

Need for Human Reliability Data Collection for Extending the EMBRACE Method to the i-SMR Integrated Control Room

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1. Introduction

EMBRACE is an empirically based human reliability analysis (HRA) method developed at KAERI to produce plant-specific human error probabilities (HEPs) from empirical simulator data [1]. A human failure event is decomposed into the primitive tasks that operators actually perform in the main control room (MCR), for each of which a primitive error probability (PEP) estimated from the Human Reliability data EXtraction (HuREX) database is assigned. The PEPs are then adjusted by performance shaping factor (PSF) multipliers and credited with recovery factors (RFs) by applying recovery failure probabilities (RFPs). EMBRACE-APR1400, derived for the digitalized computer-based control room of APR1400, is currently available [2].

The innovative Small Modular Reactor (i-SMR) adopts a multi-module integrated control room (ICR) whose design concept and operation strategy may differ from those of the APR1400 MCR [3]. Because EMBRACE pursues or builds upon plant-specific HRA data, a dedicated HRA data set for EMBRACE-iSMR needs to be established from HRA data collection in the i-SMR environment. The purpose of this paper is to identify which specific elements of the taxonomy of EMBRACE need to be newly defined, modified or re-examined from EMBRACE-APR1400 to reflect the i-SMR ICR, prior to a simulator-based data collection activity, so that data collection and task analysis can be prepared accordingly.

2. Design Features of the i-SMR ICR from the HRA perspective

The following design features of the i-SMR ICR are judged to influence the EMBRACE parameters directly.

- Extensive adoption of passive safety systems and automatic actuation systems, which shifts much of the operator's role from manual actuation toward monitoring and verification of safety functions.
- An advanced HMI and computer-based procedures (CBP) equipped with highly automation functions, including automated procedure execution.
- Multi-module operation by a single operating crew, composed of limited number of staff, which may introduce the need to allocate limited manpower and attentional resources across modules.

- A crew composition and role allocation differing from conventional NPPs; in particular, an individual reactor operator (RO) performs procedure following, information gathering, response planning, and response execution, for the module under control.
- A time available for operator action spanning from tens of minutes to more than three days, which affects the operating crew's shift change and the potential for recovery opportunity.

3. Data collection considerations for EMBRACE-iSMR

3.1. Primitive Task Types (PTTs) and PEPs

Table I lists the primitive task types (PTTs) and PEPs currently used for EMBRACE-APR1400. The existing classification scheme is expected to remain applicable largely, but partial revision is required to reflect the changes in crew roles and task requirements described in Section 2. The following are candidates for a new PTT or for modification of an existing one.

- (a) Monitoring of the functional status of passive and automatic safety systems. This is close to, but not identical with, the existing information gathering (IG) types, since the object of monitoring is the adequate functionality of a safety function rather than the value of a single indicator.
- (b) Mode awareness of automated equipment. This is related to the potential for wrong awareness of an operating mode of an equipment or the potential for mode confusion between operating modes for an automated system and component.
- (c) Module awareness, i.e., the potential for module confusion when a single crew operates several modules.
- (d) Adjustment of the response planning and instruction (RP) types. The 'Directing ...' PTTs need modification, because an individual RO conducts most of required operations by himself or herself for a module under control, including procedure following, information gathering and response execution. For information items or manipulations required outside the MCR, however, 'Directing or requesting ...' PTTs are still valid.
- (e) Adjustment of the PTTs to reflect automated procedure execution; a PTT such as 'initiating an automatic execution' may need to be introduced.

- (f) Information and situation sharing activities at key steps or stages. These are worth treating as separate task types because they affect the subsequent error recovery capability by the shift supervisor (SS).
- (g) The judgment of the SS and the resulting direction on assigning responsible operators when events occur in more than one module. Failure of this activity is somewhat ambiguous to classify as an error because the allocation itself does not invoke any prompt erroneous actions. A further criterion for its inclusion has to be established first.

Table I: PTTs and PEPs for EMBRACE-APR1400 [2]

Cognitive activity	Primitive task type (PTT)	PEP
Information gathering (IG)	Verifying alarm occurrence	1.10E-04
	Verifying the state of an indicator	1.10E-04
	Synthetically verifying information	1.51E-03
	Reading a simple value	1.10E-04
	Comparing parameters	1.10E-04
	Comparing in graph constraint	1.10E-04
	Comparing for abnormality	1.10E-04
	Evaluating a trend	3.08E-04
Situation interpretation (SI)	Diagnosing cause of problem	2.16E-03
	Identifying overall plant status	2.16E-03
	Predicting future status	2.16E-03
Response planning and instruction (RP)	Entering the succeeding step in the proc.	1.85E-04
	Transferring to another proc.	5.62E-03
	Transferring to step in the same proc.	5.62E-03
	Directing information acquisition	6.22E-05
	Directing (simple/dynamic) manipulation	1.96E-03
	Directing external notification/request	1.85E-04
Execution (EX)	Manipulation – simple/discrete control	1.84E-03
	Manipulation – simple/cont. control	1.53E-02
	Manipulation – dynamic manipulation	1.49E-02
	Notifying/requesting to MCR outside	1.84E-03

3.2. PSFs and Multipliers

Table II shows the PSFs and their multipliers for EMBRACE-APR1400. Two kinds of extension are considered: PSFs to be newly added, and new attributes to be reflected within an existing PSF.

As a new PSF, the effect of multi-module events should be introduced, characterized by attributes such as the number of modules concurrently occurring and the degree of (in)homogeneity among the accidents progressing in individual modules.

New attributes to be reflected within existing PSFs include the following items by PSFs:

- Complexity of required task and complexity of HMI: The complexity associated with mode awareness.
- Subjective stress: In the i-SMR, all emergency operating procedures (EOPs) are expected to be formulated as functional recovery procedures (FRPs), thus an appropriate level of stress for this structure needs to be defined.
- Procedure quality and support function of CBP: Design attributes such as logic representation, response-not-obtained (RNO) column, and key steps, the automated functions provided, and the number of steps in a single procedure or in the overall EOP. The potential for confusion between, or omission of, automated and manual procedure steps also belongs here.

- Communication level: Need to be considered in evaluation of key steps or stages at which situation or information sharing takes place.

Table II: PSFs and multipliers for EMBRACE-APR1400 [2]

PSF	Multiplier for a procedure transition	Multiplier for an equipment manipulation
Complexity of required task	3	3
Subjective stress	[High] 5 / [Medium] 2.5	[High] 5 / [Medium] 2.5
Complexity of HMI	3	5
Procedure quality	5	5
Support function of CBP	2	3
Communication level	2	2
Training level	5	3
Accident-procedure mismatch	10	10

3.3. RFs and RFPs

Table III presents the RFs and RFPs for EMBRACE-APR1400. Since the time available in the i-SMR spans tens of minutes to over three days, the degree of recovery potential — and hence the set of applicable RFs and the credit given to each RF — has to be re-examined. The main items or questions for considerations are as follows.

- (a) Recovery by procedure: When the procedure steps are simple and few in number, is separate credit appropriate, or is it more reasonable to subsume the effect in the individual PEPs?
- (b) A new RF for post-auto-execution monitoring, i.e., monitoring of the plant status after an automated procedure execution.
- (c) STA monitoring recovery: The shift technical advisor (STA) function may be transferred to the SS, in which case the period of the safety function status check and the number of modules to be monitored become the governing attributes.
- (d) Recheck in stable status: The time point of starting a full re-execution of the EOPs in the i-SMR ICR environment.
- (e) Shift change recovery: When the time available is as long as 72 h, several shift changes can occur. The number of shift changes that may be credited for error recovery should be decided together with the question of what minimum RFP or minimum HEP is appropriate.

Table III: RFs and RFPs for EMBRACE-APR1400 [2]

Recovery factor	Dependency level	RFP
Shift change recovery	Zero	0.016
Recovery from apparent cue	Zero	0.016
Recheck in stable status	Low	0.05
STA monitoring (TM > 37 m)	Medium	0.14
STA monitoring (TM > 22 m)	High	0.5
Recovery by procedure	High	0.5

4. Conclusions

The HRA taxonomy for EMBRACE-iSMR requiring new definition or revision for the i-SMR ICR were identified. For the PTTs, new types for passive systems

or automatic function monitoring, mode awareness, module awareness, automated procedure execution and information sharing are needed. For the PSFs, a multi-module event PSF is to be newly added, and the PSF attributes for mode awareness, the FRP-based procedure structure, and the CBP automation functions need to be reflected in existing PSFs. For the RFs, the wide range of time available and the role transfer of the STA to SS require the RF set and RFPs to be reconstructed, including a decision on minimum RFP or HEP. These items will serve as the basis for designing data collection at the i-SMR ICR simulator environment and further task analysis and HRA for crew's tasks using EMBRACE-iSMR to be developed in the future.

REFERENCES

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