INL/MIS-22-68803-Revision-0

Natural Language Processing-Enhanced Nuclear Industry Operating Experience Data Analysis to Support Risk Model Parameter Estimations

September 2022

Sai Zhang, Fei Xu, Zhegang Ma

Changing the World's Energy Future

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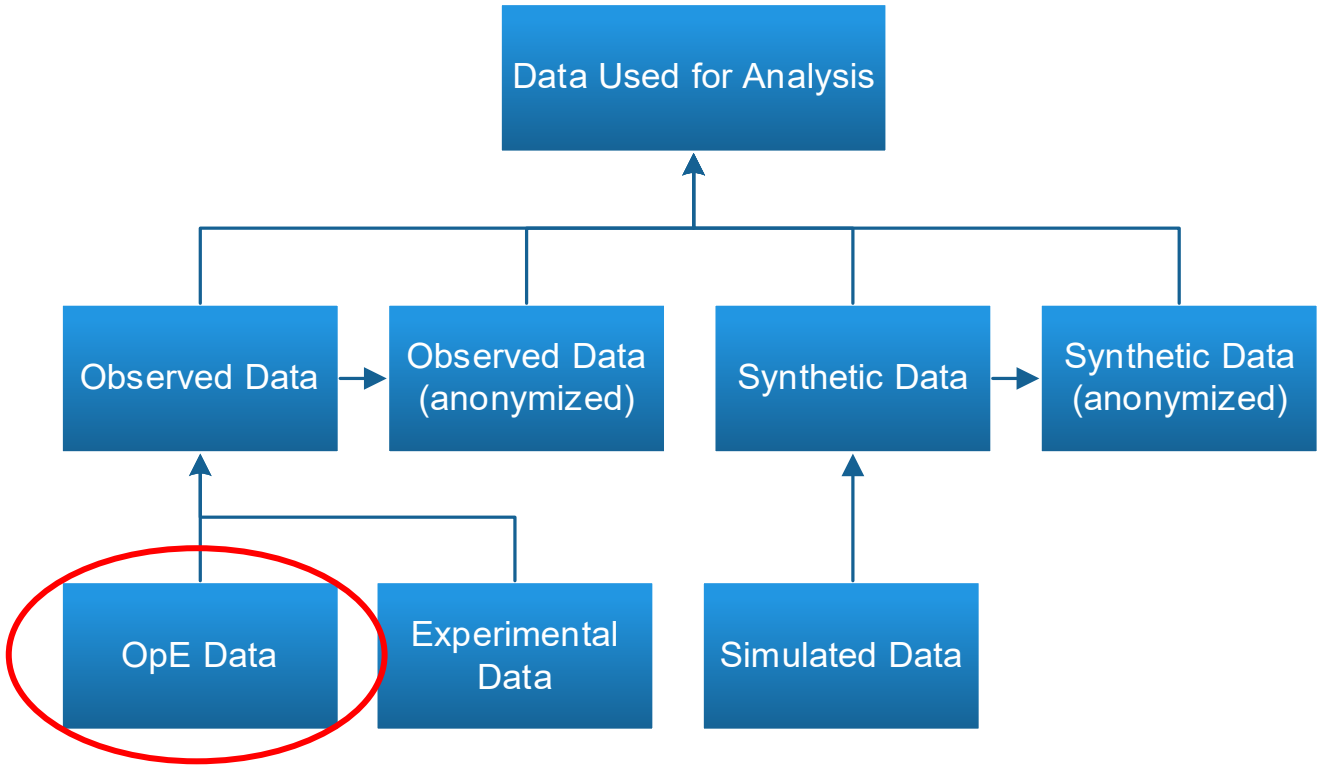
Idaho National Laboratory

Presentation Outline

- Background
  - Nuclear power plant operating experience data sources
- Research focus and motivation
  - Analyzing free-text operating experience data: present and future
- Research method
  - Input
  - Methodological steps
  - Output
- Conclusions and next steps

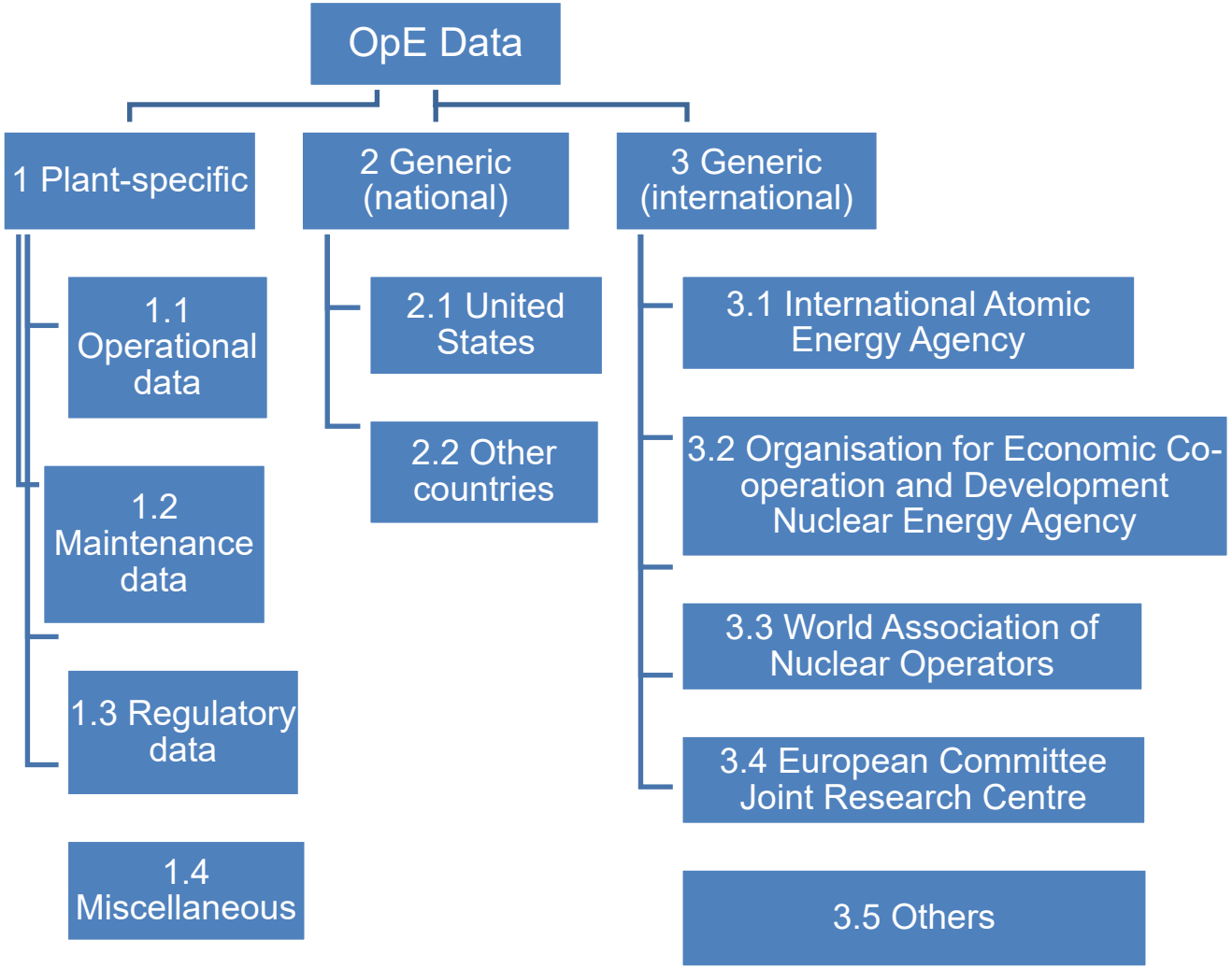
Background

- Nuclear power plant operating experience (OpE) data
  - The data observed and harvested as nuclear power plants operate (including during maintenance activities)



Ma et al. (2022) Exploring Advanced Computational Tools and Techniques with Artificial Intelligence and Machine Learning in Operating Nuclear Plants, NUREG/CR-7294, INL/EXT-21-61117. U.S. Nuclear Regulatory Commission.

Background (cont.)



- Nuclear power plant OpE data can be further categorized using multiple characteristics including:
  - Data (or file) format
    - e.g., free-text data
  - Data structure
  - Data velocity
  - Data accessibility
  - Relevancy to probabilistic risk assessment (PRA)

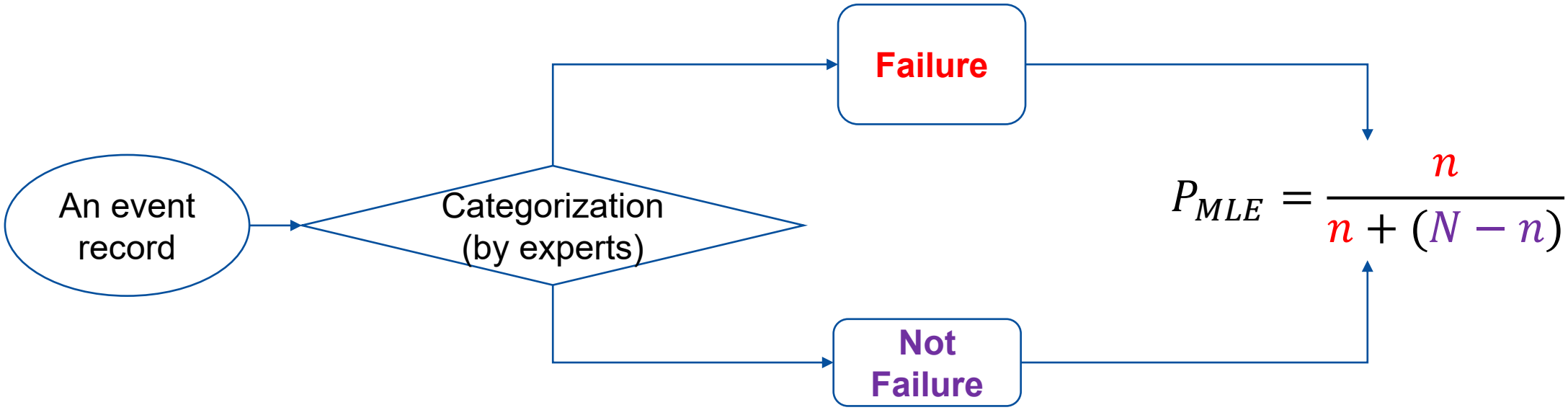
Ma et al. (2022) Exploring Advanced Computational Tools and Techniques with Artificial Intelligence and Machine Learning in Operating Nuclear Plants, NUREG/CR-7294, INL/EXT-21-61117. U.S. Nuclear Regulatory Commission.

Research Focus and Motivation

- Analyzing free-text OpE data for risk model parameter estimates
  - **What are we doing now at Idaho National Laboratory (INL)?**
    - Storing and coding part of U.S. nuclear industry OpE data in the Nuclear Regulatory Commission (NRC) Reactor Operating Experience Data (NROD) database (https://nrod.inl.gov)
    - Using NROD data to estimate parameters for standardized plant analysis risk (SPAR) models through the NRC Reliability and Availability Data System (RADS) web calculation app (https://rads.inl.gov)
    - The NRC NROD and RADS contain proprietary information and are accessible to NRC and Institute of Nuclear Power Operations (INPO) members only
    - The SPAR parameter estimate results are publicly accessible through the NRC Reactor Operational Experience Results and Database (https://nrcoe.inl.gov)

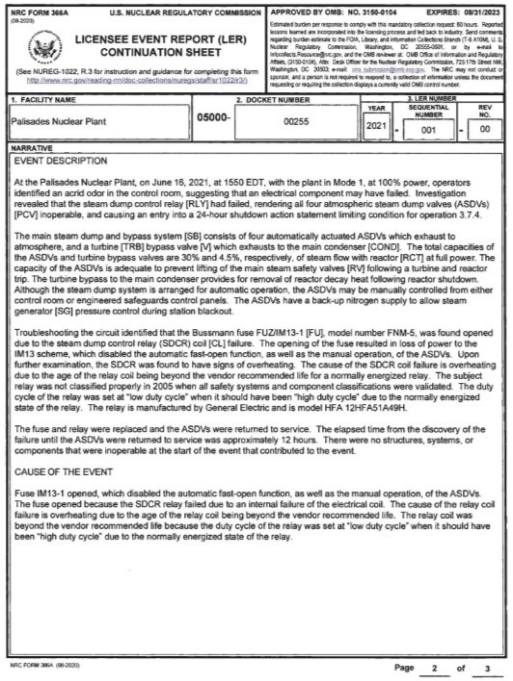
Research Focus and Motivation (cont.)

- Analyzing free-text OpE data for risk model parameter estimates
  - **Current challenges**
    - "Cherry-picking" from an event record
    - Small number of observed failures (i.e., *n* values)
    - Difficulty in justifying and expanding data applications, e.g., to advanced reactors



Research Focus and Motivation (cont.)

- Analyzing free-text OpE data for risk model parameter estimates
  - **Candidate for future considerations**
    - Leveraging advanced techniques and tools such as natural language processing (NLP)
  - **Research focus of this study**
    - To develop a fully automated NLP tool to analyze free-text event report



NRC FORM 366A U.S. NUCLEAR REGULATORY COMMISSION

LICENSEE EVENT REPORT (LER)
CONTINUATION SHEET

(See NUREG-1022, R.3 for instruction and guidance for completing this form)

1. FACILITY NAME	2. DOCKET NUMBER		3. LER NUMBER		
			YEAR	SEQUENTIAL NUMBER	REV NO.
Palisades Nuclear Plant	05000-	00255	2021	- 001	- 00

NARRATIVE

EVENT DESCRIPTION

At the Palisades Nuclear Plant, on June 16, 2021, at 1550 EDT, with the plant in Mode 1, at 100% power, operators identified an acrid odor in the control room, suggesting that an electrical component may have failed. Investigation revealed that the steam dump control relay [RLY] had failed, rendering all four atmospheric steam dump valves (ASDVs) [PCV] inoperable, and causing an entry into a 24-hour shutdown action statement limiting condition for operation 3.7.4.

The main steam dump and bypass system [SB] consists of four automatically actuated ASDVs which exhaust to atmosphere, and a turbine [TRB] bypass valve [V] which exhausts to the main condenser [COND]. The total capacities of the ASDVs and turbine bypass valves are 30% and 4.5%, respectively, of steam flow with reactor [RCT] at full power. The capacity of the ASDVs is adequate to prevent lifting of the main steam safety valves [RV] following a turbine and reactor trip. The turbine bypass to the main condenser provides for removal of reactor decay heat following reactor shutdown. Although the steam dump system is arranged for automatic operation, the ASDVs may be manually controlled from either control room or engineered safeguards control panels. The ASDVs have a back-up nitrogen supply to allow steam generator [SG] pressure control during station blackout.

Troubleshooting the circuit identified that the Bussmann fuse FUZ/IM13-1 [FU], model number FNM-5, was found opened due to the steam dump control relay (SDCR) coil [CL] failure. The opening of the fuse resulted in loss of power to the IM13 scheme, which disabled the automatic fast-open function, as well as the manual operation, of the ASDVs. Upon further examination, the SDCR was found to have signs of overheating. The cause of the SDCR coil failure is overheating due to the age of the relay coil being beyond the vendor recommended life for a normally energized relay. The subject relay was not classified properly in 2005 when all safety systems and component classifications were validated. The duty cycle of the relay was set at "low duty cycle" when it should have been "high duty cycle" due to the normally energized state of the relay. The relay is manufactured by General Electric and is model HFA 12HFA51A49H.

The fuse and relay were replaced and the ASDVs were returned to service. The elapsed time from the discovery of the failure until the ASDVs were returned to service was approximately 12 hours. There were no structures, systems, or components that were inoperable at the start of the event that contributed to the event.

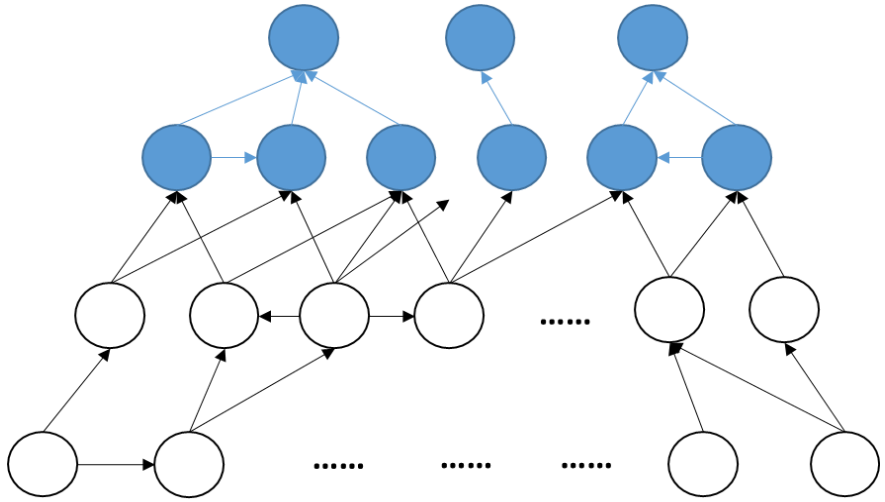
CAUSE OF THE EVENT

Fuse IM13-1 opened, which disabled the automatic fast-open function, as well as the manual operation, of the ASDVs. The fuse opened because the SDCR relay failed due to an internal failure of the electrical coil. The cause of the relay coil failure is overheating due to the age of the relay coil being beyond the vendor recommended life. The relay coil was beyond the vendor recommended life because the duty cycle of the relay was set at "low duty cycle" when it should have been "high duty cycle" due to the normally energized state of the relay.

NRC FORM 366A (08-2020) Page 2 of 3

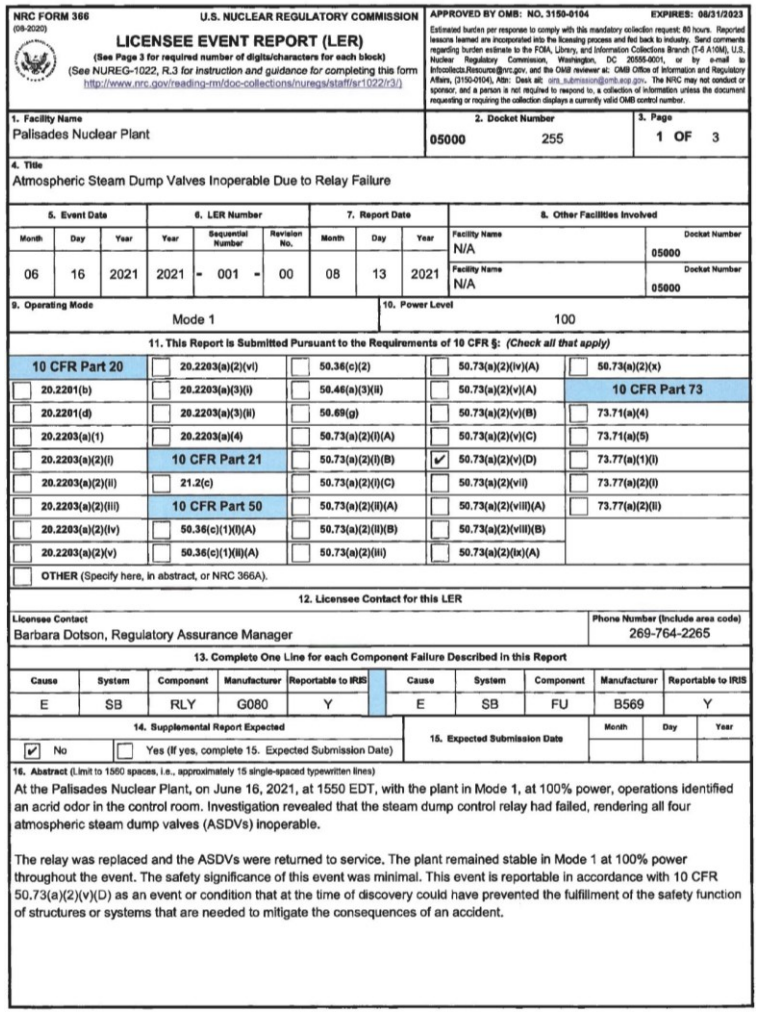
Input: free-text event report

Automated NLP Tool



Output: directed acyclic graph

Input to Automated NLP Tool



NRC FORM 366 (08-2020) U.S. NUCLEAR REGULATORY COMMISSION

APPROVED BY OMB: NO. 3150-0104 EXPIRES: 08/31/2023

Estimated burden per response to comply with this mandatory collection request: 80 hours. Reported lessons learned are incorporated into the licensing process and fed back to industry. Send comments regarding burden estimate to the FOIA, Library, and Information Collections Branch (T-6 A10M), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and the OMB reviewer at: OMB Office of Information and Regulatory Affairs, (3150-0104), Attn: Desk at: ora_submission@omb.eop.gov. The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

LICENSEE EVENT REPORT (LER)

(See Page 3 for required number of digits/characters for each block)

(See NUREG-1022, R.3 for instruction and guidance for completing this form http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1022/r3/)

1. Facility Name	2. Docket Number	3. Page
Palisades Nuclear Plant	05000 255	1 OF 3

4. Title: Atmospheric Steam Dump Valves Inoperable Due to Relay Failure

5. Event Date			6. LER Number			7. Report Date			8. Other Facilities Involved	
Month	Day	Year	Year	Sequential Number	Revision No.	Month	Day	Year	Facility Name	Docket Number
06	16	2021	2021	- 001 -	00	08	13	2021	N/A	05000
									N/A	05000

9. Operating Mode	10. Power Level
Mode 1	100

11. This Report is Submitted Pursuant to the Requirements of 10 CFR §: *(Check all that apply)*

10 CFR Part 20	20.2203(a)(2)(vi)	50.36(c)(2)	50.73(a)(2)(iv)(A)	50.73(a)(2)(x)
20.2201(b)	20.2203(a)(3)(i)	50.46(a)(3)(ii)	50.73(a)(2)(v)(A)	10 CFR Part 73
20.2201(d)	20.2203(a)(3)(ii)	50.69(g)	50.73(a)(2)(v)(B)	73.71(a)(4)
20.2203(a)(1)	20.2203(a)(4)	50.73(a)(2)(i)(A)	50.73(a)(2)(v)(C)	73.71(a)(5)
20.2203(a)(2)(i)	10 CFR Part 21	50.73(a)(2)(i)(B)	☑ 50.73(a)(2)(v)(D)	73.77(a)(1)(i)
20.2203(a)(2)(ii)	21.2(c)	50.73(a)(2)(i)(C)	50.73(a)(2)(vii)	73.77(a)(2)(i)
20.2203(a)(2)(iii)	10 CFR Part 50	50.73(a)(2)(ii)(A)	50.73(a)(2)(viii)(A)	73.77(a)(2)(ii)
20.2203(a)(2)(iv)	50.36(c)(1)(i)(A)	50.73(a)(2)(ii)(B)	50.73(a)(2)(viii)(B)	
20.2203(a)(2)(v)	50.36(c)(1)(ii)(A)	50.73(a)(2)(iii)	50.73(a)(2)(ix)(A)	

☐ OTHER (Specify here, in abstract, or NRC 366A).

12. Licensee Contact for this LER

Licensee Contact	Phone Number (Include area code)
Barbara Dotson, Regulatory Assurance Manager	269-764-2265

13. Complete One Line for each Component Failure Described in this Report

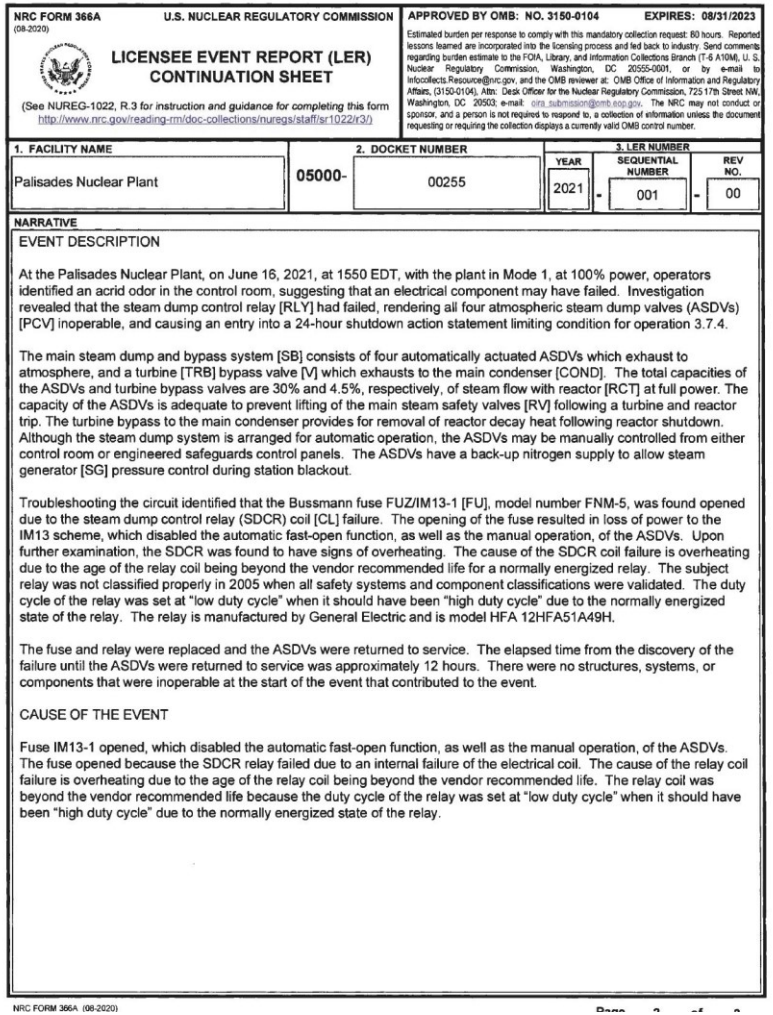
Cause	System	Component	Manufacturer	Reportable to IRIS	Cause	System	Component	Manufacturer	Reportable to IRIS
E	SB	RLY	G080	Y	E	SB	FU	B569	Y

14. Supplemental Report Expected	15. Expected Submission Date	Month	Day	Year
☑ No ☐ Yes (If yes, complete 15. Expected Submission Date)				

16. Abstract (Limit to 1560 spaces, i.e., approximately 15 single-spaced typewritten lines)

At the Palisades Nuclear Plant, on June 16, 2021, at 1550 EDT, with the plant in Mode 1, at 100% power, operations identified an acrid odor in the control room. Investigation revealed that the steam dump control relay had failed, rendering all four atmospheric steam dump valves (ASDVs) inoperable.

The relay was replaced and the ASDVs were returned to service. The plant remained stable in Mode 1 at 100% power throughout the event. The safety significance of this event was minimal. This event is reportable in accordance with 10 CFR 50.73(a)(2)(v)(D) as an event or condition that at the time of discovery could have prevented the fulfillment of the safety function of structures or systems that are needed to mitigate the consequences of an accident.



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Palisades Nuclear Plant	05000- 00255	2021	- 001	- 00

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The fuse and relay were replaced and the ASDVs were returned to service. The elapsed time from the discovery of the failure until the ASDVs were returned to service was approximately 12 hours. There were no structures, systems, or components that were inoperable at the start of the event that contributed to the event.

CAUSE OF THE EVENT

Fuse IM13-1 opened, which disabled the automatic fast-open function, as well as the manual operation, of the ASDVs. The fuse opened because the SDCR relay failed due to an internal failure of the electrical coil. The cause of the relay coil failure is overheating due to the age of the relay coil being beyond the vendor recommended life. The relay coil was beyond the vendor recommended life because the duty cycle of the relay was set at "low duty cycle" when it should have been "high duty cycle" due to the normally energized state of the relay.

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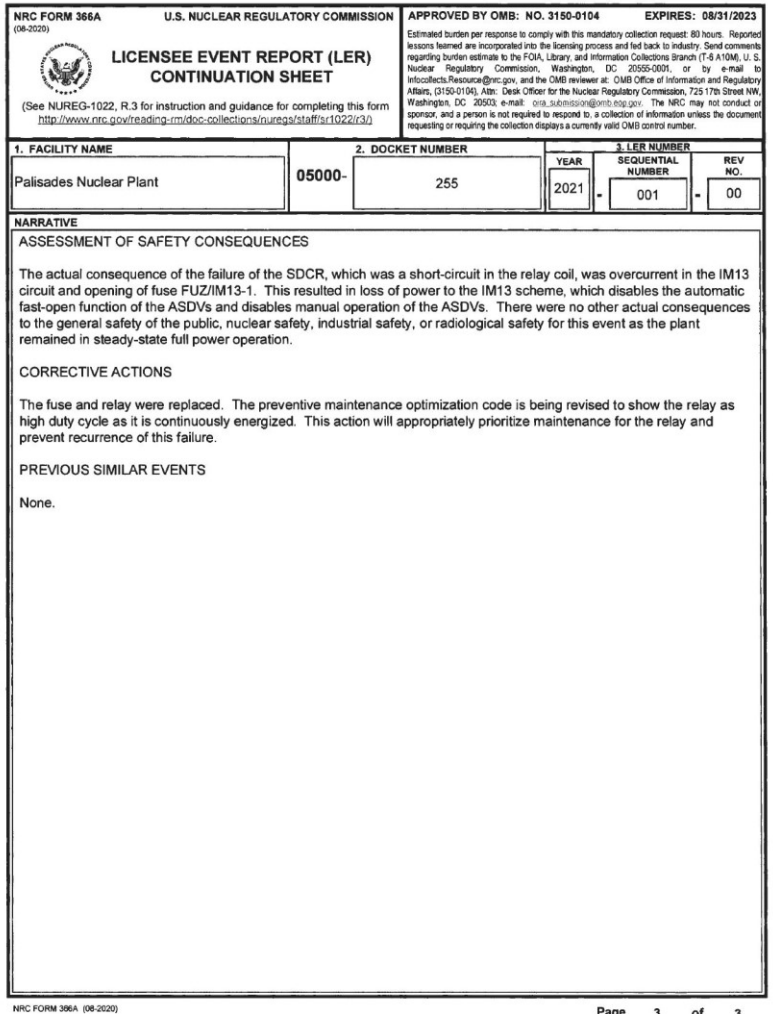

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1. FACILITY NAME	2. DOCKET NUMBER	3. LER NUMBER		
		YEAR	SEQUENTIAL NUMBER	REV NO.
Palisades Nuclear Plant	05000- 255	2021	- 001	- 00

NARRATIVE

ASSESSMENT OF SAFETY CONSEQUENCES

The actual consequence of the failure of the SDCR, which was a short-circuit in the relay coil, was overcurrent in the IM13 circuit and opening of fuse FUZ/IM13-1. This resulted in loss of power to the IM13 scheme, which disables the automatic fast-open function of the ASDVs and disables manual operation of the ASDVs. There were no other actual consequences to the general safety of the public, nuclear safety, industrial safety, or radiological safety for this event as the plant remained in steady-state full power operation.

CORRECTIVE ACTIONS

The fuse and relay were replaced. The preventive maintenance optimization code is being revised to show the relay as high duty cycle as it is continuously energized. This action will appropriately prioritize maintenance for the relay and prevent recurrence of this failure.

PREVIOUS SIMILAR EVENTS

None.

NRC FORM 366A (08-2020) Page 3 of 3

- Selected a publicly available data source (i.e., licensee event report [LER]) for this study

Methodological Steps to Analyze a Single Event Report

Step 1: Identify sentences containing causal relationships

- Prepare keywords list
- Extract causal sentences

Step 2: Process single sentence

- Keyword tuples
- Extract dependencies
- Create the cause-and-effect nodes
- Parts of 45 nodes (in this case study)

Step 3: Combine/process relationships from multiple sentences

- Calculate the similarity between the causes and effects
- Remove the duplicate relationships
- Replace the similar causes or effects by using consistent phrases
- Reduce to 13 refined nodes (in this case study)

Step 4: Generate the visualized relationship graph

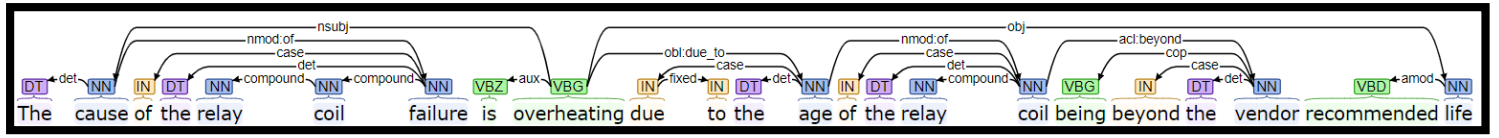
Identifying Causal Relationships

```
['  Investigation revealed that the steam dump control relay had failed,  rendering all four  atmospheric steam dump valves (AS
DVs) inoperable', '  The opening of the fuse resulted in  loss of power to the  IM13 scheme, which disabled the automatic fast-
open function,  as well as the manual operation, of the ASDVs', '  The cause of the SDCR coil failure is overheating  due to th
e age of the relay coil being beyond the vendor recommended life for a normally energized relay', '  Troubleshooting the circu
it identified that the Bussmann fuse FUZ/IM13-1  [FU],  model number FNM-5, was found opened  due to the steam dump control rel
ay (SDCR) coil [CL] failure', '  The cause of the SDCR coil failure is overheating  due to the age of the relay coil being beyo
nd the vendor recommended life for a normally energized relay', '  The duty  cycle of the relay was set at "low duty cycle" whe
n it should have been "high duty cycle" due to the normally energized  state of the relay', '  The opening of the fuse resulted
in  loss of power to the  IM13 scheme, which disabled the automatic fast-open function,  as well as the manual operation, of th
e ASDVs', '  Investigation  revealed that the steam dump control  relay [RL Y] had failed,  rendering all four atmospheric stea
m d                                    and causing an entry into a 24-hour shutdown action statement limiting condition for
```

a) Keyword filter result

```
[(13, 13, 'rendering')]
[(19, 19, 'rendering'), (37, 37, 'causing')]
[(6, 6, 'resulted'), (19, 19, 'disabled'), (28, 30, 'as well as')]
[(6, 6, 'resulted'), (19, 19, 'disabled'), (28, 30, 'as well as')]
[(2, 2, 'cause'), (11, 12, 'due to')]
[(6, 6, 'resulted'), (19, 19, 'disabled'), (28, 30, 'as well as')]
[(28, 29, 'due to')]
[(
```

b) Tuple information for each sentence



4	overheating	cause	the SDCR coil failure
4	the age of the relay coil being beyond	due to	overheating

c) Dependencies and relationship extraction for a single sentence

Identifying and Combining Duplicated Entities

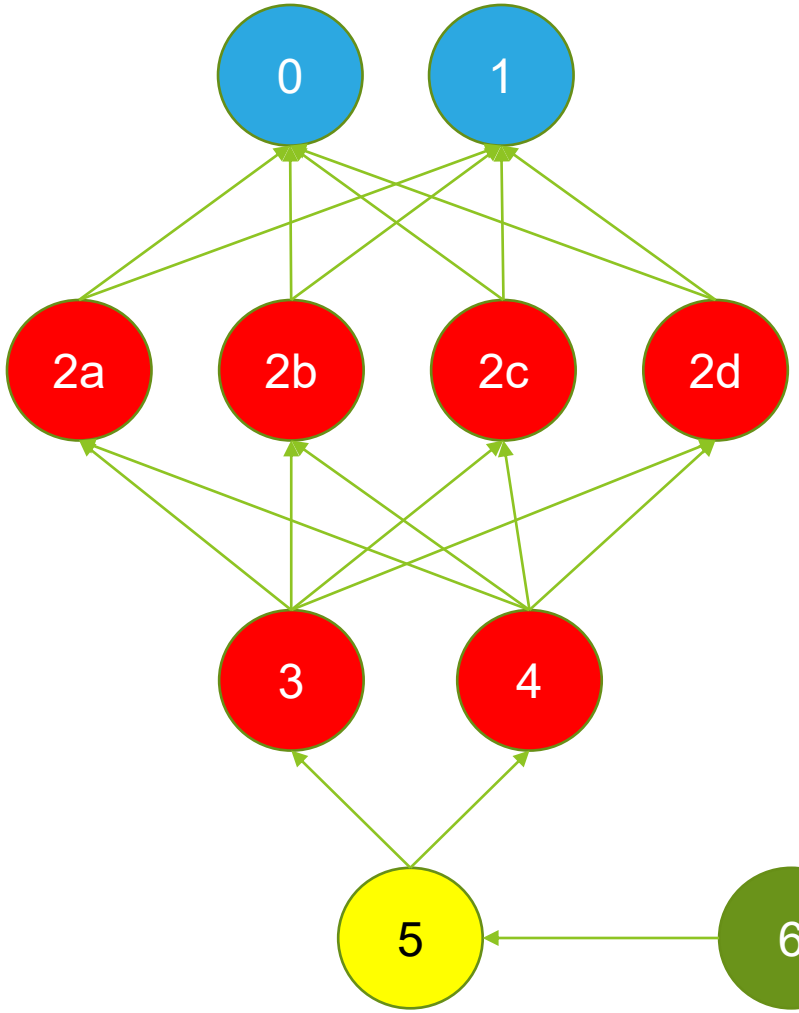
s#	cause	key word	effect
0	Investigation revealed that the steam dump control relay had failed,	rendering	all four atmospheric steam dump valves (ASDVs) inoperable
1	Investigation revealed that the steam dump control relay [RL Y] had failed,	rendering	all four atmospheric steam dump valves (ASDVs) [PCV] inoperable, and
1	Investigation revealed that the steam dump control relay [RL Y] had failed,	causing	an entry into a 24-hour shutdown action statement limiting condition fo
2	The opening of the fuse	resulted	in loss of power to the IM13 scheme, which
2	in loss of power to the IM13 scheme, which	disabled	the automatic fast-open function,
2	in loss of power to the IM13 scheme, which	disabled	the manual operation, of the ASDVs
3	The opening of the fuse	resulted	in loss of power to the IM13 scheme, which
3	in loss of power to the IM13 scheme, which	disabled	the automatic fast-open function,
3	in loss of power to the IM13 scheme, which	disabled	the manual operation, of the ASDVs
4	overheating	cause	the SDCR coil failure
4	the age of the relay coil being beyond the vendor recommended life for a norm	due to	overheating
5	The opening of the fuse	resulted	in loss of power to the IM13 scheme, which
5	in loss of power to the IM13 scheme, which	disabled	the automatic fast-open function,
5	in loss of power to the IM13 scheme, which	disabled	the manual operation, of the ASDVs

a) Original single sentence relationships

s#	cause	key word	effect
0	the steam dump control relay failure	rendering	all four atmospheric steam dump valves (ASDVs) inoperable
1	overheating	cause	the steam dump control relay failure
1	the age of the relay coil being beyond the vend	due to	overheating
2	The opening of the fuse	resulted	in loss of power to the IM13 scheme
2	in loss of power to the IM13 scheme	disabled	the automatic fast-open function,
2	in loss of power to the IM13 scheme	disabled	the manual operation, of the ASDVs
4	the steam dump control relay failure	causing	an entry into a 24-hour shutdown action statement limiting condition for operation 3
7	the steam dump control relay failure	due to	The opening of the fuse
9	the normally energized state of the relay	due to	the duty cycle of the relay was set at "low duty cycle" when it should have been "high duty cycle"
10	an internal failure of the electrical coil	due to	the steam dump control relay failure
12	the duty cycle of the relay was set at "low duty	because	the age of the relay coil being beyond the vendor recommended life

b) Refined multiple sentences' relationships

Output from Automated NLP Tool



0. An acrid odor in control room
1. Entry into a 24-hour shutdown action statement
2. Four atmospheric steam dump valves inoperable
3. Valve automatic operation disabled
4. Valve manual operation disabled
5. Fuse opened
6. Steam dump control relay coil failure
7. Relay coil overheating
8. Relay coil age being beyond the vendor recommended life
9. Wrong determination of relay duty cycle (high vs. low)

Consequences

Valve

Fuse

Relay

Conclusions and Next Steps

- Conclusions
  - Developed a fully-automated NLP tool to analyze a single report
    - Input: a free-text, event-describing report
    - Output: a causal network representing event initiation and propagation
- Next steps – a long way to go
  - **Make full use of past**
    - Expand tool capability to analyze multiple reports and aggregate results
  - **Use "past" to inform future**
    - Utilize results to inform risk model parameter estimations
      - Enhance physical understanding of failure initiation and propagation
      - Complement limited data pool of failure events with analysis of non-failure events (e.g., near misses, failure precursors, or even success data)
      - Investigate applicability of existing data to, for example, advanced reactors

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.