INSIGHTS FROM A CASE STUDY ON THE QUANTIFICATION OF OPERATOR MANUAL ACTIONS

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EXTENDED ABSTRACT

Fires in nuclear power plants (NPPs) pose significant risks as they can simultaneously damage multiple safety-critical components, potentially leading to core damage and severe accidents. Fire probabilistic safety assessment (PSA)[1] is employed, incorporating fire human reliability analysis (HRA)[2] to assess the risks. This study focuses on quantifying the human error probability (HEP) of operator manual actions (OMA) in fire scenarios, applying the Fire HRA[3-4] methodology developed by the Korea Atomic Energy Research Institute (KAERI) based on the K-HRA, Rev.1 framework[5].

The study adopts a structured approach to OMA quantification in fire conditions:

- Selection of OMA cases: 12 OMA cases were identified, based on multi-spurious operation (MSO) scenarios that could impact post-fire safe shutdown. These cases include reactor coolant pump (RCP) breaker trips, containment spray pump (CSP) pump trips, two kinds of CSP outlet valve operations, and essential service water pump (ESP) outlet valve operations.
- Time parameter and performance shaping factor (PSF) analysis: Key time parameters, including cue recognition and execution times, were analyzed alongside PSFs such as procedure quality, stress levels, and operator training.
- HEP calculation: Using the Fire HRA methodology, HEPs were derived by integrating diagnosis and execution probabilities, adjusted based on environmental constraints and fire-specific PSFs.

The quantification results revealed significant variations in HEPs depending on the fire location, task complexity, and environmental factors:

- Higher HEPs for MCR fires: OMAs performed during fires inside the main control room (MCR) exhibited higher HEPs than those for fires outside the MCR. This increase was attributed to reduced time available for diagnosis, increased stress, and procedural challenges
- Impact of power availability on RCP operations: RCP breaker trip operations showed higher HEPs under Non-1E 125V DC unavailability, as operators had to diagnose the failure and manually operate the switchgear under increased time pressure
- Complexity in CSP valve operations: OMAs involving CSP outlet motor operated valves (MOVs) and manual valve operations recorded elevated HEPs due to task complexity, inadequate procedures, and challenging working conditions.
- ESP outlet MOVs in MCR abandonment (MCRA) scenarios: The highest HEP was observed in ESP outlet MOV operations during MCRA scenarios, where environmental constraints, procedural limitations, and the transition to remote shutdown panel (RSP) heightened the likelihood of errors.

The study underscores the necessity of quantitative OMA assessments to support risk-informed decision-making. Key recommendations include:

- Enhancing fire PSA models: Existing fire PSA frameworks should incorporate refined OMA quantifications to improve fire risk evaluations.
- Improving procedures and training: Operators require enhanced procedures and repetitive training to mitigate human error in fire emergencies

By quantifying the HEP of fire-induced OMAs, this study provides a foundation for strengthening NPP fire safety and human reliability assessments. The findings demonstrate that MCR fires pose heightened risks, and that task complexity, procedural adequacy, and power availability significantly influence OMA reliability. Future research should focus on datadriven refinements to Fire HRA models and simulation-based validation of operator responses to enhance emergency preparedness and risk management strategies.

TABLE I. OMAs Selected for Quantification

Component	OMA	Fire Area	Description	MSO
RCP	RCP trip (Non-1E 125V DC is unavailable)	Outside MCR	Opening the RCP's breaker at a switchgear room	MSO #1 (Loss of all RCP seal cooling)
	RCP trip (Non-1E 125V DC is available)	Outside MCR		
	RCP trip (Non-1E 125V DC is available)	Inside MCR		
CSP	CSPs trip	① Outside MCR ② Inside MCR	Opening the CSPs' breakers at switchgear rooms (A/B)	MSO #16 (RWST (Refueling Water Storage Tank) drain down via containment spray)
MOV on CSP discharge line	CSPs discharge MOVs close	① Outside MCR ② Inside MCR	• Opening the breakers of CSPs discharge MOVs' at switchgear rooms (A/B) • Closing the MOVs manually at mechanical penetration rooms (A/B)	MSO #16 (RWST drain down via containment spray)
Manual valve on CSP discharge line	CSPs discharge manual valves close	① Outside MCR ② Inside MCR	Closing the manual valves at SC(Shutdown Cooling) Hx (Heat Exchanger) rooms	MSO #16 (RWST drain down via containment spray)
MOV on ESP discharge line	ESP and CCW(Component Cooling Water) Hx discharge MOV open	① Outside MCR ② Inside MCR ③ MCRA	• Opening the breaker of a ESP and CCW Hx discharge MOV at switchgear room • Opening the MOV manually at CCW Hx room	MSO #43 (ESW header isolation)

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REFERENCES

[1] R. P. Kassawara and J. S. Hyslop, "EPRI/NRC-RES Fire PSA Methodology for Nuclear Power Facilities," *NUREG/CR-6850* (2005).
[2] US NRC, "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," *NUREG-1921* (2012).
[3] S. Y. Choi and D. I. Kang, "Development of a Fire Human Reliability Analysis Procedure for Full Power Operation of the Korean Nuclear Power Plants," *Journal of the Korean Society of Safety*, Vol 35 No 1, pp. 87-96 (2020).
[4] S. Y. Choi, D. I. Kang, Y. H. Jung, "Improvement of Fire Human Reliability Analysis for Operator Manual Action Quantification," *ESREL 2024* (2024).
[5] S. Y. Choi, D. I. Kang, Y. H. Jung, "Case study for quantification of post-fire OMA(Operator Manual Action) based on a fire HRA(Human Reliability Analysis) methodology," *KAERI/TR-10673/2024* (2024).
[6] J. Kim, Y Kim, W. Jung, H. Jeon, H. Lee and K. Oh, "The K-HRA, Rev.1 Method for Post-Initiator Human Action at Internal Event Scenario," *Transactions of the Korean Nuclear Society Autumn Meeting 2023* (2023).