Identification and Prioritization of Sources of Uncertainty in External Hazard Probabilistic Risk Assessment: Project Update

Project funded by:
U.S. Department of Energy, Nuclear Energy University Program

Michelle Bensi (UMD) ● Zeyun Wu (VCU) ● Katrina Groth (UMD)
Zhegang Ma (INL) ● Ray Schneider (WEC) ● Tao Liu (VCU)
Kaveh Faraji Najarkolaie (UMD) ● Ahmad Al-Douri (UMD) ● Camille Levine (UMD)

PSA 2023
Knoxville, TN

Motivation & Research Needs

Motivation:

- Significant sources of uncertainties in XHPRA are associated with the frequency, severity, and temporal evolution of external hazard events and event impacts on plant response.

Research Needs:

- Develop a technically sound, risk-informed strategy to:
  - Identify and characterize drivers of hazard uncertainty
- Risk-informed strategy must account for:
  - Impacts of hazard events on SSCs and event progressions
  - Close coupling of the physical aspects of hazard events with plant response and human performance

Project Outcomes

- Develop a **structured process** for identifying, evaluating, categorizing, and assessing the impact of uncertainties on XHPRA modeling elements and **create a common taxonomy** for communicating these uncertainties across hazard groups
- Investigate the spectrum of uncertainties involved in the **physical processes** that underlie external hazards and assess the uncertainties associated with **estimation of hazard frequencies** and **parsing of hazard information** into the XHPRA
- Investigate how uncertainties in the physical hazard characteristics and associated **hazard timing interfaces with plant processes** to prepare for, mitigate, cope, and recover from the external challenge
  - Connect the uncertainties in the **hazard severity/evolution with human response**
- Integrate insights

Project Outcomes

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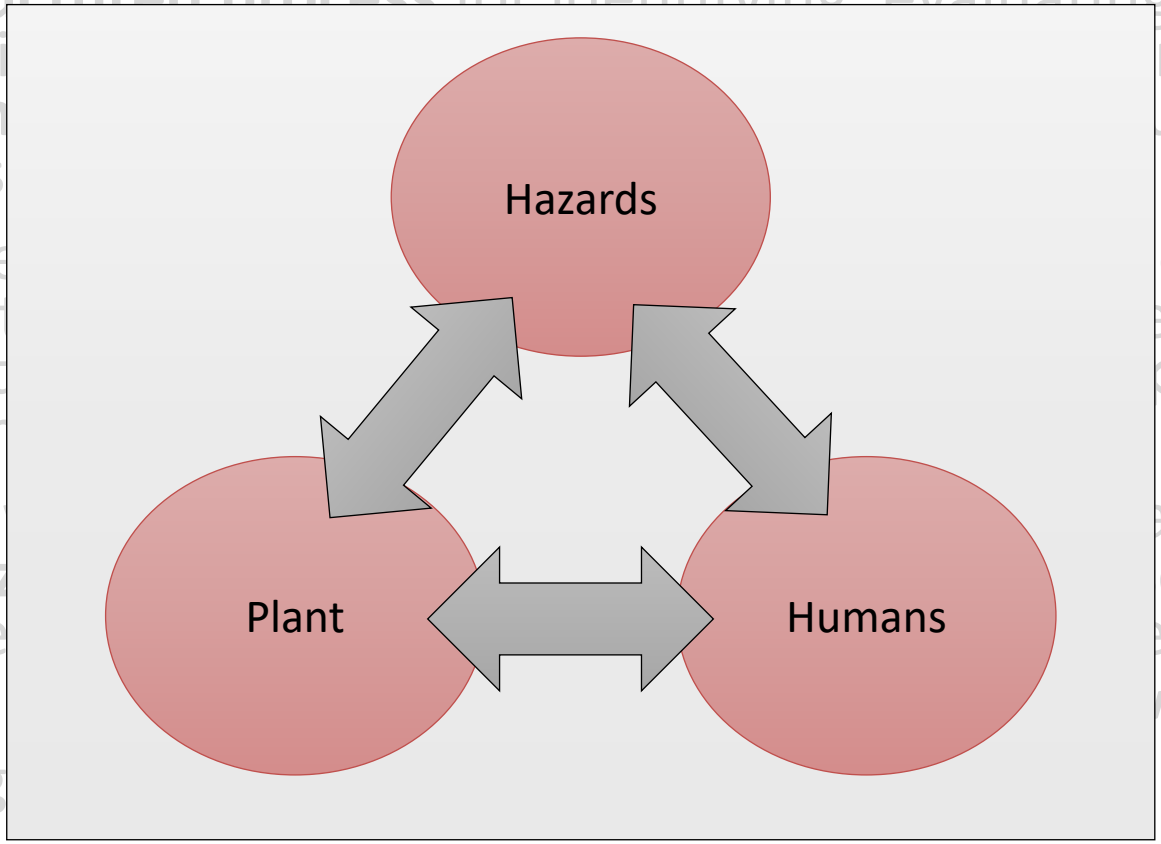
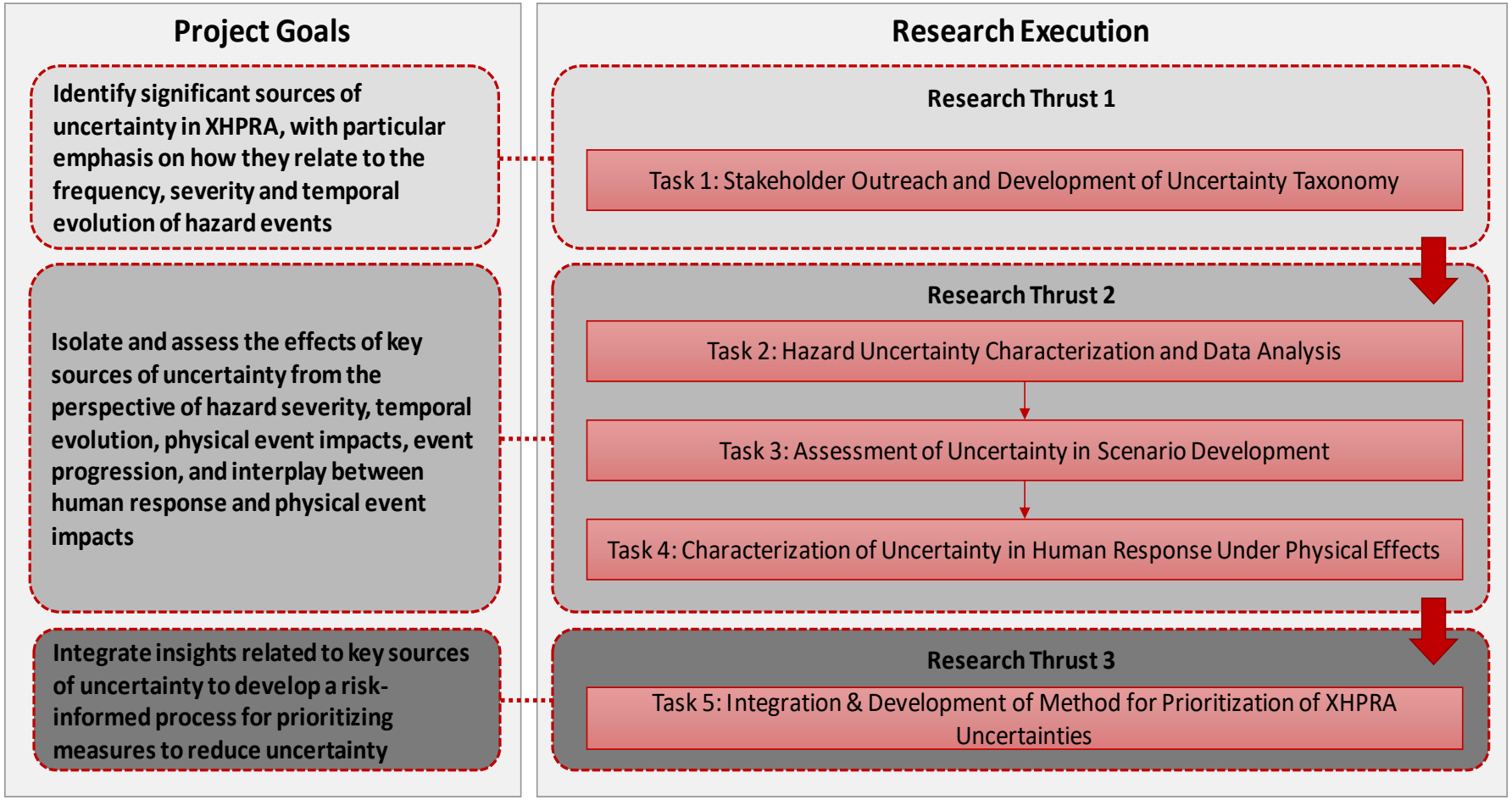
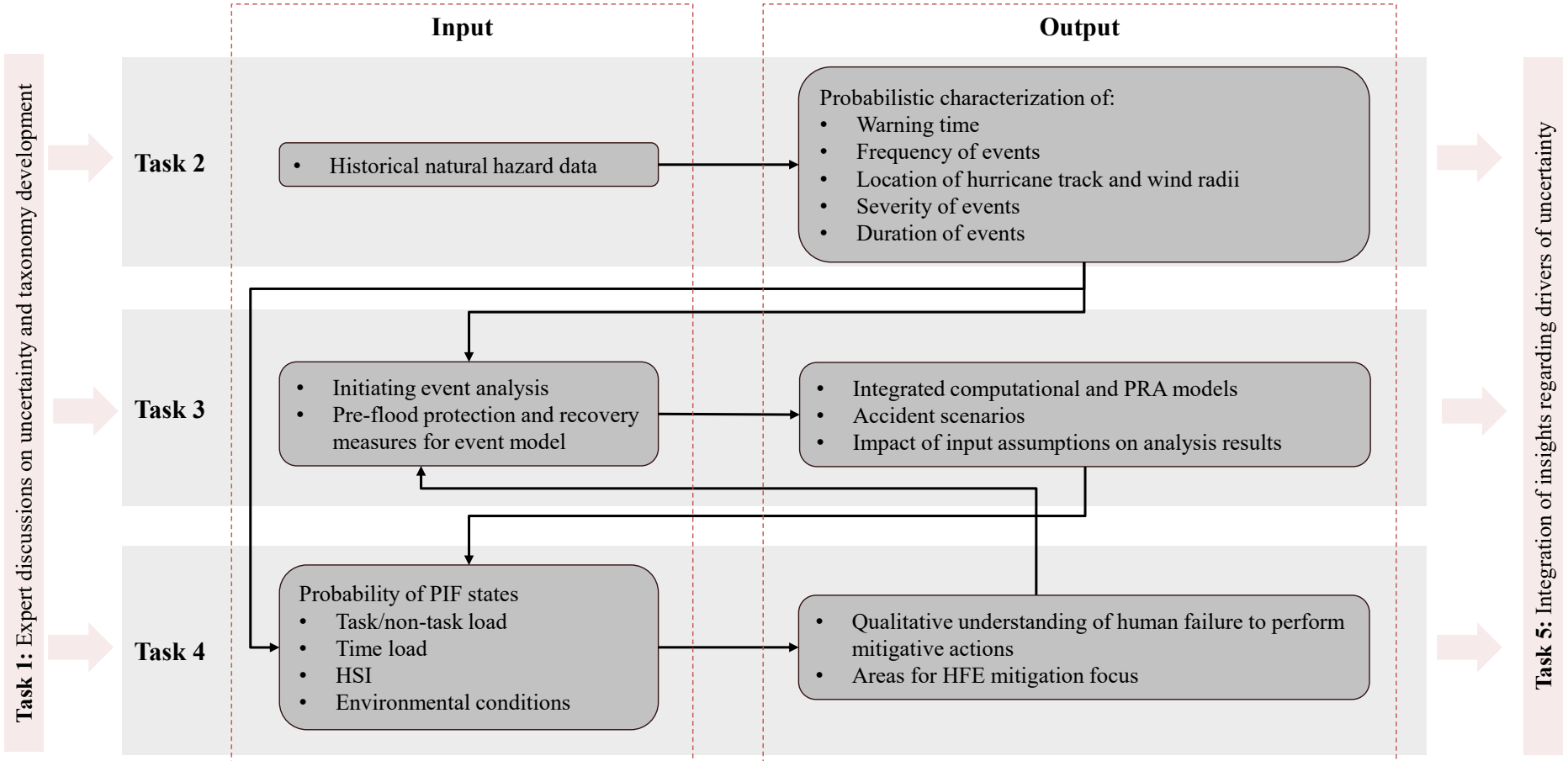


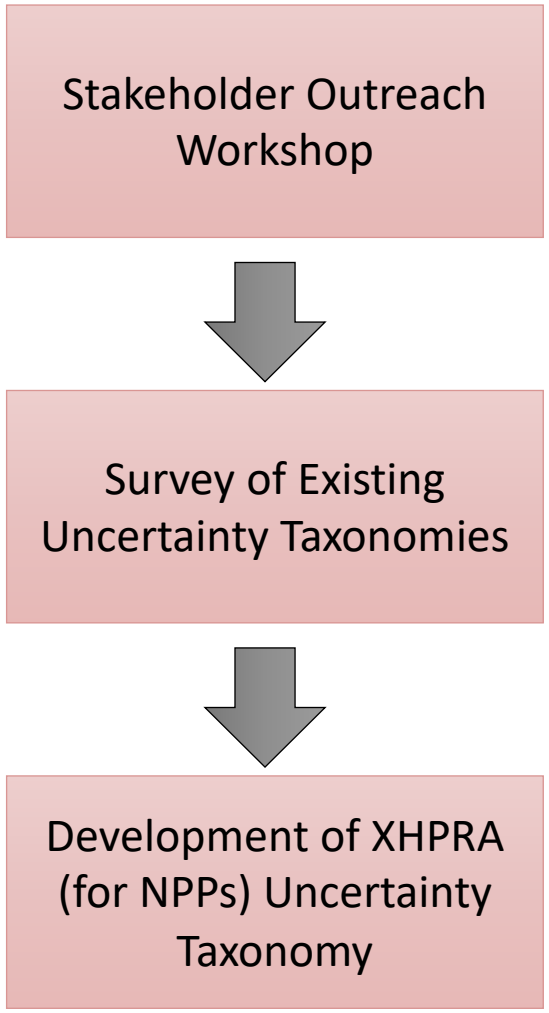
Project Goals and Structure



Task Integration
(using hurricanes as demonstration hazard)



Task 1: Stakeholder Outreach and Development of Uncertainty Taxonomy



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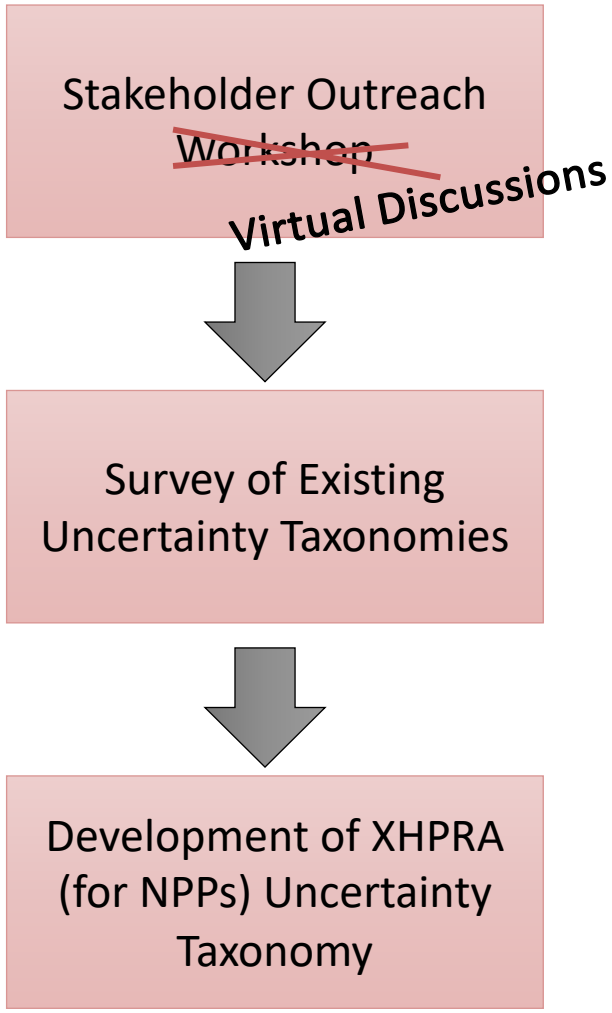

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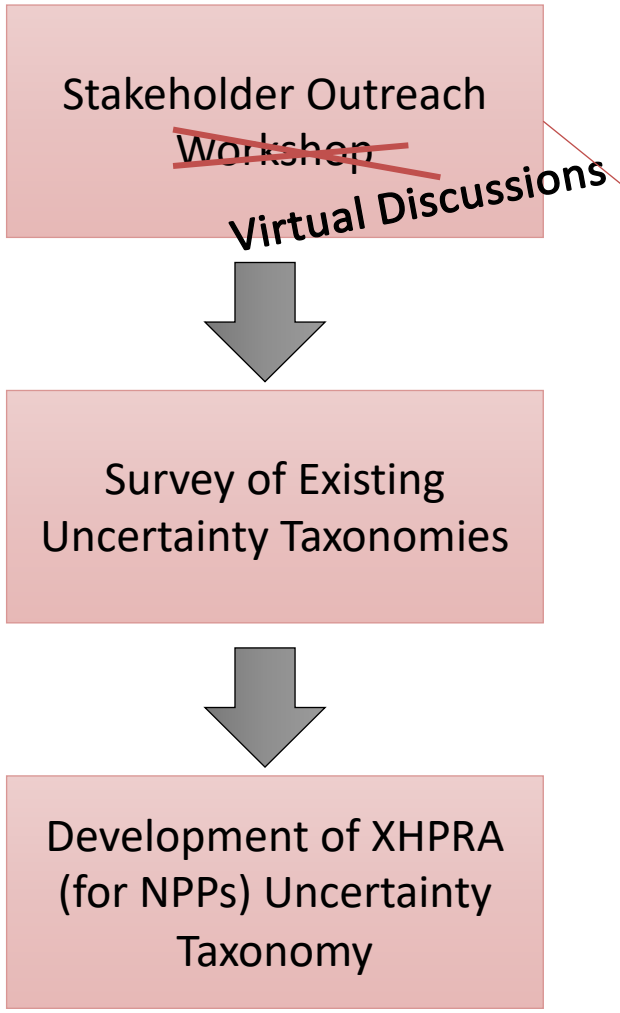

- Insights regarding the "most pressing" sources of uncertainty
- The strategies used to address drivers of uncertainty
- Identification of uncertainties w/ potential to change risk metrics
- Sources of "compounding conservatisms" and "blindspots"
- Inconsistencies in practices, conventions, etc. between hazard groups, technical elements, and other aspects of PRAs

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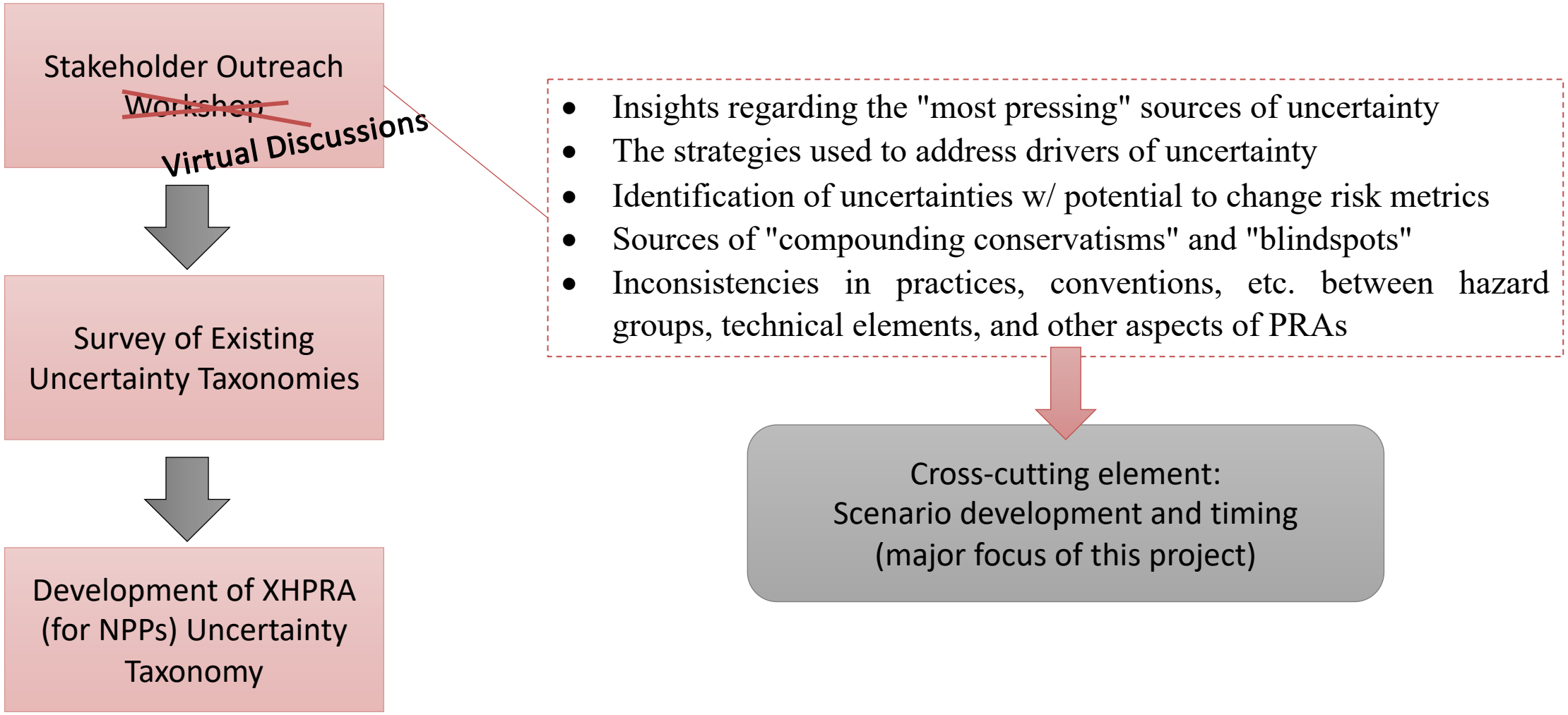
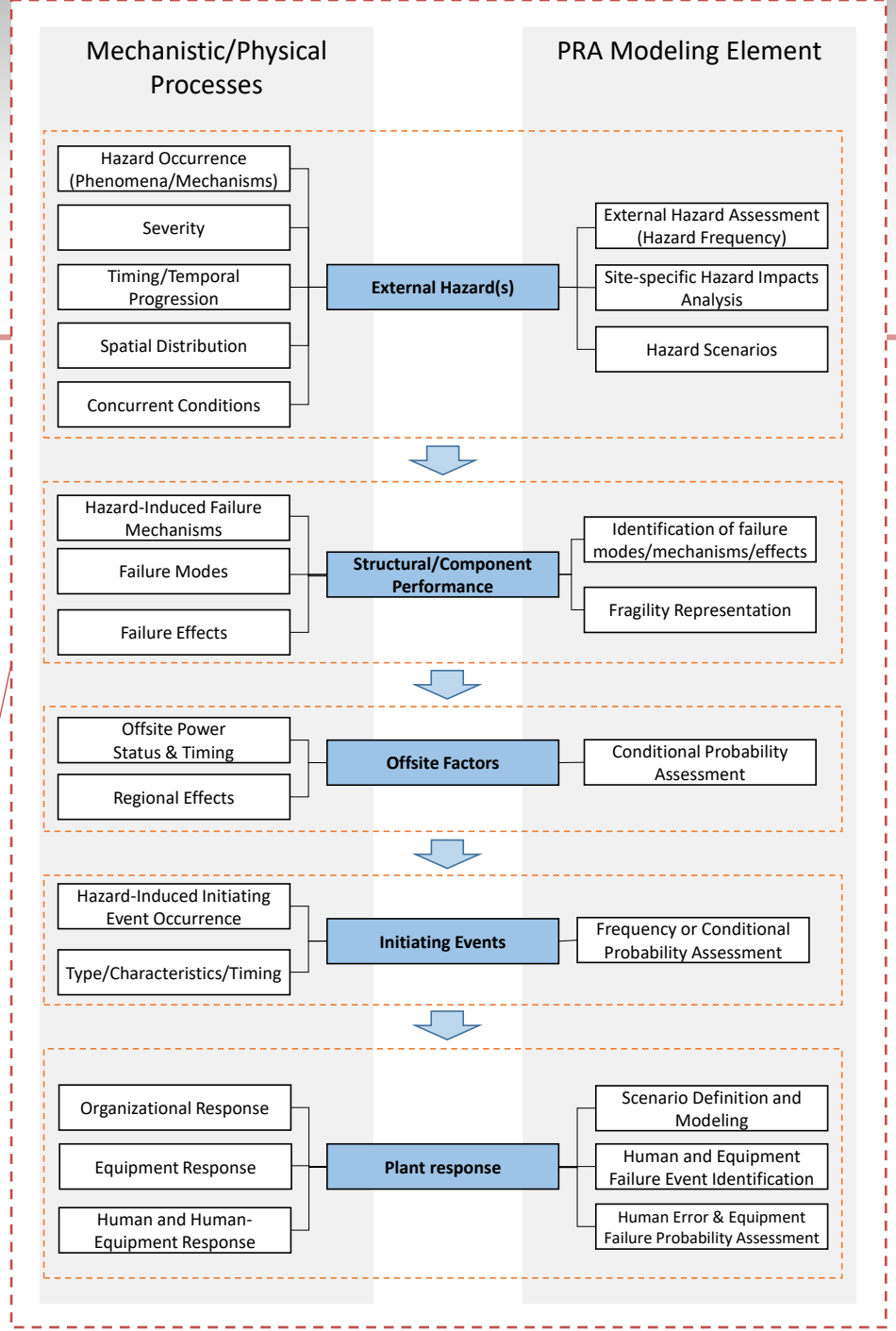


Stakeholder Outreach

~~Workshop~~ Virtual Discussions

Survey of Existing Uncertainty Taxonomies

Development of XHPRA (for NPPs) Uncertainty Taxonomy



Cross-cutting element:
Scenario development and timing (major focus of this project)

Bensi, M., S. Mohammadi, N. Ghosh, T. Liu, C. Levine, A. Al-Douri, R. Schneider, Z. Wu, K. Groth, Z. Ma (2022) "**Uncertainty in External Hazard Probabilistic Risk Assessment (PRA): A Structured Taxonomy**," at Probabilistic Safety Assessment and Management (PSAM16) Conference, July 2022, Honolulu, Hawaii.

Task 2: Hazard Uncertainty Characterization and Data Analysis

- Focus on external flooding hazards
- Identify key sources of uncertainty related to the probabilistic characterization of:
  - External hazard occurrence
  - Severity (e.g., flood depth, elevation)
  - Timing (e.g., warning time, duration)
- Inform assessments of plant mechanistic response and human performance

RISE Lab
Risk-Informed Solutions in Engineering Laboratory

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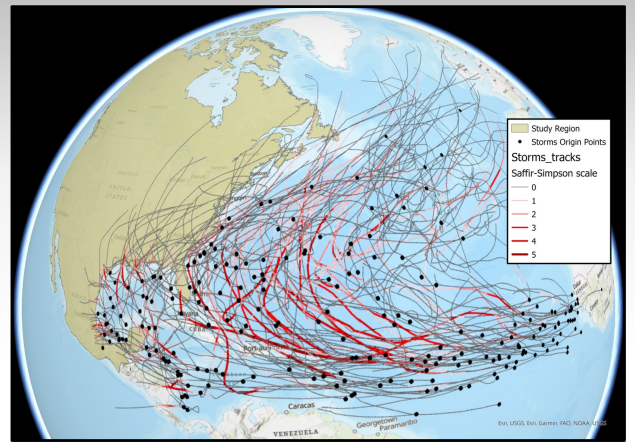
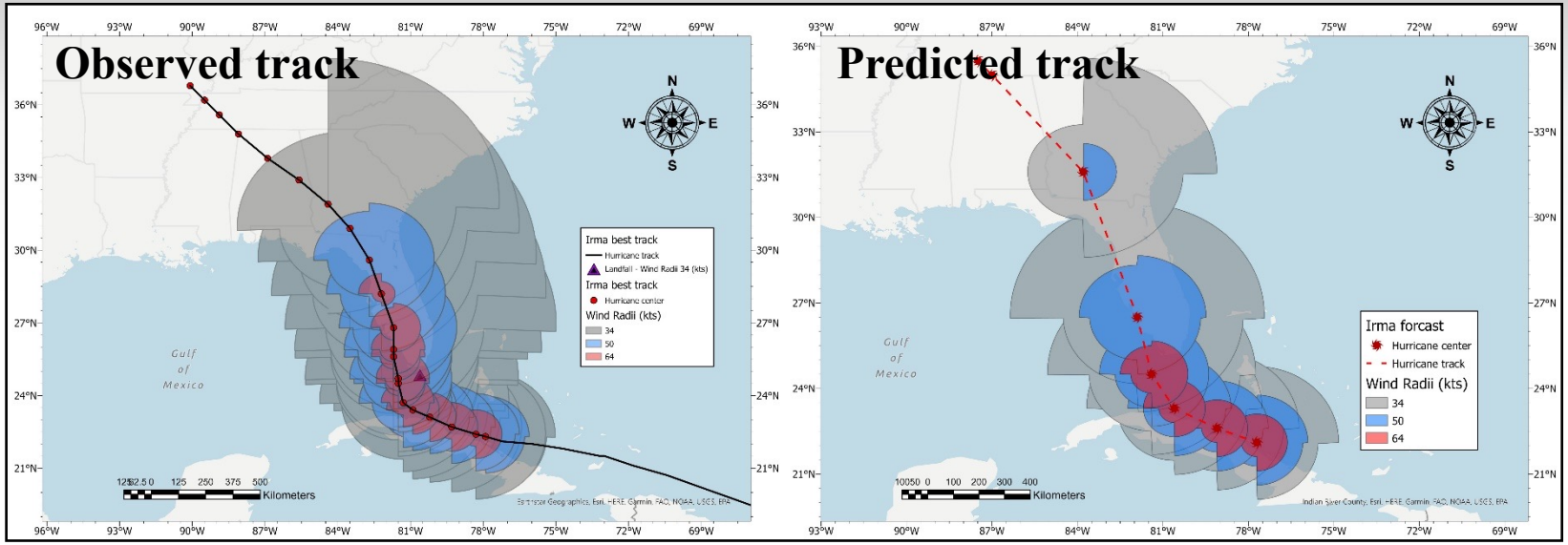
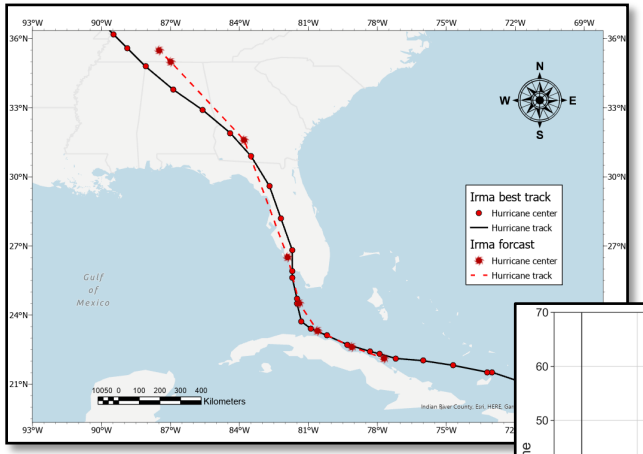
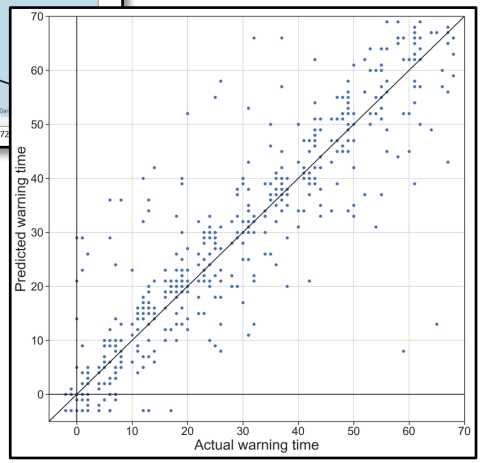
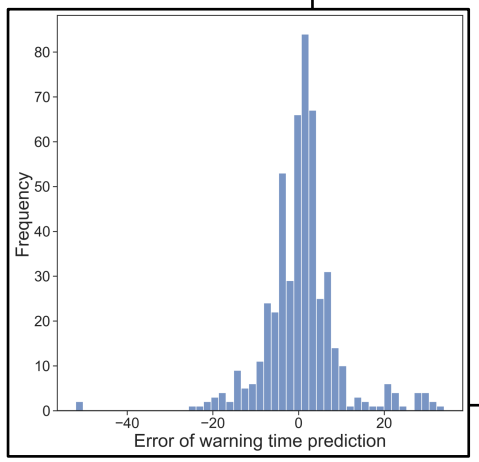


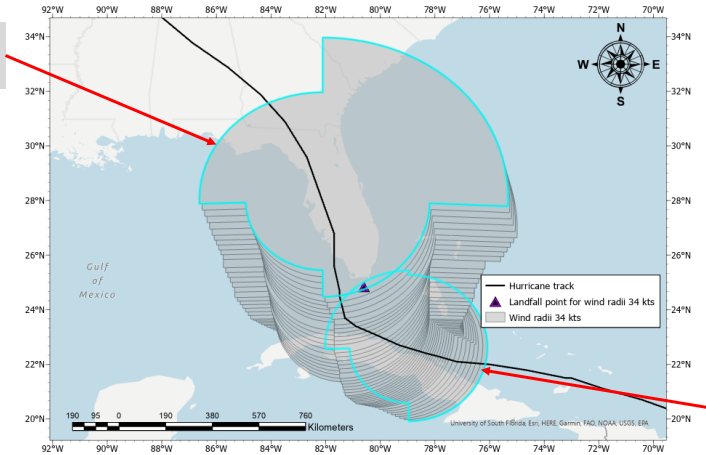








End (after 43 hours):
05:00 September 11



Start (Wind radii landfall):
10:00 September 9

RISELab
Risk-Informed Solutions in Engineering Laboratory

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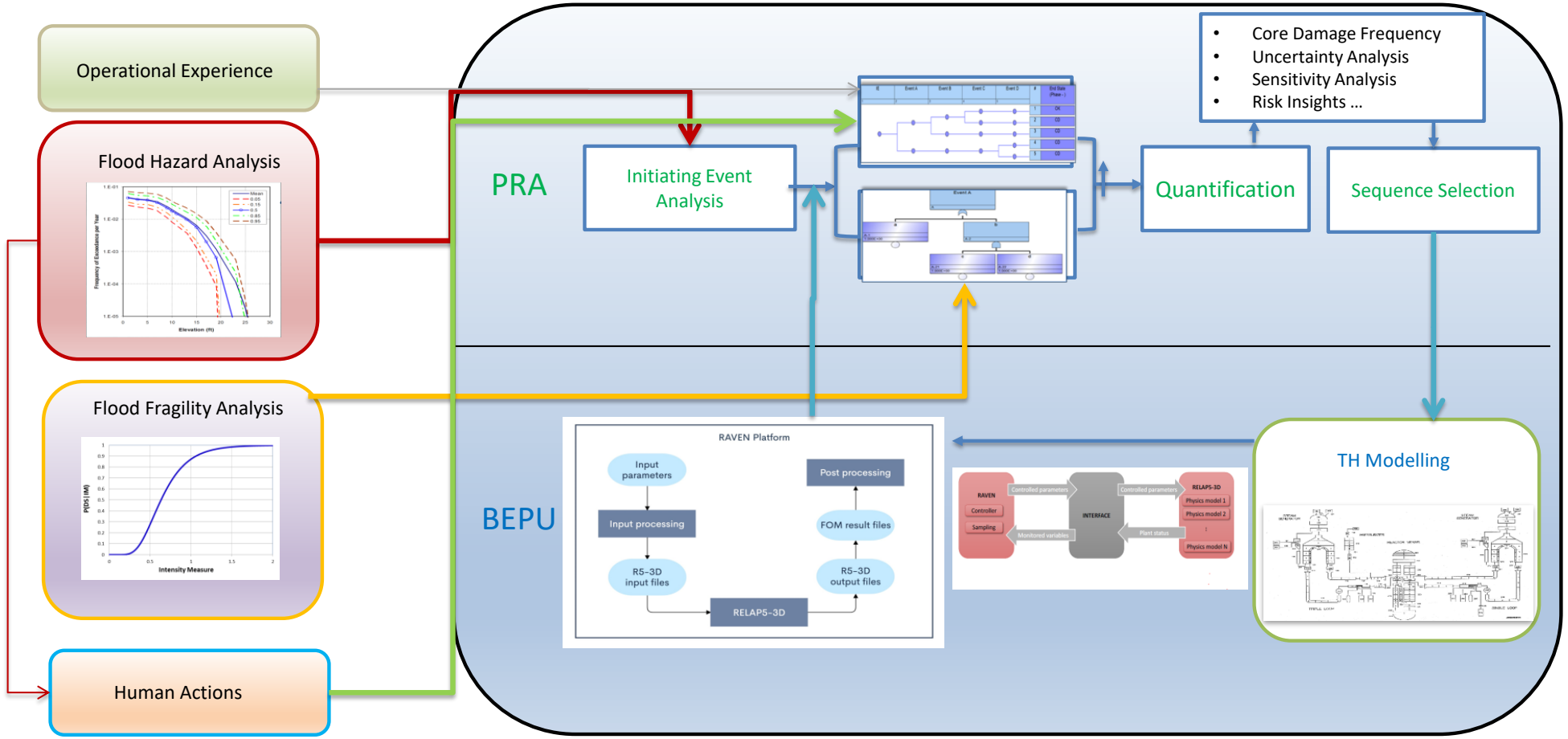
Mohammadi, S., M. Bensi, Z. Ma, and K. Faraji Najarkolaie (2022) "Uncertainty in Predicted Tropical Cyclone Path and Landfall Characteristics for Landfalling Storms to Support External Hazard Probabilistic Risk Assessments for Critical Infrastructure – A Preliminary Analysis," at Probabilistic Safety Assessment and Management (PSAM16) Conference, July 2022, Honolulu, Hawaii.

Faraji Najarkolaie, K., M. Bensi, Z. Ma (2023) "Assessment of Uncertainty Associated with Tropical Cyclone Forecasts to Support Probabilistic Risk Assessments for Nuclear Power Plants" at 18th International Probabilistic Safety Assessment and Analysis (PSA 2023), July 2023, Knoxville, TN.

Task 3: Assessment of Uncertainty in Scenario Development



T. Liu, Z. Wu, M. Bensi, K. Groth, Z. Ma, and R. Schneider, "**Assessment of Uncertainty in Scenario Development for External Hazard Probabilistic Risk Assessment for Nuclear Power Plants**," PSA 2023, Knoxville, TN, USA, July 15–20 (2023).

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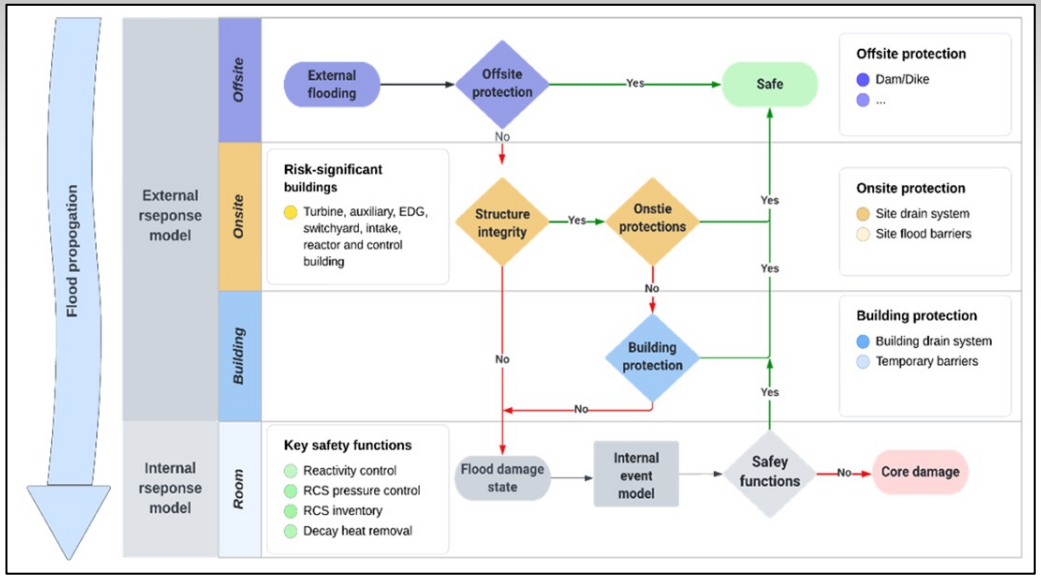

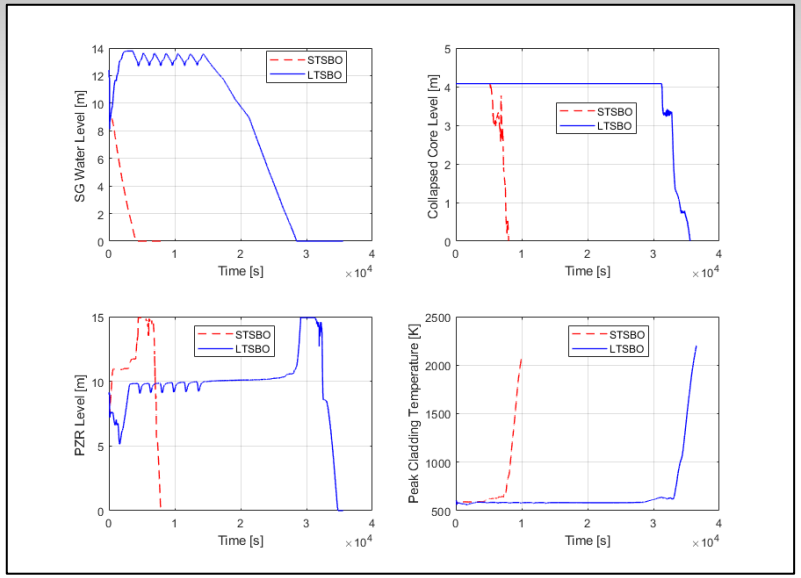

Event sequence	Short-term SBO (STSBO)	Long-term SBO (LTSBO)
External Flooding	Heavy rainfall and overtopping of nearby river dikes can cause external flooding of the plant site. Flood height may reach x feet above ground level, with a short duration of up to 24 hours.	Heavy rainfall and overtopping of nearby river dikes can cause external flooding of the plant site. Flood height may reach y feet above ground level, with a long duration exceeding 24 hours.
Onsite Flood protection system	Activated, including sandbags, temporary barriers, and pumps. However, the floodwaters breach the perimeter and inundate the plant site.	Activated, including sandbags, temporary barriers, and pumps. However, the floodwaters breach the perimeter and inundate the plant site.
Loss of Offsite Power	Floodwaters inundate the electrical switchyard, causing a loss of offsite power.	Floodwaters inundate the electrical switchyard, causing a loss of offsite power.
Loss of Onsite Power	Floodwaters breach the EDG building, and DG fails. Station Blackout SBO is initiated.	Floodwaters breach the EDG building, and DG fails. Station Blackout SBO is initiated.
Loss of Emergency Core Cooling System	Flood waters enter the turbine building, causing the Turbine Driven Auxiliary Feedwater Pump (TDAFWP) to fail due to flooding damage, leading to a loss of the ECCS.	Adequate flood protection of turbine building or lower flood heights prevented flooding of TDAFWP and allowed for the continued operation of ECCS.
Core damage	The fuel begins to heat up without cooling, and core damage occurs after x hours.	TDAFWP operates until DC batteries are depleted or fail due to flooding, and fuel eventually melts, causing core damage.

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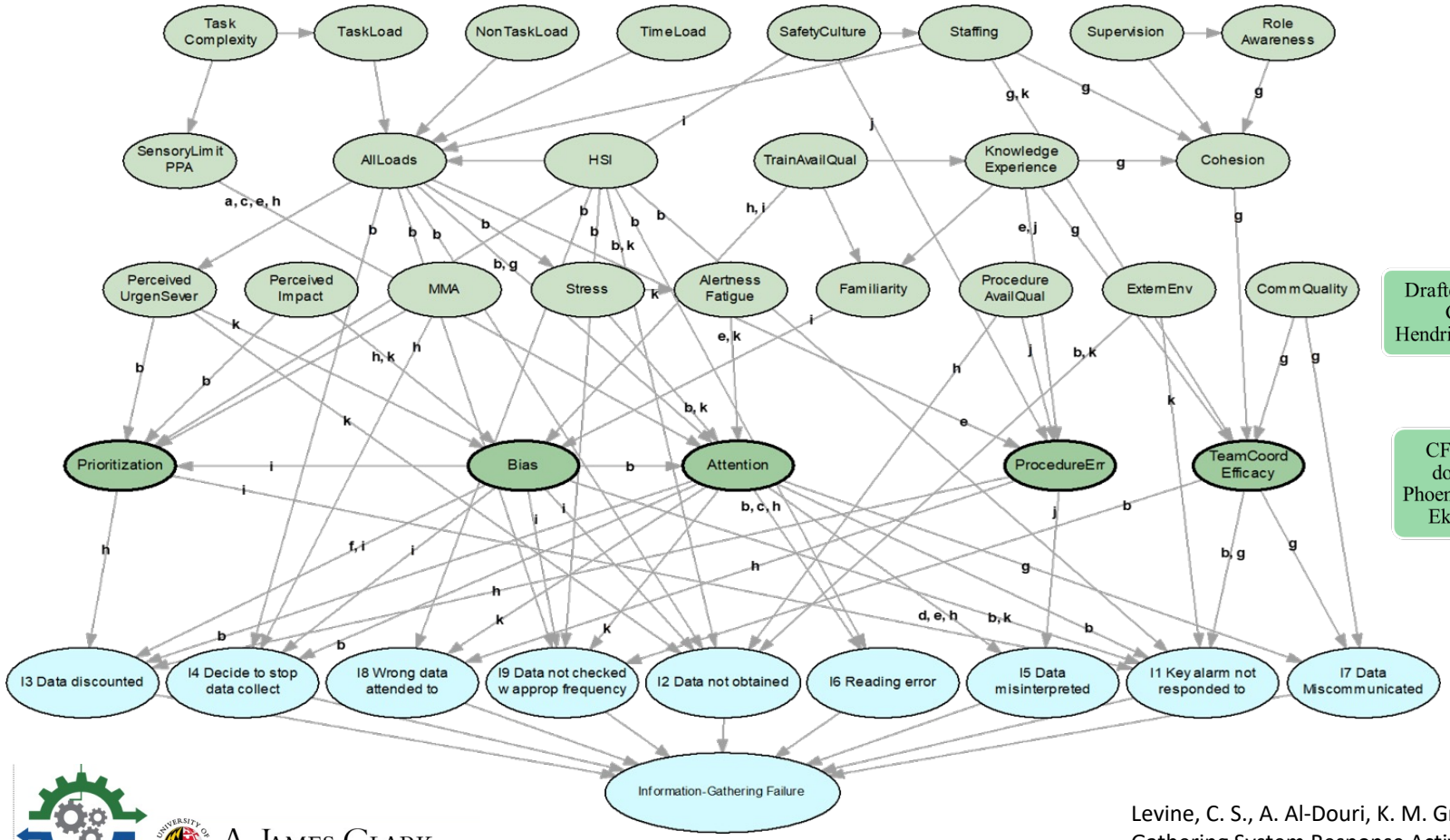
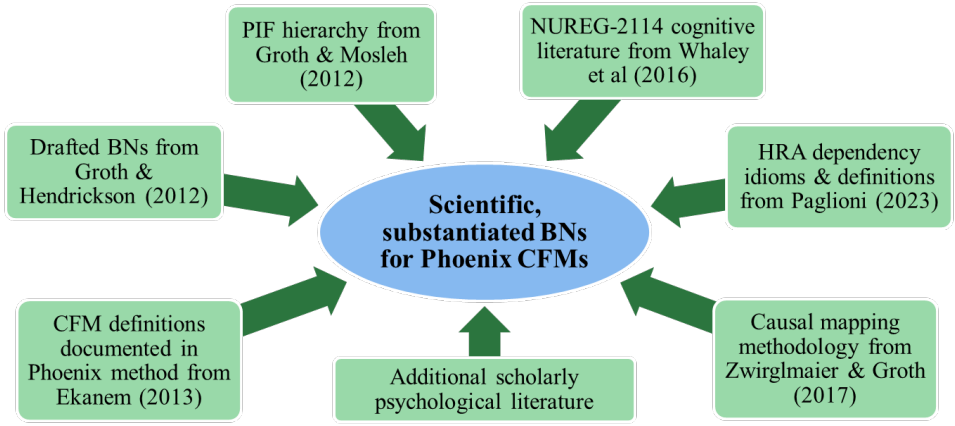
T. Liu, Z. Wu, M. Bensi, K. Groth, Z. Ma, and R. Schneider, "**Assessment of Uncertainty in Scenario Development for External Hazard Probabilistic Risk Assessment for Nuclear Power Plants**," PSA 2023, Knoxville, TN, USA, July 15–20 (2023).

Task 4: Characterization of Uncertainty in Human Response Under Physical Effects





SYRRA

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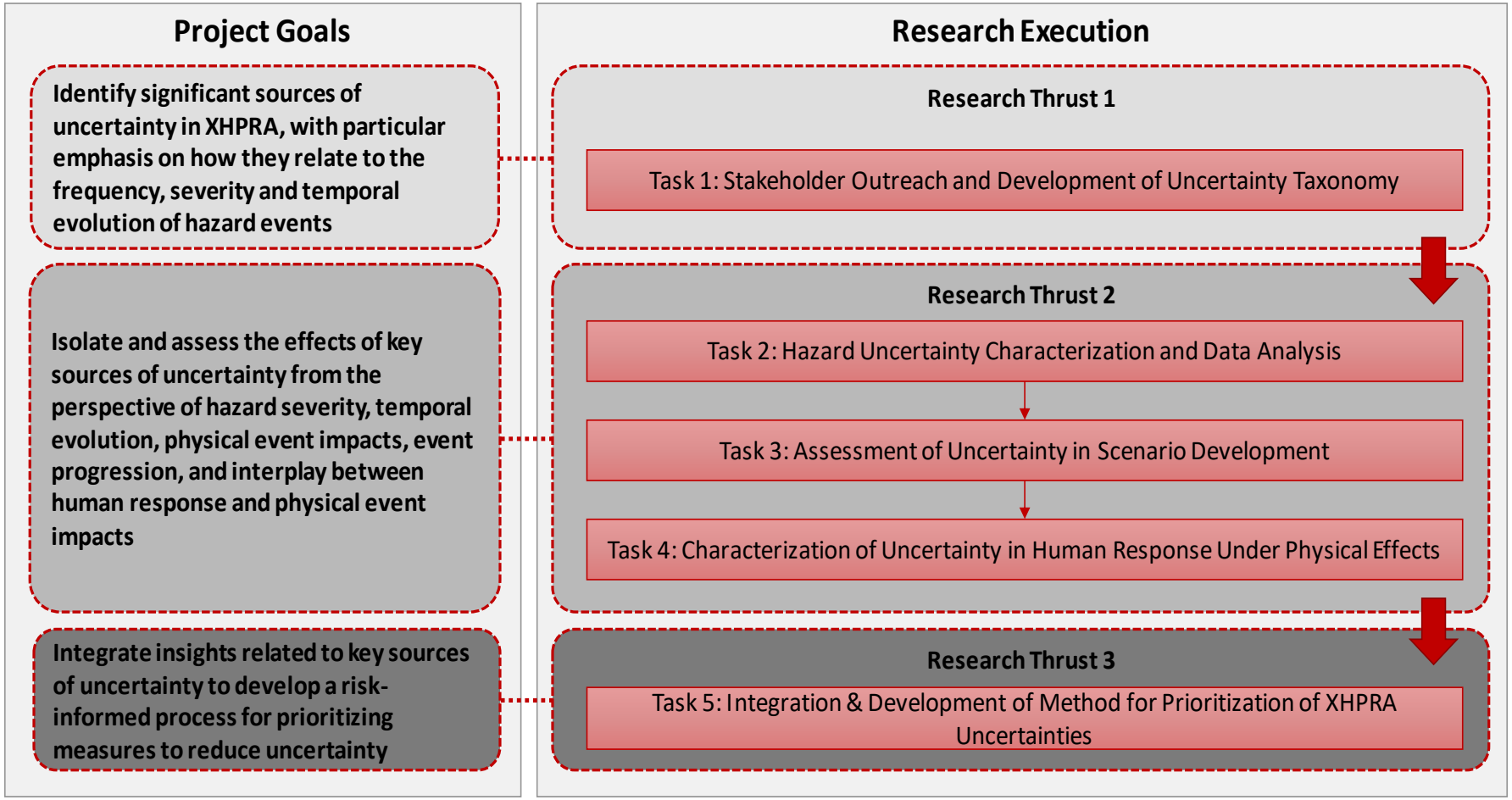
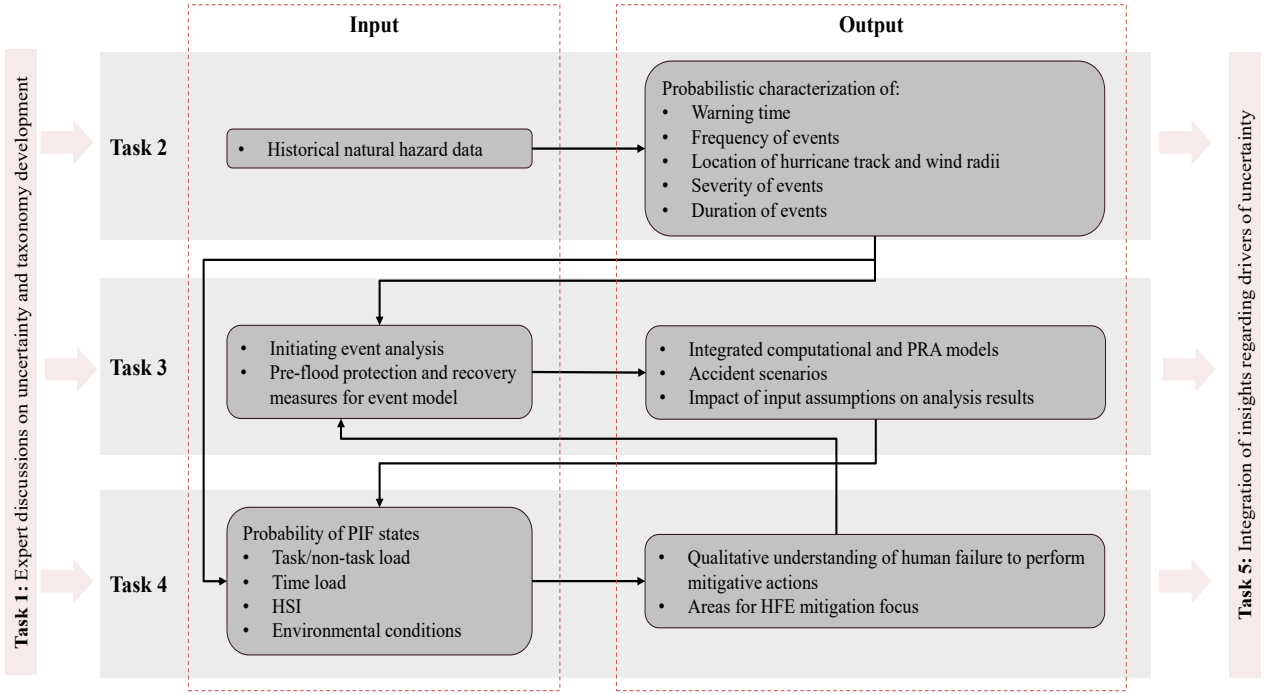
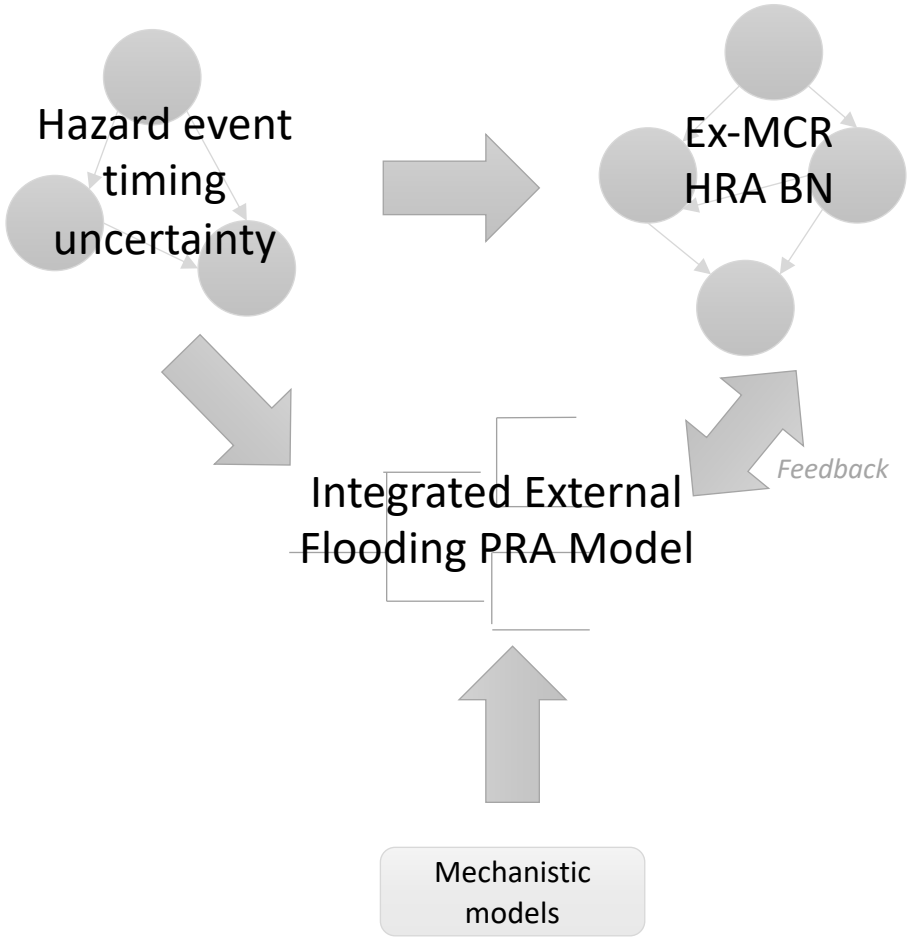
Levine, C. S., A. Al-Douri, K. M. Groth (2023) "Causal Pathways Leading to Human Failure Events in Information-Gathering System Response Activities" at 13th Nuclear Plant Instrumentation, Control, & Human-Machine Interface Technologies (NPIC&HMIT 2023), July 2023, Knoxville, TN.

Next Steps


Project Goals
Identify significant sources of uncertainty in XHPRA, with particular emphasis on how they relate to the frequency, severity and temporal evolution of hazard events
Isolate and assess the effects of key sources of uncertainty from the perspective of hazard severity, temporal evolution, physical event impacts, event progression, and interplay between human response and physical event impacts
Integrate insights related to key sources of uncertainty to develop a risk-informed process for prioritizing measures to reduce uncertainty
Research Execution
Research Thrust 1
Task 1: Stakeholder Outreach and Development of Uncertainty Taxonomy
Research Thrust 2
Task 2: Hazard Uncertainty Characterization and Data Analysis
Task 3: Assessment of Uncertainty in Scenario Development
Task 4: Characterization of Uncertainty in Human Response Under Physical Effects
Research Thrust 3
Task 5: Integration & Development of Method for Prioritization of XHPRA Uncertainties

Next Steps


Input
Output
Task 1: Expert discussions on uncertainty and taxonomy development
Task 2
Historical natural hazard data
Probabilistic characterization of:
Warning time
Frequency of events
Location of hurricane track and wind radii
Severity of events
Duration of events
Task 3
Initiating event analysis
Pre-flood protection and recovery measures for event model
Integrated computational and PRA models
Accident scenarios
Impact of input assumptions on analysis results
Task 4
Probability of PIF states
Task/non-task load
Time load
HSI
Environmental conditions
Qualitative understanding of human failure to perform mitigative actions
Areas for HFE mitigation focus
Task 5: Integration of insights regarding drivers of uncertainty


Hazard event timing uncertainty
Ex-MCR HRA BN
Feedback
Integrated External Flooding PRA Model
Mechanistic models

Contributors:

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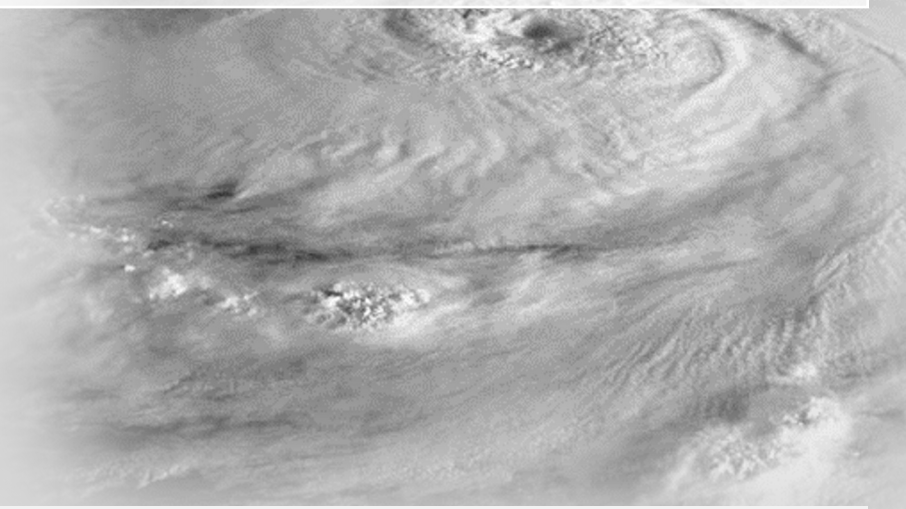
Questions?



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Any opinions, findings, and conclusions expressed in this paper/presentation are those of the authors and do not necessarily reflect the views of the funding agency or any other organization.

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