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AN EXAMPLE OF AN INPRO ASSESSMENT OF AN INS IN THE AREA OF ECONOMICS

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ABSTRACT

Following a resolution of the General Conference of the IAEA in the year 2000 an International Project on Innovative Nuclear Reactors and Fuel Cycles, referred to as INPRO, was initiated.

INPRO has defined requirements organized in a hierarchy of Basic Principles, User Requirements and Criteria (consisting of an indicator and an acceptance limit) to be met by innovative nuclear reactor systems (INS) in six areas, namely: economics, safety, waste management, environment, proliferation resistance, and infrastructure. If an INS meets all requirements in all areas it represents a sustainable system for the supply of energy, capable of making a significant contribution to meeting the energy needs of the 21st century.

Draft manuals have been developed, for each INPRO area, to provide guidance for performing an assessment of whether an INS meets the INPRO requirements in a given area.

This paper discusses the example presented in the manual for performing an INPRO assessment in the area of economics. The example considers a private utility, operating in a liberalized market that is planning for an additional supply of power of about 600 MWe within a time frame of 10 years. Two nuclear options, an LWR and a HWR, are considered as well as a gas-fired plant using liquefied gas as fuel.

INTRODUCTION

The Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established to help to ensure that nuclear energy is available to contribute, in a sustainable manner, to the energy needs in the 21st century.

In six different areas – economics, safety, waste management, proliferation resistance, environment, and infrastructure – requirements to be met by innovative nuclear energy systems (INS) have been identified. As well, a methodology has been developed to assess whether an INS complies with the requirements. On the basis of this assessment, the need for innovations in existing nuclear technology, to be achieved via research, development and demonstration, can be identified.

In this paper, a short description of the INPRO methodology in the area of economics and an example illustrating the application of the methodology are presented.

INPRO ECONOMIC BASIC PRINCIPLE, USER REQUIREMENTS AND CRITERIA

In the area of economics one basic principle has been enunciated by INPRO [1], namely that to contribute to sustainable development:

- Energy and related products and services from INSs shall be affordable and available.

In total four user requirements are linked to this basic principle, as shown in Table 1 (end of paper).

If energy and related products and services are to be affordable the price to the consumer must be competitive with low cost/priced alternatives. If energy and related products and services are to be available, systems to supply the energy and related products need to be developed and deployed. To develop and deploy innovative energy systems requires investment and those making the investment, be they industry or governments, must be convinced that their choice of investment is wise. The alternatives for investment may be other energy technologies seeking investment for development or deployment or non-energy technology areas. So, to be developed and deployed, INS must compete successfully for investment. In different markets and regions and at different times and stages in the cycle of development and deployment the investor(s) may be different and different factors may assume more or less importance in determining attractiveness of investment. But in any case a sound business case must be made.

Given the nature of nuclear technology, it is recognized that government policies and actions (in some Member States, governments may participate in investment) will have a significant bearing and influence on investor decision making, both when deciding whether or not to invest in development and when deciding to invest in technology deployment/acquisition. For private sector investment, profitability and return will be key factors in the business case. It follows that if the price to the consumer is to be competitive and at the same time investors are to receive an attractive return, the cost of production must also be competitive with that of alternatives. To be cost competitive all component costs, e.g., capital costs, operating and maintenance costs, fuel costs, must be considered and managed to keep the total unit energy cost competitive. Limits on fuel costs in turn imply limits on the capital and operating cost of fuel cycle facilities, including mines, fuel processing and enrichment, fuel reprocessing and the decommissioning and long-term management of the wastes from these facilities.

Cost competitiveness of energy from INSs will contribute to investor confidence, i.e. to the attractiveness of investing in INS, as will competitive financial figures of merit, e.g., rate of return, which should be at least comparable to the values for competitive energy sources and preferably better. As well, a judgment must be made that the funds required to implement a project can be raised within a given expected investment climate, taking into account other investment options and other priorities requiring a share of available capital and the risk of investment must be acceptable, taking into account the risk of investment in other energy projects.

Given the uncertainty about the future, ideally, INS should be sufficiently flexible to be able to evolve and adapt in a manner that provides competitive energy for as wide a range of plausible futures and markets as possible. Thus, the ability to adapt specific components of an INS, as well as the overall adaptability of the INS, to accommodate different sized modules, to accommodate market changes and growth, to accommodate different fuels, to meet different energy applications, and to meet the needs of different countries/ regions is desirable. In assessing flexibility of a given component or set of components, possible synergisms with other components of the INS should be considered.

BOUNDARY CONDITIONS FOR EXAMPLE OF ECONOMIC ASSESSMENT

The example assumes that the assessor applying the INPRO methodology is an expert, who wants to know whether in 2010 the deployment of a single nuclear power plant in a small developing country with a deregulated electrical market makes a sound business case.

The growth rate, from the present to 2010, of electricity consumption is estimated to average 4% per year. The size of the existing grid, 3000 MWe, for base load together with the growth rate define 900 MWe as the maximum size of the power output of the plant to be built in 2010. The maximum amount to be invested by an private sector utility is limited, by the annual cash flow of the utility, to 900 million US$. Because the market is deregulated the cheapest energy option will be chosen, and the internal rate of return (IRR) and the return of investment (ROI) for such a nuclear power program must be attractive. For a developing country a discount rate of 12% is defined and values for IRR and ROI of 14 and 15 %/year respectively. The following Table 2 summarizes the boundary conditions.

Table 2. Economic boundary conditions

Variable	Value	Dimension
Size of plant	< 900	MWe
Discount rate	12	%
IRR	> 14	%
ROI	> 15	%
Maximum Investment	< 900	Million US$

Using the boundary conditions set out in Table 2, User requirements UR 1.1 and 1.2 and the associated criteria are used to assess the economic feasibility of deploying a nuclear power plant. In this example, User requirements UR 1.3 and 1.4 are considered but in a full economic assessment they would need to be addressed. It should also be noted that an INPRO assessment requires, in addition to the economic assessment, an assessment of the nuclear option in all other INPRO areas, such as safety, environment, waste management, proliferation resistance and infrastructure.

SELECTION OF ENERGY SUPPLY OPTIONS

For the example, four different options of energy supply are taken into account based on the availability of published information that can be used to calculate parameters needed to complete the economic assessment: Two fossil power plants, i.e. a gas turbine (Siemens V83.3) and a combined cycle gas turbine (Siemens GUD 1S.94.3), both using liquefied natural gas as fuel. Two types of nuclear power plants will be considered, one is a PWR (Westinghouse AP600) and the second one is a HWR (AECL CANDU6). Without any indigenous national fuel source, the fuel for all energy options is assumed to be obtained via import from international markets. The following Table 3 summarizes the available energy supply options.

Table3. Energy supply options

Option No.	Energy Type	Technology	Fuel
1	Nuclear	PWR AP600	Enriched Uranium
2	Nuclear	HWR CANDU6	Natural Uranium
3	Gas	GT	LNG Diesel
4	Gas	CCGT	LNG Diesel

COST DATA OF POWER PLANTS

Based on published literature the following list of main plant cost data is accumulated.

Table 4. Main power plant cost data

Energy Option/ Data	PWR AP600	HWR CANDU6	GT V84.3	CCGT GUD 1S.94.3
Thermal; output [MWth]	1940	2158	474	650
Net electrical [MWe]	600	666	180	380
Load factor [%]	90	80	75	75
Fuel burn up [MWd/THM]	40000	7500		
Fuel enrichment [%]	3.55	Natural U		
Power density [KWth/KgU]	28.9	23.5		
Investment over night cost [$/KWe]	1507	1782	380	794

Table 4. Main power plant cost data (continued)

Energy Option/ Data	PWR AP600	HWR CANDU6	GT V84.3	CCGT GUD 1S.94.3
Fixed O&M cost [$/KWe]	49	54.9	0	0
Variable O&M cost [mills/KWh]	0.9	0	5	6
Fuel back end cost [$/Kg]	400	73	0	0

DETERMINATION OF ECONOMIC INDICATORS AND ACCEPTANCE LIMITS

The indicators of the first user requirement are the costs (levelized unit energy costs, LUEC) of the nuclear (C_N) and fossil (C_A) options. For all four options the levelized unit energy costs, consisting of the capital amortization cost (LUAC), the operating costs (LUOMC), and the fuel costs (LUFC), are calculated using the economic data from table 4.

In the following table, for each energy supply option, the values of LUAC, LUOMC and LUFC are shown.

Table5. LUEC, LUAC, LUOMC, LUFC of the four power options.

Power option/ Costs [mills/KWh]	PWR	HWR	GT	CCGT
LUAC	32.5	36.86	7.02	15.51
LUOMC	7.1	7.84	5	6
LUFC	7.5	4.10	45.31	29.43
LUEC	47.1	48.80	57.33	50.95

From Table 5, the values of C_N are 47.1 mills/KWh for the PWR and 48.8 mills/KWh for the HWR while the values of C_A are 57.33 mills/KWh for the GT plant and 50.95 mills/KWh for the CCGT plant. The acceptance limit (see Table 1) is that the nuclear energy options must be cheaper than the cheapest alternative option, and it can be seen that both nuclear options evaluated fulfill this acceptance limit and therefore the first user requirement is also fulfilled.

For assessing the attractiveness of the nuclear power program to a private investor, as specified in user requirement No.2 in Table1, financial figures of merit, ROI and IRR, and the total investment have to be determined. The following table shows these figures of merit for each energy option and the corresponding total investment.

Table 6. Financial figures of merit and total investment

Plant type	**PWR**	**HWR**	**GT**	**CCGT**
IRR [%/year]	15.68	15.54	12.32	19.54
ROI [%/year]I	24.43	19.4	12.3	21.4
Investment [Mio US$]	1391	1565	76.6	358

The corresponding acceptance limits for the financial figures of merit and the total investment are defined by the market conditions in the country, as shown in Table 2 above. Comparing Table 2 with Table 6 it is shown that both nuclear options fulfill the acceptance limit for IRR and ROI, however fail the acceptance limit for the maximum total investment.

CONCLUSION

The example of an INPRO evaluation presented shows that in the defined country, although nuclear power could compete on a cost basis against alternative energy supply options, and the attractiveness of the investment is acceptable, the necessary total investment is too high for the chosen boundary conditions. One of the theoretical consequences of this assessment is that there is a need for R&D by the nuclear supplier to reduce the total investment costs, but also keeping the specific investment cost $/KWe in a range assuring that other indicators stay below their acceptance limit. Another possibility is that the private investor (utility) delays the deployment until his cash flow increases sufficiently to afford a higher investment, or the investor investigates other possible sources of financing.

NOMENCLATURE

CCGT	Combined cycle gas turbine
GT	Gas turbine
LWR	Light water reactor
INPRO	International Project on innovative nuclear reactors and fuel cycles
INS	Innovative Nuclear Energy System
IRR	Internal rate of return
HWR	Heavy water moderated reactor
O&M	Operating and maintenance
PWR	Pressurized water reactor
R&D	Research and Development
ROI	Return of investment
THM	Tons of heavy metal

REFERENCES

[1] INTERNATIONAL ATOMIC AGENCY, Methodology for the assessment of innovative nuclear reactors and fuel cycles, Report of Phase 1B (first part) of INPRO, IAEA-TECDOC-1434, Vienna (2004).

Table .1 INPRO Basic Principle, User Requirements and Criteria in Economics [1]

Economic Basic Principle BP1: ***Energy and related products and services from Innovative Nuclear Energy Systems shall be affordable and available***.		
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.1 *The cost of energy from innovative nuclear energy systems, taking all relevant costs and credits into account, C_N, should be competitive with that of alternative energy sources, C_A that are available for a given application in the same time frame and geographic region.*	1.1.1 Cost of nuclear energy, C_N. 1.1.2 Cost of energy from alternative source, C_A.	For item 1.1.1 and.1.1.2: $C_N < k*C_A$
UR1.2 *The total investment required to design, construct, and commission innovative nuclear energy systems, including interest during construction, should be such that the necessary investment funds can be raised.*	1.2.1 Financial figures of merit. 1.2.2 Total investment.	1.2.1 Figures of merit are comparable with or better than those for competing energy technologies of comparable size. 1.2.2 The total investment required should be compatible with the ability to raise capital in a given market climate.
UR1.3 *The risk of investment in innovative nuclear energy systems should be acceptable to investors taking into account the risk of investment in other energy projects.*	1.3.1 Licensing status. 1.3.2 Project construction and commissioning times. 1.3.3 Relevant indicators of the political environment show long-term support for nuclear power.	1.3.1 Pre-licensing possible in country of origin. 1.3.2 Schedule analyzed to demonstrate that scheduled times are realistic. Times comparable with those for other energy supply alternatives. 1.3.3 yes.
UR1.4 *Innovative energy systems should be compatible with meeting the requirements of different markets.*	1.4.1 Flexibility (Robustness) of INS.	1.4.1 Ability to demonstrate design flexibility (robustness) to accommodate different postulated sets of circumstances.