Approaches to Assess Competitiveness of Small and Medium Reactors

Anil Antony,
Bhabha Atomic Research Centre,
Mumbai, India

Specific cost of Large Vs SMR

- Smaller size reactors are the logical choice for smaller countries or those with a limited electrical grid.
- IAEA defines as ‘small’ those reactors with a power <300 MW(e) and ‘medium’ with a power <700 MW(e).
- Smaller reactors are now in different stages of development throughout the world, and interest in their deployment has also been expressed.
- With regards to decisions on the addition of power plant capacity, small reactors have many attractive characteristics, namely size, simplicity, enhanced safety, cost savings and lower financial resource requirements. On the downside, the specific costs of some components and systems of small and medium sized reactors (SMRs) may be higher as a result of economy of scale effects.

$$\mathrm{OCC}_{\mathrm{SMR}} = \mathrm{OCC}_{\mathrm{LR}} \times \left(\frac{\mathrm{size}_{\mathrm{SMR}}}{\mathrm{size}_{\mathrm{LR}}} \right)^{n-1}$$

OCC: Overnight Specific Capital Cost
n: scaling factor
LR: Large reactor

Recovering loss of economy of scale

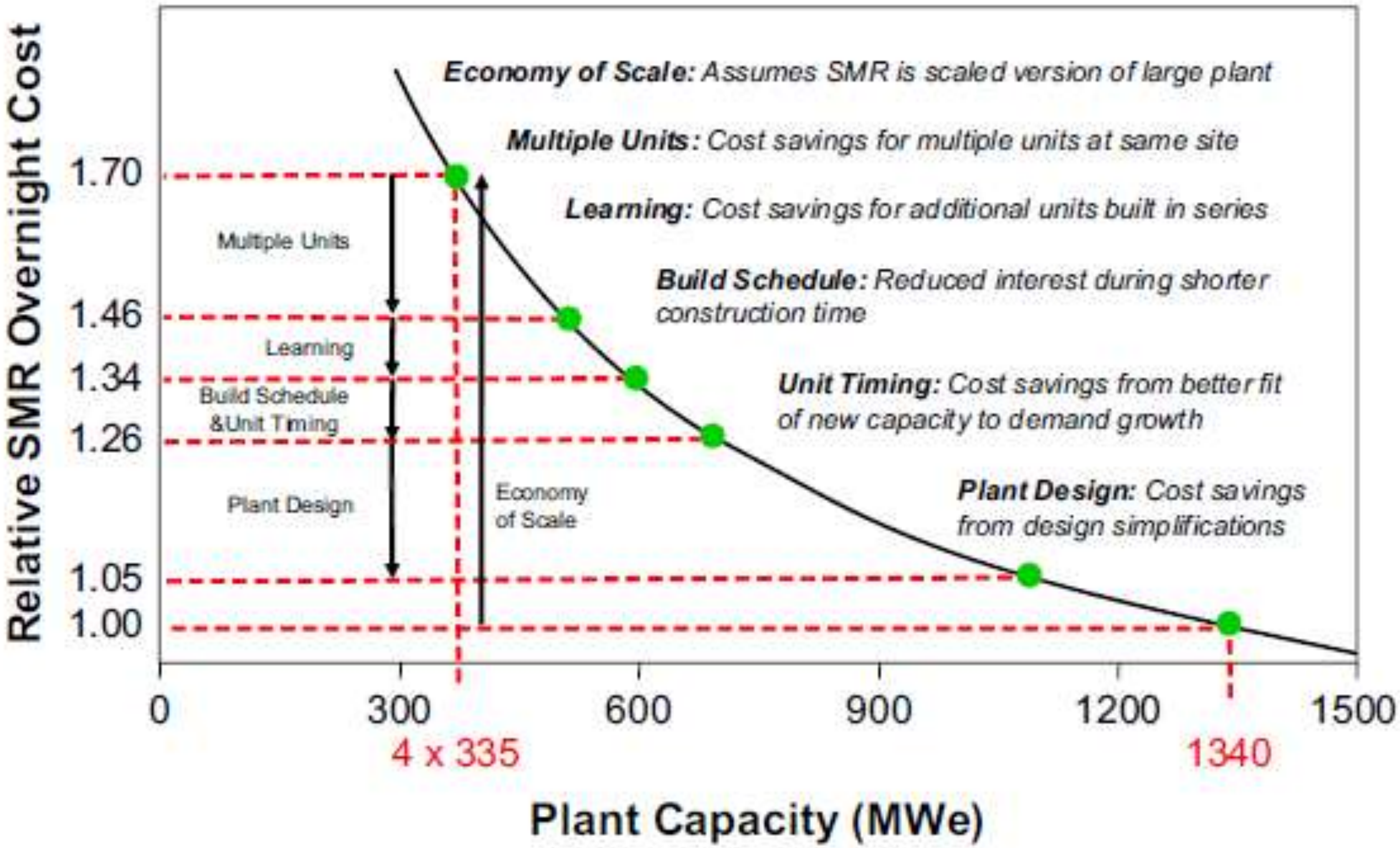


Fig-1 Economic factors that contribute to offsetting the economy of scale for 4 unit SMR plant compared to a single large plant

Ref[1]: Carelli, M.D., Petrovic, B., Mycoff, C.W., 2007. Smaller sized reactors can be economically attractive. In: Proceedings of the International Conference on Advanced Power Plants, ICAPP 2007, Nice.

Cost saving areas for SMRs

- Cost reduction areas
  - *Multiple units and learning*
    - More number of units leads to learning in construction hence cost reduction
    - Fixed and non-repeatable costs are shared by multiple units
    - Sharing of infrastructure

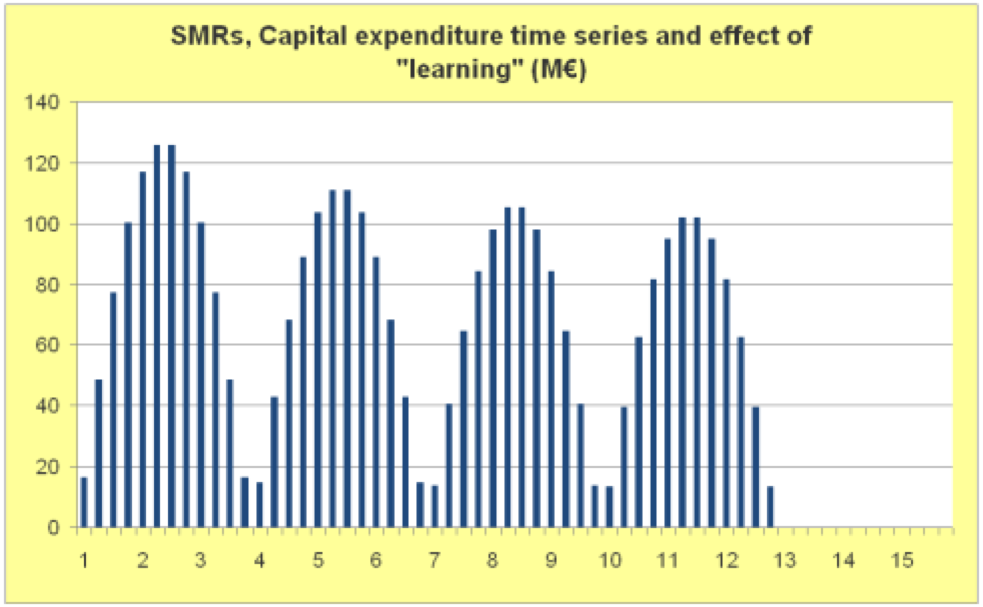


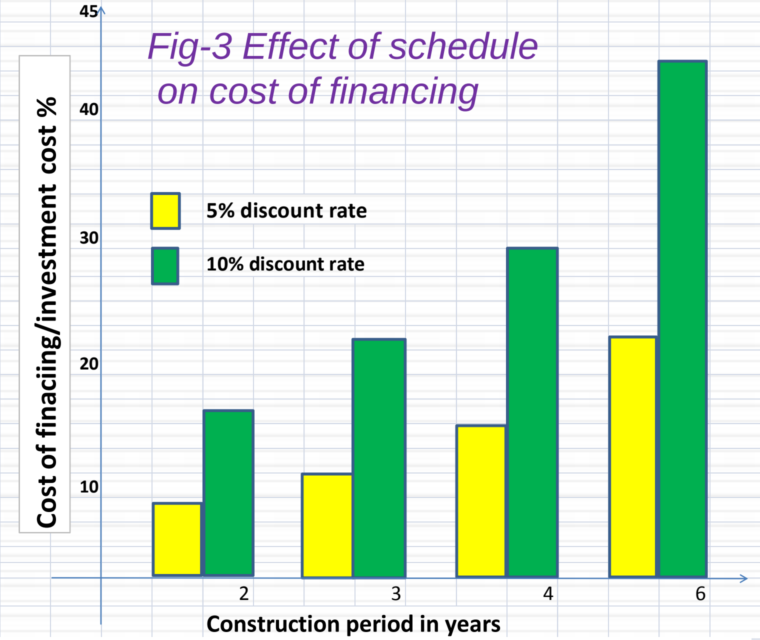
Fig-2 Financing of SMRs of series construction[2]

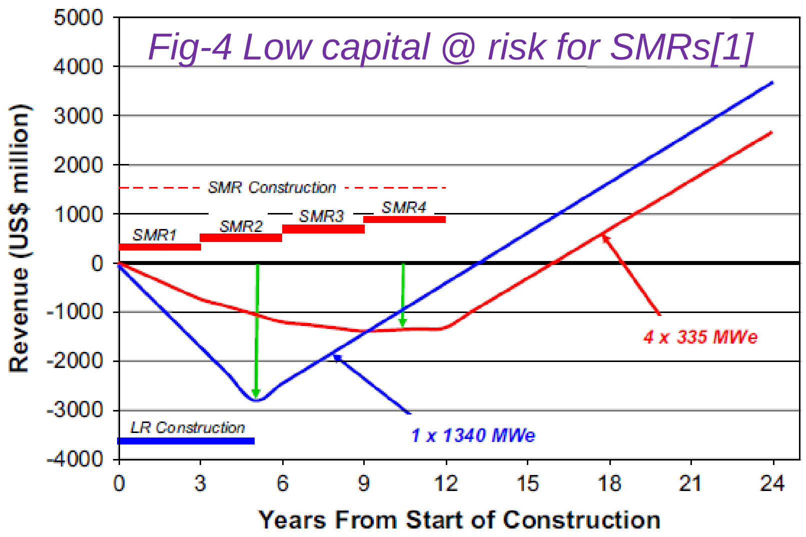
- *Plant design and modularization*
  - Simpler, fewer, less complicated components.
  - Alternative safety system approaches (passive safety system, safety by design).
  - A greater degree of modularization and factory fabrication.

Ref[2]: IAEA Technical Meeting, Vienna, 01-04 July 2008, Presentation of M.Ricotti et.al

Cost saving areas for SMRs

- ***Shorter schedule, low financing cost***
  - Smaller physical plant sizes can be constructed with shorter construction schedules leads to lower IDC and total cost. Particularly important where interest rates are high.
- ***Unit timing , Capital at risk and easy financing***
  - Better fit with base load capacity growth
  - SMRs could be incrementally deployed in shorter time frames & allows a significant reduction in front end investment and capital at risk (max. negative values of cash flow).
  - Improve the ability to finance capacity expansion projects. These smaller investments are more easily financed, especially for countries and utility systems with more limited financial resources.





Cost saving areas for SMRs

- *Self financing is possible*
  - Series builds of SMRs allows the earlier reactors to begin operation while others are still being completed, this facilitates self-financing at the expense of profits obtained from sales of electricity from already built and commenced units, with minimum reliance on external funds.

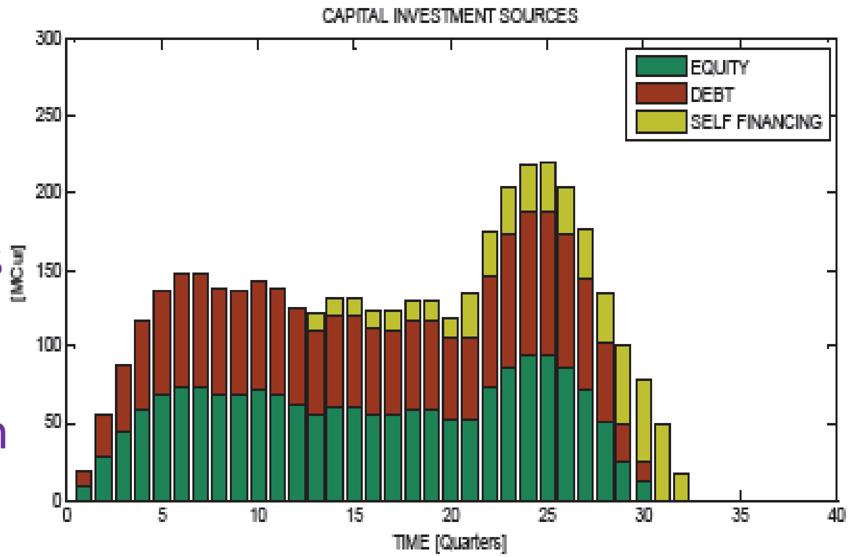


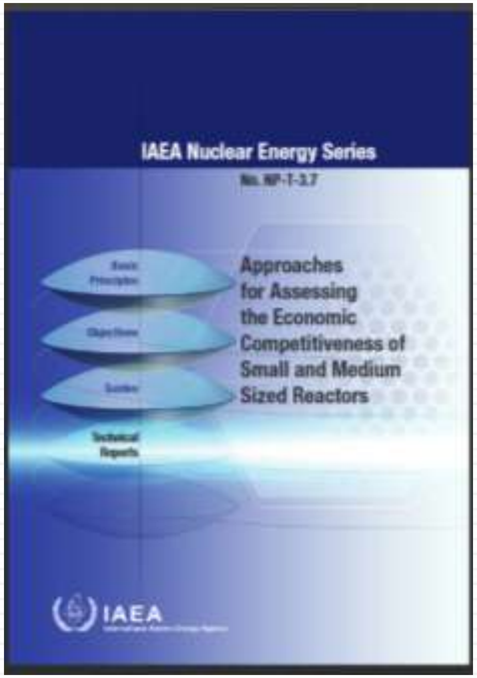
Fig-5 Source of financing for 4 SMRs staggered build [3]

- **Other factors**
  - *More suitable for Grid size (electrical grids with limited capacity)*
  - *Demand growth (baseload growth for nuclear)*
  - *Central site versus dispersed sites for series builds*
  - *Local construction infrastructure*

Ref[3]: IAEA Nuclear Energy Series, No. NP-T-3.7, Approaches for Assessing the Economic Competitiveness of Small and Medium Sized Reactors

EVALUATION OF SMR COMPETITIVENESS

- A number of methods are mentioned IAEA Nuclear Energy Series No. NP-T-3.7, titled ‘Approaches for Assessing the Economic Competitiveness of Small and Medium Sized Reactors’ for evaluation of competitiveness of SMRs Vs LRs. One of them is the Present Value Capital Cost (PVCC) model developed by Westinghouse Electric Company LLC, United States of America; Nexia Solutions Ltd, United Kingdom and is a generic model taking into factors described above to evaluate SMR economics Vs LR.



- A study using PVCC model indicates that when the various factors are combined, a pack of four SMRs has a 16% higher overnight capital cost, a 9% higher total capital investment cost, and only a 4% higher PVCC than a single LR with the same total capacity.

EVALUATION OF SMR COMPETITIVENESS

- In IAEA Nuclear Energy Series No. NP-T-3.7, a methodology called INCAS: Integrated model for competitiveness assessment of small and medium sized reactors developed by Politecnico di Milano (Italy) is mentioned and it evaluates following indices:

  - LUEC
  - NPV
  - Internal rate of return (IRR)
  - Payback time (PBT)

Series of reactors in Nest

- Calculation of series of reactors
- Calculation of levelized cost of electricity for a series of power plants of different types and commissioned in different moments within a period of 40 years (maximum difference between the first and the last power plant start-up dates) can be performed in NEST. The cost of electricity from a group of power plants *GL (mills/kWh)* is defined by the following equation:

$$GL = \frac{\sum_{j}\sum_{t=0}^{40a}\frac{U(j,t)\cdot P(j)\cdot LUEC(j)\cdot Lh(j)}{(1+r_j)^t}}{\sum_{j}\sum_{t=0}^{40a}\frac{U(j,t)\cdot P(j)\cdot Lh(j)}{(1+r_j)^t}} \qquad \text{Eq. (40)}$$

- Where *U(j,t)* is the amount of power units of type *j* introduced in the moment *t*; r_j is a discount rate for a particular type of power plant. *LUEC*, *Lh*, *P* are defined in equations (8), (22) and (23). Summing is made with a step of 0.1 annum; up to 400 power plants can be introduced simultaneously.

Using Nest for SMR Vs LR

- Generally SMR (of single type) economics is compared with respect to a large reactor (LR) i.e. a number of SMRs Vs a single LR. For example 4 number of 300 MWe SMR vs one 1200 MWe LR.
- In such cases, we have to run the NEST first for a number of SMRs to evaluate LUEC using group calculation and then run for a single LR to estimate its LUEC separately. Presently hence no side by side comparison of a number of SMR Vs LR possible in NEST?

Using nest for SMRs

INPUT DATA

Version 1 - Basic version

Row	names (term in equations)	units	PWR numbers	PWR years	HWR numbers	HWR years	fossil PP numbers	fossil PP years
12	Net electric power (P)	kWe	600000		666000		380000	
13	Construction time (T_c)	years	4		6		3	
14	Lifetime of the plant (t_{life})	years	60		35		40	
15	Average load factor (L_f)	%/100	0.9		0.8		0.75	
16	Decommissioning cost ($LUAC_D$, *see comments*)	*in commen*	1		0.0448		0	
17	Backfitting cost ($LUAC_{bf}$)	mills/kWh	0		0		0	
18	Overnight construction cost (OCC) } (ONT)	$/kWe	1145		1697		376	
19	Contingency cost (CC)	$/kWe	225		85		38	
20	Owners cost (CO)	$/kWe	137		0		380	
21	Normalized capital investments schedule (share per year) during construction (ω). Option with the calculations on exact date (according to TECDOC-1575) is chosen	%/100	0	0	0.074	0	0	0
22		%/100	0	-1	0.217	-1	1	-1.5
23		%/100	0	-2	0.282	-2	0	-2
24		%/100	1	-4	0.223	-3	0	-3
25		%/100	0	-4	0.132	-4	0	-4
26		%/100	0	-5	0.061	-5	0	-5
27		%/100	0	-6	0.011	-6	0	-6
28	Real discount rate (r)	1/year	0.12		0.12		0.12	
29	Tax rate (tax)	%/100	0.37		0.37		0.37	
30	Inflation rate (in)	1/year						
31	Interest rate of debt (dir)	1/year						
32	Expected return to equity investor (eir)	1/year						
33	Debt fraction (df)	%/100						
34	Median value of investments (p)	%/100						
35	Income tax rate (te)	%/100						
36	Other preoperational expenses rate (Fpreop)	%/100						
37	Real estate tax rate (Ftax)	%/100						
38	Insurance fee (Fins)	%/100						
39	Price per unit of electricity sold (PUES)	mills/kWh	61.28		61.28		61.28	
40	Market income (M) } These parameters are used for calculation of an investment limit only	M$/year	3000		3000		3000	
41	Market share (Sh)	%/100	0.5		0.5		0.5	
42	Profit margin (Pm)	%/100	0.1		0.1		0.1	
43	Time of growth (t_{GR})	year	6		6		6	
44	Adjusting coefficient (α)	%/100	1		1		1	
45								
46	Fixed operation&maintenance cost ($(O\&M)_{fix}$)	$/kWe	49		54.94		0	
47	Variable operation&maintenance cost ($(O\&M)_{var}$)	mills/kWh	0.9		0		6	
48	O&M real escalation rate (rom)	%/100						

Version 4 = Version 1 + FC by HU

Row	System 1 PWR MOX numbers	years	System 2 FR equilibr numbers	years	System 3 FR breeding numbers	years
12	600000		600000		600000	
13	4		4		4	
14	60		60		60	
15	0.9		0.9		0.9	
16	1		1		1	
17	0		0		0	
18	1145		1145		1145	
19	225		225		225	
20	137		137		137	
21	0	0	0	0	0	0
22	0	-1	0	-1	0	-1
23	0	-2	0	-2	0	-2
24	1	-3.8	1	-4	1	-3.8
25	0	-4	0	-4	0	-4
26	0	-5	0	-5	0	-5
27	0	-6	0	-6	0	-6
28	0.12		0.12		0.12	
29	0.37		0.37		0.37	
39	61.28		61.28		61.28	
40	3000		3000		3000	
41	0.5		0.5		0.5	
42	0.1		0.1		0.1	
43	6		6		6	
44	1		1		1	
46	49		49		49	
47	0.9		0.9		0.9	

Version 2 - based on HU Model

Row	System 1 NPP once-thru numbers	years	System 2 NPP MOX numbers	years	System 3 FR equilibr numbers	years
12	600000		600000		600000	
13	6		6		6	
14	60		60		60	
15	0.85		0.85		0.85	
16	150		150		150	
18	2000		2000		2000	
19	200		200		200	
29	0.37		0.37		0.37	
31	0.05		0.05		0.05	
32	0.07		0.07		0.07	
33	0.3		0.3		0.3	
34	0.65		0.65		0.65	
35	0.1		0.1		0.1	
36	0.1		0.1		0.1	
37	0.027		0.027		0.027	
38	0.027		0.027		0.027	
39	61.28		61.28		61.28	
40	3000		3000		3000	
41	0.5		0.5		0.5	
42	0.1		0.1		0.1	
43	6		6		6	
44	1		1		1	
46	80		80		80	

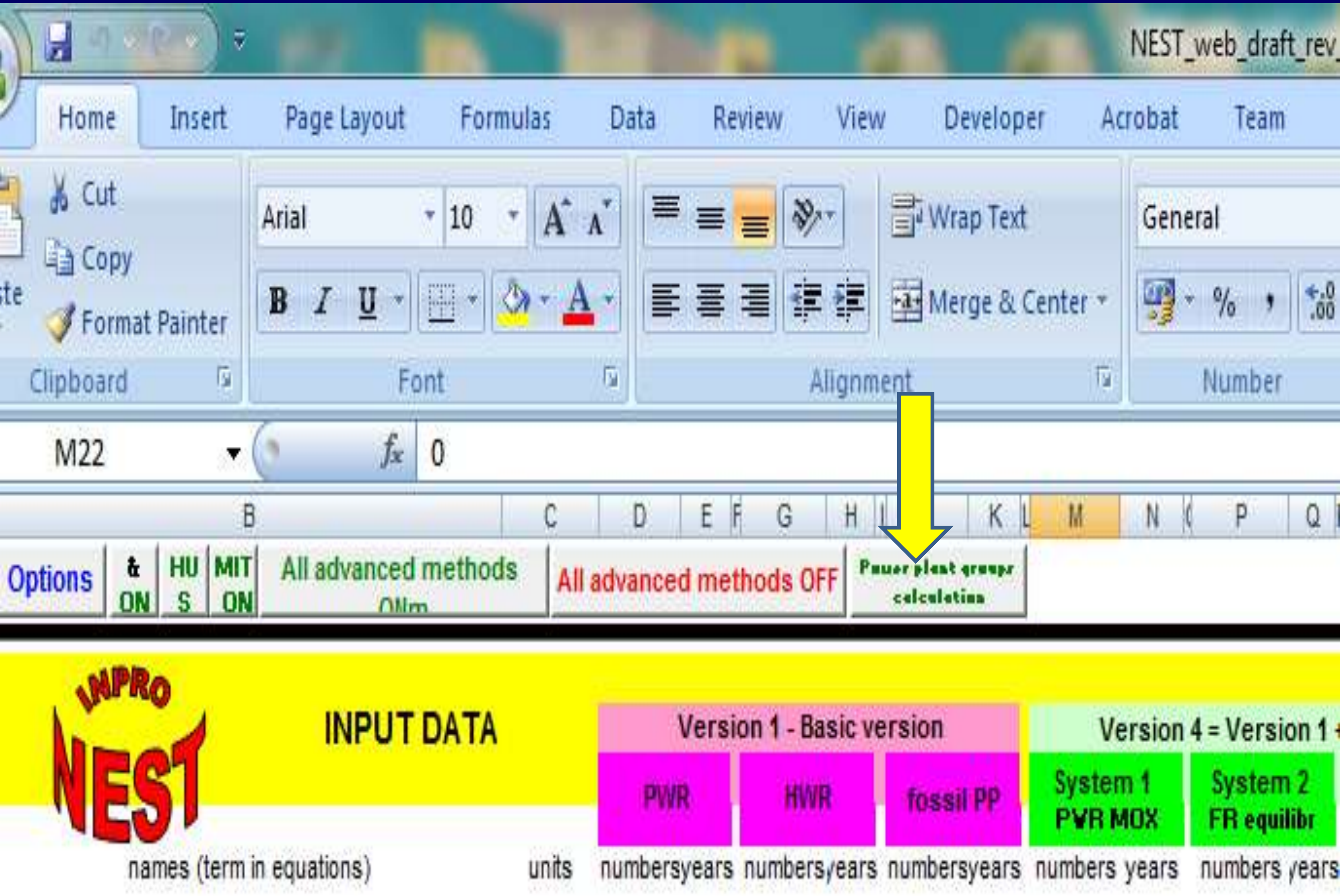
Version 3 - based on MIT Model

Row	System 1 NPP open FC off numbers	years	System 2 NPPopen FC on numbers	years	System 3 NPP MOX numbers	years	System 4 fossil PP numbers	years	
12	1000000		1E+06		1E+06		1E+06		LUEC (
13	5		5		5		2		LUEC (
14	40		40		40		40		LUEC (
15	0.85		0.85		0.85		0.85		NPV (P
16	350		350		350		0		NPV (H
17									NPV (F
18	2000		2000		2000		500		IRR (PW
19									IRR (HW
20									IRR (alt
21	0	0	0	0	0	0	0	0	ROI (PW
22	0.09528	-1	0.0953	-1	0.0953	-1	0.5	-1	ROI (HW
23	0.24986	-2	0.2499	-2	0.2499	-2	0.5	-2	ROI alt
24	0.30925	-3	0.3093	-3	0.3093	-3	0	-3	total_inv
25	0.24986	-4	0.2499	-4	0.2499	-4	0	-4	total_inv
26	0.09565	-5	0.0957	-5	0.0957	-5	0	-5	total_inv
27	0	-6	0	-6	0	-6	0	-6	investm
28									investm
29	0.37		0.37		0.37		0.37		inv_limit
30	0.03		0.03		0.03		0.03		
31	0.08		0.08		0.08		0.08		
32	0.15		0.15		0.15		0.12		
33	0.5		0.5		0.5		0.6		
39	61.28		61.28		61.28		61.28		Sensit
40	3000		3000		3000		3000		are be
41	0.5		0.5		0.5		0.5		
42	0.1		0.1		0.1		0.1		
43	6		6		6		6		
44	1		1		1		1		
46	63		63		63		16		
47	0.47		0.47		0.47		0.52		
48	0.01		0.01		0.01		0.01		

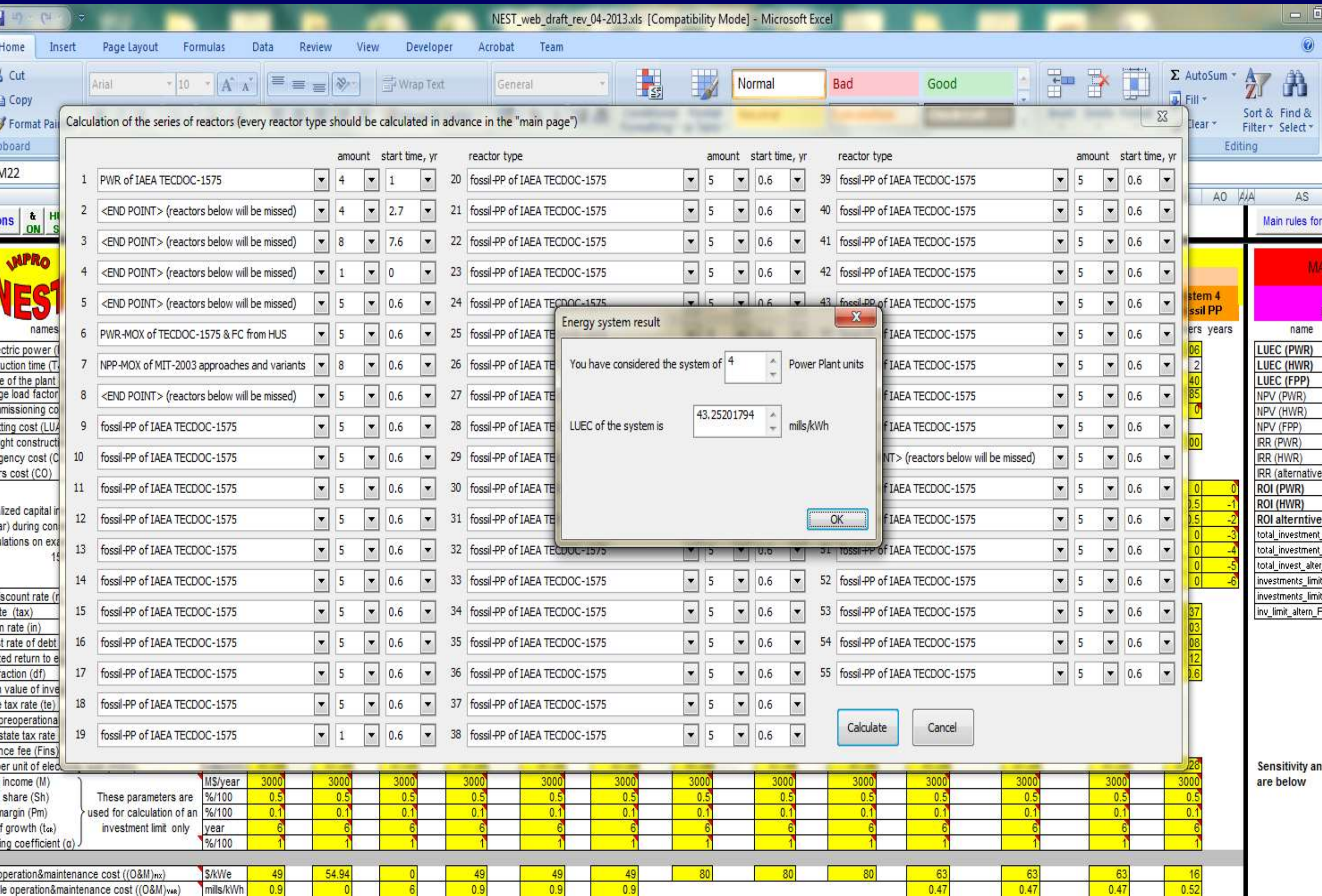
main_page | E1_LUEC_PWR | E1_LUEC_HWR | E2_LUEC_FPP | E1_LUEC_PWR_MOX | LUEC_FR_equil | LUEC_FRgrow | HUS_LUEC_onethr | HUS_LUEC_MOX | HUS_LUEC_FR_equil | E1_MIT_LUEC_1

Ready 80%

Group calculation option in Nest



Series reactor calculation in Nest



Conclusions

- The NEST can simulate economics for a series of SMRs constructed simultaneously or different points of time spaced at equidistant intervals (a min of 0.1 yr apart). It evaluates a single LUEC figure from the individual calculated LUECs for each type of SMR, by using equation (40) of INPRO economics manual.

- Evaluation of other following indices *for series of reactors* are NOT reported in INPRO manual on economics
  - 1. NPV, 2. Pay back time , 3. Internal rate of return (IRR)

- *A suggestion for equivalent NPV for series of reactors*
  - NPV of a series of reactors *may be* estimated from the individual NPVs by using the formulae:

$$NPV_s = \sum_{t_i} NPV_i / (1 + r_i)^{t_i}$$

Where NPV_s is the combined NPV of series of reactors, t_i is the start of operation of individual reactors counted from the reference year, r_i is the discount rate of each reactors.

Thank you!