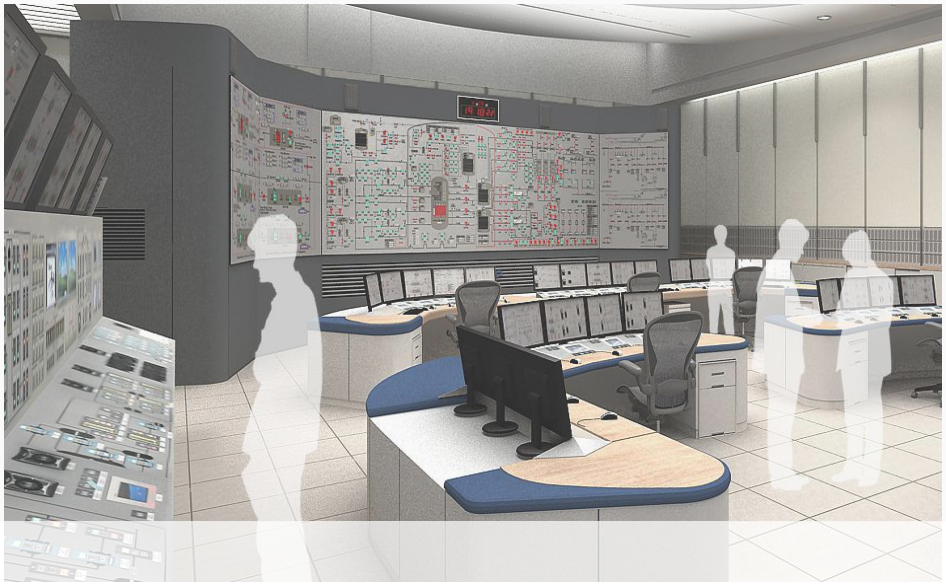

Development of a Method and Questionnaire to Quantify the Resilience of the Emergency Response Organizations

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HERA Lab. Human Engineering & Risk Analysis

Contents

1. Introduction

Background

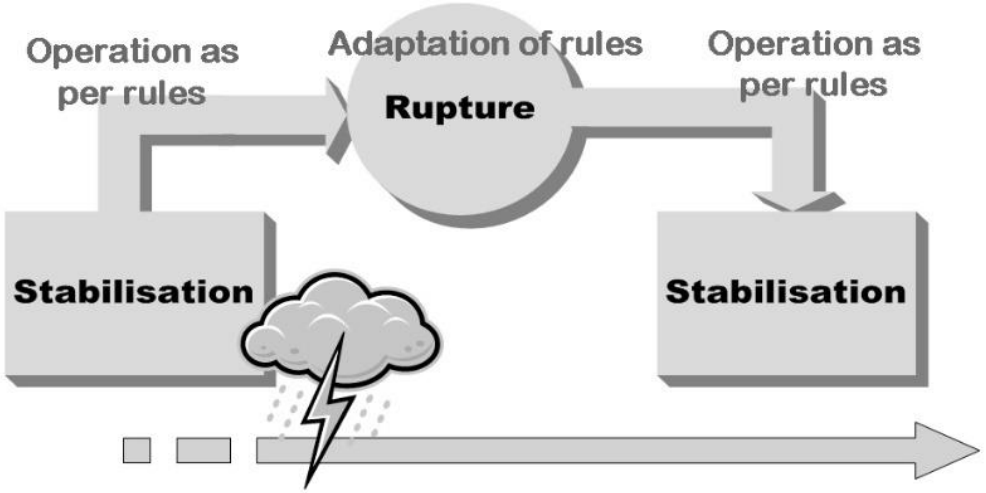
- After the Fukushima accident, the international experts meeting (IEM) at international atomic energy agency (IAEA) participants considered the accident to be not just a disaster triggered by natural events or a technically based disaster, but also a human induced disaster.
- One of the major lessons learned from the Fukushima accident is that the nuclear community needs to understand better and implement an integrated, or systemic approach to safety.

International Atomic Energy Agency (IAEA). (2013). Human and Organizational Factors in Nuclear Safety in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant.

1. Introduction

Background

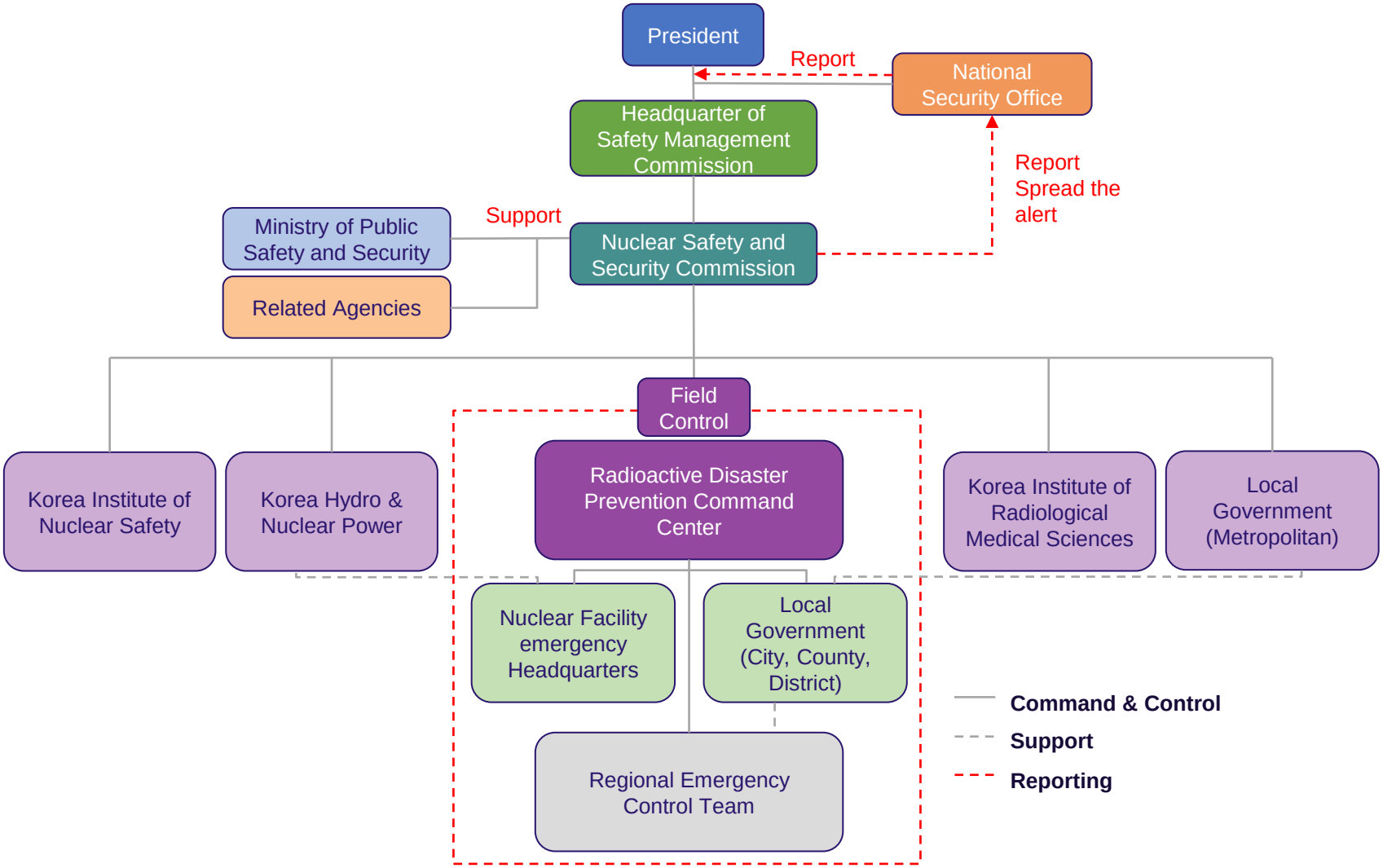
- **Concept of the resilience**
  - Resilience is the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain the required operation under both expected and unexpected conditions.
  - Resilience engineering is a relatively new paradigm for safety management that focuses on how to cope with complexity under pressure or disturbance to achieve success.



Erik Hollnagel, David Woods and Nancy Leveson; International Symposium on Resilience Engineering, Soderoping Sweden, October 20-25, 2004

1. Introduction

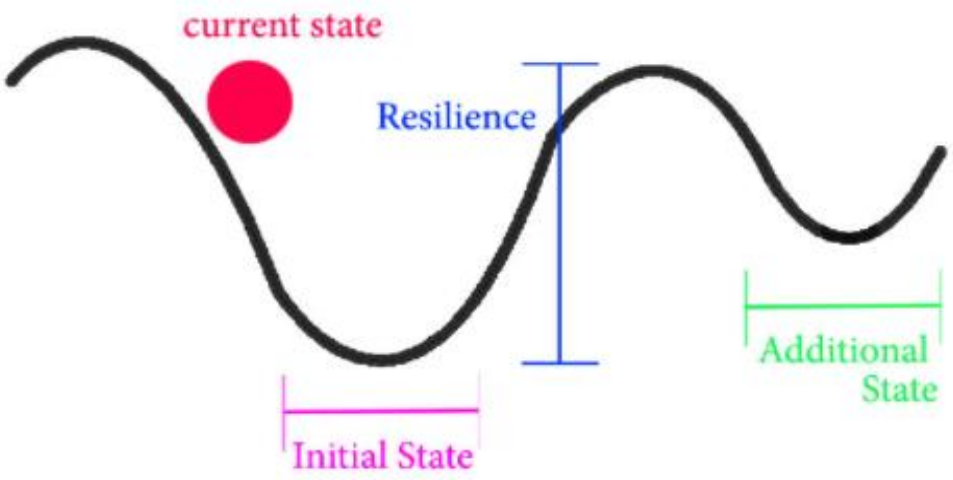
Emergency Response Organizations (ERO) in Korea



1. Introduction

❖ Reliability of the ERO

- **The reliability of the ERO means the possibility that an organization successfully performs its intended functions/roles in responding to an accident in NPPs.**
- **A reliable system can be interpreted as a resilient system.**



Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., ... & Von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake spectra, 19(4), 733-752.

1. Introduction

Resilience Project

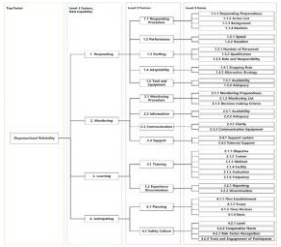
- Chosun Univ. has been carrying out a research project “Develop a reliability evaluation method for ERO in NPPs based on resilience concept” since 2020 with the support of the KoFONS.
- The purpose of this project is to apply the evaluation method to ERO and to develop a reliability evaluation package.

1. Introduction

❖ Purpose

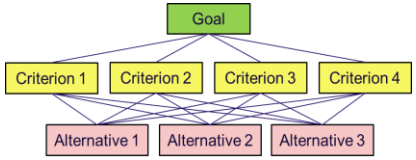
- **Suggesting a method and questionnaire to assess the reliability of ERO in nuclear power plants (NPPs) based on the resilience engineering concept.**
  - Identifying the contributing factors to the resilience of the ERO from the literature survey and the Delphi survey (section 2)
  - Evaluating the relative importance of the contributing factors with the Analytic Hierarchy Process (AHP) (section 3)
  - Suggesting the method and questionnaire to quantify the resilience of ERO (section 4)

Identifying the Contributing Factors



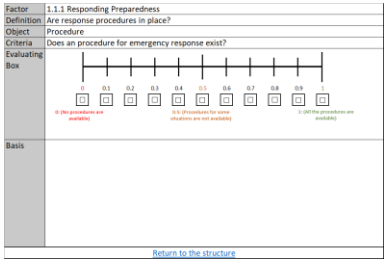
- Contributing Factors are identified from the literature survey on resilience and the Delphi survey

Evaluating the Contributing Factors



- Relative importance (weights) are calculated by 6 experts using AHP

Suggesting the Method and Questionnaire



- The method and questionnaire to quantify the resilience of the ERO are suggested

2. Identification of the Contributing Factors

The Process of Identifying the Contributing Factors

- First, the contributing factors relevant to the ERO of the NPPs were identified with literature survey on the resilience.
- Then, these contributing factors are modified based on the experts' knowledge using the Delphi technique.

2. Identification of the Contributing Factors

Literature Survey

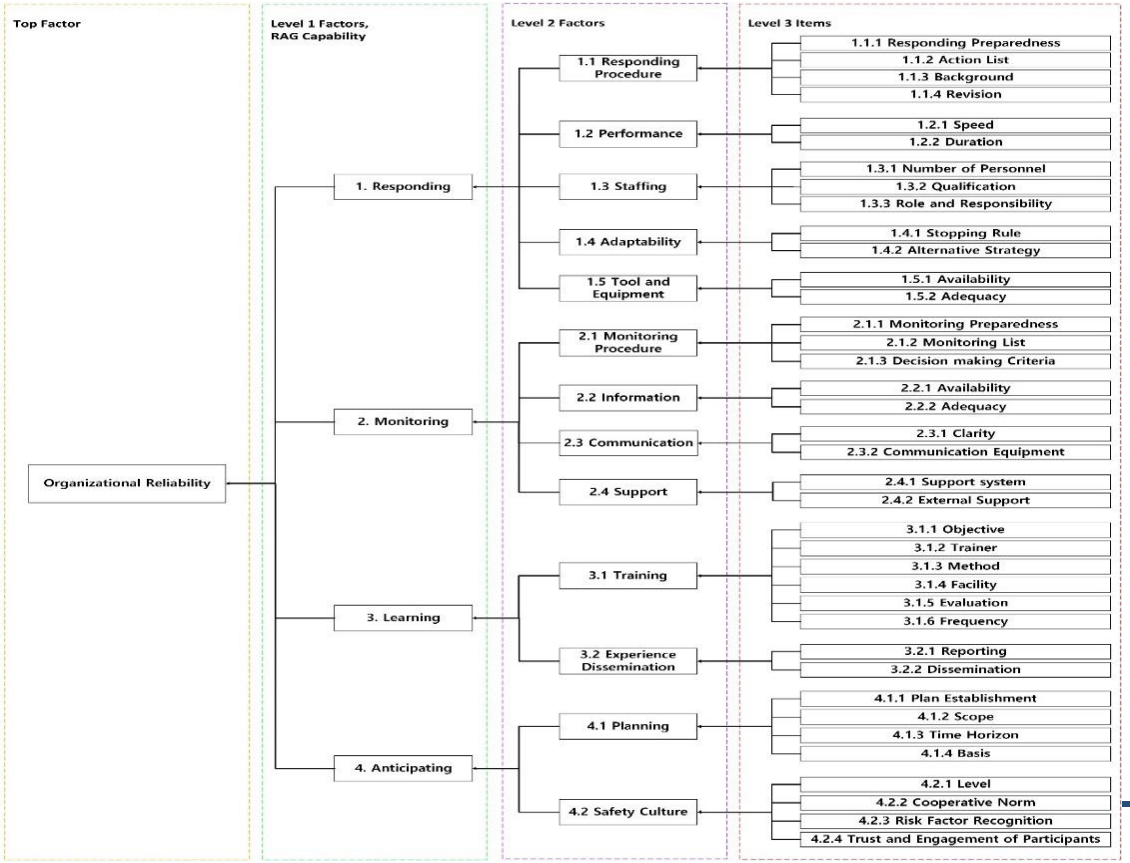
- **Search Relevant Documents**
  - **Keywords**
    - Resilience, Resilience Analysis Grid, High Reliability Organization, Organizational Resilience, Resilience Contributing Factors, Resilience Evaluation.
  - **A total of 166 papers related to resilience were accumulated initially.**
  - **A total of 69 papers relevant to the purpose of this study were thoroughly reviewed.**

Domains	Examples of the Factors
1) General (14)	Training, Duration, and Expertise (Hollnagel, 2013)
2) Process Plant (14)	Procedures, Anticipation, and Human Resource (J. Park, 2018)
3) Business (5)	Continuous Monitoring, Redundancy, and Anticipation Ability (Annarelli, 2020)
4) Medical & Healthcare (7)	Adaptive Capacity, A System of Roles, and Planning (Gonçalves, 2019)
5) Transportation (11)	Awareness, Efficiency, and Adaptability (Huber, 2012)
6) Infrastructure (15)	Stop Rule, Learning Target, and Frequency (JH Lee, 2018)
7) The Others (3)	Reporting, Preparedness, and Learning (Gonzalo, 2018)

2. Identification of the Contributing Factors

❖ Identifying the Contributing Factors to the Resilience of the NPPs Organizations

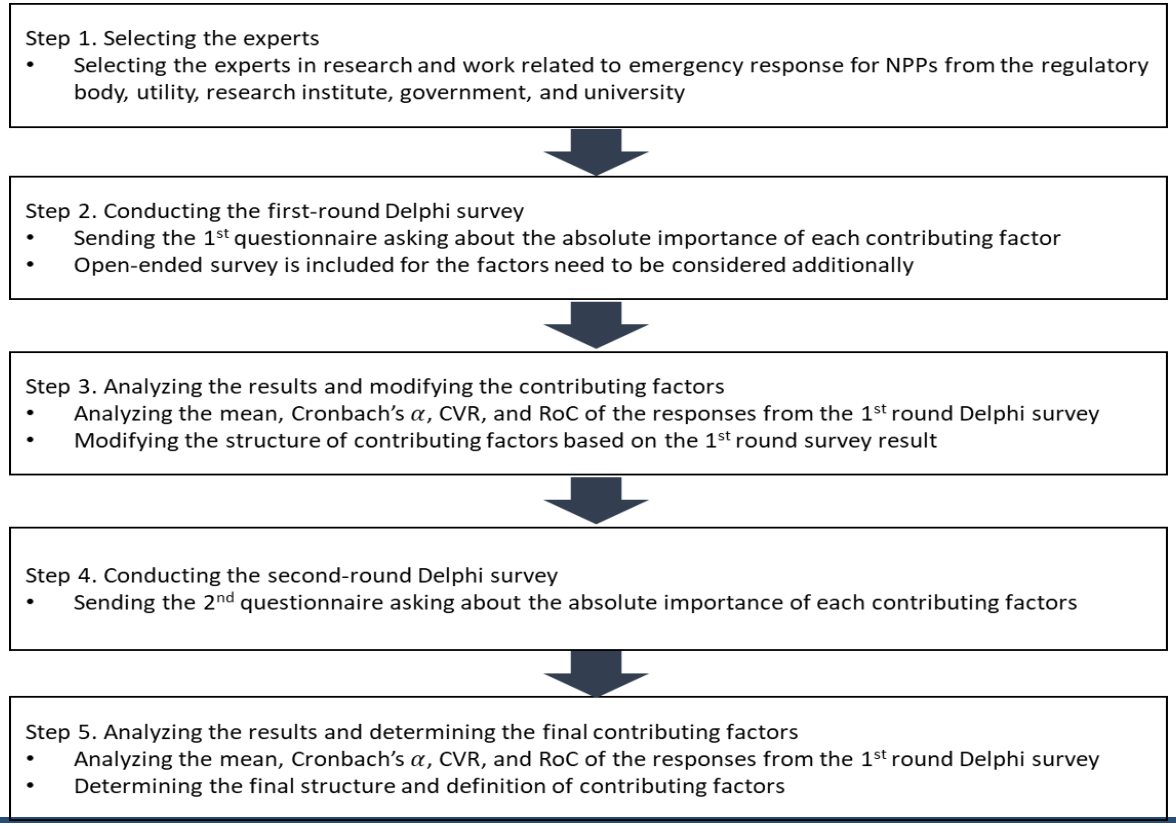
- **The initial contributing factors are organized into three levels.**
  - Level 1: Responding, Monitoring, Learning, and Anticipating (resilience analysis grid)
  - Level 2: 13 factors, Level 3: 38 factors



2. Identification of the Contributing Factors

❖ Modifying the Contributing Factors Using the Delphi

- **The Delphi has been conducted to modify the contributing factors based on the experts' opinions.**
- **The validity, resilience, and convergence of the survey were checked with content validity ratio (CVR), Cronbach's α, and ratio of convergence (RoC).**



2. Identification of the Contributing Factors

Steps 1 & 2: Selecting the Experts and Conducting the First-Round Delphi Survey

- **20 experts from various institutions participated in the Delphi surveys.**
- **Experts are asked to evaluate the importance of each contributing factor and to describe any suggestions.**

Institution	Number of Experts
KINS	5
KAERI	4
KHNP	4
University	3
Government	3
KEPCO E&C	1

1.1 The definition of the Responding Procedure, the first evaluating factor of Responding, is as follows. How important do you think the Responding Procedure is in terms of the reliability of emergency response organizations? *

No.	Level 2 factor	Definition
1.1	Responding Procedure	Can organization respond to the emergency with its Procedure?

- ○ Not Important
- ○ Weakly Important
- ○ Fairly Important
- ○ Strongly Important
- ○ Absolutely Important
- ○ I don't know

2. Identification of the Contributing Factors

Step 3: Analyzing the Results and Modifying the Contributing Factors

- **The Cronbach's α and CVR of 16 factors were not acceptable.**
  - Ex) Background, Revision, Duration…
- **Some experts suggested that new factor should be considered.**
  - Ex) Effectiveness
- **Based on the result of the first-round Delphi, 6 modifications were made.**

2. Identification of the Contributing Factors

Factor	Modification	Reason
Communication	Moved from "Monitoring" to "Anticipating"	-It was highlighted that "Communication" is needed not only for the "Monitoring" but also for the "Responding" and the "Anticipating" in the open-ended survey.
Clarity	Redefined • Clarity: Are information providers, targets to be provided, and information exchanged clearly presented in manuals and protocols for communication?	-There were opinions that in a real accident, organization often do not know what information to send and receive in the open-ended survey.
Support System	Redefined • Support System: Is there any system in place to provide or share information necessary for monitoring or decision-making?	-The experts' opinions were not considered to be converged according to the RoC checking. -The experts' opinion on Support System is considered to be not valid according to the CVR checking. -The rapid sharing of monitoring information is emphasized in the open-ended survey.
Availability	Redefined • Availability: Is the information required for monitoring available in a timely manner?	-There were opinions that information must be provided in a timely manner in the open-ended survey.
Reporting	Redefined • Reporting: Are there any procedure and system to report and manage the good practice and bad practice?	-To make it easier to distinguish the meaning between "Reporting" and "Dissemination".
Effectiveness	Added • Effectiveness: Have effective and accurate countermeasures been taken (or is it possible)?	-There were opinions that accuracy and effectiveness should be added in terms of human error prevention as well as rapid, sustaining in the open-ended survey.

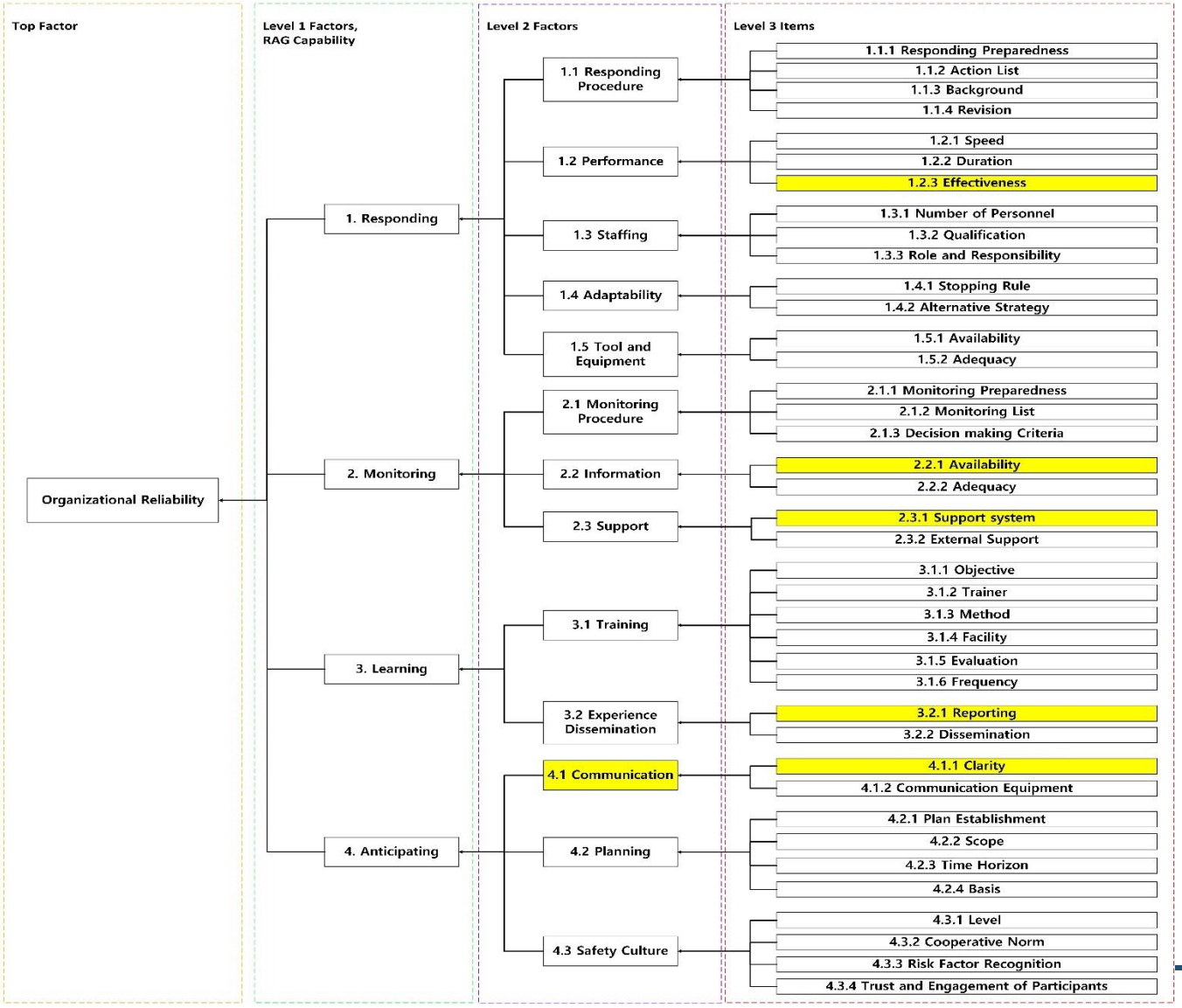
2. Identification of the Contributing Factors

Steps 4 & 5: Conducting the Second-Round Delphi survey and Determining the Final Contributing Factors

- Experts evaluated the importance of the contributing factors in the same way as the first-round Delphi.
- The result of the second-round Delphi indicated that all the contributing factors are determined to be acceptable and important.
- The final structure of the contributing factors is determined.

2. Identification of the Contributing Factors

❖ Determined the Final Structure of the Contributing Factors



Yellow Color: Modified Factors

3. Calculating the Weightings of the Contributing Factors

The Process of the Analytic Hierarchy Process (AHP)

- **The relative importance of contributing factors are calculated to be used as the weightings.**
- **The consistency of the responses were checked using the consistency ratio (CR).**

Step 1. Selecting Experts
- Selecting the experts in research and work related to emergency response for NPPs from regulatory body, utility, research institute, government, and university

Step 2. Distributing the AHP tool
- Distributing the AHP tools and definitions of each contributing factors
- Asking about the relative importance of each contributing factors

Step 3. Calculating the relative importance of contributing factors
- Calculating the relative importance and consistency ratio based on the experts' responses

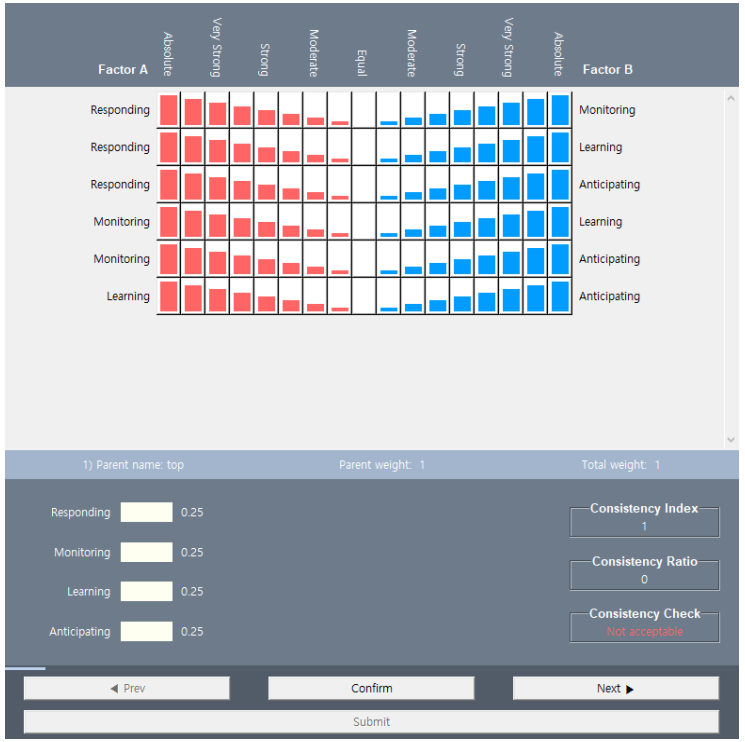
Step 4. Determining the final relative importance of contributing factors
- Normalizing the relative importance to be used as a weights of each contributing factors

3. Calculating the Weightings of the Contributing Factors

Steps 1 & 2: Selecting Experts and Distributing the AHP Tool

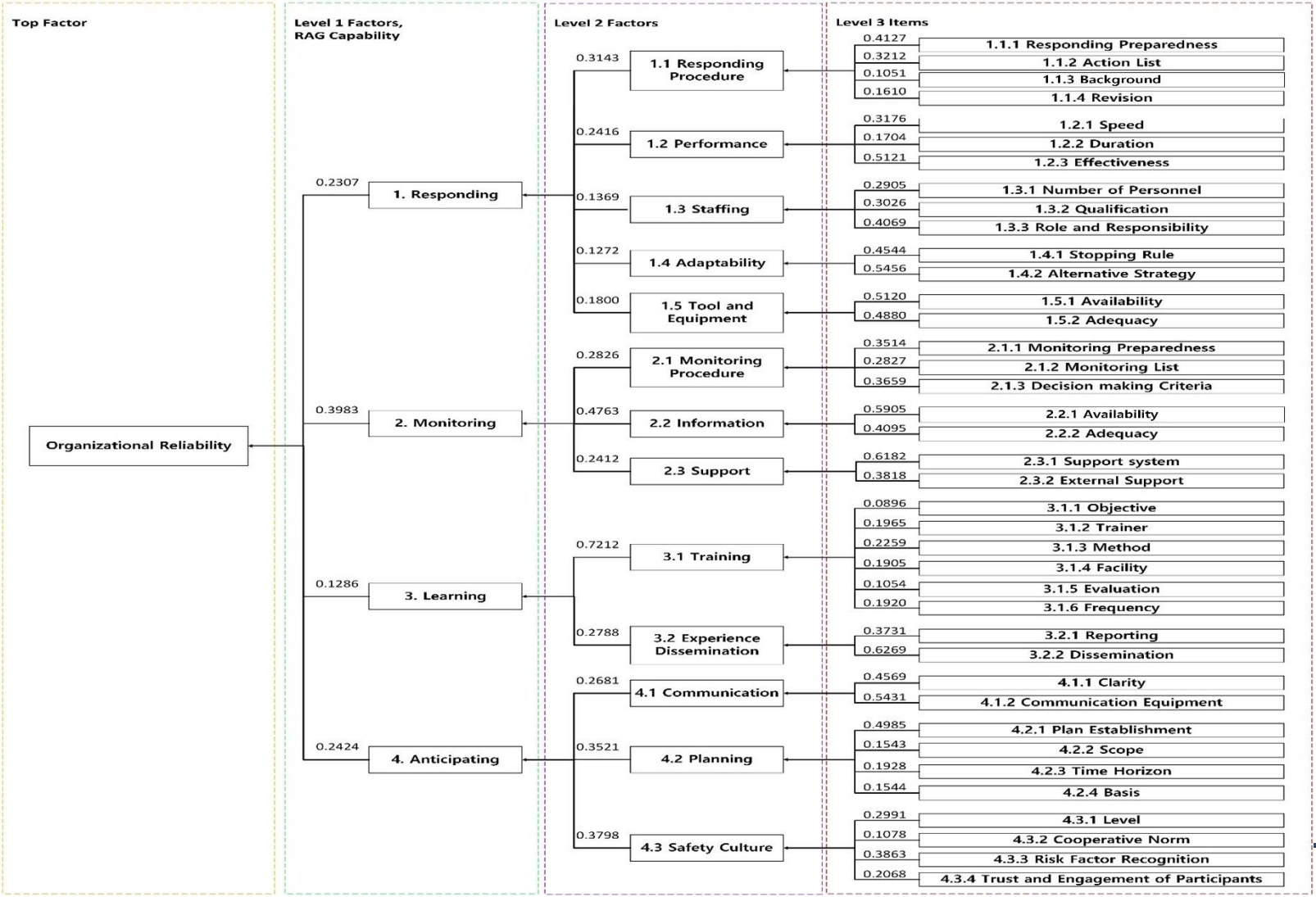
- 6 experts who participated in the Delphi as a panel participated in the AHP.
- Each expert represents their fields.
- AHP survey was conducted using a software that substitutes the AHP questionnaire.

Institution	Number of Experts
KINS	1
KAERI	1
KHNP	1
University	1
Government	1
KEPCO E&C	1



3. Calculating the Weightings of the Contributing Factors

❖ Steps 3 & 4: Calculating and Determining the Weightings of the Contributing Factors



3. Calculating the Weightings of the Contributing Factors

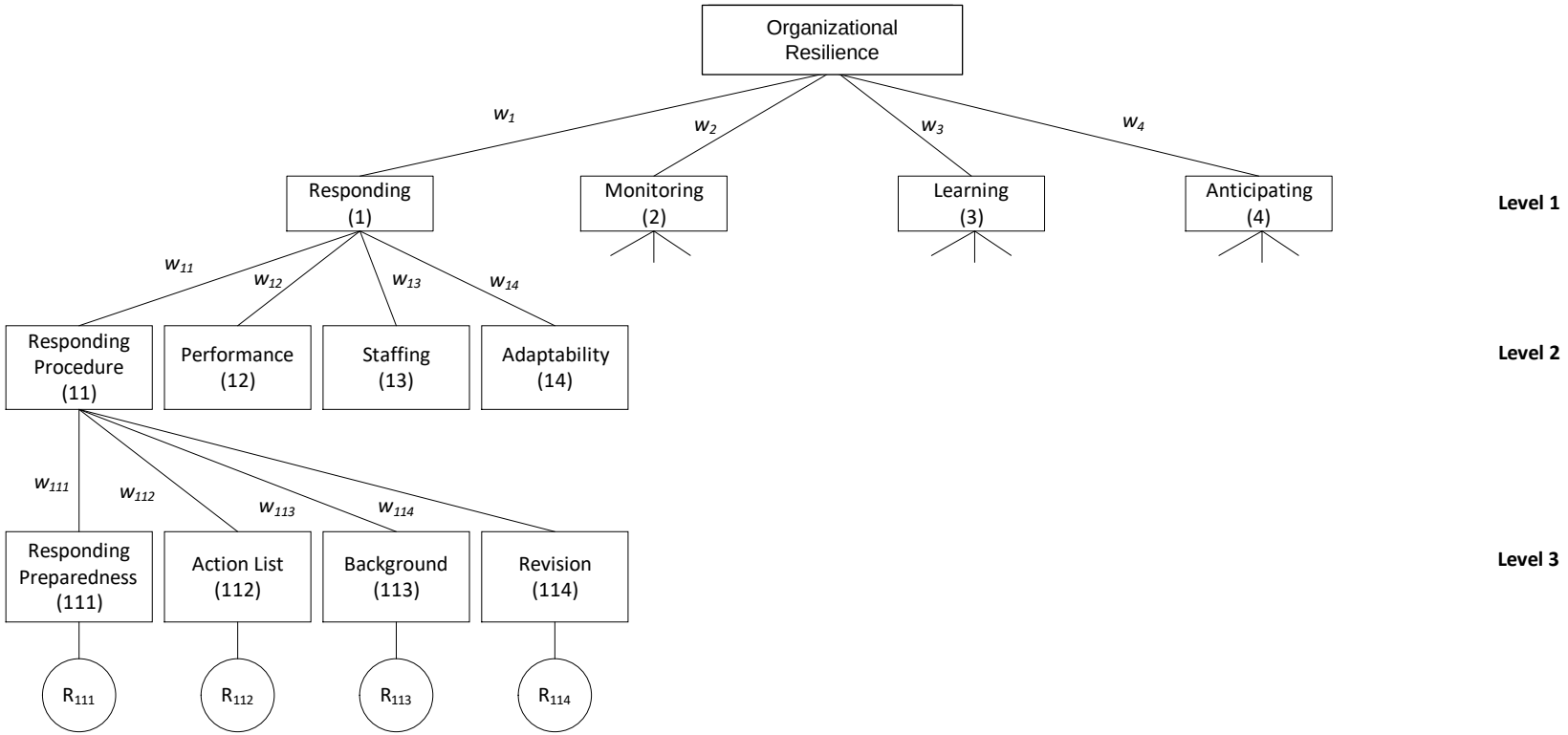
❖ Identification of the Top Five Important Contributing Factors

Rank	Factor	Definition
1	2.2.1 Availability	Is the information required for monitoring available in a timely manner?
2	2.2.2 Adequacy	Is the information required for monitoring provided in an appropriate manner?
3	2.3.1 Support System	Is there a system in place to provide or share the information necessary for monitoring or decision-making?
4	4.2.1 Plan Establishment	Are radioactive disaster prevention plans and on-site action manuals established in preparation for accidents?
5	2.1.3 Decision Making Criteria	If decision-making is required as a result of monitoring, are standards presented for this?

4. A Method and Questionnaire to Quantify the Resilience

❖ Equation for Calculating the Organizational Resilience

$$Organizational\ Resilience = \sum_i w_i \left[\sum_{ij} w_{ij} \left(\sum_{ijk}\left(w_{ijk} \times R_{ijk}\right)\right)\right] = [0, 1]$$



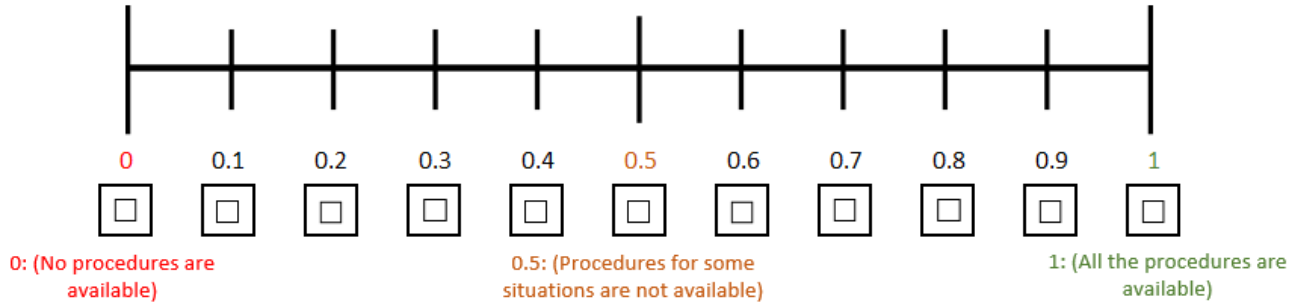
4. A Method and Questionnaire to Quantify the Resilience

An Example of the Questionnaire (1)

Top Level	Value	Level 1		Value	Level 2		Value	Level 3		Value
Organizational Resilience	0	1	Responding	0	1.1	Responding Procedure	0	1.1.1	Responding Preparedness	0
								1.1.2	Action List	0
								1.1.3	Background	0
								1.1.4	Revision	0
					1.2	Performance	0	1.2.1	Speed	0
								1.2.2	Duration	0
								1.2.3	Effectiveness	0
					1.3	Staffing	0	1.3.1	Number of Personnel	0
								1.3.2	Qualification	0
								1.3.3	Role & Responsibility	0
					1.4	Adaptability	0	1.4.1	Stopping Rule	0
								1.4.2	Alternative Strategy	0
					1.5	Tool & Equipment	0	1.5.1	Availability	0
								1.5.2	Adequacy	0
		2	Monitoring	0	2.1	Monitoring Procedure	0	2.1.1	Monitoring Preparedness	0
								2.1.2	Monitoring List	0
								2.1.3	Decision Making Criteria	0
					2.2	Information	0	2.2.1	Availability	0
								2.2.2	Adequacy	0
					2.3	Support	0	2.3.1	Support System	0
								2.3.2	External Support	0
		3	Learning	0	3.1	Training	0	3.1.1	Objective	0
								3.1.2	Trainer	0
								3.1.3	Method	0
								3.1.4	Facility	0
								3.1.5	Evaluation	0
								3.1.6	Frequency	0
					3.2	Experience Dissemination	0	3.2.1	Reporting	0
								3.2.2	Dissemination	0
		4	Anticipating	0	4.1	Communication	0	4.1.1	Clarity	0
								4.1.2	Communication Equipment	0
					4.2	Planning	0	4.2.1	Plan Establishment	0
								4.2.2	Scope	0
								4.2.3	Time Horizon	0
								4.2.4	Basis	0
					4.3	Safety Culture	0	4.3.1	Level	0
								4.3.2	Cooperative Norms	0
								4.3.3	Risk Factor Recognition	0
								4.3.4	Trust & Engagement	0

4. A Method and Questionnaire to Quantify the Resilience

An Example of the Questionnaire (2)

Factor	1.1.1 Responding Preparedness
Definition	Are response procedures in place?
Object	Procedure
Criteria	Does an procedure for emergency response exist?
Evaluating Box	
Basis	

Return to the structure

4. A Method and Questionnaire to Quantify the Resilience

❖ Checklist for Ensuring Objectivity

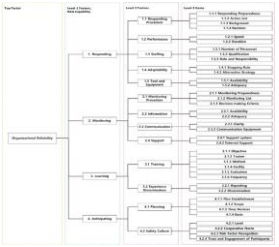
사고목록 (사고관리계획서 1.1)		가상사고	절차서 예시	절차서 존재 여부	비고	Responding Preparedness 정량화 값 (0 ~ 1)
						0
설계기준사고	이차계통에 의한 열제거 증가	주증기계통 배관파단사고	우선-01	☐ 존재		
			우선-02	☐ 존재		
			비상-04	☐ 존재		
			계통-3441	☐ 존재		
			계통-3451-01	☐ 존재		
			계통-3820	☐ 존재		
			계통-3881-01	☐ 존재		
			종합-3005	☐ 존재		
	이차계통에 의한 열제거 감소	주급수계통 배관파단사고	우선-01	☐ 존재		
			우선-02	☐ 존재		
			비상-05	☐ 존재		
			회복-01	☐ 존재		
			계통-3451-01	☐ 존재		
			계통-3820	☐ 존재		
			계통-3881-01	☐ 존재		
			종합-3005	☐ 존재		
			MOG-02	☐ 존재		
			MOG-03	☐ 존재		
	원자로냉각재 유량 감소	소외전원상실을 동반한 단일 원자로냉각재펌프 회전자 고착 및 소외전원상실을 동반한 단일 원자로냉각재펌프 축 파손사고	우선-01	☐ 존재		
			우선-02	☐ 존재		
			비상-06	☐ 존재		
			회복-03	☐ 존재		
			계통-3451-01	☐ 존재		
			계통-3820	☐ 존재		
			계통-3881-01	☐ 존재		
	반응도 및 출력분포 이상	제어봉집합체 이탈사고	우선-01	☐ 존재		
			우선-02	☐ 존재		
			회복-01	☐ 존재		
			회복-02	☐ 존재		
			회복-05	☐ 존재		
			회복-06	☐ 존재		
	원자로냉각재 재고량 증가	가상사고 없음	우선-01	☐ 존재		
			우선-02	☐ 존재		
			우선-01	☐ 존재		
			우선-02	☐ 존재		

5. Conclusion & Future Work

❖ Conclusion

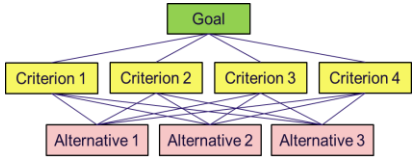
- **Suggesting a method and questionnaire to assess the reliability of ERO in nuclear power plants (NPPs) based on the resilience engineering concept.**
  - The contributing factors on the resilience of the ERO are identified
  - The relative importance of the contributing factors are identified using the AHP method
  - The method and questionnaire to quantify the resilience of ERO is suggested

Identifying the Contributing Factors



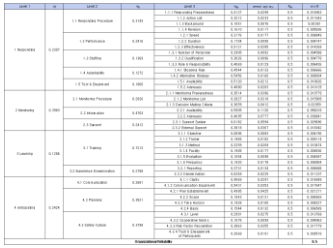
- Contributing Factors are identified from the literature survey on resilience and the Delphi survey

Evaluating the Contributing Factors



- Relative importance (weights) are calculated by 6 experts using AHP

Suggesting the Method and Questionnaire

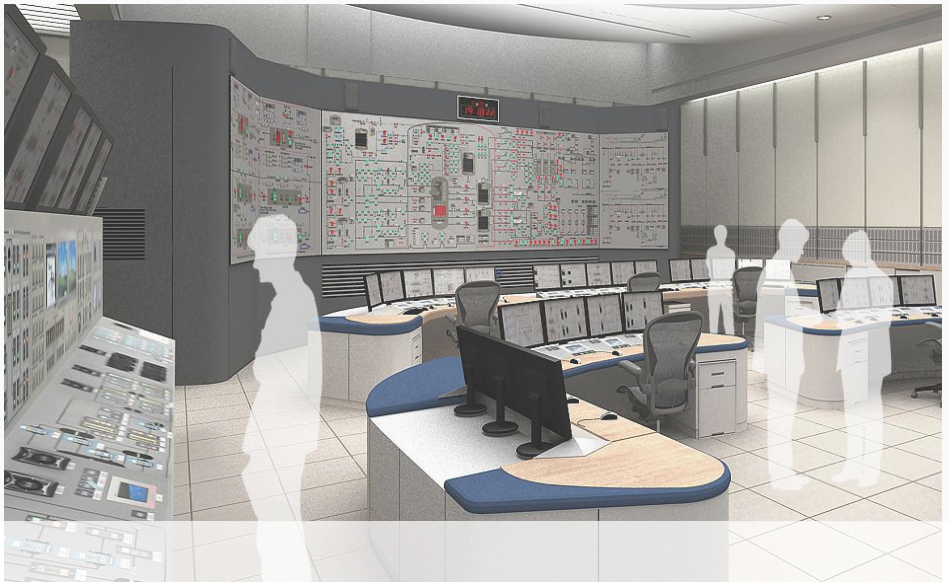


- The resilience of the ERO is quantified with evaluation of the level 3 factors

5. Conclusion & Future Work

Future Work

- Applying the methodology suggested in this study to the actual ERO in Korean NPPs.
- Identifying and suggesting the strength and weakness of the current ERO.



Thank you for your attention!

Email address: wogus9493@chosun.kr