Halden Reactor Project experiments on extreme scenarios: Results and insights on training, risk assessment, crew organization and design

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HAMMLAB experiments

Experiments in HAMMLAB, purpose

- Support HRA with information and data
  - Improve understanding by narratives, support for HRA practitioners
  - Support HRA method development
- Support improvements and new designs
  - Develop and test principles for Human System Interfaces (HSI) and support tools
  - Propose improved teamwork and work processes (conduct of operation)
  - Identify principles for training
  - Identify potential mismatches between procedures and scenarios
- Develop tools and methods for studying and measuring human performance

HRA experiments in HAMMLAB 2002 – 2014

- **7 data collections**
- **50 operator crews**
  - **11 U.S. crews (2011 and 2014)**
- **25 scenarios, e.g.,**
  - SGTR (Steam Generator Tube Rupture) (incl multiple)
  - LOFW (Loss of Feedwater) (and combined with SGTR)
  - ISLOCA (Interfacing System Loss of Coolant Accident, LOCA outside containment)
  - H.B. Robinson fire
- **215 simulator runs**
- **30 Halden work reports**

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Topics studied

- Task complexity: time pressure, information load
- Masking: multiple malfunctions with overlapping symptoms, indicators' failures and misalignments
- Team cognition (teamwork)
- Mismatch between procedures and plant situation: Non-typical conditions, lack of detailed guidance
- Resilient procedure use (how to operate when procedure – situation mismatches occur)
  - Shift Technical Advisor (STA) impact on procedure use
  - Procedure overview and procedure backgrounds tool

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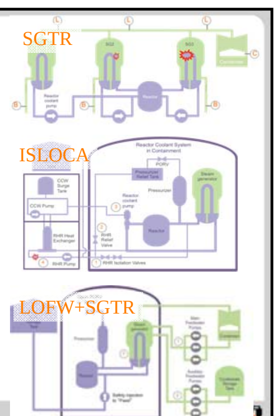
Scenarios and mismatches (2011)

Aspects of the procedures did not match the situation

1. Inserted multiple malfunctions
2. Key indicators referred in the EOPs unreliable
3. Situation not fully covered by the relevant EOP
4. Ambiguous guidance/conflict between documents

Also, mismatches late into all the events

could not follow step-by-step



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Recurring themes

- High crew-to-crew performance variability
  - In within-design-basis accidents covered by EOPs
- Difficulties when the EOPs
  - Lacked detailed guidance
  - Required interpretation
- The more so in non-typical conditions
- Degraded indications (instrument failures, overlapping malfunctions, and miscommunications) are extremely challenging to the crews and can seriously affect plant safety

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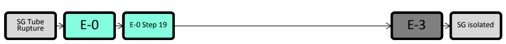
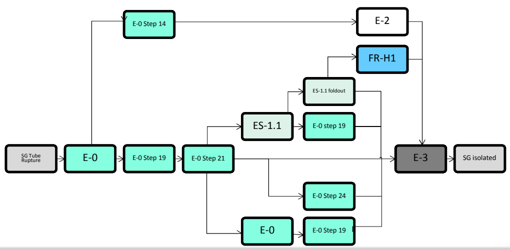
Typical conditions



Non-typical conditions



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Did the operators effectively handle the situation/procedure mismatches?

Inappropriate handlings occurred

- In all scenarios
- By all crews

Consequences observed in the simulations due to the inappropriate handlings

- Vessel integrity challenges (e.g., relevant EOP not entered, 1 hour “soak” not respected)
- Radiation releases outside the plant (e.g., avoidable releases through SG PORVs)
- Induced equipment failures (e.g., late stop and likely RCPs damage)
- Inventory depletion (e.g., lack of efforts to identify and isolate RCS leak)

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Challenges and operator strategies

- Ref S. Massaiu, HWR-1121

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Situation understood?

- Operators trust control room information,
  - …but some rely *only* on control room information
- Operators validate CR information with info from outside the CR
  - …but some follow up too little with plant personnel

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Procedure understood?

Observed strategies:

1. Keep historical information for interpretation
   - Memorize
   - Note down, write on procedures
2. Understand how to implement the step
   - …but sometimes don't understand step/procedure's intention
3. Understand why procedure is entered
   - …but not necessarily the aim or benefit of the procedure

Challenging aspects with multiple events/failures:

- Conditions of applicability
- Entering and exiting procedures
- Selectively performing steps vs. doing all
- Serial vs. parallel use

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Procedure – situation mismatch recognized?

Observed operator strategies and challenges

- Some operators trust the procedure when one key indicator match the procedure
  - …but one key indicator may be misleading
- Conflicting instruction sometimes not read, not known
- Mismatch recognized but no departure to avoid delays or aggravating errors
- Mismatch not recognized due to lack of knowledge of procedure background

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Resolve procedure/situation mismatch

1. Collect extra information to discriminate
2. Refer to other guidance documents that support own understanding
3. Follow procedure *and* perform extra actions
   - Might include enter/leave procedure without explicit condition
4. Follow procedure but keep evaluating alternatives
5. Follow procedure to avoid delays, errors and sanctions
   - Keep pace, distribute procedure work and overview

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What we learned - Training

- Nature of scenarios to include in training
- Strict procedure followers generally underperformed in the studied scenarios
- Crew aspects, teamwork and decision making strategies must be trained to cope with non-typical scenarios/plant conditions
- (more from plant perspective in the next talk)

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What we learned – HRA

- Do not over-emphasize procedure following, not enough to analyze Error of Omission
  - After the first-hour into an emergency the procedure-situation fit is likely to decrease while fatigue effects arise: Higher likelihood for operators' autonomous decisions... and errors
- Always include analysis of cognitive aspects
  - Interpretations may be required also to apparently straightforward steps
- Extreme scenarios require lots of cognitive work from the crew:
  - Analyze procedures to identify possible procedure-situation mismatches. Degraded indications will result in mismatches
  - A deeper understanding of the nature of the difficulties for the crews is required, hence a thorough scenario analysis is needed for HRA (tasks/procedures)
  - Crew aspects must be analyzed, not only individual factors

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What we learned – crew organization

- Team factors and crew cognition critical for performance in difficult scenarios
  - E.g., role of the supervisor, distributed leadership, team orientation, backup and support
- Quality of teamwork decreases with complexity and fatigue
  - Less structured meetings, poor quality of briefings/discussions
  - Communication errors
- Role of STA and independence of STA
  - Tendency of STAs to work mainly as "procedure following double-checker"
- Importance of local information (e.g., local radiation measurements)

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What we learned – interface and support tools

- Support tools can improve crew performance in non-typical condition
  - Overview display with safety critical information "at a glance"
  - Procedure flowchart tool to promote anticipation strategies
  - Procedure flowchart tool to facilitate on-line access to critical information contained in the procedure backgrounds
  - Advanced interfaces (dynamic subcooling margin graphs, SGs mass-balances) speed up procedure progression and reduce workload
- Technology is available for improving communication with the field

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Conclusions

- HAMMLAB experiments provide good and relevant information to plants and authorities about extreme scenarios
  - Throw light on performance aspects not commonly investigated at training/requalification sessions
  - Range of human performance measures
  - Detailed audio/video analysis uncovers problems not easily spotted on-line
  - Lab for nuclear-specific technology testing and development
- Best output to the participating plants and their operating crews

Participating Crews

- Professional attitude
- Learned the computerized interface fast
- Were able to operate the plant well after two days training
  - Knew the procedures (based on Westinghouse ERGs)

References

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