CONSTELLATION Nuclear Security:

Building a Technical Basis for Security Decisions

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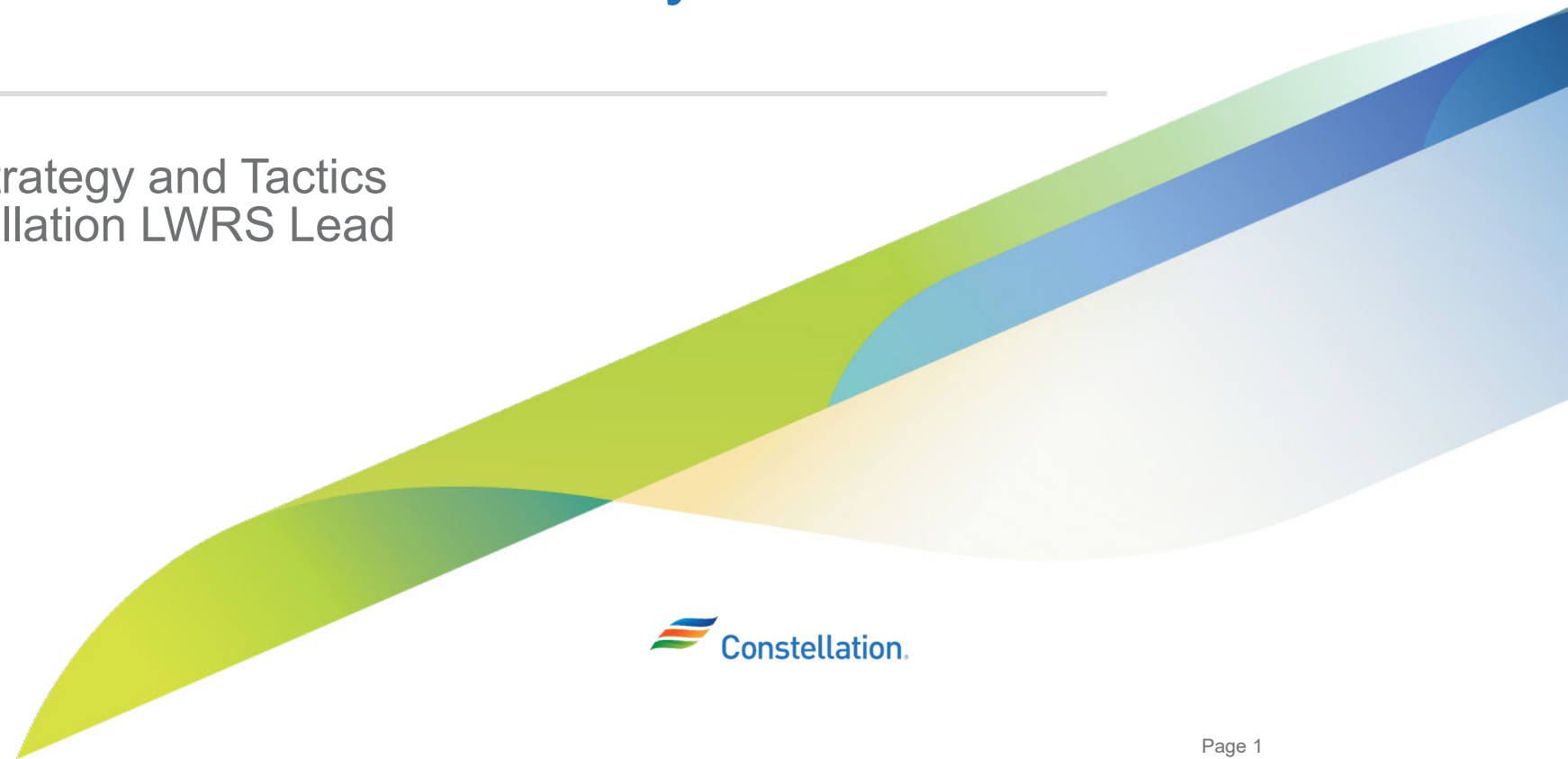

Constellation.

BACKGROUND: Constellation Nuclear Security Strategic Initiatives

- Ongoing, focused effort over the last decade to optimize Nuclear Security
  - Senior Management understanding, engagement and resource investment
  - 3 Criteria: Positive impact on Defensive Strategy and Tactics / Physical Security Plan, Human Performance, and Net Present Value ($100M+)
  - Share successes with Industry through direct interactions with Peers and NEI
- Multiple successful initiatives with NRC review / challenge
  - Handgun elimination (Exelon COI to NEI DNP)
  - Suppressor usage for range training, T&E and analysis
  - First (and only) successful Remote Operated Weapons System development and implementation in industry
  - Ammunition T&E and analysis
  - Defensive Strategy Optimization (fleet mods and PSP changes)
- Building on successful interaction with LWRS (T&E / analysis in progress)
  - Force-on-Force (FoF) control measures for mock explosive usage (informs timelines)
  - FoF control measures for precision marksmanship and other range activities

CURRENT STATE: Key Points for Building a Technical Basis

- Ongoing gap analysis
  - Definition of problems, goals, and success criteria
- Strategic planning and prioritization for resource allocation
  - SWOT and Cost / Benefit analysis, to include Net Present Value calculations
- Diversity of Subject Matter Expertise / prevention of “group think”
- Collective stakeholder engagement for development of final concept(s)
- Senior management challenge and select peer reviews
- Regulatory review and formal analysis
  - Objective, quantifiable, and repeatable
- Fleet implementation planning supports industry implementation and other key stakeholders’ priorities

ON-GOING AND FUTURE STATE: Constellation Strategic Initiatives

- Continued focus on long-term business goals with LWRS as a key partner
- Build on previous LWRS Security Pathway successes to define tactical realism
  - Common bulk explosives breaching charge:
    - Phase 1: Mock charge “right sizing” success with LWRS, complete with NEI / NRC (2Q24)
    - Phase 2: Explosive initiators T&E / analysis in progress (3Q24)
    - Phase 3: Blast effects, T&E complete, analysis in progress (4Q24)
  - Precision marksmanship testing and data analysis: Most T&E complete, analysis in progress (4Q24 and beyond, incrementally)
- Long-term planning (3-5 year) with LWRS/Industry to support Constellation/Industry Nuclear Security Strategic Initiatives
  - Including focus beyond traditional nuclear security
- Explore other LWRS pathways for potential model of security path forward

MOVING FORWARD: Key Lessons Learned

- No single issue, no single solution, no single resource
- LWRS T&E philosophy is synergistic with Constellation's, with proper communications
- Analysis to support change is regulatory responsibility of the licensee
- Long term process, with incremental successes, to reach cumulative goals

QUESTIONS / DISCUSSION

Thank You

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THE OHIO STATE UNIVERSITY

A Virtual Reality Environment for Human Reliability Assessment in the Context of Physical Security Attacks

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Outline

- Project Summary
- Schedule
- Achieved Tasks
- Interactions with LWRS
- Outcomes
- Next Steps

Project Summary

Research Goals

- Develop a **virtual reality environment (tool)** for **human reliability assessment** in the context of physical security attacks on nuclear power plants.
- The virtual reality (VR) tool will be used in the conduct of experiments to collect human performance data representative of physical security attack conditions.
- The performance data will be used to expand current HRA models to cover physical attacks on the plant.

Main Expected Outcome

- Improved knowledge of human reliability in the context of physical attacks.
- Support more informed decision-making to help reduce operation costs.

Timeline

- Started October 1, 2021.
- Three-year project.
- Presentation covers year 1 ~ 2.5 of the project.

Team

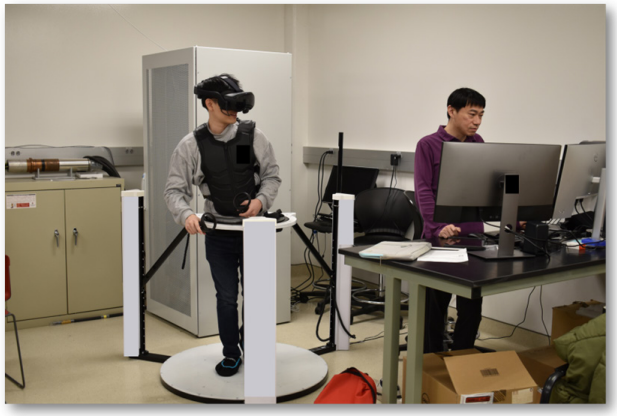
- Dr. Carol Smidts (lead, The Ohio State University)
- Dr. Ronald Boring (Idaho National Laboratory)
- Dr. Vaibhav Yadav (Idaho National Laboratory)
- Dr. Abdollah Shafieezadeh (The Ohio State University)
- Dr. Alper Yilmaz (The Ohio State University)
- Mr. Thomas Myers (Duke Energy)

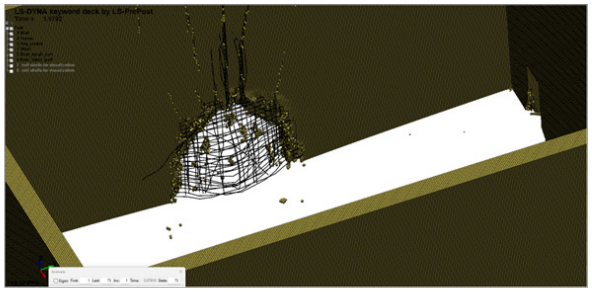
Schedule

Milestone	Participants	Start Date	End Date
Literature Review	All	10/1/2021	12/31/2021
Human Reliability Models Reuse	Smidts (Lead), Boring	1/1/2022	6/30/2022
First Year Annual Report	All	9/1/2022	10/30/2022
Simulation of the Physical Effects of Attack and Defense	Shafieezadeh	7/1/2022	12/31/2023
Virtual Reality Integration	Smidts (Lead), Shafieezadeh	7/1/2022	12/31/2023
Second Year Annual Report	All	9/1/2023	10/30/2023
Design of Experiments	Smidts (Lead), Boring, Shafieezadeh, Yadav, Myers	7/1/2023	12/31/2023
Run Experiments	Smidts (Lead), Boring	1/1/2024	6/30/2024
Modify and Augment human reliability models	Smidts (Lead), Boring, Yadav	4/1/2024	9/30/2024
Publish Lessons Learnt	All	7/1/2024	9/30/2024
Final Report	All	10/1/2024	12/29/2024

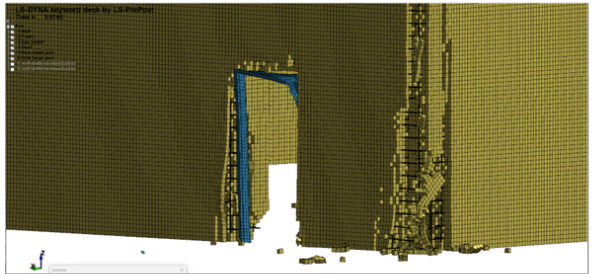
Achieved Tasks

- Designed and developed a virtual reality (VR) environment for simulating physical attack scenarios and sampling human reactions during the physical attacks.
- Integrated the 3D models of concrete structures with the 3D models of nuclear power plants used in the VR environment to simulate the destruction of protection architectures (e.g., walls, doors) caused by the adversaries.
- Designed the demonstration scenarios for verifying the effectiveness of the VR environment.
- Developed 3D models of reinforced concrete panels impacted by projectiles and explosions using the Lagrangian finite element technique in the commercial finite element platform LS-DYNA.
- Reviewed several Human Reliability Models. Determined several Performance Shaping Factors (PSFs) that need to be considered and established a causal HRA model that will be updated through experiments.





Damage from the inside wall



Damage on security door

Achieved Tasks - Design of the experiment: Attack Scenario

Actions of the attacker:

- Cause a loss-of-offsite power event
- Plans to first destroy the diesel generators (DG)
- Proceed to the control room

Actions of the security personnel:

- Make sure the operator is safe
- Escort the operator to the steam-driven cooling pump
- If encounters the attacker, neutralize the attacker

Actions of the operator:

- Open the control room door and go towards the steam-driven cooling pump
- Start the steam-driven cooling pump

Experiment

- Identified Control variables, Reaction variables, and potential Biases.
- Defined a set of Individual Characteristics and Behaviors.

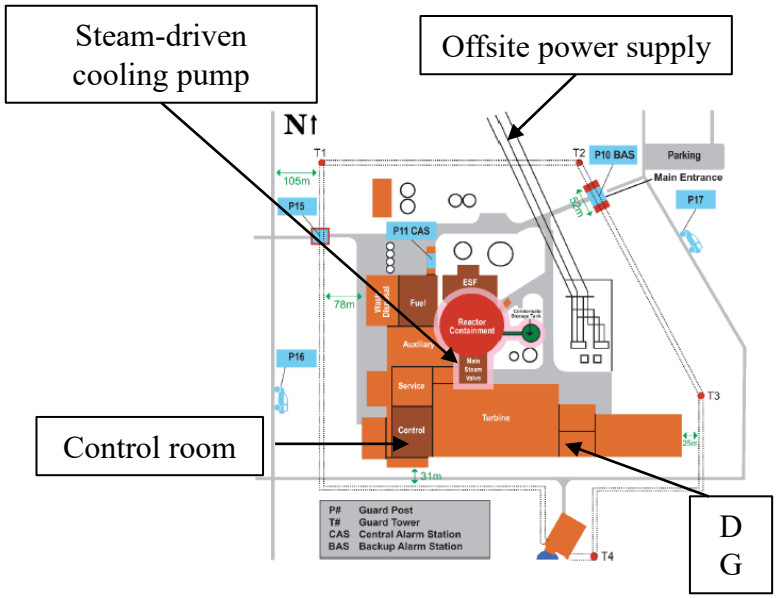


Figure 1: Lone Pine power plant model*

* Osborn, D., Parks, M. J., Knudsen, R. A., Ross, K., Faucett, C., Haskin, T. C., ... & Cohn, B. (2019). *Modeling for Existing Nuclear Power Plant Security Regime* (No. SAND2019-12014). Sandia National Lab.(SNL-NM), Albuquerque, NM (United States).

Interactions with LWRS

- Received repeated guidance and support from the LWRS physical security pathway lead through meetings and in person visits as well as supporting our requests such as:
  - Received the Lone Pine Power Plant Model from Sandia National Laboratory for the VR environment.
  - Received technical support (e.g., model adaptation, rendering optimization, bug fix, etc.) from the developers of the Lone Pine model.
  - Received equipment suggestions to build the VR environment.

Publications

- Md Ragib Rownak, Samuel Abiodun Olatubosun, Yunfei Zhao, Carol Smidts, Abdollah Shafieezadeh, **Human reliability assessment for physical security: human responses under extreme threats**, NPIC-HMIT, 2023
- Xiaoxu Diao, Md Ragib Rownak, Carol Smidts, **Human Reliability under Physical Security Threats: Modeling and Experimental Design**, 70th Annual Reliability and Maintainability Symposium, 2024
- Xiaoxu Diao, Md Ragib Rownak, Carol Smidts, **Design and Implementation of a Virtual Reality Environment for Human Reliability Assessment under Physical Security Threats**, Pacific Basin Nuclear Conference 2024 (PBNC), Under Review

Students and Staff Supported

- 2 MS Students from ME and CGE – one graduated, and one is planning to graduate this semester.
- 2 research staff were partially supported. One is now an Assistant Professor at University of Maryland.
- 3 postdoctoral researchers were partially supported.

Next Steps

- Run Experiments
- Update the HRA models based on the experimental data.
- Publish lessons learnt
- Final Report

Acknowledgement

- This research is being performed using funding from the DOE Office of Nuclear Energy's Nuclear Energy University Programs.

NEUP Nuclear Energy University Programs
U.S. Department of Energy

- We thank Sandia National Laboratory and LWRS for providing the Lone Pine NPP model for the virtual environment and providing their valuable feedback during the study.

LWRS LIGHT WATER REACTOR SUSTAINABILITY

Bio – Prof. Carol Smidts

Carol S. Smidts (Ohio State, PI) is a Full Professor at The Ohio State University with more than 30 years of research experience. Professor Smidts' research lies in human reliability analysis, dynamic probabilistic risk assessment, instrumentation and control, and risk and reliability analysis, including distributed test facility design, reliability analysis of digital instrumentation and control systems, software reliability modeling and software test automation, and cybersecurity and cyber risk assessment for industrial control systems. She is the author of more than 200 refereed journal and conference publications and is the recipient of multiple awards and 4 patents. Her contributions to the field of HRA include the IDA model.

Dr. Smidts' research has been sponsored by Government (DOE, AFSOR, AFRL, NRC, NASA, NSF, FAA, DOD, NSA) as well as by industry (Texas Instruments, IBM). She is an IEEE Fellow, AAIA Fellow was the conference co-chair of the IEEE International Symposium on Software Reliability Engineering (2006 and 2013), IEEE High Assurance Systems Engineering (2008), is an Associate Editor for Software Testing Verification and Reliability, was one of the Technical Program Committee Co-Chairs of NPIC-HMIT 2019, was the Program Chair of 2021 International Topical Meeting on Probabilistic Safety Assessment and Analysis (PSA 2021), a honorary professor at Amity University, India, holds a joint appointment with INL, is a regular member on review panels (DOE, NSF, FDA, ISSRE, HASE, DSN) and has been awarded the Lifetime Achievement Award in 2019 by the Society for Reliability and Safety, in recognition to her pioneering contributions in the area of digital systems reliability.

Q & A

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Past and Future Collaborations with the LWRS Program

William Gross, NEI

May 1, 2024

NUCLEAR ENERGY INSTITUTE

Security Coordination and Interface

Where we've been…

Program stand-up

Early activity

Looking toward the future

Continue priority projects, learn from prior efforts

Identify opportunities for increasing awareness, engagement and results


Thank You
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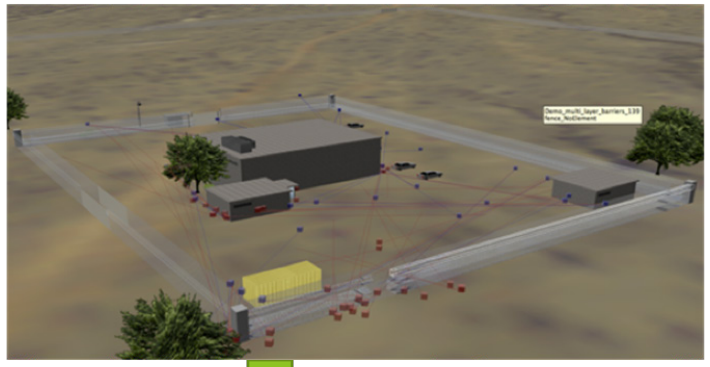
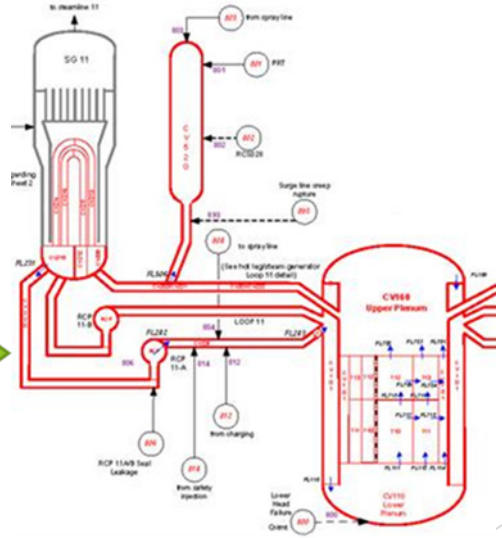
LWRS
LIGHT WATER REACTOR SUSTAINABILITY

RhinoCorps

Palo Verde Risk Informing Physical Security Program Changes with EMRALD



EMRALD



Simulation Process Results

Reviewed scenarios, for all that would benefit from manual TDP operation or Protection Pump.

- ~50% of scenarios benefited
- Developed exaggerated scenarios for each. (Average 41.3% adversary success)
- Average 12.5% adversary success with added protection strategy
  - Research resulted in opportunity for a 29% margin for post reduction or operational flexibility
- Performed reduction process

Response force posts reduced by ~20%

Operational Impact

- No change in equipment tie-in locations for FLEX
  - B.5.b locations would require additional analysis, guidance, equipment
- Purchase identical equipment to FLEX
- Minimal administrative changes to Abnormal Operating Procedure (AOP) for security events
- Additional risk margin can be gained by maximizing SG level before and/or after trip
  - No evaluation currently in progress for higher pre-trip/post-trip SG level or higher feedrates
- No change to credited operator actions during the security event (before the “all-clear”)
  - Potential B.5.b connection guidance needed
- Fire water for SG makeup via B.5.b not a viable option for Palo Verde – Equipment outside Protected Area

Palo Verde Cost Estimates for Increased Margin

- Two “Security Pumps” for SG Makeup $500K
- New Bullet Resistant Enclosure for “Security Pumps” $500K
- Yearly PM cost for new SG Makeup Pumps $50K
- Cost of Operator Training and Procedure changes expected to be minimal due to leveraging existing guidance for “FLEX” SG Makeup Pumps.
- Estimated time to recoup initial and ongoing investment is conservatively estimated to be 1-2 years.

Questions?