The IAEA desalination economic evaluation programme (DEEP)

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IAEA

Atoms for Peace: The First Half Century

1957–2007

Summary of Presentation

- Introduction
- General structure of DEEP
- Further development
- Conclusion

Introduction

Following successive general conference resolutions:

- The IAEA held its first symposium on nuclear desalination at Madrid 1968.
- The IAEA renewed its activities on nuclear desalination in 1989.
- The IAEA published a report assessed the need for desalination and the most promising desalination processes and energy sources, including nuclear systems proposed by potential suppliers in 1990.
- In 1991-92, 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.

Introduction

- 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.
- The methodology included cost and technical performance models of several types of nuclear and fossil energy sources as well as seawater desalination processes.

Introduction

- At IAEA's request, the "Co-generation and Desalination Economic Evaluation" Spreadsheet, CDEE was developed by General Atomics under contract.

- CDEE was converted into a more user friendly software, called DEEP with the possibilities for :
  - 1- Preliminary economic evaluation of desalination by a wide range of fossil and nuclear energy sources, coupled to selected desalination technologies.
  - 2- Feasibility studies of nuclear desalination

To be used by designers and decision makers

Introduction

It is a spreadsheet tools (based on linked Microsoft Excel Spreadsheets: Case, Comparative Presentation, and Control files)

- *DEEP has been widely used within the nuclear & conventional desalination community. It is now an international reference code for desalination*
- *Efforts have been made to expand its scope over the years.*
- *DEEP is oversized & in need of thorough review.*
- *Recent efforts have been made to "upgrade" it with contributions from the " DEEP Users Group".*
- *Specific changes were proposed during RCM-2 of CRP-2.*

Introduction

DEEP

- *is not intended for precise calculation of the cost of either potable water or electricity, nor as engineering or design tool for detailed design.*
- *To be used to provide guidance for strategic analysis and generic studies*
- *DEEP is based on empirical performance and cost models which are valid for certain ranges of input parameters (in particular unit sizes of power and desalination plants, Ro feedwater temperature and salinity)*

Role of thump: Analysis should be kept within 10-20%

Inherent Drawbacks of DEEP

Simplified models and correlations for Power Plant Calculations

1. Inherent assumptions and limitation on the models will result in approximate results.

1. Total construction costs of the power plant are calculated in DEEP on the basis of specific construction cost which is user input value.

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Inherent Drawbacks of DEEP

Simplified models and correlations for Power Plant Calculations

1. Method of calculating power plant operating availability from “planned and unplanned outage rates” is based on the plant either out of service or operating continuously at full power over the rest of the year.

2. Calculation of net saleable power plant coupled to MED is based on the adjusted power level (to account for the steam conditions of MED)

Inherent Drawbacks of DEEP

Simplified models and correlations for Desalination Plant Calculations

1. Capacity of Desalination plant is made of smaller units (multiples of 12000 m3/d).
2. Water plant costs are calculated on the basis of " base unit cost" with introduction of correcting factor for #s of units.
3. DEEP is not suitable to calculate the beneficial effect of spiral wound membrane performance characteristics in RO case, or the lower water cost for the preheated feed water.
4. Absence of recirculation stages in the MSF process.

Drawbacks of DEEP (corrected in DEEP-3)

1. *Clear distinction between backpressure & extraction steam cases (Lost shaft work error-prone) was needed.*
2. *Levelized electricity cost calculation*

   did not properly account for the penalty effect introduced by the desalination unit.
3. *The "minimum maximum brine temperature" calculation was questionable.*

Drawbacks of DEEP

4. *The number of effects/stages was an important distillation design parameter, but was not left at the user's disposal for input.*
5. *The RO performance curves needed a major overhaul.*
6. *Many constants dispersed in the code are still unnecessarily hardwired and in need of validation.*

Drawbacks of DEEP

7. *Advanced reactor design concepts, which are relevant to nuclear desalination, are not included as built-in models.*
8. *The presentation of the user interface (input/output) does not seem to make a clear distinction between important & less-important parameters. The user is left with a false sense of program control.*
9. *The documentation is in line with the above.*
10. *Error checking is minimal (the user is cautioned to check for the accuracy of his input data)*

Main functions of DEEP

- DEEP main calculation sheet supports both nuclear and fossil power options.

- Supports dual and single purpose power plants.

- Supports distillation processes MSF, and MED, and RO as stand alone models or hybrid systems.

The Various energy options considered in DEEP

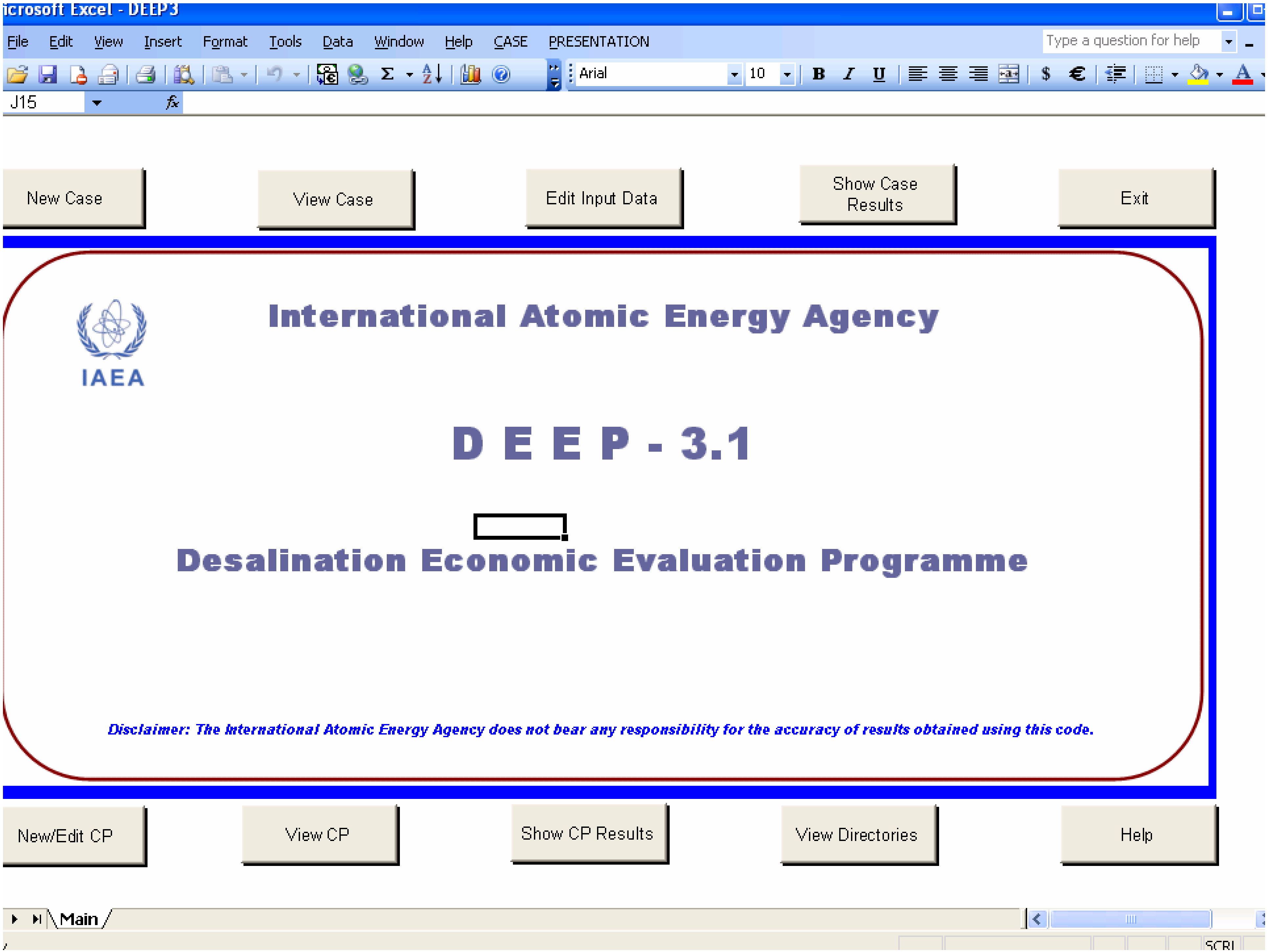
Desalination is an energy-intensive process

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
4	Fossil oil - gas	SSBOG	Superheated steam boiler	Co-generation plant
5	Fossil	GT	Open cycle gas turbine	Co-generation plant
6	Fossil	CC	Combined cycle	Co-generation plant
7	Nuclear	HR	Heat reactor (steam or hot water)	Heat-only plant
8	Fossil	B	Boiler (steam or hot water)	Heat-only plant
9	Nuclear	GTMHR	Gas turbine modular helium reactor	Power plant
10	Fossil	D	Diesel	Power plant
11	Nuclear	SPWR	Small PWR	Co-generation plant

The desalination processes considered in DEEP

Desalination requires LOW-TEMP steam for distillation and HIGH-PRESS pumping power for RO

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


icrosoft Excel - DEEP3
File Edit View Insert Format Tools Data Window Help CASE PRESENTATION
Type a question for help
Arial 10
J15
New Case
View Case
Edit Input Data
Show Case Results
Exit
International Atomic Energy Agency
IAEA
D E E P - 3.1
Desalination Economic Evaluation Programme
Disclaimer: The International Atomic Energy Agency does not bear any responsibility for the accuracy of results obtained using this code.
New/Edit CP
View CP
Show CP Results
View Directories
Help
Main

Case input form

Specify Case and Configuration Data

Project: My Site | Case: My Case

Water Plant Capacity
Total Capacity: 100000 m3/d

Feed Salinity 35000 ppm | Feed Temperature 30 deg C
Interest Rate 5 % | Purchased Electricity Cost 0.06 $ / kWh

Power Plant Data
- Thermal Power 2000 MWt
- Net Electric Power 600 MWe
- Fuel Cost 6 $/MWh
- Specific Construction Cost 1700 $ / kW

Distillation Plant Data
- Maximum Brine N/A deg C
- Heating Steam Temperature N/A deg C
- Specific Construction Cost N/A $ / (m3/d)

Reverse Osmosis Plant Data
- Energy Recovery Fraction 95 %
- Recovery Ratio (optional) 0 %
- Design Flux 13.6 l / (m2 h)
- Specific Construction Cost 900 $ / (m3/d)

Pipeline Transport Option
- [x] Transport cost
- 50 Distance (kms)
- 0 Power (MWe)
- 1 scc (M$/km)
- 7 o&m (% of scc)

First, select a coupling configuration from the matrix of supported energy sources and desalination technologies

		MED	MSF	RO	MED-RO	MSF-RO
NUCLEAR	NUCLEAR STEAM TURBINE	NSC+MED	NSC+MSF	NSC+RO	NSC+MED-RO	NSC+MSF-RO
	NUCLEAR GAS TURBINE	NBC+MED	NBC+MSF	NBC+RO	NBC+MED-RO	NBC+MSF-RO
	NUCLEAR HEAT	NH+MED	NH+MSF			
FOSSIL	STEAM CYCLE - COAL	COAL+MED	COAL+MSF	COAL+RO	COAL+MED-RO	COAL+MSF-RO
	STEAM CYCLE - OIL	OIL+MED	OIL+MSF	OIL+RO	OIL+MED-RO	OIL+MSF-RO
	GAS TURBINE / HRSG	GT+MED	GT+MSF	GT+RO	GT+MED-RO	GT+MSF-RO
	COMBINED CYCLE	CC+MED	CC+MSF	CC+RO	CC+MED-RO	CC+MSF-RO
	FOSSIL HEAT	FH+MED	FH+MSF			
REN	RENEWABLE HEAT	RH+MED	RH+MSF			
	STAND-ALONE RO			SA-RO		

Desalination Type: RO
Power Source: NSC

Configuration Switches

Steam Source
- (•) Extraction / Condensing
- ( ) Backpressure

Thermal Vapor Compression
- ( ) Yes
- (•) No

- [ ] Backup heat source

Carbon Tax Option
- [x] Carbon Tax
- 0 CO2 emission (t/MWh)
- 50 Carbon tax ($/t)

File Name: New NSC+RO

O.K. | Cancel

DEEP edit input data

Microsoft Excel - DEEP3

File Edit View Insert Format Tools Data Window Help CASE PRESENTATION

DistPivot

CASE IDENTIFICATION & BASIC CONFIGURATION

Double-click on any green input cell to edit its value

Close

Project identification	text	Project	My Site
Case identification	text	Case	My Case
Energy plant type	text	EnPlt	NSC
Desalination plant type	text	DslpType	RO
Reference coupling diagram	#	RefDiag	N/A

Required total desalination capacity | Hybrid plant capacities

Required total desalination capacity	m³/d	Wc_t	100 000

ENERGY PLANT PERFORMANCE DATA

Ref. thermal power	MWt	Qtp	2 000
Ref. net electric power	Mwe	Pen	600
Planned outage rate		opp	0.100
Unplanned outage rate		oup	0.110
Operating availability (if 0, value is calculated)		Appo	0.900
Lifetime of energy plant	a	Lep	60
Energy plant contingency factor		kec	0.00
Construction lead time	m	Le	60
specific CO2 emission	kg/kW.h	CO2e	N/A
Site specific inlet air temp (for GT/CC cases)	°C	Tair	N/A
Condenser-to-Interm. loop approach temp.	°C	DTca	
Turbine type (ExtrCon / BackPr)		TurType	N/A
Interm. loop temperature drop	°C	DTft	N/A
Difference between feed steam temp. and max br	°C	DT1s	N/A
Intermediate loop pressure loss	bar	DPip	N/A
Intermediate loop pump efficiency		Eip	N/A

DISTILLATION PLANT PERFORMANCE DATA

Seawater feed temp. (if 0, default of 30 is used)	°C	Tsdo	N/A
Feed salinity	ppm	TDS	35 000
GOR (if 0, value is calculated)		GORo	N/A
Distillation plant modular unit size	m³/d	Wduo	N/A
Condenser range	°C	DTdcr	N/A
Condenser approach	°C	DTdca	N/A
Steam temperature (if 0, value is calculated)	oC	Tcmo	N/A
Max. brine temperature (if 0, value is calculated)	°C	Tmbo	N/A
Thermal vaport compression option (TVC)	Y/N	TVC	N/A
TVC vapor entrainment ratio (if 0, default of 1 is used)		Rtvco	N/A
Seawater pump head	bar	DPsd	N/A
Seawater pump efficiency		Esd	N/A
Specific power use	kW(e)h/m³	Qsdp	N/A
Planned outage rate		opd	N/A
Unplanned outage rate		oud	N/A
Plant availability (if 0, value is calculated)		Adpo	N/A

Main | Input | Output | #P-I | #W-I | #P-I B&W | #W-I B&W

Ready

DEEP result

Microsoft Excel - DEEP3

Summary of Performance and Cost Results

Main Input Parameters

Project	**My Site**			**Case**	**My Case**
Power Plant Data			**Water Plant Data**		
Type	NSC		Type	RO	
Ref. Thermal Power	2 000	MW	Required capacity	100 000	m^3/d
Ref. Net Electric Power	600	MW	Hybrid Dist. Capacity	N/A	m^3/d
Construction Cost	1 700	$ / kW	Dist. Construction Cost	N/A	$ / (m^3/d)
Fuel Cost	6	$/MWh	Maximum Brine Temp.	N/A	°C
Purchased Electricity Cost	0.06	$/kWh	Heating Steam Temp.	N/A	°C
Interest Rate	5	%	Dist. Feed Temp.	N/A	°C
			Seawater Feed Salinity	35000.0	ppm
Configuration Switches			Hybrid RO Capacity	N/A	m^3/d
Steam Source	N/A		RO Construction Cost	900	m^3/d
Intermediate Loop	Y		RO Recovery Ratio	0.00	
TVC Option	N/A		RO Energy Recovery Fraction	0.95	
Backup Heat	N/A		RO Design Flux	13.6	l / (m^2 hour)
			RO Feed Temp.	30.0	°C
Water Transport					
Distance	50	km	**Carbon Tax**		
Pipeline System Construction Cost	1	M$ / km	Specific Carbon Tax	N/A	$ / ton
Pumping Power	0	MWe	Specific CO2e Emission	N/A	tons / MWh
O&M Cost	7	% of scc			

Performance Results

Improvements **(some have already been made or under consideration)**

DEEP 3.1 includes very simplified models for Water transport cost and Carbon Tax

1. *Proper calculation of lost shaft work & levelized electricity cost.*

2. *Clear distinction in the code between extraction & back-pressure systems.*

3. *Minimum maximum brine temperature calculation are cleared out.*

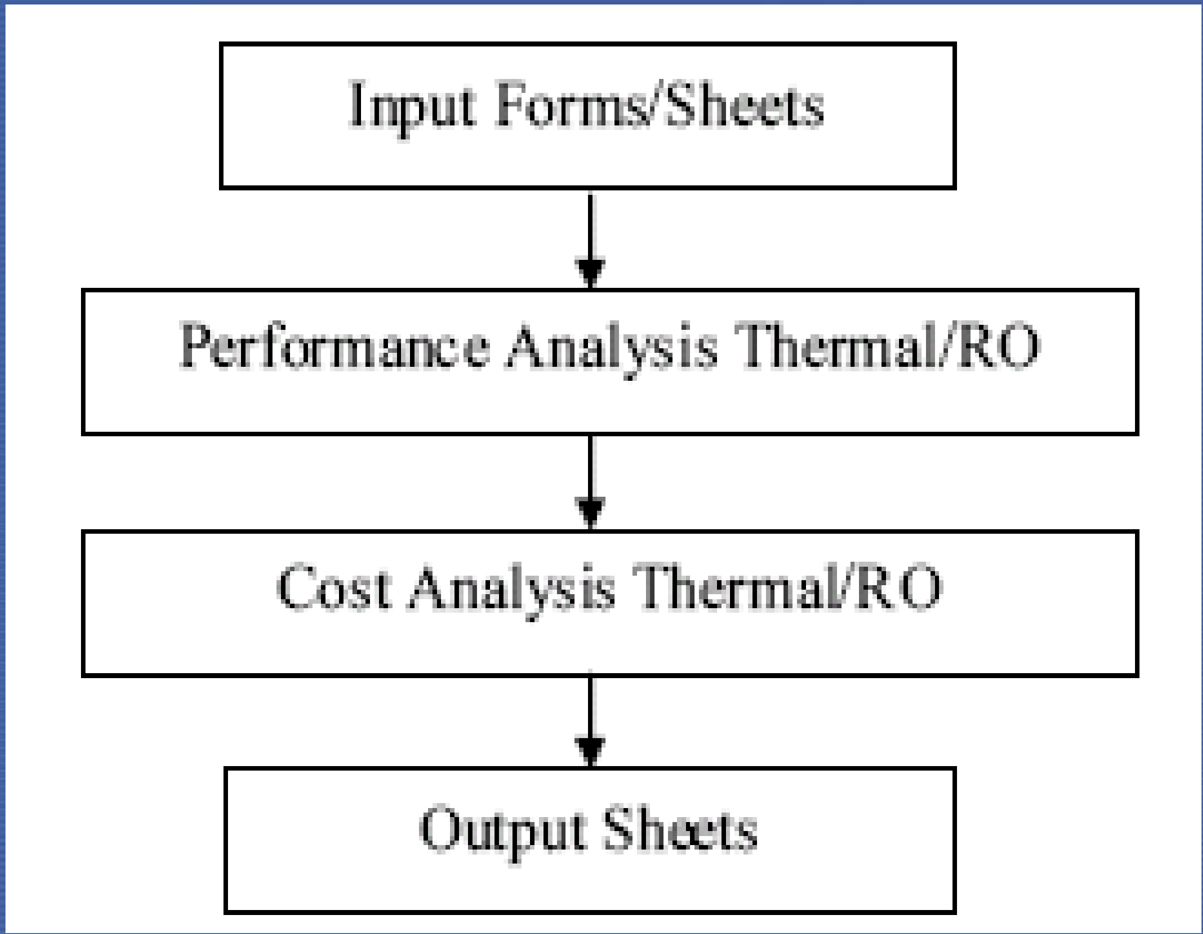
Improvements (some have already been made or under consideration)

4- Design parameters such as the number of effects/stages and temperature range to user input has been modified.

(Minor correction to GOR correlations)

Result: easier estimation of GOR, steam flow & its temperature/pressure conditions.

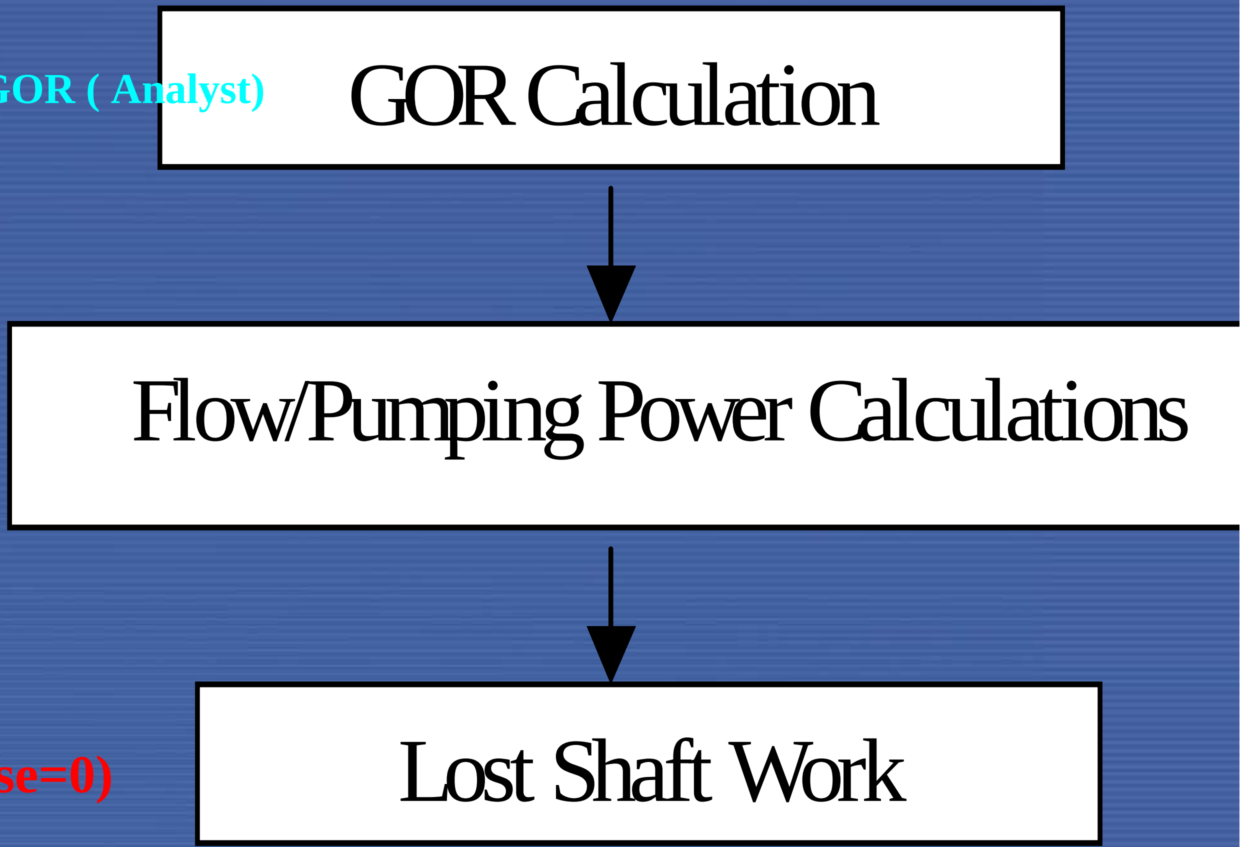
Flow chart of the overall DEEP



Thermal performance model

Two Options:

Specify GOR (designer), Estimate GOR (Analyst)



Calculated (for Heat only case=0)

Improvements (some have already been made or under consideration)

5. *Updated RO performance data where*
   - *Feed is characterized by salinity, temp. & pressure.*
   - *Permeate is characterized by flux, salinity & recovery ratio.*
6. *Validation of all hardwired data.*

Validation of DEEP using recent operational data (power & water) is needed.

RO performance model

User: either specify, or estimate RR

Recovery ratio estimate

↓

Product flow & quality estimate

↓

Feed flow & pressure estimate

↓

Pumping power requirements

Improvements (some have already been made or under consideration)

7. *Upgrade & validation of built-in heat source models (nuclear & non-nuclear).*
8. *Consolidation of input/output sheets. Separation of important from less-important parameters where the user is given the level of control is needed.*
9. *Upgrade the DEEP documentation.*

Conclusions

- Deep is suitable for feasibility studies of nuclear desalination (not as a design code)
- Upgrade of DEEP is a continuous process as the cost parameters of both nuclear reactors and desalination processes are changing with time (due to numerous innovations in the technologies).
- New development is made (DEEP3.1) and further ones will be made (some soon).
- More and more scientists/ engineers and researchers (including some commercial firms) from various countries are using DEEP for cost estimation of desalination plants using nuclear/ fossil energy sources. Therefore, Benchmark of DEEP is needed.
- DEEP has been and still be distributed by the IAEA free of charge. Any comments or feedback is most welcome.

Announcement

New CRP on
“Advances in Nuclear Power Process Heat Applications”

Big remark:
Only research Agreements will be accepted (No money)

Info sheet is available at the Conference desk

THANK YOU