STUDY ON EVALUATION SYSTEM FOR ADVANCED NUCLEAR POWER PLANTS IN CHINA

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Contents

Background

- Nuclear Power Plants (NPP) in operation provide about 17% of the total electricity of the world.
  - **Energy shortage**
  - **High safety and good economy**
  - **No environment pressure**
- Nuclear power will play more significant role in future global electric market, especially in China.
  - **Current capacity of NPPs is 8 Gwe(In 2004)**
  - **Increase to 40GWe in 2020 (40 Billion USD)**
  - **Increase to 240GWe in the 2050**
  - **The new installations will adopt advanced NPPs**

Motivation

- **So,evaluation of the advanced NPPs in a scientific, comprehensive and objective manner is badly needed for Chinese utilities and government to make decisions;**
- **But, no this kind of evaluation system exist in China now， CAEA(also the technique center of DayaBay Nuclear Power Company) financed a project to establish such a evaluation system.**

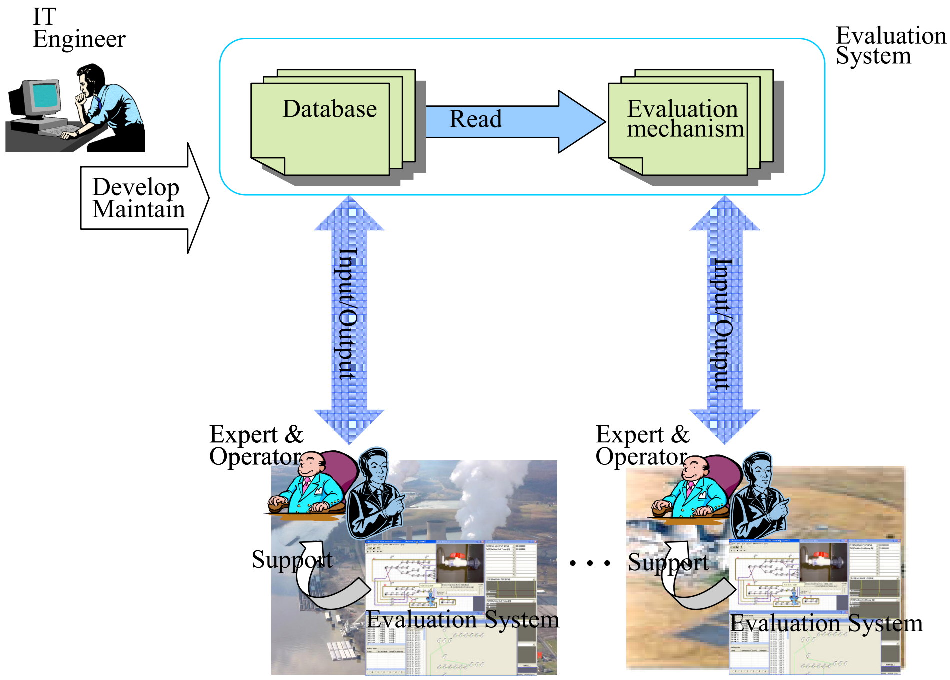
Objectives

- **Designing/realizing a data management system based on database and software technologies;**
- **Establishing indices for the evaluation of NPPs;**
- **Implementing a plurality of evaluation based on AHP, Fuzzy Comprehensive and Borda Number Fuzzy evaluation methods;**
- **Developing a user friendly software platform.**

Evaluation indices

First-level Indices	Second-level Indices
Economic Competitiveness	Investment competitiveness
	Comparison with coal-fired electricity.
	Generation cost and the price on electric power network
	Operation cost
	Total decommission cost
	Economic risk
Safety	Consistent with the existing nuclearsafety regulations
	Integrality of the safe function
	The ability to prevent from accident and to alleviate the damage
	Passive removal of afterheat
Sustainability	Nuclear fuel
	Environment
	Social acceptance
	Disposal of nuclear waste
Technology	Maturity of technology
	Advanced technology
	Developing Prospects
Infrastructure	Design, manufacture and construction
	Research ability and infrastructuer
	Technology transfer
Untroubledness	Resist to nuclear proliferation
	Resist to terror attack

System Design



Software Design

- **Modeling: the UML (Unified Modeling Language);**
- **Coding: the language of Microsoft— Visual C#.net;**
- **Database: Microsoft SQL-Server2000;**
- **Data Management Model: C/S(Client/Sever)-very safe**
- **Evaluation Model: B/S(Browser/Sever)-easy to maintenance and used universally**

AHP Method to Compute the Weight of Evaluation Indices

The Analytic Hierarchy Process(AHP) method :

The AHP is applied to obtain the weight of each index, and then to analyze all indices in the complex evaluation problems and their relationships.

The Contrast relationship between index A and B as follows:

Definition	Description of definition
1	A is the same as B
3	A is slightly better than B
5	A is superior to B
7	A is significantly better than B
9	A is much better than B
2,4,6,8	The medium value between two scaling values

AHP Method to Compute the Weight of Evaluation Indices

The judgment matrix B is determined as follows:

$$B = \begin{pmatrix} b_{11} & \cdots & b_{1m} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mm} \end{pmatrix}$$

In the matrix ***B***, the element b_{ij} denotes the importance of index[i] relative to the index[j]， with $b_{ij} > 0$, $b_{ii}=1$, $b_{ij}=1/b_{ji}$.

AHP Method to Compute the Weight of Evaluation Indices

$$BW = \lambda_{max} W$$

- **Assuming that the maximal eigenvalue of Matrix *B* is λ_{max}, and the corresponding eigenvector is *W*.**

$$\begin{cases} z^{(k)} = BW^{(k-1)} \\ \lambda_k = \max(z^{(k)}) = \| z^{(k)} \|_\infty \\ W^{(k)} = \dfrac{z^{(k)}}{\lambda_k}, k = 1, 2....... \end{cases}$$

- **when the error between λ_{k-1} and λ_k less than 10^{-4}, the iterative calculation stops;**
- **The Vector *W* is the weight of evaluation indices.**

AHP Method to Compute the Weight of Evaluation Indices

- In order to judge the coherence of B, the coherence index is imposed as:

$$CI = (\lambda_{max} - n)/(n - 1)$$

- where the n is the number of the indices. The smaller the is, the better the coherence of the judgment matrix B is.

$$CR = CI/RI < 0.10$$

- In order to judge the validity of the coherence index, the random coherence index is introduced. If the random coherence ratio CR<0.1, the judgment matrix is valid.

The weights of evaluation indices

First-level Indices	Second-level Indices	Weight of 2nd-level Indices	weight of 1st- level Indices
Economic Competitiveness	Investment competitiveness	0.2	0.228
	Comparison with coal-fired elec.	0.2	
	Generation cost and the price on electric power network	0.2	
	Operation cost	0.2	
	Total decommission cost	0.1	
	Economic risk	0.1	
Safety	Consistent with the existing nuclear safety regulations	0.2	0.107
	Integrality of the safe function	0.2	
	The ability to prevent from accident and alleviate the damage	0.3	
	Passive removal of afterheat	0.3	
Sustainability	Nuclear fuel	0.2	0.135
	Environment	0.1	
	Social acceptance	0.4	
	Disposal of nuclear waste	0.3	
Technology	Maturity of technology	0.5	0.288
	Advanced technology	0.3	
	Developing Prospects	0.2	
Infrastructure	Design, manufacture and construction	0.5	0.170
	Research ability and infrastructuer	0.4	
	Technology transfer	0.1	
Untroubledness	Resist to nuclear proliferation	0.6	0.072
	Resist to terror attack	0.4	

random coherence ratio CR=0.033

AHP-weighted Summation method

$Z = \sum W_i Z_i$

Evaluation result=∑First-level indices' value×First-level indices' weight

First-level indice's value=∑Second-level indices' value×Second-level indices' weight

The result of AHP-weighted summation method

Index NPPs	Economy	Safety	Sustainability	Technology	Infrastructure	Untroubledness	Sum Score	Ranking
ABWR	3.4	4	3.23	4.02	2.33	3.33	3.43	3
APWR	3.38	4.29	3.46	3.94	2.98	3.18	3.56	1
CANDU	3.14	3.19	3.06	3.53	2.57	3.15	3.15	5
FBR	1.84	2.71	3.62	3.05	2.03	2.72	2.62	6
HTGR	3.02	3.84	3.38	3.54	3.13	3.94	3.39	4
PWR	3.14	3.09	3.14	3.82	4.05	2.92	3.47	2

The result of AHP-weighted summation method

By computating the population standard deviation , assuming confidence level 95％, get the confidence intervel.

NPPs	Confidence Intervel (Confidence Level 95%)	Sum Score	Ranking
ABWR	(2.77,4.09)	3.43	3
APWR	(3.00,4.15)	3.56	1
CANDU	(2.64,3.65)	3.15	5
FBR	(2.00,3.24)	2.62	6
HTGR	(2.75,4.03)	3.39	4
PWR	(2.88,4.05)	3.47	2

Fuzzy Comprehensive Evaluation Method

The Matrix *R* is evaluation matrix calculated from the expert marks.

$$R = (R_{ij})_{m \times n}$$

The Vector *A* is the indice weight get by AHP method described above, the vector *B* is the Fuzzy Evaluation result.

$$B = A \circ R = (a_1, a_2, \ldots, a_n) \bullet \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1m} \\ \ldots & \ldots & \ldots & \ldots \\ r_{n1} & r_{n2} & \ldots & r_{nm} \end{bmatrix} = (B_1, B_2, \ldots B_m)$$

$$B_j = \sum_{i=1}^{n} \left(A_i \square R_{i,j} \right)$$

The Result of Fuzzy Comprehensive Evaluation Method

The evaluation results are expressed as the attributions to the fuzzy evaluation set - {"bad", "normal", "good", "very good", "excellent" }

NPP	Bad	Normal	Good	Very Good	Excellent
ABWR	6. 97%	18. 58%	19. 31%	34. 61%	20. 53%
APWR	4. 56%	12. 49%	22. 62%	42. 62%	17. 71%
CANDU	5. 48%	14. 41%	44. 67%	30. 53%	4. 90%
FBR	22. 45%	25. 96%	29. 49%	11. 52%	10. 58%
HTGR	2. 98%	20. 34%	28. 08%	31. 65%	16. 95%
PWR	6. 04%	10. 53%	32. 33%	32. 68%	18. 41%

The Result of Fuzzy Comprehensive Method

Set the fuzzy evaluation set as values {60,70,80,90,100} responding to {"bad", "normal", "good", "very good", "excellent" } ,the fuzzy evaluation result as follows:

NPPs	Economy	Safety	Sustainability	Technology	Infrastructure	Untroubledness	Sum	Ranking
ABWR	83.96	90.00	82.28	90.20	73.70	83.33	84.31	3
APWR	83.76	92.91	84.56	89.36	79.82	81.78	85.64	1
CANDU	81.35	81.89	80.58	85.32	75.70	81.50	81.50	5
FBR	68.45	77.06	86.23	80.50	70.31	77.17	76.18	6
HTGR	80.21	88.38	83.78	85.45	81.30	89.43	83.92	4
PWR	81.39	80.92	81.42	88.18	90.45	79.24	84.69	2

Fuzzy Borda Evaluation Method

Different from fuzzy comprehensive method, emphasize the predominant index and evaluate the NPP from the viewpoint of predominance. Including steps:

1.Atrribution Determination

$$u_{ij} = G_i(x_j) / \max\{G_i(x_j)\}$$

2: Seting up the frequency statistic table

$$f_{hj} = \sum_{i=1}^{m} \sigma_i^h(x_j) u_{ij} w_i \qquad R_j = \sum_{h=1}^{N} f_{hj}$$

If the ranking of the X_j's ith index is h $\sigma_i^h(x_j) = 1$ **else** $\sigma_i^h(x_j) = 0$

Fuzzy Borda Frequency Statistic Table

Ranking	ABWR	APWR	CANDU	FBR	HTGR	PWR
1	0.52	0.11	0	0.13	0.07	0.17
2	0.16	0.64	0	0	0.13	0
3	0	0.18	0	0	0.22	0.48
4	0.12	0	0.46	0	0.25	0
5	0.1	0	0.25	0	0.2	0.25
6	0	0	0.11	0.54	0	0
R	0.89	0.93	0.82	0.68	0.88	0.9

All the indices of APWR rank the first,second and third.
In the contrary, all the indices of CANDU rank the last one, two and three.
And all the indices of FBR rank either the first or the last.
So it is very obvious to find the sequence of indices of each NPP.

Fuzzy Borda Method

3 Computation of Borda Number

$$FB(x_j) = \sum_{h=1}^{N} \frac{f_{hj}}{R_j} Q_h$$ Wherein $$Q_h = \frac{1}{2}(N-h)(N-h+1)$$

Where the "N" represent the total number and the "h" represent ranking of the aimed index. It is obvious that the higher the ranking the larger the value, and the last ranking contributes nothing.

So it can emphasize the predominant index.

The result of Fuzzy Borda Method

NPP	Result	Order
ABWR	10.95	1
APWR	9.78	2
CANDU	1.97	6
FBR	2.98	5
HTGR	5.33	4
PWR	6.33	3

Some differences with the Fuzzy comprehensive method,

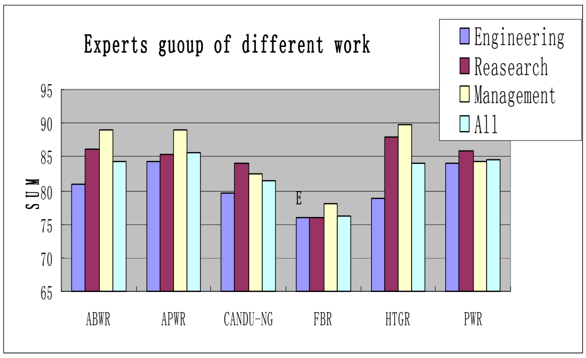
for example the rankings of the APWR and ABWR are interconverted.

Emphasize the prodominant index

The result of evaluation according to different expert group

The different group of profession:

profession	ABWR	APWR	CANDU	FBR	HTGR	PWR
Engineering	80.82	84.31	79.71	75.9	78.79	84.02
Research	86.15	85.25	84.11	75.98	88.01	85.92
Managment	89.11	89.07	82.58	77.98	89.84	84.38
All	84.31	85.64	81.5	76.18	83.92	84.69



As to the HTGR,

the experts whose profession is "Research" or "Management" consider the HTGR is a very excellent and hopeful NPP,

but the experts whose profession is "Engineering" consider that there are not too much operation experience of HTGR, so it is not as excellent as in theory.

Conclusion

From the evaluation results described in above tables, we can get the conclusions:

- **APWR is best in general, and its score on economy, safety and technology are all excellent. AP1000 ,EPR and other APWRs are expected to be first choice in the next two decades in China.**
- **FBR is not highly evaluated in general, but its sustainability is the best. It could be developed after 2040 in China.**
- **HTGR is evaluated very well in general, especially, the indices of safety and Untroubledness. Chinese domestic technology is at a world advanced level (HTR-10 at INET of Tsinghua University).**
- **Different group experts have the different idea about the evaluation.**

Future Work

- **Developing rule data(including Fuzzy Logic) as a inference engin;**
- **Implementing Artificial Intelligence;**
- **Coupling the experts knowledge with fact data to produce the evaluation result;**
- **Make the system suitable for different countries(China,Japan, America or the world), and can compare with each other;**
- **Evaluate the G4th Nuclear Reactor using this system.**

End

Thank you very much
for your attention