INL/CON-22-67067-Revision-0

Collecting Human Reliability Data Using a Simplified Simulator (Part II)

May 2022

Jooyoung Park

Changing the World's Energy Future

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Idaho National Laboratory

1. Introduction
2. The SHEEP Framework
3. Future Works

1. Introduction

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Efforts to Collect HRA Data to Date

- A lack of data has been identified as one of the challenges in human reliability analysis (HRA).
- The most recent studies are concentrating on collecting the data from full-scope studies using full-scope simulator and actual operator.
  - U.S.NRC (SACADA) / KAERI (HuREX)
    - *SACADA: Scenario, Authoring, Characterization, and Debriefing Application*
    - *HuREX: Human Reliability data EXtraction*
  - Good to collect high fidelity simulator data instead of historical operational data

Challenges to Perform Full-Scope Studies

- Difficult to get actual operators for continuously collecting a variety of data due to the high cost
- Utilities' cooperation and data release are relatively limited to few organizations.

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    - Third level
      - Fourth level
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INL's Approach to HRA Data Collection

- To collect HRA data through the Simplified Human Error Experimental Program (SHEEP)
  - To use simplified simulators and students as a complement – not a replacement – for full-scope studies.
  - To provide the data to support full-scope data collection efforts such as HuREX and SACADA

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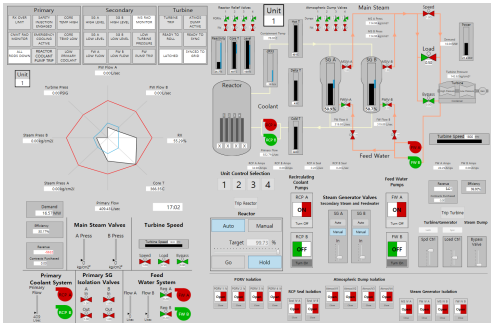
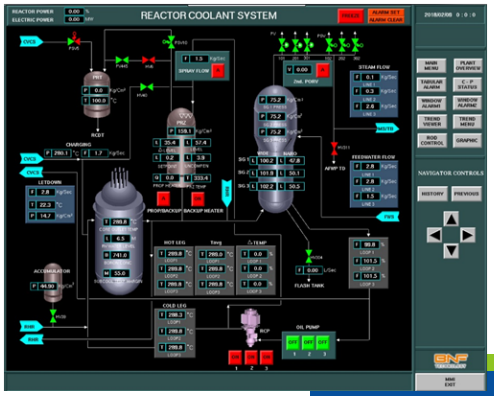
Collecting and analyzing data from simplified simulators, students and operators



<Rancor Microworld>



<Compact Nuclear Simulator (CNS)>

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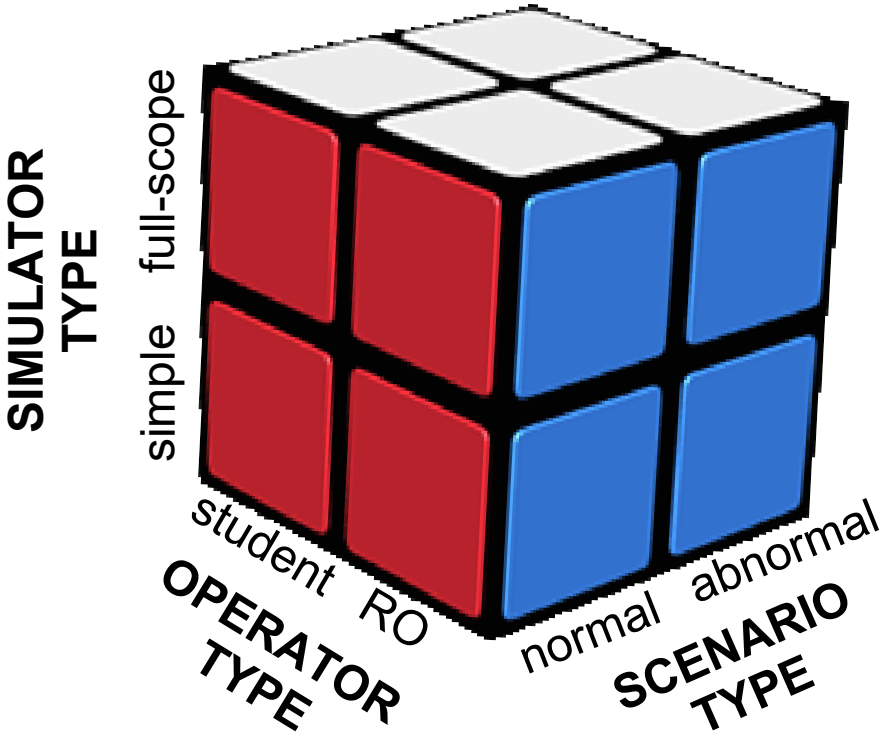
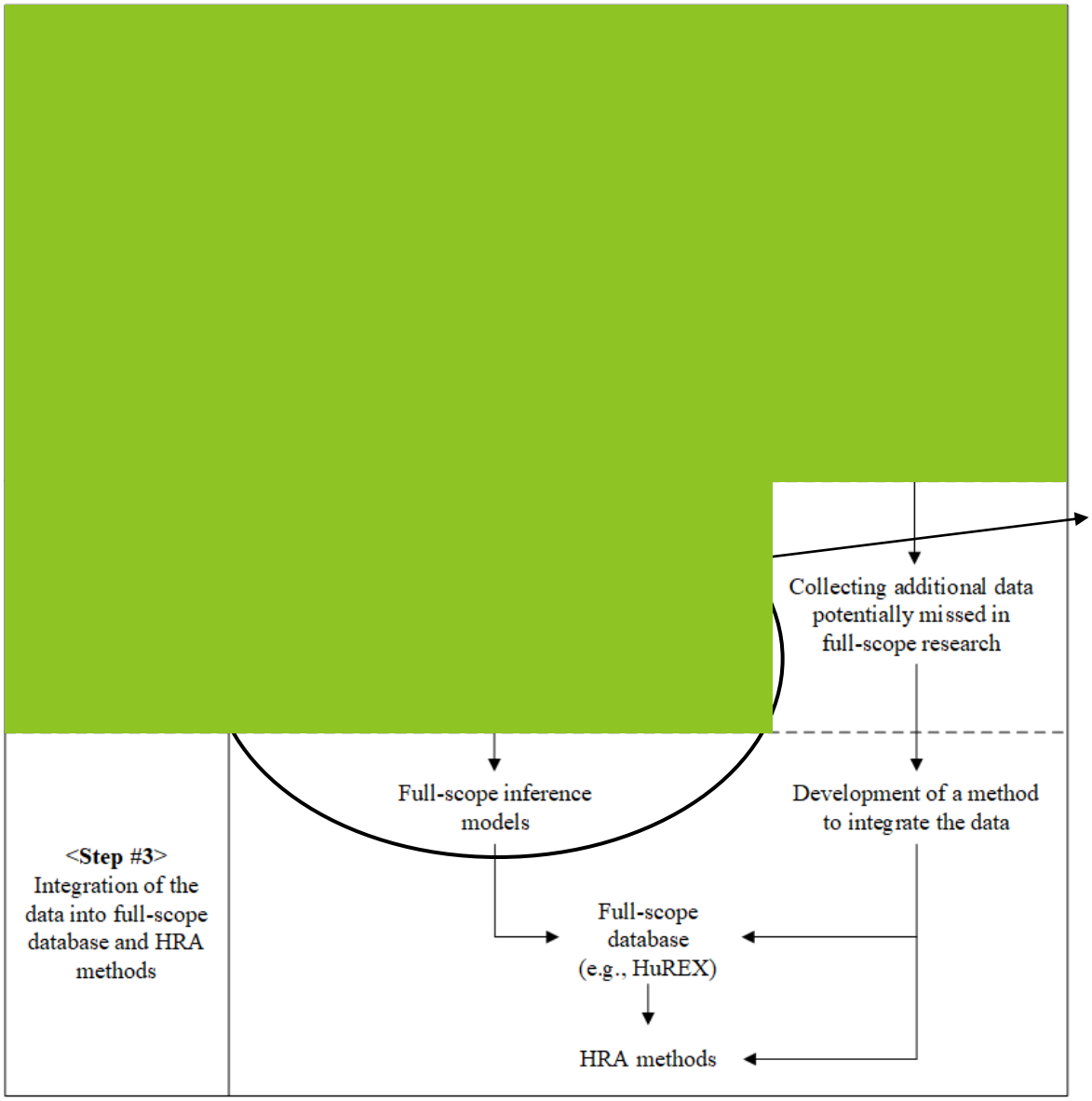
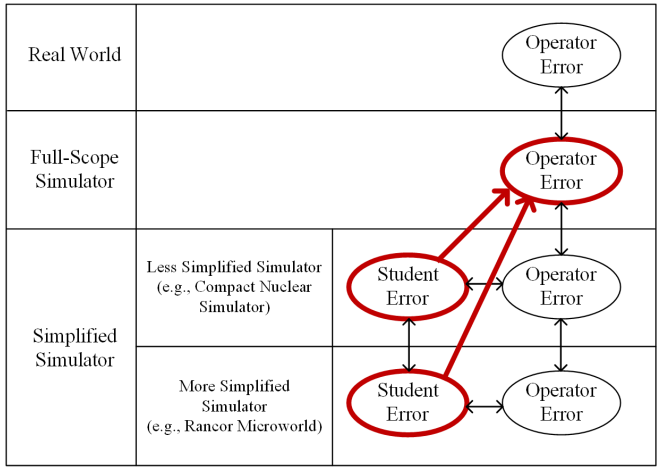
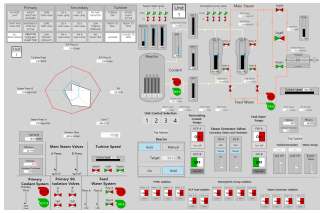
- Basic Design
  - Operator Type (Student vs. Reactor Operator)
  - Simulator Type (Simplified vs. Less Simplified vs. full-scope)
  - Scenario Type (Normal vs. Abnormal)



2. The SHEP Framework







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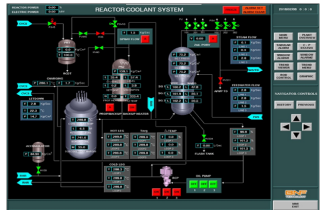

<Compact Nuclear Simulator (CNS)>

2. The SHERPA Framework

Step #1 : Identification of HRA items collectible in simplified simulators

- Items collectible in both simplified and full-scope simulators
  - 22 HuREX task types

Table 1
Task types collectible in full-scope simulators and collectability of those task types in the Rancor Microworld.

Cognitive activity	Task types collectible in a full-scope simulator (HuREX)	Collectability using the rancor microworld
Information gathering and reporting (IG)	IG-alarm	Collectible
	IG-indicator	Collectible
	IG-synthesis	Uncollectible
	IG-value	Collectible
	IG-comparison	Collectible
	IG-graph	Uncollectible
	IG-abnormality	Uncollectible
	IG-trend	Collectible
Response planning and instruction (RP)	RP-entry	Collectible
	RP-procedure	Collectible
	RP-step	Collectible
	RP-information	Uncollectible
	RP-manipulation	Uncollectible
	RP-notification	Uncollectible
Situation interpreting (SI)	SI-diagnosis	Uncollectible
	SI-identification	Uncollectible
	SI-prediction	Uncollectible
Execution (EX)	EX-discrete	Collectible
	EX-continuous	Collectible
	EX-dynamic	Collectible
	EX-notification	Uncollectible
Other (OT)	OT-manipulation	Collectible

- Items only collectible in simplified simulators
  - 88 generic data items collectible in simulator studies

Table 2
HRA items only collectible in simplified simulators [40].

Category	Subcategory	HRA Item	Representatively measurable instance
HSI	Ergonomics	The existence of barriers	- Failsafe designs - Administrative control - Physical guards or stops - Logical/mechanical interlocks
		The existence of buffers	- Redundant structures or processes - Features to accept time delays - Design for reversible, confirmatory, or staged actions
		The provision of memory aids	- Memory aid from human-machine interface
	Panel design	The conformity of standards, conventions, and nomenclature	- Consistent use of measurement units, information coding, or device configuration - Standard nomenclature defined from NPP administrative procedures
		The availability of indications (clarity of cues/indicators)	- Not specified from existing references
		The availability of controls (devices)	- Not specified from existing references
	Status indication	The existence of wrong or inadequate information	- Not specified from existing references
		The appropriateness of task feedbacks	- Clear, prompt, or precise feedback information
		The provision of clear decision criteria	- Clear decision criteria from the human-machine interface Ambiguous decision criteria in a procedure

※ Park, J., et al.: A guideline to collect HRA data in the simulator of nuclear power plants. KAERI/TR-5206/2013 (2013)

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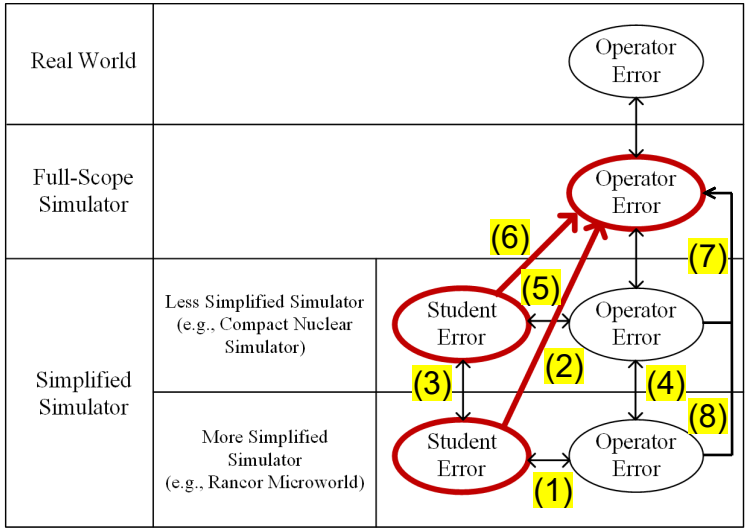
    - Third level
      - Fourth level
        - Fifth level

No.	The Relationship	Experiment	Data Analysis		
			Human Performance Analysis	HuREX Analysis	TACOM Analysis
(1)	Student and operator when using Rancor	Part I (Done) Part I (Done)	Part I (Done) / Part II (Working)	Done	N/A
(2)	Student and operator when using CNS	Done	Done	Working	N/A
(3)	CNS and Rancor with students	Done	Done	Working	N/A
(4)	CNS and Rancor with operators	Done	Done	Working	N/A
(5)	Student with Rancor and operator with full-scope simulators	N/A	N/A	Done	Working
(6)	Student with CNS and operator with full-scope simulators	N/A	N/A	Done	Not Started

(7)	Rancor and full-scope simulators with operators	N/A	N/A	Done	Working
(8)	CNS and full-scope simulators with operators	N/A	N/A	Done	Not Started

2. The SHEEP Framework

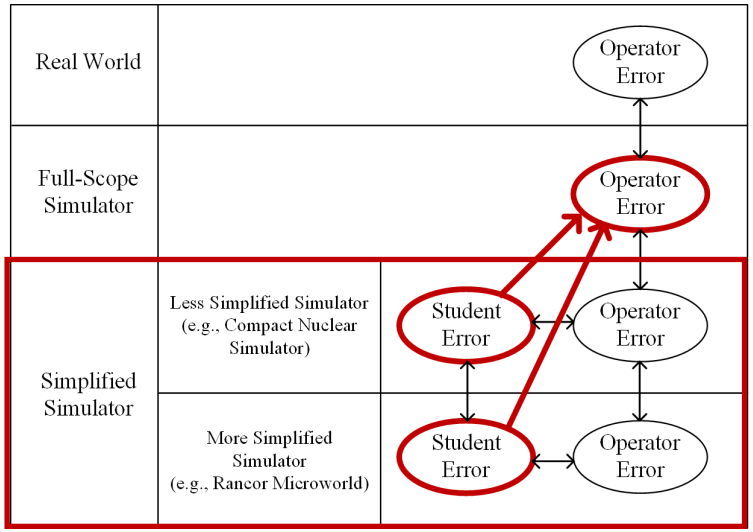
▶ Step #2: Treatment of the HRA items based on experiment

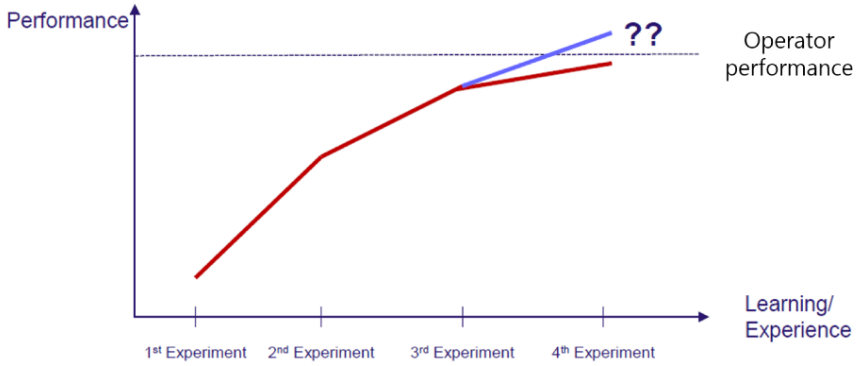


2. The SHERPA Framework

- Step #2: Treatment of the HRA items based on experiment
  - Experiment

Part I	Part II
Collecting data for understanding gaps depending on participant type (student vs. operator) and simulator complexity (Rancor vs. CNS)	Investigating students' learning effects with Rancor (time interval: approx. 16 days)





2. The SLIM Framework

Step #2: Treatment of the HRA items based on experiment

- Experiment (Cont'd)
  - Experimental Design
    - Two independent variables, i.e., participant type and event class

<The Randomized Factorial Experiment with Rancor Microworld>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			• Fully auto start-up (0% to 100%) • Shutdown (100% to 0%) • Start-up with manual rod control (0% to 100%) • Start-up with manual feedwater flow control (0% to 100%)
Event			• Failure of a reactor coolant pump under full-power operation • Failure of a control rod under full-power operation • Failure of a feedwater pump under full-power operation • Abnormal turbine trip under full-power operation • Steam generator tube rupture with an indicator failure • Loss of feedwater pump

<The Randomized Factorial Experiment with CNS>

Event Class	Participant Type		Scenario
	Actual Operator	Student	
Non-Event			• Fully auto startup (0% to 100%) • Shutdown (100% to 0%)
Event			• Steam generator tube rupture with an indicator failure • Loss of feed-water pump

2. The SHERPA Framework

Step #2: Treatment of the HRA items based on experiment

- Experiment (Cont'd)
  - Human Performance

Human Performance Categories	Human Performance Measurements
Workload	Modified Cooper-Harper (MCH)
Situation awareness	Situation Awareness Rating Technique (SART)
Error	Error rate
Time to completion	Average time to complete a step
	Average time to complete an instruction
	Average time to complete a task
Eye movements	Eye fixation count per task
	Eye fixation duration per task
	Blink rate (i.e., blink count per task)
	Heatmap over area of interest (AOI)
Number of manipulations	Number of manipulations per task
	Number of manipulations per scenario completion time

2. The SLIM Framework

Step #2: Treatment of the HRA items based on experiment

- Experiment (Cont'd)
  - Participants
    - Students
      - Undergraduate senior students and master students at the department of nuclear engineering in Chosun University
      - They took courses such as "Introduction to Nuclear Engineering," "Reactor Theory," "Reactor Control", and "Simulator Operation."
    - Operators
      - Licensed operators for Westinghouse type
      - Working at Hanbit Nuclear Site in Korea

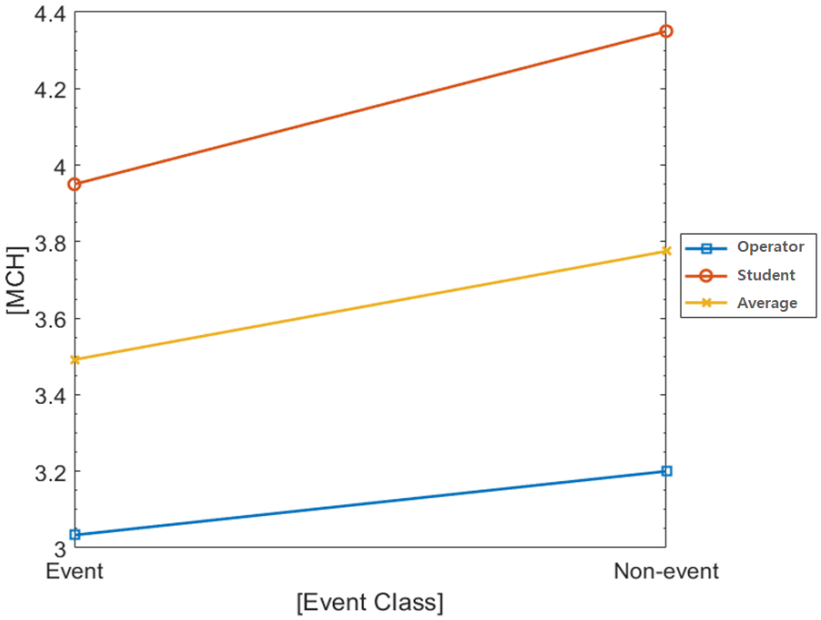
Simulator	Part I		Part II
	Student	Operator	Student
Microworld	Twenty	Twenty	Fifteen
CNS	Twenty	Twenty	N/A

2. The SHEP Framework

Step #2: Treatment of the HRA items based on experiment

- Human Performance Analysis
  - ANOVA Test
    - To identify statistical differences on human performance measurements depending on participant type and event class
  - Correlation Analysis
    - To identify the relationship between human performance measurements

<Workload trend>



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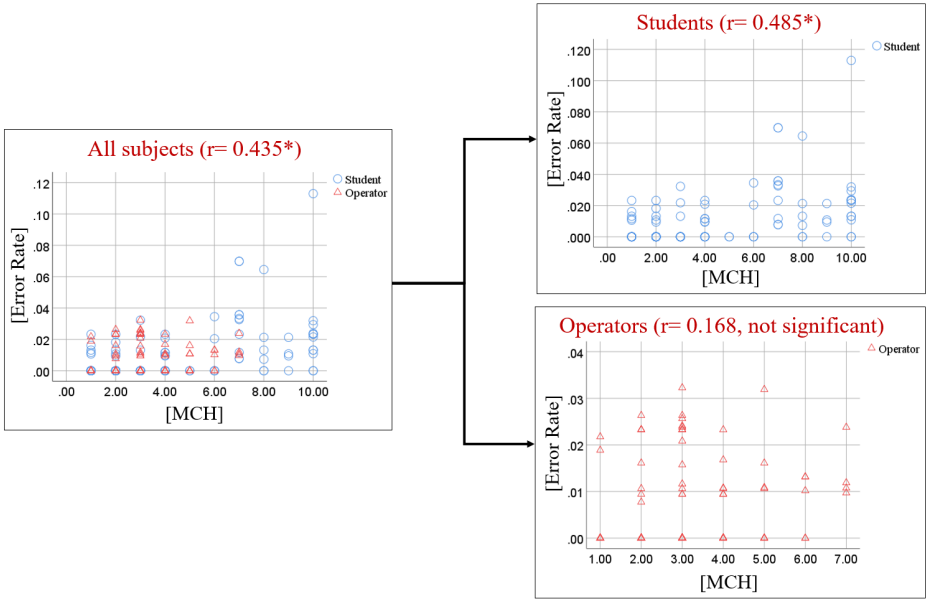
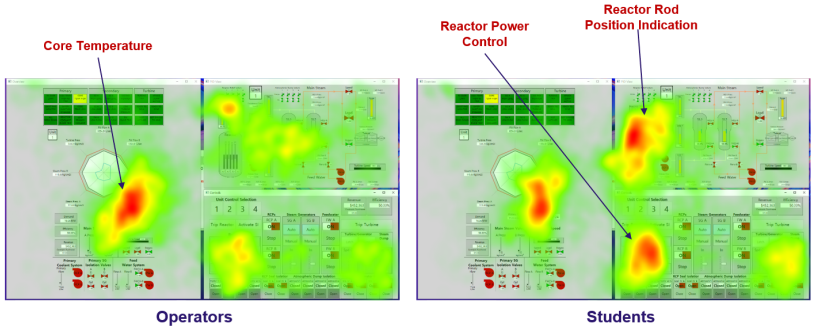
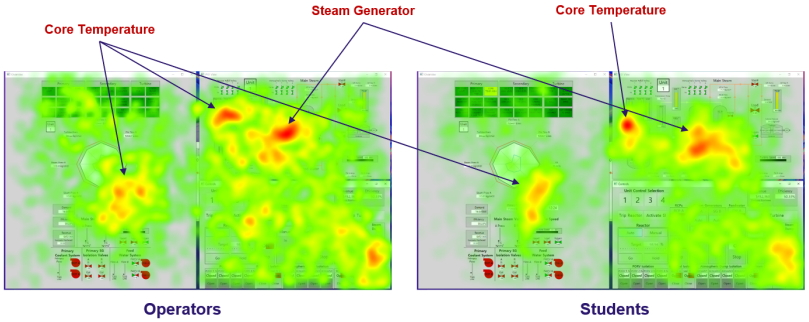


2. The SHERPA Framework

- Step #2: Treatment of the HRA items based on experiment
  - Human Performance Analysis (Cont'd)
    - Eye Tracking Data Analysis
      - The operators are more likely to concentrate on major parameters necessary to the context of a given scenario as well as monitor overall interface.
      - Because the students are unfamiliar with the basic structure of the simulator and its interface, they may continually seek out options in the control window, as well as changes implemented due to a particular manipulation.



Non-event scenarios



Event scenarios

2. The SHEEP Framework

Step #2: Treatment of the HRA items based on experiment

- The HuREX Analysis

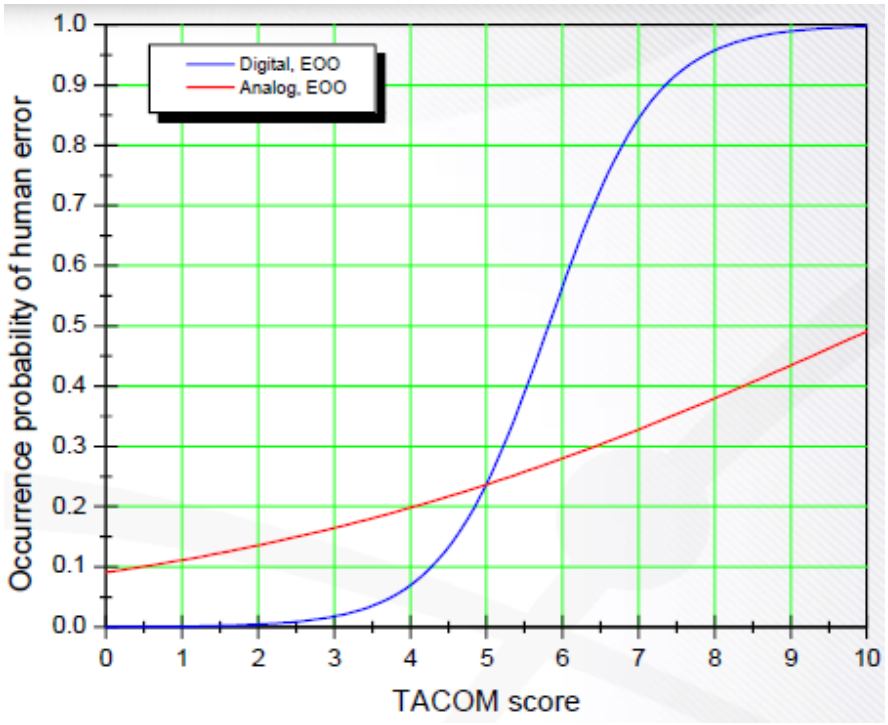
Cognitive Activity	Task Type	HUREX Study		SHEEP Study (Using the Rancor Microworld)			
		HEP (EOO)	HEP (EOC)	HEP (EOO) - Student	HEP (EOC) - Student	HEP (EOO) - Operator	HEP (EOC) - Operator
Information Gathering and Reporting	IG-alarm	-	3.610e-4	-	-	-	-
	IG-indicator	-	9.940e-4	-	4.380e-03	-	-
	IG-synthesis	-	1.680e-3	-	-	-	-
	IG-value	-	-	-	-	-	-
	IG-comparison	-	7.220e-5	-	-	-	-
	IG-graph	-	-	-	-	-	-
	IG-abnormality	-	-	-	-	-	-
	IG-trend	-	9.450e-4	-	-	-	-
Response Planning and Instruction	RP-entry	3.205e-3 (analog)	-	-	-	-	-
	RP-procedure	3.953e-3 (analog)	-	-	4.545e-02	-	2.222e-02
	RP-step	5.634e-2 (analog)	-	2.014e-03	7.049e-03	9.165e-03	6.110e-03
	RP-information	2.490e-3	5.110e-4	-	-	-	-
	RP-manipulation	1.230e-2	2.590e-3	-	-	-	-
	RP-notification	4.650e-2	-	-	-	-	-
Situation Interpreting	SI-diagnosis	-	-	-	-	-	-
	SI-identification	-	2.550e-3	-	-	-	-
	SI-prediction	-	-	-	-	-	-
Execution	EX-discrete	1.230e-2	5.500e-4	1.490e-03	-	1.512e-03	-
	EX-continuous	4.600e-2	-	-	4.137e-02	8.850e-03	2.124e-02
	EX-dynamic	3.660e-2	8.540e-3	-	5.000e-01	-	3.488e-01

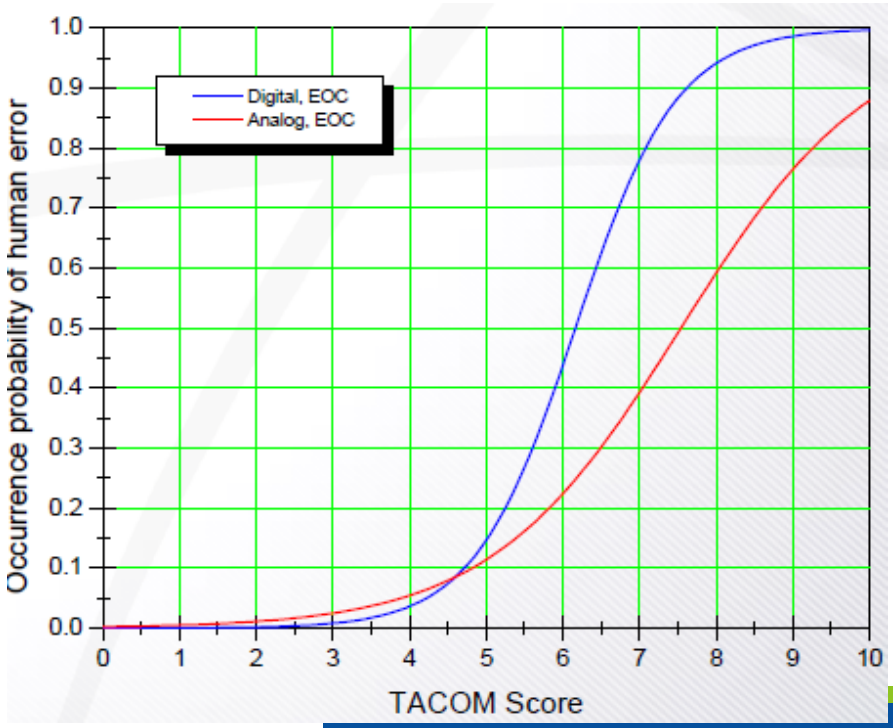
	EX-notification	1.910e-2	-	-	-	-	-
Other	OT-manipulation	-	-	-	-	-	-

2. The SHEP Framework

Step #2: Treatment of the HRA items based on experiment

- The TACOM Analysis
  - Task COMplexity (TACOM) method
    - A tool to represent the effect of task complexity on human performance in an objective manner
      - Used to compare student and operator data when using Rancor and CNS with operator data when using full-scope simulators





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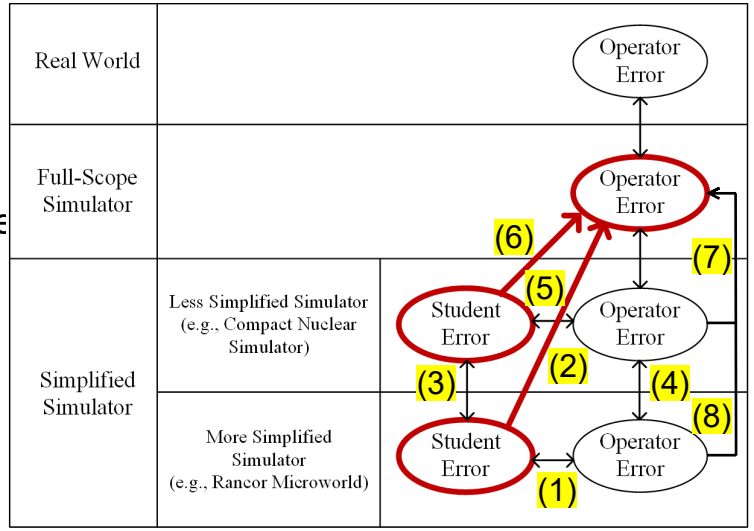

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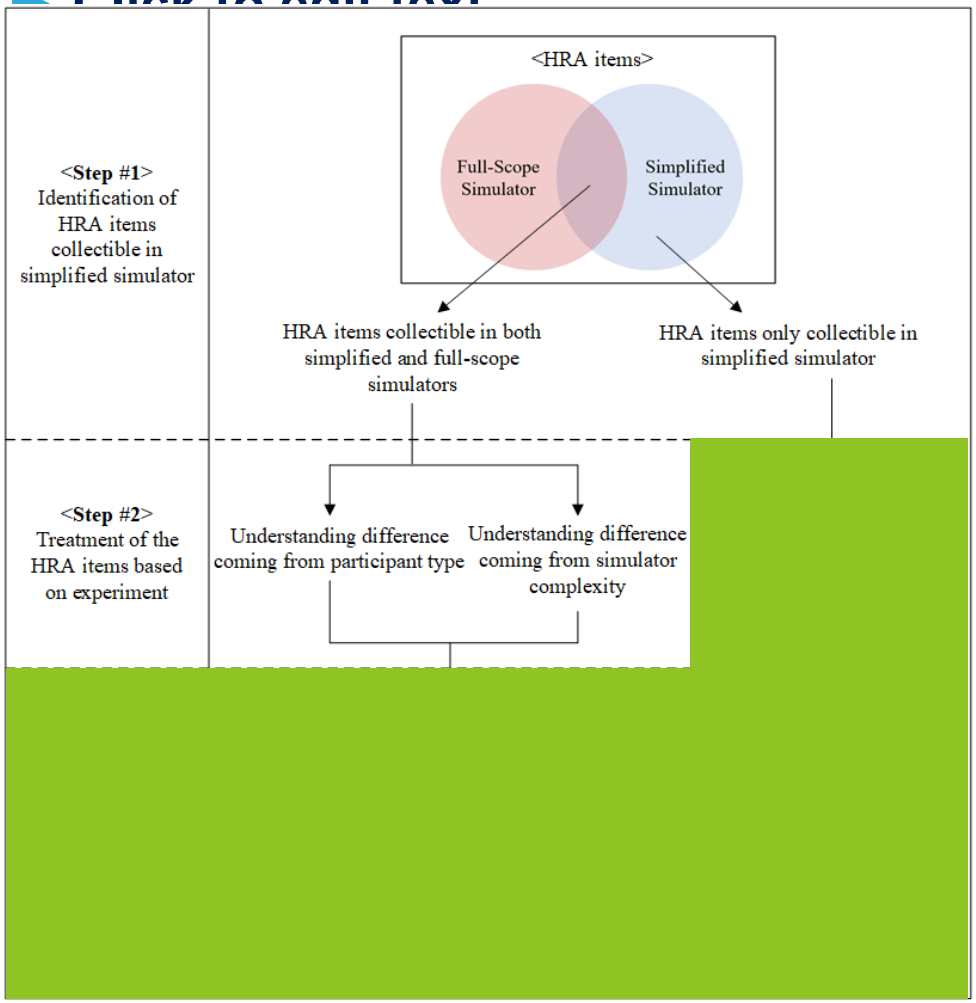

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		The provision of clear decision criteria	- Clear decision criteria from the human-machine interface Ambiguous decision criteria in a procedure

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Journal Articles

- Park, J. et al. "A Framework to Collect Human Reliability Analysis Data for Nuclear Power Plants Using a Simplified Simulator and Student Operators." *Reliability Engineering & System Safety* (2022): 108326.
- Park, J. et al. "Analysis of Human Performance Differences between Students and Operators When Using the Rancor Microworld Simulator." *Safety Science*, Submitted.

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- Park, B. et al. “Comparison of Human Performance between Operators and Students Using Rancor Microworld Simulator: A Preliminary Result”, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, July 8 - 10, 2020.
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- Yang, T. et al. “An Experimental Analysis of Human Performance According to the Simulator Complexity”, 5th International Conference on System Reliability and Safety, Palermo, Italy, November 24-26, 2021.
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- Yang, T. et al. “Human Performance Analysis Depending on Expertise and Simulator Complexity”, 2022 American Nuclear Society Annual Meeting, Anaheim, CA, Jun 12-16, 2022.
- Park, J. et al., “A framework to integrate HRA data obtained from different sources based on the complexity scores of proceduralized tasks”, Probabilistic Safety Assessment and Management PSAM 16, June 26 – July 1, Honolulu, Hawaii, 2022, Submitted.

Idaho National Laboratory

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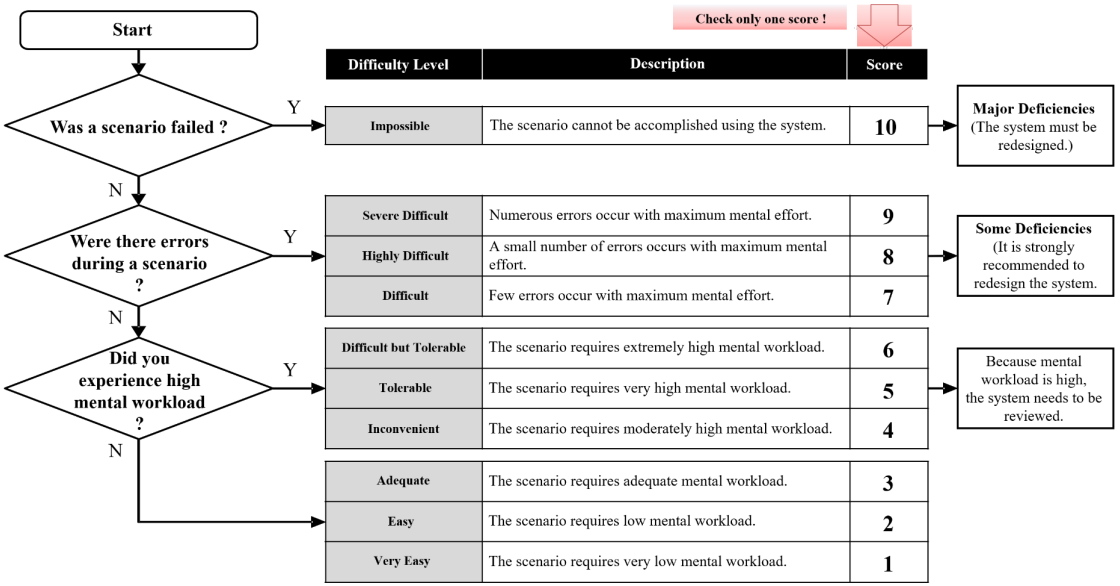
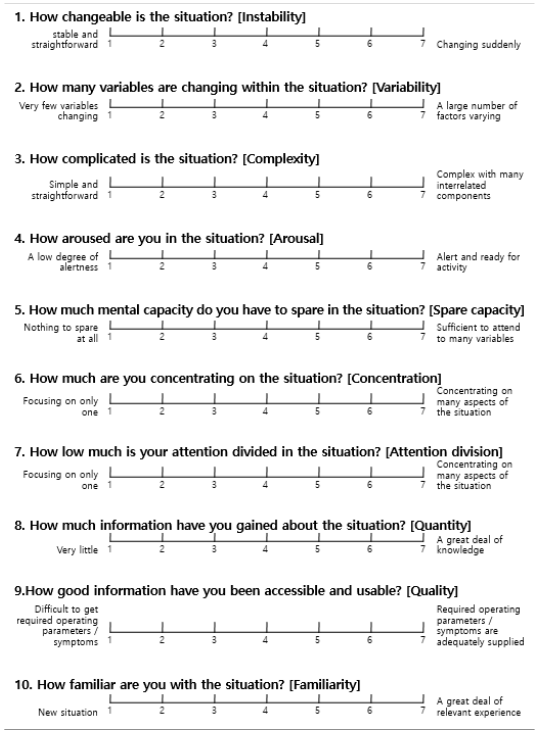
- Human Performance
  - Workload: MCH Scores
  - Situation Awareness: SART Scores
    - Fourth level
      - Fifth level



Modified Cooper-Harper (MCH)



Situation Awareness Rating Technique (SART)

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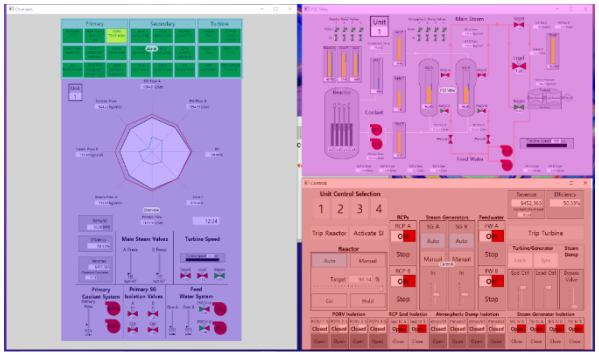
- Human Performance (Cont'd)
  - Error Rate
    - Error is defined as deviation from expected performances.
      - Same rules used in the HuREX data collection are applied.
      - The HuREX analysts participated in the error analysis.
  - **Time to Completion**: Average Time to Complete A Step / An Instruction / A Task
    - Analyzed based on procedures and video records

	Scenario	Type of Error	Stu.01	Sum	Stu.02	Sum	Stu.03	Sum	Stu.04	Sum
Non-event	Start-up(#1)	RP-Step(EOC)	2	3		0		1		0
		Ex-Continuous(EOC)					1			
		Ex-Dynamic(EOC)	1							
		RP-Step(EOO)								
	Shutdown(#2)	Ex-Continuous(EOC)		0		0		0		0
		Ex-Dynamic(EOC)								
	Manual Rod during Start_up(#3)	Ex-Dynamic(EOC)	2	2		0		1	1	1
		RP-Step(EOC)					1			
		RP-Step(EOO)								
		RP-Procedure(EOC)								
		OT-Manipulation(EOC)								
		Ex-Continuous(EOO)								
		Ex-Continuous (EOC)								

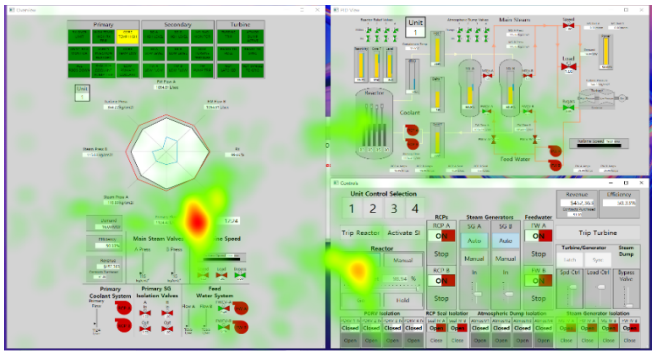
Procedure	Step	Step Num.	Task	Task-Verb	Error	Time	Description
OP-003	3. Primary side coolant injection	Pre-C	Reactor must be provided with adequate coolant to prevent overheating for reactor core. Primary side coolant flow should be maintained at least 127.0 L/sec.			22:24:40	
		3.1	Activate the RCP.			22:24:45	
		3.1.1	·Click RCP A start button.	Perform		22:24:48	
		3.1.2	·Click RCP B start button.	Perform	EOO/R	22:24:50	1. Time: 22:24:50 2. Current State: During the Start-up, RCP B not operation. 3. Action: He didn't click the RCP B start button 4. Result: RCP B not started 5. Description: Recovery by operation knowledge
		3.2	See below to determine if the primary coolant is sufficient.			22:24:50	
		3.2.1	·Low Primary Coolant alarm off confirmation.	Check		22:24:51	
		3.2.2	·Primary Flow indicator is higher than 508.0L / sec	Check		22:24:53	
		3.3	If the above conditions are satisfied, the process moves to step 4.	Move		22:24:55	
	4. Reactivity Control	4.1	To increase Reactivity to 20% using Manual, go to the OP-004 procedure.	Check/Move		22:25:00	

Appendix: Master title

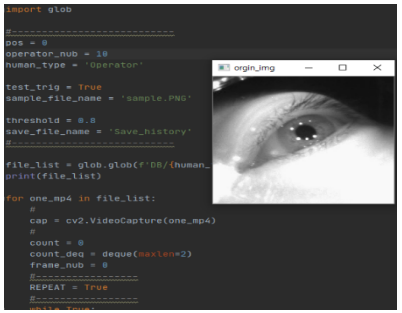
- Human Performance (Cont'd)
  - **Eye Movements**: Eye Fixation Count / Duration Per Task, Blink Rate, Heatmap Over Area of Interests (AOI)
    - Fixation duration and counts, eye blinking, and gaze movement
    - Tobii Pro Glasses 2
    - Four Areas of Interest (AOIs): Alarm, Overview, P&ID, Control Area



<AOIs>



<Heatmap>



<Eye Blinking Rate>

  - **Number of Manipulations**: Number of Manipulations per Task / per Scenario Completion Time
    - Estimated from simulator log data

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{"EventType":"Alarm", "Tag":"AtmosDumpActive", "State":"Cleared", "Unit":1, "Time":1.0093952, "RX":98.2286081374419, "MW":54.5491744984957}
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