm) *and the electric motor efficiency* (Eem).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Fsmc * DPbm / 10000 / Ebm / Eem

Row	Parameter	Unit	Variable name
260	**High head pump power**	**MW(e)**	**Qhpc**

The seawater volumetric flow (Fsmc) *multiplied by the high head pump pressure rise* (DPhmc) *divided by the product of the high head pump efficiency* (Ehm)*, the hydraulic pump hydraulic coupling efficiency* (Ehhm) *and the electric motor efficiency* (Eem).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Fsmc * DPhmc / 10000 / Ehm / Eem / Ehhm

Row	Parameter	Unit	Variable name
261	**Energy recovery**	**MW(e)**	**Qerc**

Energy recovery is modelled as a reverse running pump, mechanically coupled to the shaft of the high head pump. The calculation formula is minus the seawater volumetric flow (Fsmc) *times the high head pump pressure rise* (DPhmc) *times the ratio of reject brine flow to seawater flow times the energy recovery efficiency* (Eer). *[ratio of reject brine* = (1–the recovery ratio Rrc)]

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= – Fsmc * (1–Rrc) / 10000 * Eer * DPhmc

Row	Parameter	Unit	Variable name
262	**Other power**	**MW(e)**	**Qomc**

The installed water plant production capacity (Wacc) *times the other specific power use* (Qsom).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
=Wacc * Qsom / 24 / 1000

Row	Parameter	Unit	Variable name
263	**Total contiguous power use**	**MW(e)**	**Qmc**

The sum of the stand-alone seawater pumping (Qspc)*, the booster pump power* (Qbpc)*, the high head power* (Qhpc)*, the energy recovery* (Qerc) *and the other power* (Qomc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Qcpc + Qbpc + Qhpc + Qerc + Qomc

Row	Parameter	Unit	Variable name
264	**Annual water production**	**m^3/a**	**Wpmc**

The installed water production capacity (Wacc) *times the RO plant availability* (Apm) *times number of days per year.*

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wacc * Apm * 365

Row	Parameter	Unit	Variable name
265	**Average daily water production**	**m^3/d**	**Wpmcad**

The installed water plant production capacity (Wacc) *times the RO plant availability* (Apm).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wacc * Apm

Row	Parameter	Unit	Variable name
266	**Specific contiguous power consumption**	**$kW(e)\cdot h/m^3$**	**Qsmc**

The total contiguous power use (Qmc) *times the number of hours per day divided by the installed water plant production capacity* (Wacc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Qmc * 24 / Wacc * 1000

Row	Parameter	Unit	Variable name
267	**Net contiguous saleable power**	**MW(e)**	**Qcsp**

The total base power plant net output (Pen) *minus the total contiguous power use* (Qmc).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Pen – Qmc

7.2.6. Distillation plus RO (hybrid) performance

Row	Parameter	Unit	Variable name
270	**Required hybrid water plant production capacity**	**m^3/d**	**Wcht**

Should be higher in value than maximum distillation water plant capacity Wcd.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wdhs

Row	Parameter	Unit	Variable name
271	**Maximum (distillation) water production capacity**	**m^3/d**	**Wcd1**

The value as calculated under 7.2.3 is used.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wcd

Row	Parameter	Unit	Variable name
272	**Distillation plant product water quality**	**ppm**	**dsd1**

The value as given under 7.1.5 is used.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= dsd

Row	Parameter	Unit	Variable name
273	**Required RO production capacity**	**m^3/d**	**Wcmht**

The difference between the required hybrid water plant capacity and the maximum distillation water plant capacity. See Row 11 and 270 to follow the required hybrid water plant capacity value transfer.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= IF (Wcht–Wcd1<0 ; 0 ; Wcht–Wcd1)

Row	Parameter	Unit	Variable name
274	**RO product water quality before posttreatment**	**ppm**	**dspms1**

Value is taken from Row 227, where a simplification of a more detailed code is used for calculation.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= dspms

Row	Parameter	Unit	Variable name
275	**Selected RO unit size**	**m^3/d**	**Wmuh**

Similarly to Row 229:
*If optional unit size (*Wmuo *— see the row 83) is specified, this optional value* (Wmuo) *is taken; else (optional unit size is not specified —* Wmuo <= 0*] the default unit size is calculated like in Row 228, where a formula is used for the selection of the default water plant unit size. The composite expression shown in formula evaluates according following rules (all values and parameters are in m^3/d)*

For HR, B, GTMHR and D energy plants not applicable.

Wmuh = Wmuo	for	Wmuo >0		
Wmuh = 12 000	for	Wmuo <=0	and	0 <= Wcmht < 99 000
Wmuh = 24 000	for	Wmuo <=0	and	99 000 <= Wcmht

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
=IF(Wmuo>0;Wmuo;IF(Wcmht<100000;(INT(Wcmht/99000)+1)*12000;24000))

Row	Parameter	Unit	Variable name
276	**RO feedwater inlet temperature**	**°C**	**Timh**

Stand-alone RO feed inlet temperature (Tim) *plus condenser range* (DTcr). *It is in fact the membrane water plant design cooling water temperature* (Tsm) *if specified, else the seawater temperature* (Tsw), *both plus condenser range.*

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Tim + DTdcr
where Tim = IF (Tsm>0; Tsm; Tsw) see Row 220.

Row	Parameter	Unit	Variable name
277	**RO recovery ratio**		**Rrh**

See the row 222.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= memrec (MemType ; TDS ; Timh)

Row	Parameter	Unit	Variable name
278	**High head pump pressure rise**	**bar**	**DPhmh**

The function in following formula is stored in module in the calculation file.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= mempres (MemType ; TDS ; Timh) – 1

Row	Parameter	Unit	Variable name
279	**Membrane area factor**		**Fmah**

See Row 225 for Fma *and Row 251 for* Fmac.

For HR, B, GTMHR and D energy plants not applicable.

The function in following formula is stored in module in the calculation file.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= IF (MemType = "SPIRAL WOUND" ; memarea(MemType; TDS; Timh) / 228;
memarea(MemType; TDS; Timh) / 345)
resp.
= memareaw(MemType;TDS;Timh)

Row	Parameter	Unit	Variable name
280	**Pretreatment, pump and piping size increase factor**		**Fpph**

Typical algorithm used in economic analysis, with 0.5 as a typical equipment-scaling factor.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= IF (MemType = "HOLLOW FIBER" ; (0,5/Rrh)^0,5 ; (0,411/Rrh)^0,5)

Row	Parameter	Unit	Variable name
281	**Number of RO units**		**Nmh**

The number of RO units necessary to provide the required water plant production capacity (Wcmht) *with respect to selected unit size* (Wmuh).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= INT (Wcmht / Wmuh) + 1

Row	Parameter	Unit	Variable name
282	**Installed hybrid RO water plant capacity**	**m^3/d**	**Wacm**

The product of the unit size (Wmuc) *times plant the number of RO units* (Nmc).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wmuh * Nmh

Row	Parameter	Unit	Variable name
283	**RO plant seawater flow**	**kg/s**	**Fswh**

The installed RO water plant capacity divided by the RO recovery ratio.

Dimension check: [m3/d] x 1000 [kg/m3] / (24 [h/d] x 3600 [s/h])

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacm / Rrh * 1000 / 24 / 3600

Row	Parameter	Unit	Variable name
284	**RO plant seawater transfer pumping power**	**MW(e)**	**Qmp**

The seawater volumetric flow (Fswh) *times the contiguous/ hybrid RO transfer pump head* (DPtm) *divided by the contiguous /hybrid RO transfer pump efficiency* (Etpm) *and the electric motor efficiency* (Eem).

Dimension check: [kg/s]x[bar]x101,325[N/m2.bar] 1000[kg/m3]x106[Nm/s.MW(e)]

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= DPtm * Fswh / Etpm / 10000 / Eem

Row	Parameter	Unit	Variable name
285	**RO plant booster pump power**	**MW(e)**	**Qbph**

The seawater volumetric flow (Fswh) *times the booster pump head divided by the booster pump efficiency* (Ebm) *and the electric motor efficiency* (Eem).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Fswh * DPbm / 10000 / Ebm / Eem

Row	Parameter	Unit	Variable name
286	**RO plant high head pump power**	**MW(e)**	**Qhph**

The seawater volumetric flow (Fsmh) *multiplied by the high head pump pressure rise* (DPhmh) *divided by the product of the high head pump efficiency* (Ehm)*, the hydraulic pump hydraulic coupling efficiency* (Ehhm) *and the electric motor efficiency* (Eem).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Fswh * DPhmh / 10000 / Ehm / Eem / Ehhm

Row	Parameter	Unit	Variable name
287	**RO plant energy recovery**	**MW(e)**	**Qerh**

Energy recovery is modelled as a reverse running pump, mechanically coupled to the shaft of the high head pump. The calculation formula is minus the seawater volumetric flow (Fsmh) *times the high head pump pressure rise* (DPhmh) *times the ratio of reject brine flow to seawater flow times the energy recovery efficiency* (Eer). *[ratio of reject brine* = (1–the recovery ratio Rrh)]

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= – Fswh * (1–Rrh) / 10000 * Eer * DPhmh

Row	Parameter	Unit	Variable name
288	**RO other power**	**MW(e)**	**Qomh**

The installed water plant production capacity (Wacm) *times the other specific power use* (Qsom).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacm * Qsom / 24 / 1000

Row	Parameter	Unit	Variable name
289	**Total RO plant power use**	**MW(e)**	**Qmh**

The sum of the RO seawater transfer pumping power (Qmp)*, the RO plant booster pump power* (Qbph)*, the RO plant high head pump power* (Qhph)*, the RO plant energy recovery* (Qerh) *and the RO plant other power* (Qomh).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Qmp + Qbph + Qhph + Qerh + Qomh

Row	Parameter	Unit	Variable name
290	**RO plant annual water production**	**m^3/a**	**Wpmh**

The installed RO plant capacity (Wacm) *times the RO plant availability* (Apm) *times the number of days per year.*

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacm * 365 * Apm

Row	Parameter	Unit	Variable name
291	**RO plant average daily water production**	**m^3/d**	**Wpmhad**

The installed RO plant capacity (Wacm) *times the RO plant availability* (Apm).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacm * Apm

Row	Parameter	Unit	Variable name
292	**Specific RO power consumption**	**$kW(e)\cdot h/m^3$**	**Qsmh**

The total RO power use (Qmh) *times the number of hours per day divided by the installed RO production capacity* (Wacm).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Qmh * 24 / Wacm * 1000

Row	Parameter	Unit	Variable name
293	**Total distillation + RO power use**	**MW(e)**	**Qdm**

The sum of the total distillation water plant power use (Qdp) *and the total RO plant power use* (Qmh).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Qdp + Qmh

Row	Parameter	Unit	Variable name
294	**Total distillation+RO annual water production**	**m^3/a**	**Wph**

The sum of the annual average water production of the distillation plant (Wpd) *and the RO plant* (Wpmh).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wpd + Wpmh

Row	Parameter	Unit	Variable name
295	**Total distillation+RO average daily water production**	**m^3/d**	**Wphad**

The sum of the daily average water production of the distillation plant (Wpdad) *and RO plant* (Wpmhad).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wpdad + Wpmhad

Row	Parameter	Unit	Variable name
296	**Installed hybrid water production capacity**	**m^3/d**	**Wach**

The sum of the installed distillation plant production capacity (Wacd) *and the installed RO plant production capacity* (Wacm).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacd + Wacm

Row	Parameter	Unit	Variable name
297	**Total spec. equiv. dist.+ RO power consumption**	**kW(e)·h/m^3**	**Qsdm**

The ratio of the total distillation + RO plant power use and the lost electricity production to the total distillation + RO average daily water production times the number of hours per day.

Qsdm = (Qdm + Qle) / wph x 24 x 1000 for steam power plants
Qsdm = Qdm / wph x 24 x 1000 for gas turbine

For HR, B, GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (Qdm+Qle) * 24 / (Wcd1 + Wacm) * 1000

For GT energy plants:
= Qdm * 24 / (Wcd1 + Wacm) * 1000

Row	Parameter	Unit	Variable name
298	**Net saleable power**	**MW(e)**	**Qhsp**

The difference between the net electricity produced by the dual purpose plant (Qnep) *and the total distillation plant + RO plant power use* (Qdm).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Qnep – Qdm

Row	Parameter	Unit	Variable name
299	**Distillation+RO combined water quality**	**ppm**	**dsph**

The distillation water plant production (Wpdad) *times the distillation water plant product water quality* (dsd1) *+ the RO water plant production* (Wpmhad) *times the RO product water plant quality* (dspm1) *divided by the total hybrid water production capacity* (Wphad).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (Wpdad * dsd1 + Wpmhad * dspm1) / Wphad

7.3. COST CALCULATIONS

7.3.1. Distillation plant costs

Row	Parameter	Unit	Variable name
306	**Number of units**		**Ndu1**

The number of units calculated in section 7.2.3

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Ndu

Row	Parameter	Unit	Variable name
307	**Correction factor for unit size**		**kdus**

Assumed that 70% of the cost of a single effect/stage is for tubing and 30% for the shell; the algorithm uses a scaling factor of 0.5.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
For MED: = 0,7 + 0,3 * (Wdur / Wdu)^0,5
For MSF: = 1,1918 – 0,1918 * (Wdu / Wdur)

Row	Parameter	Unit	Variable name
308	**Correction factor for: number of effects (MED)** **GOR (MSF)**		**kdne**

For MED, **kdne** *is e a function of the number of effects* (Nemed)*; for MSF,* **kdne** *is a function of* Gor.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
For MED: = 0,8333 + Nemed * 0,012 ;
For MSF: = (1717,7 – 52,731 * Gor1 + 4,1287 * Gor1^2) / Cdu / 0,933033)

Row	Parameter	Unit	Variable name
309	**Correction factor for number of units**		**kdnu**

A simple learning curve of units.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= 1 / Ndu1^0,1

Row	Parameter	Unit	Variable name
310	**Water plant specific base cost**	**$/(m^3/d)**	**Cds**

The corrected input base unit cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= kdus * Cdu * kdnu * kdne

Row	Parameter	Unit	Variable name
311	**(Incremental) In / Outfall specific base cost**	**$/(m^3/d)**	**Cdio**

Cdio *is a function of the seawater flow* (Fsd) *and the plant capacity* (Wacd)*, based on a more detailed code. If heat is supplied by a dual purpose plant and the seawater flow through the water plant condenser is larger than the seawater flow through the power plant condenser this will be the incremental cost.*

For GTMHR and D energy plants not applicable.

If **Csdo** *is specified (> 0) in row 125, this value is supplied as the (incremental) in / outfall specific base cost* **Cdio***. Otherwise* **Cdio** *is calculated according following formulas.*

If heat is supplied by a dual purpose plant and Fsd > Fcc
$= 7400200 \times [((Fcc+Fsd*DTdcr/DTcr) / 486)^{0.45} – (Fcc / 486)^{0.45}] / Wacd$;

If heat is supplied by a heat-only plant
$= 7400200 \times (Fsd / 486)^{0.45} / Wacd$;

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (Csdo > 0 ; Csdo ;
7400200*(((Fcc+Fsd*DTdcr/DTcr) / 486)^0,45 – (Fcc / 486)^0,45) / Wacd)

For GT, HR and B energy plants:
= IF (Csdo > 0; Csdo; 7400200 * (Fsd / 486) ^0,45 / Wacd)

Row	Parameter	Unit	Variable name
312	**Intermediate loop specific cost**	**$/(m^3/d)**	**Cinl**

Is equal to the input value Cil if specified, else is a function of GOR assuming 100 $\$ \times d/m^3$ for a plant with GOR of 11; the size of the intermediate loop is reduced by increasing GOR at constant water product delivery, using a scaling factor of 0.6, which is typical for heat exchangers, pipes and pumps.

For fossil energy plants SSB, GT, CC, B (there is no intermediate loop in fossil plants) and for GTMHR and D energy plants not applicable (distillation is not applicable for these plants).

Also not applicable for MSF desalination plants without intermediate loop (In such a case the value of Cinl *has to be set* 0*).*

Formula:
For PWR, PHWR, HR and SPWR energy plants:
For MED: = IF (Cil > 0 ; Cil; (11 / Gor1)^0,6 * 100)
For MSF: = IF (CILMSF="N" ; 0; IF (Cil > 0 ; Cil; (11 / Gor1)^0,6 * 100))

Row	Parameter	Unit	Variable name
313	**Total specific base cost**	**$/($m^3$/d)**	**Cdst**

The sum of the water plant specific base cost, the (incremental) in/outfall specific base cost and the intermediate loop specific cost.

For GTMHR and D energy plants not applicable.

Formulas:
For PWR, PHWR and SPWR energy plants:
= Cds + Cdio + Cinl
For SSB, CC, GT and B energy plants:
= Cds + Cdio

Row	Parameter	Unit	Variable name
314	**Water plant adjusted base cost**	**M$**	**Cda**

The installed water plant capacity times the total specific base cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Wacd * Cdst / 1000000

Row	Parameter	Unit	Variable name
315	**Backup heat source base cost**	**M$**	**Cbh**

The backup heat source unit cost times the backup heat source size.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Bhs * Cbu / 1000000

Row	Parameter	Unit	Variable name
316	**Total water plant base cost**	**M$**	**Cdt**

The sum of the water plant adjusted base cost and the backup heat source base cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cda + Cbh

Row	Parameter	Unit	Variable name
317	**Water plant owners cost**	**M$**	**DCdo**

The product of the water plant owners cost factor and the total water plant base cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdt * kdo

Row	Parameter	Unit	Variable name
318	**Water plant contingency cost**	**M$**	**DCdc**

The product of the water plant contingency factor and the sum of the total water plant base cost and the water plant owners cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= (Cdt + Dcdo) * kdc

Row	Parameter	Unit	Variable name
319	**Water plant total construction cost**	**M$**	**Cdcon**

The sum of the total water plant base cost, the water plant owners cost and the water plant contingency cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdt + DCdo + DCdc

Row	Parameter	Unit	Variable name
320	**Number of management personnel**		**Ndm**

A function of the installed water plant production capacity (Wacd).

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= INT ((5 + Wacd / 55000) / 2)

Row	Parameter	Unit	Variable name
321	**Water plant O&M management cost**	**M$/a**	**Cdm**

The average management salary times the number of management personnel.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Ndm * Sdm / 1000000

Row	Parameter	Unit	Variable name
322	**Number of labour personnel**		**Ndl**

A function of the installed water plant production capacity (Wacd).

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= INT ((Wacd * 264 / 1000000 / 6)^0,4 * 18 / 1,4)

Row	Parameter	Unit	Variable name
323	**Water plant O&M labour cost**	**M$/a**	**Cdl**

The average labour salary times the number of labour personnel.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Ndl * Sdl / 1000000

Row	Parameter	Unit	Variable name
324	**Water plant annual materials cost**	**M$/a**	**Cdmt**

The sum of the specific O&M chemicals and spare part cost times the annual average water production.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= (csds + cdtr + cdcpr + cdcpo) * Wpd / 1000000

Row	Parameter	Unit	Variable name
325	**Water plant annual insurance cost**	**M$/a**	**Cdins**

The product of the water plant O&M insurance cost factor and the total water plant base cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= kdi / 100 * Cdt

Row	Parameter	Unit	Variable name
326	**Water plant annual O&M cost**	**M$/a**	**Cdom**

The sum of the water plant O&M management cost, the water plant O&M labour cost, water plant annual materials cost and water plant annual insurance cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdm + Cdl + Cdmt + Cdins

7.3.2. Stand-alone RO water plant costs

Row	Parameter	Unit	Variable name
329	**Number of units**		**Nms1**

The number of RO units calculated under 7.2.4.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Nms

Row	Parameter	Unit	Variable name
330	**Correction factor for unit size**		**kmsus**

A simple learning curve.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= 1 / (Wmu / 24000)^0,15

Row	Parameter	Unit	Variable name
331	**Correction factor for number of units**		**kmsnu**

A simple learning curve of units.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= 1 / Nms1^0,1

Row	Parameter	Unit	Variable name
332	**Correction factor for TDS and temperature**		**kmstt**

The sum of the product of the membrane area factor and the ratio membrane equipment cost to total cost and of the product of the pretreatment and piping size increase factor with the complement of the ratio membrane equipment cost to total cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Fma * kme + Fpp * (1–kme)

Row	Parameter	Unit	Variable name
333	**Adjusted water plant specific cost**	**$/(m^3/d)**	**Cmsa**

The base unit cost (Cmu) times correction factor for unit size (kmsus) times correction factor for number of units (kmsnu) times correction factor for TDS and temperature (kmstt).

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmu * kmsus * kmsnu * kmstt

Row	Parameter	Unit	Variable name
334	**Stand-alone in/outfall specific cost**	**$/(m^3/d)**	**Cmio**

Is a function of the seawater flow and the installed plant water capacity based on a more detailed code.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= IF (Csmo > 0 ; Csmo ; 7400200 * (Fsms/486)^0,45 / Wacs)

Row	Parameter	Unit	Variable name
335	**Stand-alone water plant specific cost**	**$/(m^3/d)**	**Cms**

The sum of the adjusted water plant specific cost and the stand-alone in/outfall specific cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsa + Cmio

Row	Parameter	Unit	Variable name
336	**Stand-alone water plant adjusted base cost**	**M$**	**Cmsab**

The product of the installed water plant capacity and the stand-alone water plant specific cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs * Cms / 1000000

Row	Parameter	Unit	Variable name
337	**Water plant owners cost**	**M$**	**DCmso**

The product of the stand-alone water plant adjusted base cost and the water plant owners cost factor.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsab * kmo

Row	Parameter	Unit	Variable name
338	**Water plant contingency cost**	**M$**	**DCmsc**

The sum of the stand-alone water plant adjusted base cost and the water plant owners cost times the water plant contingency factor.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (Cmsab + DCmso) * kmc

Row	Parameter	Unit	Variable name
339	**Stand-alone water plant total construction cost**	**M$**	**Cmscon**

The sum of the stand-alone water plant adjusted base cost, the water plant owners cost and the water plant contingency cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsab + DCmso + DCmsc

Row	Parameter	Unit	Variable name
340	**Number of management personnel**		**Nmsm**

A function of the installed water plant capacity.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= INT ((5 + Wacs / 55000) / 2)

Row	Parameter	Unit	Variable name
341	**O&M management cost**	**M$/a**	**Cmsm**

The average management salary times the number of management personnel.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Nmsm * Smm / 1000000

Row	Parameter	Unit	Variable name
342	**Number of labour personnel**		**Nmsl**

A function of the installed water plant production capacity (Wacs).

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= INT ((Wacs * 264 / 1000000 / 6)^0,4 * 18 / 1,4)

Row	Parameter	Unit	Variable name
343	**O&M labour cost**	**M$/a**	**Cmsl**

The average labour salary times the number of labour personnel.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Nmsl * Sml / 1000000

Row	Parameter	Unit	Variable name
344	**Annual materials cost**	**M$/a**	**Csmt**

The sum of the O&M membrane replacement cost, the O&M spare parts cost and the specific chemicals cost times the annual average water production.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (cmm * Fma + cmsp * Fpp + cmcpr + cmcpo) * Wpms / 1000000

Row	Parameter	Unit	Variable name
345	**Annual insurance cost**	**M$/a**	**Csins**

The water plant O&M insurance cost factor times stand-alone water plant total construction cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (kmi / 100) * Cmscon

Row	Parameter	Unit	Variable name
346	**Water plant O&M cost**	**M$/a**	**Cmsom**

The sum of the O&M management cost, the O&M labour cost, the annual materials cost and the annual insurance cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsm + Cmsl + Csmt + Csins

7.3.3. Contiguous RO water plant costs

Row	Parameter	Unit	Variable name
349	**Number of units**		**Nmc1**

The number of RO units calculated under 7.2.5.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Nmc

Row	Parameter	Unit	Variable name
350	**Correction factor for unit size**		**kmcus**

A simple learning curve.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= 1 / (Wmuc / 24000)^0,15

Row	Parameter	Unit	Variable name
351	**Correction factor for number of units**		**kmcnu**

A simple learning curve of units.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= 1 / Nmc1^0,1

Row	Parameter	Unit	Variable name
352	**Correction factor for TDS and temperature**		**kmctt**

The sum of the product of the membrane area factor (Fma) *and the ratio membrane equipment cost to total cost* (kme) *and of the product of the pretreatment and piping size increase factor* (Fppc) *with the complement* (1–kme) *of the ratio membrane equipment cost to total cost* (kme).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Fma * kme + Fppc * (1–kme)

Row	Parameter	Unit	Variable name
353	**Adjusted water plant specific cost**	**$/($m^3$/d)**	**Cmca**

The base unit cost (Cmu) *times correction factor for unit size* (kmcus) *times correction factor for number of units* (kmcnu) *times correction factor for TDS and temperature* (kmctt).

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmu * kmcus * kmcnu * kmctt

Row	Parameter	Unit	Variable name
354	**Contiguous water plant adjusted base cost**	**M$**	**Cmcab**

The product of the installed water plant capacity and the adjusted water plant specific cost.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wacc * Cmca / 1000000

Row	Parameter	Unit	Variable name
355	**Water plant owners cost**	**M$**	**DCmco**

The product of the contiguous water plant adjusted base cost and the water plant owners cost factor.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmcab * kmo

Row	Parameter	Unit	Variable name
356	**Water plant contingency cost**	**M$**	**DCmcc**

The sum of the contiguous water plant adjusted base cost and the water plant owners cost times the water plant cost contingency factor.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (Cmcab + Dcmco) * kmc

Row	Parameter	Unit	Variable name
357	**Contiguous water plant total construction cost**	**M$**	**Cmccon**

The sum of the contiguous water plant adjusted base cost, the water plant owners cost and the water plant contingency cost.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmcab + Dcmco + DCmcc

Row	Parameter	Unit	Variable name
358	**Annual materials cost**		**Ccmt**

The sum of the O&M membrane replacement cost, the O&M spare parts cost and the specific chemicals cost times the annual average water production.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (cmm * Fmac + cmsp * Fppc + cmcpr + cmcpo) * Wpmc / 1000000

Row	Parameter	Unit	Variable name
359	**Annual insurance cost**	**M$/a**	**Ccins**

The water plant O&M insurance cost factor times contiguous water plant total construction cost.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (kmi / 100) * Cmccon

Row	Parameter	Unit	Variable name
360	**Water plant O&M cost**	**M$/a**	**Cmcom**

The sum of the O&M management cost, the O&M labour cost, the annual materials cost and the annual insurance cost.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmsm + Cmsl + Ccmt + Ccins

7.3.4. Distillation plus RO (hybrid) water plant costs

Row	Parameter	Unit	Variable name
363	**Total distillation plant construction cost**	**M$**	**Cdcon1**

Total distillation water plant construction cost Cdcon as calculated under 7.3.1.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cdcon

Row	Parameter	Unit	Variable name
364	**Distillation plant annual O&M cost**	**M$/a**	**Cdom1**

Distillation water plant annual O&M cost Cdom as calculated under 7.3.1.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cdom

Row	Parameter	Unit	Variable name
365	**Number of RO units**		**Nmh1**

Number of RO units Nmh as calculated under 7.2.6 .

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Nmh

Row	Parameter	Unit	Variable name
366	**Correction factor for unit size**		**khus**

A simple learning curve.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= 1 / (Wmuh / 24000)^0,15

Row	Parameter	Unit	Variable name
367	**Correction factor for number of RO units**		**kmhnu**

Correction factor for a simple learning curve number of RO unit.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= 1 / Nmh1^0,1

Row	Parameter	Unit	Variable name
368	**Correction factor for TDS and temperature**		**kmhtt**

The sum of the product of the membrane area factor (Fmah) *and the ratio membrane equipment cost to total cost* (kme) *and of the product of the pretreatment and piping size increase factor* (Fpph) *with the complement* (1-kme) *of the ratio membrane equipment cost to total cost* (kme).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Fmah * kme + Fpph * (1-kme)

Row	Parameter	Unit	Variable name
369	**RO adjusted water plant specific cost**	**$\$/(m^3/d)$**	**Cmha**

The base unit cost (Cmu) *times correction factor for unit size* (khus) *times correction factor for number of units* (kmhnu) *times correction factor for TDS and temperature* (kmhtt).

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cmu * khus * kmhnu * kmhtt

Row	Parameter	Unit	Variable name
370	**RO water plant adjusted base cost**	**M$**	**Cmhab**

The product of the installed RO (hybrid) water plant capacity and the RO adjusted water plant specific cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wacm * Cmha / 1000000

Row	Parameter	Unit	Variable name
371	**RO water plant owners cost**	**M$**	**DCmho**

The product of the RO water plant adjusted base cost and the water plant owners cost factor.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cmhab * kmo

Row	Parameter	Unit	Variable name
372	**RO water plant contingency cost**	**M$**	**DCmhc**

The sum of the RO water plant adjusted base cost and the RO water plant owners cost times the water plant cost contingency factor.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (Cmhab+DCmho)*kmc

Row	Parameter	Unit	Variable name
373	**RO water plant total construction cost**	**M$**	**Cmhcon**

The sum of the RO water plant adjusted base cost, the RO water plant owners cost and the RO water plant contingency cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cmhab + Dcmho + DCmhc

Row	Parameter	Unit	Variable name
374	**Incremental RO water plant number of management personnel**		**Nmhm**

A function of the installed hybrid water plant capacity minus the number of management personnel in the distillation plant.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= INT ((5 + Wach / 55000) / 2) – Ndm

Row	Parameter	Unit	Variable name
375	**Incremental RO water plant O&M management cost**	**M$/a**	**Cmhm**

The average management salary times the RO water plant number of management personnel.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Nmhm * Smm / 1000000

Row	Parameter	Unit	Variable name
376	**Incremental RO water plant number of labour personnel**		**Nmhl**

A function of the installed RO water plant capacity minus the number of labour personnel in the distillation plant.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= INT ((Wach * 264 / 1000000 / 6)^0,4 * 18 / 1,4) – Ndl

Row Parameter Unit Variable name

377	**Incremental RO water plant O&M labour cost**	**M$/a**	**Cmhl**

The average labour salary times the RO water plant number of labour personnel.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Nmhl * Sml / 1000000

Row	Parameter	Unit	Variable name
378	**RO water plant annual materials cost**	**M$/a**	**Chchem**

For HR, B, GTMHR and D energy plants not applicable.

The sum of the O&M membrane replacement cost, the O&M spare parts cost and the specific chemicals cost times the annual average RO water plant production.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (cmm * Fmah + cmsp * Fpph + cmcpr + cmcpo) * Wpmh / 1000000

Row	Parameter	Unit	Variable name
379	**RO water plant annual insurance cost**	**M$/a**	**Chins**

For HR, B, GTMHR and D energy plants not applicable.

The water plant O&M insurance cost factor times RO water plant total construction cost.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (kmi / 100) * Cmhcon

Row	Parameter	Unit	Variable name
380	**RO water plant annual O&M cost**	**M$/a**	**Cmhom**

For HR, B, GTMHR and D energy plants not applicable.

The sum of the RO water plant O&M management cost , the RO water plant O&M labour cost, the RO water plant annual materials cost and the RO water plant annual insurance cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cmhm + Cmhl + Chchem + Chins

Row	Parameter	Unit	Variable name
381	**Total distillation + RO plant construction cost**	**M$**	**Chcon**

The sum of the RO water plant total construction cost and the total distillation water plant construction cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Cmhcon + Cdcon1

Row	Parameter	Unit	Variable name
382	**Total distillation + RO plant annual O&M cost**	**M$/a**	**Chom**

The sum of the RO water plant annual O&M cost and the distillation water plant annual O&M cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
=Cmhom+Cdom1

7.4. ECONOMIC EVALUATIONS

7.4.1. Power plant

Row	Parameter	Unit	Variable name
389	**Total specific construction cost**	**$/kW(e) ($/kW(t))**	**Cets**

The sum of the specific construction cost and the additional site related construction cost adjusted by energy plant contingency factor (kec).

Formula: =(Ce+DCrs)*(1+kec)

Row	Parameter	Unit	Variable name
390	**Total construction cost**	**M$**	**Cecon**

The product of the total specific construction cost and reference base power plant unit net output times the number of power plant unit at site.

Formula:
For PWR, PHWR, SSB, HR, B, GTMHR, D and SPWR energy plants:
= Cets * Qbn * Nb / 1000
For CC and GT energy plants:
= Cets * Qbg * Nb / 1000

Row	Parameter	Unit	Variable name
391	**Interest during construction (IDC)**	**M$**	**IDCp**

A function of the total construction cost, the interest rate during construction and the construction lead time.

Formula: = Cecon * ((1 + ir/100)^(Le / 24) – 1)

Row	Parameter	Unit	Variable name
392	**Total plant investment**	**M$**	**Ceinv**

The sum of the total construction cost and the IDC.

Formula: =Cecon + IDCp

Row	Parameter	Unit	Variable name
393	**Specific investment cost**	**$/kW**	**Cesi**

The total plant investment divided (Ceinv) by total site specific base power plant net output (Pen).

Formula: =Ceinv/Pen*1000

Row	Parameter	Unit	Variable name
394	**Levelised fixed charge rate**	**%**	**lfc**

The annuity function with the interest rate and the plant economic life as parameter (resulting in the annual payment for an annuity per $ invested).

Formula: = PMT (i / 100 ; Lep ; –1) * 100

Row	Parameter	Unit	Variable name
395	**Fuel levelisation factor**		**lff**

The ratio of the present value of the fuel costs and the present value of the electricity revenues, which is a function of the fuel annual escalation rate, the real interest rate, the initial year of operation, the currency reference year and the plant economic life.

$$\mathbf{lff} = (1+ e / 100)^{Yi-Ycr} \text{ x lfc / 100 x } [1-\{(1+e / 100) / (1+ i / 100)\}^{Lep}] \;/\; [(1+i / 100) / (1+ e /100) - 1]$$

For nuclear fuel e = efn; *for fossil fuel* e = eff.

For PWR, PHWR, HR, GTMHR and SPWR energy plants:

=(1+efn/100)^(Yi–Ycr)*lfc/100/((1+i/100)/(1+efn/100)–1)*(1–((1+efn/100)/(1+i/100))^Lep)

For SSB, CC, GT, B and D energy plants:

=(1+eff/100)^(Yi–Ycr)*lfc/100/((1+i/100)/(1+eff/100)–1)*(1–((1+eff/100)/(1+i/100))^Lep)

Row	Parameter	Unit	Variable name
396	**Annual levelised capital cost**	**M$/a**	**alcc**

The product of the total plant investment and the levelised fixed charge rate.

Formula: = Ceinv * lfc / 100

Row	Parameter	Unit	Variable name
397	**Specific fuel cost**	**\$/MW(e)·h (\$/MW(t)×h)**	**Csf**

For nuclear, the input specific fuel cost. For fossil, it is equal to the fossil fuel price at startup divided by the reference net thermal efficiency of the energy plant and divided by the conversion factor of MW×h per bbl (1.6471) or per t (6500x4.1869/3600).

Formula:

For PWR, PHWR, HR, GTMHR and SPWR energy plants: = Csnf
For SSBC energy plants: = Cff * 100 / Ebpnr * 3600 / 6500 / 4,1868
For SSBOG and D energy plants: = Cff * 100 / Ebpnr / 1,6471
For CC, GT energy plants: = Cff * 100 / Ebpgr / 1,6471
For B energy plants: = Cff / 1.6471

Row	Parameter	Unit	Variable name
398	**Annual fuel cost**	**M\$/a**	**afc**

The specific fuel cost times the reference base power plant unit net output times number of power plant units at site times the total base power net output times the operating hours times the fuel levelisation factor.

Formula:

For PWR, PHWR, SSB, HR, B, GTMHR, D and SPWR energy plants:
= Csf * Qbn * Nb * 8760 * App / 1000000 * lff

For CC and GT energy plants:
= Csf * Qbg * Nb * 8760 * App / 1000000 * lff

Row	Parameter	Unit	Variable name
399	**Annual O&M cost**	**M\$/a**	**aom**

The specific O&M cost times reference base power plant unit net output times number of power plant units at site times the total base power net output times the operating availability times the number of hours per year.

Formula:

For PWR, PHWR, SSB, HR, B, GTMHR, D and SPWR energy plants:
= Ceom * Qbn * Nb * App * 8760 / 1000000

For CC and GT energy plants:
= Ceom * Qbg * Nb * App * 8760 / 1000000

Row	Parameter	Unit	Variable name
400	**Annual electric power cost (heat only plants)**	**M\$/a**	**aelpc**

The plant auxiliary loads times the combined power/water plant load factor times the purchased electricity cost (only for heat only plants).

For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants not applicable.

Formula:

For HR and B energy plants:
= Cpe * Pal * 1000 * 8760 * Acpd / 1000000

Row	Parameter	Unit	Variable name
401	**Annual levelised decommissioning cost**	**M$/a**	**adec**

For nuclear only. Is assumed

	1.0 mill/kW(e)×h	*for nuclear power plants,*
and	*0.33 mill/kW(t)×h*	*for nuclear heat only plants;*

the reference base power plant unit net output times number of power plant units at site times the operating hours.

For SSB, CC, GT, B and D energy plants not applicable.

Formula:
For PWR, PHWR, HR, GTMHR and SPWR energy plants:
= Qbn * Nb * Csde * 8760 * App / 1000000

Row	Parameter	Unit	Variable name
402	**Total annual required revenue**	**M$/a**	**arev**

The sum of the annual levelised capital cost, the annual fuel cost, the annual O&M cost and the annual levelised decommissioning cost.

Formulas:
For PWR, PHWR, GTMHR and SPWR energy plants:
= alcc + afc + aom + adec;
For SSB, CC, GT and D energy plants:
=alcc+afc+aom
For HR energy plants:
= alcc + afc + aom + adec + aelpc
For B energy plants:
=alcc+afc+aom+aelpc

Row	Parameter	Unit	Variable name
403	**Annual electricity production**	**GW(e)·h**	**adpr**

Total site specific base power plant net output times the operating hours. For heat only plants not applicable.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Pen * 8760 * App / 1000

Row	Parameter	Unit	Variable name
404	**Levelised power cost**	**$/kW(e)·h**	**lpc**

The ratio of the total annual required revenue and the annual electricity production.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= arev / adpr

7.4.2. Distillation plant

Row	Parameter	Unit	Variable name
407	**Installed water plant production capacity**	**m^3/d**	**Wacd1**

Installed water plant production capacity as calculated under 7.2.3.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Wacd

Row	Parameter	Unit	Variable name
408	**Annual average water production**	**m^3/a**	**Wpd1**

Annual average water production as calculated under 7.2.3.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Wpd

Row	Parameter	Unit	Variable name
409	**Annual average electricity production**	**GW(e)·h/a**	**Qde**

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR and D energy plants:
= 8760 * (Qnep * Acpd + Pen * (App – Acpd) – Qdp * Acpd) / 1000

Row	Parameter	Unit	Variable name
410	**Total construction cost**	**M$**	**Cdcon2**

Total construction cost as calculated under 7.3.1 .

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdcon

Row	Parameter	Unit	Variable name
411	**Interest during construction**	**M$**	**IDCd**

A function of the total construction cost, the interest rate during construction and the water plant lead time.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdcon2 * ((1 + ir / 100)^(Ld / 24) – 1)

Row	Parameter	Unit	Variable name
412	**Total investment**	**M$**	**Csinv**

The sum of the total construction cost and IDC.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdcon2 + IDCd

Row	Parameter	Unit	Variable name
413	**Specific investment cost**	**$\$/(m^3/d)$**	**cdinv**

The ratio of the total investment cost and the installed water plant production capacity.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Csinv / Wacd1 * 1000000

Row	Parameter	Unit	Variable name
414	**Annual water plant fixed charge**	**M$/a**	**adfc**

Total investment times the fixed charge rate.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Csinv * lfc / 100

Row	Parameter	Unit	Variable name
415	**Annual water plant heat cost (power plant)**	**M$/a**	**adhc**

For power plants (except gas turbine, but combined cycle included):
The lost electricity production times the operating availability factor times the number of hours per year times the levelised power cost.

For gas turbines:
There is no cost taken into account; waste heat is used for distillation plant.

For heat only plants:
Total required revenue arev *is taken as annual water plant heat cost.*

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, and SPWR energy plants:
= Qle * Acpd * 1000 * 8760 * lpc / 1000000
For GT energy plants:
0 *(in fact, this is no formula, only the value of zero)*
For HR, B energy plants:
= arev

Row	Parameter	Unit	Variable name
416	**Fossil fuel levelisation factor (backup heat source)**		**efbh**

With backup heat source, the value of efbh *is calculated similarly as* lff *under 7.4.1 (previous section) with the parameter of* effb *(for backup heat source) instead of* efn *or* eff *(for fuel of main energy source).*

Without backup heat source this parameter is not applicable.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= IF (BK = "Y";
(1+effb/100)^(Yi–Ycr)*lfc/100/[(1+i/100)/(1+effb/100)–1]*[1–[(1+effb/100)/(1+i/100)]^Lep]); 0)

Row	Parameter	Unit	Variable name
417	**Annual fuel cost of backup heat source**	**M$/a**	**adfbh**

With backup heat source, the fossil fuel levelisation factor (backup heat source) times the back up heat source size times the backup heat source load factor times the backup heat source fossil fuel price at startup divided by the conversion factor 1.6471.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= IF (BK = "Y" ; Bhs * 8760 * Abh * Cffb * efbh / 1,6471 / 1000000 ; 0)

Row	Parameter	Unit	Variable name
418	**Annual water plant electric power cost**	**M$/a**	**adepc**

The total distillation water plant power use times the combined power/water plant capacity factor times the number of hours per year times the levelised power cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Qdp * 1000 * Acpd * 8760 * lpc / 1000000

Row	Parameter	Unit	Variable name
419	**Annual purchased electric power cost**	**M$/a**	**adepu**

The purchased electricity cost times the sum of total distillation plant power use (and condenser cooling water pump power for nuclear and fossil steam power plant) times the backup heat load factor (for heat only power plants, it is the total power/water plant load factor), times the numbers of hours per year.

With backup heat source:
= (Qdp + qcc) x 1000 x Abh x 8760 x Cpe / 10^6 for steam power plants (nuclear and fossil)
= Qdp x 1000 x Abh x 8760 x Cpe / 10^6 for gas turbine
= Qdp x 1000 x Apd x 8760 x Cpe / 10^6 for heat only plants

Without backup heat source:
= 0

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= IF (BK = "Y" ; (Qdp + qcc) * 1000 * Abh * 8760 * Cpe / 1000000 ; 0)
For GT energy plants:
= IF (BK="Y"; Qdp * 1000 * Abh * 8760 * Cpe / 1000000 ; 0)
For HR and B energy plants:
= Qdp * Apd * 1000 * 8760 * Cpe / 1000000

Row	Parameter	Unit	Variable name
420	**Annual water plant O&M cost**	**M$/a**	**Cdom2**

Annual water plant O&M cost as calculated under 7.3.1 .

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= Cdom

Row	Parameter	Unit	Variable name
421	**Total annual required revenue**	**M$/a**	**adrev**

The sum of the annual water plant fixed charge, the annual water plant heat cost, the annual fuel cost of backup heat source, annual water plant electric power cost, annual purchased electric power cost and the annual water plant O&M cost.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= adfc + adhc + adfbh + adepc + adepu + Cdom2
For GT energy plants:
= adfc + adfbh + adepc + adepu + Cdom2
For HR and B energy plants:
= adfc + adhc + adfbh + adepu + Cdom2

Row	Parameter	Unit	Variable name
422	**Total water cost**	**$/m^3**	**Wdt**

Total annual required revenue divided by annual average water production.

For GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, HR, B and SPWR energy plants:
= adrev / Wpd1 * 1000000

Row	Parameter	Unit	Variable name
423	**Total required revenue allocated to water**	**$/m^3**	**Trrawd**

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (arev + adrev) / Wpd1 * 1000000

Row	Parameter	Unit	Variable name
424	**Total required revenue allocated to power**	**$/kW(e)·h**	**Trrapd**

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (arev + adrev) * 1000000 / (Qnep * App – Qdp * Acpd + qcc * Acpd) / 8760 / 1000
For GT energy plants:
= (arev + adrev) * 1000000 / (Qnep * App – Qdp * Acpd) / 8760 / 1000

7.4.3. Stand-alone RO plant

Row	Parameter	Unit	Variable name
427	**Installed water plant production capacity**	**m^3/d**	**Wacs1**

Installed water plant production capacity as calculated under 7.2.4 .

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wacs

Row	Parameter	Unit	Variable name
428	**Annual average water production**	**m^3/a**	**Wpms1**

Annual average water production as calculated under 7.2.4 .

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Wpms

Row	Parameter	Unit	Variable name
429	**Total construction cost**	**M$**	**Cmscon1**

Total construction cost as calculated under 7.3.2 .

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmscon

Row	Parameter	Unit	Variable name
430	**Interest during construction**	**M$**	**IDCs**

A function of the total construction cost, the interest rate during construction and the water plant lead time.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmscon1 * ((1+ir/100)^(Lm/24) – 1)

Row	Parameter	Unit	Variable name
431	**Total investment**	**M$**	**Cmsinv**

The sum of the total construction cost and IDC.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmscon1 + IDCs

Row	Parameter	Unit	Variable name
432	**Specific investment cost**	**$/(m^3/d)**	**csmsinv**

The ratio of the total investment and the installed water plant production capacity.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsinv / Wacs1 * 1000000

Row	Parameter	Unit	Variable name
433	**Annual water plant fixed charge**	**M$/a**	**amsfc**

The total investment times the charge fixed charge rate.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsinv * lfc / 100

Row	Parameter	Unit	Variable name
434	**Annual water plant electric power cost**	**M$/a**	**amsepc**

The total stand-alone water plant power use times the combined power/water plant load factor times the number of hours per year times the levelised power cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Qms * 1000 * Acpm * 8760 * lpc / 1000000

Row	Parameter	Unit	Variable name
435	**Annual water plant purchased electric power cost**	**M$/a**	**amsepu**

The purchased electricity cost times the difference between the membrane water plant load factor and the combined power/water plant load factor times the numbers of hours per year and times the total stand-alone RO plant power use.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cpe * 1000 * (Apm – Acpm) * 8760 * Qms / 1000000

Row	Parameter	Unit	Variable name
436	**Annual water plant O&M cost**	**M$/a**	**Cmsom1**

Annual water plant O&M cost as calculated in 7.3.2 .

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= Cmsom

Row	Parameter	Unit	Variable name
437	**Total annual required revenue**	**M$/a**	**amsrev**

The sum of the annual water plant fixed charge, the annual water plant electric power cost, the annual water plant purchased electric power cost and the annual water plant O&M cost.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= amsfc + amsepc + amsepu + Cmsom1

Row	Parameter	Unit	Variable name
438	**Total water cost**	**$/m^3**	**Wmst**

Total annual required revenue divided by annual average water production.

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= amsrev / Wpms1 * 1000000

Row	Parameter	Unit	Variable name
439	**Total required revenue allocated to water**	**$/m^3**	**Trraws**

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (arev + amsrev) / Wpms1 * 1000000

Row	Parameter	Unit	Variable name
440	**Total required revenue allocated to power**	**$/kW(e)·h**	**Trraps**

For HR and B energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT, GTMHR, D and SPWR energy plants:
= (arev + amsrev) * 1000000 / 8760 / 1000 / (Pen * App – Qms * Acpm)

7.4.4. Contiguous RO plant

Row	Parameter	Unit	Variable name
443	**Installed water plant production capacity**	**m^3/d**	**Wacc1**

Installed water plant production capacity as calculated in 7.2.5 .

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wacc

Row	Parameter	Unit	Variable name
444	**Annual average water production**	**m^3/a**	**Wpmc1**

Annual average water production as calculated in 7.2.5 .

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Wpmc

Row	Parameter	Unit	Variable name
445	**Total construction cost**	**M$**	**Cmccon1**

Total construction cost as calculated in 7.3.3 .

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmccon

Row	Parameter	Unit	Variable name
446	**Interest during construction**	**M$**	**IDCr**

A function of the total construction cost, the interest rate during construction and the water plant lead time.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmccon1 * ((1+ir/100)^(Lm/24) – 1)

Row	Parameter	Unit	Variable name
447	**Total investment**	**M$**	**Cmcinv**

The sum of the total construction cost and IDC.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmccon1 + IDCr

Row	Parameter	Unit	Variable name
448	**Specific investment cost**	**$/(m^3/d)**	**csmcinv**

The ratio of the total investment and the installed water plant production capacity.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmcinv / Wacc1 * 1000000

Row	Parameter	Unit	Variable name
449	**Annual water plant fixed charge**	**M$/a**	**amcfc**

The total investment times the fixed charge rate.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmcinv * lfc / 100

Row	Parameter	Unit	Variable name
450	**Annual water plant electric power cost**	**M$/a**	**amcepc**

The total contiguous power use times the combined power/water plant load factor times the number of hours per year times the levelised power cost .

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Qmc * 1000 * Acpm * 8760 * lpc / 1000000

Row	Parameter	Unit	Variable name
451	**Annual water plant purchased electric power cost**	**M$/a**	**amcepu**

The purchased electricity cost times the difference between the membrane water plant load factor and the combined power/water plant load factor times the numbers of hours per year and times the total contiguous RO plant power use.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Qmc * 1000 * (Apm–Acpm) * 8760 * Cpe / 1000000

Row	Parameter	Unit	Variable name
452	**Annual water plant O&M cost**	**M$/a**	**Cmcom1**

Annual water plant O&M cost as calculated in 7.3.3.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= Cmcom

Row	Parameter	Unit	Variable name
453	**Total annual required revenue**	**M$/a**	**amcrev**

The sum of the annual water plant fixed charge, the annual water plant electric power cost, the annual water plant purchased electric power cost and the annual water plant O&M cost.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= amcfc + amcepc + amcepu + Cmcom1

Row	Parameter	Unit	Variable name
454	**Total water cost**	**$/m^3**	**Wmct**

Total annual required revenue divided by annual average water production.

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= amcrev / Wpmc1 * 1000000

Row	Parameter	Unit	Variable name
455	**Total required revenue allocated to water**	**$/m^3**	**Trrawc**

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (arev + amcrev) / Wpmc1 * 1000000

Row	Parameter	Unit	Variable name
456	**Total required revenue allocated to power**	**\$/kW(e)·h**	**Trrapc**

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (arev + amcrev) * 1000000 / 8760 / 1000 / (Pen * App – Qmc * Acpm)

7.4.5. Distillation plus RO (hybrid) water plant

Row	Parameter	Unit	Variable name
459	**Installed water plant production capacity**	**m^3/d**	**Wach1**

Installed water plant production capacity as calculated in 7.2.6 .

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wach

Row	Parameter	Unit	Variable name
460	**Annual average water production**	**m^3/a**	**Wph1**

Annual average water production capacity as calculated in 7.2.6 .

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Wph

Row	Parameter	Unit	Variable name
461	**Total construction cost**	**M\$**	**Chcon1**

Total construction cost as calculated in 7.3.4 .

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chcon

Row	Parameter	Unit	Variable name
462	**Interest during construction**	**M\$**	**IDCh**

A function of the total construction cost, the interest rate during construction and the water plant lead time.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chcon1 * ((1+ir/100)^(Lm/24) – 1)

Row	Parameter	Unit	Variable name
463	**Total investment**	**M$**	**Chinv**

The sum of the total construction cost and IDC.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chcon1 + IDCh

Row	Parameter	Unit	Variable name
464	**Specific investment cost**	**$/($m^3$/d)**	**cshinv**

The ratio of the total investment and the installed water plant production capacity.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chinv / Wach1 * 1000000

Row	Parameter	Unit	Variable name
465	**Annual water plant fixed charge**	**M$/a**	**ahfc**

The total investment times the fixed charge rate.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chinv * lfc / 100

Row	Parameter	Unit	Variable name
466	**Annual water plant heat cost**	**M$/a**	**ahhc**

Annual water plant heat cost as calculated in 7.4.2 .

For GT, HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= adhc

Row	Parameter	Unit	Variable name
467	**Annual water plant electric power cost**	**M$/a**	**ahepc**

Total distillation plant and RO plant power use times the respective load factor times the levelised power cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (Qdp * Acpd + Qmh * Acpm) * 1000 * 8760 * lpc / 1000000

Row	Parameter	Unit	Variable name
468	**Annual water plant purchased electric power cost**	**M$/a**	**ahepu**

The annual water plant purchased electric power cost for the distillation plant plus the purchased electricity cost times the difference between the membrane water plant load factor and the combined power/water plant load factor times the numbers of hours per year and times the hybrid RO plant power use.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
=adepu + Qmh * 1000 * (Apm – Acpm) * 8760 * Cpe / 1000000

Row	Parameter	Unit	Variable name
469	**Annual water plant O&M cost**	**M$/a**	**Chom1**

Annual water plant O&M cost as calculated in 7.3.4.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= Chom

Row	Parameter	Unit	Variable name
470	**Total annual required revenue**	**M$/a**	**ahrev**

The sum of the annual water plant fixed charge, the annual water plant heat cost, the annual water plant electric power cost, the annual water plant purchased electric power cost and the annual water plant O&M cost.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= ahfc + ahhc + ahepc + ahepu + Chom1
For GT energy plants:
= ahfc + ahepc + ahepu + Chom1

Row	Parameter	Unit	Variable name
471	**Total water cost**	**$/m^3**	**Wht**

Total annual required revenue divided by annual average water production.

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= ahrev / Wph1 * 1000000

Row	Parameter	Unit	Variable name
472	**Total required revenue allocated to water**	**$/m³**	**Trrawh**

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC, GT and SPWR energy plants:
= (arev + ahrev) / Wph1 * 1000000

Row	Parameter	Unit	Variable name
473	**Total required revenue allocated to power**	**$/kW(e)·h**	**Trraph**

For HR, B, GTMHR and D energy plants not applicable.

Formula:
For PWR, PHWR, SSB, CC and SPWR energy plants:
= (arev + ahrev) * 1000000 / 8760 / 1000 / (Qnep*App + qcc*Acpd – Qdp*Acpd – Qmh*Acpm)
For GT energy plants:
= (arev + ahrev) * 1000000 / 8760 / 1000 / (Qnep*App – Qdp*Acpd – Qmh*Acpm)

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ABBREVIATIONS

CC	combined cycle plant (GT and steam power plant)
CP	comparative presentation in DEEP
C-RO	contiguous RO
GOR	gain–output ratio (t desalted water/t steam supplied to distillation plant)
GT	gas turbine (mostly open cycle gas turbine)
GTMHR	gas turbine modular helium reactor (HTR with direct GT cycle)
HP	high pressure
HT	high temperature
HTR	high temperature reactor
IDC	interest during construction
LP	low pressure
LT	low temperature
MED	multi-effect distillation
MSF	multi-stage flash
NPP	nuclear power plant
O&M	operation and maintenance
OT	once-through
PWR	pressurised light water reactor
PHWR	pressurised heavy water reactor
RC	reference case in DEEP
RO	reverse osmosis
SA-RO	stand-alone RO
SPWR	small pressurised light water reactor
SSB	superheated steam boiler
SSBC	superheated steam boiler powered by coal
SSBOG	superheated steam boiler powered by oil or gas
TDS	total dissolved solids

Annex

COUPLING DIAGRAMS
FOR ENERGY SOURCES AND DESALINATION PLANTS

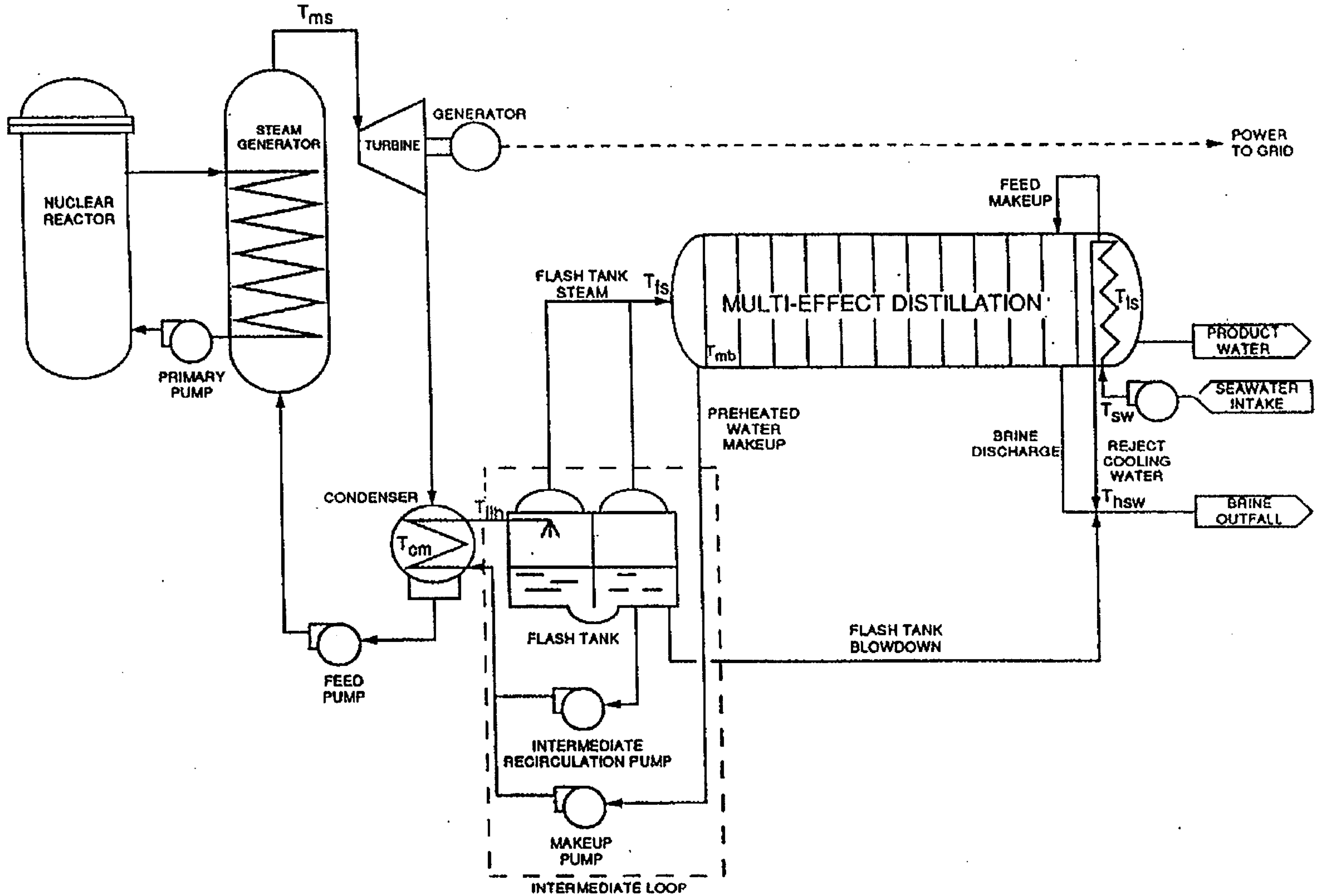

FIG. A-1. *Nuclear power reactor with backpressure steam cycle and MED.*

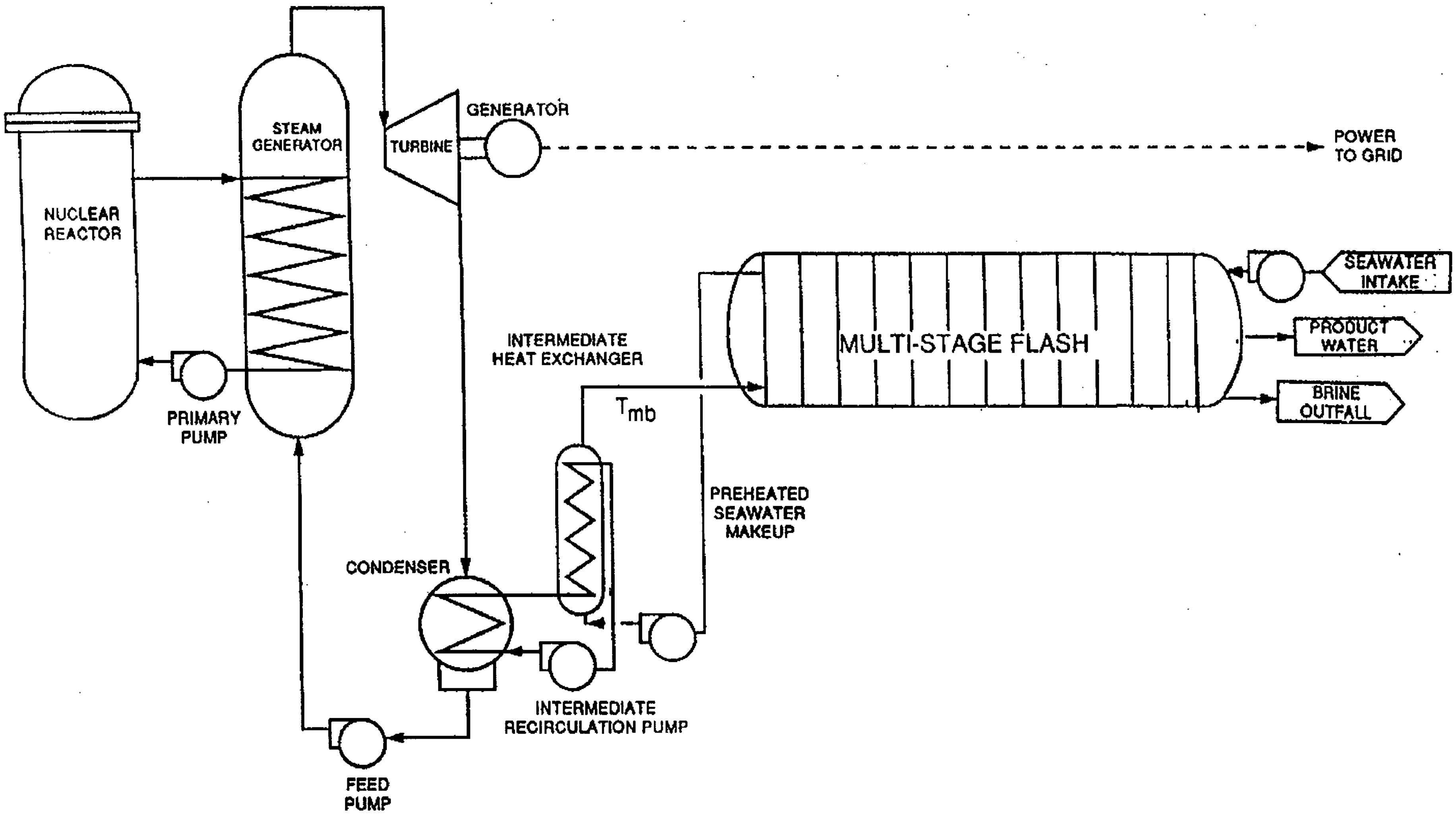

FIG. A-2. *Nuclear power reactor with backpressure steam cycle and MSF.*

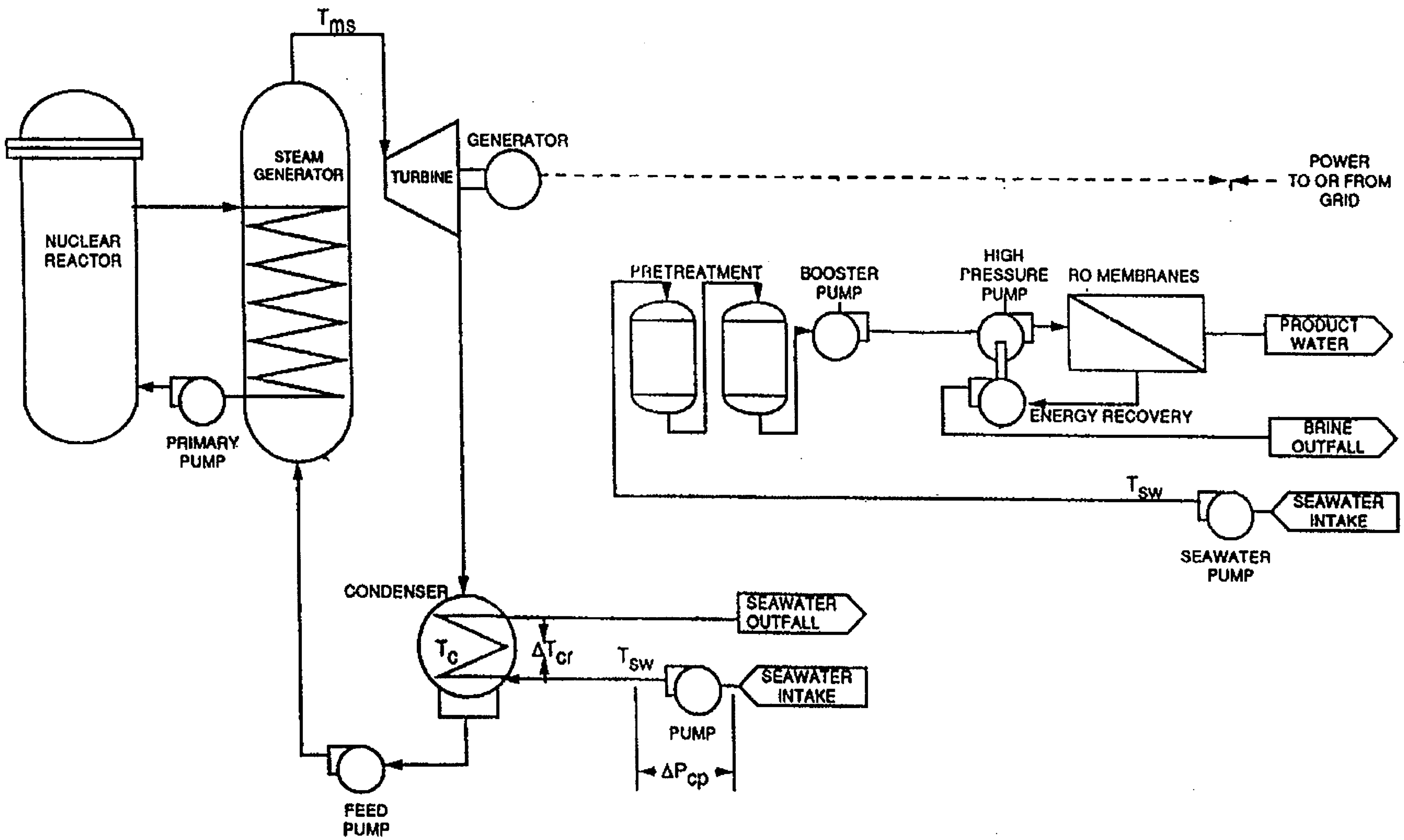

FIG. A-3. *Nuclear power reactor with stand-alone RO system.*

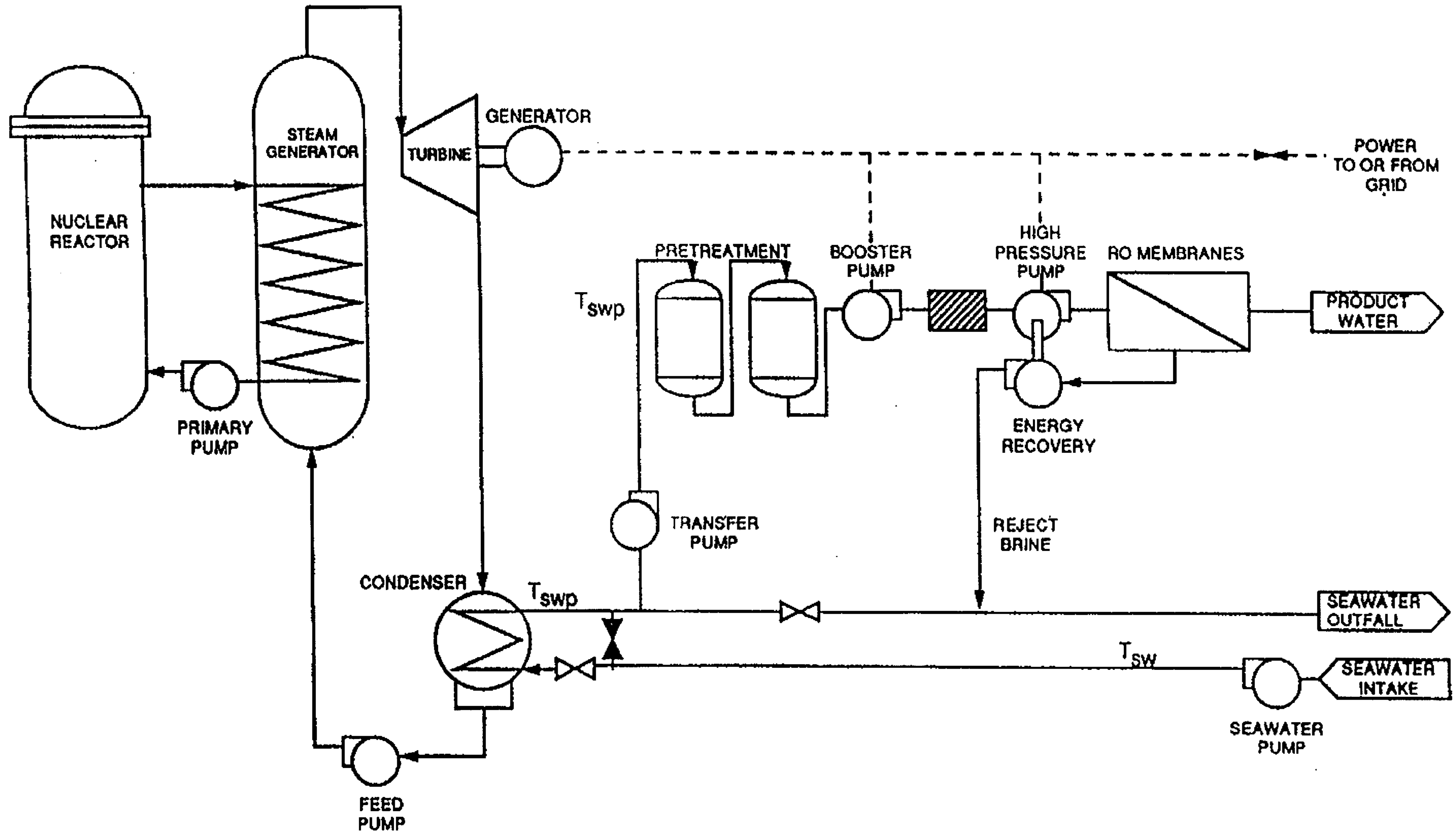

FIG. A-4. Nuclear power reactor with contiguous RO system.

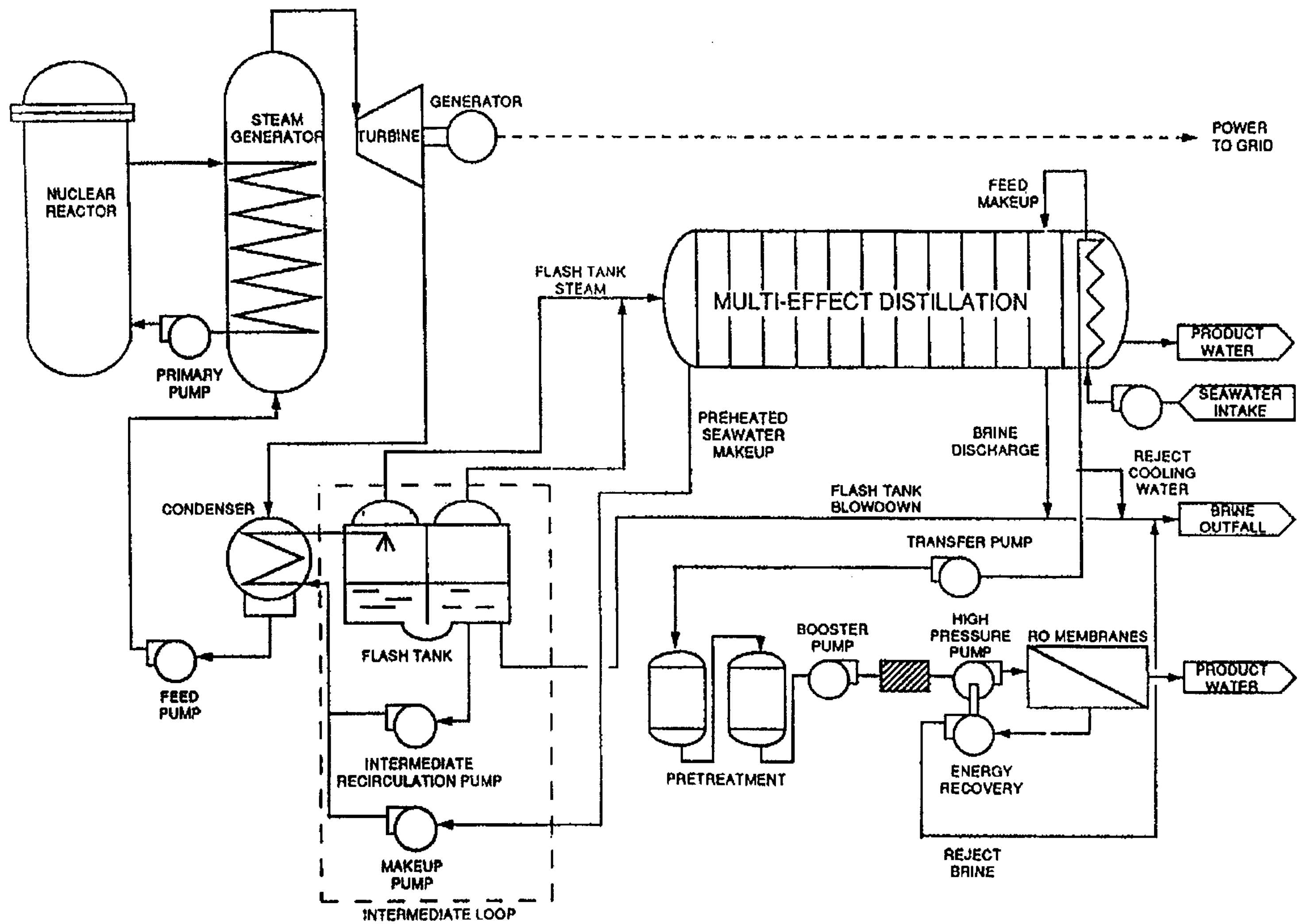

FIG. A-5. *Nuclear power reactor with hybrid MED and RO.*

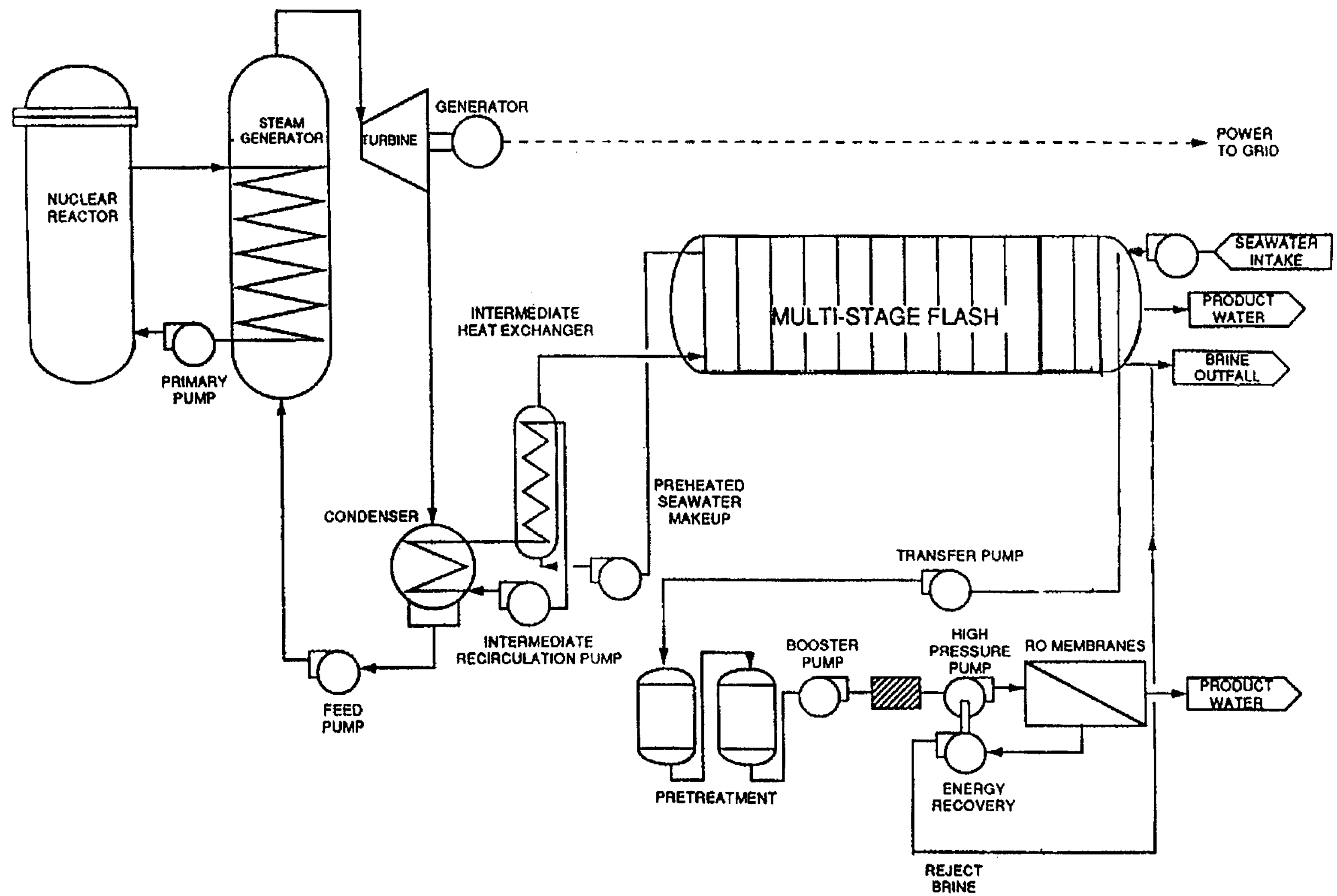

FIG. A-6. Nuclear power reactor with hybrid MSF and RO.

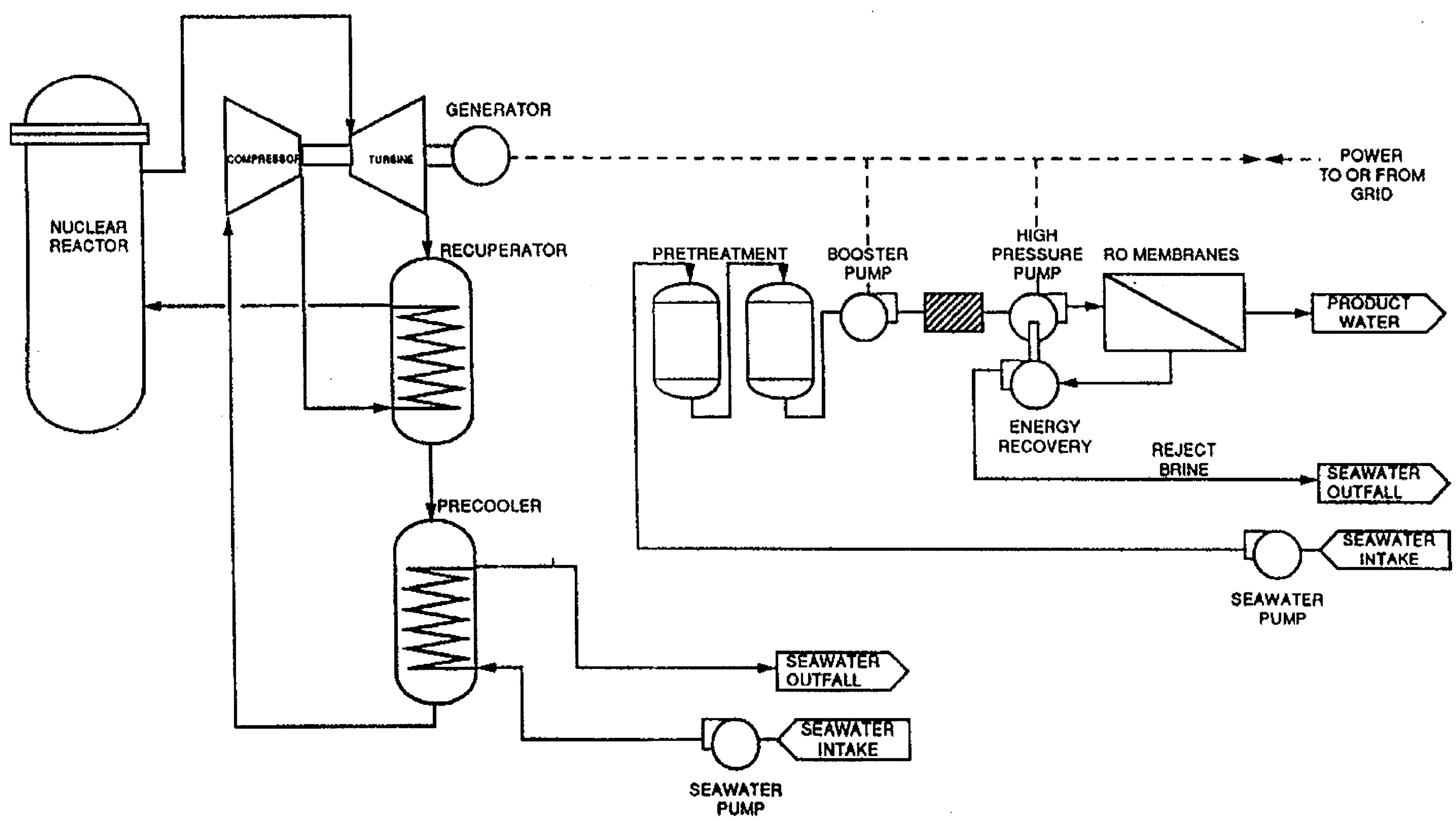

FIG. A-7. *Nuclear gas turbine power reactor with stand-alone RO system.*

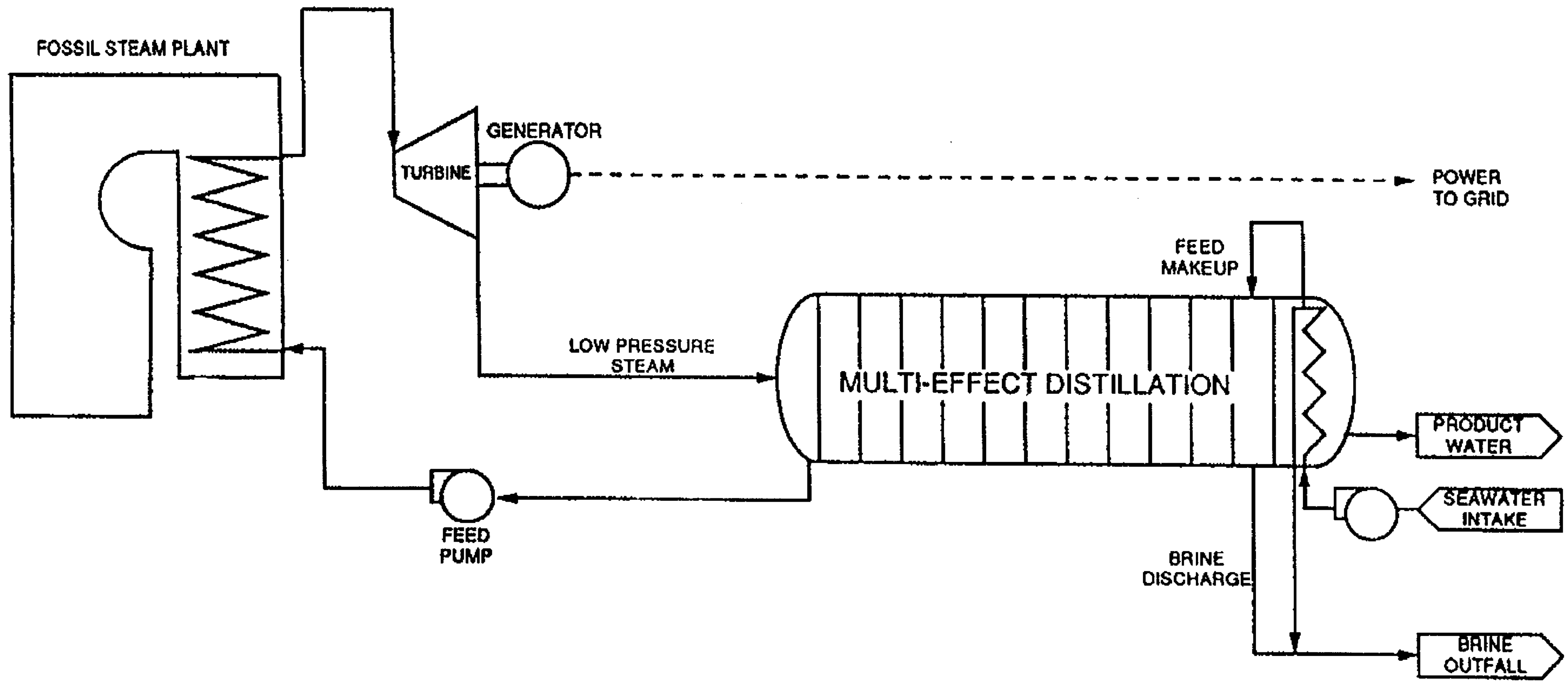

FIG. A-8. *Fossil steam boiler with MED.*

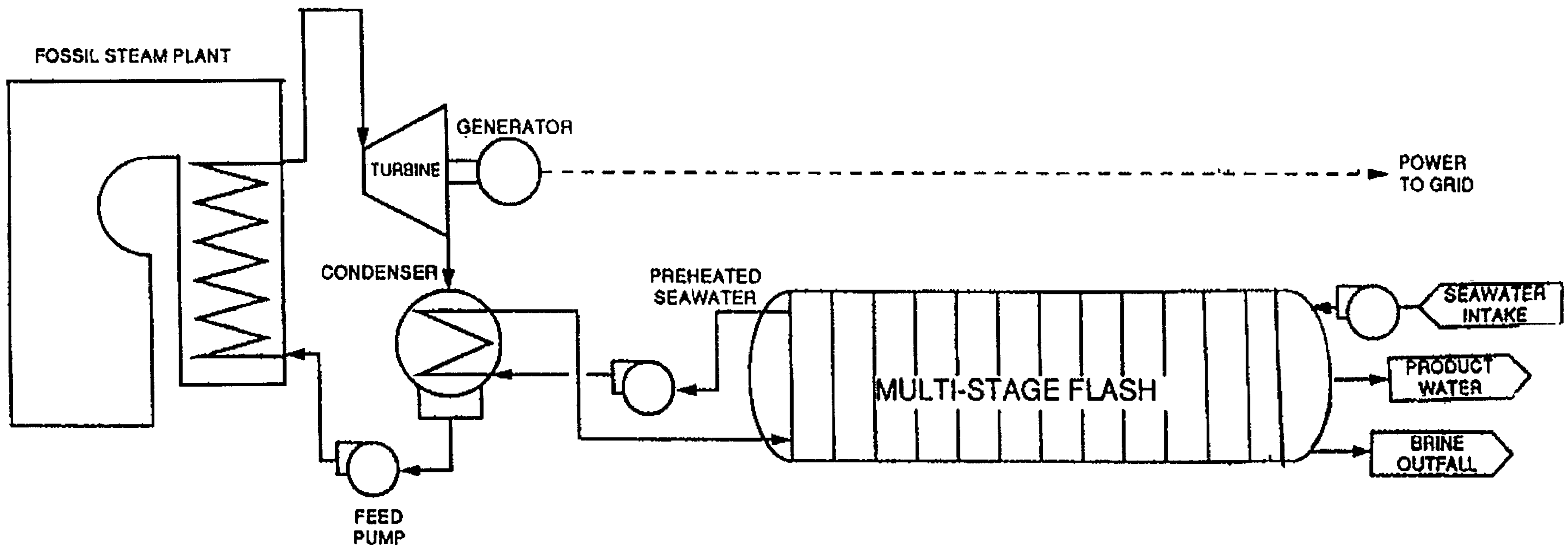

FIG. A-9. Fossil steam boiler with MSF.

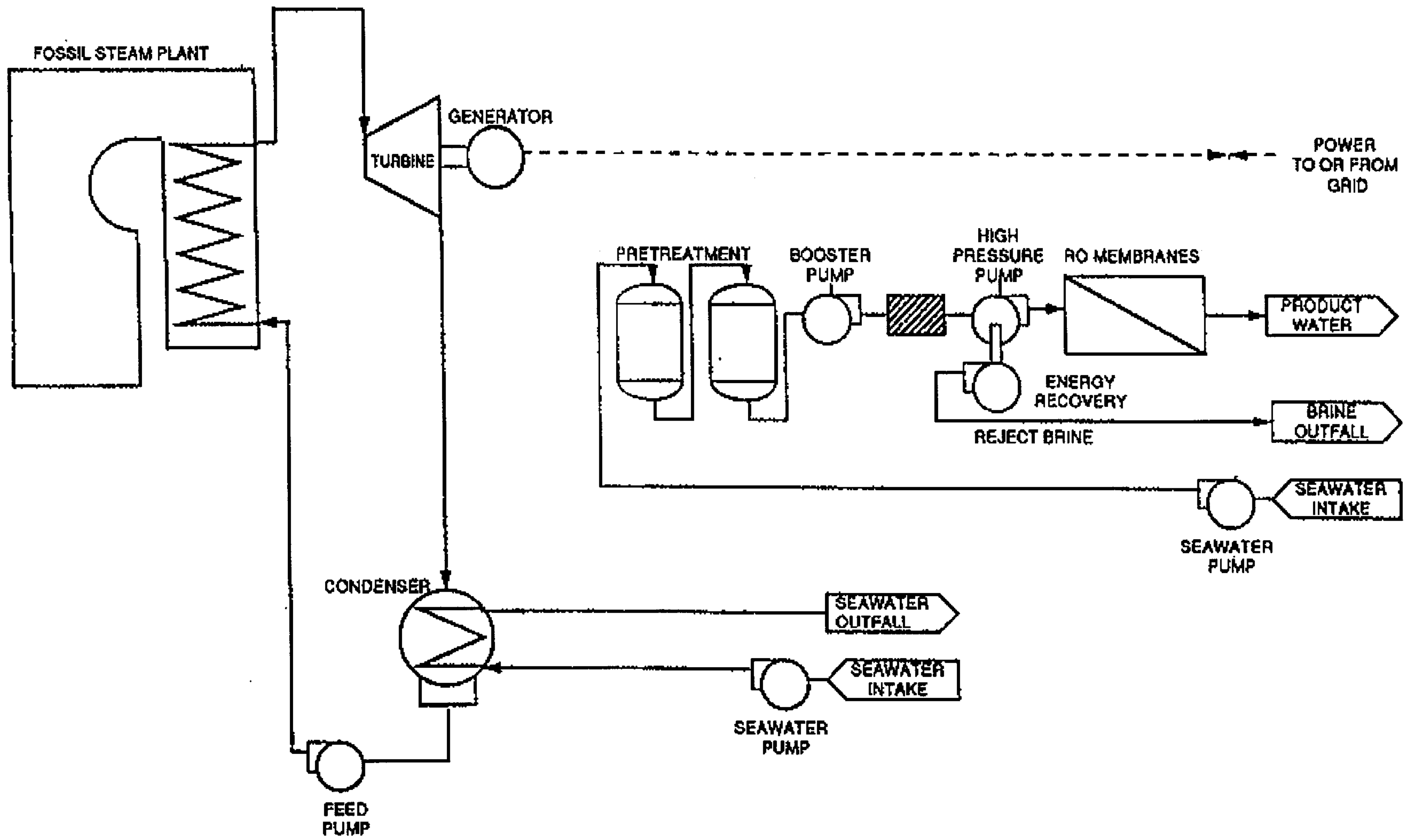

FIG. A-10. *Fossil steam boiler with stand-alone RO system.*

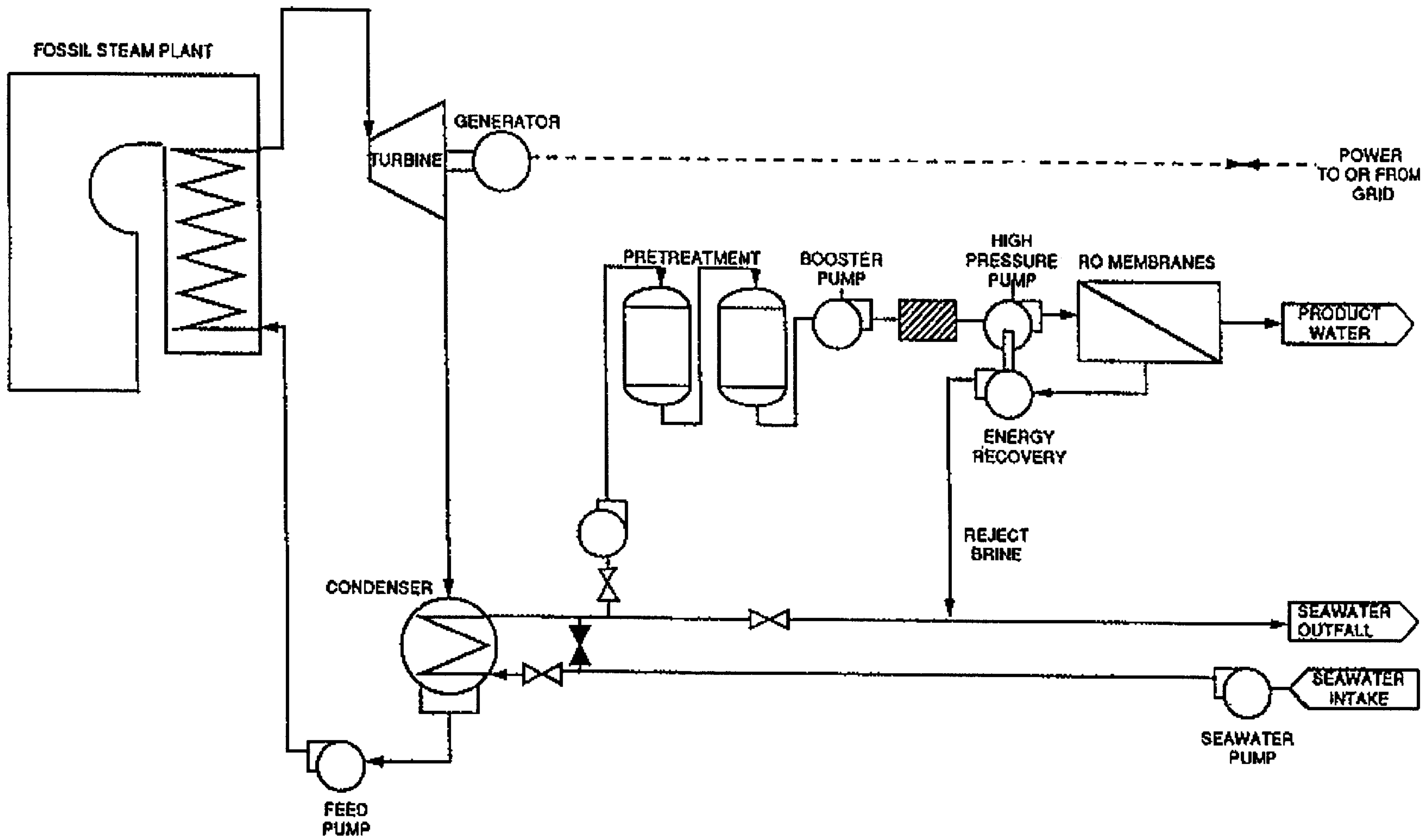

FIG. A-11. *Fossil steam boiler with contiguous RO system.*

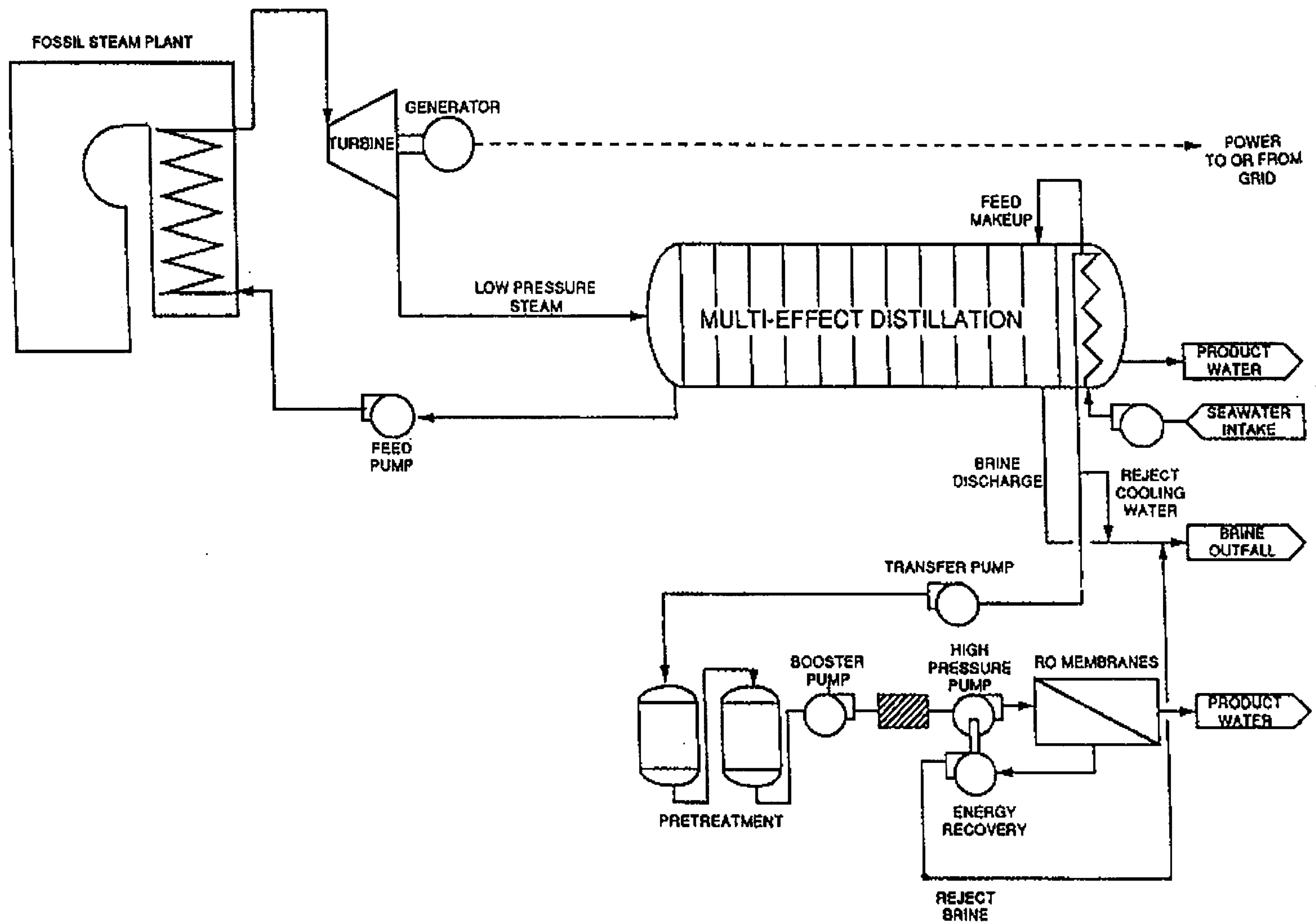

FIG. A-12. Fossil steam boiler with hybrid MED and RO.

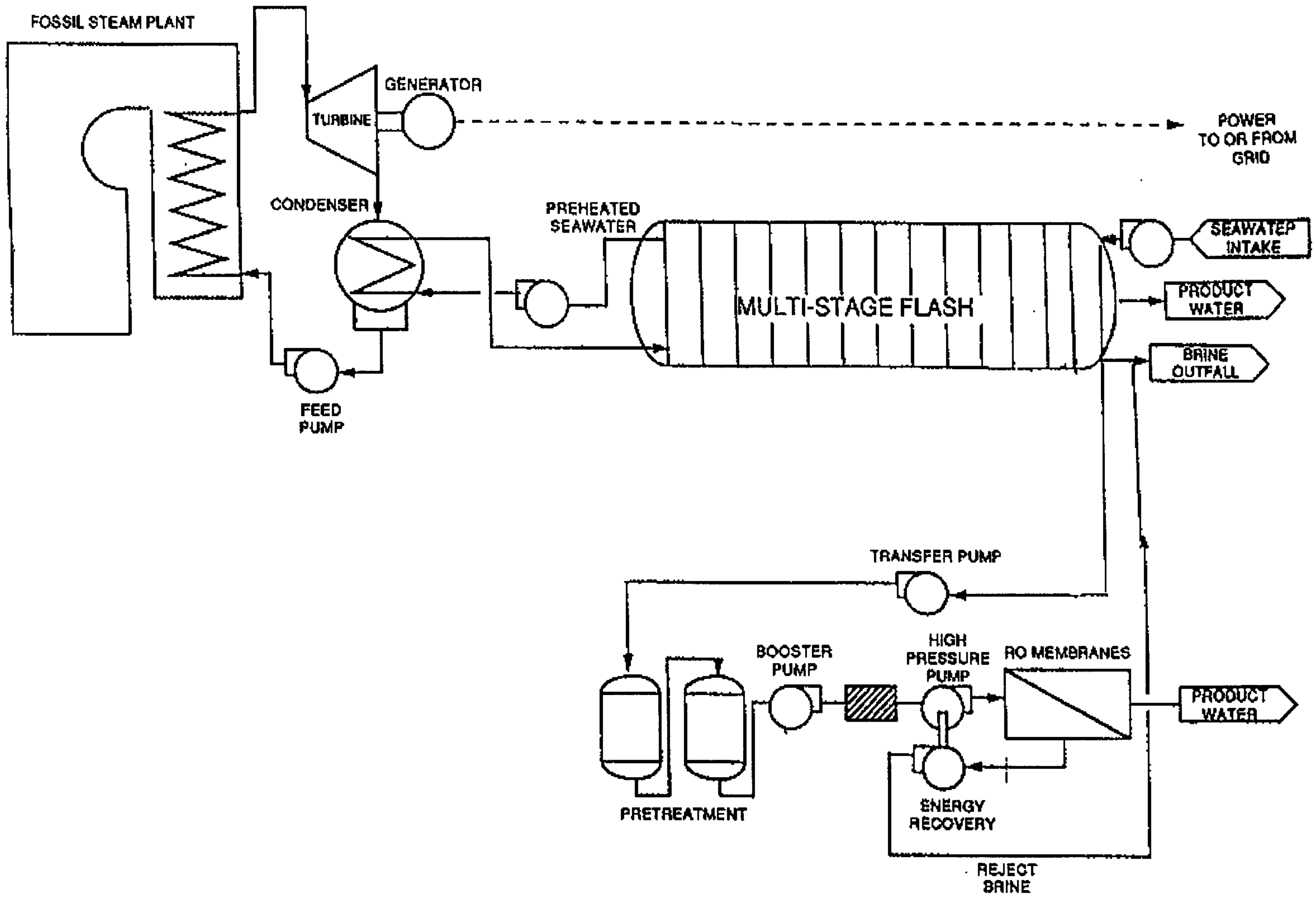

FIG. A-13. Fossil steam boiler with hybrid MSF and RO.

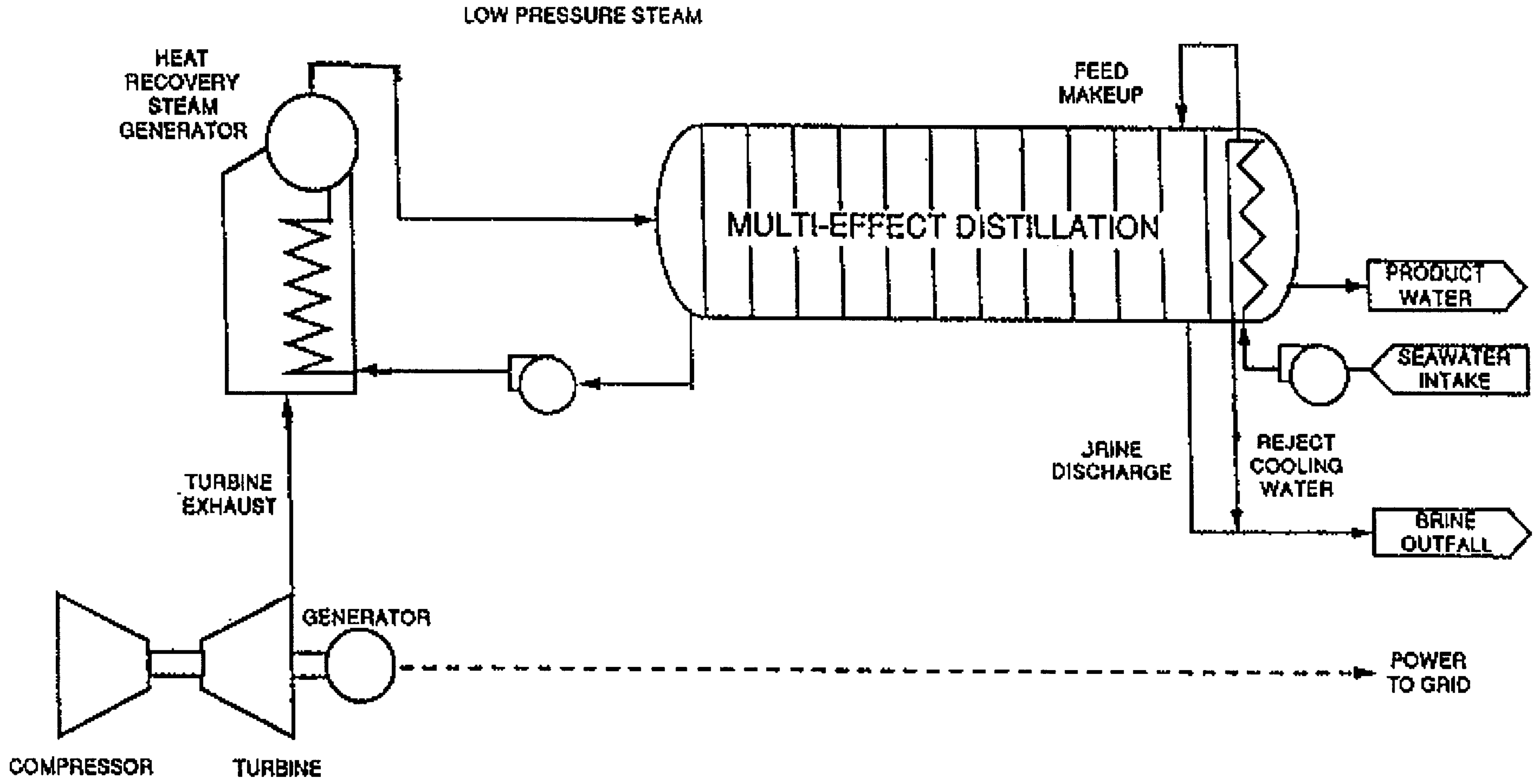

FIG. A-14. *Fossil gas turbine with MED.*

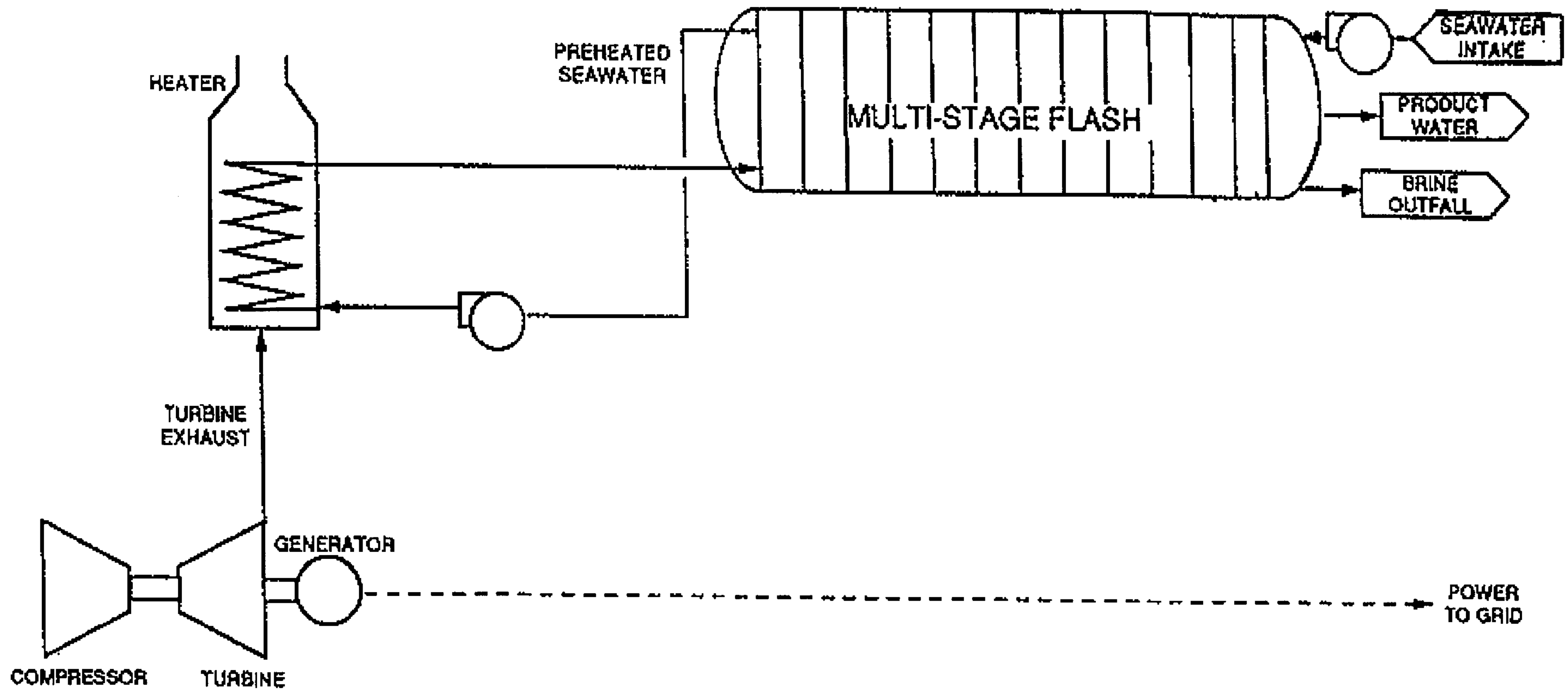

FIG. A-15. Fossil gas turbine with MSF.

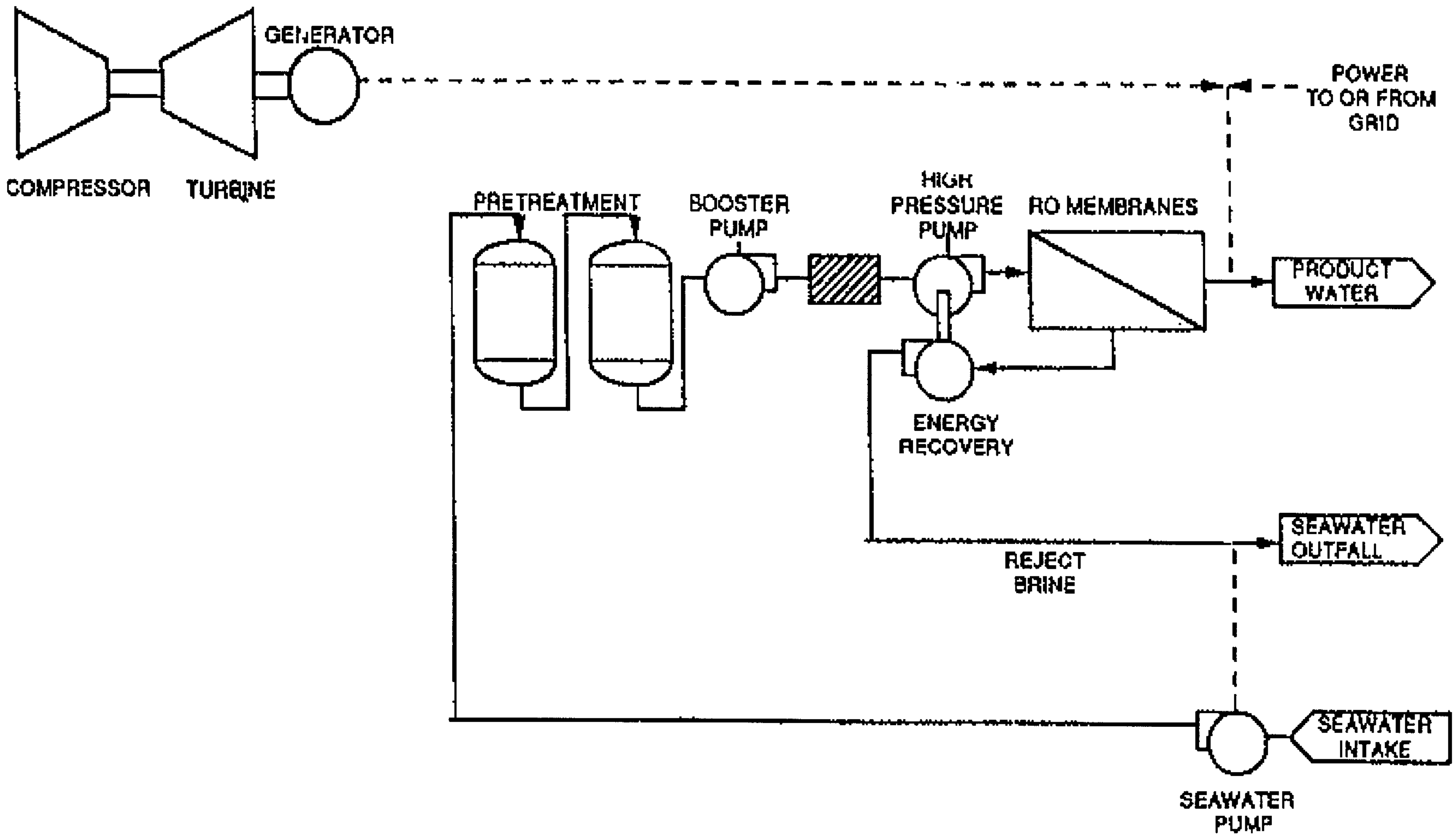

FIG. A-16. *Fossil gas turbine with stand-alone RO system.*

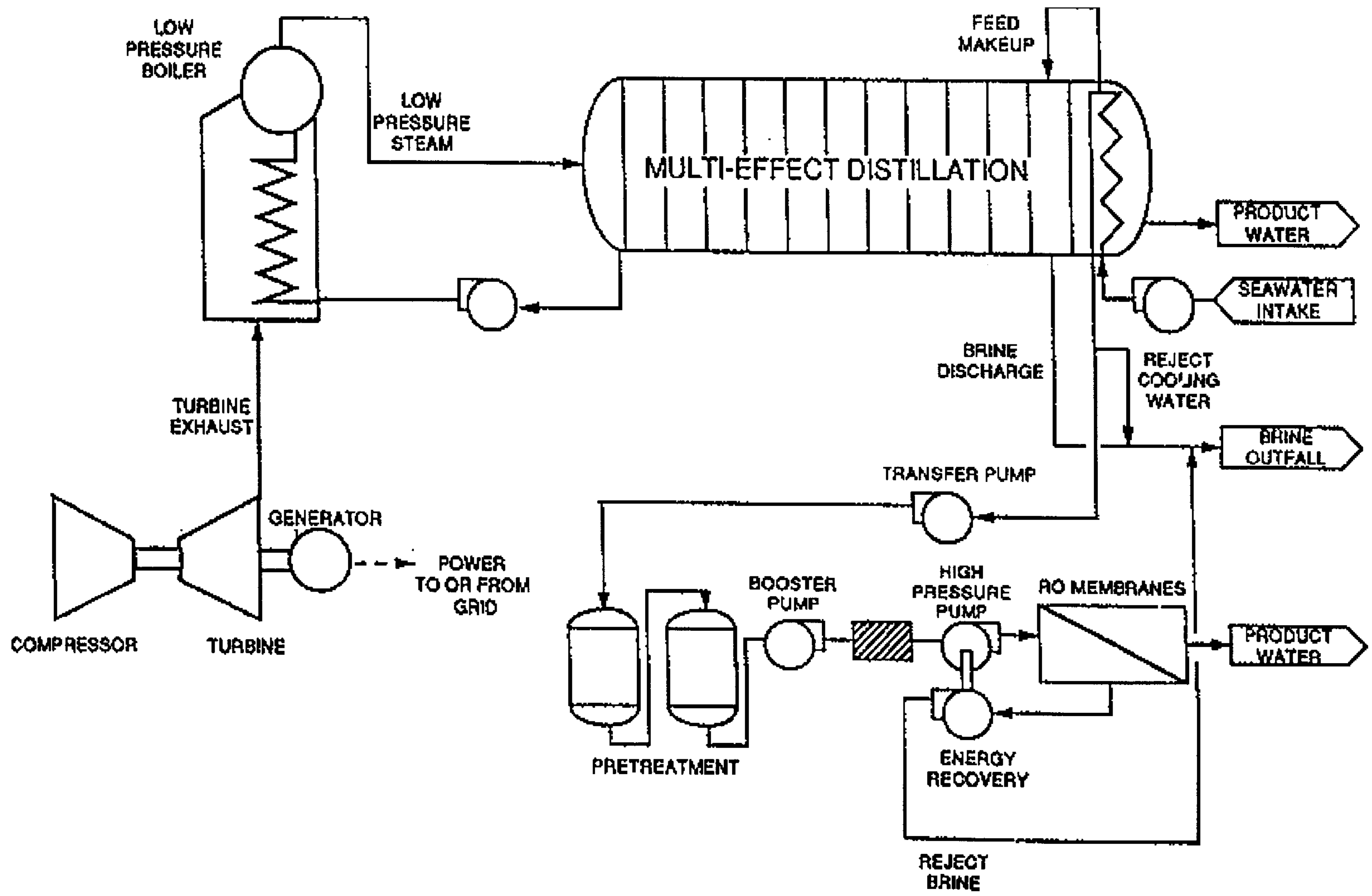

FIG. A-17. Fossil gas turbine with hybrid MED and RO.

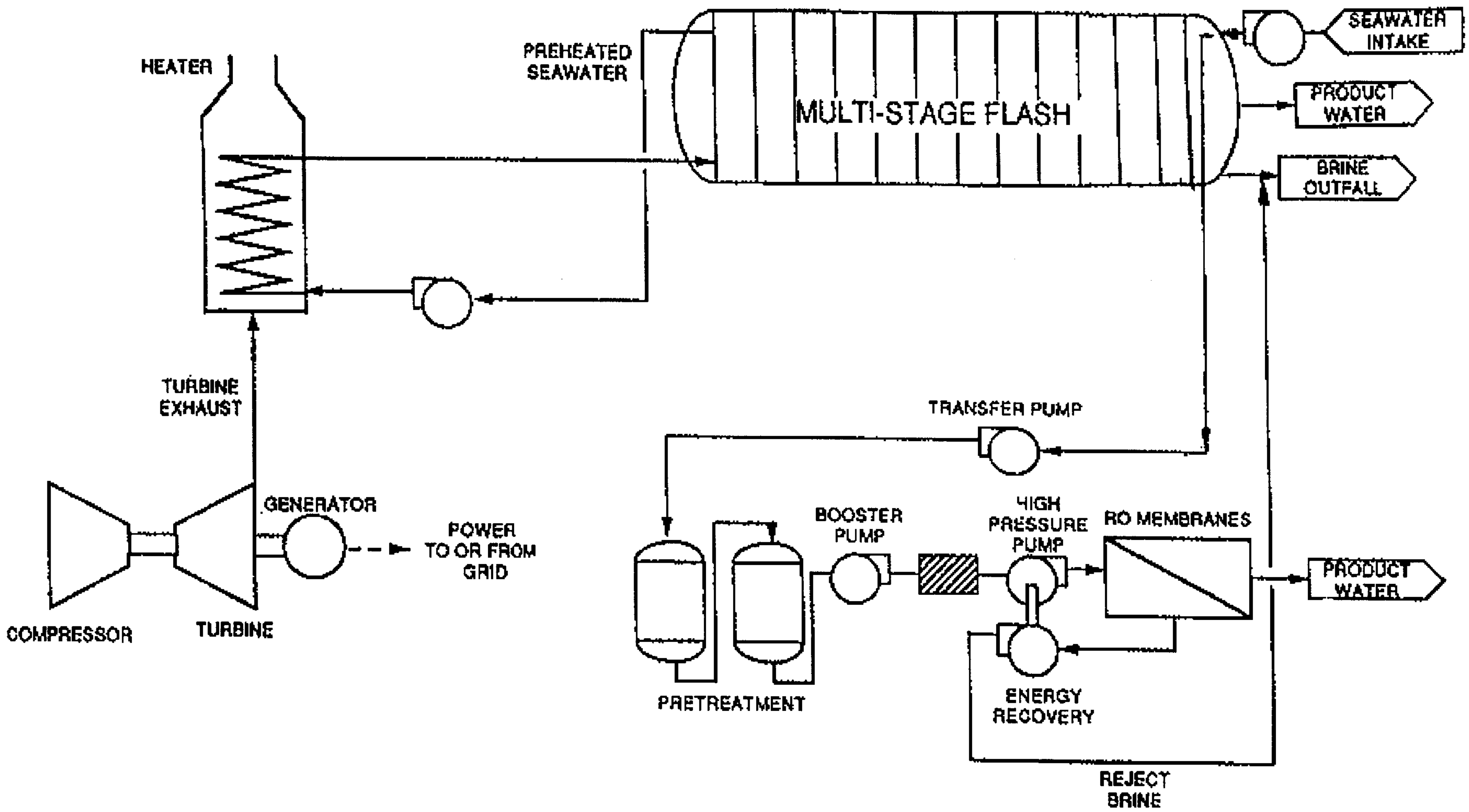

FIG. A-18. Fossil gas turbine with hybrid MSF and RO.

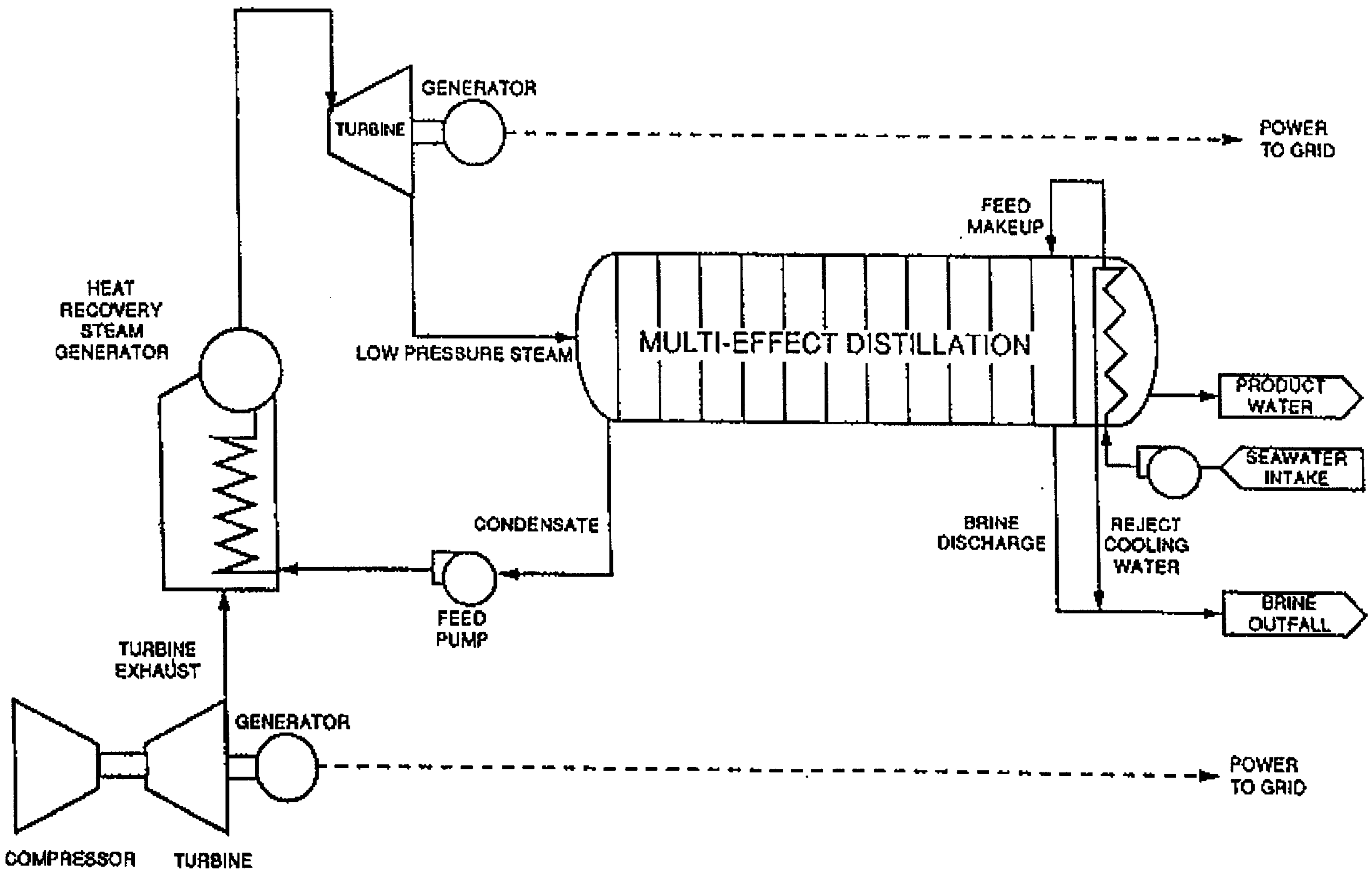

FIG. A-19. *Fossil combined cycle with MED.*

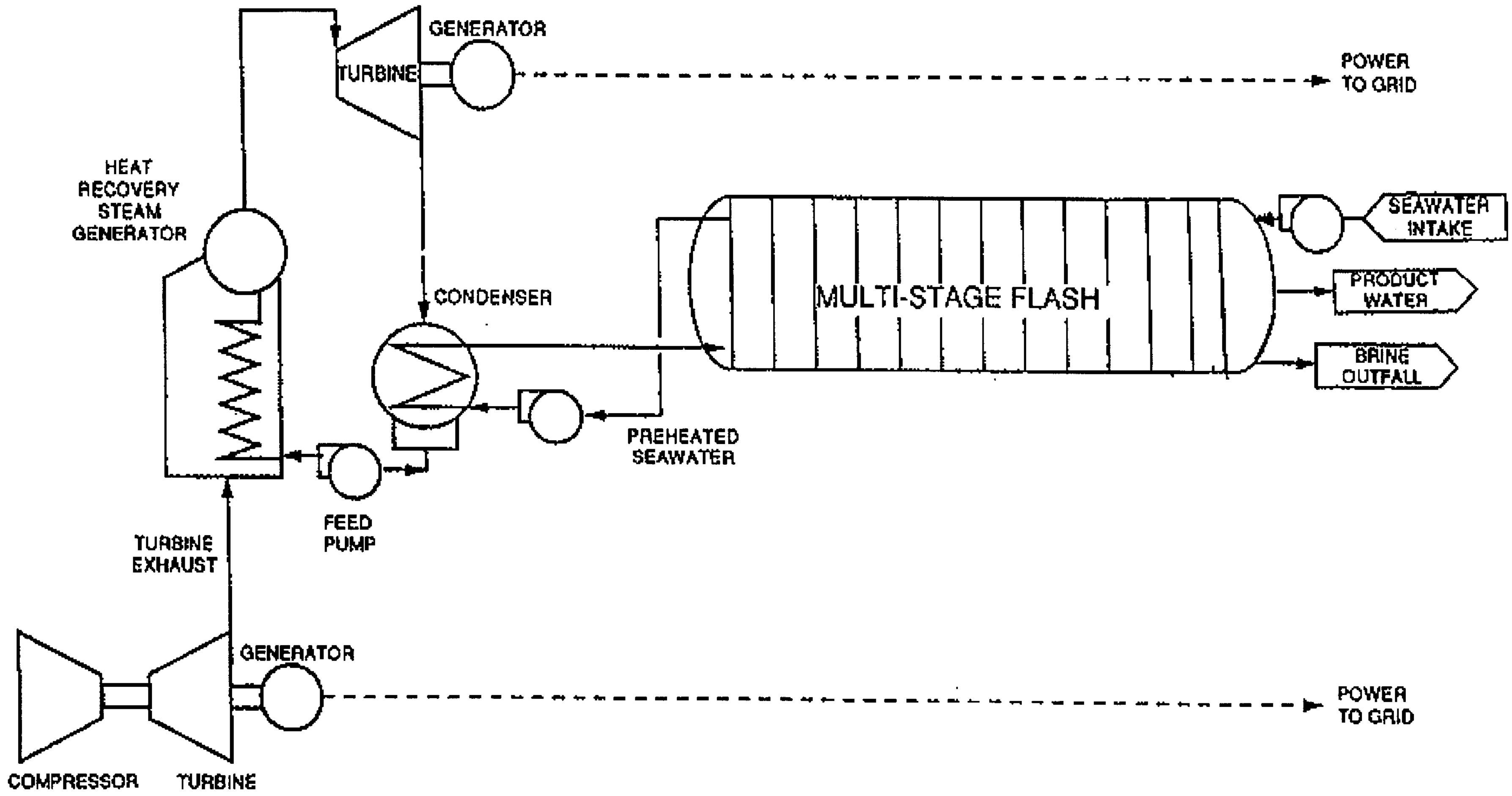

FIG. A-20. Fossil combined cycle with MSF.

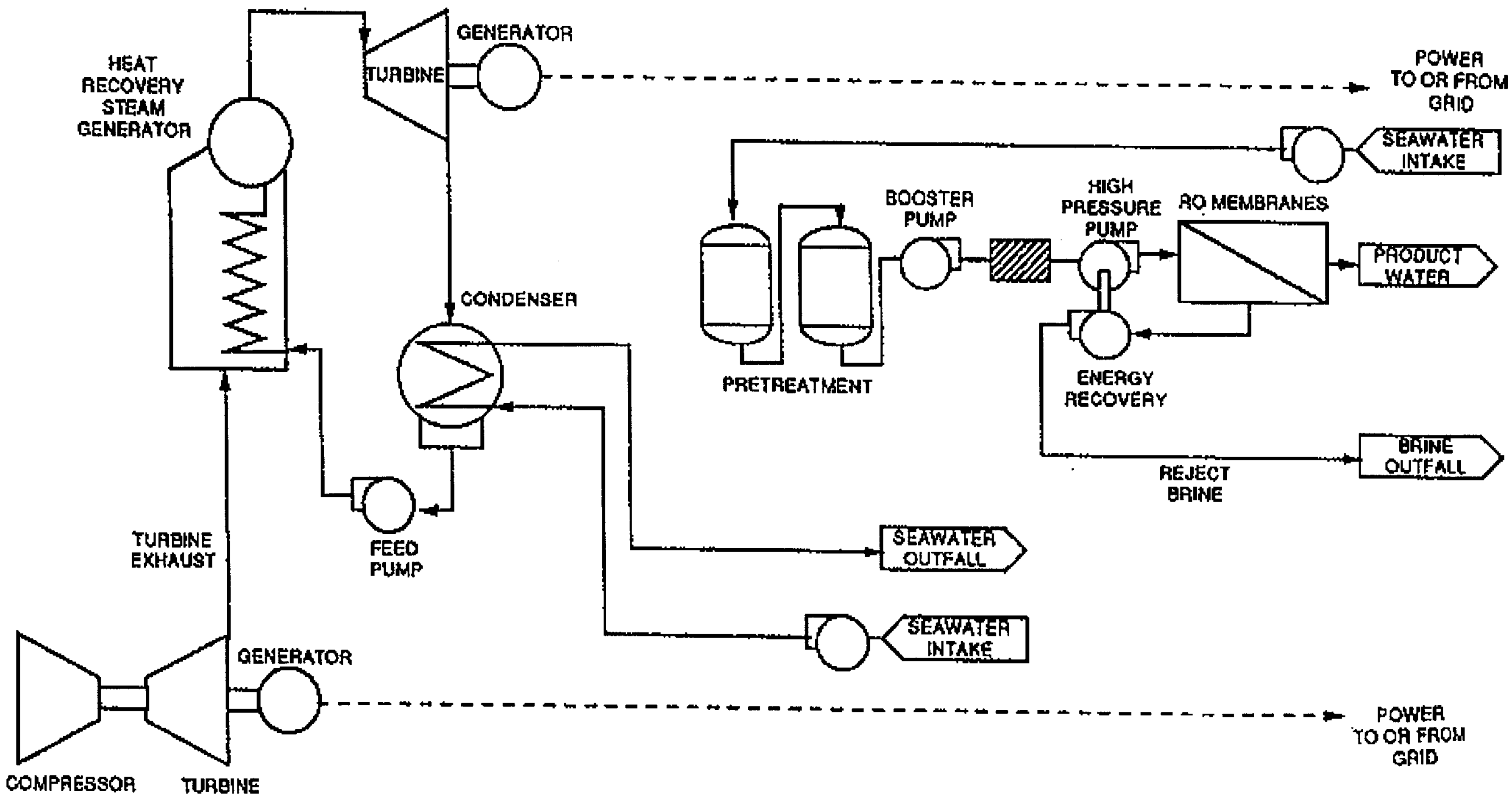

FIG. A-21. *Fossil combined cycle with stand-alone RO.*

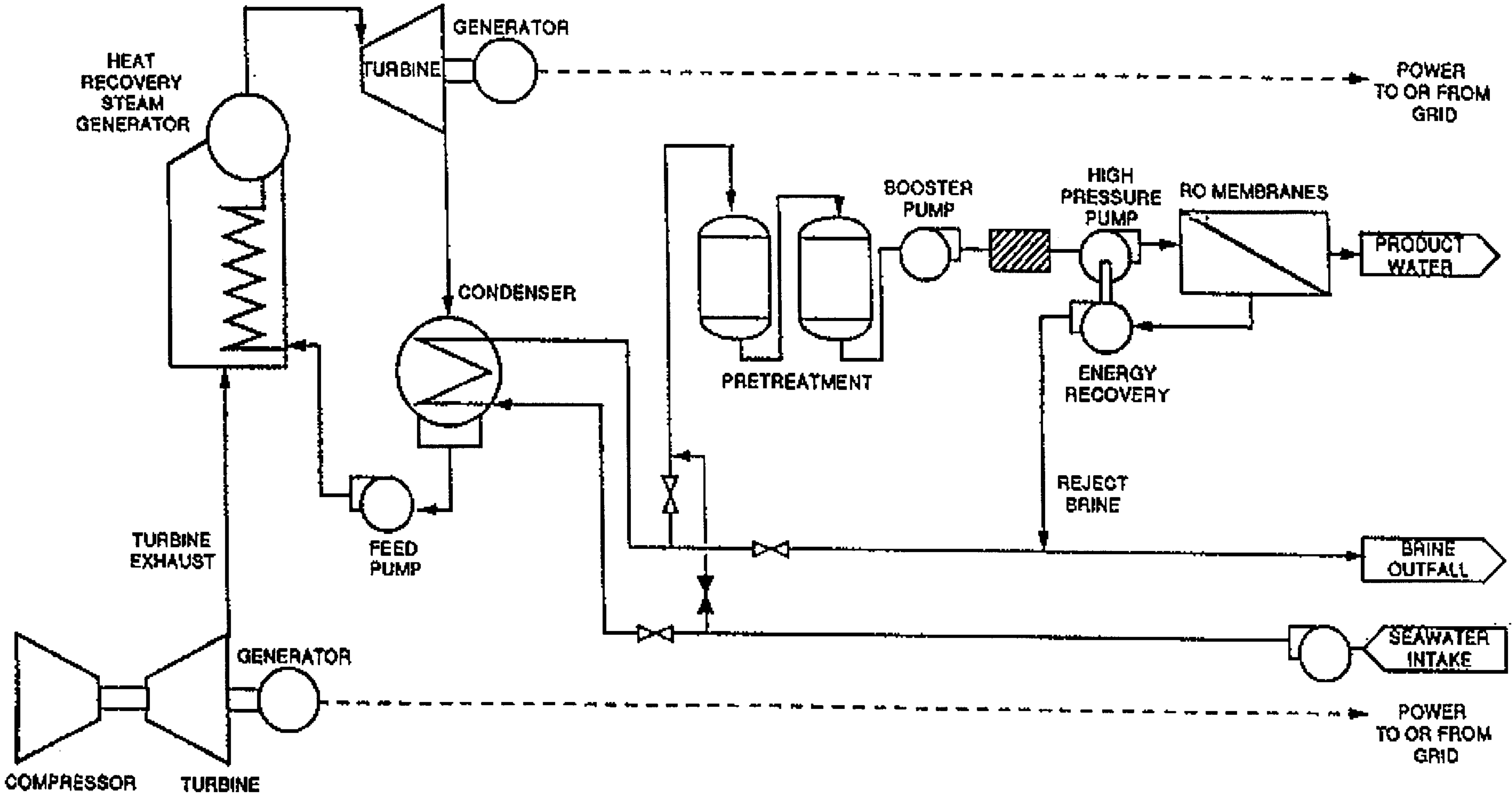

FIG. A-22. *Fossil combined cycle with contiguous RO.*

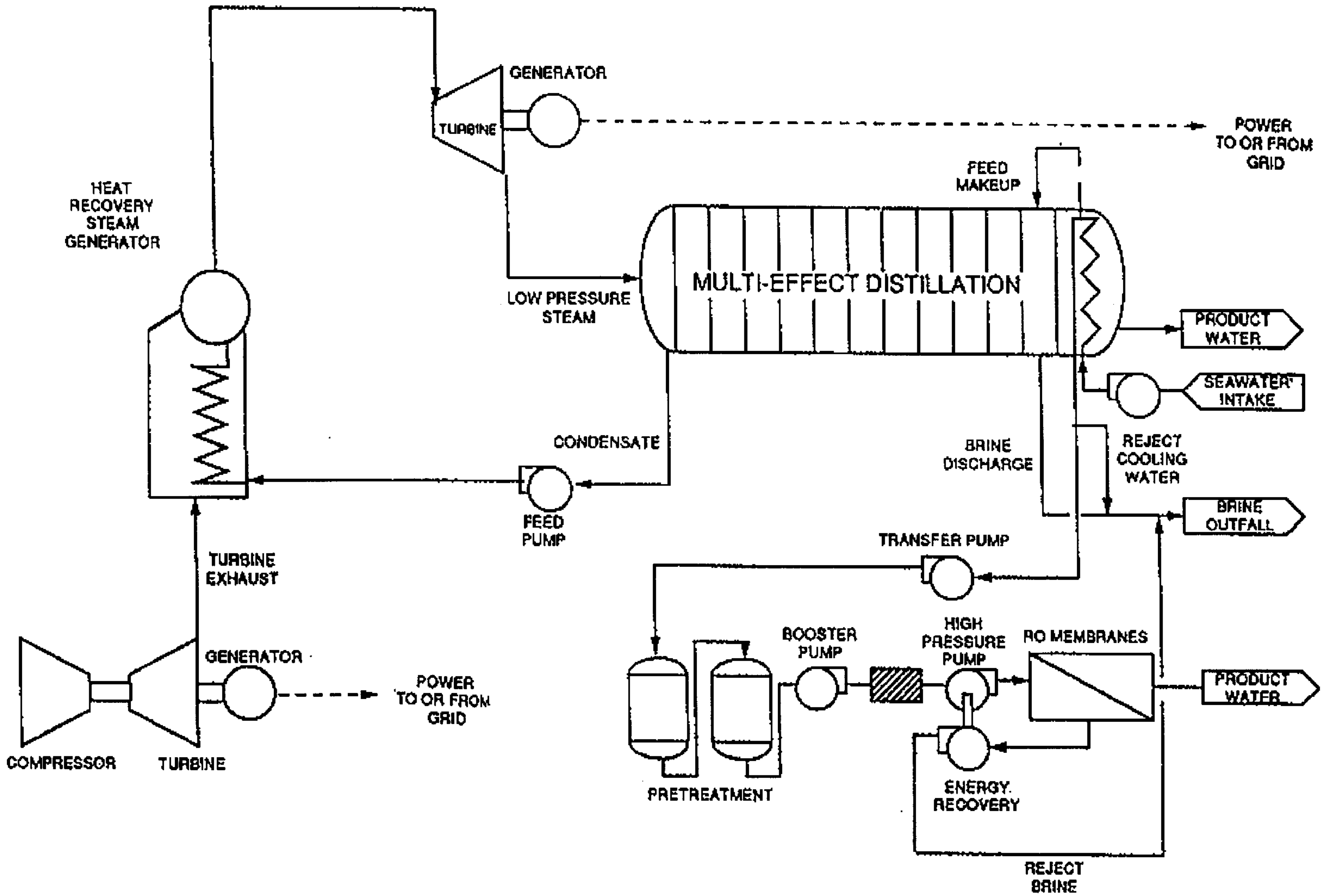

FIG. A-23. *Fossil combined cycle with hybrid MED and RO.*

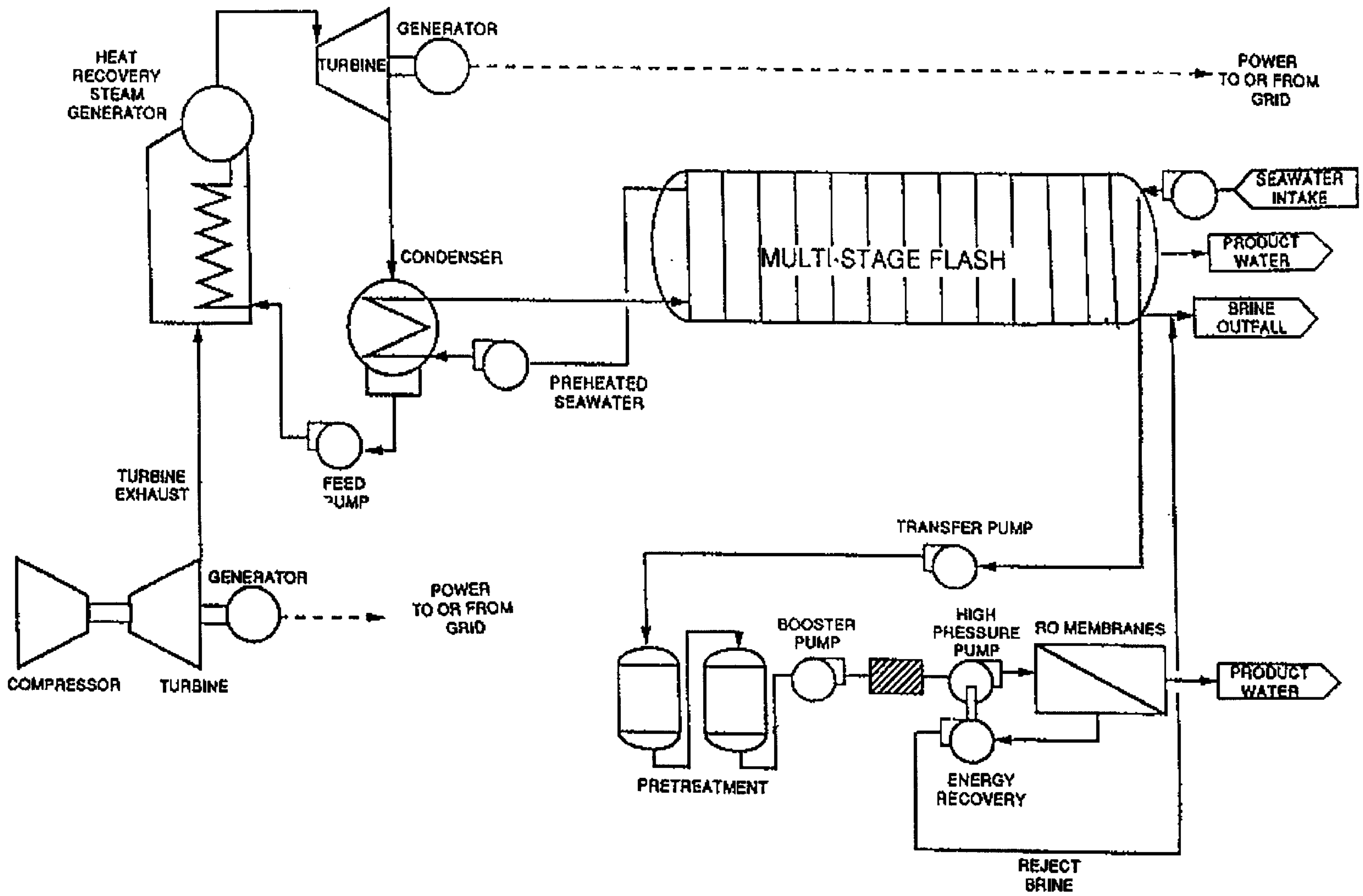

FIG. A-24. *Fossil combined cycle with hybrid MSF and RO.*

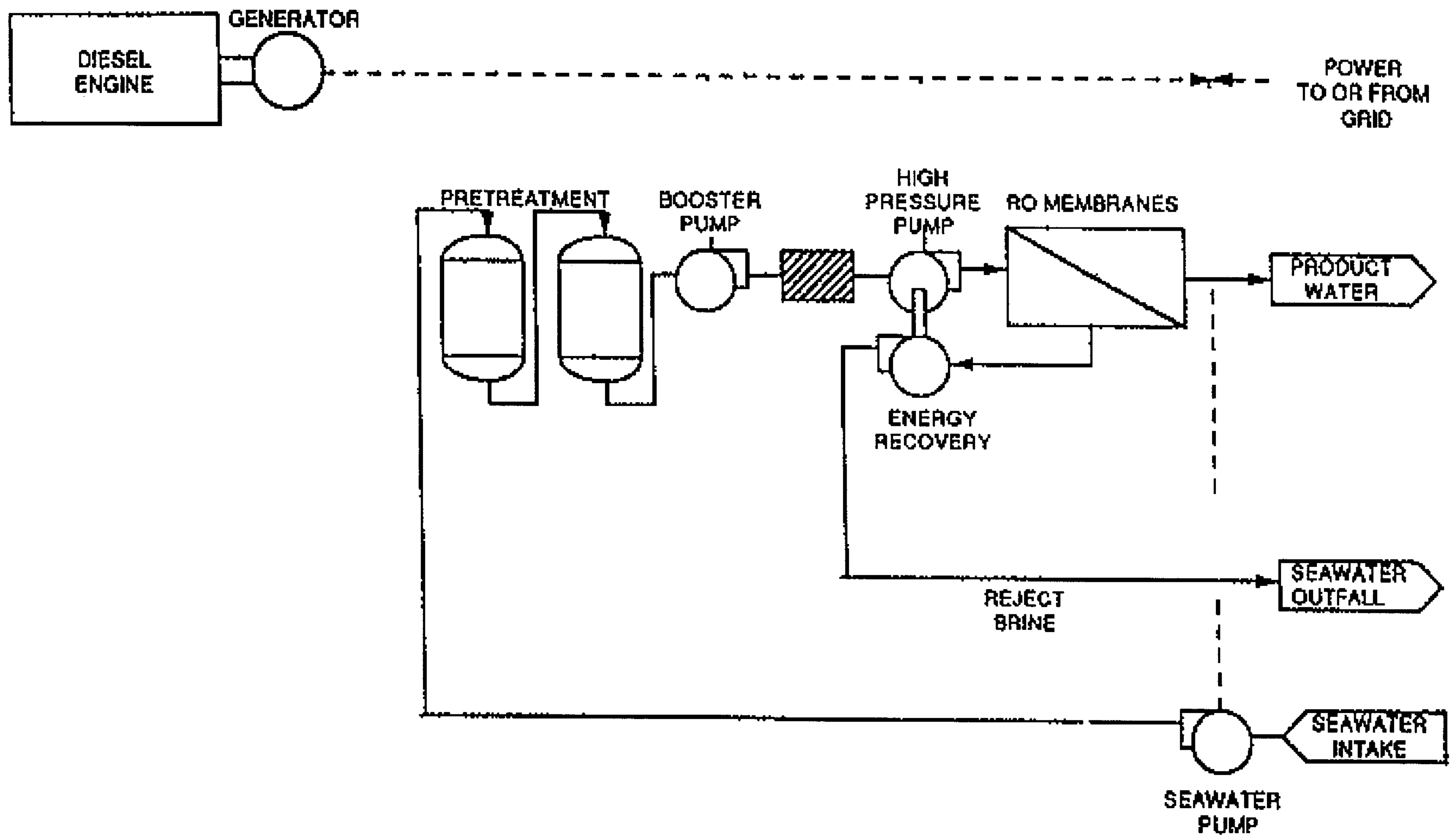

FIG. A-25. Diesel with stand-alone RO system.

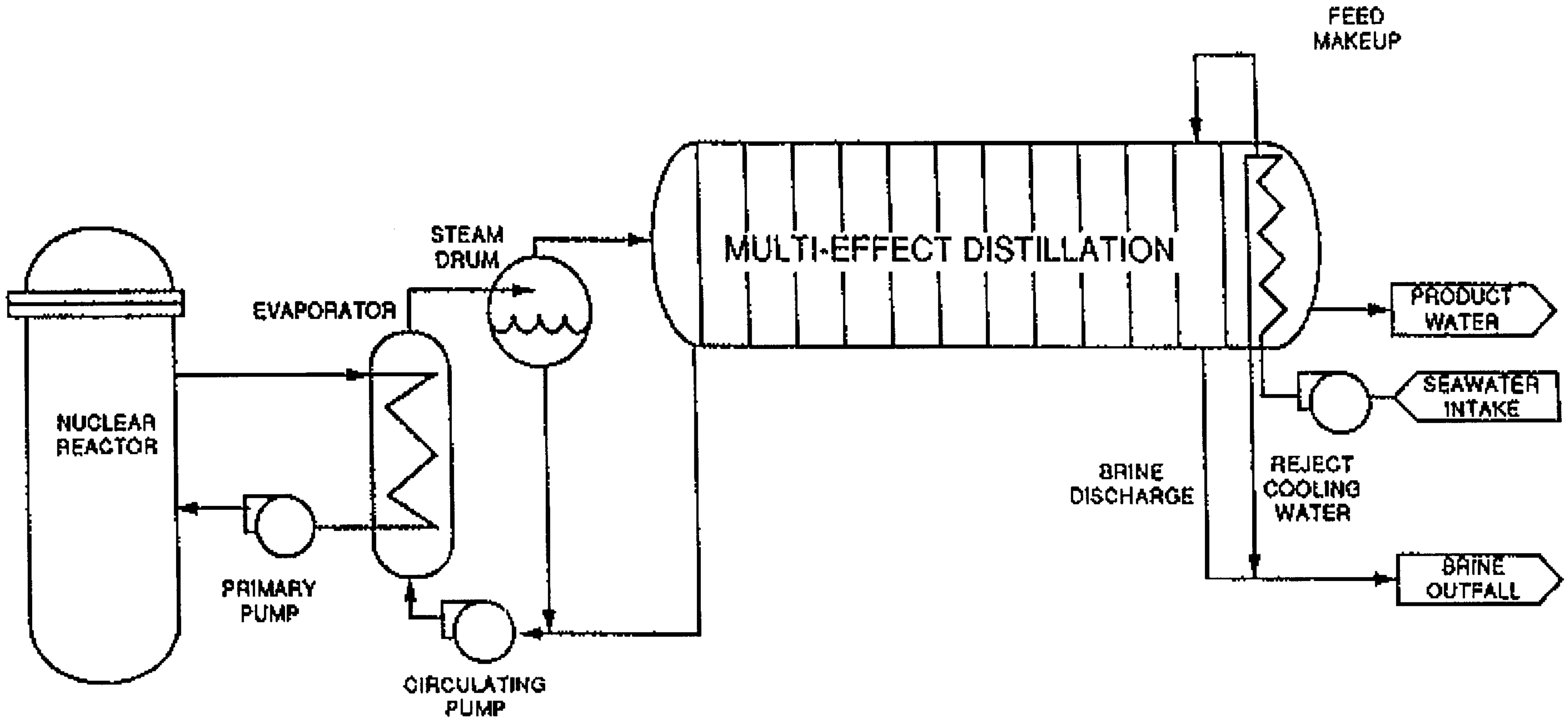

FIG. A-26. *Nuclear heat reactor with MED.*

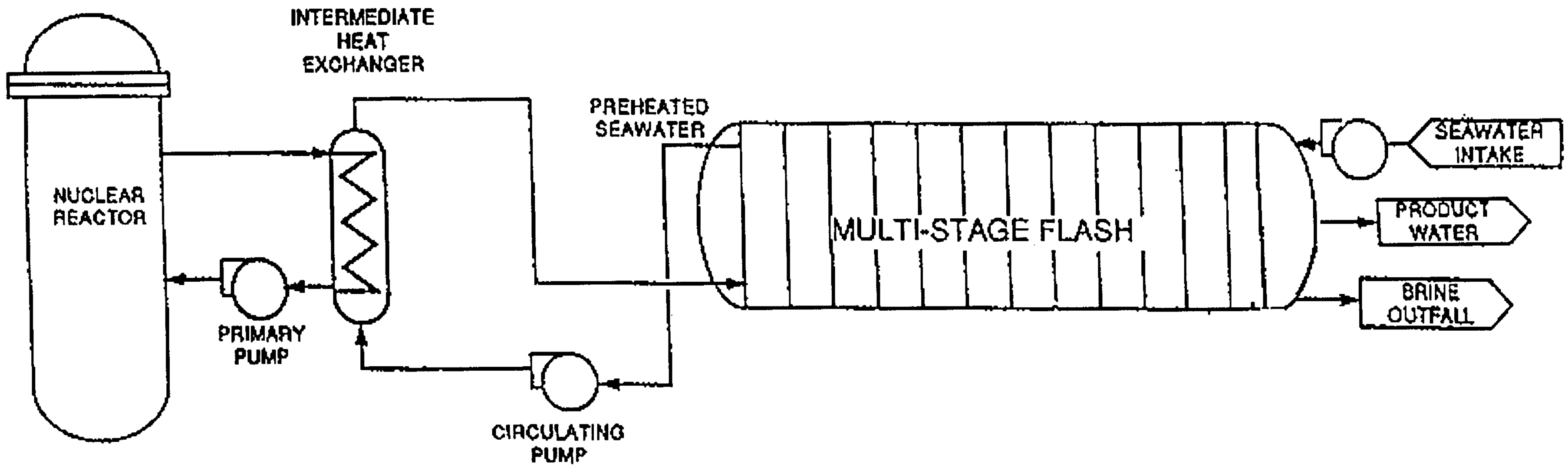

FIG. A-27. *Nuclear heat reactor with MSF.*

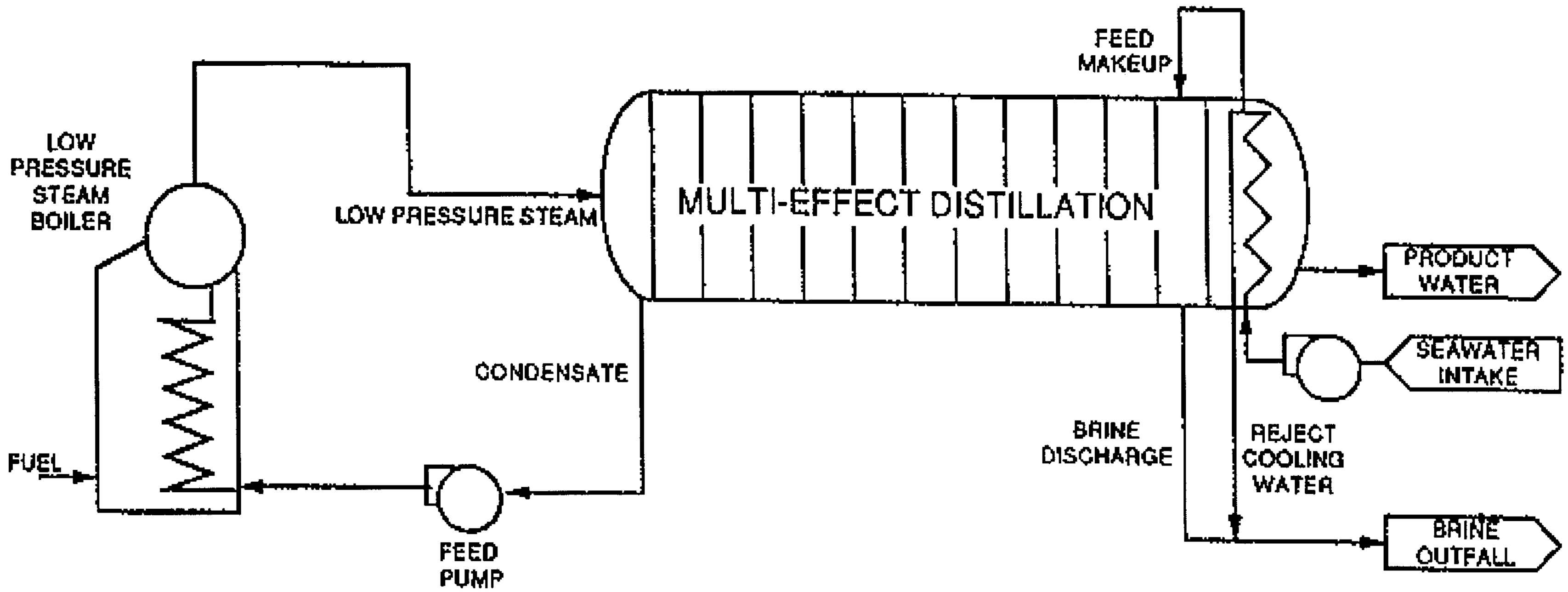

FIG. A-28. *Fossil heat boiler with MED.*

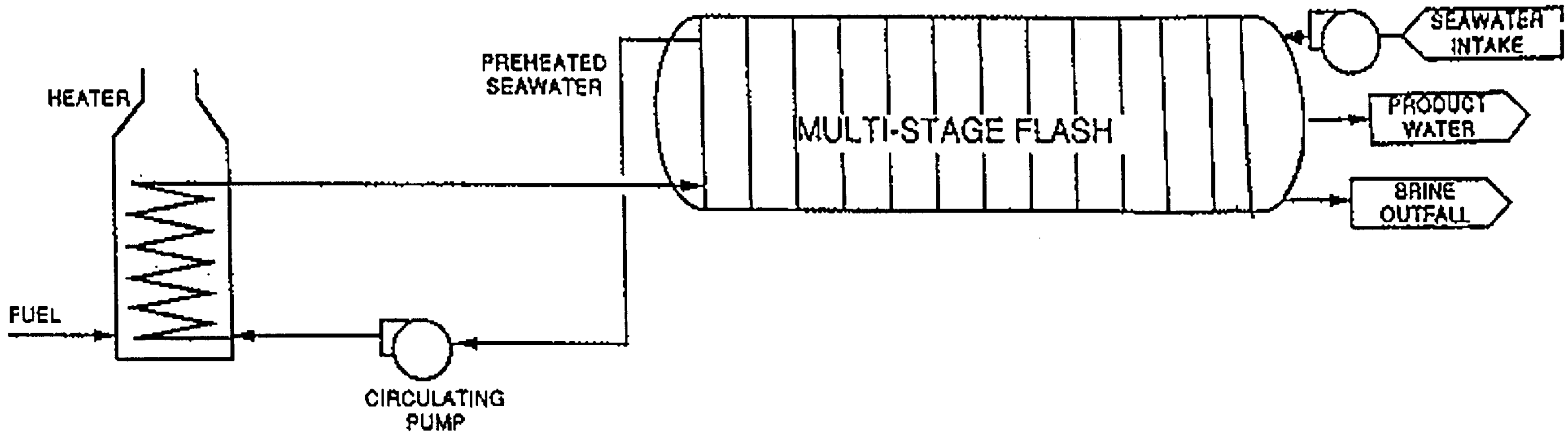

FIG. A-29. Fossil heat boiler with MSF.

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