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Original Article

A classification of electrical component failures and their human error types in South Korean NPPs during last 10 years

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ABSTRACT

The international nuclear industry has undergone a lot of changes since the Fukushima, Chernobyl and TMI nuclear power plant accidents. However, there are still large and small component deficiencies at nuclear power plants in the world. There are many causes of electrical equipment defects. There are also factors that cause component failures due to human errors. This paper analyzed the root causes of failure and types of human error in 300 cases of electrical component failures. We analyzed the operating experience of electrical components by methods of root causes in K-HPES (Korean-version of Human Performance Enhancement System) and by methods of human error types in HuRAM+ (Human error-Related event root cause Analysis Method Plus). As a result of analysis, the most electrical component failures appeared as circuit breakers and emergency generators. The major causes of failure showed deterioration and contact failure of electrical components by human error of operations management. The causes of direct failure were due to aged components. Types of human error affecting the causes of electrical equipment failure are as follows. The human error type group I showed that errors of commission (EOC) were 97%, the human error type group II showed that slip/lapse errors were 74%, and the human error type group III showed that latent errors were 95%. This paper is meaningful in that we have approached the causes of electrical equipment failures from a comprehensive human error perspective and found a countermeasure against the root cause. This study will help human performance enhancement in nuclear power plants. However, this paper has done a lot of research on improving human performance in the maintenance field rather than in the design and construction stages. In the future, continuous research on types of human error and prevention measures in the design and construction sector will be required.

1. Introduction

The TMI accident on March 28 in 1973 sparked interest in nuclear safety around the world. The Institute of Nuclear Power Operations (INPO) was established in response to the TMI accident. There were human errors among the main cause of the accident, so many studies on human error at nuclear power plants were carried out. As a result, INPO's Human Performance Enhancement System (HPES) was developed. HPES is a human behavior improvement system that systematically analyzes human error to prevent recurrence of human error such as the TMI accident. INPO HPES was inefficient in South Korea due to differences in behavior and thinking between Americans and Korean people. To compensate for these shortcomings, the Korean HPES was developed in 1993 [6]. The main cause of the Chernobyl disaster on April 16 in 1986 was a chain event and a potential error related to it. The World Association of Nuclear Operators (WANO) was then established. The WANO issued guidance to improve an organization's overall activities to ensure safety and reliable operation of nuclear power plants. Organizing culture that eliminates the factors that impede human performance can reduce plant accidents [13]. Human error is related to all human activities. Lee (2015) presented the concept of 'human error 3.0' that human error analysis should be reviewed as a single event rather than as a mistake of a unit of error [10]. This study analyzed causes of failure and types of human error in 300 events of operating experiences during the last 10 years registered in Korea Hydro Nuclear Power (KHPP)'s nuclear information system (KONIS) [7]. This study analyzes the relationship between electrical

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Table 1
Concept 'Human error 3.0'.

Concept version of human error	Key point	Related concept
1.0	Failures in Human Behavior	Traditional industrial safety A functional achievement Procedure and Training, etc.
2.0	Human Caused/Induced System Failure	After TMI incident Treat risks of human error Interface improvement, etc.
3.0	System Failure including Human Factors	Human factors in Chernobyl/Fukushima Preemptive response to an accident failure Resilience Engineering

(Source: Lee, 2015).

equipment failure and human error to prevent the failure of electrical equipment and the inability of systems to minimize electrical equipment failure by taking preemptive measures against the entire project, including design, purchase, construction and maintenance. Therefore, the purpose of this study is to contribute to the safe operation of nuclear power plants by analyzing the root causes of electric equipment failures from the viewpoint of a broad sense of human error and to emphasize the necessity of improvement in human activities throughout the life cycle of electrical equipment.

1.1. Changes in human error approach

There have been many changes in the approach of classifying human error to better analyze and respond to human error. The concept of human error 1.0 strengthened human task behavior through repeated training. The human error 2.0 concept is the view that human error is not a cause of accidents but a symptom of a system or a new independent event. Human error should be provided comprehensive definitions of human and mechanical systems. Human error 3.0 (see Table 1) is a scenario-based response to the possibility of structural errors that are difficult to deal with by applying tightened standards and managing them individually in order to prevent major accidents such as Fukushima [10].

1.2. Workflow of human error analysis in K-HPES

The three elements of human error root cause analysis are error reports, investigation methods, and workflow. Human error reports should be able to characterize the operational organization and should be written in a report form. K-HPES has been developed to perform cause analysis in the order shown in Fig. 1. First, the span of time must be drawn up (horizontal line). Then, find the cause for human error or device failure (vertical line). Keep track of the cause until the root cause is reached. Finally, for each cause, the barrier is identified, and corrective action is drawn [8].

1.3. Classification of root causes for human error in K-HPES

K-HPES has subdivided the causal factors into large, middle and detailed categories based on Korea's nuclear power plant

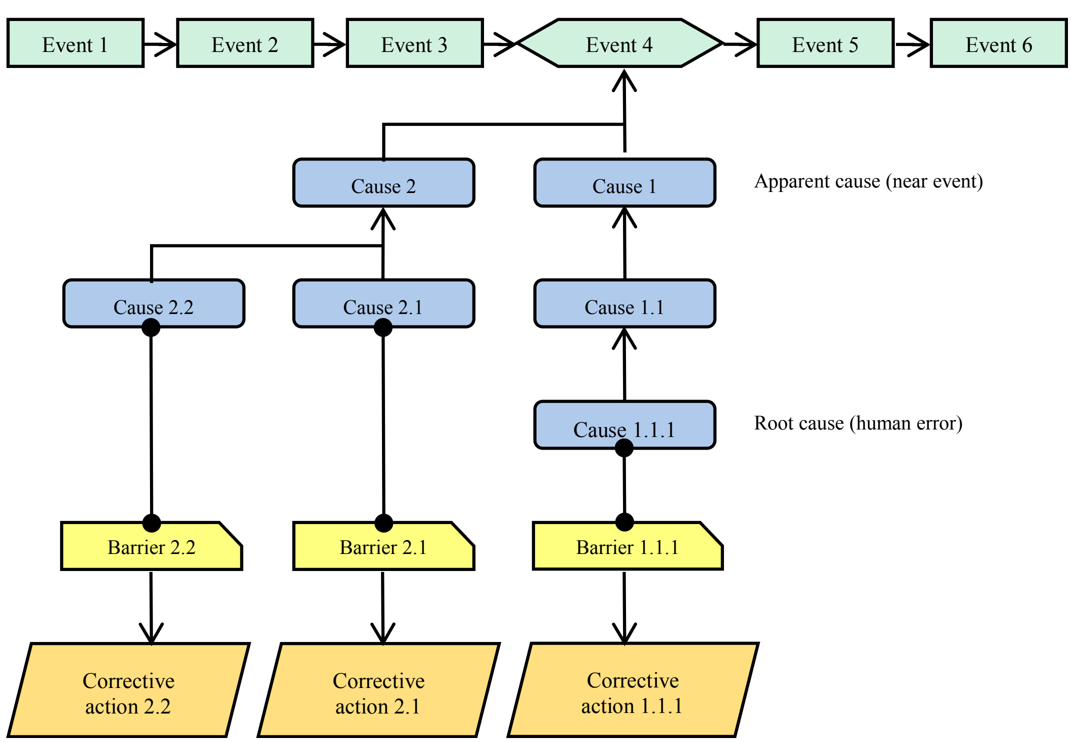

Fig. 1. Workflow of human error analysis.
(Source: K-HPES user's manual).

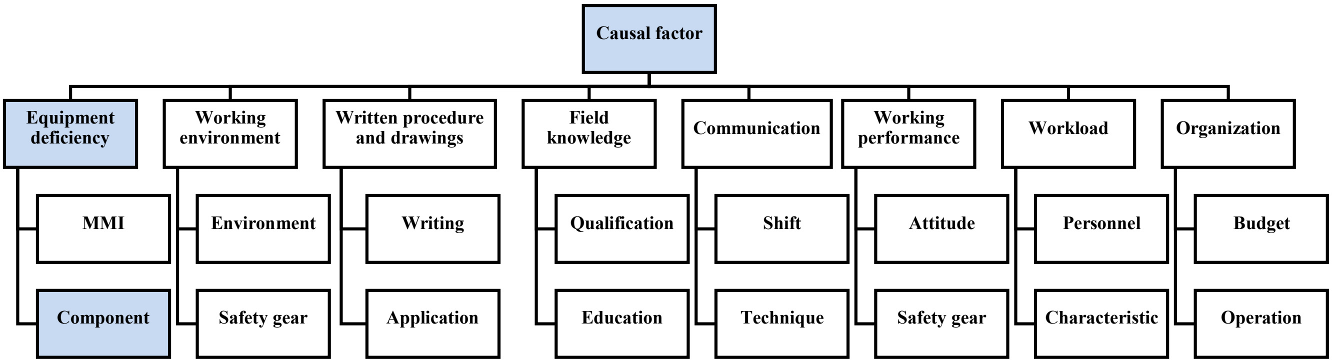

Fig. 2. Classification of causal factor.
(Source: K-HPES user's manual).

Table 2
Checklist of equipment deficiency.

Main category	Middle category	Detailed category	Related
Equipment deficiency	Component (battery, circuit breaker, MCC, fuse, cooler, communication network, generator, motor, power supply, protection relay, transformer, compressor, CRDM, diesel generator, pipe, valve, pump, dryer, filter, fire prevention equipment, heater, turbine, crane, door, damper, HVAC, printed circuit board, sensor, transmitter, inverter, switch, etc.)	Do not install the component/device	Y/N
		Poor component/device performance	Y/N
		Component/device deficiency	Y/N
		Interrupting the water (or lubricating oil, air, power, etc.) supply to the equipment	Y/N
		External events beyond design requirements (e.g. earthquake)	Y/N

(Source: K-HPES user's manual)

construction and operational experience since the commercial operation of Kori #1 NPP in 1978. Fig. 2 and Table 2 are used to identify the cause of the accident. A checklist technique allows the analyst to investigate without omission so that he can examine step-by-step whether this trigger contributes to the accident being analyzed. Research techniques first look for causes by hierarchy. Then, the barrier and corrective action are found. Specific examples of survey techniques include change analysis, literature investigation, interviews, and field verification [4]. Checklist techniques should exclude preconceptions. Each one is checked according to the well-defined causes of NPP. When looking at overseas accident investigation techniques, it is recommended to find the cause of the accident in terms of the 4M (Man Machine Management Method). These checklist techniques are complete but involve efforts to check many items. Table 2 may be used for inspection purposes but may also be used to classify the cause of the accident. In some cases, the flow of work is completed by an analysis by each organization, and after use, the flow is completed by spreading to other businesses. In particular, the workflow is very important until the analysis report is prepared [5].

1.4. Workflow of human error analysis and human error types in HuRAM+

Human factor research is being conducted in a variety of fields, including human engineers, reliability engineers, cognitive psychologists, human factor experts, and safety managers. The cognitive psychologist sees human error as an important clue to the study of human behavior control. However, the human error field analyst recognizes human error as a major safety threat. Therefore, theoretical researchers collect and develop error cases to categorize them, and field analysts want to get rid of errors [5].

HuRAM+ is part of the investigation process of the Korean nuclear industry regulatory agency. It was developed in-depth to analyze the cause of error in cases involving human error and to assist in the preparation of case studies, including measures to prevent recurrence. Fig. 3 is a graphical representation of the process and relationship of case studies.

2. Methods

In this paper, the operating experience of an electrical component is analyzed by two methods that are causes of failure in K-HPES and types of human error in HuRAM+. HuRAM + suggested human error types reflected the opinions of global human error experts. In this study, human error types of HuRAM + were applied in the analysis because is it easy for the field engineer to analyze the operating experience.

2.1. Definition of human error

Human error is related to most human activities. This paper applies a comprehensive concept of human error that results in unintended consequences throughout the life cycle of an electrical component or equipment. It includes human engineering error, manufacturing error, inspection error, installation errors, maintenance error, operating error, handling error, and so on.

Ergonomics experts try to collect and classify human error cases. However, field workers do a lot of research to eliminate human error. Human error can occur unknowingly because of human incompleteness [1]. If the engineers and other knowledge workers analyze the cause of electrical equipment breakdown and utilize the classification system created by the ergonomic expert, it will be very helpful to establish more accurate human performance improvement.

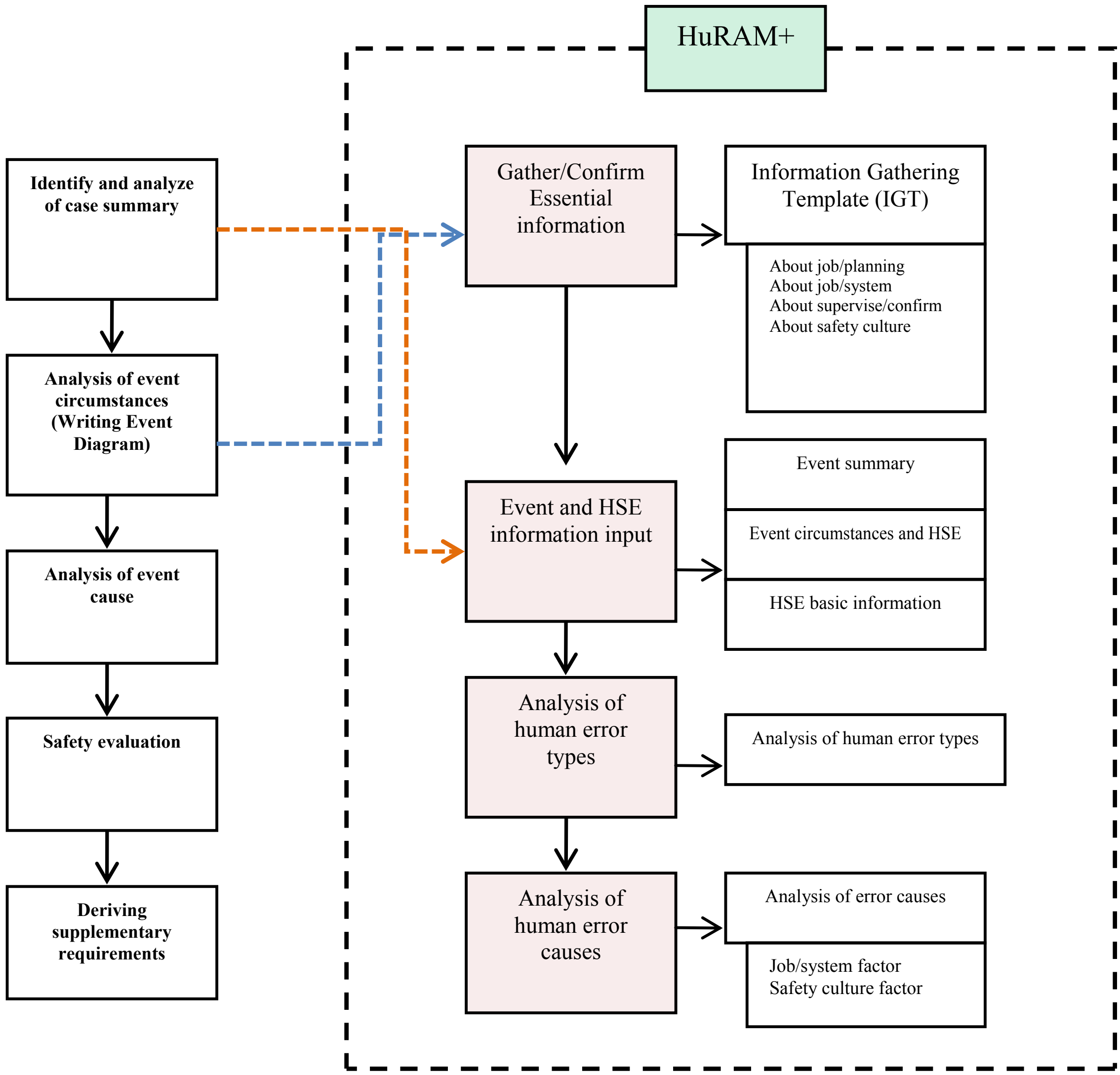

Fig. 3. Workflows of human error analysis and event investigation.
(Source: KINS/HR-1393).

2.2. *Causes of faulty electrical component*

The Korean Human Performance Enhancement System (K-HPES) classifies the cause of a faulty electrical component as direct cause, root cause, and contributing cause. Direct cause is an activity or condition that triggers an event. Direct causes in K-HPES include contact failure, disconnection, circuit failure, circuit opening, overheating, short circuit, arc occurrence, leakage, mistake, mechanic defect, wear, under voltage, discharge, vibration, over voltage, clogging, insulation failure, ground fault, hardware defects, cracks, humidity, violations, and so on. Root cause is the most fundamental cause of any breakdown or condition, and if it is corrected, it can prevent the recurrence of events or negative trends. Contributing cause is the source of interaction with a series of events that increase the risk of the final event. This can increase the likelihood of the event or the consequence or severity of the event. The root and contributing cause factors include aging of the equipment, inadequate production and installation by manufacturer, inadequate preventive maintenance, inadequate rearrangement, improper design, and so on [3,8]. The flow of the root cause analysis is as shown in Fig. 4.

2.3. *Types of human error*

The Korea Institute of Nuclear Safety (KINS), which regulates the construction and operation of domestic nuclear power plants, operates the human-related event root cause analysis method plus (HuRAM+) to analyze systematic causes of accidents caused by personnel errors. HuRAM + uses error types that were researched by human error experts such as Reason (1990) [11] and Swain & Guttman (1983) [12] etc. In addition, human error types are grouped into three categories in order to enhance the safety of workers in nuclear power industries that have a high impact upon accident [9].

There are three human error types in HuRAM+ (see Table 3). The first, human error type group I, consists of errors of omission (EOO) and errors of commission (EOC). The second, human error type group II, consists of mistake, slip/lapse, and violation. The third, human error type group III, consists of latent errors and active errors [9]. A mistake is an error in diagnosis or decision making. A slip/lapse is a performance error such as carelessness or illusion. A violation is an intentional performance of a procedure or regulation. A latent error is a potential error type that becomes

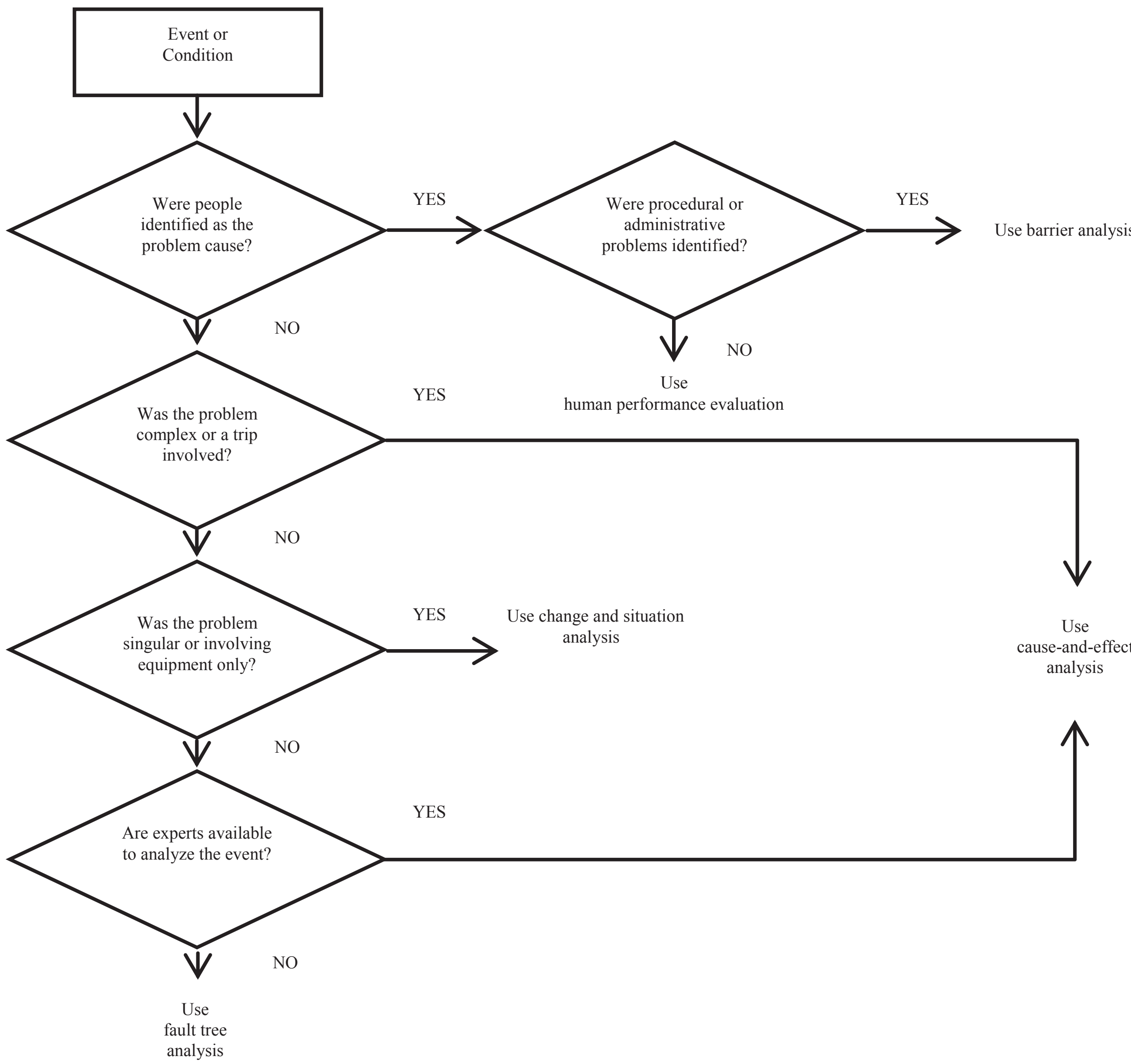

Fig. 4. Summary of root cause method.
(Source: INPO 90-004).

Table 3
Human error type in HuRAM+.

Human error type group	Human error type		
Group I	☐ EOO	☐ EOC	
Group II	☐ Mistake	☐ Slip/Lapse	☐ Violation
Group III	☐ Latent error	☐ Active error	

(Source: KINS/HR-1393).

unavailable due to human activity but learned later when operating the device/system [11].

2.3.1. Human error type group I

Swain & Guttman (1983) divided the error types into EOO and EOC [12]. EOO is an error type that is caused by system or device problems due to missing actions or procedures. EOC is an error type that occurs due to wrong actions or procedures being performed. For example, when testing circuit breakers, the location of the breaker was changed to the position 'rack-in', 'test position' or 'rack out'. However, maintenance work was completed without restoring the location of the breaker in correct order after inspection. The breaker could be out of service. This type of error is EOO. EOC means an error in which a problem arises by performing an action or procedure incorrectly or taking actions that affect other devices. For example, the stop button of a certain device must be pressed, but the operation button is pressed or different device is operated [9].

2.3.2. Human error type group II

Reason (1990) divided the error type classification system into Mistake, Slip/Lapse, and Violation [11]. Mistake means the failure of intention formation. In other words, it is an error that occurred during the diagnosis or decision-making process. For example, errors that occur during the performance of a task in accordance with the planning and procedures established by the operator in an unfamiliar environment with little experience or information. Slip/Lapse is a failure of action on the correct intention. They are errors due to momentary misunderstanding or carelessness. Slip is an inadvertent failure to perform a task. For example, too much force is given or vice versa when working. Lapse is the inability to remember work actions, places, etc. when performing work. Violation is an act of deliberately breaking away from regulations or guidelines. For example, there are workers who do not wear safety equipment in high voltage workspace [9].

2.3.3. Human error type group III

Latent error is a type of error that has potential effects because the device or system is inoperable due to operator error, but the device and system are kept in standby mode. In contrast, active error is such that the device immediately becomes unavailable [9].

2.4. Techniques for the prevention of human error

The Institute of Nuclear Power Operations (INPO) provides two tools to prevent human errors by engineers. They are basic tools and conditional tools.

2.4.1. Basic tools of prevent human errors in engineers

Business mistakes by technical management personnel such as engineers have a very negative potential for plant safety and economic performance. Potential errors cause potential defects in plant equipment or related documents. The basic tools include those that are regularly used in any activity, regardless of the risk or complexity of the task. Table 4 shows five basic tools [1].

2.4.2. Conditional tools of prevent human errors in engineers

Conditional tools (see Table 5) provide engineers with error management methods that depend on circumstances, tasks, needs of work, and associated risks. These are used as needed and depending on the circumstances of the project [2].

2.4.3. Tools of prevent human errors in operator and worker

The techniques (see Table 6) for preventing human error during task performance are situational awareness, self-checking, effective communication, use and compliance of procedures, verification techniques, pre-job meeting, peer check, installation of flagging & operational barriers, place keeping, turnover and post-job critique [2].

3. Analysis of survey results

The survey was conducted of 300 cases of electrical component failures of a nuclear power plant. Cases of the electrical component failures in NPP referenced the data recorded from 2006 to 2016 in KHNP's nuclear information system (KONIS).

3.1. Types of faulty electrical equipment

Types of faulty electrical equipment are such as circuit breaker, emergency generator, transformer, motor, and others. Details are as shown in Fig. 5.

According to reports of the operational experiences by KONIS, the number of breakers and emergency generators accounted for 37.4% of the total. There have been more than five cases registered annually in the last five years, with the number of breakers, emergency generators, transformers and motors on a steady rise.

Table 4
Basic tools to prevent human errors by engineers.

Tools	Description
Technical task pre-job briefing	The pre-work meeting identifies additional controls or obstacles. Results related to human error can be identified for specific attributes of a project.
Self-checking	Self-checking promotes attention to important points in an activity. It takes time to focus attention and consider the planned measures and expected results.
Questioning attitude	This helps to ensure that planning, judging and making decisions about the activities are appropriate.
Assumptions	Engineers make additional efforts to prove that additional assumptions are conservative and to provide specific evidence to support them. Engineers can inadvertently treat assumptions as facts or forget that they have made them.
Documentation	Individuals complete work by signing or sealing documents. This means that the work was accurate and complete according to all criteria, procedures and code requirements.

(Source: INPO 05-002).

Table 5
Conditional tools to prevent human errors by engineers.

Tools	Description
Project planning	Project management includes activities or tasks related to achieving goals while optimizing limited resources. Document these project management activities.
Vendor oversight	Seller, contractor and plant-external personnel are involved in significant accidents at the plant by about 50%.
"Do not disturb" sign	Engineers should concentrate when the task being performed includes a test or proof-of-work results. The purpose of this sign is to limit access or interference to personnel performing work or review.
Peer review	The purpose of the peer review is to detect errors in risk-critical tasks or to verify that the action plan or decision is appropriate before performance.
Problem solving	Problem solving involves combining cause-result relationships in reverse order to determine why there is a problem.
Decision making	Decision making is a progressive method used to predict the potential effects of a conclusion. Power plants and personal safety require conservative decisions.
Turnover	Turnover is the overall and sequential transfer of work-related information between two individuals. This can happen during major activities such as shift work.
Product review meeting	Product review meetings are used to coordinate initial design review and design change review. Important opinions are assessed and specific incidents are required for all product reviews.
Technical task post-job review	Post-job reviews can identify vulnerabilities in procedures, programs, and policies that negatively affect activity. An effective review can yield learning effects.
Work product review	The work result review provides accurate feedback to the document author and identifies opportunities for improvement.

(Source: INPO 06-002).

Table 6
Tools to prevent human errors in operator and worker.

Tools	Description
Situation awareness	Situation awareness compares the conditions and time of the work to the site conditions and provides detailed information sharing. This is to ensure that supervisors and workers get the right work results.
Self-checking	Self-checking uses STAR (stop-think-act-review) techniques to ensure that the worker is able to focus and clearly judge the actions of each step in the procedure.
Effective communication	To ensure accurate communication, the sender should ensure that the recipient understands the instructions correctly.
Use and compliance of procedure	Use pre-approved procedures to obtain accurate results of the job performance. This will allow you to perform safer tasks.
Verification techniques	The verification technique includes simultaneous verification and independent verification. Simultaneous verification is a technique in which two workers simultaneously check procedures, operate devices, and perform tasks. Independent verification is a way for workers to check for human error after device manipulation.
Pre-job meeting	Pre-job meetings include preparation and discussion of work activities. It is common to assign specific tasks to participants. This section provides a brief introduction to low-difficulty tasks and details of high-difficulty tasks.
Peer check	Peer check is a verification technique that involves inspection from a colleague who knows the equipment well.
Installation of flagging & operational barriers	Flagging is the marking of the device to be clearly identified. An operational barrier is installed in a location adjacent to the device, such as a cover or a fence, to physically isolate a device that has the same function and shape.
Place keeping	Place keeping marks physically the major working steps to prevent a procedure omission or duplication.
Turnover	Turnover can help the acquirer understand what needs to be focused on and what can be predicted.
Post-job critique	Post-job critique is a meeting to identify and improve the progress of the work procedure and the vulnerabilities to the results.

(Source: INPO 06-002).

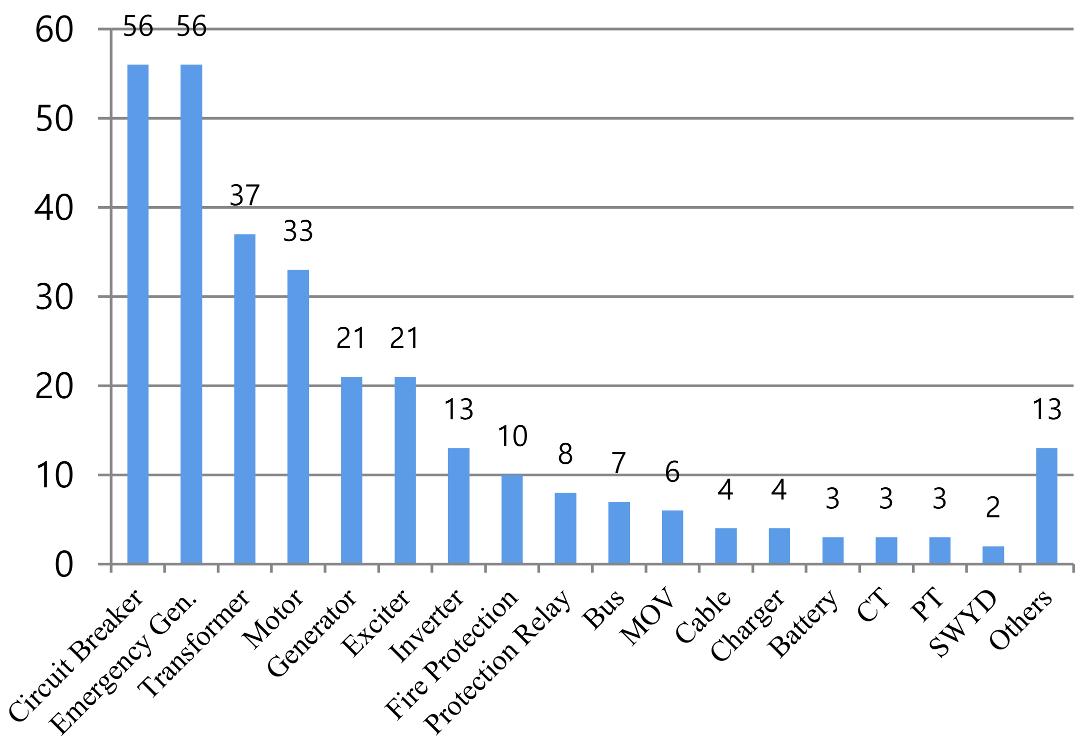

Fig. 5. Types of faulty electrical equipment.

3.2. Analysis of direct cause types

The direct causes of electrical component failure are very diverse. The major types of cause were loose connections/disconnection (18%), circuit failure/open (14%) and overheating (6%). Human errors of electrical works account for more than 10% of the total. Details are as shown in Fig. 6.

The direct causes of electrical equipment failure have been found in many ways. Among them, contact problems, open circuit, overheating, and circuit malfunction accounted for 51.3%. Addressing these causes, through proper replacement and maintenance of electrical equipment, can significantly reduce the failure rate.

3.3. Analysis of root cause types

The root causes of electrical equipment failure were aging of the equipment, improper production and construction, degraded performance of component and others. Details are as shown in Table 7.

The types of root cause can be simplified to fields of aging (15.7%), production/construction (12.7%), degraded performance of component (11.3%), maintenance (6%), design (5%), operation (3.3%), and others (15.7%). More than half of causes are associated with aged equipment and improper maintenance. This is considered to be an inadequate predictive maintenance and overhaul due to the aging of the electrical equipment, resulting in electrical equipment failure.

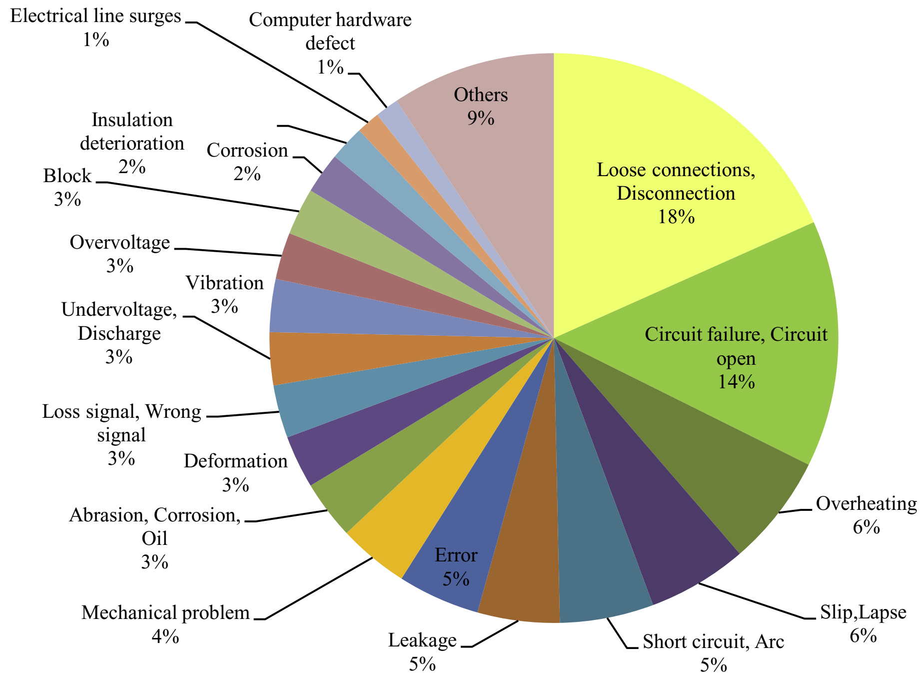

Fig. 6. Direct causes of faulty electrical component.

Table 7
Types of root cause.

Types of root cause	Case count	Ratio
Aging of the equipment	47	15.7%
Improper production/construction	38	12.7%
Degraded performance of component	34	11.3%
Maintenance performed incorrectly	18	6.0%
Improper preventive maintenance	16	5.3%
Improper arrangement	16	5.3%
Improper original design	15	5.0%
Operation of outside design specification	10	3.3%
Inadequate installation technology	9	3.0%
Inappropriate monitoring	5	1.7%
Failure within expected life	5	1.7%
Inappropriate material selection	5	1.7%
Absence of attention information	5	1.7%
Technically inaccurate/incomplete	4	1.3%
Inadequate use of materials	4	1.3%
Inadequate testing after maintenance	4	1.3%
Inappropriate equipment selection	3	1.0%
Inadequate review of design changes	3	1.0%
Design analysis failures	3	1.0%
Corrosion/erosion of equipment	3	1.0%
Incorrect recovery after maintenance & test	3	1.0%
Worker skills are not familiar with job performance criteria	3	1.0%
Others	47	15.7%

3.4. Analysis of contributing cause types

The contributing causes of the electrical equipment failure were degraded performance of component, aging of the equipment, improper production/construction, improper preventive maintenance, and others. Details are as shown in Table 8.

3.5. Analysis of human error type group Ⅰ

This paper analyzed the cause of electrical component failure by human error types in HuRAM+. The analysis of human error type group Ⅰ in electrical component failure showed that EOC was 97% and EOO was 3%. Details are as shown in Fig. 7. This is the classification of surface behavioral levels for human error of electrical equipment, which categorizes errors according to the readily observable characteristics of incorrect behavior. The failure causes of electrical equipment are mostly classified as improper performance errors from a human error perspective. A wide range of facility reliability needs to be established, including facility assessment, development and implementation of mid-term to long-term facilities maintenance plan, and facility performance and status monitoring, using five basic preventative tools for human error of engineers.

Table 8
Types of contributing cause.

Types of contributing cause	Case count	Ratio
Degraded performance of component	42	14.0%
Aging of the equipment	41	13.7%
Improper production/construction	20	6.7%
Improper preventive maintenance	19	6.3%
Maintenance performed incorrectly	16	5.3%
Inappropriate monitoring	13	4.3%
Corrosion/erosion of equipment	9	3.0%
Improper original design	9	3.0%
Absence of a valid document	8	2.7%
Inadequate installation technology	7	2.3%
Technically incomplete	6	2.0%
Absence of attention information	5	1.7%
Inadequate testing after maintenance	5	1.7%
Operation of outside design specification	5	1.7%
Lack of awareness	5	1.7%
Inappropriate equipment selection	4	1.3%
Inadequate field education/experience	4	1.3%
Incorrect recovery after maintenance & test	4	1.3%
Technically inaccurate	4	1.3%
Inappropriate monitoring of progress	4	1.3%
Inadequate review of design changes	4	1.3%
Unknown status before operation	4	1.3%
Others	62	20.7%

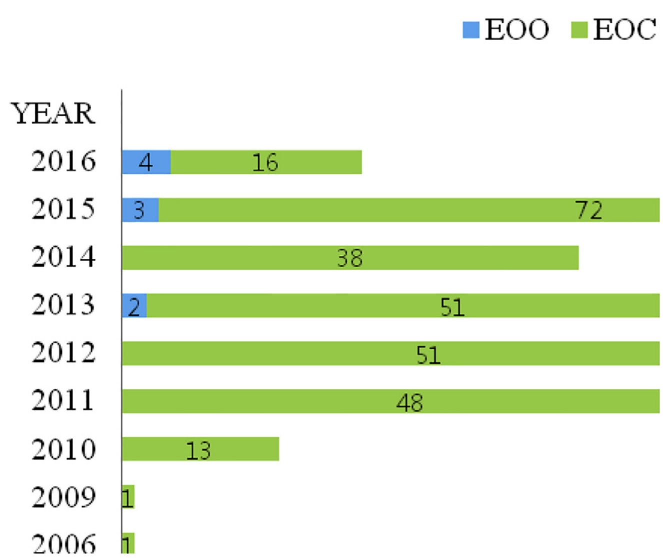

Fig. 7. Human error type group I.

3.6. Analysis of human error type group II

The human error type group II was applied to cause of electrical component failure. The results were in the order of slip/lapse (74%), mistake (25%) and violation (1%). Details are as shown in Fig. 8. The causes of electrical equipment failure under this classification are divided into diagnosis and decision errors (25%) and performance errors (74%). In the human vulnerability of operators, supervisors and workers, errors are generated by an underestimate or oversize. There were more human errors of maintenance than human errors of operating. According to the details of the work performance, errors occurred due to the lack of prediction of the work results before work, independent check during work and peer check and verification after work. In field knowledge, errors occurred due to lack of knowledge rather than experience. In the workload category, the failure of working hours is the main cause. The communication sector is due to too much or too little information and

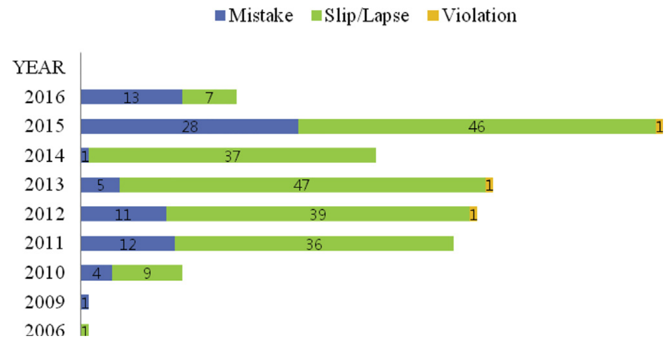

Fig. 8. Human error type group II.

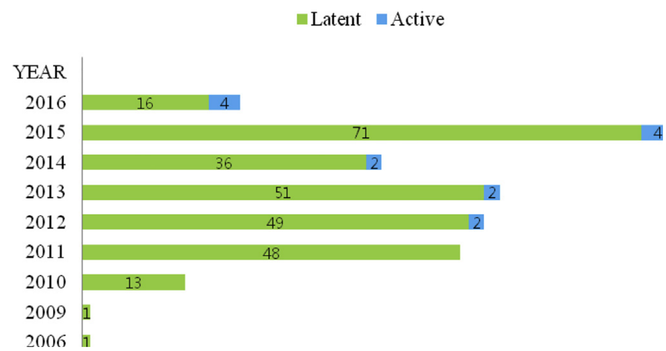

Fig. 9. Human error type group III.

inaccurate content. In the equipment defects section, the number of failures due to aging of the equipment was higher than of insufficient functions. In the working environment, there were intensive degradation factors that caused human error. Comprehensive and prior reflection of the operation experiences was insufficient at the organization's point of view.

3.7. Analysis of human error type group III

The result in applying human error type group III to electrical equipment operation experiences was latent (95%) and active (5%) errors. Details are as shown in Fig. 9. Most nuclear power plants are operated and maintained based on procedures. Therefore, there are many types of error based on procedure. These errors are a potential source of error, resulting in the inability and malfunction of electrical equipment.

3.8. The cause and prevention of electrical equipment failure in human performance

The failure of electrical equipment is related to humans. The failure cause of all electrical equipment is a result of extensive human error by designers, constructors, operators and workers. Analysis of human error patterns related to electrical equipment failure revealed that most of the errors were based on performance errors, potential errors, and procedures. Table 9 lists the human error prevention techniques for the causes of electrical equipment failure.

4. Conclusions

This paper has found that faulty electrical components have a variety of influencing factors in terms of comprehensive human

Table 9
Prevention techniques by detailed factors of human error.

Human error type	Category	Detailed Factor	Prevention techniques
EOC, Slip/Lapse, Latent	Electrical equipment failure	Loose connection and open circuit	Resilience engineering for a positive response
	Working environment	Obstacles to concentration	Situation awareness Use and compliance of procedure Pre-job meeting Peer review Post-job critique
	Procedure/drawings	Missing procedures and steps	Use and compliance of procedure
	Working management	Insufficient checking of job status	Situation awareness Questioning attitude Pre-review Stop in case of uncertain situation pre-check
	Field knowledge	A lack of knowledge	Situation awareness Use and compliance of procedure
	Communication	Provide too much or too little or short of information	Effective communication
	Work performance	Insufficient understanding of influence before work	Situation awareness Pre-job meeting Post-job critique Verification technique Peer review
	Work load	Lots of work in inadequate time	“Do not disturb” sign
	Organization	Inadequate reflection of operating experience	Active support

performance in nuclear power plants. Prevention techniques and types of human error related to electrical equipment failures were identified and analyzed. Major faulty electrical components of operating experience consist of circuit breaker, emergency generator, transformer and motor. The main direct causes of faulty electrical components are contact failures and circuit opening. The major root and contributing causes of electrical component failure were the aging of component/equipment and production/construction defects. The root cause is that it can be a human error factor throughout the life cycle of the product, from design to installation and maintenance. In the present industrial field, the focus is on the prevention of human error in the narrow viewpoint of the worker’s behavior. The characteristics of human error type are mostly inadequate performance errors that produce potentially erroneous results. Nuclear power plants are continuously improving human performance prevention techniques related to maintenance. However, efforts to prevent human error in design and construction are much less than those of operating power plants. In conclusion, all stakeholders (supplier, designer, subsupplier, construction contractor, and so on) should actively work to improve human performance. This study was analyzed through limited operation experiences related to the electrical installation of nuclear power plants. Human error can also be caused by different causes and consequences depending on various and complex environments. There is a lack of research to link and integrate human error and facility management for each industrial site. Research is needed to establish an integrated human error management system for engineers, designers, and manufacturers.

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