Microworld Studies to Support Human Reliability Data Collection

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1. Introduction

1. Introduction

1.1 Background

►The challenge of HRA: A lack of adequate data

- Many HRA methods widely used by NPP utilities and regulatory agencies (e.g., ASEP, SPAR-H and K-HRA) have been developed on the basis of THERP data.
  - Generated from the early 1970s until the late 1980s
  - Relies on expert judgment as well as sparse empirical and experience-based data mostly from non-nuclear experience
- Although new technologies like digital MCRs are already implemented in new or upgraded NPPs, these HRA methods still have been applied as is without modification to accommodate differences due to digital technologies.

<Analog MCR> ➡ <Digital MCR>

1. Introduction

1.1 Background

▶ Several studies for HRA data collection

- Several institutes and researchers have attempted to collect HRA data from event reports or simulator studies (Jung et al., 2018).
- Most of current studies are concentrating on collecting the data from simulator studies.
  - U.S.NRC (SACADA) / KAERI (HuREX)

Data source	Name of study, database, or method	HRA data
Event reports (Data from actual historical measurements)	CAHR (Connectionism Assessment of Human Reliability)	70 HEPs
	HERA (Human Event Repository and Analysis)	Qualitative PSFs data
	HEPs based on operating experiences in German NPPs	74 HEPs
Simulator studies (Data from simulator studies and experimental researches)	HCR/ORE (Human Cognitive Reliability/Operator Reliability Experiments)	Formula of non-response probability
	HAMMLAB simulator experiments for an international HRA empirical study	14 crews' response times and qualitative PSFs data
	OPERA (Operator Performance and Reliability Analysis)	Performance times for 89 procedural tasks
Multiple sources (Data from event reports, simulator and expert judgment)	THERP (Technique for Human Error Rate Prediction)	20 HEP tables
	NUCLARR (Nuclear Computerized Library for Assessing Reactor Reliability)	400 HEPs
	CORE (Computerized Operator Reliability and Error)-DATA	100 HEPs (related to NPPs)

1. Introduction

1.1 Background

►INL's approach for HRA data collection

- Trying to collecting HRA data using a simplified simulator (i.e., Rancor Microworld), in contrast to the U.S. NRC and KAERI using full-scope simulators
  - An opposite approach with full-scope studies
  - To offer and support additional data beyond what KAERI and U.S.NRC are collecting through full-scope simulators
  - To collect specific data for digital main control room as well as dynamic HRA

<Pros and cons depending on simulator types>

	Full scope simulator	Simplified simulator
Advantages	• High fidelity to actual NPPs	• Possible to get large sample sizes – Possible to train less experienced participants like non-licensed operators or students to be used for experiments. • Simple to develop and customize for specific experimental conditions
Disadvantages	• The Simulators are rare and costly. • Operators are equally rare and costly. • Scenarios are complex to set up and analyze.	• Low fidelity to actual NPPs in comparison with full scope simulators

1. Introduction

1.2 Objective & contents

▶ Purpose

- Introducing microworld studies to support human reliability data collection

▶ Contents

Overview of Microworld studies → **Future Microworld Studies**

- What is Rancor Microworld ?
- What data does microworld collect?
- Prior data collection efforts
- Current development state

- Future microworld studies
- Collaboration with other institutes

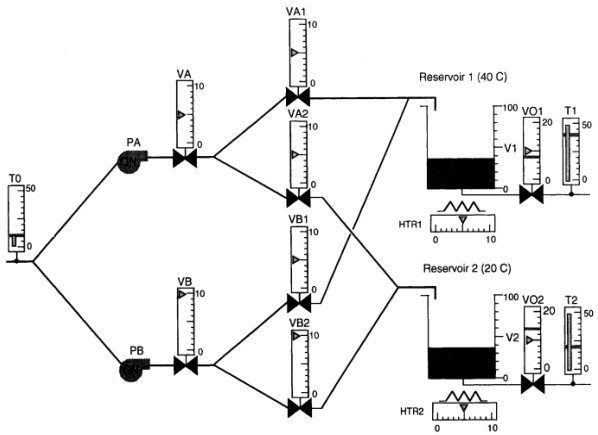
2. Overview of Microworld Studies

2. Overview of Microworld Studies

►What is Rancor Microworld ?

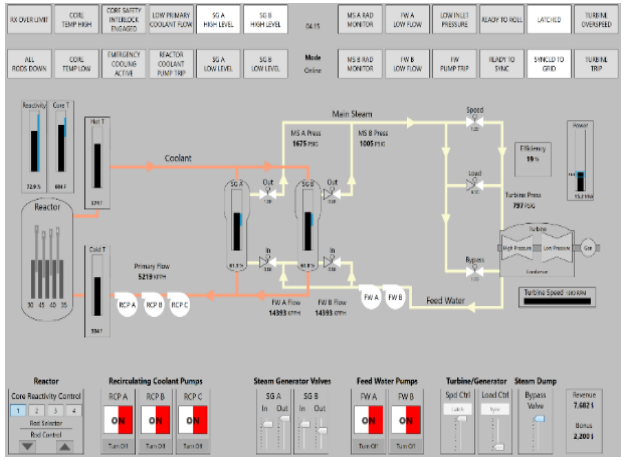
- Simplified simulation environments designed to reproduce important characteristics of real situations while leaving open the possibility of manipulation and experimental control (Funke, 1993)
  - Examining theoretical and practical concepts related to process control
  - Providing a graphical user interface that would allow the researchers to create process control systems in a generic manner

- Current nuclear-related microworlds
  - DURESS II (Vicente et al., 1995; Vicente et al., 1996)
  - Microsimulator (Dyre et al., 2013)



<DURESS II interface – other nuclear related microworlds>

- More specific systems
- Higher level of automation
- Higher reality



<Rancor microworld>

2. Overview of Microworld Studies

►What is Rancor Microworld ? (Cont'd)

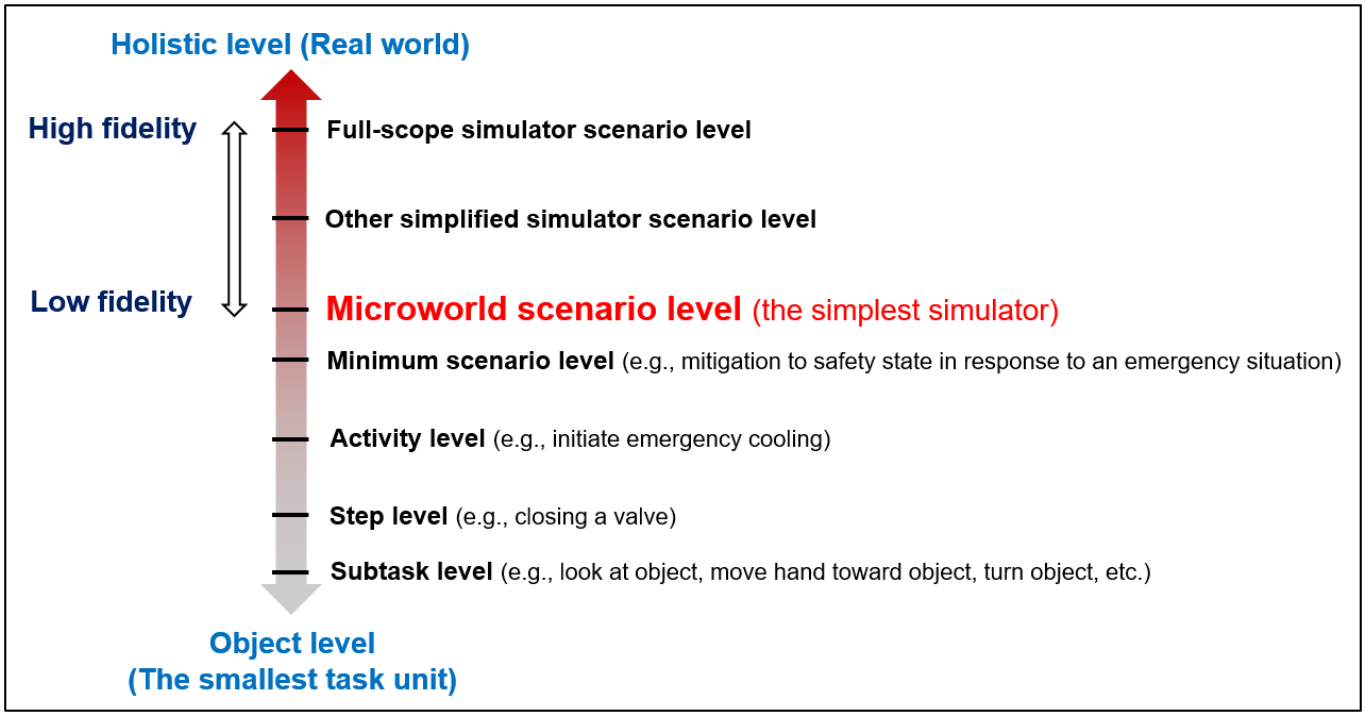
- A comparison of major features between 1) Full scope simulator, 2) A simplified simulator (Compact Nuclear Simulator) and 3) Microworld (The simplest simulator)

Major features	Full scope simulator	Simplified simulator (Compact nuclear simulator)	Microworld (The simplest simulator)
Cost to perform experiments	**High**	Low	**Low**
Building up scenarios	**Difficult**	Intermediate	**Easy**
Getting subjects	**Difficult (mainly actual NPP operators)**	Easy (Non-actual NPP operators like students)	**Easy (non-actual NPP operators like students)**
Institutes possible to perform experiments	**Institutes limited only with Utilities' cooperation**	Possible at University level	**Possible at University level**
Data release	**Mostly confidential (limited)**	Public available	**Public available**
Fidelity (Reality)	**High**	Intermediate	**Relatively low**

2. Overview of Microworld Studies

►What data does microworld collect ?

- A data classifications that can be collected at different levels of tasks and simulators

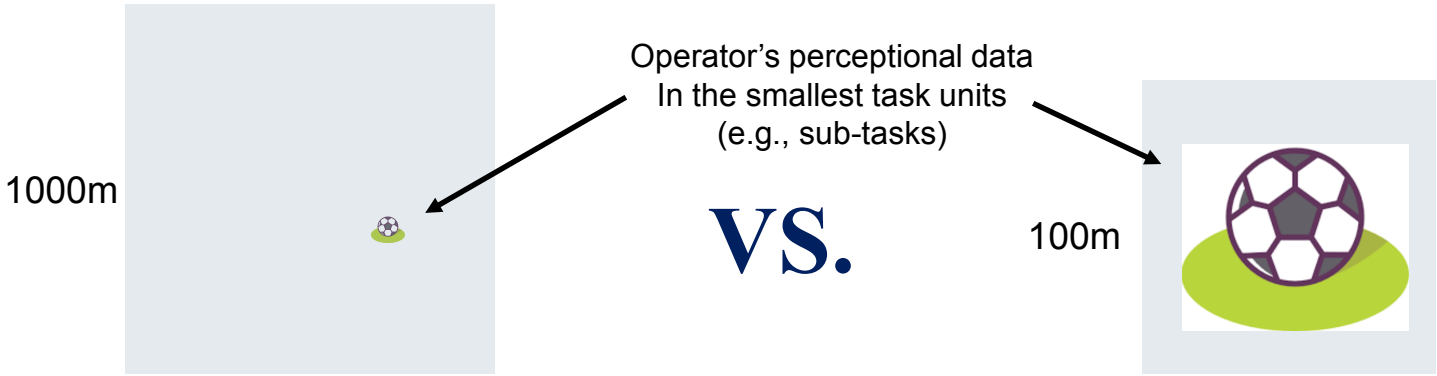


- As the simplest simulator close to the minimum scenario level, microworld focuses mainly on how operators use their perception to gather information and make decisions that are confounded by the complexity in full scope simulator studies
  - Ex) how quickly they find information, or how fully they comprehend at a glance, etc.
  - In this aspect, low fidelity to actual NPPs may not be important.

2. Overview of Microworld Studies

►What data does microworld collect ? (Cont'd)

- To say it easily (For example),
  - If you want to find a soccer ball (e.g., operator's perceptional data in the smallest task units) in both a large area (e.g., full scope studies) and a small area (e.g., microworld studies), which one could be easier ?
    - ➢ Full scope studies usually focuses on the larger task units (e.g., step, activity or scenario levels), therefore getting information from the smaller task units could be missed on full-scope simulator studies.

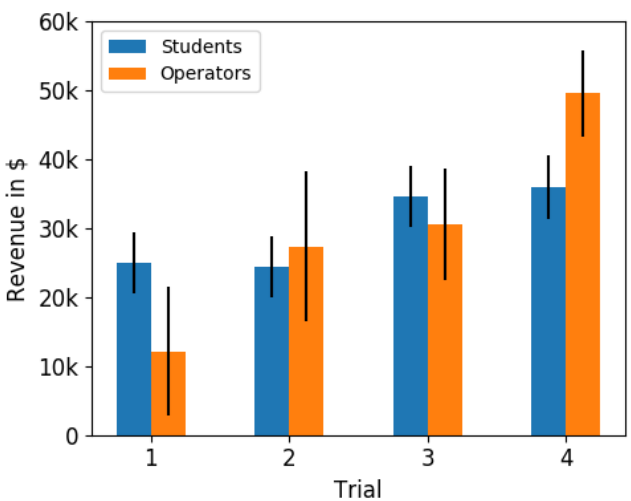


- At INL, we've developed a microworld simulator to collect specific data at the smaller task levels (e.g., subtask levels → input to dynamic HRA)

2. Overview of Microworld Studies

▶ Prior data collection efforts

- **Having tried to establish correspondence between microworld and full-scope studies**
  - Study #1: Empirical studies to identify the applicability of less experienced participants like students
    - A comparison of human performances between students and licensed operators (but, non-nuclear operators)
      - ✓ Human Performances: 1) Revenue, 2) Reactivity, and 3) Attention
    - This study concludes that students and operators demonstrate similar performances with operators demonstrating a steeper learning curve.
    - Major results from experiments:



1) Revenue

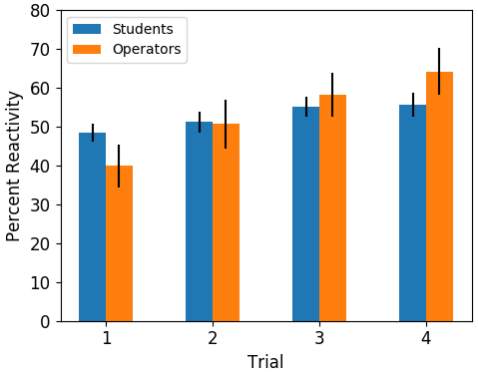
- A function of the cost of operating the plant subtracted from the value of electrical power produced

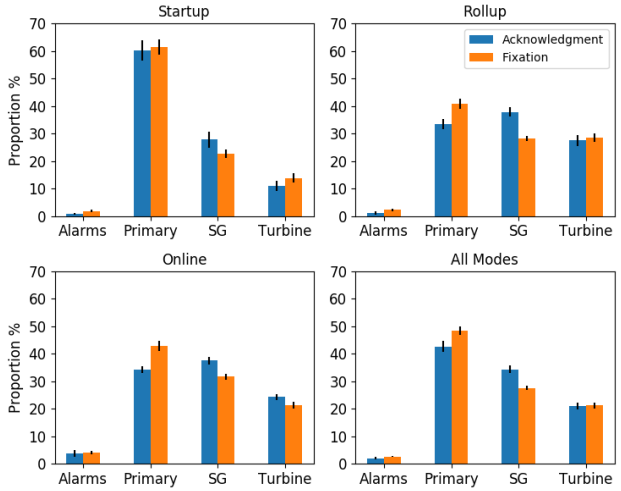
$$Revenue = (MW - 0.5Recirc_{Pumps} - 0.3FW_{Pumps})Rate_{Electric}t - 250t - 10000Fine_{Trip}$$

- Operators ultimately outperformed students after overcoming negative expertise transfer
  - Microworld differed from their specific plant and they made faulty assumptions that had to be realigned.

2. Overview of Microworld Studies

▶ Prior data collection efforts





2) Reactivity

- Higher reactivity indicates a better control strategy because you are using your heat source more effectively to produce steam and ultimately electricity.
- The results show similar performances, but operators had steeper learning curve indicating they would significantly outperform students given more trials.

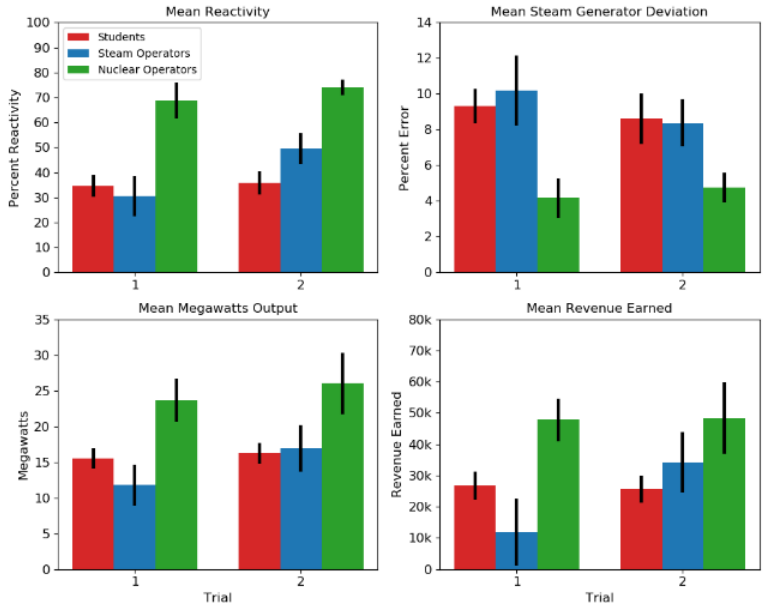
3) Attention

- Proportion that operators focus on major information among 1) alarms, 2) primary system, 4) steam generator and 4) turbine system
- Estimated by eye tracking system
- These results indicate that the proportion of focus on the information is close between students and operators.

2. Overview of Microworld Studies

▶ Prior data collection efforts

- Study #2: Feasibility studies to generalize human performance data from microworld to apply in NPPs
  - ➢ A comparison of human performances for experience/training PSF between 1) students, 2) non-nuclear operators and 3) nuclear operators



- These results identified nuclear operators consistently demonstrated better performance over 2 experimental trials.
  - Red bar: Students
  - Blue bar: Non-nuclear operators
  - Green bar: Nuclear operators

  - ➢ This study concludes that the data from microworld could be used for updating PSF multiplier values on several PSF levels in HRA.

2. Overview of Microworld Studies

►Current development state

- Three goals;

Collecting data for **digital MCRs**	Collecting data for **dynamic HRA**	Collecting data for **multi-unit controls**

1. **Update of microworld design for experiments in digital MCRs**
2. **Update of microworld automation level for digital I & C**
3. **Comparison of human performances when using computer-based procedures and paper based procedures**
4. **Development of microworld interface for multi-unit controls**
5. **Development of microworld scenarios**

2. Overview of Microworld Studies

►Current development state

1. **Update of microworld design for experiments in digital MCRs**
   - Review of microworld design aspects of human factor engineering
     - NUREG-0700, "Human-system interface design review guidelines"
     - Wickens et al., "Engineering psychology and human performance"
     - Consideration of basic principles in human factor engineering
       - ✓ Color and size coding
       - ✓ Data-ink ratio principle
       - ✓ Indicator and controller designs
       - ✓ The proximity compatibility principle
       - ✓ Reactor system in Microworld
   - Review of the characteristics for digital I & C
     - NUREG/CR-6992, "Instrumentation and controls in nuclear power plants: An emerging technologies update"
     - Distinguished features of digital main control room versus analog one
       - ✓ 1) advanced alarm systems, 2) graphic display, 3) computerized procedure systems, and 4) soft control

2. Overview of Microworld Studies

►Current development state

2. **Update of microworld automation level for digital I & C**
   - Increased automation is a major trends in the evolution of digital MCRs (Park et al., 2017)
     - Billings's levels of automation (Billings, 1997)

Automation Level	Automatic Functions	Human Functions
Autonomous Operations	Fully **autonomous** operation. Human not usually informed. System may or may not be capable of being disabled.	Human generally has no role in operation and monitoring is limited.
Operation by Exception	Essentially **autonomous** operation unless specific situation or circumstances are encountered.	Human must approve of critical decisions and may intervene.
Operation by Consent	Full **automatic** control under close monitoring and supervision.	Human monitors closely, approves actions, and may intervene.
Operation by Delegation	**Automatic** control when directed by human to do so.	Human provides supervisory commands that automation follows.
Shared Control	**Automatic** control of some functions task.	Manual control of some functions/tasks
Assisted Manual Control	Primarily manual control with some **automation** support.	Human manually controls with assistance from partial automation.
Direct Manual Control	No automation.	Human manually controls all functions and tasks.

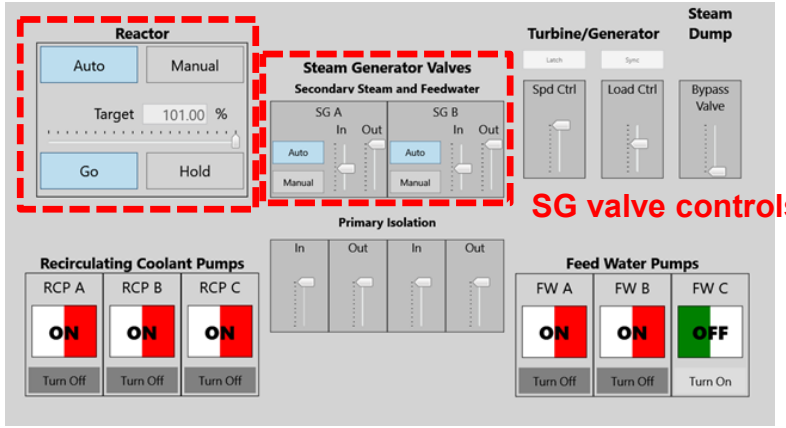
2. Overview of Microworld Studies

►Current development state

2. Update of microworld automation level for digital I & C (Cont'd)

- Review of automation levels for digital MCRs
- Update of microworld's automation levels
  - An example of updated results for reactor power controls and SG valve controls in microworld's interface;

Reactor power controls



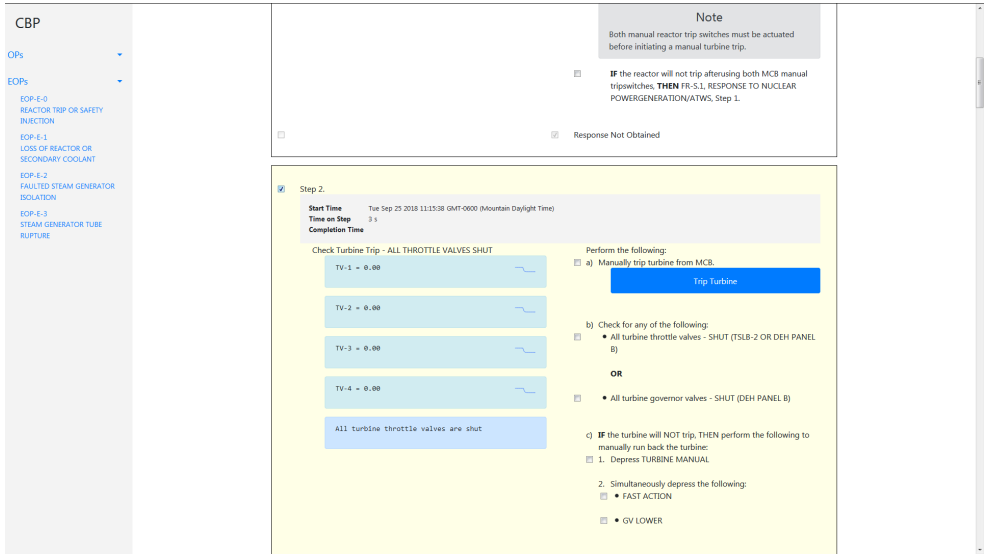
SG valve controls

- Enables research to examine:
  - <u>Exploring automation PSFs</u>
    - ✓ From an HRA perspective, automation as a PSF can be explored.
  - <u>Investigating effect of the automation PSF on operator performances in digital main control room</u>
  - <u>Studying how to quantify the effect of automation PSF in regard to human error</u>

2. Overview of Microworld Studies

►Current development state

3. **Comparison of human performances when using computer-based procedures and paper-based procedures**
   - Impact on speed and accuracy (lower error rate) in task execution



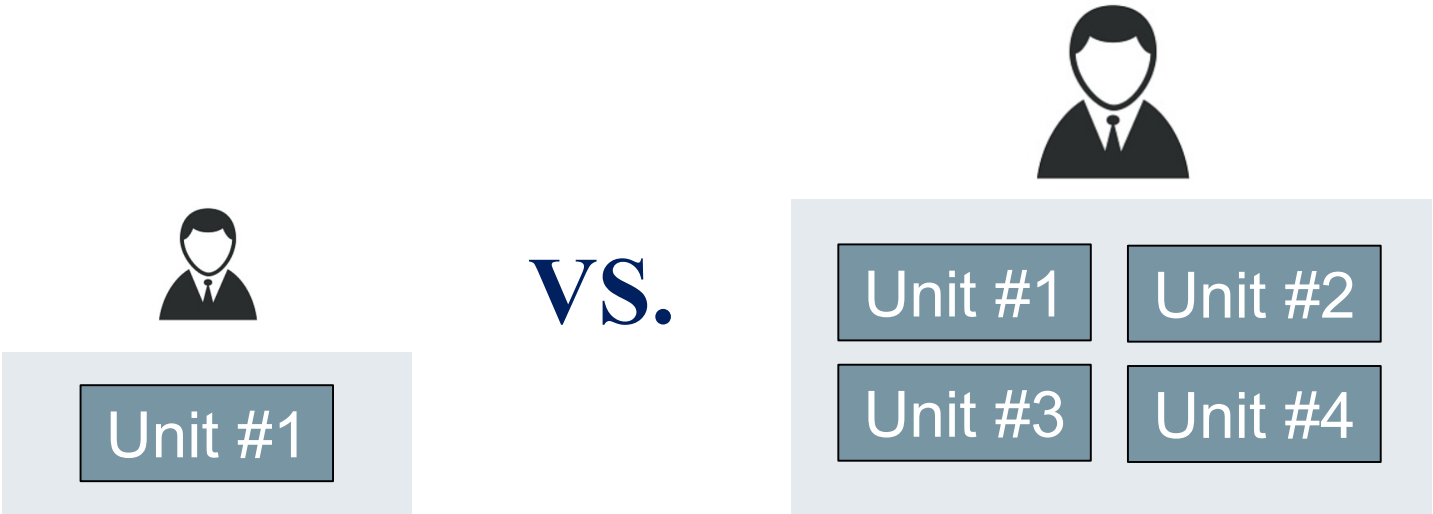
<Computer-based procedures of full scope simulator>

Addition of simplified verson of computer-based procedures to microworld

2. Overview of Microworld Studies

►Current development state

4. **Development of microworld interface for multi-unit controls**
   - Difference between controlling one unit and four units simultaneously
     - For example, when an initiating event occurs,



- #1: An initiating event occurs.
- #2: One operator treats the event for a unit.

- #1: An initiating event occurs in a unit.
- #2: One operator treats the event for a unit.
- #3: Simultaneously, one operator performs load following operation for the other units.

2. Overview of Microworld Studies

►Current development state

4. Development of microworld interface for multi-unit controls (Cont'd)

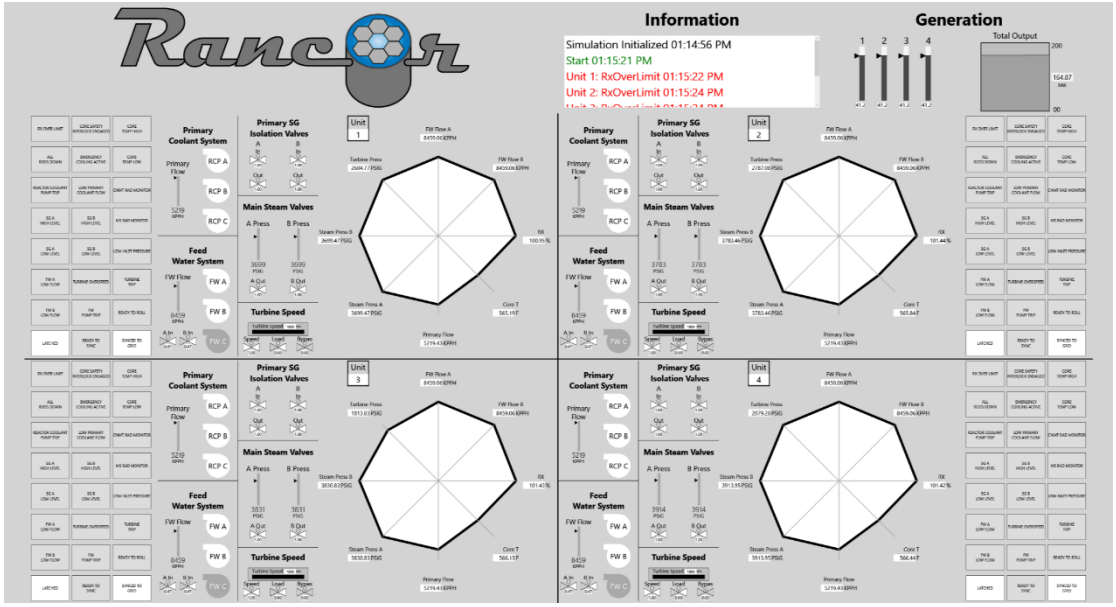
- An example of microworld interface for controlling four units simultaneously

Unit #1

Unit #2

Unit #3

Unit #4



- Enables research to examine:
  - Testing NuScales concept of operations – 3 member crews for 12 SMR units
  - Empirical manipulations of PSFs (e.g., complexity PSF) for multi-unit controls
  - Identifying human performance issues associated with load following operations predicted to become a larger factor in future operations

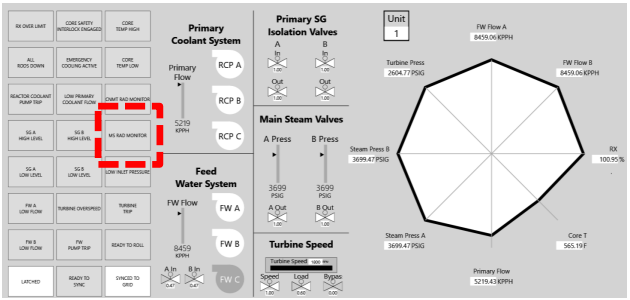
2. Overview of Microworld Studies

▶ Current development state

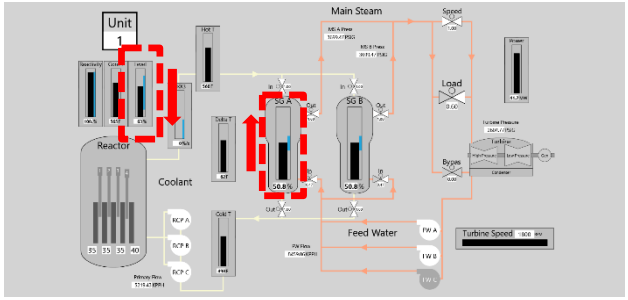
5. Development of microworld scenarios

- More simple scenario in comparison with the scenarios of full-scope simulator
- An example of a SGTR scenario
  - ➢ Isolation of faulted SG

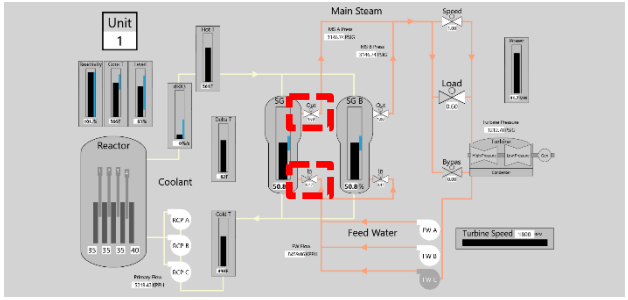
Action #1: Main steam radiation monitor alerts operators to initial issue.



Action #2: Reactor level begins to decrease and affect SG begins to increase.



Action #3: Affected SG isolation valves must be closed to mitigate leakage.



- Consideration of experimental manipulations (examples)
  - ➢ Task characteristics in digital MCR versus analog one
    - ✓ For example, computer-based procedures versus paper-based procedures
  - ➢ Single unit accident versus multi-unit configuration with one unit suffering the accident

2. Overview of Microworld Studies

►Current development state

5. **Development of microworld scenarios (Cont'd)**
   - Estimation of human performances planning to collect from Microworld simulator
     - Primary tasks
       - ✓ Time to recognize and accurately diagnose an initiating event
       - ✓ Time to respond and perform mitigating actions
       - ✓ Perturbed process value error which is the deviation from optimal process value, e.g., SG level deviations from 50%
       - ✓ Completion time for a procedure step or instruction
     - Secondly tasks
       - ✓ The number of secondary tasks
     - Error rates for tasks
     - Situation awareness
     - Workload

3. Future Microworld Studies

3. Future Microworld Studies

►Future microworld studies

- We are interested in:
  1. Crew dynamics
     - Looking to conduct a study with more than a single operator
  2. Screening students for particular aptitudes, like skills at gaming, to compare how they will do compared to regular students and operators
     - This will bring student results even closer to operators due to their experience or aptitude.
     - In other words, if we find a high skill group of students, is their performance better than regular students, and does it more closely match operators?
  3. Building non-nuclear microworlds (e.g., oil refinery or drilling processes) to help explore HRA beyond nuclear
  4. Building a version of a dynamic HRA simulation based on the reduced order model in Rancor
     - This will allow us to validate several dynamic HRA modeling assumptions we haven't been able to do easily before.

3. Future Microworld Studies

►Future microworld studies

- We are interested in: (Cont'd)
  5. The use the microworld for design studies, where performance is the determiner of the best HSI, not subjective usability
  6. Exploring if the microworld would be useful for testing operator performance during cyber security interdictions
     - Using actual operators with different types of digital HMIs in the microworld

3. Future Microworld Studies

►Collaboration with other institutes

- Universities partnering with INL to perform studies

<Ohio State University>

Studies on multi-unit operations

Studies on automation PSFs

<Norwegian University of Technology and Science>

<University of Idaho>

Studies on computer-based procedures

Microworld experiments & getting subjects (Planning)

<Chosun University>

4. Conclusion

4. Conclusion

- Microworlds are a complement--not a replacement--for full-scope simulator studies.
  - It allows us to conduct first principles research more rapidly and to screen interesting phenomena that we can explore in the full-scope simulator.

- Microworlds lower the entry point for being able to do HRA research.
  - We are using it as a testbed to interest psychological researchers in working on HRA studies.
  - We need psychologically-centered studies to inform PSF quantification.

- Microworlds may provide useful data that could be integrated into SACADA or HuREX databases in the future.
  - We are interested in supporting data HRA data collection, not just in doing research in isolation.

Thank you !

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