A DATABASE FOR HUMAN PERFORMANCE UNDER SIMULATED EMERGENCIES OF NUCLEAR POWER PLANTS

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Reliable human performance is a prerequisite in securing the safety of complicated process systems such as nuclear power plants. However, the amount of available knowledge that can explain why operators deviate from an expected performance level is so small because of the infrequency of real accidents. Therefore, in this study, a database that contains a set of useful information extracted from simulated emergencies was developed in order to provide important clues for understanding the change of operators' performance under stressful conditions (i.e., real accidents). The database was developed under Microsoft Windows™ environment using Microsoft Access 97™ and Microsoft Visual Basic 6.0™. In the database, operators' performance data obtained from the analysis of over 100 audio-visual records for simulated emergencies were stored using twenty kinds of distinctive data fields. A total of ten kinds of operators' performance data are available from the developed database. Although it is still difficult to predict operators' performance under stressful conditions based on the results of simulated emergencies, simulation studies remain the most feasible way to scrutinize performance. Accordingly, it is expected that the performance data of this study will provide a concrete foundation for understanding the change of operators' performance in emergency situations.

KEYWORDS : Nuclear Power Plant, Simulated Emergency, Operator's Performance Data

1. INTRODUCTION

The importance of human performance related problems (i.e., human factors) in securing the safety of complex process systems has been clearly demonstrated in recent decades [1-2]. Unfortunately, although many people have devoted efforts to clarifying why human performance deviates from a certain expected level, there are several difficulties in scrutinizing human performance related problems. One critical difficulty is that the amount of available knowledge from operating experiences is extremely small because of the infrequency of real accidents [3-6].

Accordingly, the use of simulators is regarded as the most practical method to solve this problem, as it allows researchers to systematically observe human behaviors in coping with a hypothetical accident. This means that a set of useful knowledge or insights can be elucidated from the results of these observations [3, 5-16]. Although there are pertinent issues regarding the use of simulators, including that the level of stress and/or fidelity felt by operators could be quite different from that of a real situation [6, 14, 16-17], the simulator is an invaluable tool to observe human behaviors under emergencies [6, 12, 14, 16].

In this study, the OPERA database has been developed based on plant-specific and domain-specific human performance data. To develop this database, more than 100 audio-visual records were gathered from re-training sessions of the reference NPP. These records were collected for over a period of three years (from September 1999 to April 2001), and in total 24 different MCR operating crews were re-trained during this period. From these records, a set of useful knowledge for scrutinizing human performance related problems has been extracted by well-known analysis techniques – a time-line and protocol analysis.

The remainder of this paper is organized as follows. In Section 2, operators' performance data extracted from the collected records are delineated with a brief explanation about the time-line and protocol analysis. Subsequently, in Section 3, a set of useful data accessible from the OPERA database is explained. Finally, a discussion of the role of the OPERA database in premeditating human performance related problems as well as a conclusion are presented in

Section 4.

2. COLLECTING OPERATORS' PERFORMANCE DATA

2.1 Re-training Course of Emergency Operations

To collect operators' performance data under simulated emergencies, a full scope simulator installed in a training center of the reference NPP was used. This full scope simulator was designed based on a 1,000MWe PWR type plant that has a conventional control interface, which includes gauges, indicators, and alarm tiles, etc. Sufficient validation and verification activities were performed to clarify the simulator's functional appropriateness. In addition, the simulator has audio-visual recording equipment that can be used to monitor operators' responses in coping with emergencies.

Using this simulator, it is mandatory that MCR operators working in the reference NPP should be regularly trained for a period of about six months. Thus, the re-training course of emergency operations was chosen as a source of operators' performance data because a sufficient number of re-training records can be secured without additional efforts.

In the re-training course, each MCR crew typically consisted of four operators who have distinct duties. For example, a SRO has a responsibility for all kinds of operations carried out under emergencies, while a RO and a TO have responsibility for operations related to the primary side (i.e., nuclear island) and the secondary side (i.e., turbine island), respectively. In addition, a SS has a responsibility for checking the status of CSFs in parallel with conducting EOPs.

The re-training records were collected during a period of more than three years (from September 1999 to April 2001). Six kinds of emergency scenarios that can cover all the DBAs of the reference NPP were simulated during this period. A total of 24 different MCR operating crews participated in the re-training.

2.2 Analysis Methods for Extracting Operators' Performance Data

To extract as much useful information as possible, both a time-line analysis and a verbal protocol analysis were carried out based on the results of the task analysis of EOPs. That is, when operators are provided with a set of prescribed procedures, it is expected that their performance can be measured within a credible boundary, since their activities are predominantly governed by procedures [18-22]. This strongly indicates that operators' performance can be measured on the basis of how the operators accomplish tasks described in procedures. From this standpoint, both time-line and verbal protocol analyses have been conducted along with significant tasks that are determined by the task analysis of EOPs, since most emergency operations of the reference NPP are highly institutionalized by diverse procedures, such as SPTA procedure, diagnosis procedure, SFSC procedure, ORPs, and FRPs (see Fig. 1).For example, Fig. 2 shows the results of a task analysis of LOCA ORP.

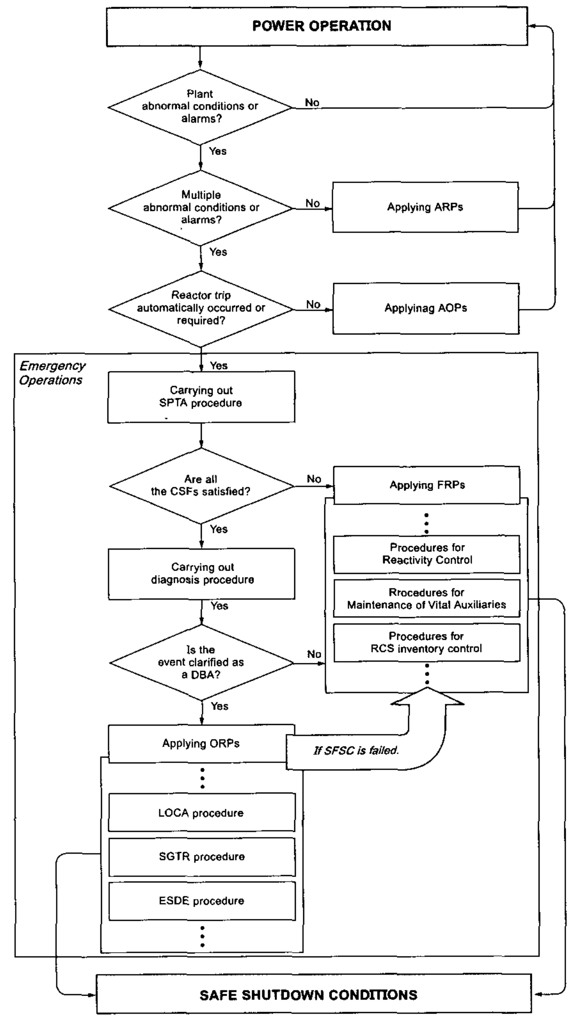


Fig. 1. Strategy of Emergency Operations in the Reference NPP

As shown in Fig. 2, each task to be accomplished by the operators consists of one or more procedural steps. This means that the operators' performance in conducting the required tasks can be objectively measured by the identification of remarkable time points, such as the ingress and /or egress time of procedural steps. In addition, if operators have to accomplish their tasks on the basis of procedural steps, then it is possible to compare the expected operators' behaviors with the actual behaviors observed in the course of re-training sessions. Accordingly, in this study, both time-line and protocol analyses were introduced in order to extract time information and types of operators' behaviors.

First, based on task analysis results, the time-line ana-

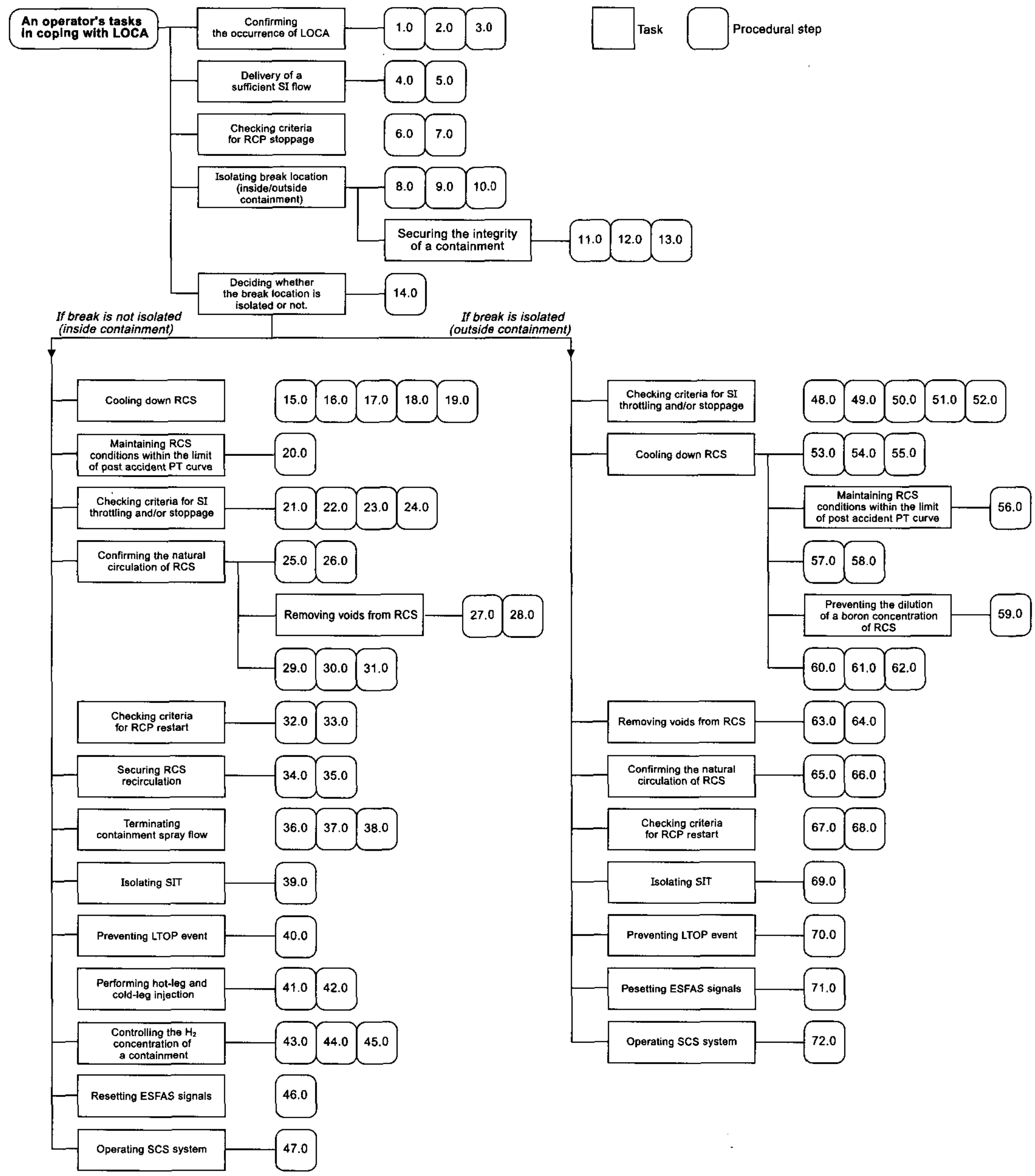


Fig. 2. Result of a Task Analysis of LOCA ORP

lysis was conducted on the basis of the following remarkable time points. Fig. 3 shows an example for the time-line analysis.

- Reactor trip (t = 0);
- Start to perform SPTA procedure;
- Completion of SPTA procedure;
- Start to perform diagnosis procedure;
- Completion of diagnosis procedure;
- Start to perform the selected ORP;
- Start to perform the i^{th} procedural step that is included in the selected ORP (i.e., ingress time);
- Completion of the i^{th} procedural step (i.e., egress time).

It is noted that the origin of the aforementioned time points was the reactor trip, since the trigger of emergency operations is the reactor trip (see Fig. 1). Consequently, a set of invaluable time information (such as mean perfo-

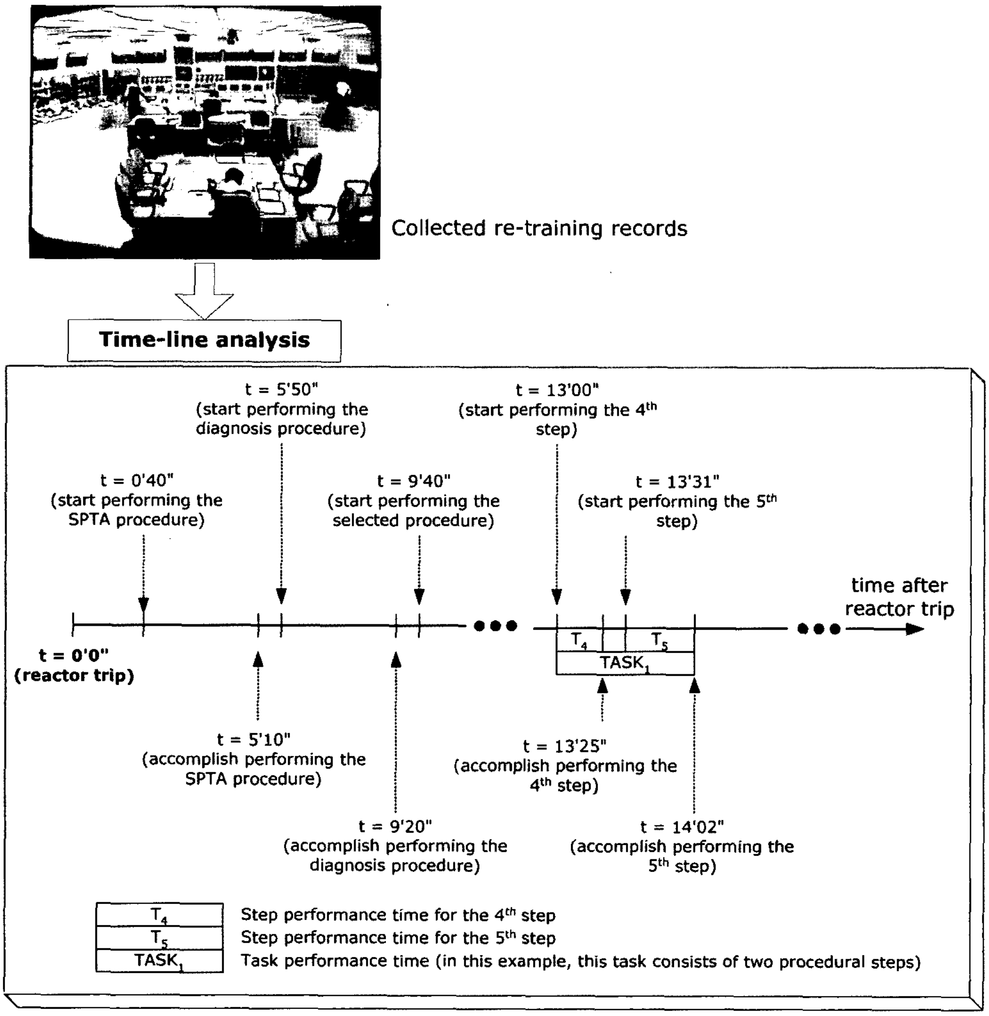


Fig. 3. Example of a Time-Line Analysis

rmance time data for event diagnosis, mean performance time data of procedural steps, and mean task performance time data, etc.) can be extracted.

In addition to the time analysis, a protocol analysis (more precisely, a verbal protocol analysis) has been conducted in order to extract noticeable features during emergency operations. Fig. 4 delineates the overall process of the protocol analysis.

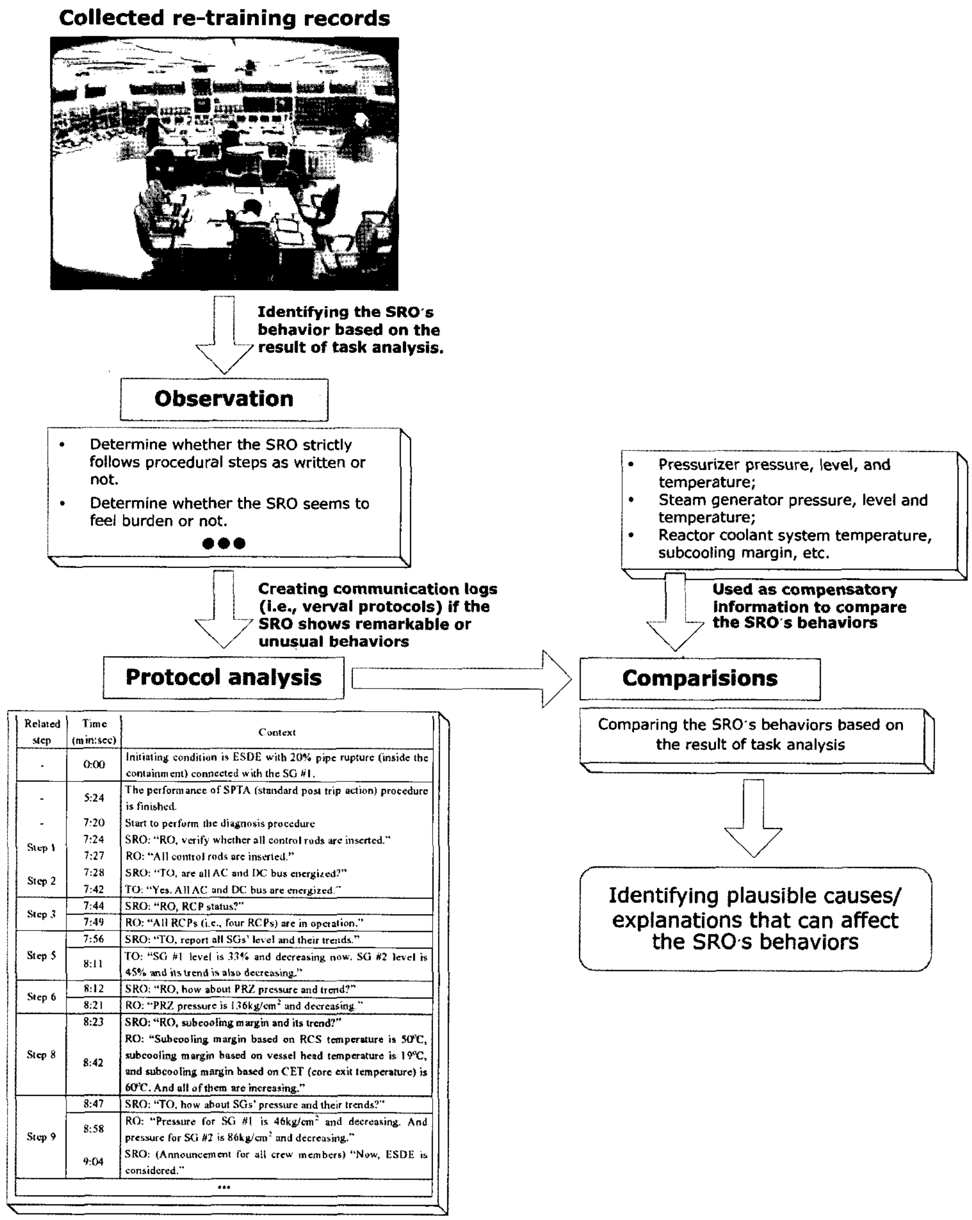
Although there are several criticisms (such as the reliability and/or the validity of verbal data) pertaining to the use of the protocol analysis, this method still appears to be meaningful, because operators' behaviors with regard to the performance of procedures can be properly described. From this point of view, all kinds of verbal communications among crew members were transcribed based on audio-visual records (see 'Protocol analysis' part in Fig. 4). The transcriptions were then meticulously compared with the required actions that are predefined in procedural steps. Through these comparisons, plausible causes and/or reasons that can soundly explain why operators had difficulties or showed unusual behaviors in the course of emergency operations were elucidated.

3. DEVELOPMENT OF OPERA DATABASE

The main objective of the OPERA database is to provide a serviceable tool that allows users to easily access operators' performance data.

Briefly, the OPERA database consists of two parts, a database and a user interface, and it has been developed under Microsoft Windows™ environment. First, in order to structuralize operators' performance data extracted from the re-training records, twenty distinct data fields were created, as summarized in Table 1. Based on the data fields shown in Table 1, all kinds of operators' performance data were stored using Microsoft Access 97™.

In order to provide a user-familiar interface, Microsoft



Related step	Time (min:sec)	Context
-	0:00	Initiating condition is ESDE with 20% pipe rupture (inside the containment) connected with the SG #1.
-	5:24	The performance of SPTA (standard post trip action) procedure is finished.
-	7:20	Start to perform the diagnosis procedure
Step 1	7:24	SRO: "RO, verify whether all control rods are inserted."
	7:27	RO: "All control rods are inserted."
Step 2	7:28	SRO: "TO, are all AC and DC bus energized?"
	7:42	TO: "Yes. All AC and DC bus are energized."
Step 3	7:44	SRO: "RO, RCP status?"
	7:49	RO: "All RCPs (i.e., four RCPs) are in operation."
Step 5	7:56	SRO: "TO, report all SGs' level and their trends."
	8:11	TO: "SG #1 level is 33% and decreasing now. SG #2 level is 45% and its trend is also decreasing."
Step 6	8:12	SRO: "RO, how about PRZ pressure and trend?"
	8:21	RO: "PRZ pressure is 136kg/cm^2 and decreasing."
Step 8	8:23	SRO: "RO, subcooling margin and its trend?"
	8:42	RO: "Subcooling margin based on RCS temperature is 50°C, subcooling margin based on vessel head temperature is 19°C, and subcooling margin based on CET (core exit temperature) is 60°C. And all of them are increasing."
Step 9	8:47	SRO: "TO, how about SGs' pressure and their trends?"
	8:58	RO: "Pressure for SG #1 is 46kg/cm^2 and decreasing. And pressure for SG #2 is 86kg/cm^2 and decreasing."
	9:04	SRO: (Announcement for all crew members) "Now, ESDE is considered."
...		

Fig. 4. Overall Structure of the Protocol Analysis

Visual Basic 6.0™ is used to create a menu-driven interface. Fig. 5 shows a screen-shot of the user interface as seen when the OPERA database is started.

From this interface, users can easily access 10 kinds of operators' performance data by selecting the appropriate menu item. Table 2 shows the list of accessible performance data.

For example, the "LOCA (Loss Of Coolant Accident) ..." item, which is a part of the "Performance Data (from Timeline analysis)" menu of Fig. 5, allows the user to access operators' performance time data for tasks included in the LOCA procedure. Fig. 6 shows operators' performance time data for a task that consists of two procedural steps (the 4th and 5th procedural steps).

As shown in Fig. 6, the user can access several kinds of time information such as a task ingress time, task egress time, task performance time, and statistical results (mean and standard deviation) when a specific task is selected (highlighted by dark color). In addition, the user can also access more detailed time information by selecting a specific procedural step, as shown in Fig. 7.

Fig. 7 gives the operators' performance time data (the ingress time, egress time, step performance time, and statistical results) when the 4th procedural step is selected by

Table 1. Data Fields of OPERA Database

Data field	Meaning
EventID	Identifier for each re-training session.
DateOfRetraining	Date of re-training.
PlantID	Name of plant to which an operating crew belongs.
CrewID	Identifier for each operating crew.
OperatorPosition	Role of operators, such as SRO, RO and TO, etc.
OperatorName	Name of operators.
OperatingExperience	Plant operating experience of operators, measured by years.
TrainingScenario	Simulated scenario, such as LOCA, SGTR and ESDE, etc.
InitiatingCondition	Initiating condition for each scenario.
TimeOfTrainingStart	Time when re-training session has started.
TimeOfReactorTrip	Time when the reactor trip has occurred.
IngressTimeOfSPTA	Time when SRO started to conduct SPTA procedure.
EgressTimeOfSPTA	Time when SRO finished SPTA procedure.
IngressTimeOfDA	Time when SRO started to conduct the diagnosis procedure.
EgressTimeOfDA	Time when SRO finished the diagnosis procedure.
IngressTimeOfORP	Time when SRO started to conduct an ORP selected by the diagnosis procedure.
StepID	Identifier for each procedural steps prescribed EOPs.
IngressTimeOfStep	Time when SRO started to conduct a procedural step.
EgressTimeOfStep	Time when SRO finished a procedural step.
TypeOfSROBehavior	SROs' behavior in conducting procedural steps.

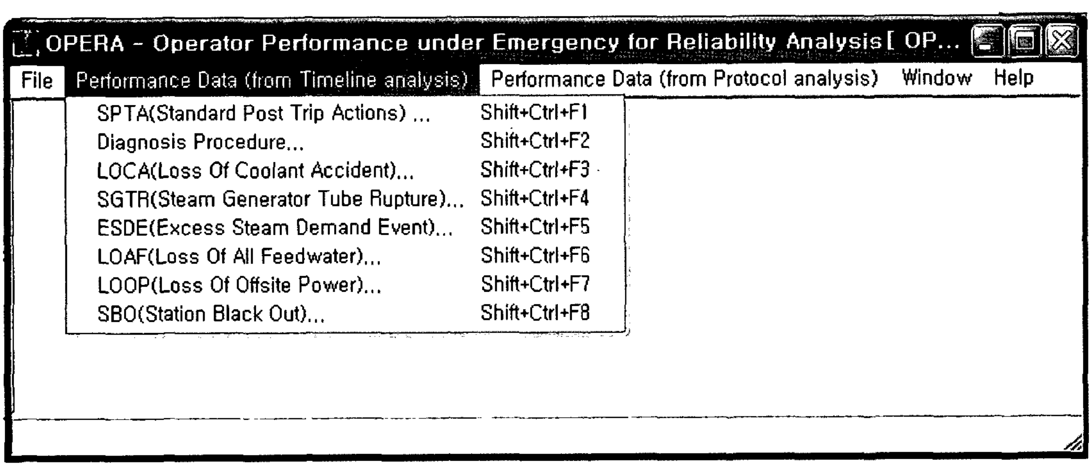


Fig. 5. An Example of the User Interface for OPERA Database

the user (highlighted by dark color). Similarly, by selecting the menu items shown in Fig. 5, various kinds of performance time data can be easily accessed.

In addition to performance data obtained from the timeline analysis, two kinds of performance data from the protocol analysis are also provided by the OPERA database: (1) the changes of step performance time data with respect to the types of operators' behaviors, and (2) the changes of operators' behaviors with respect to their experience.

It is noted that, according to the results of the protocol analysis, operators' behaviors in conducting procedural steps could be subdivided into three types, as summarized in Table 3.

Here, 'Type A' means that the operators conducted all the required actions prescribed in a procedural step along with a predefined action sequence (i.e., compliance behavior). On the contrary, both 'Type B' and 'Type C' imply non-compliance behaviors, because operators either skipped

Table 2. Accessible Performance Data from OPERA Database

Extracted by	Menu item	Meaning
Time-line analysis	SPTA (Standard Post Trip Action) Diagnosis procedure LOCA (Loss Of Coolant Accident) SGTR (Steam Generator Tube Rupture) ESDE (Excess Steam Demand Event) LOAF (Loss Of All Feed water) LOOP (Loss Of Off-site Power) SBO (Station Black Out)	Operators' performance time data related to SPTA procedure Operators' performance time data related to diagnosis procedure Operators' performance time data related to LOCA procedure Operators' performance time data related to SGTR procedure Operators' performance time data related to ESDE procedure Operators' performance time data related to LOAF procedure Operators' performance time data related to LOOP procedure Operators' performance time data related to SBO procedure
Protocol analysis	Performance time with operators' behavior	Comparison of the change of operators' performance time data with respect to operators' behaviors.
	Behavior types with operators' experience	Comparison of the change of operators' behaviors with respect to their experience

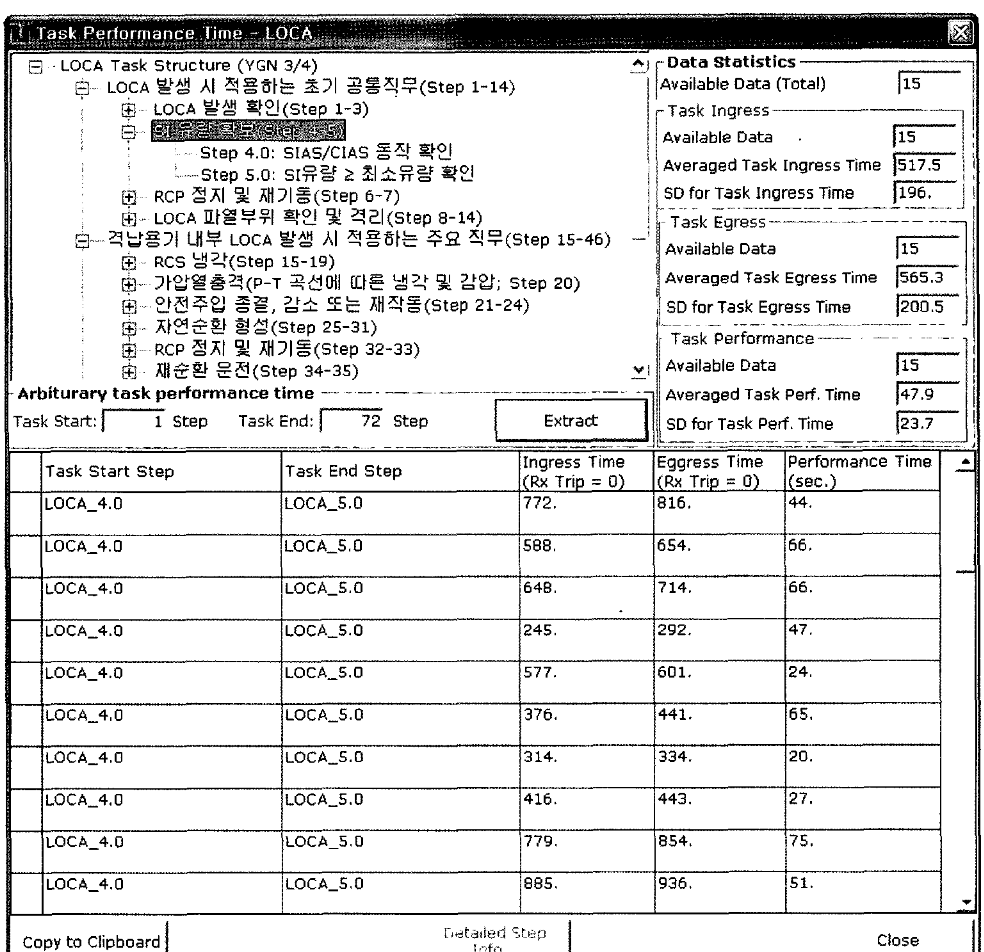


Fig. 6. Operators' Performance Time Data Related to LOCA Procedure

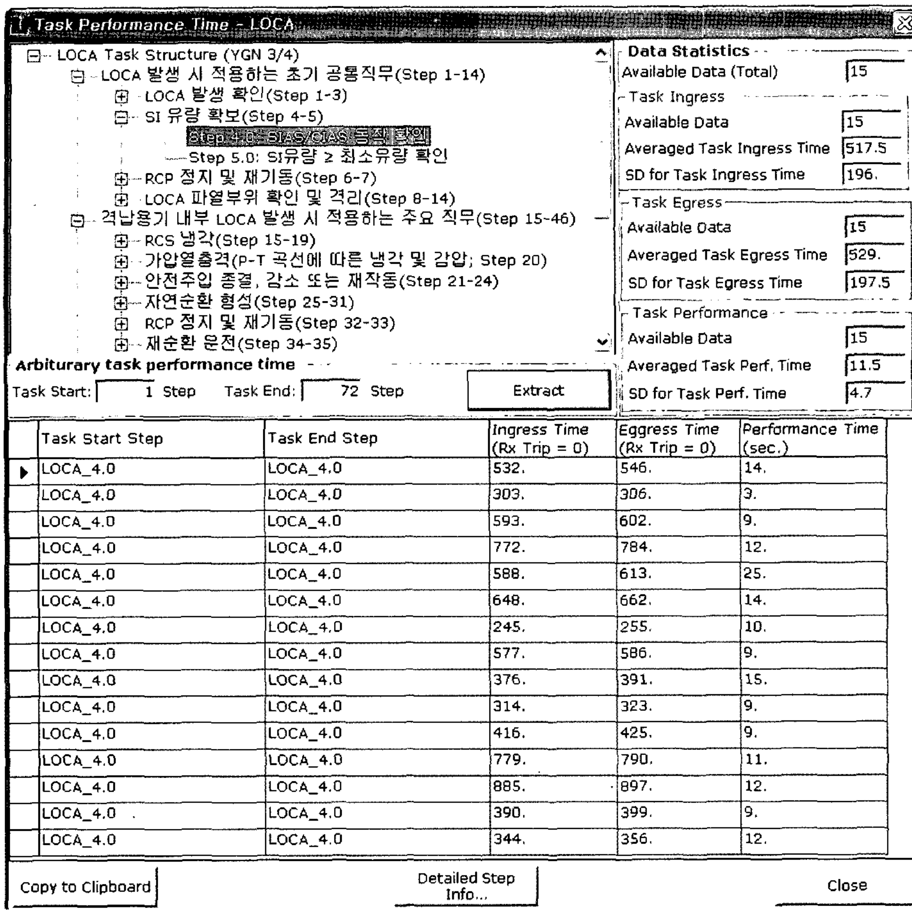


Fig. 7. Operators' Performance Time Data for the 4th Procedural Step

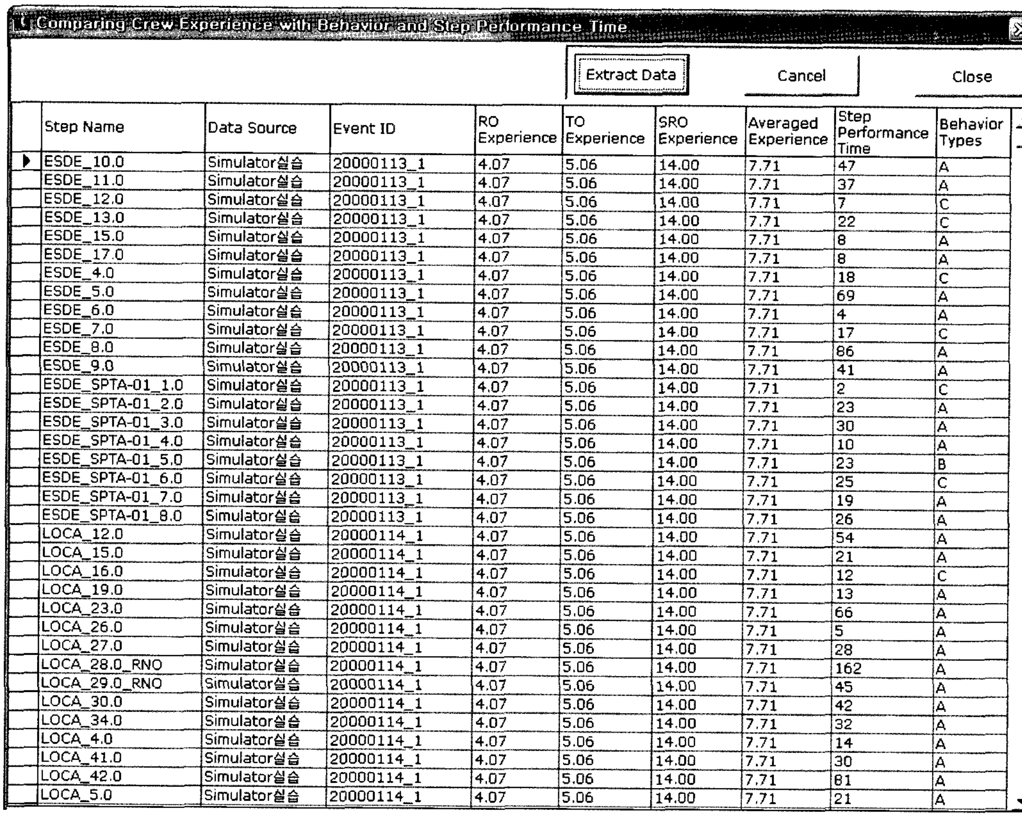
Table 3. Operators' Behaviors in Conducting Procedural Steps

Type	Meaning	Example
A	Strict adherence	Operators strictly followed a procedural step as written.
B	Skipping redundant actions	When operators entered a procedural step, they either skipped identical actions that were already conducted in the previous procedural step or conducted identical actions based on information they already knew.
B	Modifying action sequence	Operators performed a procedural step using a modified action sequence that was different from the predefined one.

several actions or did not follow a predefined action sequence. Based on these classifications, the user can access more interesting performance data. For example, Fig. 8 shows raw data related to the changes of operators' behaviors with respect to their experience.

By manipulating these raw data, the user can investigate the characteristics of operators' performance data from different angles. For example, Table 4 summarizes the result of comparisons between behavior types and operators' work experience [23].

From Table 4, it was observed that operators who have work experience ranging from 10 to 12.99 years appear to adopt non-compliance behaviors more frequently, since the percentage of occurrences is maximized (i.e., 54/130 in Table 4). In other words, many operators who belong to this range accomplished procedural steps by non-compliance



Step Name	Data Source	Event ID	RO Experience	TO Experience	SRO Experience	Averaged Experience	Step Performance Time	Behavior Types
ESDE_10.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	47	A
ESDE_11.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	37	A
ESDE_12.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	7	C
ESDE_13.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	22	C
ESDE_15.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	8	A
ESDE_17.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	8	A
ESDE_4.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	18	C
ESDE_5.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	69	A
ESDE_6.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	4	A
ESDE_7.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	17	C
ESDE_8.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	86	A
ESDE_9.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	41	A
ESDE_SPTA-01_1.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	2	C
ESDE_SPTA-01_2.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	23	A
ESDE_SPTA-01_3.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	30	A
ESDE_SPTA-01_4.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	10	A
ESDE_SPTA-01_5.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	23	B
ESDE_SPTA-01_6.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	25	C
ESDE_SPTA-01_7.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	19	A
ESDE_SPTA-01_8.0	Simulator실습	20000113_1	4.07	5.06	14.00	7.71	26	A
LOCA_12.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	54	A
LOCA_15.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	21	A
LOCA_16.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	12	C
LOCA_19.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	13	A
LOCA_23.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	66	A
LOCA_26.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	5	A
LOCA_27.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	28	A
LOCA_28.0_RNO	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	162	A
LOCA_29.0_RNO	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	45	A
LOCA_30.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	42	A
LOCA_34.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	32	A
LOCA_4.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	14	A
LOCA_41.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	30	A
LOCA_42.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	81	A
LOCA_5.0	Simulator실습	20000114_1	4.07	5.06	14.00	7.71	21	A

Fig. 8. Types of Operators' Behaviors with Respect to their Experience

Table 4. Behavior Types and Operators' Work Experience

Work experience (in years)	Number of observations		
	Type A	Type B	Type C
Under 6.99	53	1	10
7.00 ~ 9.99	35	2	12
10.00 ~ 12.99	76	9	45
13.00 ~ 15.99	392	38	94
Over 16.00	231	12	52
Total	787	62	213

behaviors such as 'skipping redundant actions' or 'modifying action sequences'. Interestingly, most operators who have either relatively low (i.e., under 10 years) or relatively high work experience (i.e., over 13 years) appear to strictly follow procedures. Thus, this relationship between operators' experience and the changes of behavior types appears to be a useful clue in understanding operators' performance.

4. DISCUSSION AND CONCLUSION

In this study, operators' performance data of the reference NPP were extracted from the re-training sessions of emergency operations. As briefly stated in Section 1, in order to resolve human performance related problems, simulators have played a crucial role, as they provide an objective means for researchers to observe human behaviors in coping with simulated emergencies. Although there are several issues about the use of simulators (such as the dependability of human behaviors in task environments or the discrepancy of human behaviors between simulated and real situations), it is nevertheless believed that the simulator is an invaluable tool to observe human behaviors under emergencies. In addition, it should be emphasized that the results of simulation studies can be more serviceable when tasks have been prescribed in the form of procedures, since human performance can be maintained within a credible range under a highly institutionalized task environment [18-22].

If operators' performance data extracted from simulated emergencies are meaningful for estimating and/or understanding their performance under real situations, these data can be widely used for many applications. Among them, typical applications are as below.

First, the OPERA database can serve as a source of HRA inputs, especially for task completion time data, since one of the critical sequences in conducting HRA is to clarify how long it takes to accomplish a given task. For example, when a SGTR occurs, one of the most important tasks to be considered in HRA is "faulty SG isolation". This means that the task completion time of this task can affect the quality of HRA, because it is a very crucial input in determining the possibility of human errors (i.e., human error probability). In other words, it is expected that securing more reliable task completion time data will accordingly yield more realistic HRA results. Fig. 9 supports this expectation.

In Fig. 9, the performance time data of four critical tasks included in the SGTR procedure of the reference NPP are compared. Besides the time information (i.e., mean task performance time) of each task, this figure presents other important information for HRA – the insight of task characteristics. For example, in the case of 'Task 1', most operators accomplished this task within a very similar time period. Interestingly, operators' performance appears to be highly deviated when carrying out 'Task 4'. This strongly implies that some element of this task affects operators' performance in carrying out procedures (i.e., performance shaping factor). Certainly this kind of insight is important for HRA practitioners, because they estimate the possibility of human errors based on various kinds of performance shaping factors [24, 25, 26].

It is noted that the extracted task completion time data are not perfectly authentic (i.e., all the operators can accomplish their tasks within these times), since all the performance time data were measured based on "as is" operators' behaviors that may be different from those under real situations. Nevertheless, a lack of available data from operating experiences is one of the critical obstacles in HRA. Therefore, although the extraction of operators' performance data from simulators remains controversial, the use of simulators is regarded as one of the most cost- and effort-effective ways in securing operators' performance data. For this reason, the collection of human performance data through simulation studies has been emphasized in enhancing the quality of HRA [27, 28].

Second, we can ameliorate the quality of procedures, because operators' performance data allow us to identify critical factors that make the performance of procedures difficult. As an example, let us consider two kinds of procedural steps shown in Fig. 10.

As shown in Fig. 10, there is a large difference from the point of view of step performance time deviation. That is, the standard deviation of the step performance time data for the left procedural step is quite low (13.7s) while that of the right is relatively high (23.8s). It is natural to initially assume that the deviation of the left procedural step will be larger than that of the right, since the length of the left procedural step (i.e., the number of required actions to be done by operators) is longer than that of the right. However, operators' step performance data extracted by the time-line analysis indicate that operators seem to be distracted in carrying out the right procedural step. In other words, operators' performance data can be regarded as evidence indicating that some operators encountered

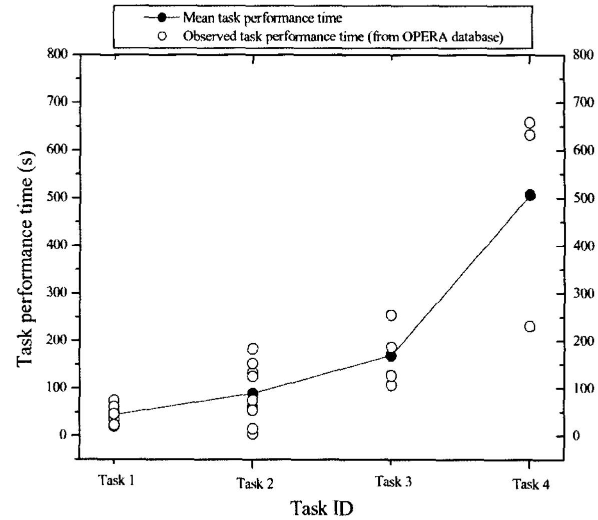


Fig. 9. Comparison of Task Performance Time Data

difficulty in performing procedures.

Thus, in order to clarify plausible factors that make the performance of procedural steps difficult, operators' step performance data were meticulously reviewed. As an outcome, two kinds of cognitive complexity factors that can affect operators' performance were elucidated. More detailed explanations can be found in Ref. [29].

One of the cognitive complexity factors is related to a difficulty due to the ambiguous description of procedural steps. In other words, operators encounter difficulty in establishing proper decision criteria because there is no clear basis. In the case of Fig. 10, the high deviation of the right procedural step can be explained by the ambiguous description, such as "IF the condenser is available...", since diverse decision criteria can be applied to determine the availability of a condenser. For example, several operators quickly determined the availability of a condenser by simply checking condenser pressure while several operators determined its availability by integrating the status of two or more process parameters.

As for the last potential application, the OPERA database can serve as a source of backup data for advanced studies, such as research related to the communication of operating crews or task allocations among crew members, etc. Furthermore, operators' performance data can be used to elicit noticeable clues that are useful in identifying the change of human performance among different NPPs or countries. For example, by comparing operators' performance data between different NPPs, it is possible to identify important issues that may be helpful for understanding the effects of HMIs and/or an organizational culture on operators' performance.

Although it remains difficult to conjecture operators' behaviors under a real situation on the basis of those under

Low deviation

Mean step performance time: 39.1s
Standard deviation: 13.7s

12. **IF** containment pressure is larger than 133.1cmH_2O **OR** there is a containment radiation alarm **THEN** ensure the following:

    a. CIAS is automatically activated.

    b. **ALL** available RCFCs are operating in emergency mode:
    - RCFCs are in operation with low speed.
    - **ALL** CCW valves linked with RCFCs are opened.

    c. **All** available CEDM fan coolers are operating.

    d. **All** available reactor cavity fan coolers are operating.

High deviation

Mean step performance time: 30.9s
Standard deviation: 23.8s

35. Perform a controlled cooldown of RCS to the entry conditions of SCS by using SBCS:

    a. **IF** the condenser is available, **THEN** perform cooldown using SBCS vales connected to condenser.

    b. **IF** the condenser is **NOT** available, **THEN** perform cooldown using atmospheric SBCS valves.

Fig. 10. Two Kinds of Procedural Steps that Show Different Characteristics

a simulated situation, previous studies have indicated that operators' performance could be homogeneous and predictable to some degree when procedures must be followed [30, 31, 32]. Thus, it is believed that operators' performance data obtained from this study will provide a concrete foundation for scrutinizing the changes of human performance under emergency situations.

Acronyms

AC	Alternating Current
AOP	Abnormal Operating Procedure
ARP	Alarm Response Procedure
CCW	Component Cooling Water
CEDM	Control Element Driving Mechanism
CET	Core Exit Temperature
CIAS	Containment Isolation Actuation Signal
CSF	Critical Safety Function
DBA	Design Basis Accident
DC	Direct Current
EOP	Emergency Operating Procedure
ESDE	Excess Steam Demand Event
ESFAS	Engineered Safety Features Actuation Signal
FRP	Functional Recovery Procedure
HMI	Human Machine Interface
HRA	Human Reliability Analysis
LOAF	Loss of All Feed Water
LOCA	Loss of Coolant Accident
LOOP	Loss of Off-site Power
LTOP	Low Temperature Over Pressure
MCR	Main Control Room
NPP	Nuclear Power Plant
OPERA	Operator Performance and Reliability Analysis
ORP	Optimal Recovery Procedure
PRZ	Pressurizer
PT	Pressure and Temperature
PWR	Pressurized Water Reactor
RCFC	Reactor Containment Fan Cooler
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RO	Reactor Operator
SBCS	Steam Bypass Control System
SBO	Station Black Out
SCS	Shutdown Cooling System
SD	Standard Deviation
SFSC	Safety Function Status Check
SG	Steam Generator
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SIT	Safety Injection Tank
SPTA	Standard Post Trip Action
SRO	Senior Reactor Operator
SS	Safety Supervisor
TO	Turbine Operator

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