# ENHANCE NUCLEAR SAFETY AND RELIABILITY OF NUCLEAR POWER PLANTS THROUGJH HUMAN RESOURCE DEVELOPMENT

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## ABSTRACT

To prevent recurrence of accidents like Fukushima Daiichi Nuclear Power Station, nuclear operators should be trained by addressing leadership in the pursuit of nuclear safety at every level, from the operators' top management to on-site staff. This paper analyzes the effectiveness of leadership education program that provides vicarious experience for shift supervisors who are engaging in nuclear plant operation at the control room. With the measurement of change in his behaviors and awareness by questioning by himself and subordinates, effectiveness of the education program was numerically measured by utilizing behavioral theory of Johari Windows and leadership model of Crew Resource Management. By dividing leadership into eight elements such as command skill and others, the program was successfully analyzed and indicated the challenges in which area should be strengthen.

## 1. Introduction

Attribute of effective leadership may be blessed with talents or intuition. Attitude of leadership in pursuing nuclear safety, however, has to be trained in those who engage in nuclear energy business. Because keeping nuclear safety in rigorous way requires continuous pursuit of excellence and it means being a man of great moral integrity. By learning the consequence of nuclear disaster, top management realizes the importance to put nuclear safety as the first priority and comes to consider carefully the balance of management resource between economic pursuit and securing public safety. Individual also has clear understanding of the role of leaders in designing, installing and operating plant systems with careful consideration towards nuclear safety.

Japan Nuclear Safety Institute (JANSI) provides the opportunity for nuclear operators to learn leadership by simulating the situation prevailing at that time of Fukushima accident.

By focusing on the leadership of a shift supervisor engaging in nuclear power plant operation at the control room, JANSI has conducted the experimental leadership training program in which participants experience the tense atmosphere of Fukushima accident with vicarious role playing exercise. The experimental result of JANSI's leadership program must be evaluated to enhance the motivation of participants towards effective leadership. However, it is very hard to be visualized in a short period since such leadership is intangible awareness. JANSI has been trying to measure the educational effect of role playing methodology which simulates panic occurred among operating crew at the time of station blackout. The analysis on the effectiveness of leadership training program is described in the following chapters. First, chapter 2 will introduce the theory of leadership as well as the operational organization of work in the main control room, which is directly related to reactor operations. Chapter 3 will introduce JANSI's leadership training program for a shift supervisor and its effectiveness by analyzing questionnaire survey results. Finally, Chapter 4 will summarize this paper and introduce challenges for the future as conclusion.

## 2.  Leadership in 24-hour duty shift group
## 2.1 Leadership model

George Terry defines leadership as "the activity of influencing people to strive willingly for group objectives."[1] Warren Bennis provides a deeper analysis of the difference between a manager and a leader, saying, "The manager administers; the leader innovates… The manager focuses on systems and structures; the leader focuses on people…   The manager asks how and when; the leader asks what and why. The manager has a short-range view; the leader has a long-range perspective. The manager accepts the status quo; the leader challenges it. The manager does things right; the leader does the right thing."[2]

In the field of behavioral science, Joseph Luft and Harry Ingham, psychologists for interpersonal communication devised "**The Johari Window**"[3], which is a graphic model of interpersonal awareness by dividing into four regions such as "**open**", "**blind**", "**hidden**" and "**unknown**". Each of these regions represents the information in terms of whether the information is known or unknown by the person and whether the information is known or unknown by others in the group. The four regions are as follows, showing the quadrant numbers; 1. **Open**, which is known by the person about him/herself and is also known by others, 2. **Blind**, which is unknown by the person about him/herself but which others know, 3. **Hidden**, which the person knows about him/herself that others do not know; and 4. **Unknown,** which is unknown by the person about him/herself and is also unknown by others. In this graphic model, it is well known that leadership should be located in the "open" region because of the necessity of influencing others. In this paper, leadership of a shift supervisor engaging in a nuclear power plant operation will be analyzed by applying this interpersonal communication model of "The Johari Window" to assess the effectiveness of JANSI's shift supervisor training program.

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In addition, by introducing the concept of leadership in the aviation industry named "**Crew Resource Management (CRM)"** [4] [5], we newly defined the leadership of shift supervisor consisted of eight contributors such as i) command skill, ii) communication ability, iii) safety prioritization awareness, iv) unification skill, v) mediation skill, vi) critical thinking, vii) situational analysis, and viii) coaching skill. These contributors were originally based on the research for developing a captain pilot leadership in aviation industry being composed of five elements such as 1) communication, 2) decision-making, 3) team building/maintenance, 4) workload management, and 5) status confirmation management. Reflecting the experience of the Fukushima Daiichi Accident, JANSI reorganized these five elements and added three more elements as described above.


## 2.2. Leadership from the experience of Fukushima Daiichi Accident

Looking back on the actions taken by the shift supervisor in the control room and the plant manager in the on-site nuclear emergency response headquarters from the perspective of crisis management at Fukushima Daiichi nuclear accident**,** it is obvious that both of them were under a great deal of stressful environment such as confusion due to chaos, psychological uncertainty due to lack of sufficient information, sense of time pressure due to lack of cooling methods. They were subject to significantly large aftershocks, hazards caused by sediment washed in by the tsunami, a highly radioactive environment following core melt, and hydrogen explosions. Under such circumstances, it could be difficult to have sound communication and it could be difficult to manage everything strategically amid confusion.

At the first stage of Fukushima Daiichi Accident, the shift supervisor tried to grasp the situation with limited amount of information. In addition, he put all effort into looking for core cooling ways by encouraging stuff under the extreme stressful situation. Under such condition, not only the technical skill related to the characteristics of the plant systems but also human skill such as the management skill to command the shift and other personnel along with strong leadership could be required.

Therefore, considering this complexed situation at Fukushima Daiichi Accident and referring the CRM theory, leadership proficiency could be divided into eight elements such as

command skill, communication ability, safety prioritization awareness, unification skill, mediation skill, critical thinking, situational analysis, and coaching skill.

## 2.3 Operational Structures of the Station

Nuclear reactors at power station are operated by the groups of 24-hour shift team with proficiency and safety culture. A typical shift team consists of a shift supervisor (the head), an assistant supervisor, a reactor operator, turbine and generator operators, and auxiliary machine assistants or field operators, etc. The shift supervisor is responsible for performing inspection and operation of components during normal operation; preventing human error and leading the team in performance of periodic surveillance activities; to accurately grasp the situation and provide operational instructions, and notify the headquarters during an emergency. In order to carry out these duties appropriately, it is necessary for a shift supervisor to have management capability such as technical knowledge and human skill for taking command and influencing one's subordinates. The communication between headquarter and control room must be indispensable to share the vision and value of nuclear business too.

## 2.4 Shift Supervisor Leadership Program

JANSI provides a program[6] for plant shift supervisors where participants can gain vicarious experience by listening to the decision by the colleague at the same position of the Fukushima Daiichi Accident and playing a simulated role in the scenario of Fukushima Daiichi Accident. Participants are able to learn the necessity of leadership for strengthening teamwork, communication and stress management. For example, the curriculum[7] deals with many scenes such as framework determination of the reactor water level by using indirect means, the coaching skill to encourage subordinates to build new core injection lines which are not described in established procedures and stress management for subordinates who have the feeling of powerless. Participants realize the importance of these proficiencies through roleplay activities. Table 1 shows the curriculum of this three day training program.

| Day | Details |
|-----|---------|
| Day 1 | Lecture on the experiences of the shift supervisor at the main control room at the time of accident |
| | Learn about the human skills necessary of shift supervisors |
| | Explanation of individual profiling based on the result of questionnaire survey |
| Day 2 | Lecture on leadership under stress in emergency situations (lecturer: former senior official of the Maritime Self Defense Force) |
| | Leadership roleplay* exercise simulating the Fukushima accident |
| Day 3 | Learn about human skills (coaching) |
| | Coaching roleplay* exercise |
| | Learn about human error examples in teamwork |
| | Roleplay* exercise of dealing with different opinions and conflicts how to ensure safety |
| | Set future goals, give presentations of their determination as commitments |

Table 1: Shift Supervisor Leadership Training Curriculum

*Roleplay: Acting-based exercise wherein participants play the role of shift supervisors in the main control room, while other participants act as their subordinates, to consider countermeasures under the psychological stress of a given task.

## 3. Effects of leadership training program

Questionnaire survey was conducted twice. One was one month before the leadership training and the other was three months after that. The questions consisted of eight elements of leadership in relation to participants' awareness and behavior. Answer sheets were

formatted with a metric evaluation system in the scale of five degree to one (5: Strongly agree; 4: Agree; 3: Neutral; 2: Disagree; 1: Strongly disagree).

At the same time the same questionnaire survey was also conducted for station personnel who work for the shift supervisors to see if the effect of the training is visible in their workplace.

These two sides of "self" and "others" survey results before and after the training program will provide the information of interpersonal relationships how participants' awareness and behaviors changed after the training. Participants have been given the feedback so that they may utilize the survey result toward greater awareness of their behaviors in the future. Analysis of these results can also serve as an index to evaluate whether JANSI's leadership training curriculum can be effective in developing leaders. This analysis is provided below.

### 3.1 Questionnaire Survey before and after the training

The survey method described as below;

a. Subjects:
   83 Participants and 164 Subordinates
b. Answer Format:
   Evaluation on a scale of five (5: Strongly agree; 4: Agree; 3: Neutral; 2: Disagree; 1: Strongly disagree)
c. Survey Questions:
   Sixty-nine questions which linked respectively to eight elements such as command skill, communication ability, safety prioritization awareness, unification skill, mediation skill, critical thinking, situational analysis, and coaching skill were posed in total.

### 3.2    Evaluation Method

The average value of the difference in each element between before and after the training is examined by two-sided Student t-value test ($p<0.01$, $p<0.0\ 5$).

Participants' leadership was defined as a vector composed of eight elements such as $p$; pre training vector ($p_i$, $i$=1~8) and $q$; post training vector ($q_i$, $i$=1~8). The effectiveness of the program can be indicated by vector $q$-$p$, and measured by its Euclidean length which summarized in Formula (1).

$$\text{Euclidean length: } |q - p| = \sqrt[2]{\sum_i^n (q_i - p_i)^2} \quad {\scriptstyle (i=1\sim8,\ n=8)} \tag{1}$$

Subordinates' followership which evaluated the leadership of the boss of shift supervisor was also defined as a vector composed of eight elements such as $s$; pre training vector ($s_i$, $i$=1~8) and $t$; post training vector ($t_i$, $i$=1~8). The effectiveness of the program can be indicated by vector $t$-$s$, and measured by its Euclidean length which summarized in Formula (2).

$$\text{Euclidean length: } |t - s| = \sqrt[2]{\sum_i^n (t_i - s_i)^2} \quad {\scriptstyle (i=1\sim8,\ n=8)} \tag{2}$$

Moreover, the effectiveness of leadership itself should be evaluated by the fact that can be affective to others. That means it is not enough to measure the result of self-awareness but to measure the result of evaluation by others. Therefore, in order to grasp the situation of mutual comprehension between the participants and their subordinates, the survey result by subordinates were also utilized.

The displacement vector may illustrate the shift of the origin of the rectangular coordinate axis, which explains the enlargement or reduction of the **open** region of The Johari Window.

Moreover, to verify the every position of the eight element of leadership numerically on the Johari Window region, the average values of the overall scores of participants before and after the training were summarized in Formula (3).

$$A_{ab} = (\sum_i^n M_{ai} + \sum_i^n M_{bi}) / 2n \tag{3}$$

$A_{ab}$: The average value of the overall score of the participants before and after the training

$i$   : Element $i$

$n$   : The number of Elements in $i$ (in this case, eight elements)

$M_{ai}$: The average score evaluated by the participants for Element $i$ after the training

$M_{bi}$: The average score evaluated by the participants for Element $i$ before the training

Next, the standard deviation of the overall scores of the participants themselves before and after the training was summarized in Formula (4).

$$St = \sqrt{\{\sum_i^n (M_{bi} - A_{ab})^2 + \sum_i^n (M_{ai} - A_{ab})^2\}/2n} \qquad (4)$$

St: the standard deviation of the overall scores as evaluated by the participants before and after the training

Further, the standard deviations for each element both before and after the training were summarized in Formulas (5) and (6).

$$D_{ai} = (M_{a_i} - A_{ab})/St \times 10 + 50 \qquad (5)$$
$$D_{bi} = (M_{b_i} - A_{ab})/St \times 10 + 50 \qquad (6)$$

$D_{ai}$: The standard deviation for Element i after training

$D_{bi}$: The standard deviation for Element i before training

Lastly, $x_i$ is defined as the standard deviation of Element $i$ as evaluated by the participants before and after the training in Formula (7). This value represents the difference in awareness as evaluated by the participants (self-evaluation) after the training.

$$x_i = D_{ai} - D_{bi} \qquad i \text{  falls between 1 and 8} \qquad (7)$$

$x_i$: the difference in awareness as evaluated by the participants after training

As for the scores evaluated by the participants' subordinates, the average value of the overall scores before and after the training and the standard deviation were obtained in the same way. Then, for each element, the standard deviation $d_{bi}$ before the training and the standard deviation $d_{ai}$ after the training were also calculated in the same way, and the difference in standard deviation before and after the training $y_i (= d_{ai} - d_{bi})$ was obtained. This value represents the difference in behaviors of the participants after the training from the perspective of their subordinates (evaluation by subordinates).

The values of element $i$ obtained were then plotted on a two-dimensional scatter diagram representing the concept of the Johari Window ($x_i, y_i$).

## 3.3 Results of the Analysis

As for the participant's analysis, the results before and after the training program are shown as means ± standard deviation of mean in Table 2. Statistical difference was determined by two-sided Student's t-test. The four elements of unification, mediation, situational analysis, and coaching are significantly increased ($p<0.01$). Conversely, other four elements of communication ability, safety prioritization, command skill and critical thinking are not increased significantly. The data of after-before difference of participants illustrates the factor of "Known - Unknown by Self" axis.

As for the subordinates' analysis, the same way of analysis was implemented as shown in Table 3. Every element did not increase significantly. The means data of participants change vector $q$-$p$ illustrates the position along with "Known by Self - Unknown by Self" axis. The means data of subordinates change vector $t$-$s$ illustrates the position along with "Known by

Others - Unknown by Others" axis. Therefore, the position on the every elements of leadership can be plotted on the Johari Window diagram in the following section. The Euclidian length of the factors calculated in formula (1) and (2) of integrated data of eight elements could be illustrated of displacement of origin of "Known by Self - Unknown by Self" axis and "Known by Others - Unknown by Others" axis.

| | Command Skill | SD | Communication Ability | SD | Unification Skill | SD | Safety Prioritization | SD |
|---|---|---|---|---|---|---|---|---|
| After (N=83) | 3.88 | 0.42 | 3.95 | 0.39 | 3.82 | 0.48 | 3.98 | 0.41 |
| Before (N=83) | 3.79 | 0.44 | 3.85 | 0.43 | 3.60 | 0.54 | 3.86 | 0.48 |
| Difference | 0.09 | | 0.10 | | 0.22** | | 0.12 | |

| | Mediation Skill | SD | Critical Thinking | SD | Situation Analysis | SD | Coaching Skill | SD |
|---|---|---|---|---|---|---|---|---|
| After (N=83) | 3.70 | 0.55 | 3.88 | 0.49 | 3.84 | 0.45 | 3.68 | 0.60 |
| Before (N=83) | 3.48 | 0.52 | 3.74 | 0.48 | 3.65 | 0.47 | 3.31 | 0.68 |
| Difference | 0.22** | | 0.14 | | 0.19** | | 0.37** | |

SD: Standard Deviation  　　　*:p<.05  　　　**:p<.01

Table 2: The average value of the difference between before and after the training program by Participants (N=83)

| | Command Skill | SD | Communication Ability | SD | Unification Skill | SD | Safety Prioritization | SD |
|---|---|---|---|---|---|---|---|---|
| After (N=164) | 4.19 | 0.56 | 4.28 | 0.51 | 4.19 | 0.56 | 4.28 | 0.54 |
| Before (N=164) | 4.12 | 0.56 | 4.22 | 0.51 | 4.12 | 0.56 | 4.22 | 0.51 |
| Difference | 0.07 | | 0.06 | | 0.06 | | 0.06 | |

| | Mediation Skill | SD | Critical Thinking | SD | Situation Analysis | SD | Coaching Skill | SD |
|---|---|---|---|---|---|---|---|---|
| After (N=164) | 4.02 | 0.63 | 4.15 | 0.65 | 4.14 | 0.55 | 3.97 | 0.66 |
| Before (N=164) | 3.90 | 0.62 | 4.11 | 0.65 | 4.10 | 0.53 | 3.87 | 0.78 |
| Difference | 0.13 | | 0.04 | | 0.04 | | 0.10 | |

SD: Standard Deviation  　　　*:p<.05  　　　**:p<.01

Table 3 : The average value of the difference between before and after the training program by Subordinates (N=164))

## 3.4 Displacement Vector of leadership:
The degree of change of Johari Window can define as the impact vector $D$ ( Euclidian length of vector $q$-$p$, Euclidian length of vector $t$-$s$). The Displacement Vector of participants can indicate such as $q$-$p$ (0.09, 0.10, 0.22**, 0.12, 0.22*, 0.14, 0.19**, 0.37**) . From these factors of the vector, the participants' Euclidian length is calculated in 0.57. The Displacement Vector of subordinates can indicate such as $t$-$s$ (0.07, 0.06, 0.06, 0.06, 0.13, 0.04, 0.04, 0.10 ). From these factors of the vector, the subordinates' Euclidian length is calculated in 0.23. Therefore, impact vector $D$ concludes $D$ (0.57, 0.23).

## 3.5 Johari Window Diagram:
Johari Window Diagram is divided into 4 regions such as Open, Blind, Hidden and Unknown.

Eight elements of leadership can be deployed on one dimension by Johari Window Diagram as shown in Figure 1. Displacement Vector on each dimension can be plot on the surface of regions of Johari Window by using calculated average value of the difference between before and after the training program.

Impact vector **D** (0.57, 0.23) means the degree of expansion of the region of Johari Window diagram, which is shown in Figure 2. This result shows the effectiveness of leadership program.
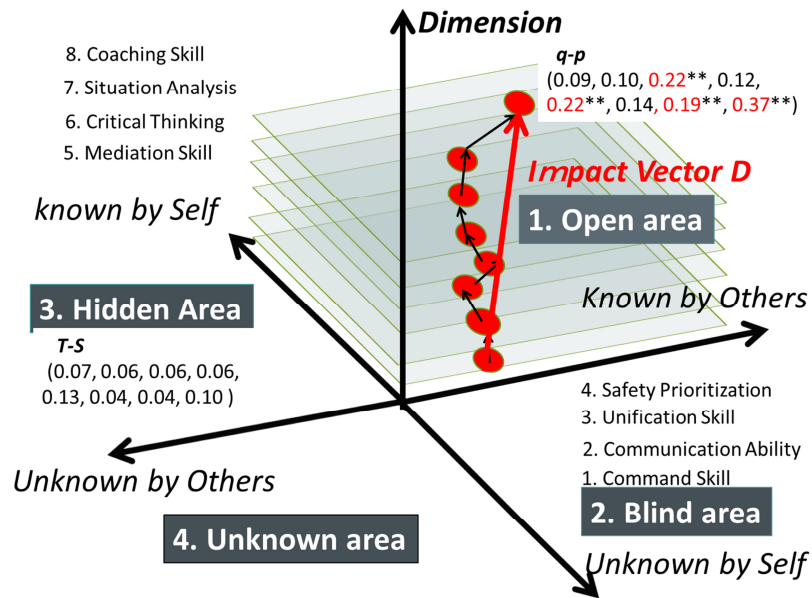


Fig. 1 Impact of Leadership Training Program indicated by Johari Windows Region.
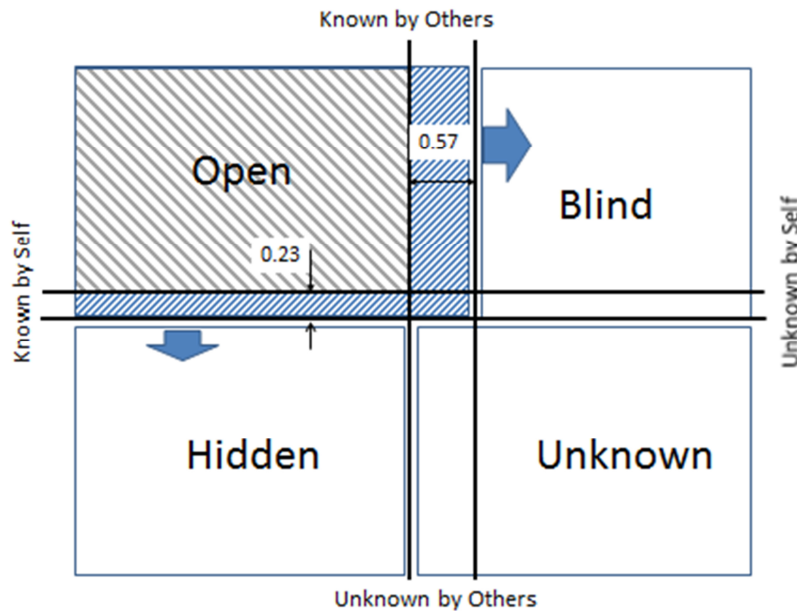


Fig. 2.   Change of Johari Window Region by Displacement Vector **D**.

As shown in Figure 3, the average value of the overall scores before and after the training of all points of eight elements was deployed on the open region respectively. From this it was found that participants had self-awareness of awareness and behavior and that changes in superiors' behavior were discernible by subordinates in the area.
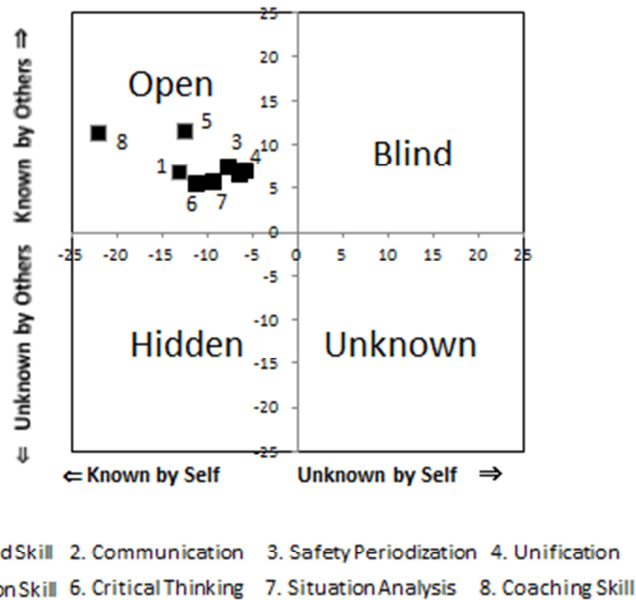


I. Command Skill    2. Communication    3. Safety Periodization    4. Unification
5. Mediation Skill    6. Critical Thinking    7. Situation Analysis    8. Coaching Skill

Fig. 3 Changes in Behaviors and Awareness of All Participants Before and After Training on the Johari Window Diagram.

### 3.6    Consideration

Considering the survey result that indicated the significant increase of four elements of participants' leadership such as unification, mediation, situational analysis, and coaching, it suggested that the participants could be so much influenced by the roleplay exercise of Day 3 whicn dealt with confliction and ploblem solving among the shift members. Conversely, no significant increase of other four elements such as communication, safety prioritization, command skill and critical thinking suggested that the another scenario of roleplay exercise should be developed to be effective for latter four elements.

Through the roleplay exercises, they must have gained an understanding of the importance of coaching skill and mediation skill by encouraging their subordinates to make a cooperative and constructive decision by judging the situation, which would lead their group to a strongly unified team under extreme severe environmental conditions.

On the other hand, evaluation by subordinates did not show meaningful improvement in the scores for eight elements respectively. This result suggested that the shift supervisors did not have shown their awareness to subordinates yet. Part of the reason for this result might be the authority in the station was well-structured in the daily situation. The participants might not have faced any serious problems requiring the time to show leadership because of prolonged shutdown state after the Fukushima Daiichi accident in Japan.

Evaluation of the training curriculum also shows the assumption that the shift supervisors should disclose their awareness and solicit subordinates for feedback so as to be more effective of their leadership since awareness is closely connected to behaviors.

## 4.　Conclusion

By utilizing Johari Window Model in analyzing the experimental leadership training program in which participants of shift supervisors experience the tense atmosphere of simulated Fukushima accident with vicarious roleplay scenario exercise, the effectiveness of JANSI's leadership program could be numerically measured. Through the roleplay exercises, participants of shift supervisor successfully gained leadership skill of coaching, mediation, unification and skill of situation analysis under extreme severe environmental conditions. As a result, area of awareness and behaviour that open to subordinates increased in the view of the interpersonal relationship. It also revealed that the weakness of the role play scenario and other curriculum to ehhance command skill, communication, safety prioritization and critical thinking. This suggests the necessity to revise or strengthen the curriculum for further effectiveness.

Leadership begins with an individual's self-awareness and manifests in his/her behavior. It continues to evolve interpersonal relationships in the group and eventually influences the organizational culture. It will take time and be difficult to pass through each of individual and organizational stage. While leadership is often considered an inborn quality, it is also strengthened through experience of difficulties. Therefore, the objective of JANSI's leadership training program is aiming at providing such opportunities of experiences for participants to gain leadership skill. In this perspective, it is crutial to measure the effectiveness of our leadership program.

In the theoretical viewpoints, the method of measuring the effectiveness of leadership program for shift supervisors could be successful by utilizing Johari Window diagram model. Through this leadership training program, JANSI hopes to take the accident at Fukushima Daiichi NPS as an opportunity to increase our own awareness and foster leaders who will act in pursuit of an even higher level of nuclear safety.

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