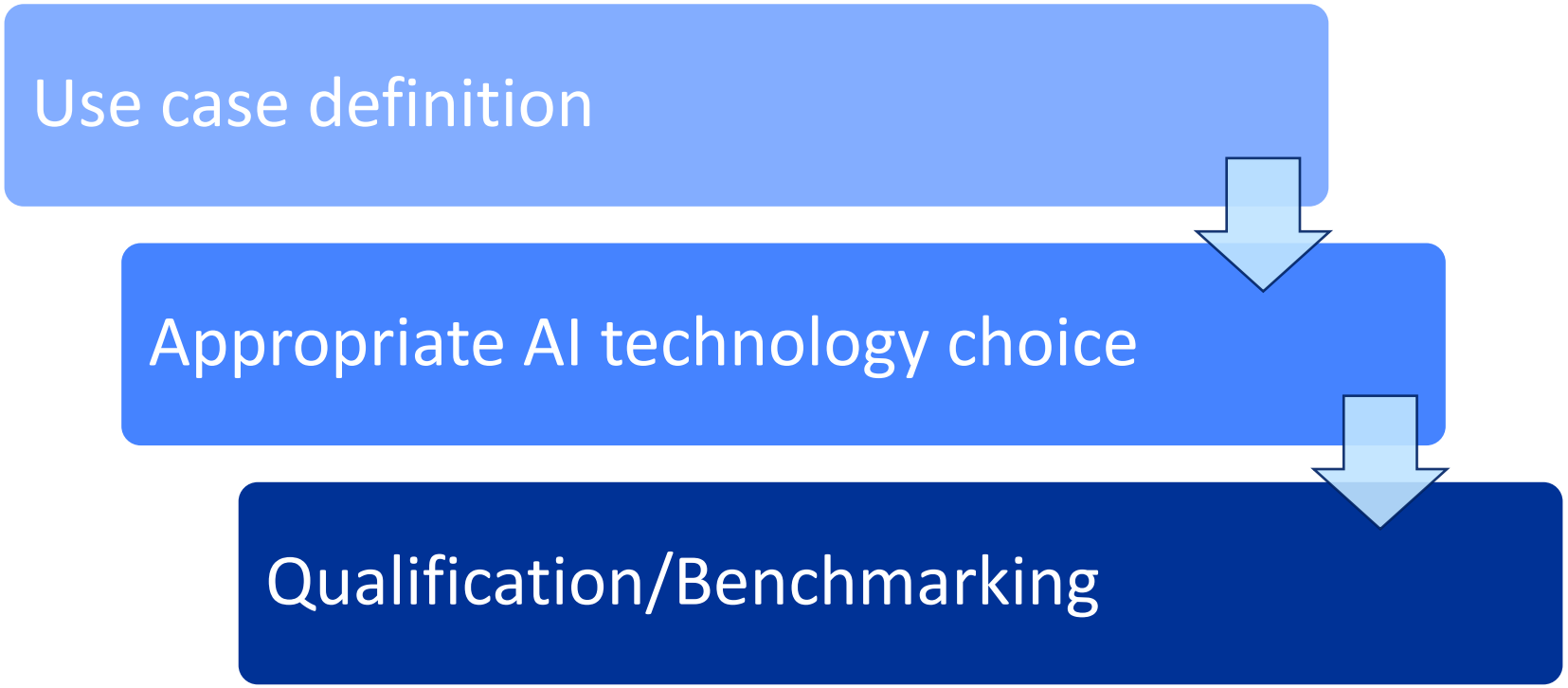
Applying AI in the Nuclear Industry

Perspective of the Electric Power Research Institute (EPRI)

Agnieszka Czeszumska, PhD
Senior Technical Leader
EPRI Europe DAC

IAEA General Conference
September 18th, 2025

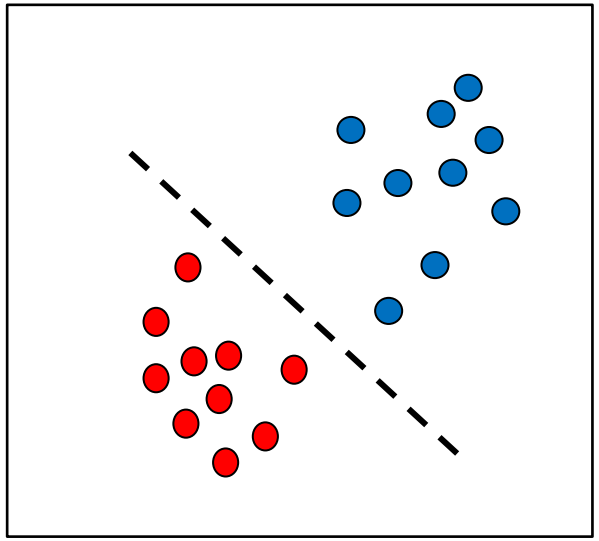
If AI is the answer, what is the question?



Possibly an iterative process

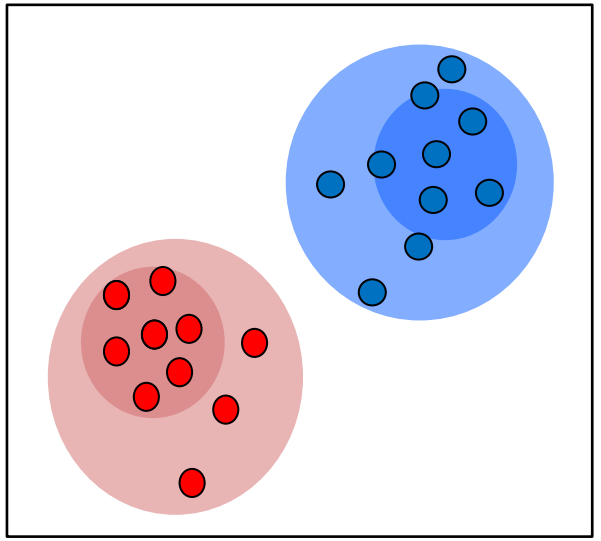
Discriminative vs. Generative AI

Discriminative AI



- Discrete boundaries
- Learn conditional probabilities to distinguish between classes effectively
- Examples:
  - Linear regression
  - Decision trees
  - Statistical NLP
  - Object detection

Generative AI



- Probabilities in space; learn data distribution to create new, contextually relevant content similar to training data
- Versatile but computationally intensive and harder to pinpoint accuracy
- Examples:
  - Diffusion models
  - Large Language Models

Select use cases applicable in nuclear safety

Discriminative AI

Nondestructive Evaluation (NDE)

- Concrete Defect Detection Tool for aerial drones
- Acoustic Emission sensor for steel cracking background reduction
- Ultrasonic Testing

Automation in monitoring

- Analog Gauge Reader

Generative AI

Large Language Model-powered expert systems

- Troubleshooting Chatbot
- Decommissioning Knowledge Management

NILLM: Nuclear Industry Large Language Model

- In collaboration with INPO and NEI

LLM used in data extraction

- Part 21 reports data extraction

Automated Analog Gauge Reader

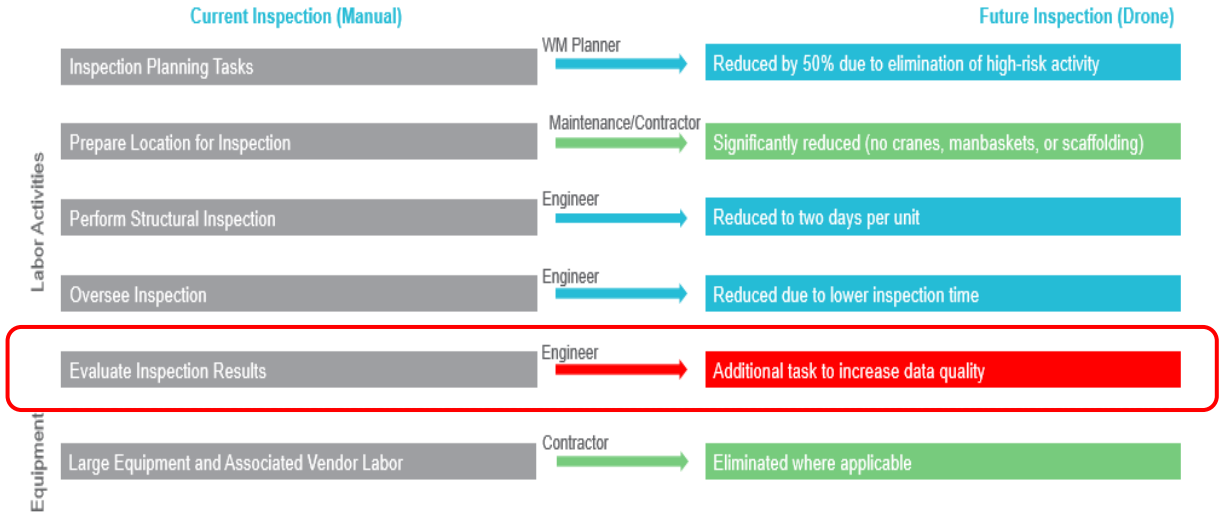
Automated Analog Gauge Reader: Benchmarking and Python Source Code (3002021055)

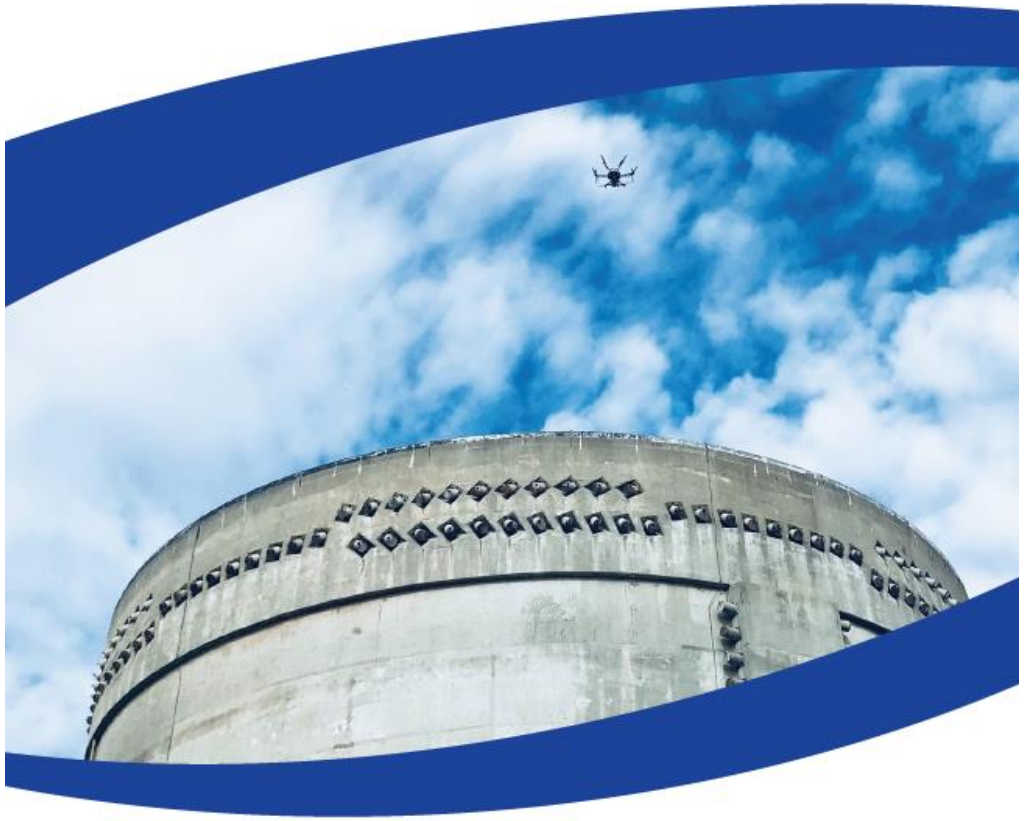
- Provides a methodology to infer readings of analog gauges from images
  - Multiple gauges with same hardware
  - Does not obscure gauge
- It can be deployed to automate monitoring and replace walkdowns

Contact Christine Lee if interested in field implementation

Remote Visual Inspections with Unmanned Aerial Systems

- Benefits during data collection
  - Saves time, reduces costs, increases safety
  - Provides better inspection data record
- Increased burden on analysis
  - Large quantity of monotonous images or videos
- From BCAM (3002021027) & UAS User's Guide for NPPs (3002020913):





Leverage Machine Vision to assist in analysis

Concrete Defect Detection

Automation

Upload Images

Set Thresholds

Create Dataset

Evaluate

View Results

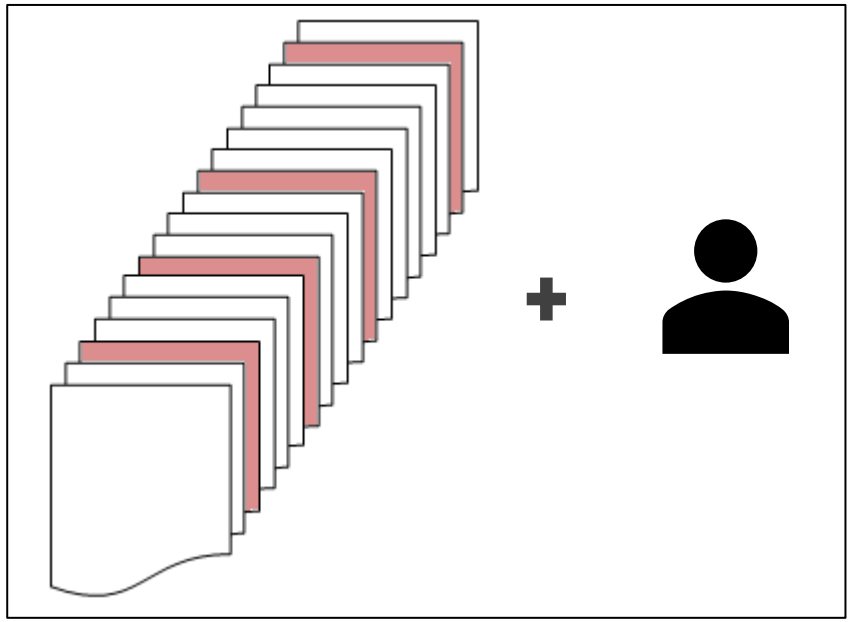
AI-Assisted Analysis of UT Inspections

- UT inspections are an important part of the scope of an NDE program
- Some inspections are challenging or have large volumes of data
- Machine learning tools can potentially **assist** in the analysis of the data
  - Increase reliability
  - Decrease analysis time
- *Assist* means AI flags regions for review: final decisions still rest with the qualified inspector.

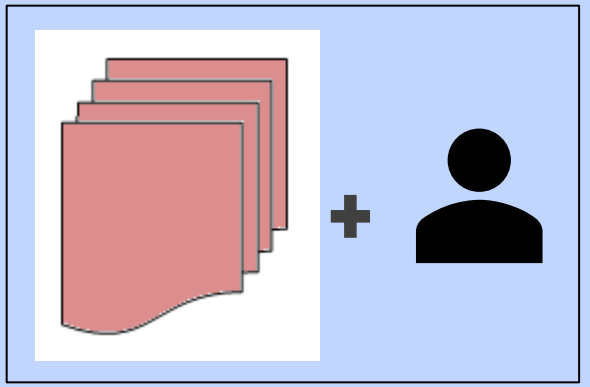
***Goal:* Develop auto-analysis tools to assist in UT inspections**

How Would AI Assist in UT Inspections?

- Current Inspection
  - Examiners distribute their energy across a high volume of (mostly benign) data

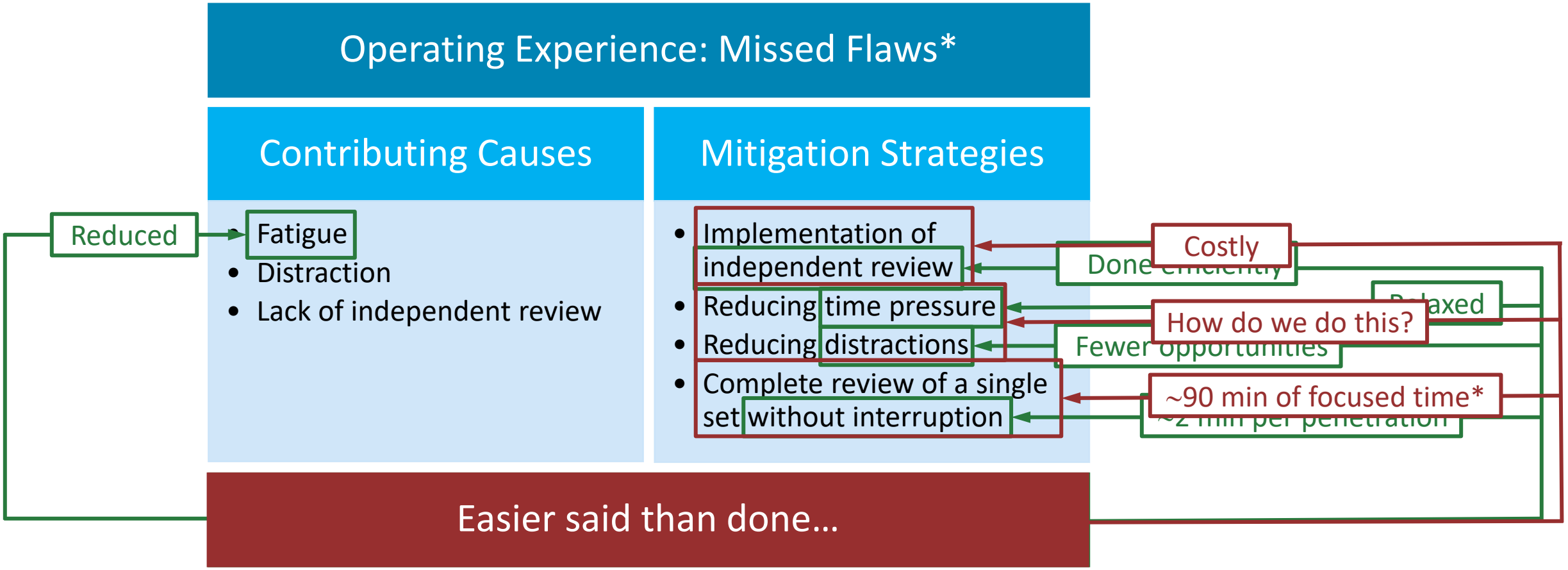


- AI Assisted Inspection
  - Examiners focus their energy on the regions that require more careful review



Value in Perspective: Faster, Focused Data Analysis

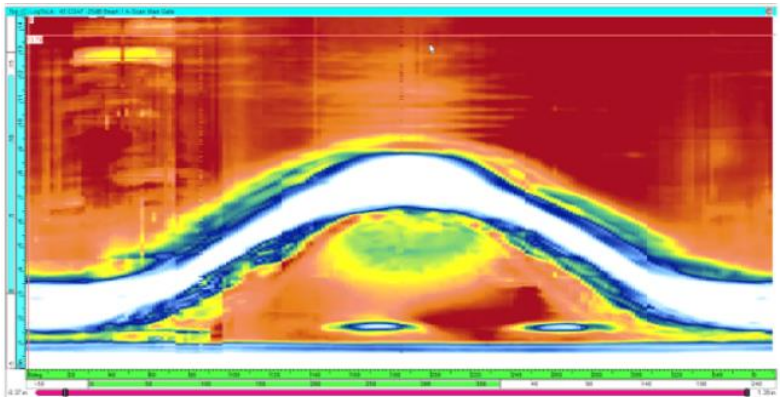
Case in Point: Human Factors

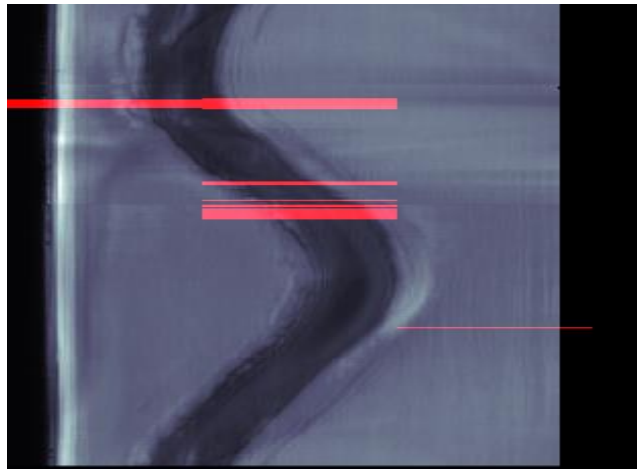


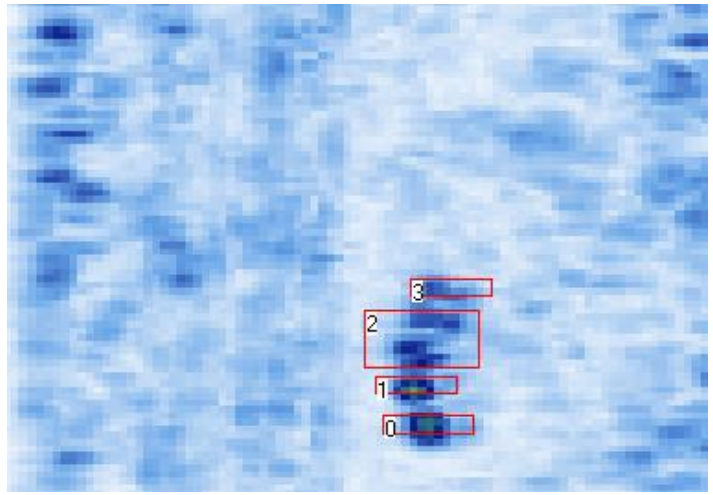
* T. Sanquist, S. Morrow, J. Harrison, C. Nove. *Human Factors in Nondestructive Evaluation*. NUREG/CR-7295 PNNL-32505 (ML22083A071)

AI-Assistance enables implementation of identified error mitigation strategies

Deployment







1 UT data is saved in ML Box through local connection

2 Box automatically detects and processes UT data…

3 … and generates output for review

All data remains local; no SW needed

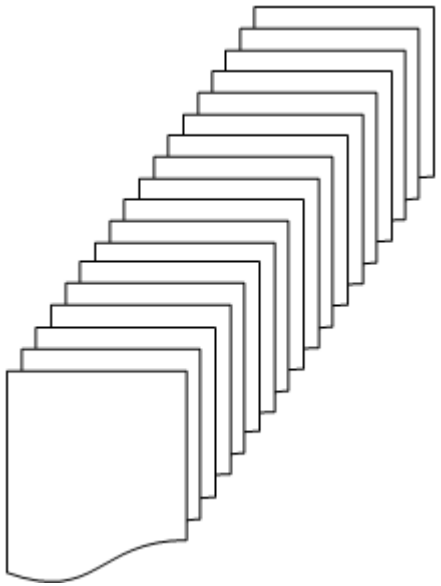
Qualification Prospects

- Looking at this as a “procedure” type:
  - Model should flag **all flawed regions** for review by inspector in “personnel” qual
  - Inspector has opportunity to detect all flaws
- Model was exposed to more than **5x** the amount of PDI data required for a traditional procedure qualification
  - Model accurately flagged flawed regions
    - Craze cracking
    - Axial, circ and off-axis oriented flaws
    - Small and large thru wall flaws
    - ID and OD surface connected

All observations point to AI being qualifiable when paired with human analyst

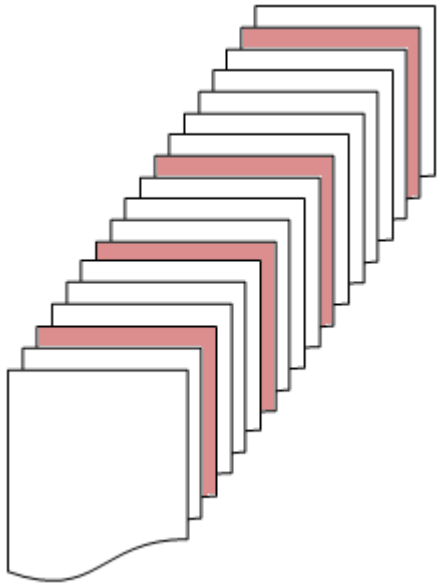
What initial qualification *may* look like

- Procedure would be updated to include a defined process for the AI evaluation
- AI algorithms for qualification would be developed and provided to the qualification body: model is **frozen** at this stage



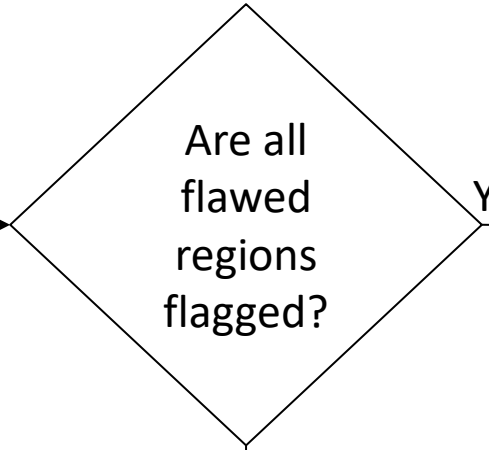
Pre-recorded data

AI model is applied

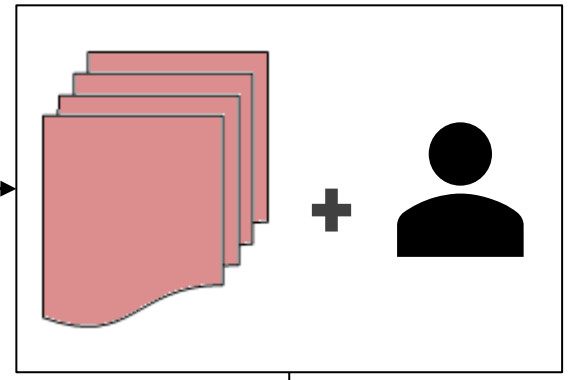


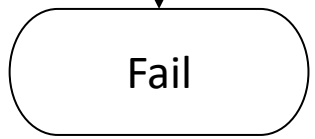
AI flags areas for review

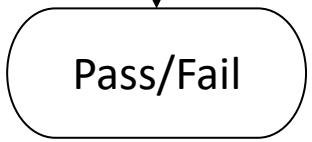
Qualification Body Determination



Candidate reviews flagged areas and makes calls







Based on typical detection + false call criteria

All observations point to AI being qualifiable when paired with human analyst

AI for Acoustic Emission NDE

- Current AE sensors are not robust against environmental noise.
- Could AE crack detection be improved with AI?
- As part of the project, data will be collected at the Charlotte Labs on various types of environmental noise, Pencil Lead Break tests, and real cracking.

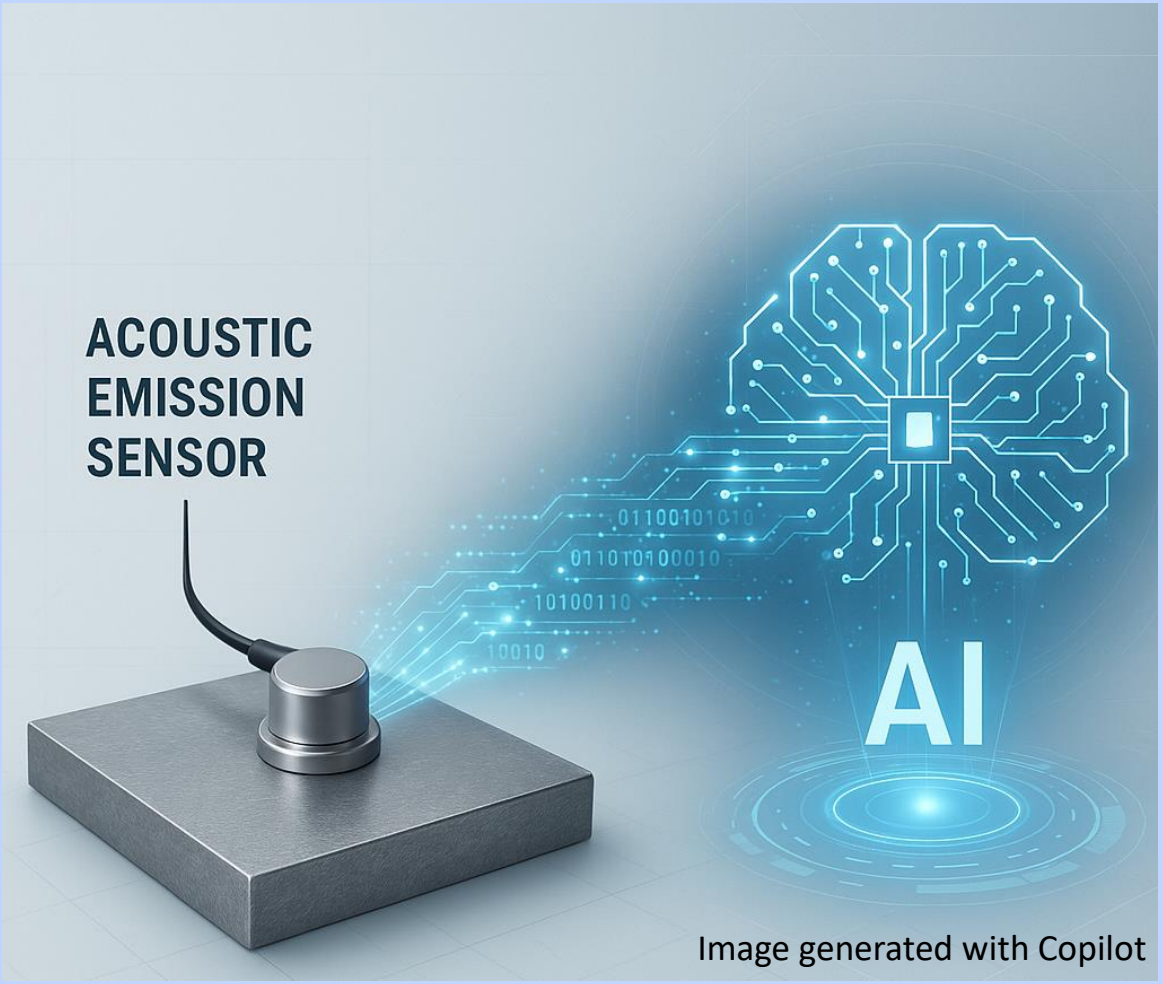
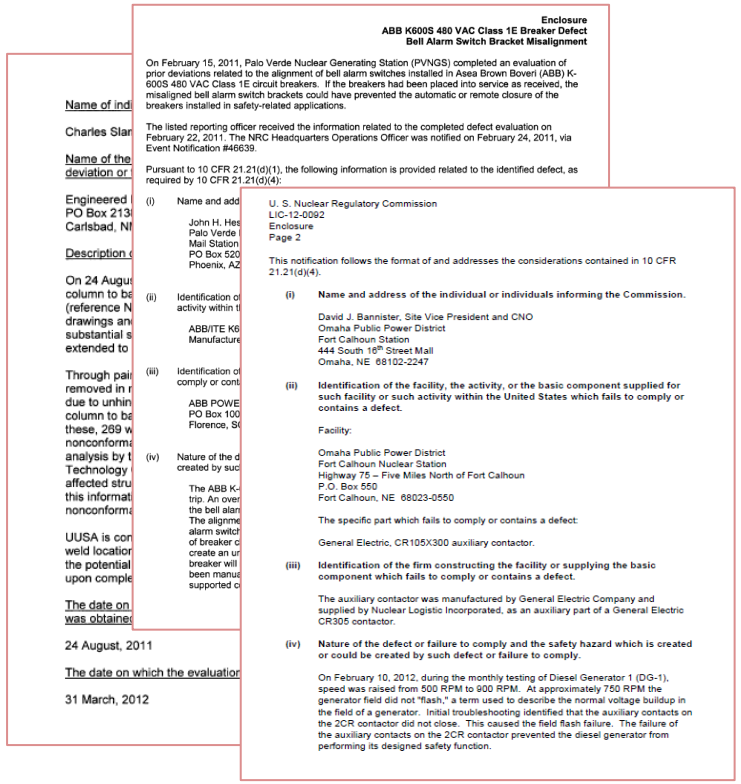


Image generated with Copilot

LLM Projects

Part 21 Reporting of Defects and Noncompliance

- Part 21 reports are submitted to the NRC. These reports are required when a licensed facility, activity, or basic component contains defects or failures to comply with NRC regulations that could create a substantial safety hazard.
- 1000's of reports from NRC website in pdf format are difficult to parse through and search for relevant information quickly



Enclosure
ABB K600S 480 VAC Class 1E Breaker Defect
Bell Alarm Switch Bracket Misalignment

On February 15, 2011, Palo Verde Nuclear Generating Station (PVNGS) completed an evaluation of prior deviations related to the alignment of bell alarm switches installed in Asea Brown Boveri (ABB) K-600S 480 VAC Class 1E circuit breakers. If the breakers had been placed into service as received, the misaligned bell alarm switch brackets could have prevented the automatic or remote closure of the breakers installed in safety-related applications.

The listed reporting officer received the information related to the completed defect evaluation on February 22, 2011. The NRC Headquarters Operations Officer was notified on February 24, 2011, via Event Notification #46639.

Pursuant to 10 CFR 21.21(d)(1), the following information is provided related to the identified defect, as required by 10 CFR 21.21(d)(4):

(i) Name and add

John H. Hes
Palo Verde
Mail Station
PO Box 520
Phoenix, AZ

(ii) Identification o
activity within t

ABB/ITE K6
Manufacture

(iii) Identification o
comply or cont

ABB POWE
PO Box 100
Florence, S

(iv) Nature of the d
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Charles Slar

Name of the
deviation or

Engineered
PO Box 213
Carlsbad, NI

Description

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The date on
was obtaine

24 August, 2011

The date on which the evaluatior

31 March, 2012

U. S. Nuclear Regulatory Commission
LIC-12-0092
Enclosure
Page 2

This notification follows the format of and addresses the considerations contained in 10 CFR 21.21(d)(4).

(i) Name and address of the individual or individuals informing the Commission.

David J. Bannister, Site Vice President and CNO
Omaha Public Power District
Fort Calhoun Station
444 South 16th Street Mall
Omaha, NE 68102-2247

(ii) Identification of the facility, the activity, or the basic component supplied for such facility or such activity within the United States which fails to comply or contains a defect.

Facility:

Omaha Public Power District
Fort Calhoun Nuclear Station
Highway 75 – Five Miles North of Fort Calhoun
P.O. Box 550
Fort Calhoun, NE 68023-0550

The specific part which fails to comply or contains a defect:

General Electric, CR105X300 auxiliary contactor.

(iii) Identification of the firm constructing the facility or supplying the basic component which fails to comply or contains a defect.

The auxiliary contactor was manufactured by General Electric Company and supplied by Nuclear Logistic Incorporated, as an auxiliary part of a General Electric CR305 contactor.

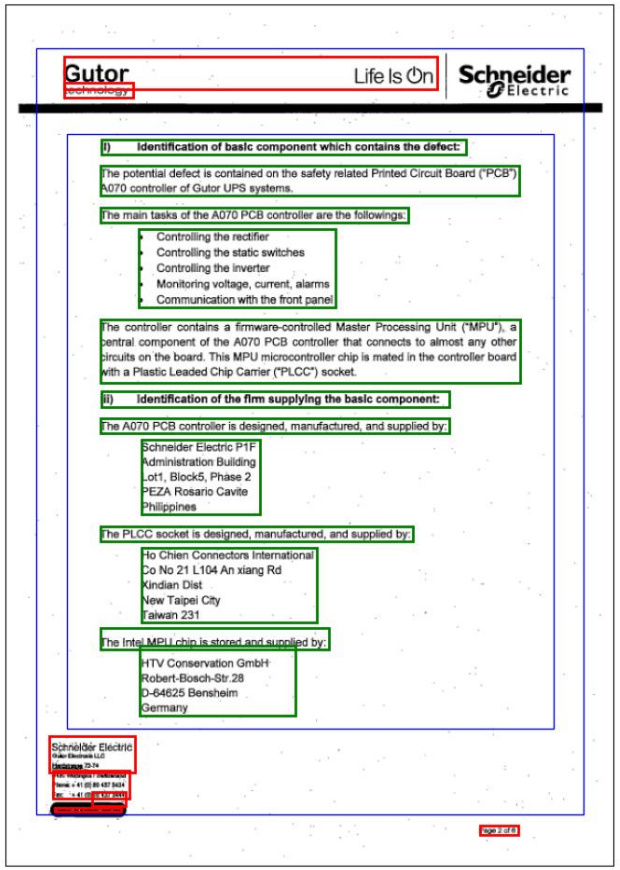
(iv) Nature of the defect or failure to comply and the safety hazard which is created or could be created by such defect or failure to comply.

On February 10, 2012, during the monthly testing of Diesel Generator 1 (DG-1), speed was raised from 500 RPM to 900 RPM. At approximately 750 RPM the generator field did not "flash," a term used to describe the normal voltage buildup in the field of a generator. Initial troubleshooting identified that the auxiliary contacts on the 2CR contactor did not close. This caused the field flash failure. The failure of the auxiliary contacts on the 2CR contactor prevented the diesel generator from performing its designed safety function.

Natural Language Processing

	A	B	C	D	E	F	G	H	I	J	K
1	Appl Id	Type	Actv	Project	PI Name(	FY	IC	Title	Abstract	SA Text	Awd Tot $
2	7987780		2 R01	HL075353-	MESSINA,	2010	HL	Mesenchy	DESCRI	I. Spe	$411,250
3	8435690		1 R21	HL113777-	LIBONATI,	2013	HL	Exercise a	DESCR	A. Spec	$200,000
4	8245505		1 R01	AR061460-	FISHER, JC	2011	AR	Applicatic	DESCRI	II. SPECI	$355,245
5	8159876		1 R01	EY021768-	KAO, WIN	2011	EY	Cell Therc	DESCRI	P.I. Kao	$530,406
6	8400215		1 R01	DK095001	MIETHKE,	2012	DK	The role o	DESCR	SPECIFIC	$333,825
7	8415397		1 U18	TR000536-(	LYNCH, JC	2012	TR	Modeling	DESCR	SPECIFIC	$375,600
8	7672945		1 R43	DK083832	POO, RAN	2009	DK	A perfluor	DESCRI	1. SPECIF	$100,000
9	8108873		1 R01	HL103709-	TZANAKAK	2011	HL	Bioproces	DESCRI	1. SPECIF	$379,711
10	8504313		1 R01	DK098787	BUCHWAL	2012	DK	Culturally	DESCR	2. SPECIF	$211,602
11	8508395		1 R21	AA021225	CALLACI,	2013	AA	Alcohol E	DESCR	2. SPECIF	$217,063
12	7581820		2 R01	AI053193-(	RIDDELL, S	2009	AI	CD8+ T C	DESCRI	2. SPECIF	$502,469
13	7731196		1 R01	CA136551	RIDDELL, S	2009	CA	Targeted	DESCRI	2. SPECIF	$551,563
14	8371082		2 R01	DK079713	ARRIOLA,	2012	DK	Project Ar	DESCR	2. Specif	$240,878
15	7735633		2 R01	AI052079-(	KEARNS-JI	2009	AI	Non-Hum	DESCRI	2. Specif	$400,000
16	8591825		1 R41	OD018402	MARSH, H	2013	OD	CDX-301 (	DESCR	2.2 SPEC	$100,000
17	7785204		1 R01	NS065109-	BELLAMKC	2009	NS	A Ration	DESCRI	A Ratior	$338,926
18	7741820		1 R01	DK083411	LIN, FANG	2009	DK	STEM CELL	DESCRI	a. Specif	$376,800
19	7811914		3 R01	DE014190-	XU, HUAKI	2009	DE	Injectable	DESCRI	A. SPECI	$416,624
20	7581433		1 R01	DK081118-	SIMINOFF,	2009	DK	A Randor	DESCRI	A. Specif	$546,293
21	8039687		1 R01	CA140243	PAN, PING	2011	CA	H5Q Deriv	DESCRI	A. Specif	$351,713

Part 21 Reports


Gutor Life Is On Schneider Electric

i) Identification of basic component which contains the defect:

The potential defect is contained on the safety related Printed Circuit Board ("PCB") A070 controller of Gutor UPS systems.

The main tasks of the A070 PCB controller are the followings:

- Controlling the rectifier
- Controlling the static switches
- Controlling the inverter
- Monitoring voltage, current, alarms
- Communication with the front panel

The controller contains a firmware-controlled Master Processing Unit ("MPU"), a central component of the A070 PCB controller that connects to almost any other circuits on the board. This MPU microcontroller chip is mated in the controller board with a Plastic Leaded Chip Carrier ("PLCC") socket.

ii) Identification of the firm supplying the basic component:

The A070 PCB controller is designed, manufactured, and supplied by:

Schneider Electric P1F
Administration Building
Lot1, Block5, Phase 2
PEZA Rosario Cavite
Philippines

The PLCC socket is designed, manufactured, and supplied by:

Ho Chien Connectors International
Co No 21 L104 An xiang Rd
Kindian Dist
New Taipei City
Taiwan 231

The Intel MPU chip is stored and supplied by:

HTV Conservation GmbH
Robert-Bosch-Str.28
D-64625 Bensheim
Germany

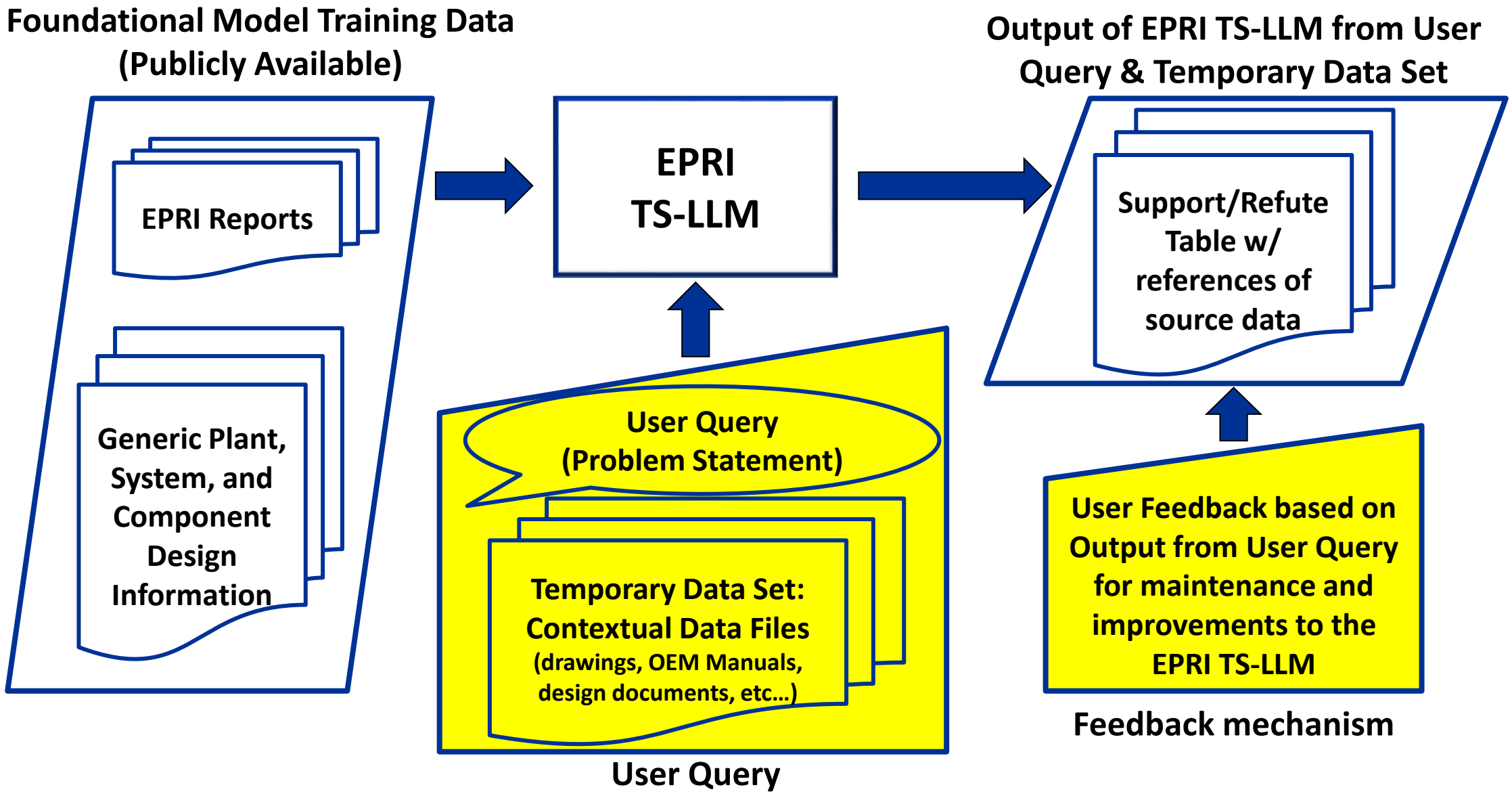
Schneider Electric

- The goal is to extract each section (i)-(ix) and information from them into a structured database
  - Not all reports follow the same structure

Accession Number	(i)	(ii)	(ii)
ML101820160	GE Hitachi Nuclear Energy	The basic component that failed is a High Pressure Coolant Injection System	The diaphragms are manufactured by Chicago-Allis as commercial grade. They are dedicated and sold as safety-related by GE Hitachi Nuclear Energy

Extracting data with NLP and LLM techniques

“EPRI LLM-for-Troubleshooting (TS-LLM)” at a glance



Deploy

Troubleshooting App

Upload file(s)

Drag and drop files here
Limit 200MB per file

Browse files

troubleshooting_doc1.pdf

troubleshooting_doc2.pdf

Semantic Search | LLM Chatbot

On 11/17/24, Centrifugal Compressor 1A was started and placed into the Lead position, with 1B in the Lag position. After 1A compressor loaded, it began surging. 1A was stopped and 1B is functioning as the Lead air compressor. No adjustments to the operating parameters of the compressor were made. 1C is now serving as the lagging air compressor.

Understood. The 1A centrifugal air compressor began surging after it was placed in the lead position and loaded.

Here is the primer for your support/refute table. The format is provided in accordance with EPRI Report 3002018211, but can be adapted to your station's or fleet's standard.

Download support/refute table to .csv

Item	Failure Mode	Validation Task	References	Sources
1	The inlet air filters are dirty, clogged, or obstructed.	Inspect, clean and or replace the inlet air filter	• troubleshooting_doc1.pdf, page 155 of 866 • troubleshooting_doc2.pdf, page 128 of 198	• source2.pdf, page 7 • source4.pdf, page 15
2	High interstage air temperature temperatures.	a. Verify cooling water valves are completely open	• troubleshooting_doc1.pdf, page 155 of 866 • troubleshooting_doc2.pdf, page 128 of 198	• source2.pdf, page 7
		b. Water temperature abnormally high	• troubleshooting_doc1.pdf, page 155 of 866 • troubleshooting_doc2.pdf, page 128 of 198	• source2.pdf, page 7 • source4.pdf, page 15
		c. Intercoolers are plugged or fouled in the air and/or water side.	• troubleshooting_doc1.pdf, page 155 of 866	• source4.pdf, page 15

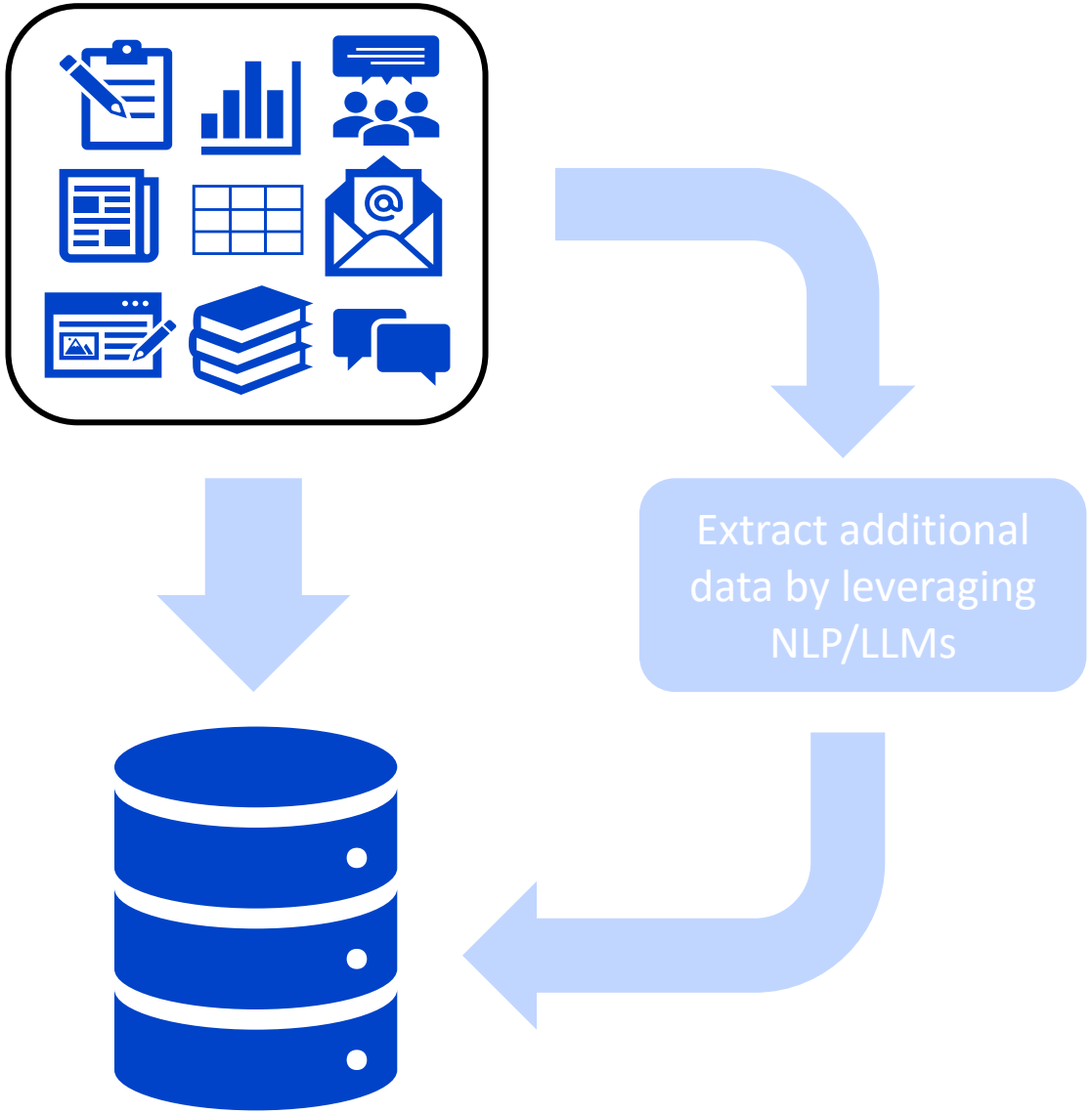
Download table to Word

Ask a question

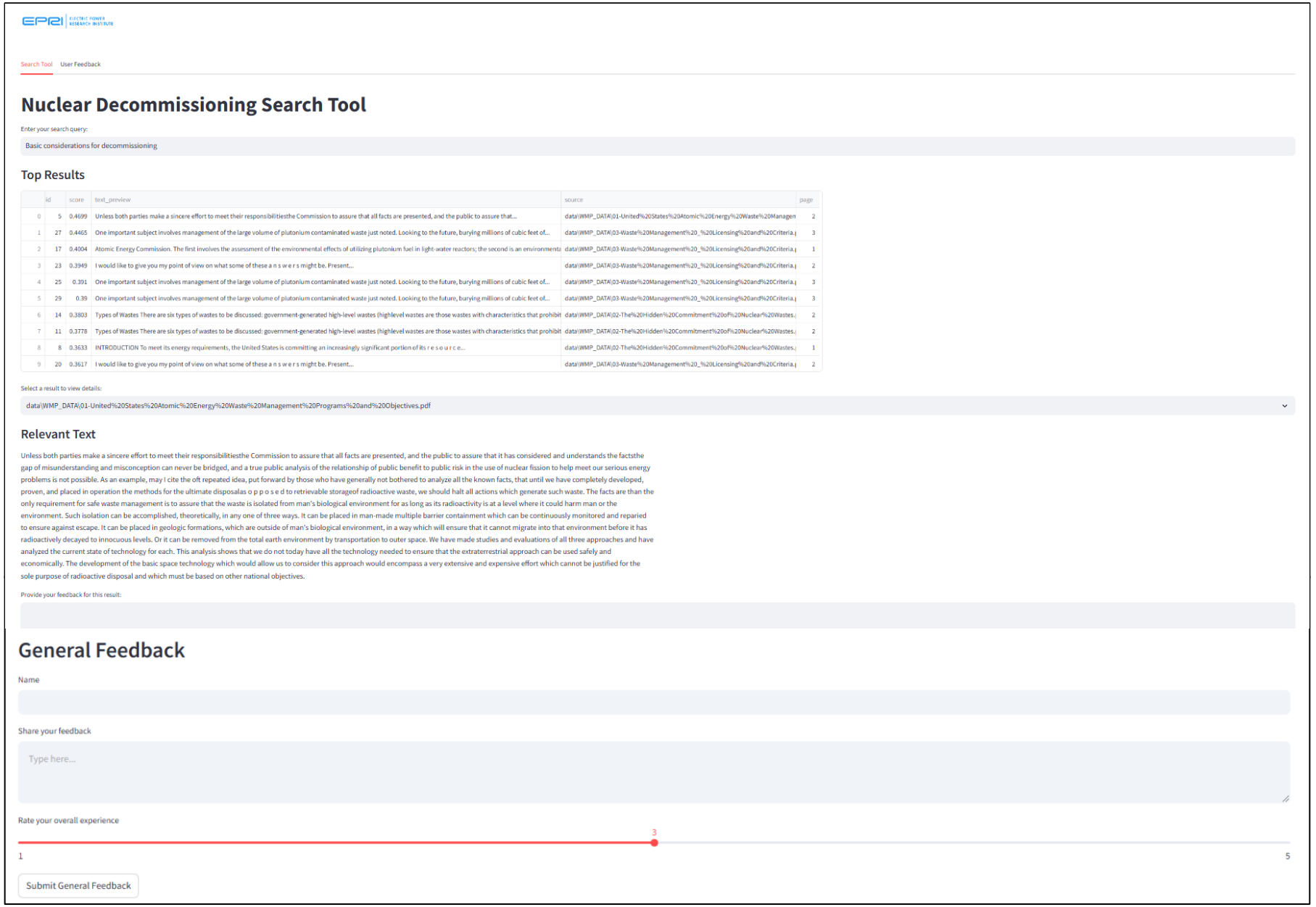
Download support/refute table to .docx

Decom KM

- The goal is to help subject matter experts in the Decommissioning program find relevant information fast
- Challenges:
  - Information spread over various formats
  - Evaluation of search results and optimization of database parameters



Streamlit User Interface (restricted access)



- Simple **Top Results** tabled to display relevant document matches with relevance score.
- **Preview** of source snippets prior to opening full file.
- **User Feedback** (work in progress) per respective document hit for model finetuning based on preliminary vectorstore.

Nuclear Industry LLM Pilot Project

Visionary Update Advancing Secure, Federated AI for the Nuclear Sector

July 2025

All Images Produced by Copilot

Project Vision & Objectives

Secure Platform

Develop a secure, federated AI platform tailored for the nuclear industry

Enhanced Operations

Enhance knowledge retrieval, decision support, and safety compliance

IP Protection

Demonstrate data sharing with IP protection and regulatory compliance

Collaboration

Foster collaboration across utilities, members, and vendors

Initial Use Cases & Scope

📚 Knowledge Transfer (led by NEI)

- Supports knowledge management and transfer by enabling overview and detailed understanding of key topics in the nuclear industry

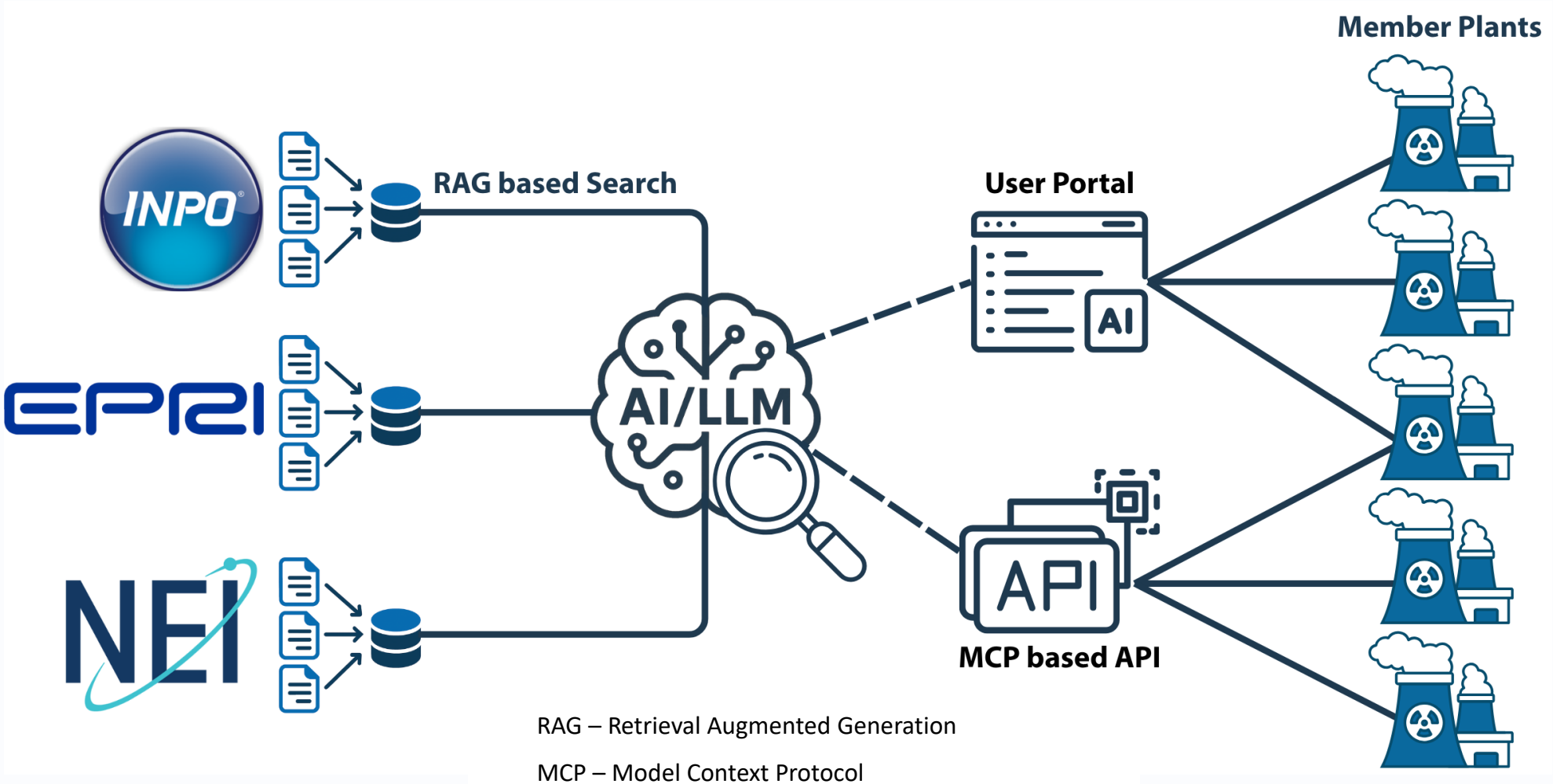
🔍 Operational Experience Search (led by INPO)

- Smart search across IRIS, INPO, EPRI, and NEI documents
- Supports plant reliability and safety initiatives

🔧 Troubleshooting (led by EPRI)

- AI-assisted plans for degraded components or system conditions

Proposed Architecture Diagram



RAG – Retrieval Augmented Generation

MCP – Model Context Protocol

API – Application Programming Interface

Governance & Collaboration

Organizational Structure:

1. Sponsor: INPO
2. Project Management: EPRI
3. Technical Contributors: NEI, Constellation, EPRI, INPO
4. Developer: TBA

Oversight Committee:

•INPO •EPRI •Constellation •NEI

•PG&E •Southern •OPG •NextEra

Project Management Approach:

- Weekly technical syncs
- Agile project management via Monday.com
- Partner organizations maintain data sovereignty and infrastructure

Questions & Contact Information

We welcome your questions and look forward to discussing the future of AI in the nuclear industry. Please reach out to the following points of contact for more information:

Points of Contact:

- **EPRI:** Rob Austin, raustin@epri.com
- **NEI:** Jim Slider, jes@nei.org
- **INPO:** Ramon Martinez, martinezr@inpo.org

AI Benchmarking Activities

LLM Benchmarking at EPRI

- Started with 5 areas within Nuclear: Future Nuclear, BWR I&E, Fuel and Chemistry, Scrams, Equipment Qualification
- ~300 curated Q&A, based on publicly available sources
- Documenting best practices on how to approach benchmarking and develop quality Q&A datasets

IAEA ISOP Taskforce 3: Benchmarking

Mission and Scope

Mission: Improve confidence in AI solutions for nuclear applications through comprehensive benchmarking of data, methods, and use cases

Scope: **Nuclear-specific focus** covering three critical areas:

Data benchmarking: Text (LLM), images, numerical (time series)	**Methods evaluation:** AI *and* supporting technologies	**Use cases:** CAP, CM/OLM, NDE, Computer Vision

Potential Deliverables:

Compilation of existing benchmarking datasets, databases, and efforts (i.e. NEA, IAEA, EPRI)	Guidelines on best practices (e.g. data synthesis)	Webinars and consultancy meetings

Data Availability Challenge

- Engage startups (Bluewave Labs, Atomic Canyon, Nuclearn), utilities, national labs (e.g. PNNL, ORNL), and regulators
- Structure existing public data for AI training
- **Kaggle competitions:** Crowdsource dataset creation and benchmarking
- **Member state survey:** Identify specific use cases and data sharing opportunities
- Data synthesis best practices

Actions

Identify current public high-quality datasets/use cases

- Compile list of use cases we want to focus on
- Identify gaps in data availability

Identify potential sources of benchmarking data

- Send out survey to ISOP members
- Engage with externals on available data
- Find potential resources for cleaning/improving quality of existing public data

Set up events/webinars, provide guidance on benchmarking

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