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STUDY ON ADVANCED NUCLEAR POWER PLANTS EXPERT EVALUATION SYSTEM IN CHINA

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ABSTRACT: Based on current status and developing trend of nuclear power plant technology, an evaluation software system is developed to assess advanced NPPs systematically according to a set of pre-established evaluation indices. The selection and classification of the indices, the determination of their weighting factors in applying AHP (analytic hierarchy process) method are discussed. The Fuzzy Comprehensive method and the Fuzzy Borda Number method are studied in detail. The original input data required by the evaluation system are deduced from the expert survey sheets Evaluation results with common significance of public attraction are discussed and analyzed according to the opinions of different experts grouped by age, profession and working expertise etc. The evaluation system is computer network based with high flexible and user friendly human-machine interface on which it is easy to manipulate and update the evaluation system, and to display evaluation results as well.

KEYWORDS: *Nuclear Power Plants (NPPs), Evaluation system, Fuzzy comprehensive method, AHP, Borda Number*

I. INTRODUCTION

With the fast development of economy and the limitation of the capacity of environment, the clean and safe nuclear energy will be vitally needed in China. Current nuclear electricity installed capacity in China is about 8GW and is less than 2% of the total installation of electricity generation capacity of China. According to the development plan, nuclear power in China will reach 36-39GWe, about 4% of the country's total installed electricity capacity in 2020. The forecast by China's National Key Research Program (the so-called 863 project) in Energy Technology, the potential capacity of 240GW nuclear power installation will be needed in China in the year of 2050[1]. Thus, to evaluate the new generation of advanced NPPs and analyze the evaluation result in a scientific, comprehensive and objective way so as to provide scientific advices to Chinese government for decision-making in selecting future advanced NPPs for Chinese market is the major motivation of the present study. Evaluation to the advantages and disadvantages of various types of Nuclear Power Plants involves very important, complex and fuzzy subjects. To make reasonable and correct decision with a few evaluation criteria and with the expert judgments from various professions, the inaccuracy and vagueness of expert opinions and their aggregations should be considered. Generally speaking, to evaluate significant characteristics of advanced NPPs, all important aspects should been taken into account for forming the comprehensive and objective evaluation indices, in applying the fuzzy system analysis method based on the selected indices and in establishing the advanced comprehensive evaluation system.

II. THE DESIGN OF SOFTWARE

The software of the comprehensive evaluation system is composed of two modules. One is the Database Management Module which manages all input data needed in the evaluation system, and the other is the Evaluation Module which is coded based on AHP method and fuzzy mathematics for processing and displaying the evaluation results. The software is designed in objective oriented methodology, and the relevant modeling is configured with the UML (Unified Modeling Language). The software is coded on the platform of the new version of Microsoft－ Visual C#.net. The database employed is the powerful and user-friendly Microsoft SQL-Server2000.

III. EVALUATION INDICES AND WEIGHT

1. Evaluation Indices

Based on comprehensive opinions of the experts about the advanced designs of various types of NPPs from numerous discussions and interviews, 6 first-level indices with 22 second-level indices have been selected as the cornerstones of the evaluation system. The first-level indices include Economy, Safety, Sustainability, Technology, Infrastructure and Untroubledness. Every first-level index is composed of some second-level indices [2].

2. Weight of Indices

Each evaluation index is of different influence from different aspects on assessing the advantages and shortcomings of various types of NPPs. The weight of each index should be decided separately. The Analytic Hierarchy Process (AHP) method is applied to obtain the weight of each index, and then to analyze all indices in the complex evaluation problems and their relationships. The problems are decoupled into layers corresponding to different indices [3].

IV. EVALUATON METHOD

1. Fuzzy comprehensive evaluation method

Based on fuzzy theory, the evaluation index which affects the evaluation results is quantified, and then the fuzzy comprehensive method is presented [4].

(1) Construction of the Evaluation Attribution Set

In applying the fuzzy evaluation method, the present study defines the evaluation attribution set V={V_1, V_2,……V_n} as the qualitative remarks of “bad”, “normal”, “good”, “very good”, “excellent”. The evaluation results are expressed as the attributions to the evaluation set.

(2)Fuzzy Matrix

The fuzzy matrix R=$(r_{ij})_{m\times n}$, r_{ij} is the possibility of index U_i evaluated as V_j. Let n be the numbers of valid consultants, y_{ij} be the numbers of index U_i evaluated as V_j, then $r_{ij}=y_{ij}/n$. The fuzzy evaluation results in:

$$\boldsymbol{B}=\boldsymbol{A}\circ\boldsymbol{R}=(a_1,a_2,\cdots,a_n)\cdot\begin{bmatrix}\gamma_{11} & \gamma_{12} & \cdots & \gamma_{1m}\\ \cdots & \cdots & \cdots & \cdots\\ \gamma_{n1} & \gamma_{n2} & \cdots & \gamma_{nm}\end{bmatrix}=(B_1,B_2\cdots B_m) \quad (1)$$

where the mathematical symbol “ ∘ ” denotes the fuzzy arithmetic operators M(•,+).

if $\sum_{j=1}^{n}\boldsymbol{B}_j\neq 1$, the normalization in form of $\boldsymbol{B}'_j=\boldsymbol{B}_j\Big/\sum_{j=1}^{n}\boldsymbol{B}_j$, (j = 1, 2,…, n) should be implemented.

(3) Evaluation Results

With the evaluation attribution set V={60,70,80,90,100}, we get the evaluation results shown in table 1 and 2.

Table.1 The characteristics of the general evaluation

Results of Evaluation Advanced NPPs	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-NG	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%

Table.2 Evaluation results and scores related to indices

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

2. Fuzzy Borda Number evaluation method

Fuzzy Borda Number method is an evaluation method which can emphasize the predominant index and evaluate the NPPs in favor to the predominant indices [5]. The steps comprising:

(1) Attribution Determination

In the ith $(i=1,2,\cdots,m)$ index of the jth NPP-x_j $(j=1,2,\cdots,N)$, the attribution to “good” is:

$$u_{ij}=G_i(x_j)/\max\{G_i(x_j)\} \quad (2)$$

(2) Setting up the Frequency Statistic Table

As shown in the following formula, the W_i is the weight of the ith index which is determined by the AHP method described above. The frequency statistic table is shown in table 3.

$$f_{hj}=\sum_{i=1}^{m}\sigma_i^h(x_j)u_{ij}w_i \quad (3)$$

$$R_j=\sum_{h=1}^{N}f_{hj} \quad (4)$$

where $\sigma_i^h(x_j)=1$, if the ith index of x_j is ranking the hth $(h=1,2,\cdots,N)$ in the all the ith indices of all the x, otherwise $\sigma_i^h(x_j)=0$。

Table.3 The frequency result of Fuzzy Borda method

NPP	ABWR	APWR	CANDU-NG	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
$\sum$(R)	0.89	0.93	0.82	0.68	0.88	0.9

As shown in table 3, all the indices of APWR rank first, second and third, in the contrary, all the indices of CANDU-NG rank last one, two and three, all the indices of FBR are either the first or the last. This table can show the predominance relationship of indices for each NPP clearly.

(3) Computation of the Borda Number $FB(x_j)$

$$FB(x_j) = \sum_{h=1}^{N} \frac{f_{hj}}{R_j} Q_h \quad (5)$$

$$Q_h = \frac{1}{2}(N-h)(N-h+1) \quad (6)$$

According to the $FB(x_j)$, the ranking of all the x can be obtained. The evaluation results with Fuzzy Borda Number method described by the equation (5) and (6) are shown in table 4.

Table.4 The evaluation result of Fuzzy Borda method

NPP	Score	Ranking
ABWR	100	1
APWR	89.29	2
CANDU-NG	17.98	6
FBR	27.16	5
HTGR	48.62	4
PWR	57.75	3

The results of Fuzzy Borda Number evaluation method are somewhat different from the result of Fuzzy comprehensive evaluation method. That is because these two methods evaluate the NPP from different viewpoints. The Fuzzy comprehensive evaluation method takes into account for all aspects while the Fuzzy Borda Number evaluation method emphasizes only the predominant indices.

IV. THE EVALUATION RESULTS BY DIFFERENT EXPERT GROUPS

All the experts are assigned into a number of groups according to their age, profession and expertise. The evaluation by expert groups with different professions is used as an example herewith.

Table.5 The evaluation result of different expert group

NPP / Profession	ABWR	APWR	CANDU-NG	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
Management	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

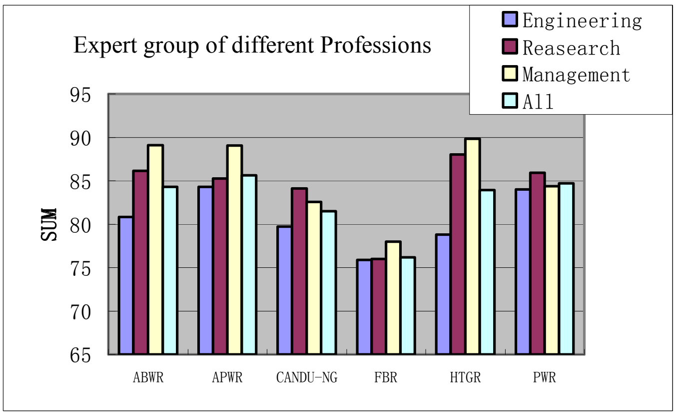

Figure.1 Evaluation result of expert groups with different professions

From the table 5 and Fig.1, we can see that different expert groups have different views towards various types of advanced NPPs, respectively. For example, all the expert groups consider that the APWR is outstanding. However as to HTGR, the experts whose profession is management or research consider that the HTGR is very attractive, but the experts whose profession is engineering consider that the HTGR is not mature and has no practical operation-experience, so it's not very good.

Ⅵ. CONCLUSIONS

We take the APWR, FBR and HTGR as examples to discuss the evaluation results. In the two evaluation methods described above, the evaluation results of the APWR are almost the best among all types of NPPs evaluated. For example, the Westinghouse AP-1000 represents the experience of a 1300 man-year and 440 million US$ design -testing program. Overnight capital costs are projected to achieve at the level of 1000 US$ per kilowatt electric power and the modular design will reduce construction time to 36 months. The 1100 MWe AP-1000 generating costs are expected to be below US$ 3.5 cents/kWh. It has innovative passive safety features, simplified construction and operation procedures, and 60-year plant life. It is quite possible that APWR will be one of the choices of the first-wave of NPPs for China to develop in recent years.

The Fast Breeder Reactors (FBR) is designed for more effectively utilizing nuclear fuel. Overall about 60 times more energy can be extracted from the original natural uranium by the fast breeder than by current light water reactors operating in "once-through fuel cycle". The extremely high fuel utilization efficiency makes the breeder an attractive energy conversion system for the future. Table.2 shows that the score of the Sustainability Index of FBR is the highest among all types of advanced NPPs evaluated. However, high capital investment cost means that they are unlikely to be competitive for several decades to come before 2050. Table.2 also displays that the economic competitiveness of FBR is the worst. Table.3 illustrates that the sustainability of FBR is the best but all other indices are the worst.

The most attractive type of HTGR is the modular HTGR using helium as the coolant of reactor core and the working fluid of the energy conversion system, which drives a gas turbo-compressor and turbine system at the temperature up to 950°C for generating electricity efficiently (>45) with a Brayton cycle. Therefore, the economic competitiveness of HTGR is expected to be very good. The HTGR has passive and inherent safety features on which the safe reactor shutdown in the most extreme accident conditions can be ensured without relying on any emergent active shutdown system. The Table.2 show that the features related to the safety and untroubledness of HTGR are almost the best. But by comparing with the APWR or ABWR, the characteristics of HTGR in relation to the technology maturity and the construction and operation experiences are not so good, therefore the experts whose profession is engineering don't consider the HTGR is very good as shown in Table 5 and Figure 1. However, due to the advantages of its inherent safety, system simplicity, and economic competitiveness, the HTGR should have a bright future.

The results mentioned above are obtained by the evaluation system developed in this study. By combining quantitative and qualitative analyses, a comprehensive evaluation to all selected types of NPPs has been done. With the Fuzzy comprehensive method and the Fuzzy Borda Number method, the evaluation to various types of NPPs in a scientific and objective way is an achievable goal. Although there remains a large room for further improving, the results from the current version of evaluation system are quite reasonable.

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REFERENCES

1. 《863 National Key Research Program in Energy Technology》R.Zhao Atomic Energy Publishing Company
2. Yang M.，Ren J., Zhou Z. and Zhu S., “The Role of Expert Evaluation System for Deploying Advanced Advanced NPPs in China,” GENES4/ANP2003, Sept. 15-19, 2003, Kyoto, Japan, paper 1180.
3. Zhang Q., Zhu S., Zhou Z., Ren J., Yang M.，“Study on a fuzzy AHP method based evaluation system for advanced nuclear power plants” Nuthos6, Oct 4-8,2004 ,Nara, Japan, Paper N6P209
4. 《The Theory and Method of Comprehensive Evaluation》Y. Guo Scientific Publishing Company
5. Studies on NPP operators' competence assessment, L. Wei, PhD Thesis of Tsinghua University, 2004.