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Generative AI Agentic Architecture for Nuclear Safety Analysis

18th International Probabilistic Safety Assessment & Management (PSAM) Conference

Pittsburgh, PA

July 19-24, 2026

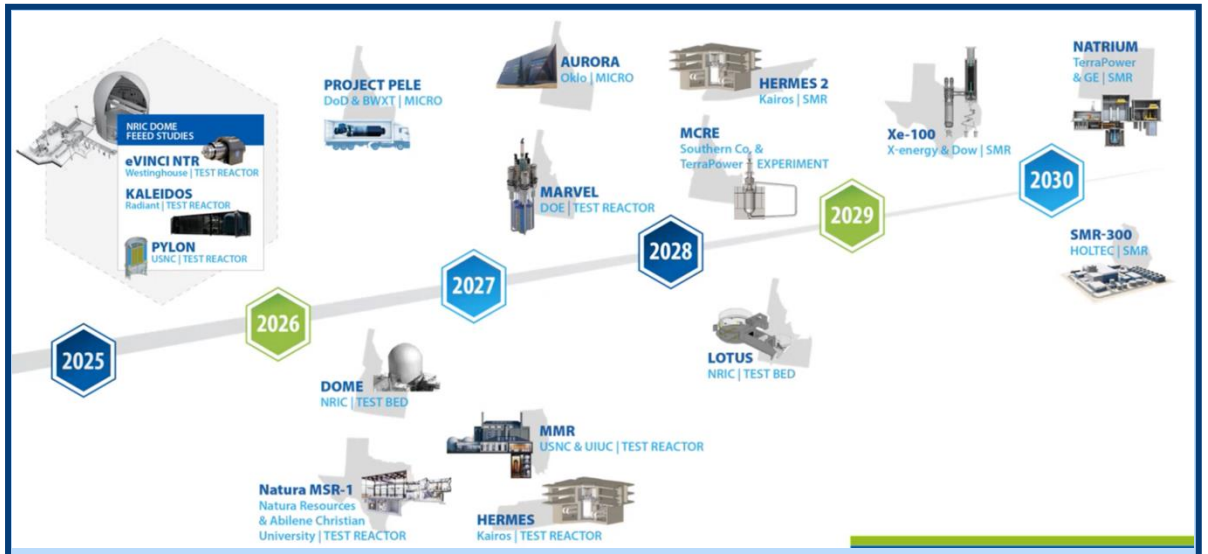
INL/CON-26-90373

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

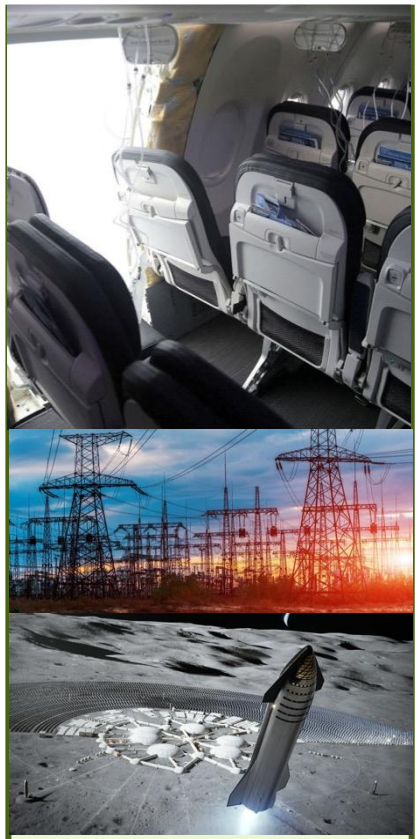
Idaho National Laboratory

Motivation

- Safety analysis is used extensively in existing nuclear power plants
- Trusted across the nuclear stakeholders including designers, operators, regulators, and researchers

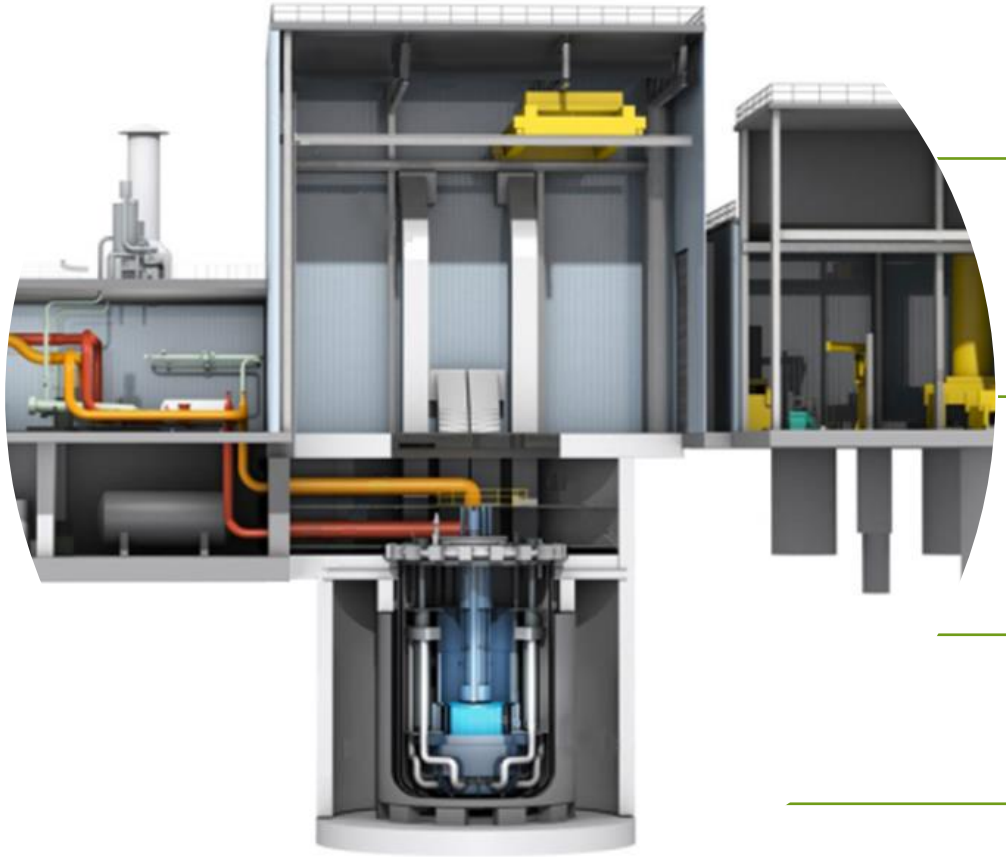


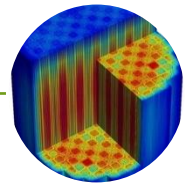
- Safety analysis is needed across advanced reactors
- ARs have novel attributes affecting safety analysis: design, fuel, location, application etc.
- Will require efficient approaches for safety and licensing processes



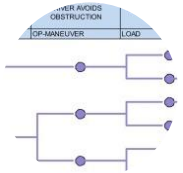
Other safety-critical applications

Elements of Nuclear Safety Analysis



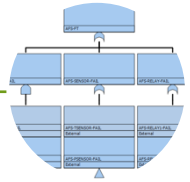


Physics-based Analysis



Accident Sequence Analysis

Failure Modes and Effects Analysis



Fault Tree Creation and Analysis

Safety Analysis Report Creation

Nuclear Safety Analysis Process

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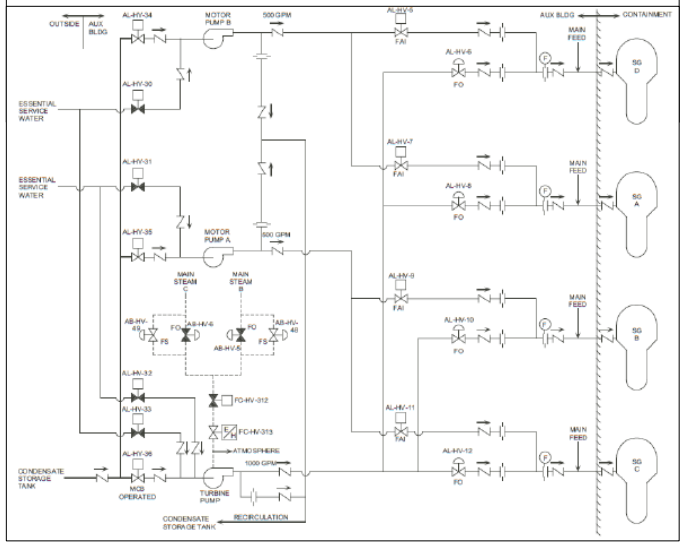
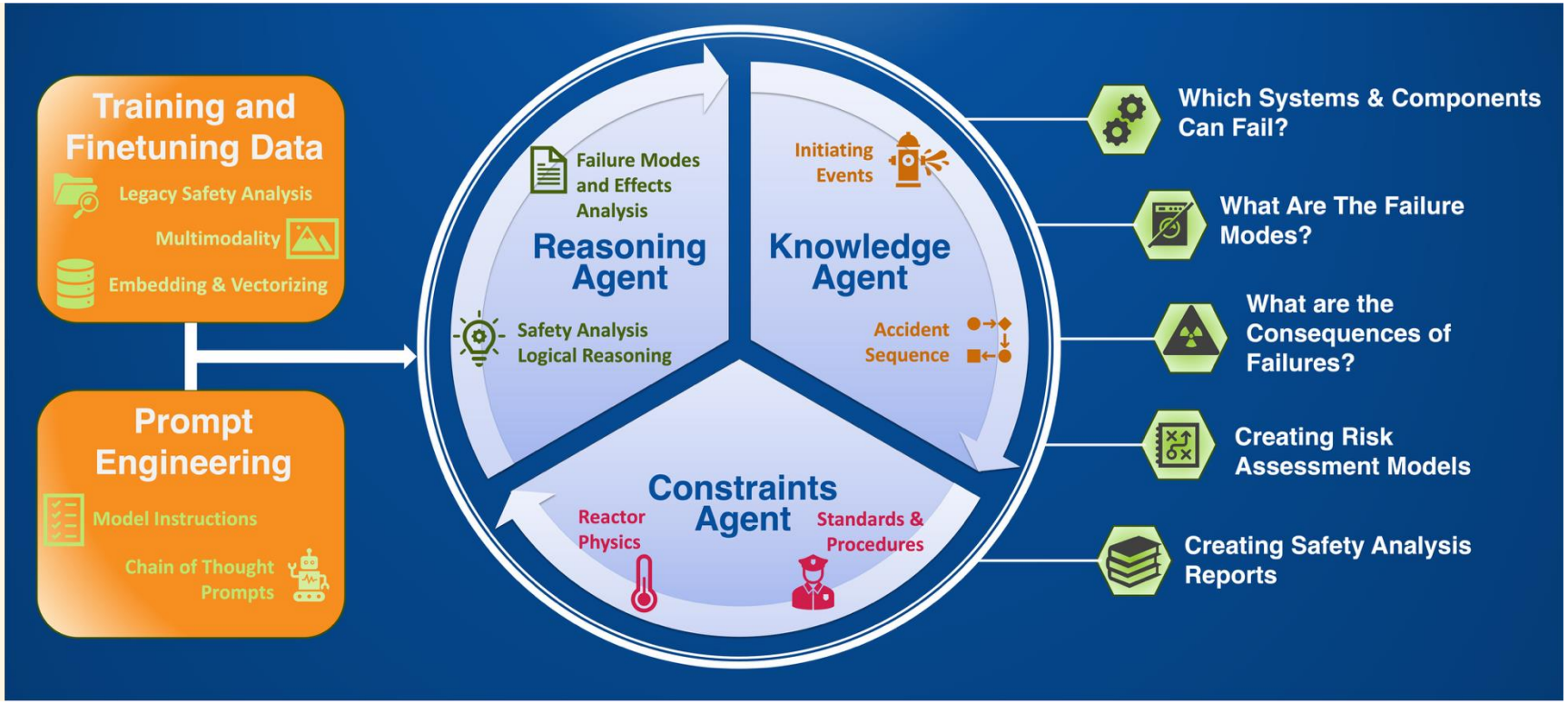


- What can fail?
- How can it fail?
- What are the consequences?
- How likely is the failure?
- What are the interconnectivity and dependencies between failures?
- Creating risk assessment models
- Creating safety analysis report

AEGIS Architecture Overview

AEGIS

AGENTIC ENGINE FOR
GENERATIVE INTELLIGENCE IN SAFETY



AEGIS: Key Tasks

Processing Legacy Data

- Nuclear specific legacy documentation
- "A Comparative Study of PRA Methodologies for Light-Water and Advanced Reactors"

Knowledge Extraction from Multimodal Input Data

- Knowledge Graph Creation
- P&ID Digitizer Tool

Knowledge Integration and Synthesis

- Performing Failure Modes and Effects Analysis
- Creating PRA models
- “Designing Generative AI Agents for Structured Nuclear Safety Analysis”

Verification and Validation of AI Output

- Developing automated algorithms for output verification
- Integrating verification feedback with model inputs for performance improvement

AEGIS

AGENTIC ENGINE FOR GENERATIVE INTELLIGENCE IN SAFETY

Agent Interface

File uploaded successfully: **AFW.pdf**

Summarizing the user uploaded document

PDF Summary

The primary purpose of this system is to remove heat from the reactor coolant system and convert it into electrical power. The described system comprises the steam generators, turbine-generator, condenser, and various feedwater and moisture separation components. Safety is maintained through automatic reactor scram during turbine trips and the utilization of turbine bypass and atmospheric relief valves for energy removal. Additionally, spring-loaded safety valves on the main steam lines provide overpressure protection to manage energy generated during a reactor trip.

Using **System Name** from Settings: **Auxiliary Feedwater System**.

Perform FMEA

Agent Interface

Completed System Analysis for "Auxiliary Feedwater System"

System Overview

The FMEA for **Auxiliary Feedwater System** identified **Provide emergency and transient feedwater to steam generators** as the main function. It contains **3** functional nodes, **9** configuration nodes, **17** system nodes, and **32** component nodes. It captures **32** failure mode nodes across the modeled hierarchy. It includes **2** credited human or recovery action nodes. Under the analyzed initiating-event context, **35** nodes are marked unavailable or impacted. Use the download, upload, and continue options below to review or refine the structured output before proceeding.

Agent Interface

⏳ Generating fault tree logic (FTL)

FTL generated (preview below):

```
PWR, AFS =
AFS-FT                    OR   AFS-FT-1 AFS-FT-2 AFS-FT-3
AFS-FT-1                  AND  AFS-MDP-1 AFS-MDP-2 AFS-MDP-3
AFS-FT-2                  AND  AFS-TNK-1 AFS-CKV-1 AFS-PUMP-1
AFS-FT-3                  OR   AFS-LOOP-1 AFS-LOOP-2 AFS-LOOP-3
AFS-MDP-1                 OR   AFS-MDP-CF-ALL AFS-MDP-FAIL-1 AFS-
MDP-FAIL-2
AFS-MDP-2                 OR   AFS-CTR-FAIL-1 AFS-CTR-FAIL-2 AFS-CTR-
FAIL-3
AFS-MDP-3                 OR   AFS-DG-FAIL-1 AFS-DC-FAIL-1
AFS-TNK-1                 OR   AFS-TNK-LOW-LVL AFS-TNK-ISOL-FAIL AFS-
SUCT-STR-PLUG
AFS-CKV-1                 OR   AFS-CKV-CC-001 AFS-CKV-CF-001 AFS-
```

Type your message here...

Agent Interface

Generating fault tree logic (FTL)

FTL generated (preview below):

```
PWR, AFS =
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MDP-FAIL-2
AFS-MDP-2               OR   AFS-CTR-FAIL-1 AFS-CTR-FAIL-2 AFS-CTR-
FAIL-3
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SUCT-STR-PLUG
AFS-CKV-1               OR   AFS-CKV-CC-001 AFS-CKV-CF-001 AFS-
```

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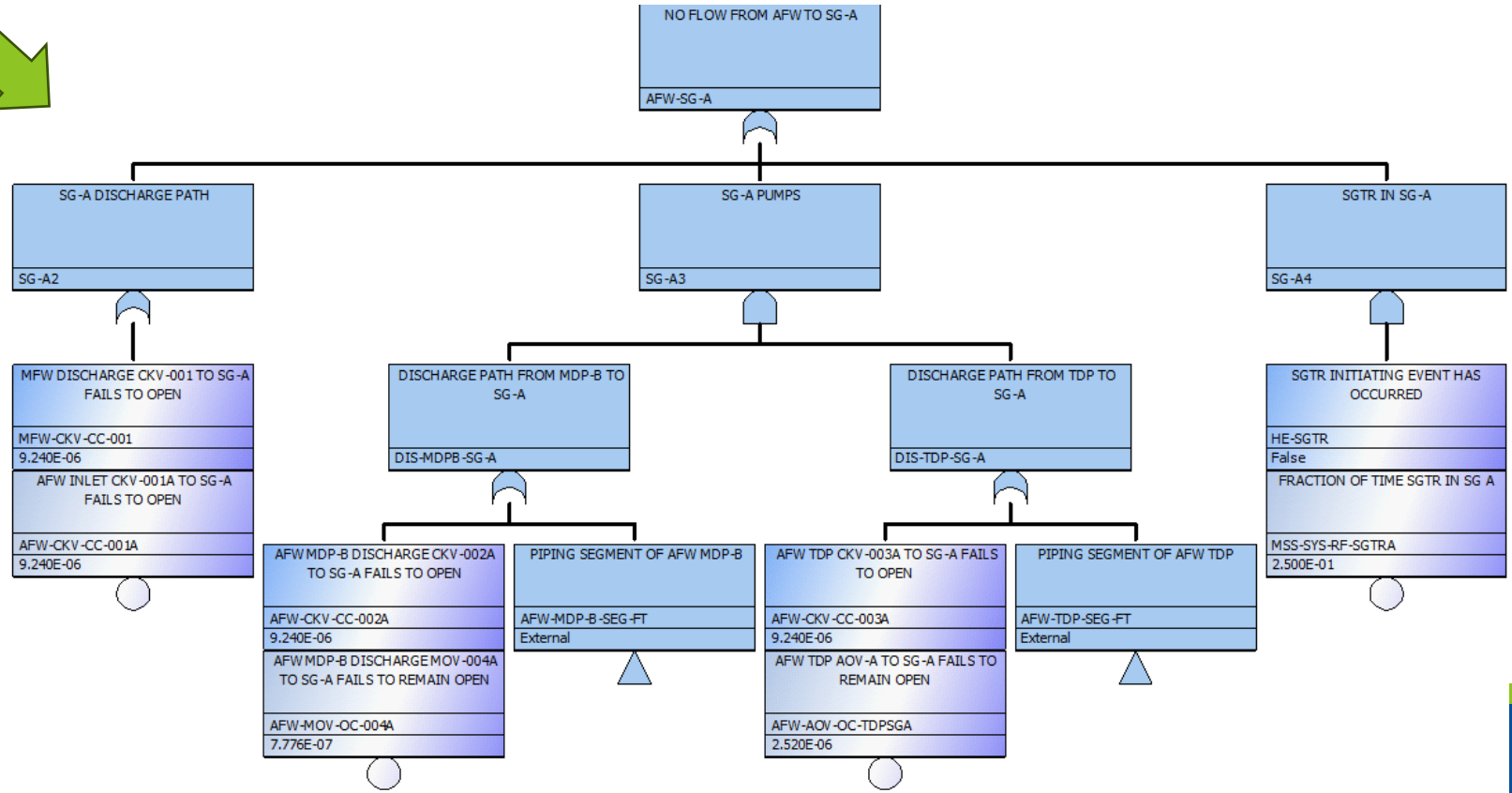
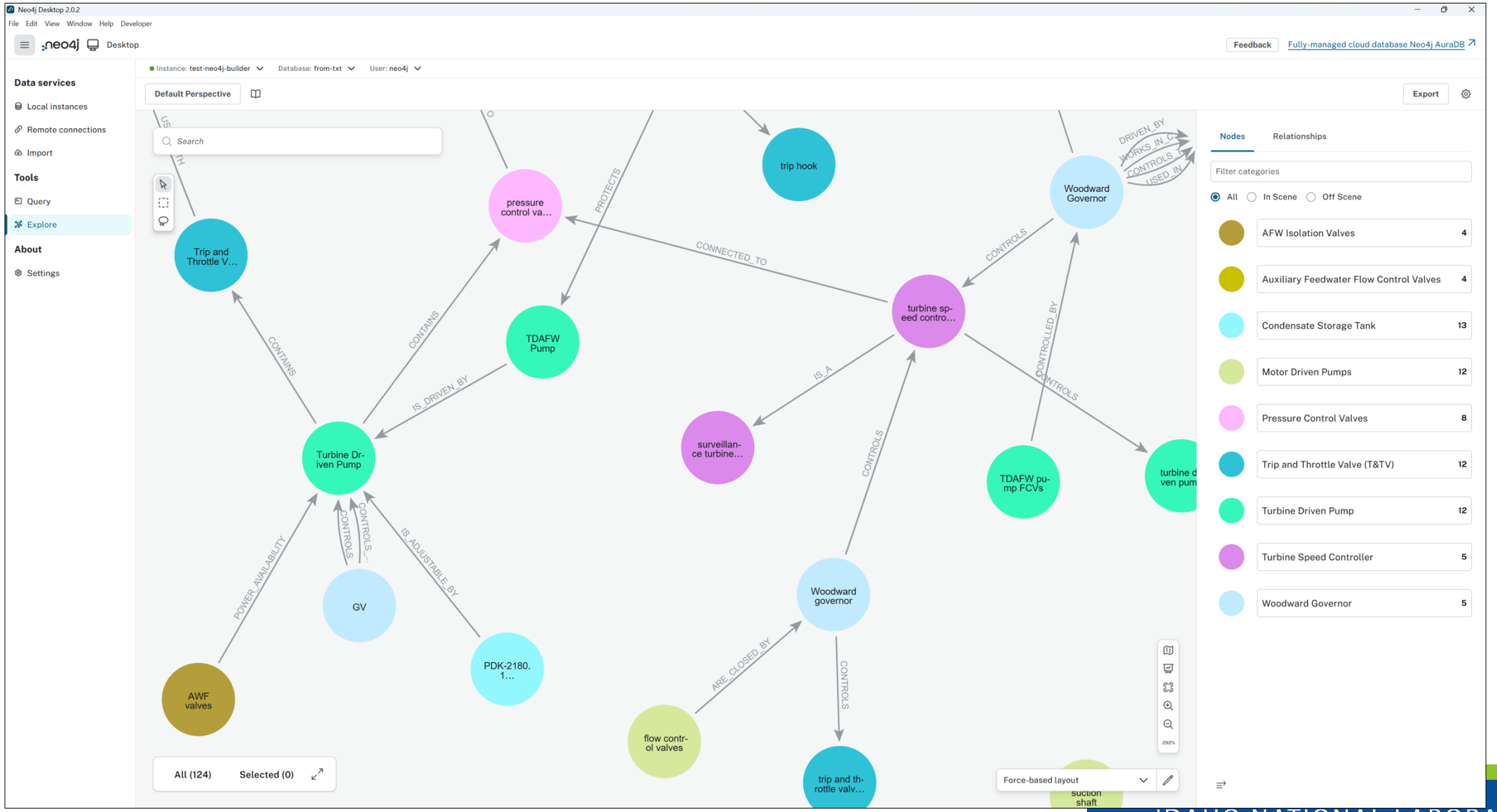
SAPHIRE

Systems Analysis Programs for Hands-On Integrated Reliability Evaluations



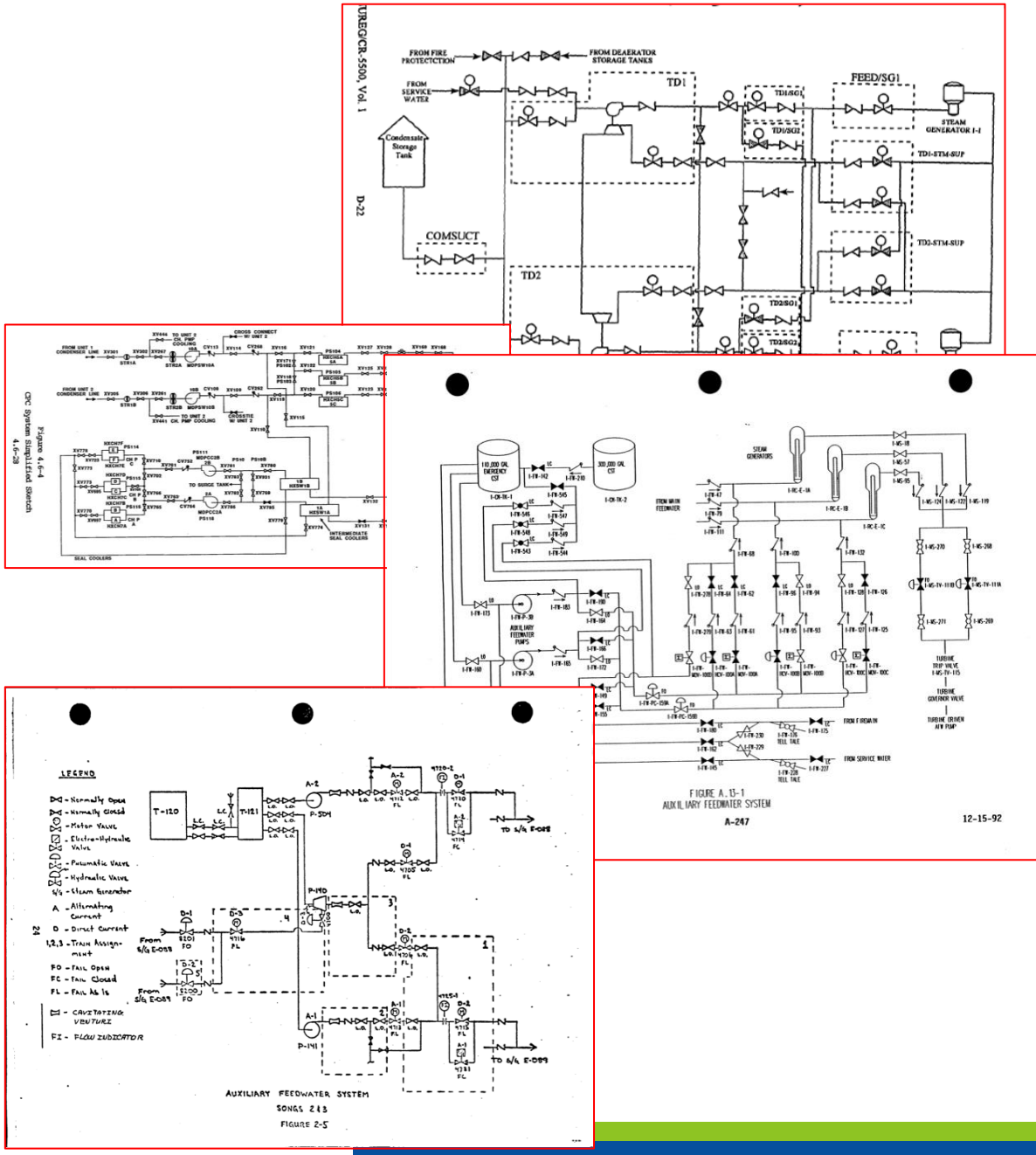
Safety Analysis Knowledge Graph



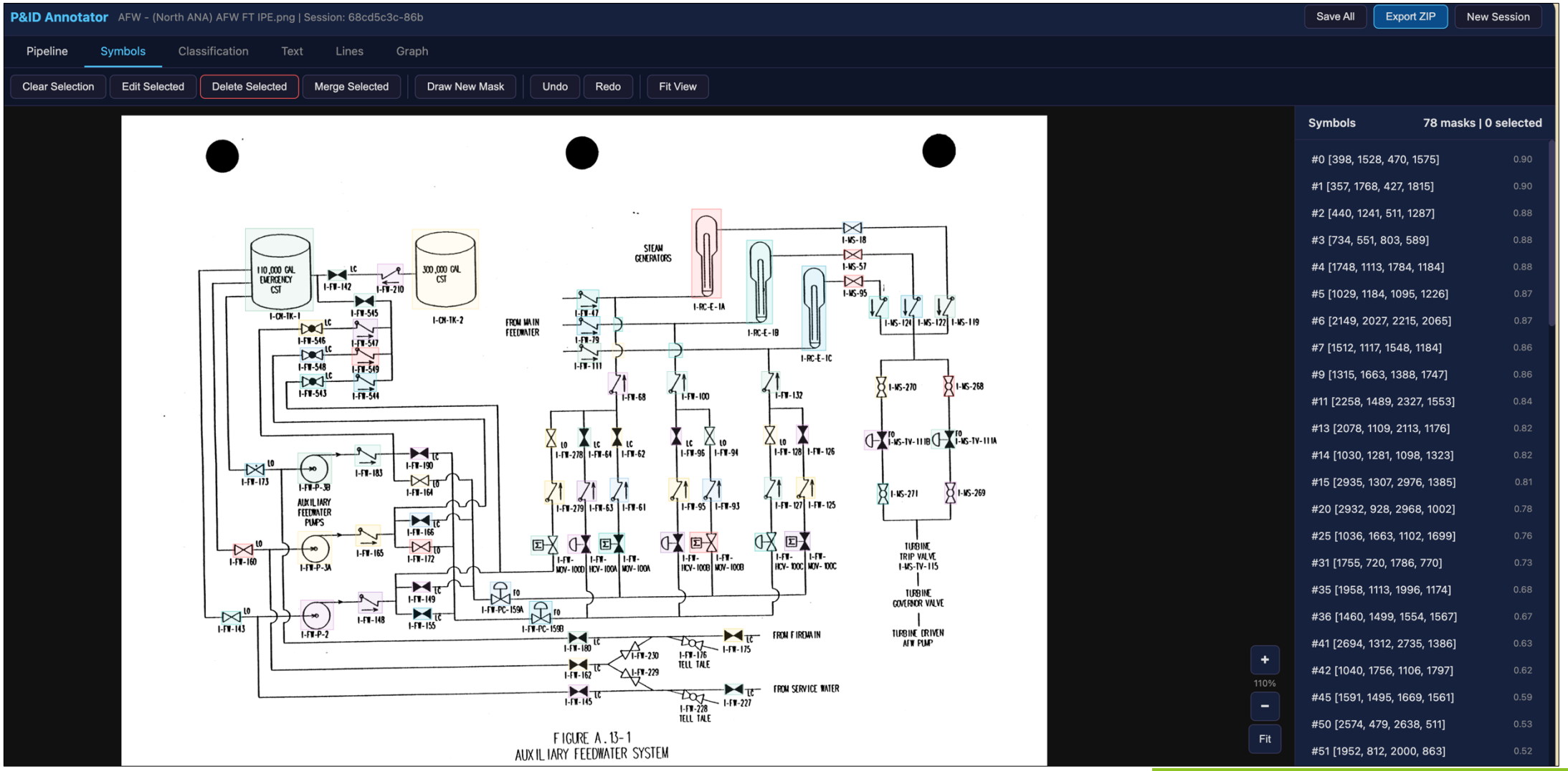
P&ID Digitizer

Motivation

- P&ID contain wealth of information about system design, sub-system, components, coolant flow direction, interconnectivity etc.
- Nuclear industry deals with thousands of legacy P&IDs
- Legacy P&IDs in nuclear are from scanned documents, hence low resolution
- Low-res P&IDs are hard for existing tools to digitize and process inherent information



P&ID Digitizer



Future Work

- Developing real time agent to agent interface with external agents
- Rigorous V&V approaches specific to fault trees
- Standalone agentic tool which can be used by AR vendors

Team

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