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Analysis of Human Errors in Trip Cases of Korean NPPs

Jung Woon Lee, Geun Ok Park, Jae Chang Park, and Bong Shick Sim
Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

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Abstract

A total of 77 cases was identified to have human errors from a total of 255 trips occurred from 1978 to 1992 in Korean NPPs. The cases were analyzed to investigate how many human errors occurred on which work conditions to find out the areas of high priority for human error reduction. For the analysis of the 77 trip cases due to human errors, classifications were made for the following four categories; plant systems, work situation, job types, and error types. Erroneous tasks critically influencing the plant trips were carefully identified and analyzed according to the classifications. Based on the results for the individual cases, the cases were counted for the classification items in each of the four categories, then also for the group of categories to investigate the relationships among the categories in aspects of human error occurrences. As results, the plant systems, work situations, and job types, and error types that are dominant in human errors related to the trips were identified.

1. Introduction

It has been reported that somewhere in the range of 30~50% of the nuclear power plant (NPP) incidents have occurred due to erroneous actions [1, 2]. This implies that human error is a very important factor affecting the safety and availability of NPPs. After it was revealed that human errors were involved in TMI-2 accident, researches on human factors in NPPs were started intensively in the advanced countries operating NPPs. The researches are the reviews and upgrades of control room design in operating NPPs, the development of operation support systems, the enhancement of human factors regulatory requirements, human error studies in cognitive aspects, etc. These efforts have a common goal to reduce human errors in NPPs. In all the efforts, however, it is very difficult to find ways to reduce human errors effectively and evidently. There can be many reasons for this. At first, an important point in handling human errors is that the characteristics of tasks in NPPs should be well considered. Since a NPP is a large and complex system and its operation requires so many types of work, it is hard to consider well the characteristics of tasks in NPPs. Many efforts tried by academic and research institutes accomplished unsatisfactory results due to in parts that the real tasks were not fully acknowledged. The second point is that human performance has variousness. Even though the tasks can be defined and well acknowledged, the variousness can make the efforts ineffective. This variousness, in many occasions, leads high level managers of NPPs to have an illusion that any efforts in human factors researches are less effective in human error reduction than the strict management and control of plant personnel, or simply exercising moral education. However, considering that human errors occur due to the mismatch between human and machine or task, as Rasmussen [3] said, it is a way of compromising human error problems to change the work conditions to be more error resistant. The work conditions that can be considered here are, for examples, work space and human machine interface design, work procedures, training, work management, job aids, and work environment. Reason [2] also argued that incidents occurred by not only human errors but also latent failures residing in work context. Improvement of work conditions or removal of latent failures can be achieved by investigating the problems existing behind and causing human errors, then by applying suitable remedial actions against the problems.

It is necessary to investigate high priority areas in task domains before we find and solve the problems through the analysis of previous human errors. In the research report by Cho et al. [2], there are valuable results on human errors and problems. But they obtain the results from interviews, surveys, and analyses of training simulator operation, which are not from human error cases in the operating plants. Nuclear Power Plant Trip Case Reports [4] contain detailed description on the trip cases occurred in Korean NPPs, and Nuclear Power Generation Annual Report [5] contains the summaries of trip cases and some statistics on Korean NPPs. In the Nuclear Power Generation Annual Report [5], it is stated that only 34 cases were caused by human errors among the 255 trip cases. This means that only 13% of the total trips caused by human errors, which is a lot lower than those in other countries operating NPPs. Human errors in these reports are acknowledged only for the evident wrong actions made by plant personnel, such as wrong operation of equipment. It is necessary to apply a comprehensive definition of human errors that is inappropriate behavior that hinders normal operation of plants. In this study, we reviewed the Nuclear Power Plant Trip Case Reports considering the comprehensive definition of human errors to collect trip cases due to human errors. Then we identified inappropriate behavior critical to the plant trips, and analyzed the related plant systems, work situations, job types, and error types to investigate the task areas having high rate of human errors related to NPP trips.

2. Analysis of Trip Cases due to Human Errors

2.1. Rate of Human Errors in Trip Cases

Nuclear Power Plant Trip Case Reports [4] published from 1984 to 1993 and Nuclear Power Generation Annual Report [5] were used in this study. Nuclear Power Plant Trip Case Reports published in the earlier years include the cases that did not reach to trips. A total of 255 trip cases was identified by comparing the summaries in Nuclear Power Generation Annual Report to the descriptions in Nuclear Power Plant Trip Case Reports. Reviewing the Nuclear Power Plant Trip Case Reports, we identified the malfunction or failures of systems or components that caused trips and then inappropriate behavior performed on the systems or components. Plant operation experience that some of authors have was utilized here. A total of 77 trip cases was identified to include human errors among the 255 cases. This means that the rate of human errors in the trips turns out to be about 30%. This figure is higher than 13% stated in Nuclear Power Generation Annual Report, but still in the lower boundary of human errors reported as 30% to 50%, recorded in other countries. Figure 1 shows the annual numbers of trip cases together with the trips due to human errors, and Figure 2, the annual percentages of the trip cases due to human errors to the total trips. In Figure 2, we can see a trend that the rates increase as operating years are accumulated. This trend also can be seen in NPPs in Japan [6]. To see this trend more precisely, the annual numbers of trips in Figure 2 are averaged for one reactor unit. Figure 3 shows the annual numbers of trips and the trips due to human errors averaged for one reactor unit. In Figure 3, the trips show a decreasing trend, however, the trips due to human errors are rather consistent. This can be interpreted by that the improvement of component manufacturing technologies and maintenance techniques reduces the trips due to component failures, which is the most dominant factor causing the plant trips, but not the same for the trips due to human errors.

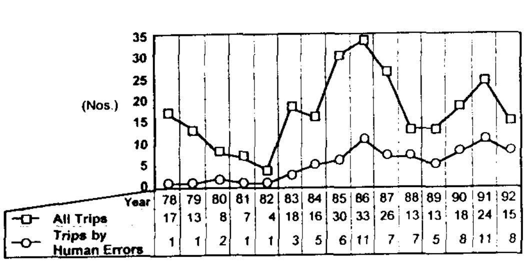

Fig. 1. The Annual Numbers of Trips and the Trips Due to Human Errors.

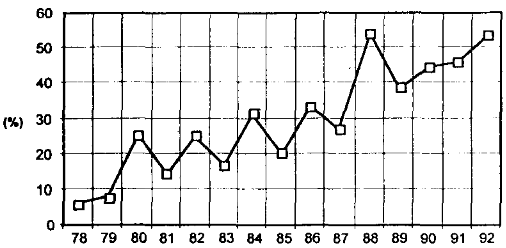

Fig. 2. The Annual Percentages of the Trips Due to Human Errors to the Total Trips.

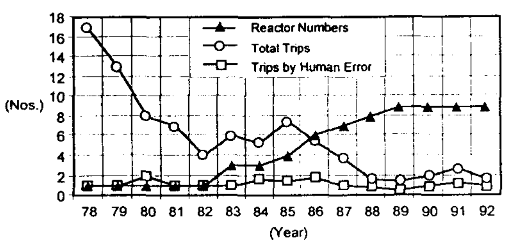

Fig. 3. The Annual Numbers of Total Trips and Those in Duced by Human Errors Averaged for one Reactor Unit.

2.2. Classifications for the Analysis

To analyze the human error occurrences, four categories were selected as follows ; plant systems related to the tasks where human errors were taken place, work situations under which the tasks were performed, and job types of personnel performing the tasks. Table 1 shows the classification items used for the analysis of trip cases. The plant systems were classified into the major systems of primary systems, secondary systems, and other facilities in NPPs. The work situations were classified into the normal operation, the periodic inspection and tests according to the regulatory requirements or manufacturer's specifications, the urgent maintenance due to abnormal states requiring urgent remedial actions, the planned maintenance according to the plant maintenance plans, and the overhaul, which is a kind of planned maintenance but performed in a large scale during refueling periods. Job types for the jobs manipulating directly the plant hardware were considered and classified into the main control room (MCR) operation, the local equipment operation, the instrument and control (I&C) job, the mechanical job, and the electrical job. The word 'other' was used for the cases by the personnel outside the plants or not clearly mentioned in the reports.

Next, the types of errors were considered in the classification. There are many classifications made by others. Among the classifications, the classification by Swain [7] (Table 2) based on a conventional ergonomic approach and the classifications based on human information processing theory, such as the classifications by Reason [1] (Table 3), by Rouse and Rouse [8] (Table 4), and by Rasmussen [9], were considered in this study.

These classifications, however, contain items too generic or comprehensive to relate to the characteristics of tasks in NPPs, such as the steps or patterns inherent to specific job types, or too extensive to human cognitive process to apply to the description in the trip case reports. Based on these classifications

Table 1. Classifications for Plant Systems, Work Situations, and Job Types Used for the Analysis of Trip Cases

Categries	Items (Abbreviations)
Plant Systems – Primary Systems	Reactor Control & Protection System (RCPS), Reactor Coolant System (RCS), Pressurizer Control & Protection System (PCPS), Steam Generator Control & Protection System (SGCPS), Steam Generator (SG), Residual Heat Removal System (RHRS), Chemical & Volume Control System (CVCS), Nuclear Instrument & Control System (NICS), Containment Humidity &Vacuum System (CHVS), Engineered Safeguard System (ESS), Primary Component Cooling Water System (PCCWS)
– Secondary Systems	Main Steam Supply & Dump System (MSSDS), Main Steam Reheat & Extraction System (MSRES), Auxiliary Steam System (ASS), Turbine Control & Protection System (TCPS), Auxiliary System for Turbine (AST), Generator Control & Protection System (GCPS), Auxiliary System for Generator (ASG), Main Feedwater System (MFS), Auxiliary Feedwater System (AFS), Condensate Polishing System (CPS), Circulating Water System (CWS), Secondary Component Cooling Water System (SCCWS), Auxiliary Electric Power Supply System (AEPSS), Electric Power Transmission System (EPTS)
– Other Systems	Instrument Air System (IAS), Fuel Handling System (FHS), Waste Material Processing System (WMPS), HVAC System (HVACS), Radiation Monitoring System (RMS), Auxiliary Subsystems (AS)
Work Situations	Normal Operation (NO), Periodic Test (PT), Urgent Maintenance (UM), Planned Maintenance (PM), Overhaul (OH)
Job Types	Main Control Room Operation (CR), Local Equipment Operation (EO), Instrument & Control Job (IC), Mechanical Job (ME), Electric Job (EL), Others (O)

Table 2. Error Classification by Swain [7]

Errors of Omission (intentional or unintentional)	Omits entire step	
	Omits a step in task	
Errors of Commission	Selection error	Selects wrong control,
		Mispositions control (includes reversal errors, loose connection, etc.),
		Issues wrong command or information (via voice or writing)
	Error of sequence	
	Time error	Too early,
		Too late
	Qualitative error	Too little,
		Too much

on human errors, a new classification system for error types was made. Table 6 shows the error classification developed and used in this study. The classification system has two levels of error types, representative and specific. The representative error types were made to cover the external manifestation of erroneous actions, and the specific error types to be suitable for discerning various errors in the case reports with terminology related to the plant tasks. This error classification was revised several times as the analysis of individual cases proceeded. Among the error types in Table 6, omission and commission of wrong action were classified in detail by considering inappropriate actions detected from the reports. The error type, lack in performance(qualitative), was additionally considered to discern the actions in this category from those of other error types. Unskilled performance was included to represent the errors in main control room operation not described in detail but as "unskilled operation" in the reports.

2.3. Analysis of Trip Cases Due to Human Errors by Each Classification Category

The collected 77 cases were analyzed in the following way. At first, all the inappropriate actions were identified for each case, then among them, one action considered as initiative and most critical to the trip was selected. For these critical actions, related plant systems, work situations, job types, and error types were identified by using the classifications in Tables 1 and 6. Based on the results for the individual cases, the cases were counted for the classification items in the categories of plant systems, work situations, task types, and error types.

As the results for the systems to which human errors were related, Figure 4 shows that the secondary systems hold 69% of the total trips due to human errors, the primary systems record 23%, and other facilities, 8%. This means that the human errors affect-

Table 3. Error Classification by Reason [1]

Cognitive Control Mode	Error Type
Skill-based Performance	Recency of prior use Frequency of prior use Environmental signals Shared "schema" properties Concurrent plans
Rule-based Performance	Mind-set Knowledge availability Matching bias Oversimplification Over-confidence
Knowledge-based Performance	Selectivity errors Short term memory limitations Bounded rationality Thematic vagabonding Encystment Reasoning by analogy Errors of deductive logic Incomplete mental model Inaccurate mental model

Table 4. Error Classification by Rouse and Rouse [8]

General Category	Specific Category
Observation of system states	a. exessive b. misinterpreted c. incorrect d. incomplete e. inappropriate f. lack
Choice of hypotheses	a. inconsistent with observations b. consistent, but unlikely c. consistent, but costly d. functionally irrelevant
Testing of hypotheses	a. incomplete b. false acceptance of wrong hypothesis c. false rejection of correct hypothesis d. lack
Choice of goal	a. incomplete b. incorrect c. unnecessary d. lack
Choice of procedure	a. incomplete b. incorrect c. unnecessary d. lack
Execution of procedure	a. step omitted b. step repeated c. step added d. steps out of sequence e. inappropriate timing f. incorrect discrete position g. incorrect continuos range h. incomplete i. unrelated inappropriate action

ing the trips occurred at most in relation to the secondary systems. Figure 5 shows the numbers of cases by the major plant systems in the classifications. From Figure 5, the systems recorded more than 4 cases can be listed as follows ; for the primary systems, the reactor control & protection system (8 cases), the steam generator control & protection system (4 cases) ; for the secondary systems, the main feedwater system (15 cases), the turbine control & protection system (7 cases), the auxiliary electric power supply system (7 cases), the auxiliary system for turbine (5 cases), the auxiliary system for generator (4 cases), the electric power transmission system (4 cases).

Table 5. Error Classification by Rasmussen[9]

Error Types
Absent-mindedness
Familiar association
Alertness low
Omission of functionally isolated acts
Other omissions
Mistakes among alternatives
Strong expectation
Side effect(s) not considered
Latent conditions not considered
Manual variability, lack of precision
Spatial misorientation
Other, unclassifiable

The rates of human error in the categories of work situations and job type are shown in Figures 6 and 7, respectively. As shown in Figure 6, the numbers of trip cases due to human errors are high in the order of the normal operation (43%), the planned maintenance (29%), the periodic test (14%), the overhaul (9%), and the urgent maintenance (5%). This order may be related to the frequency and duration of the work situations. Regarding to the rates by job types, as shown in Figure 7, the local equipment operation is the highest at 30%, followed by the electrical job (19%), the MCR operation (18%), the mechanical job (16%), the I&C job (14%), and others (3%). The rate summed for the job types other than MCR oper-

Table 6. Error Classification Developed and Used in This Study

Representative Error Types	Specific Error Types
Action at Wrong Time	Too early, Too late
Action in Wrong Type	Too fast, Too slow, Wrong direction
Action on Wrong Object	Wrong train, Similar objects, Unrelated objects
Action in Wrong Sequence	Change in the order
Omission	Omission of usual check-up, Omission of monitoring indicator, Neglect alarms or abnormal conditions, Omission of prerequisite actions, Omission of completing task, Omission of functional test, Omission of actions for parts of objects, Omission of full sequence of tasks
Lack in Performance (Quantitative)	Too much, Too little
Lack in Performance (Qualitative)	Not cleaned debris, Less than job criteria, Use of materials less than required quality
Commission of Wrong Action	Neglect side effects, Inadvertent action, Unnecessary action
Unskilled Performance	Unskilled control room operation

ation, such as local equipment operation, electrical job, mechanical job, and I&C job, becomes 79%. This tells that more efforts should be put into the tasks other than MCR operation in order to reduce trips by human errors and to enhance plant performance.

The result by error types is shown in Figure 8. The most dominant error type is omission (36%), followed by commission of wrong action (16%), action on wrong object (14%), lack in performance (qualitative) (10%), lack in performance (quantitative) (6%), action in wrong type (6%), action at wrong time (4%), unskilled performance (4%), and action in wrong sequence (3%). The result that omission is the most dominant error type agrees well with the findings that omission records the highest as 42. 5% among human errors, obtained by Rasmussen [9] from his analysis of 200 incidents due to human errors in NPPs in U. S. A.

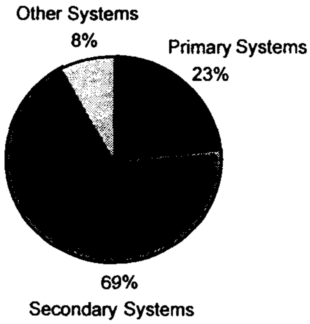

Fig. 4. The Rates of Human Errors Involved in the Primary Systems, Secondary Systems, and Other Systems

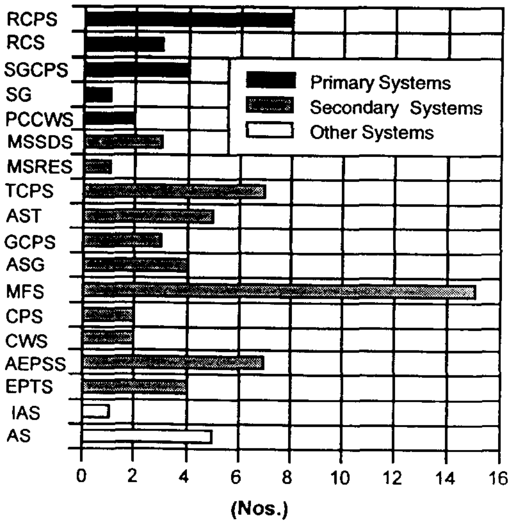

Fig. 5. The Numbers of Trip Cases Due to Human Errors at the Major Systems

2.4. Analysis of Human Errors for the Group of Categories

The trip cases due to human errors were analyzed

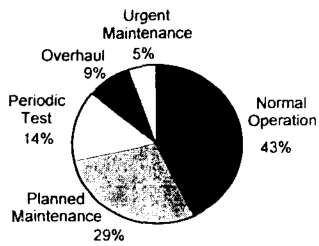

Fig. 6. The Rates of Human Errors by Work Situations

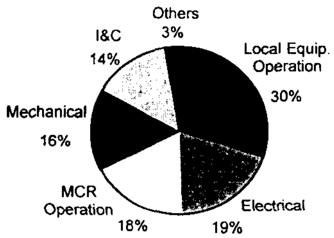

Fig. 7. The Rates of Human Errors by Job Types

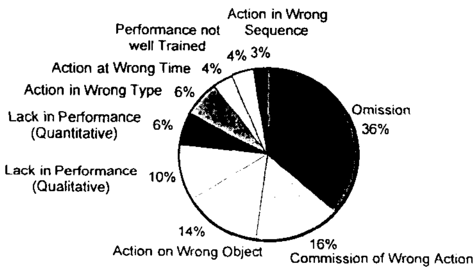

Fig. 8. The Rates of Human Errors by Error Types

Table 7. Numbers of Cases for the Group of Plant Systems, Work Situations, and Job Types (See Abbreviations in Table 1).

Work Situation	Job Type	Plant Systems																					
		Primary Systems						Secondary Systems												Others			
		RCPS	RCS	SGCPS	SG	PCCWS	total	MSSDS	MSRES	TCPS	AST	GCPS	ASG	MFS	CPS	CWS	AEPSS	EPTS	total	IAS	AS	total	Total
NO	CR			3			3							6			2		8			0	11
	EO	3	1			1	5	1						2	2	1		1	7	1		1	13
	IC						0			1									1			0	1
	ME						0							2					2			0	2
	EL						0					2					1		3			0	3
	O						0							1				1	2		1	1	3
	total	3	1	3	0	1	8	1	0	1	0	2	0	11	2	1	3	2	23	1	1	2	33
PT	CR	1					1			1									1			0	2
	EO	2					2	2		1	1								4		1	1	7
	IC	1					1												0			0	1
	ME						0			1									1			0	1
	EL						0												0			0	0
	O						0												0			0	0
	total	4	0	0	0	0	4	2	0	3	1	0	0	0	0	0	0	0	6	0	1	1	11
PM	CR						0			1									1			0	1
	EO					1	1									1			1		1	1	3
	IC		2	1			3						1						1		1	1	5
	ME						0		1		2			3					6			0	6
	EL						0			1							4	2	7			0	7
	O						0												0			0	0
	total	0	2	1	0	1	4	0	1	2	2	0	1	3	1	1	4	2	16	0	2	2	22
OH	CR						0												0			0	0
	EO						0												0			0	0
	IC						0							1					1			0	1
	ME				1		1				1								1			0	1
	EK						0					1	3						4			0	4
	O						0												0			0	0
	total	0	0	0	1	0	1	0	0	0	1	1	3	1	0	0	0	0	6	0	0	0	7
UM	CR						0												0			0	0
	EO						0												0		1	1	1
	IC	1					1			1	1								2			0	3
	ME						0												0			0	0
	EL						0												0			0	0
	O						0												0			0	0
	total	1	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	2	0	1	1	4
Total		8	3	4	1	2	18	3	1	7	5	3	4	15	2	2	7	4	53	1	5	6	77

Note) Blanks mean none.

for the group of categories to investigate relationships among the categories in aspects of human error occurrences. Table 7 shows the numbers of cases for the group of plant systems, work situations, and job types. In Table 7, the plant systems are listed at the top, work situations at the leftmost column, and job types are repeated at each work situation.

From Table 7, the cases recording more than 3 cases are selected as notable and listed as follows; during normal operation, local equipment operation at the reactor control and protection system (3 cases), MCR operation at the steam generator control and protection system (3 cases) and at the main feedwater system (6 cases); for planned maintenance, mechanical job at the main feedwater system (3 cases), electrical job at the auxiliary electric power supply system (4 cases); electrical job at the auxiliary system for generator during overhaul (3 cases).

In addition to this group analysis, the pairs of categories were selected and evaluated with the case numbers. The selected pairs are plant systems vs. work situations, plant systems vs. job types, work situations vs. job types, and job types vs. error types. Table 8 shows the case numbers by plant systems in consideration of work situations and job types separately.

From Table 8, the systems which have more than 3 cases at the specific work situations are as follows; for the normal operation, the main feedwater system records the most as 11 cases, then each of the reactor control & protection system, steam generator control & protection system, and auxiliary electric power supply system holds 3 cases; for the planned maintenance, the auxiliary electric power supply system (4

Table 8. Numbers of Cases by Plant Systems in Consideration of Work Situations and Job Types (See Abbreviations in Table 1)

Systems	Work Situations					Job Types					
	NO	PT	PM	OH	UM	EO	EL	CR	ME	IC	O
RCPS	3	4	1	1		5	1	1		2	
RCS	1		2			1				2	
SGCPS	3		1					3		1	
SG					1				1		
PCCWS	1					1					
MSSDS	1	2				3					
MSRES			1						1		
TCPS	1	3	2	1		1	1	2	1	2	
AST		1	2	1	1	1			3	1	
GCPS	2				1		3				
ASG			1		3		3			1	
MFS	11		3		1	2		6	6	1	
CPS	2					2					
CWS	1		1			2					
AEPSS	3		4				5	2			
EPTS	2		2			1	2				1
IAS	1					1					
AS	1	1	2	1		3				1	1
Total	33	11	22	4	7	23	15	14	12	11	2

* Note) Blanks mean none.

cases) and the main feedwater system (3 cases) ; for the periodic test, the reactor protection & control system (4 cases) and the turbine control & protection system (3 cases) ; during overhaul periods, the auxiliary system for generator (3 cases). In case of the urgent maintenance, no system records human error cases more than one. For the normal operation and planned maintenance, human errors are involved into many systems, but relatively few systems in cases of periodic test, overhaul, and urgent maintenance.

Similarly to the pair of plant systems & job types, the systems which have more than 3 cases can be listed as follows ; for the local equipment operation, the reactor control & protection system (5 cases), the main steam supply & dump system (3 cases) and auxiliary subsystems (3 cases) ; for the electrical job, the auxiliary electric power supply system (5 cases), the generator control & protection system (3 cases), and the auxiliary system for generator (3 cases) ; for the MCR operation, the main feedwater system (6

Table 9. Numbers of Cases by the Specific Error Types in Accordance with Job Types

Error types		Job types					
Representative	Sepcific	EO	EL	CR	ME	IC	O
Action at Wrong Time	Too early	1		2			
	Too late						
Action in Wrong Type	Too fast			2		2	
	Too slow						
	Wrong direction	1					
Action on Wrong Object	Wrong train	1		1		1	
	Similar objects		2	1		3	
	Unrelated objects				1	1	
Action in Wrong Sequence	Change in the order		1			1	
Omission	Omission of usual check-up	2	2			1	
	Omission of monitoring indicator	4					
	Neglect alarms or abnormal conditions	3	1	1	1	1	
	Omission of prerequisite actions	1		1	1		
	Omission of completing task	3					
	Omission of functional test				2		
	Omission of actions for parts of objects	2					
	Omission of full sequence of tasks	1	1	1			
Lack in Performance(Quantitative)	Too much	1					
	Too little		1		1	1	1
Lack in Performance(Qualitative)	Not cleaned debris		2				
	Less than job criteria	1			1		
	Use of materials less than required quality		1		3		
Commission of Wrong Action	Neglect side effects		1			1	
	Inadvertent action		3		1		1
	Unnecessary action	2		2	1		
Unskilled Performance	Unskilled control room operation			3			

* Note) Blanks mean none.

cases) and the steam generator protection & control system (3 cases); for the mechanical job, the main feedwater system (6 cases) and the auxiliary system for turbine (3 cases). There are no systems having more than 2 human error cases for the I&C job. Counting the numbers of plant systems related to human errors in the tasks of the specific job types, 12 systems related to the local equipment operation, 8 systems to the I&C job, 6 systems to the electrical job, 5 systems to each of the MCR operation and mechanical job. Hence, human errors in the local equipment operation, which are involved in the largest number of cases, are also related to the largest number of plant systems.

The result from the analysis for the pair of work situations and job types is shown in Figure 9. For the normal operation, the numbers for the local equipment operation and the MCR operation are high. The local equipment operation recorded more number of cases than any other job types in the periodic tests. The number for the electrical job is high during overhaul periods. For the planned maintenance, electrical, mechanical, and I&C jobs are dominant, and for the urgent maintenance, the I&C job is dominant. Another thing we can see from Figure 9 is that the higher the total number of cases for a work situation is, the more job types are involved.

Next, error types are investigated for the job types. Figure 10 shows the case numbers by representative error types in accordance with job types. Omission (16 cases) is the most dominant error type in the local equipment operation. For the electrical job, error types with high numbers are omission (4 cases), commission of wrong action (4 cases), and lack in performance (qualitative) (3 cases). For the MCR operation, omission and unskilled performance recorded 3 cases each but not dominant in comparison to other error types, all of which recorded 2 cases. For the mechanical job, the dominant error types are omission and lack in performance (quality), which recorded 4 cases each. Action on wrong object (5 cases) is the highest error type in the I&C job. Regarding to the sepcific error types, Table 9 shows the case numbers. From Table 9, the sepcific error types in more than 3 cases are as follows; for the local equipment operation, omission of monitoring indicator (4 cases), neglect alarms or abnormal conditions (3 cases), and omission of completing task (3 cases); for the electrical job, inadvertent action (3 cases); for the MCR operation, unskilled control room operation (3 cases); for the mechanical job, use of materials less than required quality (3 cases); for the I&C job, action on similar object (3 cases).

3. Conclusions and Recommendations

A total of 77 trip cases was identified to have human error involvement among the 255 trips occurred from 1978 to 1992 in Korean NPP. This can be translated into that the average rate of human error involvement in the trips becomes about 30%. This figure is in the lower boundary of human error involve-

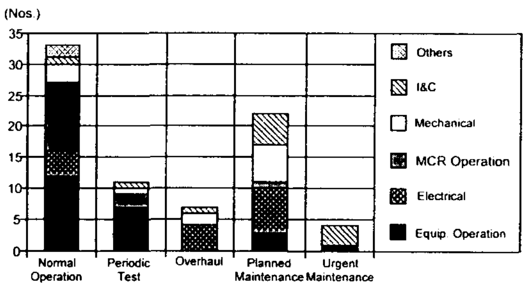

Fig. 9. Numbers of Cases by Job Types at Specific Work Situations.

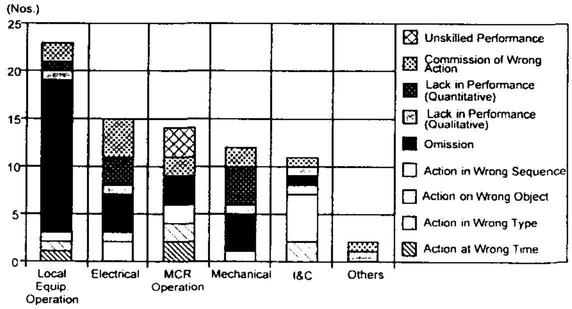

Fig. 10. Numbers of Cases by Error Types in Accordance With Job Types

ment reported as 30% to 50% for other countries. It was also found that the annual rate of human error involvement increases as operating years are accumulated. From this result, it can be concluded that it is time to put more efforts to reduce human errors in Korean NPPs.

It was found that the secondary systems are related to the cases more than the primary systems, and the major systems involved in many cases are the main feedwater system, the reactor control and protection system, the turbine control and protection system, the auxiliary electric power supply system, and the auxiliary system for turbine. Among the job types, the local equipment operation is involved into the highest number of the cases. The point here, however, the result for the job types shows that a total of 79% of the cases occurred in plant jobs other than MCR operation. Up to the present, many human factors efforts are focused to the design of human-machine interface (HMI) in the main control rooms. In case of new HMI design using visual display units (VDU), it is important to investigate the interaction between MCR operators and HMI, since that the design using VDU will bring big changes to the interaction, therefore may cause new dimensions of human errors in the MCR operation. However, for the existing plants, more efforts to reduce human errors should be put into the tasks other than MCR operation in order to enhance plant performance.

Although human error analysis, in general, cannot avoid subjectiveness, the results for the case numbers on the plant systems, work situations, job types and error types will provide valuable information for ongoing and future efforts to reduce human errors. It is not desirable to interpret the results related to job types that the personnel working in that domain make more errors than other job domain. We should assume that the job domain recording more errors brings more opportunities for plant personnel to meet work conditions shaping human errors. Also, it is desirable to let plant personnel know the importance of their tasks to plant trips. It is recommended to find and solve the problems residing in work conditions and to apply the effective training with cognitively well designed contents and methods. We will further analyze the individual cases to find the problems residing in work conditions and to build a database system for easy retrieval of the information on specific cases.

This study is performed on human errors involved in the trip cases, the description of which is not detail because of the responsibility problem. Near miss cases, which are the cases not proceeded to plant trips and usually occurred more frequently than trip cases, can provide information on human errors more detailed than the trip case reports. Since the characteristics of human errors both in trip cases and in near miss cases are similar, it will be a valuable work to analyze the near miss cases.

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