Workshop on IAEA Tools for Nuclear Energy System Assessment (NESA) for Long Term Planning and Development
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Assessment in the Area of Economics

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Overall structure (1)

Area of Economics

INS Energy (&products/services) shall be affordable and available (BP1)

General Rule for guidance

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Overall structure (2)

BP1: (*INS Energy (&products/services) shall be affordable and available*)

IN<u>S</u>: Economics is applied to the <u>System</u>
<u>Affordable:</u> competitive with alternatives
<u>Available:</u> Others product & services needs
<u>Developed & Deployed</u>: credible development & deployment fund rising
<u>Other products/services</u>: could be included in the INPRO <u>economical</u> evaluation

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Data required for the assessment (1)

Different assessors (from countries to universities)
With all needs the same prerequisites

- Scenario for Energy/Electricity including
  - Energy options (sizes, load, fuel availability, applicable constrains & requirements),
  - Calculation (published scenarios, detailed (MESSAGE, WASP) or customized (DESAE-XLS) computation
  - Complete data set (simple: units-scale-price-time)
  - Facilities capacities & performance,
  - Economical parameters (fiscal regimes, taxes)
  - Monetary real values time-base, LLC or LUEC.

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Data required for the assessment (2)

- Cost Determination for all competitors
  - All investment charges: Direct, indirect, contingency, back fitting, decommissioning (check scope between different options)
  - All fuel charges: (all stages – time – price integration or not, plant sized for specific INS) , fuel availability, applicable constrains & requirements)
  - Other fuel costs and credits (spent fuel, fissile credits)
  - Fixed and variable O&M (special materials makeup & spares, insurances and financial charge for spares)
  - Time base (inflation – deflation correction)
  - Others (currency exchange, Price settings like busbar or end price)

Data required for the assessment (3)

- Discount & Financial Rates
  - Capital costs (Discount rate & risk, serial savings and depreciation)
  - Capital sources (domestic- external, capital competitors)
  - Financial figures of merit (LUECost – IRR Price – not levelled Profit Variables ROI-Payback).
  - Price calculation (custom – modelling: MESSAGE-WASP-BALANCE)

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Data required for the assessment (4)

- Development Cycle in order to used comparable data
  - Preliminary INS definition (Government – Private), innovation degree
  - - time/effort to develop, uncertainty – risk trade off)
  - Continuous update (close supplier – client connection)
  - Complete data set (simple: units-scale-price-time)
  - Component / Plant Prototype
  - FOAK Plant
  - increasing investment – decreasing risk
  - After FOAK – Government could play a role

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Structure of BP1 (1) (Affordable INS)

(BP1) INS Affordable

General Rule for guidance

- COST C_N competitive with C_A (UR1.1)
- FINANCIAL Total investment funds could be raised (UR1.2)
- RISK Acceptable for investors (UR1.3)
- FLEXIBILITY Compatible with different markets (UR1.4)

Conditions to be met to be acceptable for the INPRO user (interest in INS application)

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Structure of UR1.1 (Competitive)

There is only one CR (set of IN and AL)

IN1.1.1	C_N , $LUEC_N$ nth of a Kind
IN1.1.1	C_A , $LUEC_A$ nth of a Kind
AL1.1.1	$C_N/C_A < k$,fixed by the assessor

CR1.1.1 Competitive of levelled real NOAK complete unit energy cost, with k factor defined by the user

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Scope of CR1.1 (1) (Competitive)

- "C_N and C_A" defined as :

  Costs of all the C_N, taking into account all relevant costs and credits con competitive with C_A, available for application in the same time frame and geographical region, .
- "relevant costs" : Depending on the jurisdiction: all relevant costs for example waste cost or not.
- "in the same time" : If is expected to change C_N and or C_A in time.
- Depending in technology, conditions and time, some cost elements criteria could be cost determinants ($/KWe) if other elements (discount rate) are not relevant for to assure the competitiveness in the evaluation time.

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Scope of CR1.1.1 (2) ($C_N < K\ C_A$)

- C_N and C_A LDC model:
  - If there are several reactors in the INS, a single C_N
  - FOAK and other R&D cost are not appropriate: commercial prices depends on profit to payback investments
  - Complete INS includes all material required for the life
  - External costs only if there are prices settings schemes
  - Evaluation period given by the plant life
  - Real prices could be time dependant, and currency exchange dependant
  - Contingency that depends on maturity level
  - Same discount rate for C_N and C_A

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Scope of CR1.1.1 (3) ($C_N < K\ C_A$)

- k defined as:

  There is a factor less, equal or greater than one fixed by the assessor taking into account other costs and credits not included in indicator

- k should include:
  - There are other credits given by C_N
  - Depends in external costs, couldn't be added
  - Still profitability is required
  - Higher costs could be acceptable for avoided emissions, sustainability, energy security, domestic resources, public acceptance
  - In longer term, market forces will constrain to k close to 1
- k could be greater or lower than 1 (usually close to 1)

Structure of UR1.2 (Funds could be raised)

There are two CR (set of IN and AL)

IN1.2.1.1/2	Financial figure or merit
AL1.2.1.1/2	Financial figure limit comparable or better than $Investor_{LIMIT}$
IN1.2.2	Total investment
AL1.2.2	Compatible with rising funds capacity

CR1.2.1. and 1.2.2. The total investment required should be such that the necessary investment funds can be raised

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Scope of UR1.2. (1) (Funds could be raised)

- "PUES" defined as :

  Selling prices that is expected to be paid to the INS electricity generation .

- "Investment Size" : Depends on many factors, funds required in a given investment climate.
- Investment climate by economical conditions, the size compared with the utilities investments, perceived risks
- Profit expectancies, & others investors decisions.
- Price setting mechanism

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Structure of UR1.2.1. (Investment financial attractive)

There are two CR (set of IN and AL)

IN1.2.1.1.	IRR
AL1.2.1.1	$IRR > IRR_{LIMIT}$
IN1.2.1.2.	ROI
AL1.2.1.2	$ROI > ROI_{LIMIT}$

CR1.2.1.1. and 1.2.1.2. The total investment required should be such that the necessary investment are attractive for the investor

Scope of CR1.2.1.1. (1) (Investment financial attractive)

- "IRR_N" defined as :

  IRR calculated at the real PUES by the complete INS, excluding cost not defined in the price setting mechanisms and including all costs for lifecycle operation, decommissioning and waste management .
- "real" : without inflation, time changes different than inflation.
- "complete INS", including in price all the fuel cycle facilities. Other selling outside the INS by price elasticity
- Only elements defined in the price settings
- All expenses and incomes need to be computed
- Very complex INS with several negative cash flows will produce not realistic IRR. Not applicable

Structure of UR1.2.1 (Affordable total investment)

There are one CR

IN1.2.2.	Total $INVESTMENT_N$
AL1.2.2.	$INVESTMENT_N < INVESTMENT_{LIMIT}$

CR1.2.1. : The highest single plant investment needs to be affordable for the investor

Structure of UR1.3.1 (Acceptable Risk)

There are 4 CR

IN1.3.1.	Licensing status: depends Maturity Design
AL1.3.1.	Acceptable maturity depending on INS stage
IN 1.3.2.	Realistic construction schedule
AL1.3.2.	Accepability depends on INS stage
IN 1.3.3.	Robust (flexibility) Index (RI)
AL 1.3.3	RI > 1
IN 1.3.4	Lon term commitment on nuclear option
AL 1.3.4	Sufficient for return on investment

Structure of UR1.3.1 (Acceptable Risk)

There are one CR 1.3.1

IN1.3.1.	Licensing Level to Construction Start (LLCS)
AL1.3.1.	$LLCS >= LLCS_{LIMIT}$

CR 1.3.1. : The licensing risk needs to be acceptable for the investor

Structure of UR1.4 (Flexibility of the INS)

There are one CR (set of IN and AL)

IN1.4.1.	Are INS components adaptable? Y/N
AL1.4.2.	YES

CR1.4.1. The INS needs to be affordable and available, if a future subject to changes

Numerical Example

Area of Economics

AP600 or CANDU6
For a medium size DC
With deregulated ES

Numerical
Example
UR 1.1. 1.2

Case Type (1)

- Expert interested in performing a fast evaluation about the potential of a single SMR that start to operate in the year 2010
- Small developing country
- With deregulated electrical system
- For base load
- Without any legislation that promote some options
- Without credits or environmental taxes.
- NP needs to do its own economic prevision for Back end and Decommissioning
- Assuming international standards
- No significant resources of fossil or uranium
- Arbitrary example only to compute the IN/AL

Data used (1)

- Usually a lot of detailed data is required to specify a given electrical system situation
- Will be assumed peak and base load proportional to the annual electricity consumption
- Significant reduction in the amount of data required
- Assumptions year 2000:
  - 40,000 GWh/Year
  - 6000 MWe installed capacity
  - Average Power in the base: 3000 MWe
  - Maximum Power Recently installed: 300 MWe
  - Average Electricity Growth/year: 4%

Electricity Scenarios (1)

- The assessor will use practical criteria used by private investors
- Very simple analytical model
- Keeping constant the load variation
- Projecting the new base load addition
- From 2010 to 2014 - 2014
- New base load could be estimated
  - 170 to 725 MWe
- 10% of the total installed capacity
  - 600 to 890 MWe
- Without local resources: any fuel for global market
  - Average Power in the base: 3000 MWe
  - Maximum Power Recently installed: 300 MWe
  - Average Electricity Growth/year: 4%

Electricity Scenarios (2)

Scenario Conditions	Criteria and Values
Economical criteria	Cheapest option will be selected for year 2010
Technical Constrains	Power limited to 10% of total grid power output: Power lower than 890 MWe
Investment Rules	Attractive IRR
	Attractive ROI
Growth Constrains	Power limited by annual new power requirement range: 1 to 4 years range: 170 to 725 MWe
Fuels availability	Fuels obtained only from the international markets

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Energy Options Alternatives (1)

- For INS
- For time frame (2010):
  - Only Few designs Available:
    - LWR: AP600 – WWER660
    - HWR: CANDU 6
    - No other NPP options
  - Select on with largest published data:
    - LWR AP600
    - HWR: CANDU 6
- For Alternatives
- For base load generation: LNG & Diesel
  - Only 3 Options
    - Piston Motors: < 40 MWe
    - GT < 200 MWe
    - CCGT < 380 MWe
  - Select Larger and similar to NPP
    - GT (Siemens)
    - CCGT (Siemens)

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Energy Options Alternatives (2)

Option Number	Energy Type	Technology	Fuel
1	Nuclear	SMR PWR	Enriched Uranium
2	Nuclear	SMR HWR	Natural Uranium
3	Gas	GT	LNG - Diesel
4	Gas	CCGT	LNG - Diesel

Technical Data & Assumptions (1)

Stage	Time (Years)	Published Time (years)	Base value	Range value	Unit	Published Range	Losses (%)
Uranium Purchase	1.5	2 [7] 1.5 [9]	50 $/Kg	40-90	Kg. U	40-90 [7] 32-130 [9]	0 [7]
Conversion	1	1.5 [7] 1 [9]	8 $/Kg	6-11	Kg U	6-11 [7] 8 [9]	0.5 [7]
Enrichment	.75	1 [7] .75 [9]	110 $/SWU	80 - 130	SWU	80–130 [7] 70–150 [9]	0 [7]
Fabrication	.5	.5 [7] .5 [9]	275 $/Kg	200 - 350	Kg U	200–350 [7] 200–350 [9]	1.0 [7]
Candu Fabrication	.8	.8 [7]	65$/Kg	-	Kg U	-	0.5 [7]

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Technical Data & Assumptions (2)

Reactor Type	AP600	
Item	Data	Reference
Thermal Output	1940 MWth	[11]
Net Electrical Output	600 MWe	[11]
Load Factor	90 %	[11]
Life of Plant (*)	60 years	[11]
Fuel Burnup	40000 MWd/THM	[11]
Fuel Enrichment	3.55 %	[11]
Initial Fuel Enrichment	2.0/3.0 %	[11]
Power Density	28.89 KWth/KgU	[11]
Overnight Cost	1145 $/KWe	[8]
Contingency Cost	225 $/KWe	[8]
Owners Costs	137 $/KWe	[8]
Foak Costs	43 $/KWe	[8]
IDC (**)	396 $/KW	[8]
Fixed O&M Costs	49 $/KWe	[8]
Variable O&M Costs	0.9 mills/KWh	[8]
Decommissioning	1 mills/KWh	[8]

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Technical Data & Assumptions (3)

Reactor Type	CANDU 6	
Item	Data	Reference
Thermal Output	2158 MWth	[11]
Net Electrical Output	666 MWe	[11]
Load Factor	80 %	[3]
Life of Plant	35 years (*)	[11]
Fuel Burnup	7500 MWd/THM	[11]
Fuel Enrichment	Natural Uranium	[6]
Initial Fuel Enrichment	Natural Uranium	[11]
Power Density	23.5 KWth/KgU	[11]
Overnight Cost	1697 $/KWe	[3]
Contingency Cost	85 $/KWe	[3]
Owners Costs	0 $/KWe	[3]
Foak Costs	0 $/KWe	[3]
Back fitting Costs	75 $/KWe	[3]
% of $ Investment/year	1.1/6.1/13.2/22.3/28.2/21.7/7.3	[3]
Fixed O&M Costs	54.94 $/KWe	[3]
Variable O&M Costs		
Decommissioning	11 $/KWe	[3]

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Technical Data & Assumptions (4)

Item	Gas Price	Reference
Gas Price in 2005	4.78 $/GJ	KR-G [3]
Lower Limit Gas price increase	0 %/year	KR-G [3]
Upper Limit Gas price increase	1 %/year	This work

Technical Data & Assumptions (5)

Especial Care in fossil fuel because those cost not always are included in handbooks and data published

GT Model	Siemens V84.3	
Item	Data	Reference
Thermal Output	474 MWth	[10]
Net Electrical Output	180 MWe	[10]
Load Factor	75%	[3]
Life of Plant	40 years	[3]
LHV Efficiency	38 %	[10]
Overnight Cost	200 $/KWe	[10]
Contingency Cost (*)	20$/KWe (1991 US)	[12]
Owners Costs (**)	160$/KWe (1995 US)	[10]
Foak Costs		
Construction Lead Time (***)	2 years	[12]
Fixed O&M Costs		
Variable O&M Costs	5 $/MWh (1991 US)	[12]
Decommissioning		

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Technical Data & Assumptions (6)

Especial Care in fossil fuel because those cost not always are included in handbooks and data published

CCGT Model	Siemens GUD 1S.94.3	
Item	Data	Reference
Thermal Output	650 MWth	[10]
Net Electrical Output	380 MWe	[10]
Load Factor	75%	[3]
Life of Plant	40 years	[3]
LHV Efficiency	58 %	[10]
Overnight Cost	376 $/KWe	[10]
Contingency Cost (*)	38$/KWe (1991 US)	[12]
Owners Costs (**)	380 $/KWe	[10]
Foak Costs		
Construction Lead Time (***)	3 years	[12]
Fixed O&M Costs		
Variable O&M Costs	6 $/MWh (1991 US)	[12]
Decommissioning		

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Completeness (1)

	SMR PWR			SMR HWR			GT			CCGT		
Item	Table in the report	Ref	Time	Table in the report	Ref	Time	Table in the report	Ref	Time	Table in the report	Ref	Time
Direct Construction Cost	4	8	1990	5	3	1996	7	10	1997	8	10	1997
Contingency Costs	4	8	1990	5	3	1996	7	12	1991	8	12	1991
Owner Costs	4	8	1990	No	No	No	7	10	1997	8	10	1995
FOAK Costs	4	8	1990	No	No	No	No	No	No	No	No	No
Back Fitting Costs	No	No	No	5	3	1996	No	No	No	No	No	No
Construction Cash Flow	4 (*)	8	1990	7	3	1996	2(**)	12	No	3(**)	12	No
Fixed O&M	4	8	1990	5	3	1996	No	No	No	No	No	No
Variable O&M	4	8	1990	No	No	No	7	12	1991	8	12	1991
Decommissioning	4	8	1990	5	3	1996	No	No	No	No	No	No

Especial Care in cash flow because published data never shows the detailed cash flow, so simplified model was used (but accurate enough as explained in Generation Cost Methodology Annex)

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Completeness (2)

	SMR PWR			SMR HWR			GT			CCGT		
Item	Table in the report	Ref	Time	Table in the report	Ref	Time	Table in the report	Ref	Time	Table in the report	Ref	Time
Uranium Purchase Value-Time-Losses	3	7 & 9	1991	3	7 & 9	1991						
Conversion Value-Time-Losses	3	7 & 9	1991	3	7 & 9	1991						
Enrichment Value-Time-Losses	3	7 & 9	1991	NA	NA	NA						
Fabrication Value-Time-Losses	3	7 & 9	1991	3	7	1991						
Natural Gas Fuel Price							6	3	1996	6	3	1996
Natural Gas Fuel Price Increase							6	3	1996	6	3	1996

Financial Data (1)

Variable	Value	Units
Real Discount Rate (*r*)	12	%/year
Average Annual Electricity Selling Price (*PUES*)	1.3 * $LDC_{cheaper}$	mills/KWh ($10^{-3}$$/KWh)
Internal Return Rate (*IRR*)	14	%/year
Return on Investment (ROI)	15	%/year

UR 1.1. (1)

Indicator	Value	Units
Indicator 1.1.1.		
$C_{N\text{-}SMR\ PWR}$	47.14	mills/KWh
$C_{N\text{-}SMR\ HWR}$	48.79	mills/KWh
Indicator 1.1.2.		
$C_{A\text{-}GT(i=0\%)}$	57.33	mills/KWh
$C_{A\text{-}CCGT(i=0\%)}$	50.95	mills/KWh

Data for IN 1.2.1. (1)

Variable	Value	Units
Cheaper *LUEC*	47.14	mills/KWh
PUES	61.28	mills/KWh

Data for IN 1.2. (1)

Indicator	Value	Units
Indicator 1.2.1.1.		
$IRR_{SMR\ PWR}$	15.68	%/year
$IRR_{SMR\ HWR}$	15.54	%/year
$IRR_{A\text{-}GT(i=0\%)}$	12.32	%/year
$IRR_{A\text{-}CCGT(i=0\%)}$	19.54	%/year
Indicator 1.2.1.2.		
$ROI_{SMR\ PWR}$	24.43	%/year
$ROI_{SMR\ HWR}$	19.4	%/year
$ROI_{A\text{-}GT(i=0\%)}$	12.3	%/year
$ROI_{A\text{-}CCGT(i=0\%)}$	21.4	%/year
Indicator 1.2.2.		
$Investment_{SMR\ PWR}$	1391	M$
$Investment_{SMR\ HWR}$	1565	M$
$Investment_{A\text{-}GT(i=0\%)}$	76.6	M$
$Investment_{A\text{-}CCGT(i=0\%)}$	358	M$

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Workshop on application of INPRO methodology for assessment of innovative nuclear energy systems (Technical Cooperation Project INT/4/141) June 26-30 2006, Vienna, Austria

Thanks

Pablo Florido
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