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Redefinition of Performance Shaping Factors (PSFs) Pertinent to Small Modular Reactors (SMRs)

Presentation Outline

Research Background

Increasing Demands for SMRs Worldwide

- Small Modular Reactor (SMR) is a type of nuclear reactor characterized by its **smaller size** and **modular design** compared to conventional gigawatt-scale nuclear power plants [1].
- Reasons for this demand increase [1,2]:
  - ➢ Meeting net-zero carbon goals;
  - ➢ Complementing renewable energy;
  - ➢ Etc.
- The question is, how do we "enjoy" the benefits of an SMR?

Source:
https://www.theengineer.co.uk/content/news/amazon-and-google-bet-big-on-smrs-to-power-ai/

Amazon and Google bet big on SMRs to power AI

News

Tech giants Amazon and Google have announced major plans to invest in small modular reactors (SMRs) to deliver clean power for energy-intensive AI.

Source:
https://www.kedglobal.com/business-politics/newsView/ked202405310013

Business & Politics

South Korea to build 3 nuclear plants, 1 SMR under new energy policy

With the latest plan, the government is reviving its goal of becoming a global nuclear powerhouse

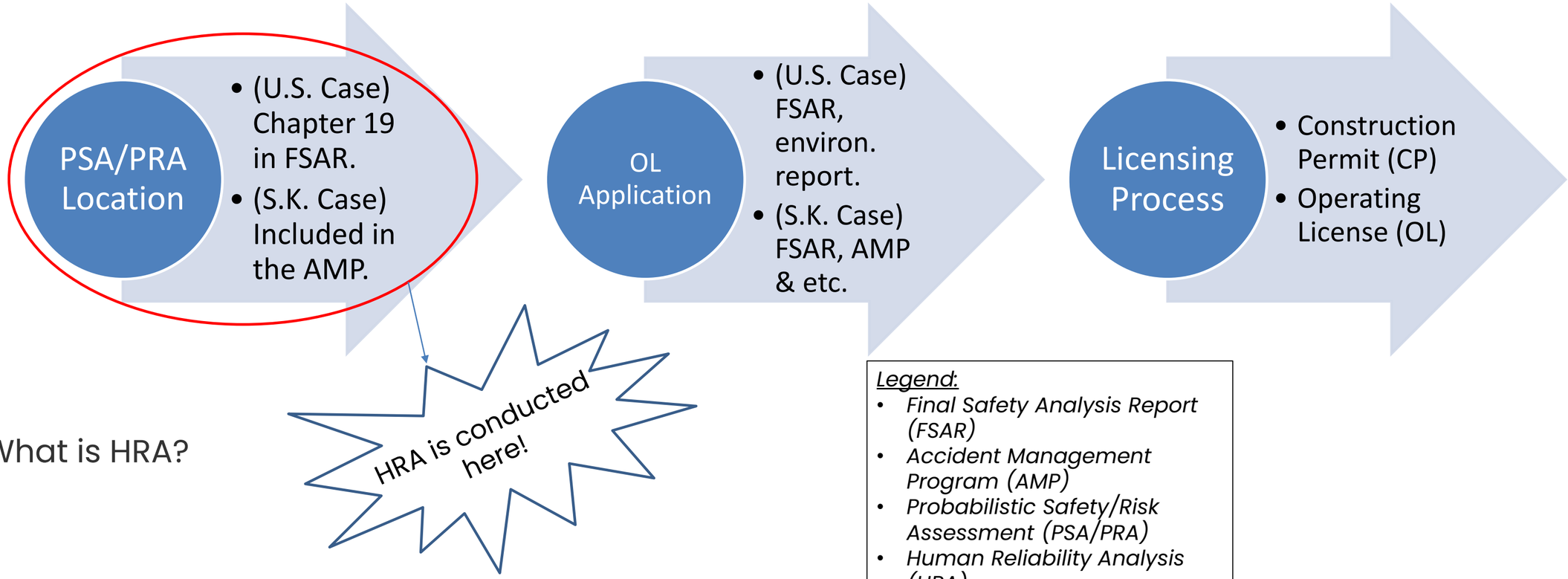
By Sul-Gi Lee and Jung-hwan Hwang May 31, 2024 (Gmt+09:00) | 3 Min read

[1] Organisation for Economic Co-operation and Development (OECD). (2023). The NEA Small Modular Reactor Dashboard (NEA No. 7650). Nuclear Energy Agency.

[2] Blackett, C., Eitrheim, M. H. R., & Bye, A. (2022). The Challenge of Assessing Human Performance and Human Reliability for First-of-a-Kind Technologies.

How do we “enjoy” the benefits of SMRs?

- The utility (e.g., KHNP) must get it licensed first. Requirements for license application [3,4]:



- What is HRA?

[3] King, M. (n.d.). NUREG/BR-0298 Rev 2 “Nuclear Power Plant Licensing Process.”

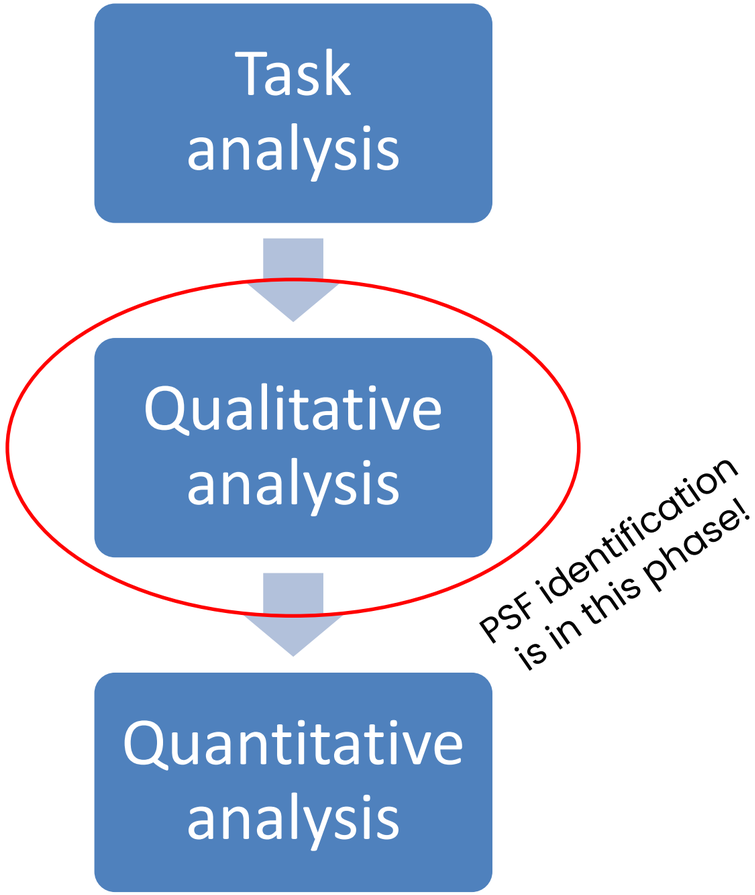
[4] 8th National Report for the Convention on Nuclear Safety 8th National Report for the Convention on Nuclear Safety. (n.d.). www.nssc.go.kr

I Research Background

What is HRA?

- Human reliability analysis (HRA) provides a value that quantifies the true risk of human error in sociotechnical systems, such as NPP [2,5].
- At its core, HRA models factors that affect human performance, which are called performance shaping factors (PSFs) [ibid].
- Are the previous PSFs still applicable to SMRs?

Figure 1: Generalized HRA process adapted from Park, J. et al. (2019) [5]



[2] Blackett, C., Eitrheim, M. H. R., & Bye, A. (2022). The Challenge of Assessing Human Performance and Human Reliability for First-of-a-Kind Technologies.

[5] Park, J., Arigi, A. M., & Kim, J. (2019). A comparison of the quantification aspects of human reliability analysis methods in nuclear power plants. Annals of Nuclear Energy, 133, 297–312. https://doi.org/10.1016/j.anucene.2019.05.031

Adapting HRA for SMRs

- Previous HRA methods focus on conventional NPP applications.
- To possibly reuse the PSFs that are commonly used in the previous HRA methods, we must **review their definitions** and **evaluate their relevancy** for SMRs.
- **Study Objective:** Redefine the PSFs (and their levels) from previous HRA methods to clarify the relevance of these PSFs in the SMR context.
- **Study Scope:**
  i. Systematic Review for PSFs Extraction;
  ii. Redefinition of SMR-relevant PSFs;
  iii. PSF Levels Suggestion.

Previous Study Approach

Pool of PSFs obtained

HF issues derived

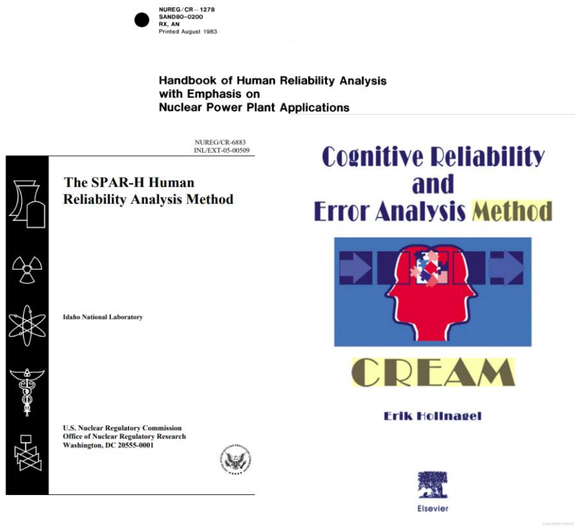
SMR-specific PSF taxonomy constructed

Proposed PSF Taxonomy for SMRs

II Proposed PSF Taxonomy for SMRs

Study Method

- The systematic review is done in the following manner:



PSFs from previous HRA methods and taxonomy studies

Category	PSFs	PSF Levels
Still applicable PSFs	Available time	Inadequate, ≈ Time required, Nominal, ≥ 5x time required, ≥ 50x time required
	Procedures	Nominal, Complete but ambiguous, Incomplete, Not available
	Fitness for duty	Nominal, Poor, Not fit
Redefined PSFs	Environmental conditions	Disadvantageous, Nominal, Advantageous
	Workload	Very low, Optimum, Nominal, High
	Experience/Training	Low, Nominal, Extensive, High
	Adequacy of staffing	Inadequate, Nominal, Extra
	Adequacy of communication protocols	Inadequate, Nominal, Good
	Human-centered HSI	Confusing, Poor, Nominal, Human-centered
	Complexity	Low, Nominal, High, Very High

SMR-specific PSF taxonomy construction (based on criteria)

PSF	Taxonomy	PSF Levels (with definition)
Experience/Training	Proposed SMR Taxonomy	➢ **Low:** less than 6 months ➢ **Nominal:** more than 6 months ➢ **Extensive:** extensive experience with conv. NPP ➢ **High:** extensive experience with SMR
	SPAR-H	➢ **Insufficient information** ➢ **Low:** less than 6 months ➢ **Nominal:** more than 6 months ➢ **High:** extensive experience
	THERP	➢ **Novice:** less than 6 months ➢ **Skilled:** more than 6 months

PSFs redefinition and levels suggestion

Criteria for PSF Selection

Below are the criteria used for the PSF selection:

i. **Commonly used in previous HRA methods** (e.g., THERP, SPAR-H, etc.);
ii. **Relevant to SMR design and operations** (e.g., high automation, multi-module operation, etc.);
iii. **Measurable using validated metrics** (e.g., NASA-TLX for 'Workload' PSF);
iv. **Independent from other performance metrics** (e.g., not considering 'Supervision' as a PSF **to avoid double-counting** in human error probability calculation, as it is already credited as recovery actions in post-HRA modeling).

II Proposed PSF Taxonomy for SMRs

Environmental conditions 

- Some SMRs might introduce new hazards. For example [6]:
  - ➢ Hazardous fumes from graphite cores in HTGRs
  - ➢ Hazardous nature of coolant in LMRs.
- Addressing these hazards requires **specialized training, usage of specialized personal protective equipment (PPE), and working in an uncomfortable atmosphere** [ibid].
- Hence, this PSF refers to how the working environment in SMR impacts the operator's performance.
- Proposed PSF levels: Disadvantageous, Nominal, Advantageous**.**

Workload 

- The focus of this PSF is to **assess the perceived workload** experienced by the operators with an **emphasis on cognitive task load**, contrary to the overarching concept of the 'Stress' PSF in previous HRA methods.
- Proposed PSF levels: **Very low (Complacent),** Optimum (Facilitative), Nominal, High (Disruptive).

[6] Ohara, John & Higgins, James & Deem, Richard & Xing, Jing & Agostino, Amy. Human Factors Aspects of Operating Small Reactors.

II Proposed PSF Taxonomy for SMRs

Experience/Training 

- Refers to how the operators' experience or training with SMR and how their **prior experience** in operating a conventional NPP may affect human performance in a multi-module SMR environment.
- SMR is a first-of-a-kind (FOAK) plant, where past operational experiences are useful but majority of it will be gained during the actual operation [7].
- Proposed PSF levels: Low, Nominal, **Extensive**, High.

Adequacy of Staffing 

- This refers to how the reduced and flexible staffing introduced in SMR will impact how quickly and efficiently the operators can react to transients and off-normal conditions.
- Plus, in the case of a common external event (e.g., tsunami) affecting multiple SMR modules at a time, **additional staffing** may be required to attend to each module [8].
- Proposed PSF levels: Inadequate, Nominal, **Extra.**

[7] Boldon, L. M., & Sabharwall, P. (2014). Small Modular Reactor: First-of-a-Kind (FOAK) and Nth-of-a-Kind (NOAK) Economic Analysis Idaho National Laboratory Summer 2014 Report. http://www.inl.gov

[8] Hidayatullah, H., Susyadi, S., & Subki, M. H. (2015). Design and technology development for small modular reactors–Safety expectations, prospects and impediments of their deployment. Progress in Nuclear Energy, 79, 127-135.

Adequacy of Communication Protocols 

- Refers to how operators' performance in responding to transients in SMR might be affected based on the communication protocols (e.g., written, two-way, three-way) that are available.
- Park (2012) mentioned in a study that examining crew communications is a logical approach to **improve the safety** of large process systems like NPP [9].
- Examples of communication-related human factors (HF) issues:
  - **Information slip** due to the amount of information from multiple modules that needs to be communicated among operators [10].
  - SMR operators **would not** benefit from the **three-way communication protocol** (best protocol to avoid misconceptions) due to the staffing reduction [11].
- Proposed PSF levels: Inadequate, Nominal, Good.

[9] Park, J., Jung, W., & Yang, J. E. (2012). Investigating the effect of communication characteristics on crew performance under the simulated emergency condition of nuclear power plants. Reliability Engineering & System Safety, 101, 1–13. https://doi.org/10.1016/J.RESS.2012.01.003

[10] OHara J. M., Higgins, H., DAgostino, A., & Erasmia, L. (2012). Human Reliability Considerations for Small Modular Reactors. https://doi.org/10.2172/1043375.

[11] Boring, R. L., & Gertman, D. I. (2012). Human Reliability Analysis for Small Modular Reactors.

II Proposed PSF Taxonomy for SMRs

Human-centered HSI

- This PSF refers to whether the human-system interface (HSI) is designed in a way that provides the operators with adequate information and feedback to maintain a safe operation of the plant.
- **Aspects of a human-centered HSI in an SMR [12,13]:**
  i. **Observable** automation/passive system;
  ii. **Integrates all the information** from the modules that the operator is responsible for;
  iii. **Effective prioritization** between modules to help with operator's cognitive workload;
  iv. **Supports transitions** between automated and manual control.
- Proposed PSF levels: Confusing, Poor, Nominal, **Human-centered.**

[12] Skjerve, A. B. M., & Skraaning, G. (2004). The quality of human-automation cooperation in human-system interface for nuclear power plants. International Journal of Human-Computer Studies, 61(5), 649–677.

[13] Hugo, Jacques V. "Human-System Interfaces (HSIs) in Small Modular Reactors (SMRs)." , Oct. 2014.

II Proposed PSF Taxonomy for SMRs

Complexity 

- Task complexity (generalized definition) = **Number of simultaneous tasks** that an operator has to execute.
- Complexity-inducing factors in SMR:
  - Multi-module operation;
  - Managing shared systems;
  - Accident homogeneity;
  - Etc.
- This PSF refers to how these complexity-inducing factors would correspond to one another, causing an increase to the overall complexity of the task.
- Proposed PSF levels: **Low**, Nominal, High, **Very High**.

[14] Gertman, D. I., Blackman, H. S., Marble, J. L., Byers, J. C., & Smith, C. L. (2005). The SPAR-H human reliability analysis method (NUREG/CR-6883). U.S. Nuclear Regulatory Commission.

SMR PSF Taxonomy Overview

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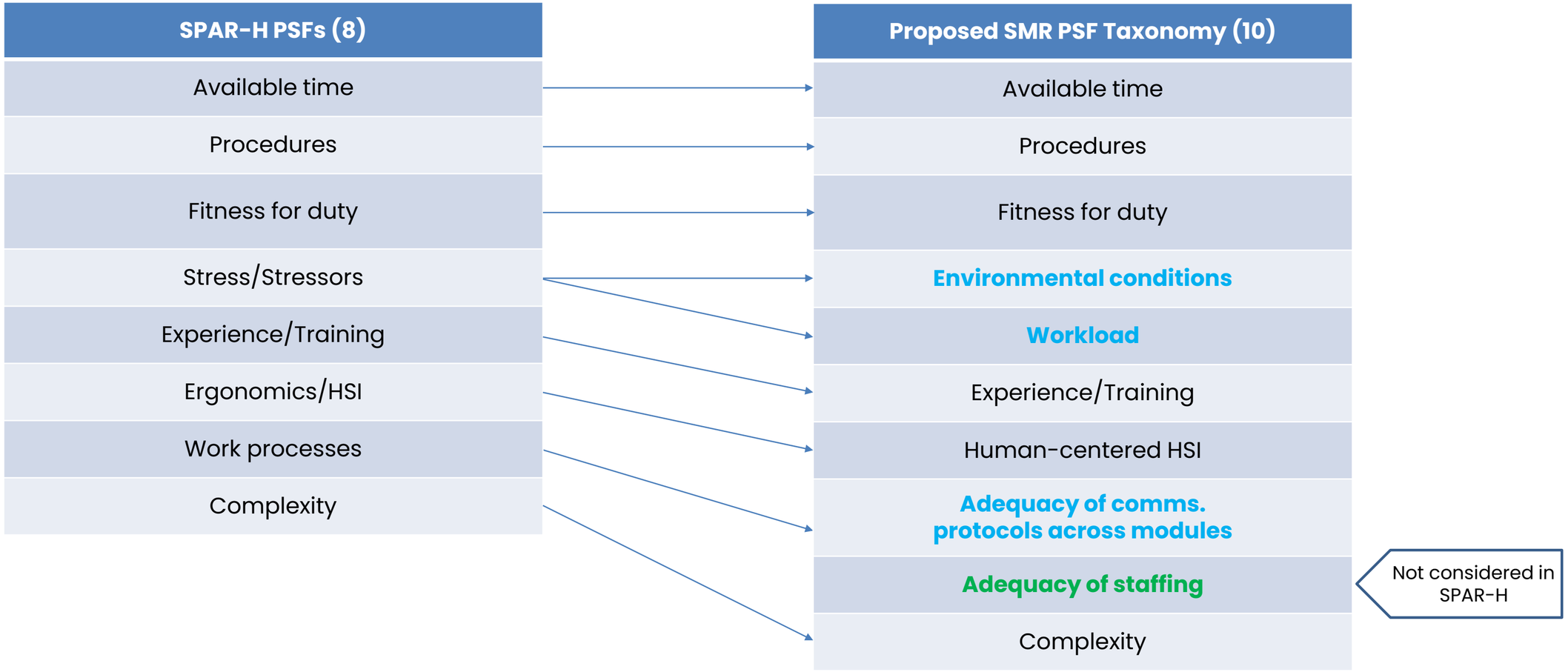
Taxonomies Differences

PSF Taxonomy Comparison with SPAR-H



PSF Levels Comparison with Previous HRA Methods

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	THERP	➢ **Novice:** less than 6 months ➢ **Skilled:** more than 6 months

Conclusion and Future Work

Conclusion 

- PSFs were redefined in this study to justify the rationale behind each PSF selection for the SMR PSF taxonomy.
- The proposed taxonomy was compared with a popular HRA method (i.e., SPAR-H).
- Levels were suggested for each selected PSF.

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Questions/ Comments?

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