Decision of Site Reuse Scenario Applying Analytical Hierarchy Process (AHP) after Decommissioning Nuclear Power Plant

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1. Introduction

The final goal of decommissioning nuclear power plant is reuse of the land for the other purposes such as a park, a factory, and residence houses, etc. Reuse scenario is a masterplan deciding what purpose the decommissioning site will be used for. The reuse scenario should be decided in the early stage of the decommissioning plan, while site reuse is the final step. Because irradiation dose must be evaluated for reuse and the residual radioactivity in soil is differed by the decommissioning process. However, deciding the site reuse scenario is complex in that there are a lot of factors to consider and it takes a very long time from reactor shutdown until dismantling completion.

Analytical Hierarchy Process (AHP) is a decision-making process that select the most suitable candidate by aggregating multiple evaluating criteria [1]. AHP provides a rational and quantified solution for complex decisions.

2. Methods and Results

2.1 Analytical Hierarchy Process (AHP)

The brief procedures of AHP [2] are given as follows: i) structuring problem having a hierarchy containing goal, evaluating criteria, and candidates, ii) setting up the priorities among elements of each hierarchy (for evaluating criteria and candidates respectively), iii) checking consistency in evaluation, iv) computing overall priorities and score of candidates.

To establish priorities, a pairwise comparison matrix is constructed for *n* objectives as shown in Eq. (1). The scale of the importance, the element of the pairwise comparison matrix, is assessed by Table I

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & & a_{2n} \\ \vdots & & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

where,

a_{ij} = relative importance of *i*-th objective to *j*-th objective,

$$a_{ii} = 1$$
$$a_{ji} = 1/a_{ij}.$$

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Table I: Fundamental scale of importance

Importance (*i* over *j*)	Description
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Value

To compute priorities of the objectives, matrix $\mathbf{A_w}$ is derived by dividing element in column *j* of the matrix **A** by the sum of the column *j* as shown in Eq. (2). The average of row *i* in the matrix A_w is computed as shown in Eq. (3). The value of the vector **C** is the priorities of the objectives.

$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} & \cdots & \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}} \\ \vdots & & \ddots & \vdots \\ \vdots & & & \vdots \\ \frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} & \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} & \cdots & \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}} \end{bmatrix} \quad (2)$$

$$C = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ \vdots \\ c_n \end{bmatrix} = \begin{bmatrix} \frac{\frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{n} a_{i2}} + \cdots + \frac{a_{1n}}{\sum_{i=1}^{n} a_{in}}}{n} \\ \frac{\frac{a_{21}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{22}}{\sum_{i=1}^{n} a_{i2}} + \cdots + \frac{a_{2n}}{\sum_{i=1}^{n} a_{in}}}{n} \\ \vdots \\ \vdots \\ \frac{\frac{a_{n1}}{\sum_{i=1}^{n} a_{i1}} + \frac{a_{n2}}{\sum_{i=1}^{n} a_{i2}} + \cdots + \frac{a_{nn}}{\sum_{i=1}^{n} a_{in}}}{n} \end{bmatrix} \quad (3)$$

Next step is to check the consistency of the assigned importance. λ_{max} is the maximum eigenvalue of matrix A where the matrix remains consistent. λ_{max} can be calculated as Eq. (4).

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{i-th\ element\ in\ A \cdot C}{i-th\ element\ in\ C} \quad (4)$$

Consistency index (CI) and consistency ratio (CR) is calculated as shown in Eq. (5) and Eq. (6), and the random index (RI) are indicated in Table II. If CR is smaller than 0.10, the assigned importance can be acceptable. Otherwise, AHP may not provide reliable results.

$$Consistency\ Index\ (CI) = \frac{\lambda_{max} - n}{n - 1} \quad (5)$$

$$Consistency\ Ratio\ (CR) = \frac{CI}{RI} \qquad (6)$$

Table II: Value of Random Index (RI)

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

2.2 Application of AHP to Select Reuse Scenario in Decommissioning Site

The hierarchy is established for applying AHP in the selection of reuse scenario as shown in Fig. 1. The reuse scenarios of the nuclear power plant site generally classified into four types; Recreational, Industrial, Residential and Residential Farmer. However, Resident Farmer scenario was excluded from the candidates in this study, because this scenario shows extremely high irradiation dose. Six evaluating criteria are considered, which are decontamination cost, benefit, expected users, detection cost, time to open the site, and public opinion. 'Decontamination cost' is a cost to reduce the radionuclide concentration to the level where the site can be opened, and 'detection cost' is the cost of site dose measurement. 'Benefit' is a commercial revenue from site reuse, and 'expected users' means an expected number of visitors to the reuse site. 'Time to open site' is the time until the site becomes available considering dose rate, and 'public opinion' is people's opinion on site reuse plan.

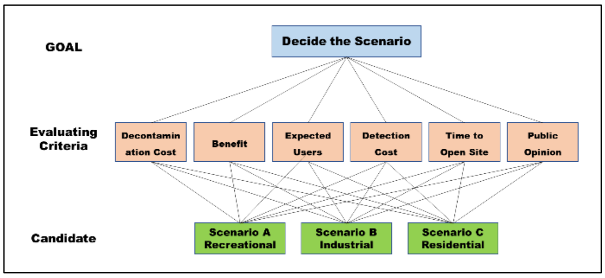

Fig. 1. AHP hierarchy in selecting site reuse scenario after decommissioning

Considering the features of each terms in the evaluating criteria and the candidates, the arbitrary importance is allocated, and priorities and consistencies are computed as shown in Table III and Table IV.

As a result, aggregating the priorities of each hierarchy, the score of recreational, industrial, and residential scenario is 0.527, 0.266, and 0.207, respectively.

Table III: The importance and priorities of evaluating criteria

	Decontamination Cost	Benefit	Expected Users	Detection Cost	Time to Open Site	Public Opinion	Priority
Decontamination Cost	1	3	5	7	9	3	0.416
Benefit	1/3	1	3	6	7	1	0.202
Expected Users	1/5	1/3	1	4	6	1/3	0.107
Detection Cost	1/7	1/6	1/4	1	3	1/6	0.046
Time to Open Site	1/9	1/7	1/6	1/3	1	1/7	0.027
Public Opinion	1/3	1	3	6	7	1	0.202
					λmax = 6.360	CI = 0.072	CR = 0.058

Table IV: The importance and priorities of reuse scenario to each evaluating criterion

Decontamination Cost	Recreational	Industrial	Residential	Priority
Recreational	1	5	9	0.748
Industrial	1/5	1	5	0.180
Residential	1/9	1/5	1	0.071
	λmax = 3.029	CI = 0.015		CR = 0.025
Benefit	Recreational	Industrial	Residential	Priority
Recreational	1	1/6	1/6	0.077
Industrial	6	1	1	0.462
Residential	6	1	1	0.462
	λmax = 3.000	CI = 0.000		CR = 0.000
Expected Users	Recreational	Industrial	Residential	Priority
Recreational	1	1/3	1/6	0.100
Industrial	3	1	1/2	0.300
Residential	6	2	1	0.600
	λmax = 3.000	CI = 0.000		CR = 0.000
Detection Cost	Recreational	Industrial	Residential	Priority
Recreational	1	3	5	0.648
Industrial	1/3	1	2	0.230
Residential	1/5	1/2	1	0.122
	λmax = 3.004	CI = 0.018		CR = 0.003
Time to Open Site	Recreational	Industrial	Residential	Priority
Recreational	1	3	6	0.639
Industrial	1/3	1	4	0.274
Residential	1/6	1/4	1	0.087
	λmax = 3.054	CI = 0.027		CR = 0.047
Public Opinion	Recreational	Industrial	Residential	Priority
Recreational	1	4	9	0.701
Industrial	1/4	1	5	0.236
Residential	1/9	1/5	1	0.062
	λmax = 3.072	CI = 0.036		CR = 0.062

3. Conclusions

In this study, method of selecting suitable reuse scenario on the nuclear power plant decommissioning site applying analytical hierarchy process (AHP) was proposed. In the consequence of evaluating reuse scenarios of the decommissioning site using AHP, the recreational scenario was the most suitable among three candidates. The recreational scenario recorded 0.527, which was higher than industrial (0.266) and residential scenario (0.207). The result shows that AHP can be utilized to decide the site reuse scenario which is a complex problem. It must be treated that more various evaluating criteria and yielding well-founded importance in the future work.

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