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Explainable AI for LLMs in the Nuclear Industry

Market Research & Analysis

Research Focus: XAI Models Applied to LLM Use Cases in Nuclear Settings

Objective: Identify solutions, analyze adoption barriers, and explore cross-industry applications

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Explainable AI

Nuclear Safety

Regulatory Compliance

Risk Management

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Solution 1: XAI-BERT

Nuclear Incident Report Summarization

Model:
DistilBERT with Attention Visualization

Architecture:
Transformer Encoder + Explainability Layer

Institution:
Hugging Face & Sanh et al. [5]

Function:
Summarizes nuclear incident reports with transparent reasoning

Nuclear Industry Fit

- Safety-Critical Documentation:** NRC requires detailed incident analysis [4]
- Rapid Response:** Operators need quick understanding of risk factors
- Audit Trail:** Attention patterns provide regulatory transparency
- Expert Validation:** Engineers can verify AI reasoning through visualizations

Adoption Barriers

- Regulatory Validation:** Extensive testing required for safety-critical AI [7]
- Domain Expertise Gap:** Limited nuclear-AI interdisciplinary knowledge
- Conservative Culture:** Nuclear industry traditionally risk-averse
- Data Sensitivity:** Incident reports contain classified information

Cross-Industry Extension: Healthcare

Application: Medical Incident Report Analysis

- Value:** Hospitals generate thousands of incident reports monthly requiring rapid, explainable analysis
- Regulatory Parallel:** FDA adverse event reporting mirrors NRC incident documentation requirements
- Safety Impact:** Quick identification of patterns could prevent medical errors

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Solution 2: NuclearDocXAI

DistilBERT + LIME for Regulatory Document Classification

Model:
DistilBERT + LIME Explanations

Architecture:
Transformer Classifier + Local Interpretability

Framework:
Hugging Face + LIME Library [2]

Function:
Classifies nuclear regulatory documents with local explanations

Nuclear Industry Fit

- Document Volume:** Nuclear facilities generate massive regulatory paperwork
- Automated Routing:** Classification enables efficient document processing
- Compliance Verification:** Ensures documents meet NRC requirements [4]
- Inspection Support:** LIME explanations aid regulatory audits

Adoption Barriers

- Domain Specificity:** Requires deep nuclear regulatory taxonomy knowledge
- LIME Stability:** Local explanations can be inconsistent across similar documents
- Integration Complexity:** Must interface with legacy nuclear documentation systems
- Liability Concerns:** Misclassification could impact regulatory compliance

Cross-Industry Extension: Financial Services

Application: Bank Compliance Document Classification

- Value:** Financial institutions face similar complex, evolving regulatory landscapes (Basel III, Dodd-Frank)
- Transparency Need:** Regulators require explainable compliance decisions and audit trails
- Volume Challenge:** Banks process thousands of compliance documents requiring accurate categorization

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Solution 3: XAI-Maintain

T5 + Attention for Maintenance Log Summarization

Model:
T5 (Text-to-Text Transfer Transformer)

Architecture:
Encoder-Decoder + Multi-Head Attention Visualization

Origin:
Google T5 [3]

Function:
Summarizes maintenance logs with attention-based explainability

Nuclear Industry Fit

- Predictive Maintenance:** Argonne National Lab emphasizes AI-enabled predictive maintenance for nuclear [1]
- Safety-Critical Equipment:** Transformer failures can lead to catastrophic consequences
- Cost Reduction:** Early failure detection reduces downtime and maintenance costs
- Regulatory Compliance:** Detailed maintenance documentation required by NRC [4]

Adoption Barriers

- Text Generation Complexity:** T5 requires sophisticated prompt engineering for maintenance domains
- Limited Training Data:** Nuclear maintenance systems face "limited degradation knowledge" [6]
- Attention Interpretation:** Multi-head attention can be complex to interpret consistently
- Legacy Integration:** Most nuclear plants use decades-old maintenance tracking systems

Cross-Industry Extension: Aviation Maintenance

Application: Aircraft Maintenance Log Analysis

- Value:** Airlines generate thousands of maintenance logs daily requiring rapid, accurate summarization
- Safety Parallel:** Similar safety-critical environment with strict regulatory requirements (FAA mirrors NRC)
- Economic Impact:** AI-driven predictive maintenance reduces aircraft downtime and operational costs

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Cross-Industry Applications Summary

Nuclear Solution	Cross-Industry Application	Industry	Key Value Proposition	Regulatory Parallel
XAI-BERT Incident Report Summarization	Medical Incident Report Analysis	Healthcare	Rapid analysis of patient safety incidents with explainable AI reasoning	FDA adverse event reporting requirements
NuclearDocXAI Regulatory Document Classification	Bank Compliance Document Classification	Financial Services	Automated categorization of regulatory documents with transparent decision-making	Basel III, Dodd-Frank compliance requirements
XAI-Maintain Maintenance Log Summarization	Aircraft Maintenance Log Analysis	Aviation	Predictive maintenance insights with attention-based explanations	FAA maintenance documentation standards

Common Success Factors Across Industries:

**Safety-Critical Context**
High-stakes environments requiring transparent AI decisions

**Regulatory Compliance**
Strict documentation and audit trail requirements

**Economic Impact**
Significant cost savings through automation and efficiency

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References

[1] Argonne National Laboratory (2024). *AI-Enabled Predictive Maintenance for Nuclear Power Plants*. U.S. Department of Energy. Retrieved from DOE Nuclear Energy Research Database.

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[3] Raffel, C., Shazeer, N., Roberts, A., Lee, K., Narang, S., Matena, M., ... & Liu, P. J. (2020). Exploring the limits of transfer learning with a unified text-to-text transformer. *Journal of Machine Learning Research*, 21(140), 1-67.

[4] U.S. Nuclear Regulatory Commission (2024). *Artificial Intelligence Strategic Plan*. NRC AI Working Group Report. Retrieved from NRC Public Document Room.

[5] Sanh, V., Debut, L., Chaumond, J., & Wolf, T. (2019). DistilBERT, a distilled version of BERT: smaller, faster, cheaper and lighter. *arXiv preprint arXiv:1910.01108*.

[6] ARPA-E (2024). *AI-Enabled Predictive Maintenance Digital Twins for Advanced Nuclear Reactors*. Advanced Research Projects Agency-Energy Funding Opportunity Announcement.

[7] International Atomic Energy Agency (2023). *Artificial Intelligence for Nuclear Applications*. IAEA Technical Reports Series No. 1987. Vienna: IAEA Publications.

Key Insights

All three XAI solutions address critical nuclear industry needs while maintaining the transparency required for safety-critical applications. The combination of proven NLP architectures with explainability frameworks creates opportunities for responsible AI adoption in regulated industries.