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A Safety Decision Analysis for Saudi Arabian Nuclear Research Facility

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ABSTRACT

The first step in planning for introducing the nuclear energy to Saudi Arabia is to establish a nuclear research facility. Selection of a research reactor type for such a case is not an easy task. The fuzzy set decision theory is selected among different decision theories to be applied for this analysis.

Four research reactors are selected for this study.These are: the University of Michigan Ford Nuclear Reactor (FNR), Massachusetts Institute of Technology Reactor(MITR), Georgia Institute of Technology Research Reactor(GTRR), and University of Wisconsion Nuclear Reactor (UWNR).

The IFDA computer code, which based on the fuzzy set theory is applied here. The results show that the FNR reactor is the best alternative for the case of Saudi Arabian nuclear research facility, and MITR is the second best.

1. INTRODUCTION

The success in transferring nuclear technology to developing countries such as Pakistan and India has attracted the attention of Saudi Arabia to consider seriously aquiring nuclear technology. As the first step, the interest of Saudi

Arabia is to plan for a national nuclear research center. However, planning and development of nuclear research center programs in developing country need detailed studies. One of the major problems to be considered is the selection of a suitable nuclear research reactor from the safety viewpoint.

Safety of nuclear research center is a complex problem since it impacts population safety [1-8]. There are several interrelated factors influencing research reactor selection which make the selection a multidimensional decision problem and, hence, multiattribute decision theories may be used.

One approach is to use the multiattribute utility theory which has been outlined by Gross et al. [3] and has been applied by Ahmed et al. [1]. The approach allows for including subjective attributes by using arbitrary quantitative measures. Among the intangibles considered is public preference. Simpler rating and ranking techniques are also used. However, assignment of numerical values to various attributes lacks precision and sensitivity analysis becomes necessary since decisions may be reversed if numerical values are changed for attributes of large weights. The use of verbal judgement can overcome this difficulty since each rating or weight is represented by a verb which is described by a fuzzy set. Fuzzy set theory has been used in decision analysis in various applications [9-11]. The theory is explained in details in a previous work [12]. The approach has been developed further here and applied to the specific case of safety selection of a nuclear research reactor for the first nuclear research center in Saudi Arabia.

Four alternative research reactor facilities have been chosen. There are pool, light water tank, heavy water tank and TRIGA reactors. The IFDA computer code [13] which based on fuzzy set theory is used here to determine the optimal choice in term of safety consideration. The results show that the pool research reactor (FNR) is the best alternative, and the light water tank type (MITR) is the second best.

2. QUANTITATIVE EVALUATION

Selection of a research reactor facility differs from one case to another due to differences among the needs to be provided. Hence, the proper choice of a research reactor facility is an important requirement to meet the overall goal of the study. In the present case, the overall goal is to enhance Saudi Arabian participation in the peaceful applications of nuclear energy by selecting the most proper research reactor facility to meet the country's needs. Four alternatives which are shown in Table 1 will be evaluated here from the safety view point.

Safety has been an important consideration from the very beginning of the development of nuclear reactors. Although nuclear reactors of various types and sizes have been built and operated without endangering public safety, the history of nuclear energy and the frequent exposure of the public to various books, popular news media and publications try to convince the public that nuclear energy is not safe. It is a fact that nuclear energy was first used as an atomic bomb for destructive purposes, but it is also a fact that nuclear reactors are inherently safe and differ greatly from a nuclear bomb. It should be emphasized that it is impossible for a nuclear reactor to behave like an atomic bomb, due to basic differences in their design, material, and underlying principles. For this reason, while considering the safety of nuclear research reactor facilities, emphasis is only paid to possible radioactivity release.

TABLE 1: Selection of existing nuclear research reactor facilities

Type.	Existing facility.	Designation
Pool type research reactor	University of Michigan Ford nuclear reactor	FNR
Light water tank type research reactor	Massachusetts Institute of Technology reactor	MITR
Heavy water tank type research reactor	Georgia Institute of Technology research reactor	GTRR
Pulse type research reactor	University of Wisconsin nuclear reactor	UWNR

Most reactors produce and accumulate large amount of radioactive isotopes in the fuel material. In adverse circumstances, a reactor may suddenly release an amount of energy which can result in large-scale dispersal of radioactive materials to the environment, creating an extremely hazardous situation [14]. The probability of such an accident can be reduced by introducing safety features in the design of the reactor, its control system and operating the reactor with proper safeguard systems. The consequences of a release of radioactive material, if an accident occurs, can be minimized by proper location of the reactor and design of its building.

An examination of the safety aspects should include an evaluation of the possible hazards to the public, to the reactor personnel, and to the reactor itself, all of which are important in selecting a research reactor facility. Safe operation of a particular reactor depends on reliability of the system taking into account mechanical failures and human errors. Safe operation also depends on the response speed of the control system. Safety considerations concerning the public and reactor personnel include the radiation level and site selection.

Human error and equipment failure, scram insertion speed, and radiation level on reactor top and on general floor area of reactor building [15] are given in Table 2.

The flexibility in locating a research reactor facility depends greatly on the type of reactor and on the availability of the land. There are two approaches to the site selection. The first is an exclusion area if sufficient land is available. The second is a gastight building or airprocessing system(complete containment) if land is not available. Since the site of the center most probably will be in a heavily populated city, a gastight building will be employed to contain fission products in case of an accident. Of course, the requirements of the type of containment depends upon the type of reactor to some extent. MITR and GTRR systems are completely sealed in a closed loop cooling system.

TABLE 2: Safety evaluation of research reactor facilities

Reactor name	Equipment error [Error/(full operation year)]	Human error [Error/(full operation year)]	Maximum time for complete scram (sec)	Radiation level on reactor top (m rem/hr)	Radiation level on general floor area (m rem/hr)	Compatibility with the site (%)
FNR	20.276	2.765	0.45	1	10	40
MITR	21.452	1.430	1.82	1	10	70
GTRR	71.800	10.980	1.21	1	10	70
UWNR	53.571	16.071	1.00	1	10	85

A tank type reactor takes less area than a pool type reactor and thus it is convenient to construct a gastight containment to cover the reactor area. However, for a pool type reactor, a gastight containment covers a much larget area including the pool and laboratory facilities. In the case of a TRIGA type reactor, a gastight containment is not required [16-17].

According to the above discussion, the compatibility of the four reactor alternatives with a populated site is given also in Table 2.

3. APPLICATION OF FUZZY SET THEORY FOR ALTERNATIVE EVALUATION

The attributes, and subattributes were selected to provide a realistic variable which will be used to measure between the alternative research reactor facilities and to which extent that each alternative will satisfy the overall objective. Table 3 lists the selection criteria and subcriteria for Saudi Arabian nuclear research facility derived from the quantitative evaluation which given in section 2.

The fuzzy set theory, as well as the IFDA computer code [13] are used here to find out the most suitable research reactors to be used for the nuclear research facility in the Kingdom of Saudi Arabia. This analysis consists of three steps, namely:

1. Weighting the criteria and subcriteria as shown in Table 3. This is to show the importance level of the criteria and subcriteria, since some of the criteria (or subcriteria) are more important than

TABLE 3: Selection criteria and subcriteria for Saudi Arabian nuclear research facility based on a safety decision analysis.

Criteria/Subcriteria	Weight	Alternatives: FNR	MITR	GTRR	UWNR
Y_1 Reliability of operation	VI				
x_{11} Equipment Error	I	G	G	F	P
x_{12} Human Error	VI	G	VG	F	P
x_{13} Scram Insertion time	MI	VG	P	F	G
Y_2 Radiation level	I				
x_{21} Radiation on Reactor Top	VI	G	G	G	G
x_{22} Radiation on general floor area	VI	G	G	G	G
Y_3 Compatibility with selected site	MI	F	G	G	VG

the others. Three weights level are used here. These are: very important (VI); important I, and moderately important (MI).

2. Rating of each alternative verbally with respect to each subcriteria alone, independently of all other alternative. This is shown also in Table 3. The four rating levels used here are: very good (VG), good (G), Fair (F), and Poor (P).

3. The membership function, final rating, and ranking of each alternative are calculated for each criteria alone by using the IFDA computer code. Also, by using the same code, the final ranking of each alternative for all the criteria and sub-

criteria, as well as the degree of preferability of the best alternative over the others are calculated and plotted.

4. RESULTS AND CONCLUSION

The final membership function, final rating, and ranking for each criteria for the four research reactors are shown in Table 4. Table 5 lists the final membership function, final rating, and final ranking of each alternative. Figures 1 and 2 show the final ranking of the four alternatives,and the membership function of preferability of the university of Michigan Ford Nuclear Reactor (FNR) over the other research reactors, respectively.

Therefore, the result of this paper show that the university of Michigan Ford Nuclear Reactor (FNR) is the most suitable research reactor to meet the needs of the Saudi Arabian nuclear research facility, and the Massachusetts Institute of Technology Reactor (MITR) is the second best.

TABLE 5: The Final Membership, Rating, and Ranking Of The Four Nuclear Research Reactors Proposed For Saudi Arabia

Alternatives	Final Membership	Final Rating	Final Ranking
FNR	1.000	0.8445	1
MITR	0.8941	0.8087	2
GTRR	0.76988	0.7665	3
UWNR	0.5599	0.6883	4

TABLE 4: The Membership, Final Ratings, and the Ranking of Each Criteria For The Four Nuclear Research Reactor Proposed For Saudi Arabia.

Criteria	The Membership I				Final Rating				Ranking			
	FNR	MITR	GTRR	UWNR	FNR	MITR	GTRR	UWNR	FNR	MITR	GTRR	UWNR
Reliability of operation	1.000	0.7403	0.4249	0.000	0.8596	0.7729	0.6655	0.4722	1	2	3	4
Radiation level	1.000	1.000	1.000	1.000	0.8333	0.8333	0.8333	0.8333	1	1	1	1
Compatibility with selected site	1.000	1.000	1.000	1.000	0.8333	0.8333	0.8333	0.8333	1	1	1	1

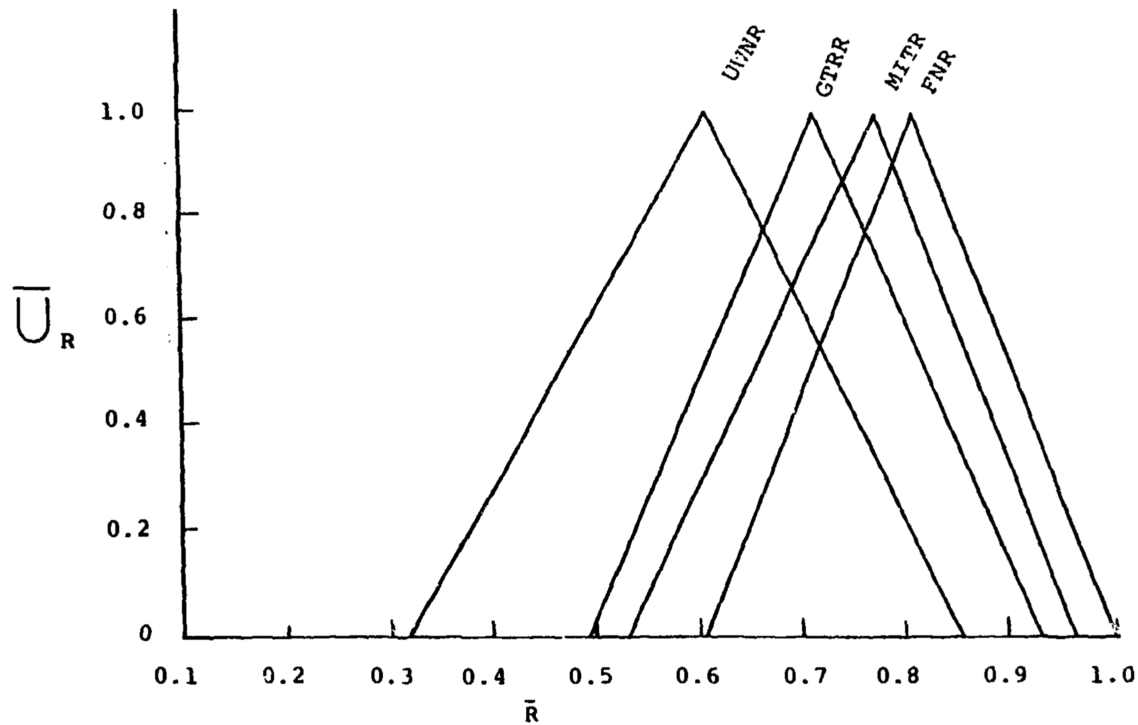

FIGURE 1: The final ranking of the four research reactors.

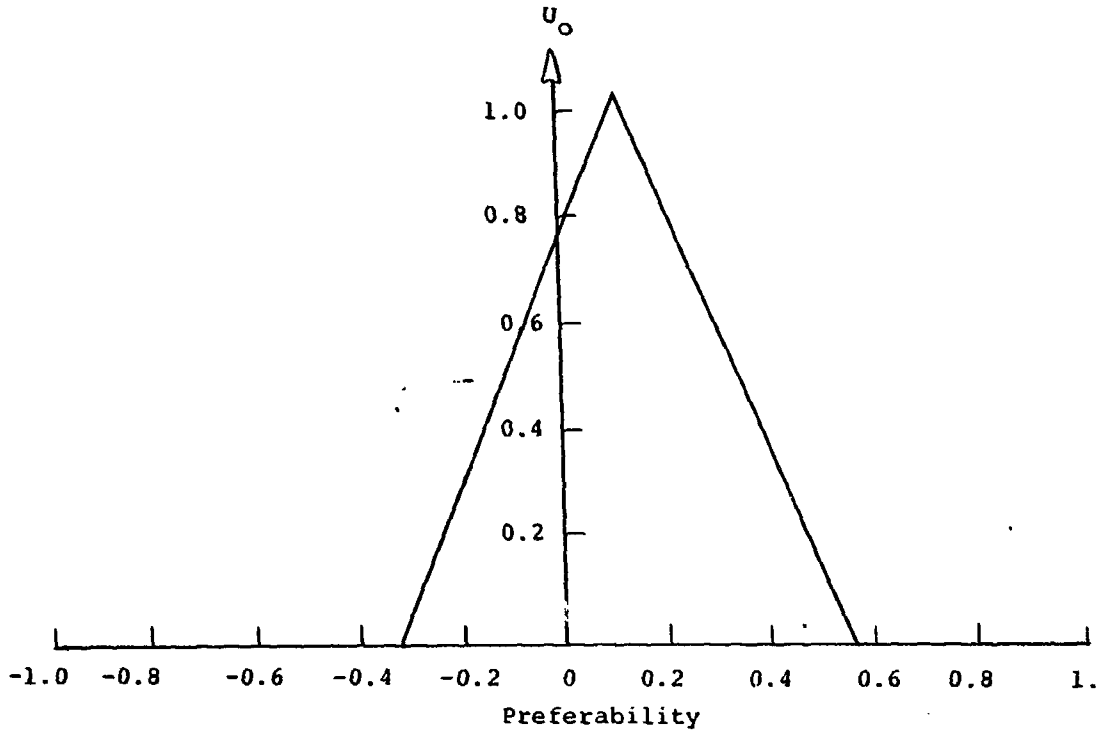

FIGURE 2: Final membership function of the preferability of FNR reactor over the other alternatives.

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