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Strengths and weakness of the methodologies for the innovative nuclear systems analysis

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Abstract

At present nuclear energy is in a transition situation. New efforts are being used trying to find the way to build more nuclear power. As the nuclear energy is an inherently multivariable system, the potential judgment at the ends tends to evolve towards multi criteria analysis methodologies trying to analyze innovative nuclear systems for the future. Nuclear energy has been an active energy player starting 50 years ago, and several times big efforts have been used trying to evaluate the potential of future development of nuclear energy depending on future scenarios using multi criteria analysis methods. Without the intention to be performed an assessment about what finally happens in the evolution of nuclear technology, performing only factual comparison and using only data available in the 1950s, in this work is analyzed if multi criteria analysis methods is sufficient to predict the final success of the currently available well-established commercial reactors. The conclusion is that if uncertainties are not included, the classical multi criteria methodologies evaluated could not be used to predict the successful deployment of PWR, BWR and CANDU, with the status of knowledge of 1956, and without including others factors and external non numerical judgment. Uncertainties produce compatible results with the further historical evolution, but if they have to be included with large margins and as a penalty in the figures of merit.
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1. Introduction

At present nuclear energy is in a transition situation, established as an excellent energy generator of reactors already built (Chinworth et al., 2001). New efforts are being used trying to find the way to build more nuclear power plants (NPP) with the exception of few countries. Options to introduce the so-called advanced design by short-term incentives (University of Chicago, 2004) until reach fully scale economy on these designs are explored.

Several initiatives have been launched trying to analyze innovative nuclear systems (INS) for the future, particularly the US-led generation IV international forum (GIF) (DOE, 2002), and the IAEA's international project on innovative nuclear reactors and fuel cycles (INPRO) (IAEA, 2003). As the nuclear energy is an inherently multivariable system, with many aspects to be considered, the potential judgment at the ends tends to evolve towards multi criteria analysis methodologies (Saaty, 1990). As an example, INPRO considered six main criteria (or dimensions) for aggregation, called economy, safety, environment, sustainability, waste management, proliferation resistance and cross cutting issues.

Such types of methodologies are intended to be used to discriminate between the different INS in order to detect options, for R&D funding for example.

But nuclear energy has been an active energy player starting 50 years ago (IAEA, 2004), and several times big efforts has been used trying to evaluate the potential of future development of nuclear energy depending on future scenarios. Particularly in the conferences of atoms for peace in Geneva (United Nations, 1955, 1958, 1964) in the 1950s and early 1960s, and international fuel cycle evaluation programme (INFCE) at IAEA headquarters in the 1970s (IAEA, 1980).

At that time many forecast energy modeling were used. Different strategies to deploy different reactors concepts were proposed, and usually the advantages and disadvantages of the different options to fulfill for future energy needs were evaluated. But it is well known that many nuclear promises at the end were never realized, at least as was originally expected (Cohn, 1997).

Then new questions could be done in the perspective of past experience. Could multi criteria analysis methods (Saaty, 1990)

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alone reproduce what happened in the last 25–50 years, if they are applied with the data available in the past?

This question is relevant not because the future will be a copy of the past, it is because if a methodology could not be enough robust to understand 25–50 years of past history, how could be expected to project what could happened in the next 50–100 years?

Usually numerical evaluation is taken as primary input to system selection, and additional factors and judgment were also usually included too in the selection process. But then is very clear that the prediction capacity could be improved or worsted depending on the quality of the strategic view behind this others factors and judgment. If it is very difficult with quantitative methods, more challenging could be with external judgment.

At the end a robust forecast assessment methodology is one in which the errors are not unacceptably amplified in time, in which the independent variables are not cross correlated, etc. And the past history could be used to test the proposed methodologies, not to claim that this is a sufficient condition to assess the future, but such type of robustness history check is a necessary condition for such methodologies to be useful and credible at least as a minimum starting point. Then this assessment is not to study what finally happens in the last 50 years in nuclear energy, but to perform a factual analysis of the perspective of the different technologies on the past. Then the limitation of this approach is that could not be used to predict what's will happened with the assessment methods, and is limited to the robustness of present numerical methods to past history.

We must emphasize the influence of the previous knowledge of the history of the power industry in the analysis with the proposed methodology. As an example an accident as the Chernobyl (a LWGR, the worst accident in nuclear power history) cannot be appointed for the present analysis.

2. Reference material for comparison

In order to not be biased, and not to select a narrow time gap not representative of the decades to be evaluated, the time period between 1945 and 1952 was excluded because experts believes that the uranium was a very rare material, and enrichment an extraordinary expensive task for commercial application.

In the second half of the 1950s, after the findings of Canada resources and the confirmation that enrichment plants could be up rated and expanded under very competitive prices, the perspective changes and then not only breeders reactors fueled with Plutonium that comes from natural fueled reactors (heavy water of graphite moderated) where explored as robust energy sources for civil application (Simpson, 1995).

To use the second half of the 1950s as a time base is in agreement with the fact that at the end of the 1970s and earliest 1980s, the reactors that today dominate the commercial use of nuclear energy were fully established, moving out other reactors types for commercial deployment.

Then comparative studies of the second half of the 1950s could be used as reference material.

Table 1
System evaluated in the references

Reactor description	Economics	Safety	Sustainability
PWR	1.5	1	2
BWR	1.5	1	2
Organic–organic	1	1	2
PHWR	2	1	1
Boiling HWR	2	1	1
Gas HWR	3	1	1
Na HWR	2	2	1
L HWR	2	2	1.5
Organic HWR	2	1	1
LWGR	3	2.5	2
Gas GR	3	1	1
Na GR	2	2	2
Organic GR	1	1	2
Na FBR	2	2	1

3. Nuclear systems in 1956

Many nuclear systems foreseen at that time were analyzed using indicators for different dimensions. This has been found in a 1956 study done in the US (Menke, 1958) after the study of many references (United Nations, 1955, 1958, 1964). It was very similar to the scope used in INPRO nowadays (Saaty, 1990). On this reference 14 reactor types were considered, and 8 different reactors types of this list were in operation or under construction at that time. Considering the maturity level of the nuclear technology in 1956, all these reactors could be considered as innovative.

Liquid and gaseous fuel reactors were included (but analyzed separately), but for simplicity they will not be included in this assessment because the number is close to the double if liquid–gaseous fuel reactors types are included, and all of them were discarded for fast deployment very shortly (in the earliest 1960s).

The systems analyzed in the study could be found in Table 1. The table includes the values used as indicators of the relative performance of each reactor type on the area of economics, safety and uranium use, adapted to INPRO wording; the uranium use indicator was called sustainability. The highest number means the worst value. With present knowledge, the values for some criteria could be debatable, but the scope is to limit the assessment to the knowledge available at that time for open discussion, then the data will be directly taken from original table.

The tree reactors types that presently clearly lead the reactors technology options are PWR, BWR and CANDU (PHWR on the reference wording) and were included as potential reactor system candidates, together with other five rectors types that were extensively tested to be used as pure commercial generator, like gas graphite reactors (Magnox and AGR on earlier stages), boiling and organic cooled HWR and sodium FBR.

4. Assessment of possible weights

As could be seen in a fast screening on Table 1, PWR, BWR and PHWR (or CANDU at present times) have relative goods

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