Implementation of IAEA Code of Conduct on the Safety of Research Reactors using Fuzzy Sets

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Abstract: A method of assessment the application of IAEA (International Atomic Energy Agency) Code of Conduct on the Safety of Research Reactors using fuzzy sets is presented. In this paper, the fuzzy sets are used to represent the linguistic answer of the experts to indicate the level of accomplishment of implementation of the Code provisions. Assessments of two areas of the Code of Conduct using fuzzy sets are presented and results are discussed. It is shown that using fuzzy sets to some extent is more realistic tool to identify areas of satisfactory application of the Code of Conduct and areas needing improvement. However, assessment through IAEA regional and international meetings is always important.
[Mohamed A. Gaheen and Adel A. M. Abdelrahman. **Implementation of IAEA Code of Conduct on the Safety of Research Reactors using Fuzzy Sets.]** *J Am Sci* 2014;10(4):70-74]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 9

Key Words: Nuclear Safety, Research Reactors, Fuzzy Sets.

1. Introduction:

The IAEA Code of Conduct on the safety of Research Reactors (RRs) provides guidance on the development and harmonization of policies, laws and regulations on the safety of RRs, and offers best practice guidance for management of Research Reactor (RR) safety. It includes technical provisions based upon consensus documents, primarily IAEA Safety fundamentals and requirements. The Code can be used as a basis to regulate and conduct RR activities. The Code applies to RRs at all stages of their lives from sitting to decommissioning [1, 2].

The objective of the Code is to achieve and maintain a high level of safety through enhancement of national measures and international co-operation. This objective is achieved by proper operating conditions, the prevention of accidents, and the mitigation of accident consequences, in order to protect workers, the public and the environment from undue radiation hazards [1, 3].

2. Method

The Code of Conduct areas consists of questions, which require more than a simple YES or NO in answering these questions. In this assessment, the answers of these questions are linguistic answers to indicate the level of accomplishment of implementation of the Code provisions. The accomplishment of implementation is intended to be indicated in five levels shown in Table 1 [4].

Table 2 shows the Code of Conduct areas on the safety of RR [1]. In each area, the questions are given and the experts will have to find the answers with levels of implementation. The assessment of specific area of the Code is the average of answers of the questions belonging to this area to be indicated in one of the five levels.

Table 1: Levels of implementation for answering questions

Fully Implemented (FI)
Partially implemented With satisfactory progress (PW)
Partially Implemented (PI)
Low Level of implementation (LL)
Not Implemented (NI)

Table 2: Areas of the Code of Conduct on the Safety of RRs

1. Assessment and verification of safety
2. Financial support
3. Quality assurance
4. Human factors
5. Radiation protection
6. Emergency preparedness
7. Sitting
8. Design, construction and commissioning
9. Operation, maintenance, modification and utilization
10. Extended shutdown
11. Decommissioning

It is normal that not all questions have the same importance. So, importance is introduced to weight the questions. This gives the experts more chance to assign their point of views. Appropriate expressions of importance to weight each question with respect to other questions are introduced in Table 3. It gives appropriate importance or weights of the questions in an area of interest. Also, these expressions can be used to weight the areas in overall assessment of the Code of Conduct.

The assessment using fuzzy sets can be done in three processes as shown in Fig. 1. In the first process, the fuzzy sets are used to represent the linguistic answers and weights of the Code questions, which is called fuzzification process. It is appropriate and simple to use triangle fuzzy sets in answering the questions as shown in Fig. 2 [5, 6]. The fuzzy sets (or fuzzy numbers) used to represent the question importance are shown in Fig. 3 [5]. The second process is the operations of addition, multiplication and division for the fuzzy sets. Defuzzifaction is the final process to deal with the output fuzzy set and obtain the result. The most popular defuzzification method is the center of fuzzy set area [7].

Table 3: Importance of questions belonging to an area of interest.

Very important (V)
Important (I)
Less important (L)

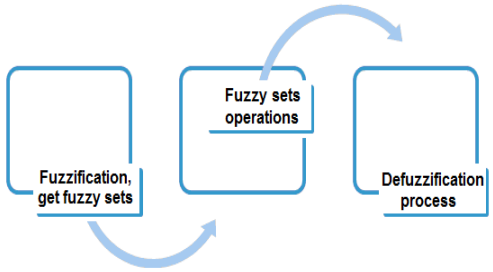
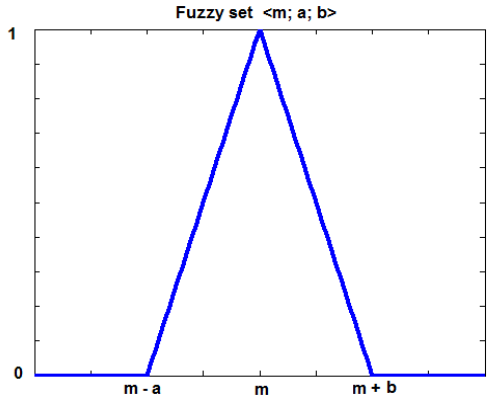
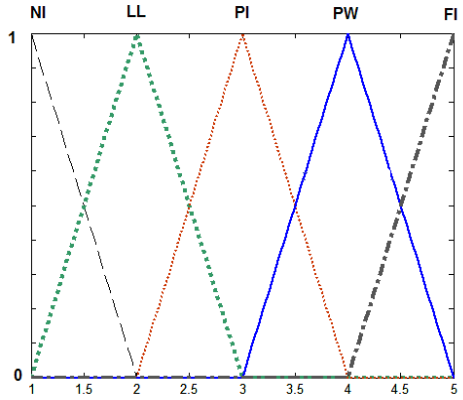


Fig. 1: Fuzzy sets processes



(a)



(b)

Fig. 2: (a) Triangle fuzzy set (b) Levels of implementation as fuzzy sets

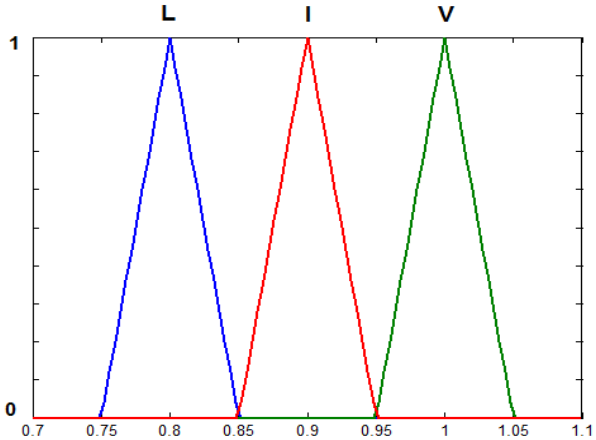


Fig. 3: Importance or weights of questions of area i as fuzzy sets

The result of assessment of Code of Conduct area A_i is obtained for area i as weighted average of the fuzzy sets q_{ij} used in answering the questions belonging to this area.

$$A_i = \frac{\sum_{j=1}^{J_i} q_{ij} \cdot W_{ij}}{\sum_{j=1}^{J_i} W_{ij}} \quad (1)$$

where J_i is the number of questions belonging to area i, and W_{ij} is the weight of the question j in area i. The level of implementation for area i is the fuzzy set in Fig. 1 that yields the highest membership value corresponding to center of A_i area. In overall assessment of the Code areas (OA), equation 2 is used:

$$OA = \frac{\sum_{i=1}^{I} A_i \cdot W_i}{\sum_{i=1}^{I} W_i} \quad (2)$$

where W_i is the weight of the area i, and I is the number of areas.

If two fuzzy sets M <m; a; b> and N<n; c; d>, then operations of addition, multiplication and division are [5]:

M (+) N = <m + n; a + c; b + d>,

M (×) N = <mn; mc + na - ac; md + nb + bd> and

N (×) M^{-1} = <n/m; (nb + mc)/m(m + b); (na + md)/ m(m - a)>.

These fuzzy sets operations are calculated for equations 1 and 2 using MATLAB as well as the defuzzification process of the output set [7].

3. Results

Table 4 describes the questions belonging to area 9 of the Code of Conduct. The weighted answers of these questions using fuzzy sets are shown in Fig 4(a). Using Equation 1, the weighted average fuzzy set A_9 is calculated and is shown in Fig. 4(b), which is the output fuzzy set. The defuzzification process is to re-plot the defuzzification value of this output fuzzy set onto Fig. 2(b) as indicated in Fig. 4 (c). The level of implementation for area 9 is the fuzzy set PW (Partially implemented With satisfactory progress) that yields the highest membership value corresponding to the defuzzification value of 3.84. It should be noted that this defuzzification value can be used also as the percentage of the implementation for that area of the Code as 76.8 %.

The proposed method is also used for assessment of area 10 of the Code of Conduct. Table 5 describes the questions and assessment and Fig. 5 shows the results. The defuzzification of the weighted average fuzzy set A_{10} is 27.2. The implementation percentage is 54.4 % and linguistic assessment is PI (Partially Implemented) level.

It is worth mentioning that similar procedures can be applied in the overall assessment of the Code Conduct areas. In this case the output fuzzy set A_i for each area is weighted and the overall assessment is obtained using Equation 2.

Table 4: Example of assessment of area 9 of the Code of Conduct using fuzzy sets

Area 9	Questions (linguistic answer, weight of question)	Assessment using fuzzy sets
Operation, maintenance, modifications, and utilization	1. Establish Operational Limits and Conditions (OLCs) and revise as necessary. (FI, V) 2. Conduct activities important to the safety in accordance with approved procedures and regulations. (FI, V) 3. Make available necessary engineering and technical support. (PI, V) 4. Report safety significant event to the Regulatory Body. (PI, I) 5. Establish a safety review committee as a part of the Operating Organization. (FI, I) 6. Minimize volume of activity of radioactive waste. (LL, L) 7. Maintain documentation secured and organized. (PI, L)	Partially implemented With satisfactory progress or 76.8 % (centre of A_9 = 3.84)

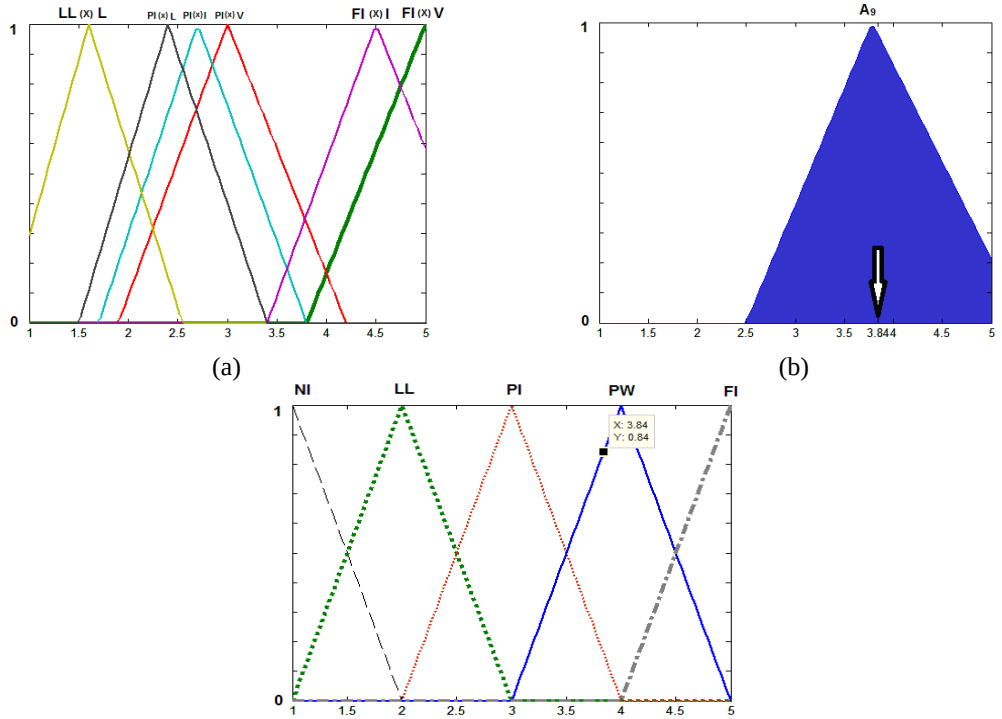


Fig. 4: (a) Weighted fuzzy answers of the seven questions in area 9 (b) Output fuzzy set A_9 (c) Defuzzification level of implementation

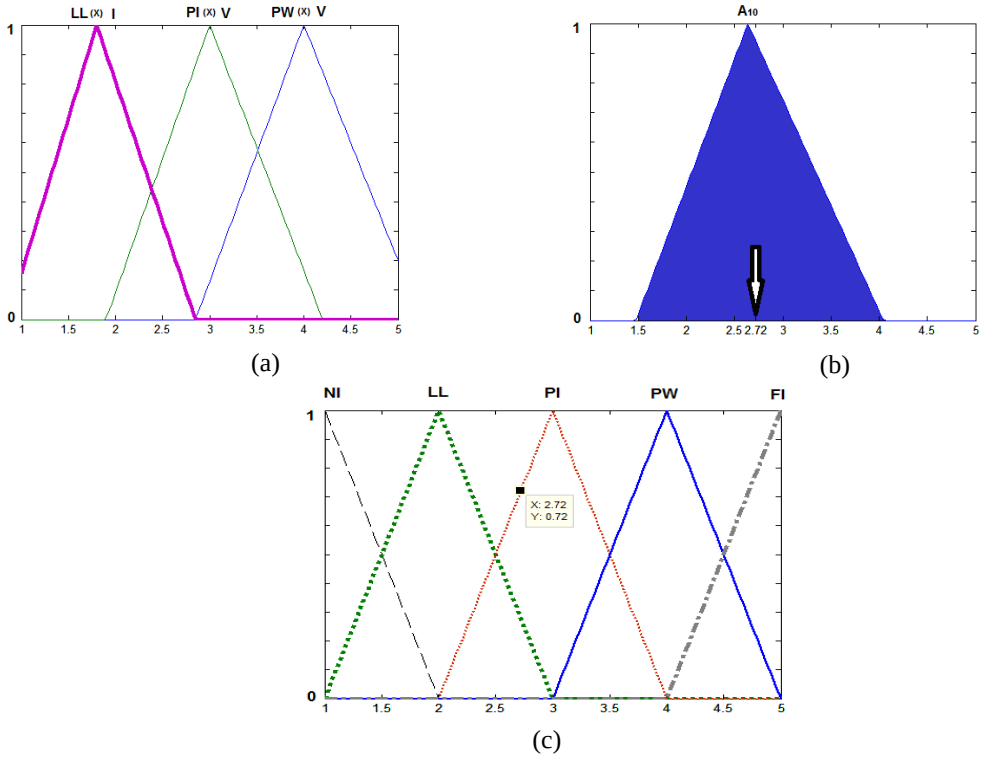


Fig. 5: (a) Weighted fuzzy answers of the five questions in area 10 (b) Output fuzzy set A_{10} (c) Defuzzification level of implementation

Table 5: Example of assessment of area 10 of the Code of Conduct using fuzzy sets

Area 10	Questions (linguistic answer, weight of question)	Assessment using fuzzy sets
Extended shutdown	If a RR is in extended shutdown, 1. Ensure that the core remains subcritical (It is preferable to unload the core). (PW, V) 2. Modify Safety Analysis Report (SAR) and OLCs. (PI, V) 3. Regular surveillance on RR systems. (LL, I) 4. Revise the emergency planning and arrangements. (LL, I) 5. Keep the RR in safe conditions and maintain knowledge about the RR. (LL, I)	Partially Implemented or 54.4 % (centre of A_{10} =2.72)

4. Conclusions

The IAEA Code of Conduct on the safety of Research Reactors offers best practice guidance for management of RR safety. The assessment of the application of the Code indicates the level of accomplishment of implementation of the Code provisions for an area. It is shown that using fuzzy sets is more realistic tool to identify areas of satisfactory application of the Code of Conduct and areas needing improvement. The proposed method is illustrated with the assessment of two areas of the Code as examples. As a result, it is found that the proposed method is practical for assessment the application of the Code. Moreover, it seems flexible, easy to use and has low calculation volume.

It is recommended to use the concept of fuzzy sets in assessment the application of the IAEA Code of Conduct on the safety of Egypt First Research Reactor (ETRR-1) and Egypt Second Research Reactor (ETRR-2). The results can be compared with conventional method to show the benefits of using the concept of fuzzy sets in assessment.

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3/19/2014