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A taxonomy of performance influencing factors for human reliability analysis of emergency tasks

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Abstract

This paper introduces the process for, and the result of, the selection of performance influencing factors (PIFs) for the use in human reliability analysis (HRA) of emergency tasks in nuclear power plants. The approach taken in this study largely consists of three steps. First, a full-set PIF system is constructed from the collection and review of existing PIF taxonomies. Secondly, PIF candidates are selected from the full-set PIF system, considering the major characteristics of emergency situations and the basic criteria of PIF for use in HRA. Finally, a set of PIFs is established by structuring representative PIFs and their detailed subitems from the candidates. As a result, a set of PIFs comprised of the 11 representative PIFs and 39 subitems was developed.

Keywords: Performance influencing factors; Performance shaping factors; Human reliability analysis; Human error analysis; Emergency operation; Accident management

1. Introduction

Computerized automation has been adopted in large parts of modern industrial high-risk and complex systems such as nuclear power plants, aircraft and chemical plants. However, humans still play important roles in various parts of the design, maintenance, operation and supervision of such systems. All human activities performed in those parts are influenced by given specific working conditions or task situations, so-called context, which is comprised of the MTO (man, technology and organization) triad (Dougherty, 1993; Hollnagel, 1998).

In human error analysis (HEA) (Kirwan, 1992a, 1992b) or human reliability analysis (HRA) in safety assessment, such conditions that influence human performance have been represented via several 'context factors'. These context factors are referred to by different terms according to method: PSF (performance shaping factors), PIF (performance influencing factors), IF (influencing factors), PAF (performance affecting factors), EPC (error producing conditions), CPC (common performance conditions), and so on. The PSFs or PIFs are used as causes or contributors to unsafe, human actions in event analysis (Paradies, Unger, Haas & Terranova, 1993; Nakanishi et al., 2002), and also give a basis for assessing human factors in safety assessment (Hollnagel, 1998; Embrey, 1984).

HRA has been performed as part of the probabilistic safety assessment (PSA) of large-scale systems, such as nuclear power plants. PSA is an approach that develops all the possible accident scenarios and evaluates the overall safety of a system probabilistically using the event tree (ET) and fault tree (FT) techniques. The accident scenarios are composed of two failure components, i.e. human failure events (HFEs) and hardware (system/component) failure events. HRA takes part in estimating the probability of those HFEs. There have been various approaches for evaluating human reliability. In general, those approaches can be classified into two categories, i.e. those using time–reliability correlation (Hannaman et al., 1984; Moieni, Spurgin & Singh, 1994; Kim and Ha, 1997) and those manipulating PIFs (Embrey, 1984; Phillips et al., 1990; Gertman et al., 1992). For the methods using PIFs, some of them use a set of PIFs in adjusting the basic HEP (human error probability) such as THERP (Swain and Guttmann, 1983), HEART (Williams, 1988), CREAM (Hollnagel, 1998), and others in producing HEP by rating and integrating PIFs such as SLIM (Embrey, 1984), STAHR

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(Phillips, Humphreys, Embrey & Selby, 1990), etc. On the other hand, recently developed methods such as CREAM, INCORECT (Kontogiannis, 1997) and ATHEANA (US NRC, 2000) use PIFs in the qualitative analysis/assessment of overall working conditions or error-forcing context, as well as in the quantification of HEP.

Generally, PIF taxonomies are so developed as to be suitable for a specific purpose and application area. HRA methodologies also have their own PIF taxonomies, or the PIF sets considered for HRA are somewhat different depending on the developer or the analyst. This may cause some important problems. The first one is of the trust between the HEP values calculated from different methodologies that use a different set of PIFs. Also, comparison between different HRA results would be meaningless, and, in order to obtain error reduction measures, different PIFs would be dealt with according to the used method. The second problem may be applicable for some methods with a limited number of PIFs. The use of a limited number of PIFs might not only cause analysts to omit important error reduction measures, but also make the contribution of human error to the overall safety of a system to be assessed lower than reality. The third problem is that the definition and the specific items to be assessed for each PIF are deficient or different by method, which can cause an inconsistent assessment of the individual PIF between assessors and, accordingly, produce different HRA results.

In this study, we suggest a new PIF taxonomy for human error/reliability analysis of emergency and accident management tasks in nuclear power plants, with consideration of the above-described problems of the existing PIF taxonomies. The approach taken in the study to achieve the goal is summarized as follows.

Firstly, approximately 220 PIFs are collected from the existing PIF taxonomies and other literature, and those factors are collated into a new set of PIFs. Among them, HRA PIFs are examined for the characteristics and trend of selection and usage, and the insights from the examination are considered in the development of the new taxonomy.

Second, the principal context under which human operators respond to emergency and severe accident situations is analyzed, and PIFs relevant to such situational characteristics are selected from the full-set of PIFs collated in the first step.

Third, the criteria of the PIF sets to be adequate for HRA are described, and, on the basis of these criteria, the candidate PIFs selected in the second step are rescreened out and structured in a two-layer hierarchy, i.e. the representative PIFs and their subitems.

The paper is structured as follows according to the above-described approach. Section 2 includes a brief review of the existing PIF taxonomies, the full-set of PIFs collated, and the characteristics and trend of the HRA PIFs. In Section 3, the principal context affecting human reliability during accident management and the selection of PIFs based on the context is described. Section 4 provides the final set of PIFs structured based on the criteria of a PIF sets for HRA. Finally, Section 5 concludes the study with a summary and remarks.

2. Collection and analysis of the existing PIF taxonomies

2.1. Review of the existing PIF taxonomies

Two types of PIF taxonomies were collected in the study: one is composed of the detailed set of PIF, which was mainly developed for human error/factor analysis, and the other is the PIF set for the use in HRA. The first one is referred to as the full set PIF taxonomy. Seven taxonomies among the detailed PIF sets and 11 taxonomies in HRA methodologies have been reviewed in this study. HRA taxonomies are categorized according to the type of use as below. A brief description on the reviewed taxonomies is provided in Table 1. The list of HRA PIFs is shown in Table 2.

- The taxonomies of full-set of PIFs

– CSNI taxonomy (Rasmussen, 1981)
– THERP (Swain and Guttman, 1983)
– HEART (Williams, 1988)
– PHECA (Whalley, 1987)
– PSF taxonomy (Bellamy, 1991)
– Influencing factors (Gerdes, 1997)
– K-HPES (KEPRI, 1998).

- The taxonomies for use in HRA

– Quantification of HEP: SLIM (Embrey, 1984), PLG-SLIM (Chu et al., 1994), INTENT (Gertman et al., 1992), STAHR (Phillips, Humphreys, Embrey & Selby, 1990), and HRMS (Kirwan, 1997)
– Analysis of errors of commission: Macwan's PIF taxonomy for errors of commission (Macwan & Mosleh, 1994), Julius' PIF taxonomy for errors of commission (Julius, Jorgenson, Parry & Mosleh, 1995), and ATHEANA (US NRC, 2000)
– Overall context assessment and error analysis: HRMS, CREAM (Hollnagel, 1998; Hollnagel, Kaarstad & Lee, 1999), and INCORECT (Kontogiannis, 1997)
– Database for HRA: Taylor-Adams' PSF taxonomy for CORE-DATA (Taylor-Adams, 1995), and Rogers' PSF taxonomy for CORE-DATA (Gibson et al., 1998).

Table 1
Summary of the existing PSF/PIF taxonomies

Methodology	Description
PIF taxonomies for HEA	
CSNI taxonomy (Rasmussen et al., 1981)	The CSNI taxonomy was developed for reporting incidents and events involving human malfunctions. In the taxonomy of PIF, main distinction is made between PSFs and situation factors. The PSFs group is again subdivided into subjective goals and intentions, mental load and resources, and affective factors. Likewise, situation factors are subdivided into task characteristics, physical environment, and work–time characteristics.
THERP (Swain & Guttmann, 1983)	Swain defines PSF (performance shaping factor) simply as factors that influence human performance. In THERP, 67 PSFs are provided. Those are classified into three groups, i.e. external PSFs, stressors PSFs and internal PSFs. Again, the external PSF group consists of three subgroups: 'situational characteristics', 'job and task instructions' and 'task and equipment characteristics', the stressors PSF group is divided into 'psychological stressors' and 'physiological stressors', and the internal PSF includes 'organismic factors'.
PHECA (Whalley, 1987)	PHECA was developed for human error analysis in chemical process plants. The taxonomy is used for the identification of deficient design factors causing specific human errors. The final set of PSFs and its structure was reorganized based on the five PSF references (Swain and Guttmann, Embrey, Singh, AMAS, ergonomic literature), various incident/accident reports of chemical power plants (company accident reports, medical department records, incident reports, plant log books, supervisor records, computer printout), and analyses of five event cases in which various PIFs are interrelated. The PSFs are classified into three groups such as PROCESS, PERSONNEL and ERGONOMIC.
HEART (Williams, 1988)	HEART provides 38 EPCs (error-producing conditions) as PSFs. EPC is used to adjust the nominal probability to obtain the final HEP.
Bellamy's (Bellamy, 1991)	Bellamy categorizes PSFs into eight groups such as individual factors, man–machine interface characteristics (displays and controls), task demands, task characteristics, instructions and procedures, stresses, environment, socio-technical factors. As in THERP, STRESSES group of PSFs is separately organized.
Gerdes' (Gerdes, 1997)	PSF is named IF (influence factor). In total, 108 IFs were organized based on 32 references on PSF. All the IFs are categorized into four groups: HUMAN, TASK, MACHINE, and ENVIRONMENT. And four groups are again divided into several subgroups.
K-HPES (KEPRI, 1998)	K-HPES was developed for analyzing and reporting human induced/involved events in nuclear power plants. It analyzes cognitive error causes and types by retrospectively searching for internal decision-making processes. It provides 33 internal affecting factors.
PIF taxonomies for HRA	
SLIM (Embrey, 1984) & PLG-SLIM (Chu et al., 1994)	In the original SLIM in (Embrey, 1984), PSFs are selected through the expert panel. The PSFs seen in Table 2 is the set used as an example in (Embrey, 1984). The set of PIF suggested in the PLG SLIM is used in the evaluation of human failure events during the low-power and shutdown period of nuclear power plants (Chu et al., 1994). Both the original SLIM and PLG SLIM are utilized to obtain the success likelihood index (SLI).
INTENT (Gertman et al., 1992)	A set of PIFs in INTENT is used for the quantification of the occurrences of errors of intention. In addition, site-specific HEPs for errors of intention are determined using the HEP upper and lower bound values.
IDA (Phillips, Humphreys, Embrey & Selby, 1990)	PIFs in IDA are represented in a hierarchical structure using influence diagram. HEPs are calculated in a step-wise fashion to the top human event.
HRMS (Kirwan, 1997)	In HRMS, tasks to be quantified are compared with the task with the same task type and with a known HEP in view of PSF profile. And then, the HEPs are modified according to the differences in the profiles to obtain HEPs of tasks to be quantified.
Macwan's (Macwan & Mosleh, 1994)	Macwan's set of PIFs is basically for the identification of misdiagnosis or errors in intention formation processes. As a basic model of human behavior in nuclear power plants, he assumes that interactions between an operator and a plant occur on the basis of emergency operating procedures (EOPs). In accordance with the model, the composed set of PIFs is comprised of the three elements, i.e. operator, EOP and plant. Another feature in Macwan's is that PIFs are classified into the scenario-dependent PIFs that change as time goes on and the scenario-independent PIFs that is irrespective of time. As shown in Table 2, most PIFs use the terminology that is closely related with a situation.
Julius' (Julius, Jorgenson, Parry & Mosleh, 1995)	Julius reorganized the PIF set on the basis of the Macwan's taxonomy. In the same way as Macwan's, PIFs are classified into the context-independent PIFs and the context-dependent PIFs. Each group contains three sub-groups of PIFs.

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Table 1 (*continued*)

Methodology	Description
CREAM (Hollnagel, 1998)	Hollnagel provides nine context factors named CPCs (common performance conditions). He suggests that the difference between the CPCs and the conventional PSF is that the former used to adjust or produce the HEP, however, the latter is used for the overall assessment of task situation as well as the quantification of HEP.
INCORECT (Kontogiannis, 1997)	Kontogiannis defines PCs (performance conditions) as a similar kind of CPCs. He suggests, however, that PCs should be evaluated at each time when situation varies or a scenario develops so that it can be applied to the dynamic risk assessment frame such as the dynamic event tree (Acosta & Siu, 1993), instead of being assessed one time at an early stage of the analysis. He did not include composite factors such as stress, workload and task complexity since those are combined effect of several performance conditions.
Taylor-Adams' (Taylor-Adams, 1995)	The taxonomy of PIF that Taylor-Adams developed aims to be used as a PSF analysis module in CORE-DATA (computerized operator reliability and error database) which is a human error database for the support of HRA. CORE-DATA has the taxonomies for five human reliability related elements, i.e. external error mode, psychological error mechanism, performance shaping factors, task-equipment taxonomy, and human action taxonomy. The PSF taxonomy was developed based on PHECA (Whalley, 1987), THERP (Swain & Guttmann, 1983), HEART (Williams, 1988).
Rogers' (Gibson et al., 1998)	Afterward Rogers developed a new set of PSFs for CORE-DATA composed of 17 PSFs.
ATHEANA (US NRC, 2000)	ATHEANA provides a comprehensive framework covering errors of commission (EOC), as well as errors of omission (EOO). It introduces the notion of error-forcing context (EFC) in which a situation is created when human error is likely to happen. An EFC comprises plant conditions and PSFs. PSFs include traditionally used terms of PSFs shown in Table 2.

Table 2
The PIF taxonomies used in HRA methods

CREAM	STAHR	HRMS	INTENT
Adequacy of organization	Quality of information	Time	HMI
Working conditions	–Design	Quality of information/interface	Stress
Adequacy of MMI and operational support	–Meaningfulness of procedures	Training/Expertise/Experience/Competence	SRK
Availability of procedures/plans	Organization	Procedures	Experience
Number of simultaneous goals	–Role of operations	Task organization	Safety culture
Available time	–Teams	Task complexity	Training
Time of day	Personal		Motivation
Adequacy of training and preparation	–Stress		Workload
	–Morale/motivation		Supervision
	–Competence		Communication
			Procedures
SLIM	**ATHEANA**	**INCORECT**	**Taylor-Adams'**
Original SLIM			
Quality of design	Plant conditions	Time availability	Alarms
Meaningfulness of procedures	Procedures	Plan availability and accessibility	Communication
Role of operations	Training	Information availability and accessibility	Ergonomic design
Teams	Communication	Simultaneous tasks	HMI ambiguous
Stress	Supervision	Decision-making criteria	HMI feedback
Morale/Motivator	Staffing	Response dynamics and system coupling	Labels
Competence	Human–system interface	Supervision	Lack of supervision/checks
PLG-SLIM	Organizational factors	Capability degrading factors (CDFs)	Procedures
Plant interface and indications of conditions	Stress	Teamwork and social factors	Refresher training
Significant preceding and concurrent actions	Environmental conditions	Organizational factors	Stress
Task complexity			Task complexity
Procedural guidance			Task criticality
Training and experience			Task novelty
Adequacy of time to accomplish action			Time pressure
Stress			Training
Other			Workload

(*continued on next page*)

Table 2 (*continued*)

Rogers'	Macwan's commission error	Julius' commission error
Adequacy of HMI	Scenario-independent PIFs	Context-independent PIFs
Training	Crew training and experience	–Training related
Procedures	Crew confidence	1. Degree of familiarity with and frequency of training on, EOPs;
Adequacy of supervision/monitoring	Relative experience of RO and SRO	2. General philosophy towards using the EOPs;
Communication	Recent experience with one or more faulty signals	3. Generic rules for handling procedural ambiguities;
Team organization	Scenario-dependent PIFs	4. Method of resolving conflicting information from different instrumentations
Stress	–Plant related	–Crew team characteristic
Task complexity	5.Values of critical parameters	5. Team structure
Task novelty/unfamiliarity	6.Rate of change of critical parameters	6.Established protocol for communication
Workload	7. Instrument failure	7. Adequacy of resources
Distractions	– EOP related	–Plant related
Adverse conditions	8. Phase of EOP	8.Human factors design of the plant
Fatigue	9. Type of logic structure	Context-dependent PIFs
Motivation	10. Number of logical conditions	–Plant related
Safety culture	– Operator related	9. Value of critical parameter
Adequacy of design	11 Operator diagnosis	10. Trend of critical parameters
Robustness of design	12 Memory of recent actions	11. Availability of equipment
	13 Perceived importance	12. Availability of instrumentation
	14 Perceived consequences	–EOP related
	15 Operator expectations	13. EOP response phase (verification, diagnosis)
		–Operator related
		14. Confidence in diagnosis
		15. Expectation
		16. Memory of previous actions and accident history

2.2. Development of a new full-set of PIF

Besides the 18 taxonomies described in the previous section, other literature dealing with important influencing factors related to team/organization behaviors have also been included in the review. For instance, Jacobs and Haber (1994) describe organizational factors that can affect system safety, and Hollnagel (1998); Salas, Dickinson, Converse and Tannenbaum (1992); Xiao, Hunter, Mackenzie, Jefferies and Horst (1996), and Urban, Weaver, Bowers and Rhodenizer (1996) deal with inter/intra team interaction. In addition to those, HRA practitioners' opinions were also utilized to derive important factors. Especially, factors related to system dynamic features were much supplemented.

All the factors collected from the above-mentioned sources were collated into a new full-set PIF taxonomy. It is assumed that the context under which an operating crew should perform given tasks can be modeled as in Fig. 1. According to the Fig. 1, the collated PIFs are classified into four main groups: HUMAN, SYSTEM, TASK, and ENVIRONMENT. The boundary of each group is defined as follows.

- HUMAN: Personal characteristics and working capabilities of the human operator.
- SYSTEM: MMI, plant hardware system, and physical characteristics of the plant process.
- TASK: Procedures and task characteristics required of the operator.
- ENVIRONMENT: Team and organization factors, and physical working environment.

The four main groups are again divided into several subgroups. The final full set PIF taxonomy collated into the new classification frame is shown in Table 3.

2.3. Principal trend in the use of PIF for HRA

This section presents the trend of the selection and the level of definition of PIFs for use in the HRA, as HRA methodology develops.

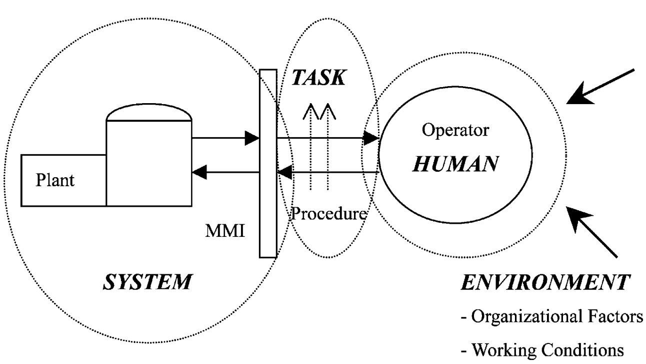

Fig. 1. The task context of nuclear power plants.

Firstly, as HRA methodology has improved, various kinds of factors have been considered. In early HRA methods such as THERP, ASEP and HCR, a very limited number of PIFs were chosen. For the methods utilizing expert judgment, such as SLIM and STAHR, 'team and organization factors', in addition to 'individual factors', could be included. In INTENT, 'safety culture' was considered as one of the important PIFs. Among the recently developed HRA methods, CREAM and INCORECT consider 'team and organization factors', 'system characteristics', and 'simultaneous goals/tasks' as important factors for human error/reliability analysis, and furthermore, the meaning of PIFs becomes more clearly defined than in the previous quantitative HRA methods. ATHEANA suggests the plant conditions, including system dynamic conditions, as the constituents that create a situation in which human error is strongly likely to happen, i.e. error-forcing context (EFC). To summarize the trend in the selection of PIFs for use in the HRA, in the initial HRA methods, a few very limited factors such as 'individual factors', 'procedures', and 'MMI' factors were considered in evaluating human reliability. Gradually, as HRA method becomes sophisticated, the assessment of overall work context is emphasized for better analysis and prediction of human error. According to this trend, 'team and organization factors', 'safety culture', 'plant dynamic features', and 'simultaneous tasks/goals' appeared as important factors which should be assessed.

Secondly, PIFs could be grouped as follows with respect to the frequency they are used in HRA methods.

- Factors that are used in the majority of HRA methods: training, experience, procedure, MMI/information, and time.
- Factors that are moderately used in HRA methods: stress, workload, motivation, task complexity, simultaneous goals/tasks, working condition, supervision, team factors, and communication.
- Factors that are used in a minority of HRA methods: adequacy of resources, decision making criteria, response dynamics and system coupling, availability of equipment, trend and value of critical parameters, time of day, organization factors, task organization, and safety culture.

Thirdly, the terminology and meanings of the selected PIFs became more specific and practical. Some of the factors being used in HRA methods are comprehensive in the meaning of their terminology. For this reason, the assessment results between analysts could be different because they assess the factors with their subjective meaning. Such factors, for instance, include stress, workload, task complexity, safety culture, organization factor, etc. For such factors, it is recommended that more apparent terminology be used or that the meaning/assessment

Table 3
The Full-set PIF Taxonomy

Main group	Subgroup	Detailed items	
HUMAN	Cognitive characteristics	Cognitive states –attention –intelligence –skill level –knowledge –experience –training	Temporal cognitive states –memory of recent actions –operator diagnosis –perceived importance –perceived consequences –operator expectations –confidence in diagnosis –memory of previous actions and accident history
	Physical and psychological characteristics	Physical states –gender/age –motor skills –physical disabilities –impediment: sight/hearing/speaking –clarity in speaking/use of standard language –fatigue/pain –discomfort –hunger, thirst	Psychological states –emotion/feeling –confusion/perplexity –task burden –fear of failure/consequences –high jeopardy risk
	Personal and social characteristics	Personal –attitude –morale/motivation –risk taking –self-esteem and self-confidence –sense of responsibility –sensation seeking –leadership ability –sociability –personality –anticipation	Social –status –role/responsibility –norms –attitudes based on influences of family and other outside persons or agencies

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Table 3 (*continued*)

Main group	Subgroup	Detailed items	
TASK	Procedures	–availability –format or type –quality –level of detail –interpretation margin –number of steps –required time for completion –clarity of instruction and terminology	–level of standardization in use of terminology –decision making criterion –logic structure –number of logical conditions (branches) –number of simultaneous tasks –adequacy of caution/warning
	Task characteristics	Task type –type of man–machine interaction: EOP phase–>procedure following, monitoring, detection, verification, diagnosis, recovery –required level of cognition –dynamic vs. step-by-step activities Task attribute/requirement –number of required information –number of necessary information to be memorized –information load –task difficulty–>multiple attempts –narrowness –task novelty –task consequences –degree of local operation –frequency and familiarity of task –degree of discrepancy with familiar tasks –number of simultaneous goals/tasks –concurrent activities and interruptions –interruption from other personnel –discrepancy between training and reality –necessity of auxiliary tools –conflicts of motives about job performance –appropriateness of required tools –multiple sensory requirements –perceptual requirements –task criticality –physical requirements –degree of manual operation –motor requirements –muscular power –speed –dexterity –precision	

Table 3 (*continued*)

Main group	Subgroup	Detailed items	
		–calculational requirement –anticipatory requirement –requirement on and type of feedback –degree of reference to other materials beside procedures –communication requirement –team cooperation requirement –necessity of decision making from higher organization	
SYSTEM	MMI	Indicator/controllers –availability –reliability –discrimination/distinguishability of signals –attributes –type of sensing –control–display relationships –orientation –labeling –location –existence of failed instrument –existence of failed indicator –stuck instrument –conflicting signals/cues	Panel/screen layout –reachability –visibility –coding/labeling –compatibility –state of arrangement –complicatedness of MCR panel Support systems –availability/adequacy –availability/adequacy of special equipment, tools and supplies –usability of required function
	System states	–inherent system complexity –organization of components –number of coupled components –reliability –redundancy –level of automation –configuration of system (on/off state of components) –stuck/failed components –previous operation of component and current operating status –availability of vital sources	
	Phenomenological characteristics	Physical characteristics –rate of change of critical parameters –trend of critical parameters –value of critical parameters –required water level vs. current status of water level –number of dynamic changing variables (plant dynamic behavior) –highly unstable plant situation–>uncertain information	Operational characteristics –suddenness of onset –overlap with previous tasks –total time to CD from the initiation of accident –time available for operator performance –time pressure (time required vs. time available) –existence of preceding information on scenario –phase of plant operation –EOP response phase (verification, diagnosis) –degree of alarm avalanche

Table 3 (*continued*)

Main group	Subgroup	Detailed items	
Environment	Physical working conditions	Physical constraints	Timing aspects
		–contamination from radioactive material	–time of day
		–physical inconvenience from protective clothing	–time on duty
		–temperature/humidity/pressure/illumination	–time into scenario
		–interference in communication	–circadian rhythm effects
		–noise	
		–vibration	
		–G-forces	
		–air pressure/quality/ ventilation/oxygen insufficiency	
		–movement constriction	
		–moving distance	
		–narrow work space or obstacles	
		–dangerous work space	
		–elevated work space	
		–accessibility of components	
		–architectural features	
		–order and cleanliness	
	Team and organization factors	Team-related factors	Training
		–clearness in job description or role definition	–simulation scope of simulator
		–clearness in responsibilities/communication line	–fidelity of simulation scenario
		–adequacy of distributed workload	–frequency and training time
		–intra/inter-team cooperation	–time period between training sessions
		–team cohesiveness/collaboration	Management and policy
		–ability/leadership/authority of team leader	–work (task) organization
		–commitment to leadership	–work/rest schedule
		Team communication-related factors	–shift organization
		–structure of instruction/information delivery	–shift rotation
		–standardization in instruction/information delivery	–supporting team
		–standard communication structure/network	–level of supervision
		–media of instruction/information delivery (page phone, fax, paper, etc.)	–inadequate instruction
		–established protocol/form of instruction/information delivery (intra-team/inter-team, oral/written, formal)	–plant policy
			–maintenance
		–procedures of instruction/information delivery	–human resource developing
		–protocol between sender and receiver	–investments and cuts
			–quality assurance
			–safety measures
			–rewards and punishments
			–work methods
			–manning
			Safety culture
			–routine violations
			–safety/economy tradeoff
			–openness in communication

items be clearly defined so that the consistency between analysts is maintained.

3. Situational characteristics during accident management

This section describes the situational characteristics during accident management (including emergency operation) in nuclear power plants. Based on those descriptions, performance influencing elements that affect operator performance during accident management are determined. Behavioral, phenomenological, organizational and environmental characteristics have been examined based on the literature dealing with accident management in nuclear power plants (KEPRI, 1997; Ha et al., 1997; US NRC, 1988).

Firstly, operator's tasks required in accident management (AM) situations are composed of not simple manipulative actions, but cyclic cognitive activities such as detection, observation, diagnosis, evaluation, planning, and decision-making. In performing such activities, procedures, information, operator support systems, training and experiences are crucial for the proper assessment of plant dynamic situations and the appropriate planning of how to cope with the given situation. Some example tasks appearing in accident management guidance are provided in Table 4.

Secondly, as an accident scenario evolves, plant systems and physical phenomena also change dynamically and multiple events can take place. Those complex and

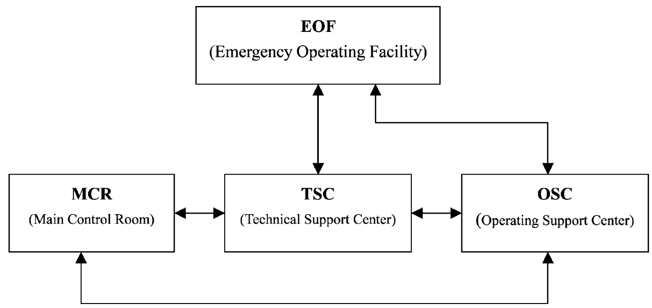

Fig. 2. Emergency organizations and interactions between organizations in nuclear power plant emergency situations.

Table 4
Sample tasks appearing in accident management guidance (adapted from WOG, 1994)

1. Evaluate the following negative impacts associated with implementing the strategy.
Check the following two conditions, and if both conditions are satisfied, there will be 'insufficient injection source'.
–Check if core has not been reflooded.
–Check the following condition: RWST level <(L09)%.
2. Evaluate mitigating actions.
If there is a possibility of insufficient containment injection source, then evaluate the following mitigating actions.
–Evaluate the action of 'Increase RWST refill rate'
–Evaluate the action of 'Control containment injection flowrate to maintain RWST water level greater than (L09)%'.
3. Evaluate the consequences of NOT injecting into the containment (Containment challenge due to Basemat Meltthrough, RPV failure may not be delayed, Fission products from ex-vessel core debris, Consequences of HPME, Combustible gas generation due to CCI, Recirculation problem)
4. Determine if containment injection should be initiated by comparing the consequences of NOT injecting into the containment versus the negative impacts of injecting into the containment.

Table 5
The situational characteristics of AM tasks and related human factors

	Situational characteristics under AM	Human factors
Behavioral characteristics	Cognitive activities (observation, diagnosis, interpretation, planning, decision-making, etc.)	–Knowledge (training, experience) –Procedure –Man–machine interface
Phenomenological characteristics	Dynamic evolution of plant systems Multiple events	–Dynamic system status –Multiple goals and tasks –Available time for task achievement
Organizational characteristics	Inter-/Intrateam cooperation Decision-making from higher organizations	–Team and organization factors –Decision-making structure –Plant policy and safety culture
Environmental characteristics	Local operation Harsh environment	–Task location and physical environment

Table 6
Candidate PIFs selected considering AM situational characteristics

HUMAN	TASK	SYSTEM	ENVIRONMENT
–knowledge, experience, training, competence –stress, burden, fear of consequences –attitude, morale, motivation –risk-taking, confidence	Procedures –Procedures	–MMI/Information –system states –trend of critical parameters –value of critical parameters –number of dynamic changing variables –degree of alarm avalanche –suddenness of onset –time adequacy	Working condition –physical constraints (for local activities) –time of day (circadian rhythm)
	Task type –type of man-machine interaction –level of cognition -dynamic/step-by-step activities		Team factors –team structure –role/responsibility –adequacy of distributed workload –team cooperation and collaboration –communication
	Task attribute/requirement –task criticality –task novelty –task consequences –degree of local operation –calculational requirement –anticipatory requirement –communication requirement –necessity of decision-making from higher organization –necessity of auxiliary tools –number of necessary information –degree of reference to other procedures –degree of discrepancy with familiar tasks –simultaneous goals/tasks		Organization factors –work organization –supervision –shift organization –plant policy –adequacy of instruction –maintenance –safety culture –organization structure and manning

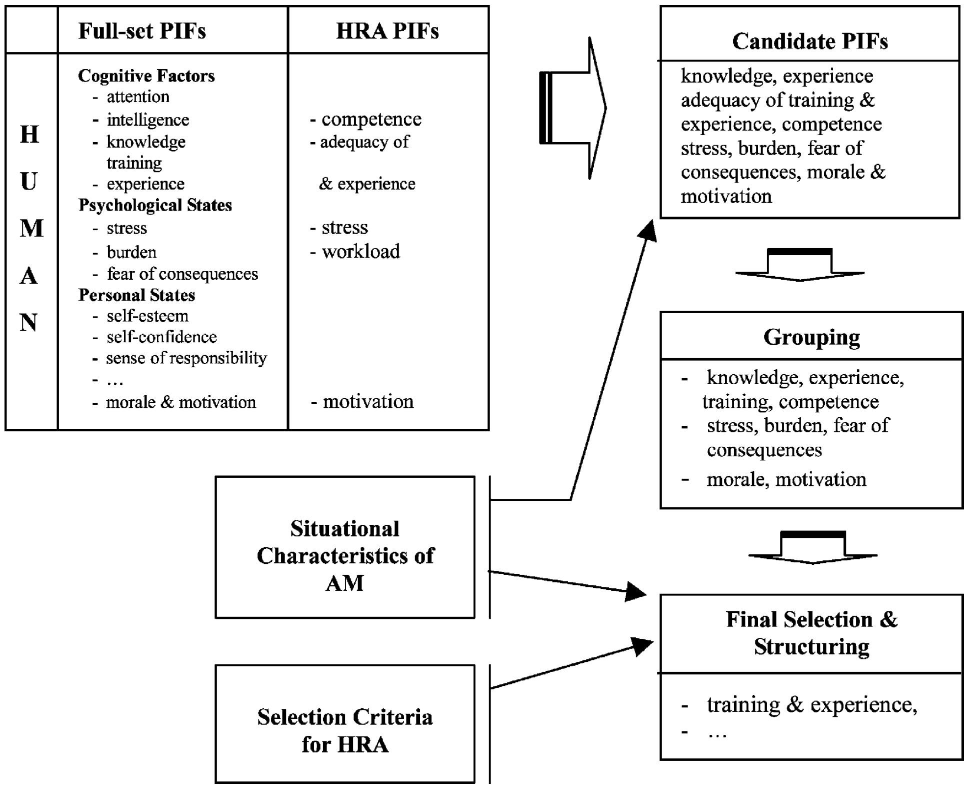

Fig. 3. Process of structuring PIFs relevant to AM situations.

Table 7
An example of structuring sub-items—procedures

Full-set PIFs	Sub-items
TASK	TASK
Procedures	Procedures
availability	✓
format or type	✓
quality	
level of detail	
margin on interpretation	
clarity of instruction and terminology	✓
level of standardization in use of terminology	
decision-making criterion	✓
logic structure	✓
number of logical conditions (branches)	
number of simultaneous tasks	
adequacy of caution/warning	

dynamic situations can be a critical influencing factor to operator performance. Multiple tasks, status of major systems and components, and temporal factors are related to this situational characteristic.

Thirdly, most of AM tasks require inter-/intra-team cooperation and decision-making in higher-level organizations beyond individual execution as in normal operation. Under those situations, various factors related to team performance, decision-making structure in a team or organization, and plant policy and safety culture can be important contributors to task performance. Fig. 2 shows the emergency organizations and interactions between those organizations in nuclear power plants.

Fourthly, harsh working environments such as high radioactivity, high pressure/temperature, and potential of hydrogen detonation, etc., may take place in some task locations. Such environmental features can be a direct obstacle, i.e. limitation in accessibility, to task performance.

Table 5 summarizes the situational characteristics of AM tasks and related human factors. Candidate PIFs for structuring to be fit for HRA are extracted from the full-set PIF taxonomy considering those situational characteristics and human factors relevant to AM. The list of extracted candidate PIFs is shown in Table 6.

4. Structuring PIFs for human reliability analysis

The candidate PIFs for AM obtained in the previous section should be reorganized to be appropriate for use in HRA. The structuring of PIFs was conducted on the basis of the insights from the Section 2.3 Principal trend in the use of PIF for HRA. Fig. 3 shows the schematic representation of the process to the construction of a set of PIFs for AM HRA. The PIFs relevant to AM situations have firstly been selected from the full-set PIF taxonomy, and those PIFs are grouped into ones with

Table 8
A set of PIFs for human error analysis of AM tasks

PIF group	Representative PIF	Subitems
HUMAN	1. Training and experience	Adequacy of training (frequency, recent training, fidelity of simulation program) Experiences/practices of real operating events Learning of the past events/experiences Career of the operators
TASK	2. Availability and quality of procedures	Availability Format or type Clarity of instruction and terminology Decision-making criterion Logic structure
	3. Simultaneous goals/tasks	Number of simultaneous goals/tasks Priority between goals/tasks Conflict between goals
	4. Task type/attributes	Type of man–machine interaction Dynamic/step-by-step Task criticality/consequences Degree of discrepancy with familiar tasks
SYSTEM	5. Availability and quality of information	Information availability (instrumentation fail/stuck) Clearness of meaning (direct indication/interpretation required/ambiguous/unreliable information) Distinguishability of information Control display relationships
	6. Status and trend of critical parameters	Value of critical parameters Trend of critical parameters (rate of change of critical parameters Number of dynamic changing variables Degree of alarm avalanche
	7. Status of safety system/component	Success/fail state of safety system/component Level of trust on the system/component Number of failed/stuck components Previous operation history and current status of safety system
	8. Time pressure	Available time vs. required time
ENVIRONMENT	9. Working environmental features	Task location: (MCR/local CR/local area) Accessibility
	10. Team cooperation and communication	Clearness in role/responsibility definition Direction, type, method, protocol Standardization in instruction/information delivery Team collaboration/cooperation Adequacy of distributed workload
	11. Plant policy and safety culture	Plant specific prioritized (or preference for/objection to) goals/strategies Attitude toward EOP/AMP training Safety/economy tradeoff Routine violations

similar meaning. Then, considering the situational characteristics of AM tasks and the criteria for use in HRA, the final taxonomy is systematized. The criteria for the selection and structuring of PIFs for HRA are established as follows, considering the practical aspects of HRA.

- It should include all the important factors to assess overall task context as comprehensively as it can.
- It should not be overlapped between factors.
- It gave the keynote for selecting factors that directly affect human error occurrences.

- It selects the factors that could be reflected into human error/reliability analysis.
- It selects the factors that are assessable in practice.
- The terminology should be as specific and practical as possible so that the meanings of the terms might be easily understood.

According to these criteria, construction of the representative PIFs and their subitems was made using one or mixed method of the following structuring processes by the property of each PIF. The first structuring method is to use the full-set PIF taxonomy illustrated in Table 7. Important subitems for the assessment of a PIF are marked out from the given detailed items of a PIF. The second method is to choose the representative PIF from the PIF group with similar meaning and to organize subitems. Thirdly, other factors from the literature and HRA experts were also incorporated into those processes.

Through repetitive modification, the final set of PIFs, which is composed of 11 representative PIFs and their subitems, is presented in Table 8. The proposed taxonomy will need a continual revision process in association with the methodology development.

5. Conclusions

In this paper, we introduced a process of the systematic construction of PIF sets for the use in HRA in a specific context, especially, AM situations (including emergency operations) in nuclear power plants. In order to achieve this goal, firstly, 18 existing PIF taxonomies including the recently developed methods have been collected and collated into a new set of PIFs consisting of approximately 220 detailed PIFs. In particular, PIF taxonomies for HRA were analytically reviewed in view of the trend and characteristics of selection and use, and the insights from the review were considered in the development of the new taxonomy. In order to reflect the task context, situational characteristics during the AM realm in nuclear power plants were described according to the behavioral, phenomenological, organizational and environmental characteristics. Based on the descriptions, PIFs relevant to such situational characteristics were selected from the full-set PIFs and, finally, those were structured in a two-layer hierarchical form considering the practical aspects of the use of PIFs in HRA.

The proposed taxonomy could be used in the assessment of overall task context, prediction of human error, such as internal/external error modes, and quantification of their probabilities, and so on. In order to use the taxonomy in those areas, an appropriate analysis/assessment framework should be developed. For example, the psychological error mechanisms (PEMs) in human cognitive functions may help find a way to consider the PIFs in a systematic manner. In accordance with the PEM, some PIFs may be directly causing factors and others be contributory or shaping factors to human error. The proposed taxonomy would require continual modifications in association with the development of HEA/HRA methodology.

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