



2245-13

#### Joint ICTP-IAEA Advanced School on the Role of Nuclear Technology in Hydrogen-Based Energy Systems

13 - 18 June 2011

**Demonstration of HEEP** 

U.D. Malshe Reactor Design and Development Group Bhabha Atomic Research Centre Mumbai India

udmalshe@barc.gov.in

### Demonstration of HEEP

I.V. Dulera, <u>U.D. Malshe</u>, P.P. Kelkar, A. Antony, A. Basak

Reactor Design and Development Group Bhabha Atomic Research Centre Trombay, Mumbai-400 085, INDIA

#### Outline of the demonstration of HEEP

- Installation of HEEP
- Use of manuals
- Using the programme
- General guidelines for entering/editing data

#### Demonstration of HEEP

Description of the case being demonstrated

### Installation of HEEP

#### Steps to install HEEP (1/3)

Request IAEA for HEEP HEEP(Beta) Setup

- Download file from IAEA website
- Unzip the file
- Run "setup.exe" from unzipped file.
- Setup will prompt to close all running programmes.



- Press Alt+Tab to switch to running programmes.
- Switch to running programmes and close them all.

#### Steps to install HEEP (2/3)

 Programme will be installed in a default folder "C:\Programme Files\HEEP(Beta0)\"

 User may choose to install in the folder other than the default folder.



Click "Change Directory" and enter required destination path if user wish to install HEEP in folder other than default folder.

• Set-up will prompt to accept or deny creation of folder. Click "yes" to create folder.

#### Steps to install HEEP (3/3)

- All files required for running HEEP and manuals will be copied to respective destinations.
  - Manuals are copied to the subfolder "Manuals" in the destination folder entered earlier.



HEEP(Beta) Setup

Installation creates HEEP(Beta0) at the location specified during installation and also creates following folders within HEEP(Beta0)

- CaseFile
- DataBase
- EXEMODULE
- POST

All permissions (read, write, modify etc.) for all folders created in HEEP needs to be set for OS users

For Windows-7- needs to set the programme attribute as "run as administrator" or "run in compatibility mode"

#### Manuals

#### List of manuals

Preprocessor manual

 Formats for data to be collected for HEEP

 Manual for execution engine

Manual for post processing



#### Contents of the pre-processing manual

- First two chapters:
  - Procedures to start using the programme
  - Options of estimating cost of hydrogen
    - Building new case
    - Read existing case
  - Information on important steps to be followed
  - Third chapter:

- Important general procedures
  - Entering the data and viewing and/or editing already entered details
  - Storing the data
  - Updating the database
  - Some important tips
- Fourth chapter:
  - Procedure for building new case
- Fifth chapter:
  - Details of information required for cost estimation using HEEP.

## Important fonts used in the pre-processing manual

Text with 'bold-italic' font indicates actions to be taken by the user.

Text in the 'italic' font gives important information to the user

### Starting the programme

#### 1. Click "Start"

2. Click "HEEP"

#### 3. Click "HEEP(Beta)"



#### Building the new case

#### Hydrogen Economic Evaluation Programme

International Atomic Energy Agency

Developed by: Bhabha Atomic Research Centre, Trombay, Mumbai-400085, India For any query regarding this software please contact: Dr. I. Khamis, Nuclear Power Technology Development Section, Division of Nuclear Power, IAEA. Email: I.Khamis@iaea.org

Read existing

case

Build new case for evaluation

> Quit Help (?)

Using of Nuclear Power Plant       Library of Hydrogen Generation Plant       List of nuclear power plant types in the library         Select Nuclear Power Plant Type       Image: Select Nuclear Power Plant Type       Image: Select Nuclear Power Plant Type         PBR200       Select Nuclear Power Plant Type       Select Nuclear Power Plant Type       Select Nuclear Power Plant Type         Description of the selected NPP       Select Nuclear Power Plant Type         Description of the selected NPP       Select Nuclear Power Plant Type         Paramete Description       Unit Value       Percenting Plant       Percenting Plant       Percenting Plant         Paramete Description       With Transport Select Nuclear Power Plant       Percenting Plant       Percenting Plant         Themad Power       Multi Value       Percenting Plant       Percenting Plant       Percenting Plant         Themad Power       Select Nuclear Power Plant       Select Nuclear Power Plant       Percenting Plant       Percenting Plant         Themad Power       Select Nuclear Power       Select Nuclear Power Plant       Percenting Plant Plant       Percenting Plant Plant Power         Select Rescription       Select Hotypo	Proceed		Go Ba	ck	Help (?) SELECT Currency Conversion Update Currency	
Ibrary of Nuclear Power Plant       List director power plant types in the kinary         Select Nuclear Power Plant Type       Ibrary of Hydrogen Generation Plant Type         PBR200       Ibrary of Hydrogen Teansportation         Description of the selected NPP       Ibrary of the selected H2 Generation Plant Type         Parenter Description       Ibrary of Hydrogen Generation Rotess Plant         Rector Case       Nuclear Power Plant Type         Select H2 Generation Plant Type       Ibrary of Hydrogen Generation Rotess Plant         Capacity Istation       Nuclear Power Plant Type         Select H2 Generation Plant Type       Ibrary of Hydrogen Generation Rotess Plant         Select H2 Generation Plant Type       Ibrary of Hydrogen Generation Rotess Plant         Capacity Istation       Ibrary of Hydrogen Generation Rotess Rotes <td< th=""><th></th><th></th><th></th><th></th><th>USD I USD I Database</th><th></th></td<>					USD I USD I Database	
Lat at nuclear power plant types in the library         Select Nuclear Power Plant Type         PBR200	ibrary of Nuclear	Pow	er Plant		Library of Hydrogen Generation Plant	
Select Nuclear Power Rant Type       Select H2 Generation Hant Type         PBR200       Select H2 Generation Plant Type         Description of the selcted NPP       Select H2 Generation Plant Type         Parameter Description       Unit Value         Description of H2OP       Temod Power         Temod Power       Parameter Description         Unit Value       Value Proceed Daton         Stat of Construction       Stat of Construction         Stat of Construction       Stat of Construction         Stat of Construction       Stat of Construction         Corbing Ine for Shuld       St	List of nuclear power pi	ant typ	es in the libi	ran/	- List of H2 Generating plant types in the library List of H2 Transport Facility types in the library -	
Select H2/depied relation H2/dep		- Dia	and the second			
PBR200       Image: Construction of the seldted NPP         Personeter Description       Unit Value         Rector Type       Image: Construction         Rector Type       Image: Construction         Themal Power       WWth         Themal Power       Image: Construction         Stat of Construction       Stat of Construction         Stat of Construction       Stat of Construction         Stat of Construction       Stat of Construction         Reductivitment inter       Years         Cooling time for Xp fuel       Years         Reductivitment inter       <	Select Nuclear Pow	rer Pia	ani type		Select Hydrogen Transportation Type	
Description of the selded NPP       Description       Unit       Value       Parameter Description       Unit       Value       <	PBR200			~	ISI_PBR200	
Parameter Description       Unit       Value         Description Control       10       State Construction (Figure Calue)         State Construction       10       State Construction (Figure Calue)       State Construction (Figure Calue)         State of Description       12       State the type of Mydoper Construction (Figure Calue)       State of Description (Figure Calue)         State of Description       12       State of Description (Figure Calue)       State of Description (Figure Calue) <td< td=""><td>Description of the selet</td><td>od NE</td><td>e.</td><td></td><td>- Description of the selfed H2 Generating Plant Description of the selfed H2 Transport Facility -</td><td></td></td<>	Description of the selet	od NE	e.		- Description of the selfed H2 Generating Plant Description of the selfed H2 Transport Facility -	
Parameter Description       Unit       Value       Parameter Description       Unit       Value         Reactor Type	creating and the actual					
Reactor Type       Incadion of H2GP       Incadion of H2GP         Reactor Class       Incadion of H2GP       Incadion of H2GP         Themal Power       MW/h         Themal Power       MW/h         Capacity factor       %         Capacity factor       %         Availability factor       %         Start of Construction       Incadion of H2GP         Start of Operation       Incadion of H2GP         Refurthment time       Years         Cooling time for Sp fuel       Years         Cooling time for Veats       Years         Refurbitment nos.       Years	Parameter Description	Unit	Value	<b>^</b>	Parameter Description Unit Value A Parameter Description Unit Value	
Reactor Class       Immail efficiency       Immail	Reactor Type	_			Location of H2GP	
Themal Power       MWh         Themal Power       MWh         Themal Power       K         Capacity facto       %         Avaiability facto       %         Avaiability facto       %         Stat of Construction       1         Stat of Construction       1         Stat of Construction       1         Stat of Decominisioning       To build a chashes for each of these facilities, use the following steps:         Stat of Decominisioning       To build a chashes for each of these facilities, use the following steps:         Cooling time for Sp fuel       Years         Refurbishment time       Years         Refurbishment nos.       Years	Reactor Class				Themal power	
Thermal efficiency       %         Capacity factor       %         Availability factor       %         Availability factor       %         Other utilities       *         Stat of Construction       *         Stat of Construction       *         Stat of Construction       *         Stat of Deration       *         End of Uperation       *         Stat of Deration       *         Stat of Operation       *         Cooling time for Stud       Years         Cooling time for Vaste       Years         Refurbishment time       Years         Refurbishment nos.       Years         Refurbishment nos.       Years	Themal Power	MWt	n		Electricity for HEEP (Bet and a second	
Capacity factor       2         Availability factor       2         Mailability factor       2         Duber utilities       1         Stat of Construction       1         Stat of Decominisioning       1         End of Dereion       1         Stat of Decominisioning       1         End of Idee       1         Refubitishment time       Years         Cooling time for Sp fuel       Years         Cooling time for Sp fuel       Years         Refubitishment nos.       Years         Refubitishment nos.       Years         Colong time for Sp fuel       Years         Cooling time for Sp fuel       Years         Refubitishment nos.       Years         Cooling time for Sp fuel       Years         Refubitishment nos.       Years         Part of Difference       Years         Cooling time for Waste       Years         Prefubitishment nos.       Years         Years       Years         Years       Years         Years       Yea	Thermal efficiency	%			Capacity facts	
Availability factor     *     Availability factor     *       Other utilities     -     -       Stat of Construction     -     -       Stat of Operation     -     -       Colong time for Sp fuel     -     -       Cooling time for Sp fuel     Years       Cooling time for Sp fuel     Years       Refurbishment time     Years       Refurbishment nos.     Years	Capacity factor	%			Efficiency of (1) Use the rollowing steps to build a new case using the available database:	
Other utilities	Availability factor	%			Availability at (2). Select the type of Nuclear Power Frank	
Start of Construction	Other utilities				Capacit of H (3)- Select the type of Hydrogen Transportation Par	
Stat of Operation       H2 storup p         End of Operation       Stat of Denomissioning         End of life       (1)- Select 'Add New Type'         Refutbishment time       Years         Cooling time for Sp fuel       Years         Refutbishment nos.       Years         Verticitishment nos.       Years	Start of Construction				H2 storpe m (4)- Click the 'Proceed' button ears	
End of Operation Start of Decommissioning Star	Start of Operation				H2 stort e pe To build a database for each of these facilities, use the following steps:	
Start of Decommissioning       Image: Control of the second	End of Operation				Start of Crest (1)- Select 'Add New Type'	
End of life Start of Deco Start of Deco Cooling time for Sp fuel Years Cooling time for Waste Years Refurbishment nos. Years ▼ Refurbishment nos. Years ▼	Start of Decommissioning				Start of Opc (2)- Click the 'Proceed' button	
Refutishment time       Years         Cooling time for Vaste       Years         Refutishment nos.       Years         Refutishment nos.       Years	End of life	_			End of Opera	
Looling time for Sp tuel       Years         Cooling time for Waste       Years         Refurbishment nos.       Years	Refurbishment time	Years			Start of Deco	
Looing time for Waste Years Refurbishment time Years Refurbishment nos. Years Interest rate on borrowing %	Cooling time for Sp fuel	Years	8		End of life	
Heturbishment nos.     Years     Interest rate on borrowing     %	Cooling time for Waste	Years	8		Helubishment time Years 200 Helubishment time 200 Helubishment time 200 Helubishment time 200 Helubishment time	
	Heturbishment nos.	Years		-	Heturbishment nos.	

#### Adding new database

- 1. Select the currency
- 2. Select "Add New Reactor Type to Library", "Add New Plant Type to Library" and "Add New Transportation Type to Library" for the three facilities.





#### Entering names of database

- Enter name of new database for nuclear power plant and click "OK"
- Enter name of new database for hydrogen generation plant and click "OK"
- Enter name of new database for hydrogen transportation and click "OK"



#### Start entering data



#### Read Existing Case

#### Hydrogen Economic Evaluation Programme

International Atomic Energy Agency

Developed by: Bhabha Atomic Research Centre, Trombay, Mumbai-400085, India For any query regarding this software please contact: Dr. I. Khamis, Nuclear Power Technology Development Section, Division of Nuclear Power, IAEA. Email: I.Khamis@iaea.org

Read existing

case

Build new case for evaluation

Quit

Help (?)



Prions for facilitie. T	vailabl	e in the libra	гу								
Proceed	)_	Go Back	:	Help (?)	LECT Cur	setting rency	USD =	= <b>1</b> USI	)	Update Currency	1
										Database	<u>_</u>
List of existing ca	<del>3505</del>										
	e-tdi										
DDDON OL DDDO											
PBR200-SI_PBR20	uu-Pip	De.apt	~								
Description of the selct	ed NP	P	$\leq$	- Description of the se	dated H2 G	Seneratina Pla	nt —	- Deseus ine of the selde	ad H2 7	Transport Facility -	
							<b></b>			▲	
Parameter Description	Unit	Value		Parameter Description	Unit	Value		Parameter Description	Unit		
Develop tree	_			Leasting of H2GP		Collegated with		H2 Transportation turns		V/abiala	
Reactor Type Reactor Class			-	Themal power for H2 Ge	n Mu <i>l</i> ih	LOHOCALED WILT		H2 Transportation distance	km	venicie	
hemal Power	MWH	1001		Electricity for H2 Gen	n. mwu Mwa	1545		Start of Construction	Year	2018	
Thermal efficiency	2 2	1 00		Capacity factor of H2GP	* *	90		Start of Operation	Year	2010	
Capacitu factor	2	9		Efficiency of process	2	45		End of Operation	Year	2021	
vailability factor	%	10		Availability factor	%	100		Start of Decommissioning	Year	2082	
Other utilities				Capacity of H2 generatio	n ka/vr	194400000		End of life	Year	2090	
tart of Construction		201	8	H2 storage method		0		Refurbishment time	Years	1	
Start of Operation		202	1	H2 storage period	Hrs.	0		Refurbishment nos.		1	
End of Operation		208	D	Start of Construction	Years	2018		Currency type		USD	
Start of Decommissioning		208	2	Start of Operation	Years	2021		Inflation rate	%	0.01	
d of life		209	D	End of Operation	Years	2080		Discount rate	%	0.05	
Reful ishment time	Years	:	1	Start of Decommissioning	) Years	2082		Base cost equity fration	%	1	
Cooling time for Sp fuel	Years	2	2	End of life	Years	2090		Base cost Debt fration	%	1	
Cooling time for Caste	Years	:	2	Refurbishment time	Years	1		Return on equity	%	0	
Refurbishment nos.	Years	:	1 -	Refurbishment nos.		1	-	Interest rate on borrowing	%	0.053 👻	
bove table/s is/a	re ai	ven for inf	orma	tion about importan	t param	eters of th	e sele	cted library file. Edit	ina o	or	
a difications of th		n arana ata		accible in cubecqu				·····, ·····	••••		
iodilications of th	iese	paramete	s is p	possible in subsequ	ient dat	a-entry ste	ps.				
start 🛛 🕅 (00) 2	2011-06-	-07 Tuto 👩	(00) <u>2</u>	2011-05-21 Tuto  🏠 Projec	t1 - Microsof	t V 🖻 Or	tions for fa	acilities a			

## Categorisation of input information for HEEP

Facilties	Categories of input parameters	
Nuclear power plant	Technical parameters	
	Chronological data	
	Cost elements	
Hydrogen generation and	Technical parameters	
storage plant	Chronological data	
	Cost elements	
Hydrogen transportation facility	Technical parameters	
	Chronological data	
	Cost elements	

#### Technical details of Nuclear power plant

- Number of units
  - Rated installed capacity per unit
- Capacity factor of unit
- Availability factor of unit
- Thermal power available for hydrogen generation
- Thermal efficiency of unit (if electricity is generated)

#### Technical details of hydrogen generation plant

- Location of plant (Co-located with NPP or isolated)
- Number of units
- Rated annual hydrogen generation rate
- Process efficiency
- Capacity factor of unit
- Availability factor of unit
- Maximum thermal power required for process by each unit
- Maximum electricity required for process by each unit
- Non-process electricity required by each unit

#### Technical details of hydrogen storage facility

- Type of hydrogen storage
  - Gaseous
  - Liquid
  - Metal hydride
- Storage equipment capacities
   Storage time
- Power requirements of storage devices

Auxiliary requirements of storage devices
 Rate of cooling water for storage compressor

# Technical details of hydrogen transportation facility

- Type of hydrogen transportation
  - Pipeline
  - Vehicle

#### For pipeline transportation

- Transportation distance
- Technical parameters affecting power required to overcome losses in pipeline transportation
- For vehicular transportation
  - Transportation distance
  - Mileage of vehicle
  - Vehicle capacity
  - Speed of vehicle

Preparation time for each trip of the vehicle

## Capital cost inputs

Quick inputs	Detailed inputs (Two levels)
<ul> <li>Nuclear power plant         <ul> <li>Specific cost</li> </ul> </li> <li>Hydrogen generation and storage plant         <ul> <li>Capital cost of hydrogen generation plant</li> <li>Parameters for quick estimates of capital cost for hydrogen storage</li> </ul> </li> <li>Hydrogen transportation         <ul> <li>Pipeline transport</li> <li>Compressor cost</li> <li>Pipe cost</li> <li>Vehicle transport</li> <li>Cost of one vehicle</li> </ul> </li> </ul>	Cost of activities sub-divided in to two levels of code of account. Example: Civil structures and buildings Reactor building cost Fuel building cost Etc. Bunsen rector cost Reactor vessel Piping etc.

## O&M cost inputs

Quick inputs	Detailed inputs (Two levels)
<ul> <li>Nuclear power plant         <ul> <li>O&amp;M cost as % of capital cost</li> </ul> </li> <li>Hydrogen generation and storage plant         <ul> <li>Maintenance cost as % of capital cost</li> <li>Operating cost</li> <li>Electricity</li> <li>Cooling water charges</li> </ul> </li> <li>Hydrogen transportation         <ul> <li>Pipeline transport</li> <li>Electricity</li> <li>Compressor cooling</li> <li>Vehicle transport</li> <li>Driver's wages, Fuel charges</li> </ul> </li> </ul>	Cost of activities sub-divided in to two levels of code of account for each year Example: Labor cost Operating cost Electricity charges Salaries

#### General guidelines for entering/editing data

#### Features for entering/editing information

HEEP - [Technical Details of facilities for nuc G Goto Execute Help Exit	ear hydrogen generation]				
Nuclear Power Plant Details         Reactor       PMR1         Type       PMR1         Reactor       PMR         class       PMR <i>Applications of Nuclear power</i> Hydrogen generation         Electricity	H2 Generation and Storage Plant Details         H2 Generation Plant details         Location of H2 Generation Plant         • Co-located       • Away from NPP         Number of hydrogen generating units in plant.       1         Parameter Description       Value         ated annual hydrogen generation process [%]       45         Unit capacity factor (%)       90         Unit availability factor (%)       100         Maximum process thermal energy required (MW/th/unit)       2160	H2 Transportation Details         Type of H2 Transportation         Transport by Vehicle         Pipe line Transportation         Details of pipeline transportation         Use in-built formulation to calculate pipe line transportation parameters         User to provide pipe line transportation			
Sof NPP       Stion     Value       Rated Thermal Power (MWth/unit)     60       Capacity factor (%)     9       Availability factor (%)     10       Thermal Power for H2 gen. (MWth/unit)     54	Maximum process electricity required (MWe/unit)       0         Maximum non-process electricity required (MWe/unit)       960         Maximum annual hydrogen generaration (kg/unit)       215910000         H2 storage dotable       Compressed Gas         Compressed Gas       Liquefaction         Maximum annual hydrogen generaration (kg/unit)       215910000         H2 storage dotable       Compressed Gas         Compressed Gas       Liquefaction         Maximum annual hydrogen generaration (kg/unit)       215910000         H2 storage dotable       Storage parameters         Par       Value         H2 stor       0         H2 storage capacity (kg)       0         H2 con       0         H2 conpressor power (kWe)       0         H2 coling water for compressor (Lit/hr)       0	Parameter Description       Value         Transport distance (km)       500         Equivalent diameter of Pipe (m)       0.25         Friction factor       0.01         Temperature of H2 (K)       230         Delivery Pressure (MPa)       5         Inlet pressure (MPa)       39.15         Compressor Power (kWe)       59275.7			
Store Technical Update NPP Database Details of NPP (Technical Details) Technical details of nuclear power plant carr be edited. These details are shown for information	Store Technical Details of H2GP Update H2GP Database (Technical Details) Proceed to next step (Add / View / Edit time schedules)	Store Technical Details of H2T Update H2T Database (Technical Details) Technical details of hydrogen transportation connot be edited. These details are shown for information			
Cells of table or text boxes with gray background are not editable.					



#### Editing entering data

1/2

 Option button: allows user to select only one choice among the available list of options
 Click required option

Check Box: multiple choices can be selected
 Click desired choices

Text Box: to enter numbers or text strings
 Click the text box and enter required input or edit contents of the text box

#### Editing entering data

2/2

Cell of the table: to enter numbers or text strings

- Click the cell to be edited
- A text box will appear at cell location along with two buttons "ü" and "X".
- Only active text boxes can be edited. (a cursor "/" appears in the text box when it is active). If the test box is not active then click once in the text box.
- Insert/Edit contents of the text box and click "ü" button to effect the changes made
- To discard without effecting any changes, click "X" button

#### Storing the data

#### Storing data

- Data stored in the memory only. It will be stored till execution of programme is not terminated.
- Once programme is terminated, user will loose all editing/ modifications made.
- Click command button starting with the word "Store"
- Example: If user wants to store technical details of Nuclear Power Plant then the command button "Store Technical Details of NPP"



#### Updating database

#### Updating database:

- Implies storing data in library files.
- If user terminates the programme and user wants to use modified/edited data once again, it can be retrieved the next time programme is used.
- Click command button starting with the word "Update"

Example: If user wants to update technical details of Nuclear Power Plant then the command button "Update NPP "



#### Demonstration of building new case, modifying data, running the case and viewing results

#### Case description

- Preliminary benchmarking CASE-I being used as basis
  - Four units of nuclear reactor generates 600 MWth (only heat and no electricity)
  - Electricity for non-process needs of hydrogen generation plant costs 0.06 USD/kWh

#### New case:

- Nuclear reactor equipped to generate electricity
  - Number of units increased to 10
  - Thermal efficiency- 30%
  - Thermal energy to hydrogen generation from each unit- 216 MWth
  - Electricity generation from remaining 384 MWth @30% thermal efficiency
  - Equipment required for electricity generation assumed to increase the capital cost by 10%
  - O&M cost of 1% considered for electricity generating euipments
- Both plants are co-located

#### On-line demonstration of HEEP