Safe Nuclear Power: Instrumentation, Human Oversight, and Infrastructure Transition

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Outline

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1. Introduction
2. Instrumentation and Control

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2. Instrumentation and Control
3. Historical Lessons
4. Human Factors

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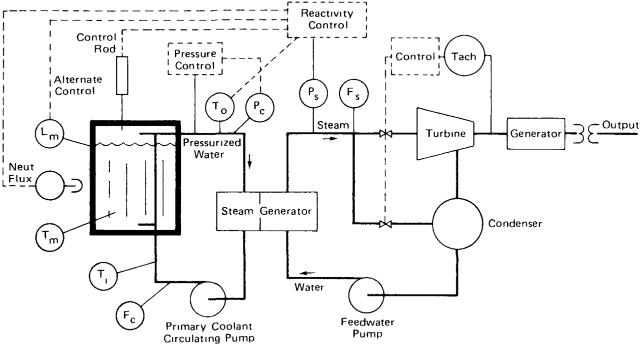
Motivation

- Zero-emission base-load power
- High energy return on investment
- Historical trauma shapes perception [24, 30]
- Paper focuses on safety through instrumentation and oversight

Types of Reactors

- Pressurized Water Reactor (PWR): most common, used in submarines and civilian fleets
- Boiling Water Reactor (BWR): direct steam path to turbine
- CANDU: heavy water as moderator and coolant
- Gas-cooled (AGR): high outlet temperature for efficiency

Instrumentation in a PWR



SL-1: Prompt Critical from Manual Control

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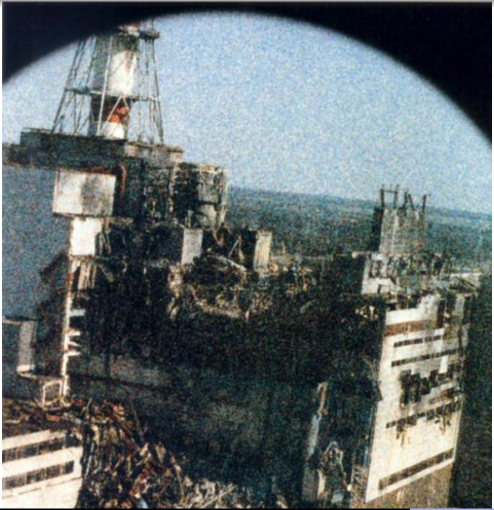
- Root cause: lack of mechanical safeguards
- Fallout: Army withdrew from nuclear reactor programs
- Image shows post-blast structural damage

Three Mile Island: Interface Confusion

- Interface design: misleading feedback lights
- Alarm overload: dozens triggered at once
- Led to sweeping changes in human-machine interfaces

Three Mile Island: Interface Confusion

Chernobyl: Design and Assumption Failures



Chernobyl: Design and Assumption Failures

- Unstable physics design, especially at low power
- Operators unaware of full core behavior
- Culture of secrecy delayed response and accountability

Fukushima: Nature and Neglect

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- Failure of backup power design
- Hydrogen explosions from vented zirconium reactions
- Ocean contamination and public trust fallout

Human Factors Engineering

- Cognitive load reduction
- Realistic training environments
- Alarm prioritization and filtering

Ethics of Automation

- Passive safety aids are essential
- But overtrust in automation can fail silently
- The human-in-the-loop design is non-negotiable

Aging Infrastructure and Waste

- On-site pools reaching capacity
- Dry cask storage: temporary fix
- Fewer experts entering the field

Modern Developments

- Factory assembly lowers construction risk
- Smaller cores, faster SCRAM times
- Potential role in green hydrogen and remote grids

Final Thoughts

- Prioritize human-machine partnerships
- Design with humility and feedback
- Build public trust through transparency

References

[1] Muhammad R. Abdussami and Aditi Verma. “Future energy landscapes: Analyzing the cost-effectiveness of nuclear-renewable integrated energy systems in retrofitting of coal power plants”. In: *Applied Energy* (2025), p. 124460. ISSN: 0306-2619. DOI: 10.1016/j.apenergy.2024.124460. URL: https://www.sciencedirect.com/science/article/pii/S0306261924018439.

[2] Jacopo Buongiorno et al. *The Future of Nuclear Energy in a Carbon-Constrained World*. Tech. rep. Massachusetts Institute of Technology, 2020. URL: https://energy.mit.edu/research/future-nuclear-energy-carbon-constrained-world/ (visited on 06/04/2024).