A Comparison of Nuclear and Chemical Industry Safety Programs

P2SAC
Purdue Process Safety & Assurance Center

Fall Conference
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Objectives:

- Nuclear and chemical sectors response to catastrophic disasters
- Government and professional organizations response
- A few of the key attributes of the safety programs:
  - ✓ Leadership & safety culture
  - ✓ Problem-solving techniques
  - ✓ Sharing lessons learned & operating experience
  - ✓ Self-assessment & independent assessments
- Premise:
  - ✓ Nuclear and chemical sectors can learn from each other and improve the safety of their respective operation.
- The nuclear industry started their safety program much earlier than chemical.
- The chemical industry initially borrowed several methods from the nuclear industry, e.g., fault trees and event trees.
- However, the two sectors have developed their own unique approaches since then.

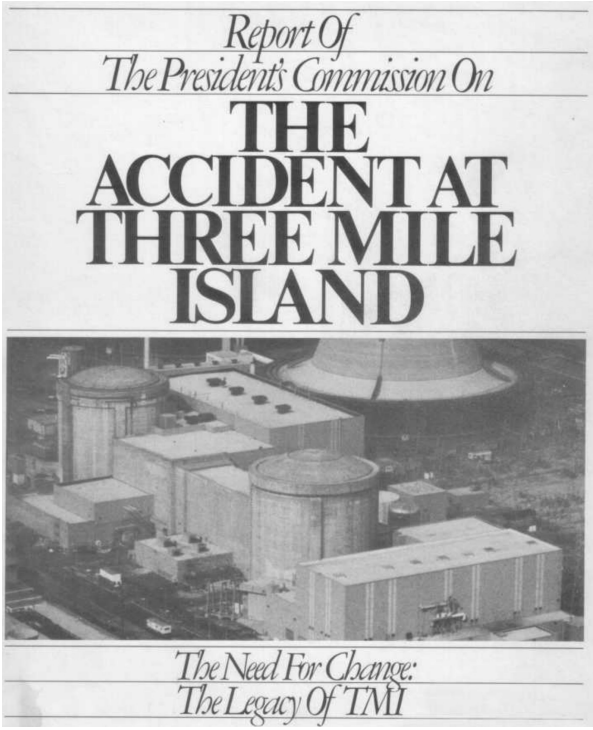
Three Mile Island – Unit 2

- March 28, 1979
- South of Harrisburg PA
- Loss of Coolant Accident resulted in partially melting the reactor core
- Health effects: ~ 2 million people around the site received ~ 1 millirem (chest x-ray 6 mr)

Courtesy American Nuclear Society

- Actual radionuclide release had negligible effects on physical heath of people or environment.
- Cleanup costs: $973 million over 12 years

Presidential Commission



The Kemeny Commission

"To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices -- and above all – in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry."

Institute of Nuclear Power Operations (INPO)

INPO formed in December 1979

MISSION:

Promoting the highest levels of safety and reliability – promoting excellence – in the operation of commercial nuclear power plants.

www.inpo.info

Institute of Nuclear Power Operations (INPO)

- Private, non-profit 501(c)3 organization.
- No governmental regulatory function.
- All 94 US nuclear power plants are members of INPO.
- Fee-based.
- Headquarters in Atlanta GA. 371 employees (IRS Form 990)
- INPO expenses in 2022 $115 million (IRS Form 990)
- Performance monitoring, evaluations, peer reviews of plants.
- Communicates evaluation results to utility CEO/Chief Nuclear Officer
- Accreditation of member training programs.
- Operating experience information and analysis.
- Continuous improvement.
- Publications (public and proprietary).

Watershed Events Influenced Nuclear Safety

- **SL-1 (January 1961) – Only fatal nuclear reactor accident in USA**
  - Inadequate procedures, inadequate reactor design, control rod worth.
- **Three Mile Island (March 1979)**
  - Hardware, procedures, training, attitudes toward safety and regulation.
- **Chernobyl (April 1986)**
  - Flawed reactor design, maintaining design configuration, plant status control, line authority for reactor safety, cultural attributes.
- **Davis-Besse (March 2002)**
  - Football-size void in the reactor vessel head caused by boric acid corrosion. Safety culture changes identified.
- **Fukushima Daiichi (March 2011)**
  - Importance of assessing nuclear safety impacts of a hypothetical, yet credible, extreme external event.

World Association of Nuclear Operators

- **Chernobyl Event (April 1986)**
- WANO was created on May 15, 1989
- WANO conducts first peer review 1992
- WANO conducts 200th peer review 2003
- Trends & Performance Monitoring, Events & Networking, Industry Working Groups, Industry Performance Improvement

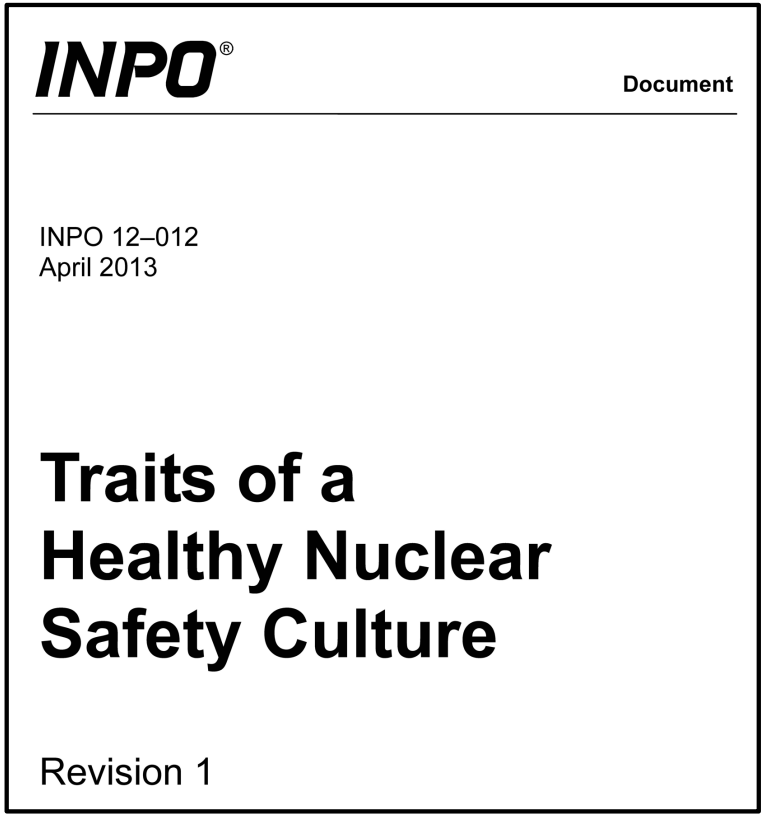
WANO

GLOBAL LEADERSHIP IN NUCLEAR SAFETY

www.wano.info

125	460	60	400+	6
Current Members	**Operating nuclear Units**	**Nuclear Units Under Construction**	**WANO Employees**	**Offices/Regional Centres**

INPO Publications (Open Distribution)



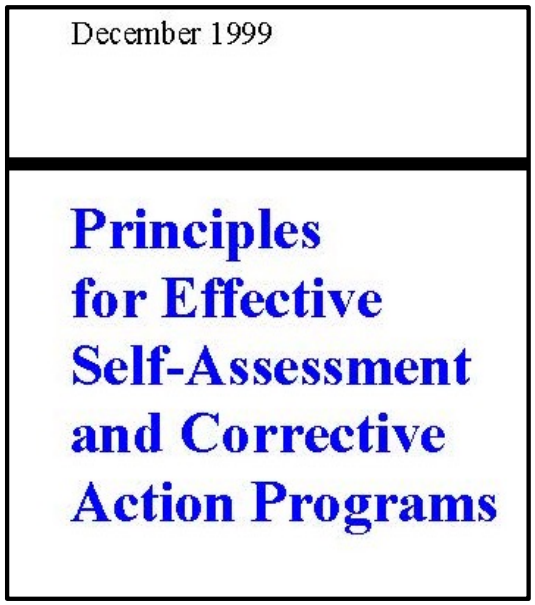
THE TRAITS AND THEIR ATTRIBUTES

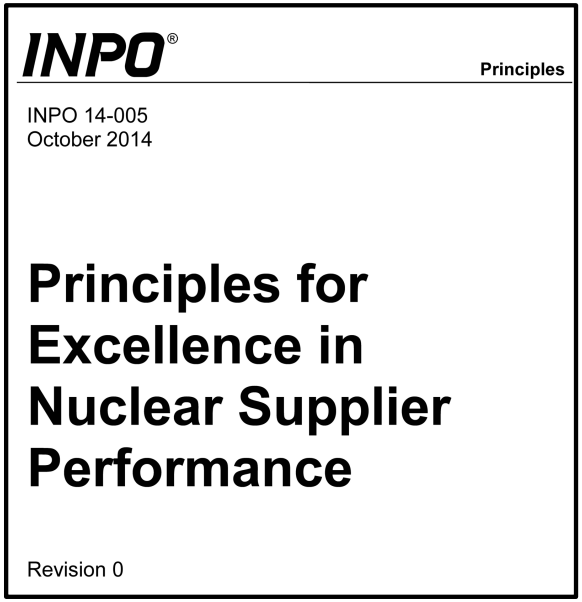
Individual Commitment to Safety
- Personal Accountability
- Questioning Attitude
- Effective Safety Communication

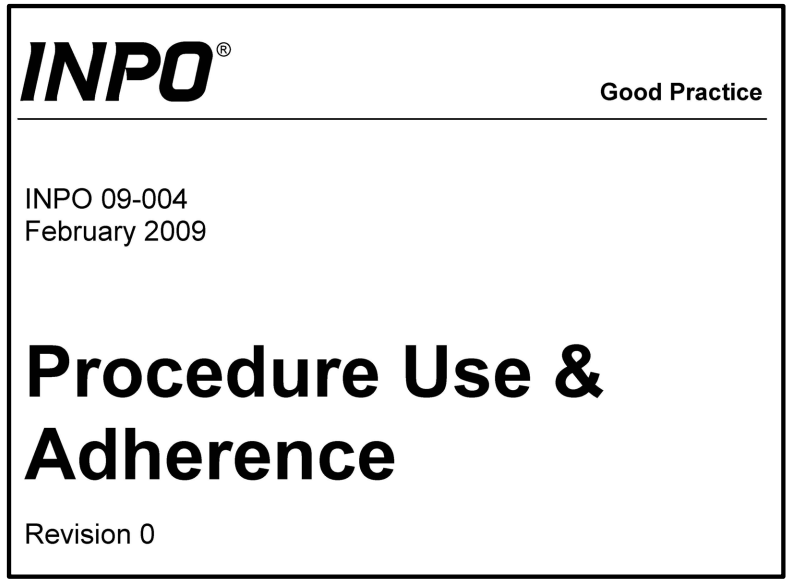
Management Commitment to Safety
- Leadership Safety Values and Actions
- Decision-Making
- Respectful Work Environment

Management Systems
- Continuous Learning
- Problem identification and Resolution
- Environment for Raising Concerns
- Work Processes

INPO Publications (Public)







INPO Performance Improvement Model

Guidelines for Performance Improvement at Nuclear Power Stations

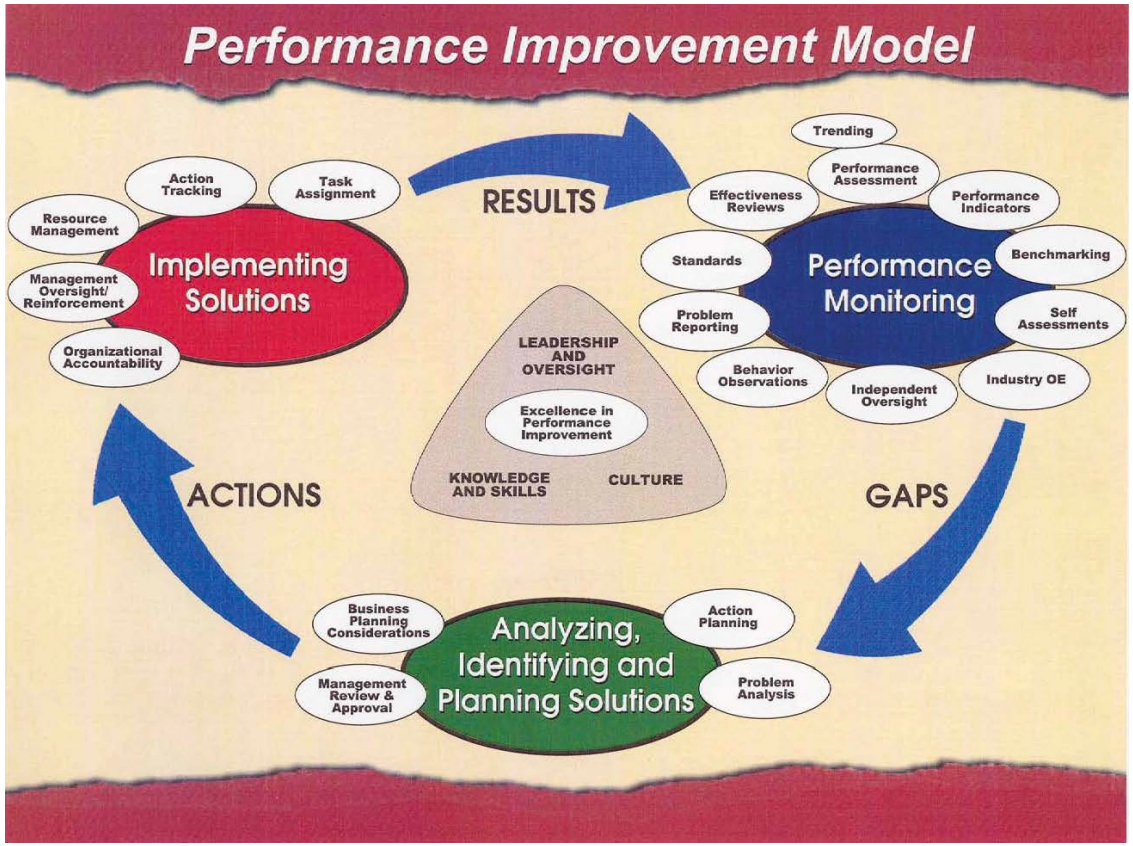
INSTITUTE OF NUCLEAR POWER OPERATIONS

August 2005

INPO 05-005

Plant Area: All

Key Words: Corrective Action Program, Self-Assessment, Benchmarking, Operating Experience, and Organizational Effectiveness



Problem Identification & Resolution

- **Condition Report or Abnormal Situation Report**
  - Typically, 6,000 reports per year for a 2-Unit plant
- **Document to Control Room**
  - Shift manager reviews document for operability, reportability
- **Screening Committee**
  - Multi-discipline team reviews, categorizes
    - Data point, Apparent Cause Evaluation, Root Cause Evaluation, Trend Evaluation
  - Assigned to Department Head with due date
- **Evaluations Reviewed by Corrective Action Review Board**
- **Approved/Rejected**

US Nuclear Regulatory Commission:

- **Atomic Energy Act (1954)**
  - Established a single agency to regulate civilian nuclear materials and develop and produce nuclear weapons.
- **Energy Reorganization Act (1974)**
  - Established NRC as an independent agency to regulate civilian use of nuclear materials and protect the public and environment.
- **Memorandum of Understanding (MOU) NRC, OSHA & EPA**
  - NRC Resident Inspectors may identify safety concerns within the area of OSHA responsibility. NRC Regional Office may inform OSHA Regional Office, as appropriate.
  - Framework of collaboration on issues relating to environmental impact.
- **NRC issues Notices of Violation, Fines, Shutdown Orders**

NRC Regulation: 10 CFR Part 50 Appendix B

Criterion XVI: Corrective Action

Measures shall be established to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances are promptly identified and corrected. In the case of **significant conditions adverse to quality**, the measures shall assure that the cause of the condition is determined and corrective action taken to preclude repetition. The identification of the **significant condition adverse to quality,** the cause of the condition, and the corrective action taken shall be documented and reported to appropriate levels of management.

Typical Screening Criteria

- **Category A: Significant Condition Adverse to Quality**
  - Condition of fission product barrier no longer able to perform its intended function
  - Reactor trip with complications
  - Loss of safety function
  - Greater-than-Green NRC Finding/Violation or Performance Indicator
  - Severity Level I, II, or III NRC Finding or Violation
  - . . . .
- **Requires a root cause evaluation**

Typical Screening Criteria of CRs

- **Category B, C and D: Adverse Conditions**
  - Failure, malfunction, deficiency or nonconformance of a safety-related systems, structures, components (SSC)
  - Failure to support function of a safety-related SSC
  - Unplanned power change greater than 25%
  - Non-compliance to a federal, state, or local regulation, code, standard, commitment
  - Non-compliance to the Quality Assurance Program
- **Category B:** Apparent Cause Evaluation and corrective actions to correct causal factors.
- **Category C:** Corrective action to fix the condition.
- **Category D:** Addressed by another CR or work management system.

Root Cause Evaluation Tools

- TapRooT® Root Cause Analysis
- The 5-WHYs
- Event & Causal Factor Chart
- Barrier Analysis
- Change Analysis
- Human Performance Evaluation
- Missed Opportunity Matrix
- Comparative TimeLine
- . . . others

Department of Energy Resources

DOE HANDBOOK

Accident and Operational Safety Analysis

Volume I: Accident Analysis Techniques

DOE-HDBK-1208-2012
July 2012

DOE HANDBOOK

Accident and Operational Safety Analysis

Volume II: Operational Safety Analysis Techniques

U.S. Department of Energy
Washington, D.C. 20585

DOE-HDBK-1028-2009
June 2009

DOE STANDARD

HUMAN PERFORMANCE IMPROVEMENT HANDBOOK

VOLUME 1: CONCEPTS AND PRINCIPLES

DOE-HDBK-1028-2009
June 2009

DOE STANDARD

HUMAN PERFORMANCE IMPROVEMENT HANDBOOK

VOLUME 2: HUMAN PERFORMANCE TOOLS FOR INDIVIDUALS, WORK TEAMS, AND MANAGEMENT

U.S. Department of Energy
Washington, D.C. 20585

AREA HFAC

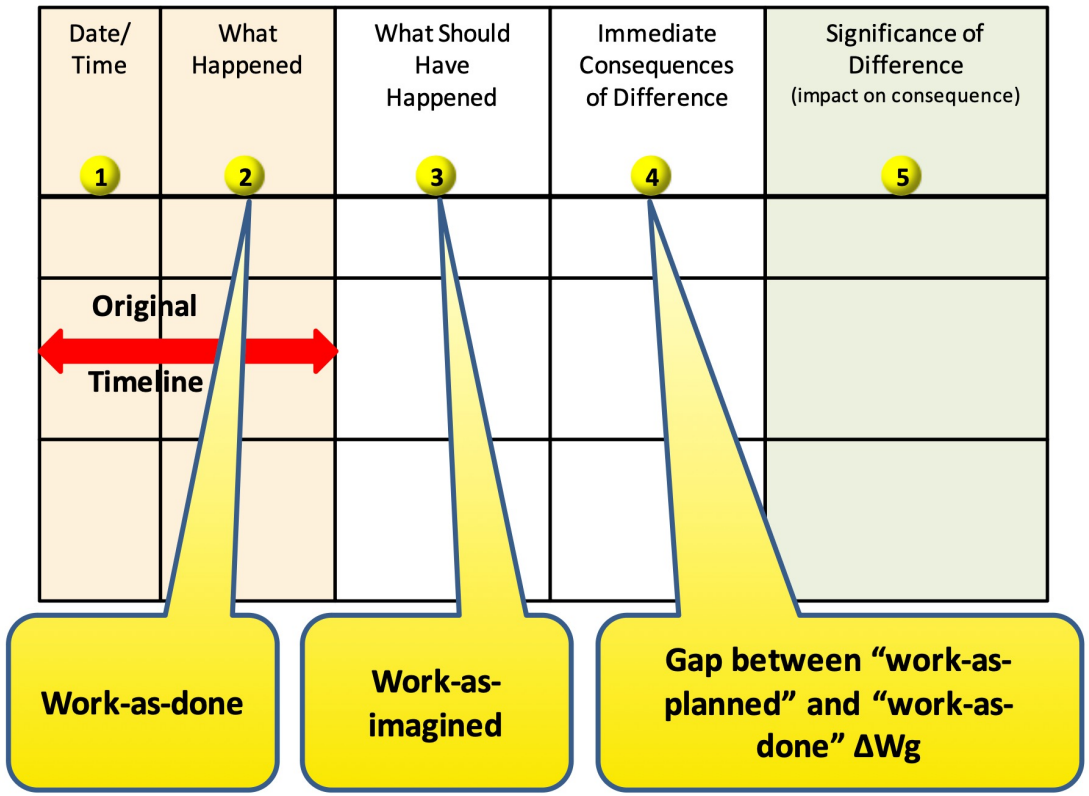
DOE G 414.1-5
3-2-06

CORRECTIVE ACTION PROGRAM GUIDE

[*This Guide describes suggested nonmandatory approaches for meeting requirements. Guides are not requirements documents and are not construed as requirements in any audit or appraisal for compliance with the parent Policy, Order, Notice, or Manual.*]

U.S. Department of Energy
Washington, D.C. 20585

Root Cause Evaluation Tool (CTL)

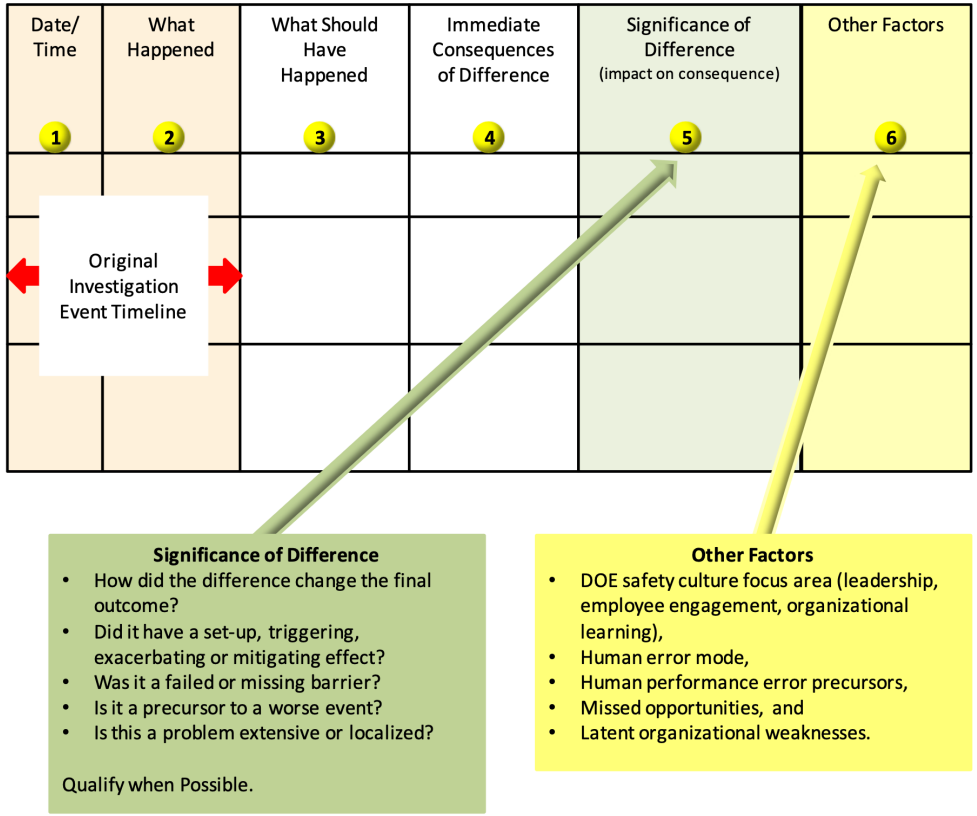


Comparative TimeLine

- **Chronology** – as fine as warranted
- Tabular format – easy to revise
- **What Happened** – Fact-based
- **What Should Have Happened** –
  - Work-as-imagined
- **Immediate consequence** –
  - Damage
  - Dose
  - Delay

Source: DOE-HDBK-1208-2012

Root Cause Evaluation Tool (CTL)



Source: DOE-HDBK-1208-2012

Comparative TimeLine

- **Significance of Difference:**
  - What does this say about the way we do work?
  - Did it have a set-up factor?
  - What triggered the difference?
  - What made the consequences as bad as it was?
  - What kept the consequence from becoming worse?
  - Was a barrier missing or failed?
- **Other Factors:**
  - Safety culture
  - Human performance error
  - Precursors
  - Missed opportunities

Root Cause Evaluation Terms

Extent of Condition:

- The extent to which the condition may be present in other plant processes, equipment or human performance activities.

Extent of Cause:

- The extent to which the causes of an identified problem are present in other plant processes, equipment, or human performance.

Root Cause Evaluation Terms (continued)

Effectiveness Review:

- Effectiveness reviews should verify not only that corrective actions were taken, but that they had the desired effect (preclude recurrence of the same or similar conditions).
- Verify expected results were achieved and they address the root cause(s).
- That new problems or unintended consequences were not introduced by implementation of the actions.
- Have all the required actions been implemented?
- Has there been an opportunity for recurrence of the same or similar conditions since the completion of all corrective actions?
- If required actions were deleted or changed, were those changes properly approved?

Chemical Industry

Chemical Industry

Contrasted to the Nuclear Industry:

- A lot more plant sites – likely thousands in US alone!
- Produce a very wide variety of products, from food additives, pharmaceuticals, plastics, energy, to name a few.
- A very wide diversity of technology and chemical processes even with the same product.
- A much more diverse set of hazards, although toxicity, chemical reactivity and flammability are the major ones. Also have mechanical hazards (trips, slips, falls) and physical hazards (high and low temperatures, etc).
- A lot more employees, although this varies a lot from site to site.

American Institute of Chemical Engineers

In the 1960s AIChE formed the Safety and Health Division (Division 11):

- 11a: Loss Prevention
- 11b: Health
- 11c: Ammonia

Each of these divisions did annual symposia with well over 100 attendees attending each. They also published the journal *Process Safety Progress.*

This year (2024) this division was renamed the *Process Safety Division.*

Twenty-one years ago AICHE combined all of its process safety programming into a **Global Congress on Process Safety**. There are over 1,000 attendees at this meeting! The 21st Global Congress for 2025 will be held in Dallas, TX April 6 – 10, 2025.

OSHA: US Occupational and Health Administration

- Created by the Occupational Safety and Health Act of 1970 and signed by President Richard Nixon on December 29, 1970.
- OSHA opened its doors on April 28, 1971
- OSHA is responsible for enforcing its standards on regulated entities, which includes chemical plants.
- Compliance Safety and Health Officers carry out inspections and assess fines for regulatory violations.
- Inspections are done on worksites in particularly hazardous industries. Inspections can also be triggered by a workplace fatality, multiple hospitalizations, worker complaints, or referrals.
- Legal authority over plant operations.
- They have stop work and fine authority!
- States have also formed their own OSHA entities.

OSHA 1910.119 Process Safety Management of Highly Hazardous Chemicals

- Promulgated on February 24, 1992
- Included:
  1. Process safety information
  2. Process hazards analysis (PHA)
  3. Operating procedures
  4. Employee participation
  5. Training
  6. Contractors
  7. Pre-startup safety reviews
  8. Mechanical Integrity
  9. Hot work permits
  10. Management of change (MOC)
  11. Incident investigations
  12. Emergency planning and response
  13. Compliance audits
  14. Trade secrets – added later.

US Environmental Protection Agency, EPA

- Proposed by President Richard Nixon on July 9, 1970. It began operation on December 2, 1970.
- The agency conducts environmental assessment, research, and education.
- It has the responsibility of maintaining and enforcing national standards under a variety of environmental laws, in consultation with state, tribal, and local governments. EPA enforcement powers include fines, sanctions, and other measures.
- Has legal authority over releases.
- They have stop work and fine authority!

EPA Risk Management Program (RMP)

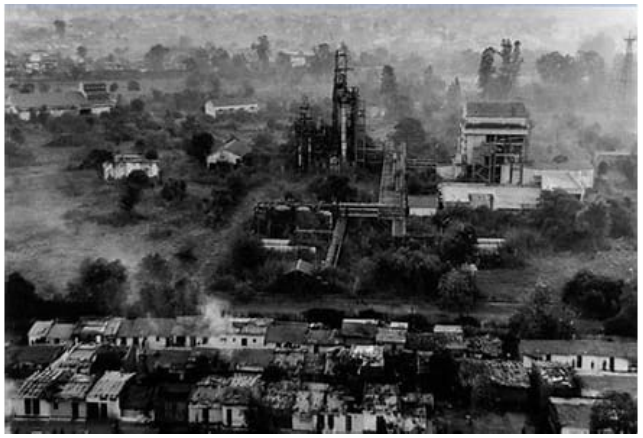
- Implemented with 1990 Clean Air Act.
- Requires facilities that use extremely hazardous substances to develop a Risk Management Plan (RMP)
- Identifies the potential effects of a chemical accident, via consequence and dispersion modelling.
- Identifies steps the facility is taking to prevent an accident, and spells out emergency response procedures should an accident occur.
- RMPs submitted to EPA and LEPC: Local Emergency Planning Committee.

DIERS: Design Institute for Emergency Relief Systems

- Up through the early 1970s many incidents occurred due to 2-phase flow through relief vents that were designed for single phase flow.
- In 1976 AICHE formed a consortium of 29 companies to develop methods for the design of emergency relief systems to handle runaway reactions.
- This included new calorimetric methods to characterize runaway reactions and new 2-phase relief sizing calculations.
- DIERS offers an annual symposium as part of the Global Congress and publishes a lot of technical papers on this topic.

Bhopal Incident, December 2-3, 1984

- More than 3,000 fatalities and over 100,000 injuries to nearby residents.
- Governments worldwide recognized that this could happen anywhere.
- Companies worldwide recognized that current process safety programs were inadequate.
- Union Carbide settlement of $470 million with the Indian government.
- To avoid bankruptcy, Union Carbide became a subsidiary of Dow Chemical (2001).



AICHE Response to Bhopal

- Early in 1985 AICHE formed the Center for Chemical Process Safety with $1 MM.
- They were so concerned about liability that they initially established it as a separate independent entity in a different location from AICHE!
- CCPS Vision Statement:
  A World without Process Safety Incidents.
- This vision also included improving process safety education in undergraduate chemical engineering programs.

How CCPS Works

- **CCPS is a non-profit organization under AICHE.**
- **2023 budget: $5.3 MM (12 Full Time Personnel)**
- **Member company dues support the activities of CCPS.**
  - Dues based on company size.
  - Currently, CCPS has over 280 global members in 47 countries.
- **Activities are selected by a Technical Steering Committee.**
  - All members companies send a representative.
  - Two face to face and three online meetings / year.
- **Activities include:**
  - Symposia all around the world
  - Writing of technical books – discussed later.
  - Creation of on-line instructional modules for professionals and students.
  - Certification of process safety professionals,
    - CCPS Certified → CCPSC
  - Occasionally support research via contractor
  - Monthly *Beacon* newsletter distributed free to anyone.
  - SACHE: Safety and Chemical Engineering Education
    - To support academic instruction in process safety

CCPS Does NOT:

- Have any regulatory function.
- Inspect or rate chemical plants.
- Monitor or evaluate plant performance.
- Investigate incidents.
- Communicate any company performance information to company CEO's.
- Accredit member training programs.

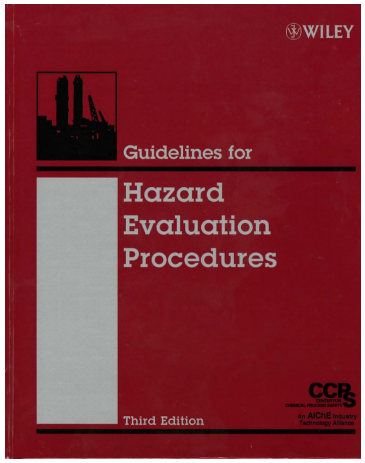
The main function of CCPS is to collect the combined wisdom of all its members and distribute that wisdom worldwide via books, symposia, workshops.

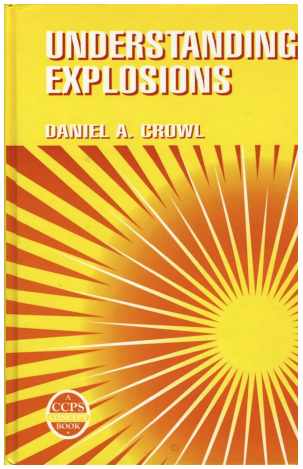
CCPS Book Writing Procedure

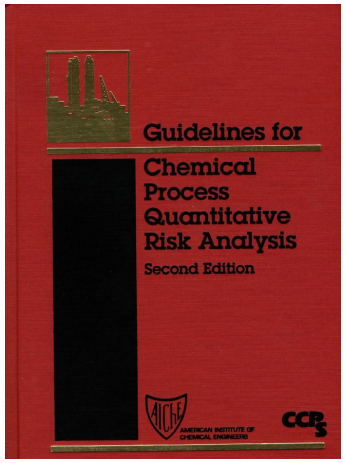
- Technical Steering committee identifies a topic of interest.
- CCPS management decides on funding.
- A committee is formed of technical experts related to this topic.
- CCPS identifies a chair for the committee.
- A book writing contractor is identified. Occasionally the committee writes the book.
- The resulting manuscript is reviewed by technical reviewers.
- Book is published.

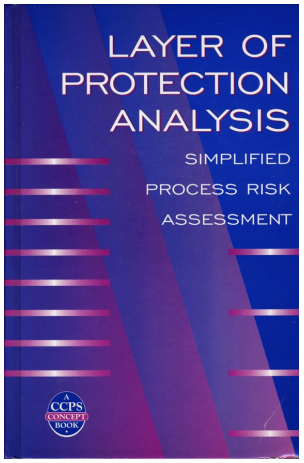
CCPS has published over 100 books on chemical process safety. Many of these books could be a reference for nuclear facilities.

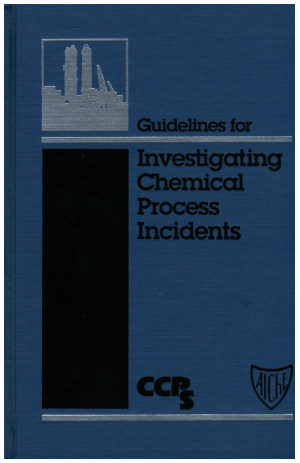
A Sampling of some of the 100+ CCPS Books:







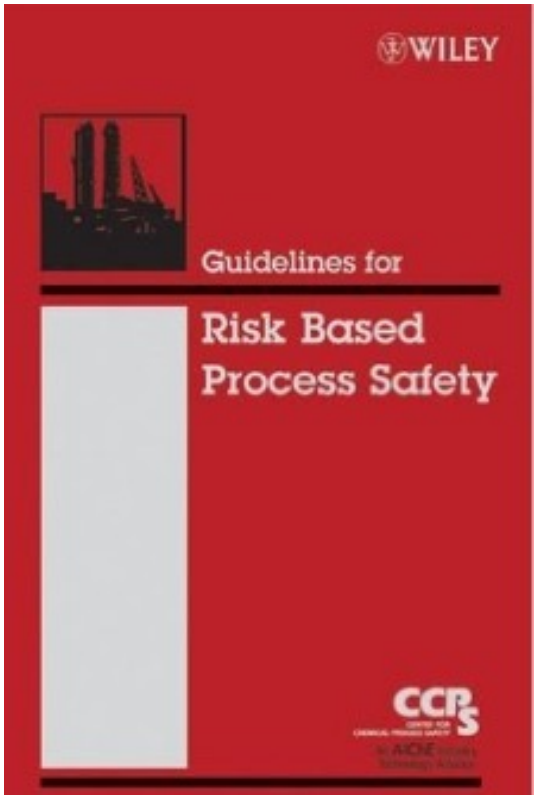




2007: AICHE/CCPS Risk Based Process Safety (RBPS)

Twenty total elements under four major foundation groups:

- **Commit to Process Safety**
  1. Process safety culture
  2. Compliance with standards
  3. Process safety competency
  4. Workforce involvement
  5. Stakeholder outreach
- **Understand Hazards and Risk**
  6. Process knowledge management
  7. Hazard identification and risk analysis
- **Manage Risk**
  8. Operating procedures
  9. Safe work practices
  10. Asset integrity and reliability
  11. Contractor management
  12. Training and performance assurance
  13. Management of change
  14. Operational readiness
  15. Conduct of operations
  16. Emergency management



750 pages!

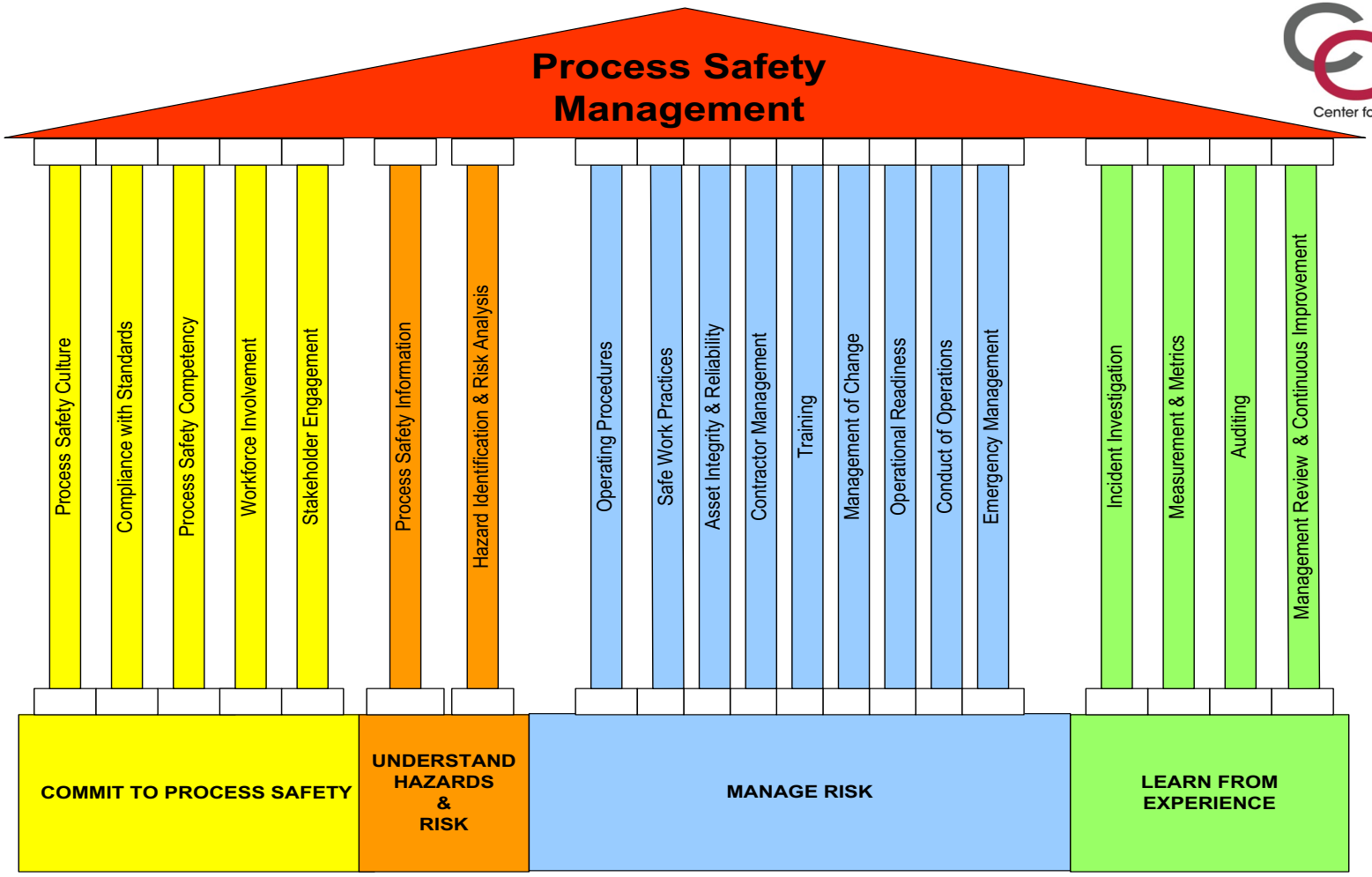
AICHE/CCPS Risk Based Process Safety - 2007

- **Learn from Experience**
  17. **Incident investigation**
  18. **Measurement and metrics**
  19. **Auditing**
  20. **Management review and continuous improvement**

Reference Material on RBPS (all free!).
Please download and read!

Short Summary: 2 pages:
http://www.aiche.org/sites/default/files/docs/summaries/short-summary-of-risk-based-process-safety.pdf

Longer Summary: 38 pages:
https://www.aiche.org/sites/default/files/docs/summaries/rbps.pdf



Source:
Guidelines for Risk Based Process Safety: A Summary (CCPS)

CCPS Risk Based Process Management Safety

All incidents follow the same path, whether chemical or nuclear!

Hazard	→ Initiating Event	→ Incident	→ Outcome	→ Consequences	→ Impacts

Bhopal

MIC in vessel → Water Introduced → Reaction occurs → Vapor Discharge → Toxic cloud formation → Fatalities

Chernobyl

Nuclear fuel → Power surge → Steam explosion → Fission products released → Radioactive contamination → Fatalities

The vocabulary might be different between chemical and nuclear ,
but the sequence of events is the same!
Other factors: latent organizational weaknesses, safety culture, etc.

The hazard identification and risk assessment (HIRA) procedure can be reduced to the following simple framework questions:

1. What are the hazards and how are they characterized?
2. How are the hazards eliminated or controlled?
3. What can go wrong and how?
4. What are the consequences?
5. What is the likelihood? Likelihood = f(probability or frequency)
6. What is the risk and how is it addressed?

These simple framework questions work for any safety program, including chemical and nuclear.

Layer of Protection Analysis (LOPA) – Simplified QRA

In the late 1990s the chemical industry realized that doing a complete Process Hazard Analysis (PHA) and/or a Chemical Process Quantitative Risk Analysis (CPQRA) for everything was a huge effort, required a huge number of resources and took a while to complete. It is sometimes called a "Poor Man's PHA."

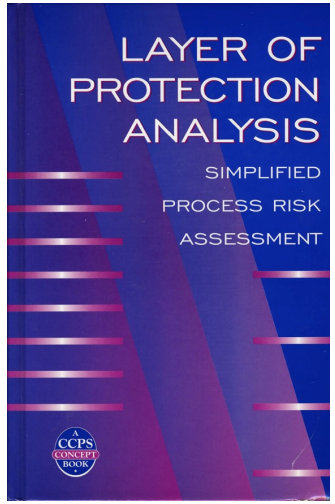
LOPA is a semi-quantitative tool for analyzing and assessing risk.

It typically uses orders of magnitude categories for initiating event frequency, consequence severity, and the likelihood of failure of independent protection layers (IPLs) to approximate the risk of a scenario.

LOPA is implemented using a set of rules.

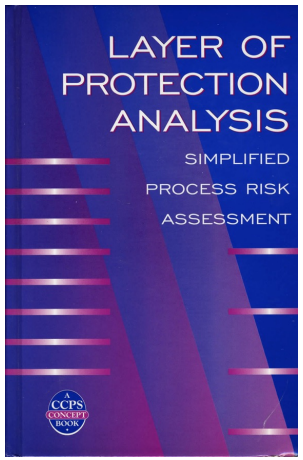
The primary purpose is to determine if there are sufficient layers of protection against an accident scenario.

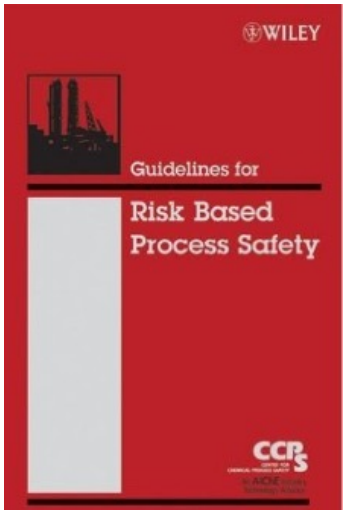
Requires Independent Protection Layers (IPLs) for implementation.



What can the Nuclear Industry Use from Process Safety?

- CCPS Library of 100+ books
- CCPS 20 Elements of Risk Based Process Safety
- AIChE programming via the Global Congress on Process Safety.
- Framework questions.
- Layer of Protection Analysis.
- Others…





Summary / Conclusions

Both the chemical and nuclear industrial communities:

- ❖ Experienced tragic incidents that negatively affected the perception and business of the industry.
- ❖ Experienced increased regulations.

However, both the chemical and nuclear industries:

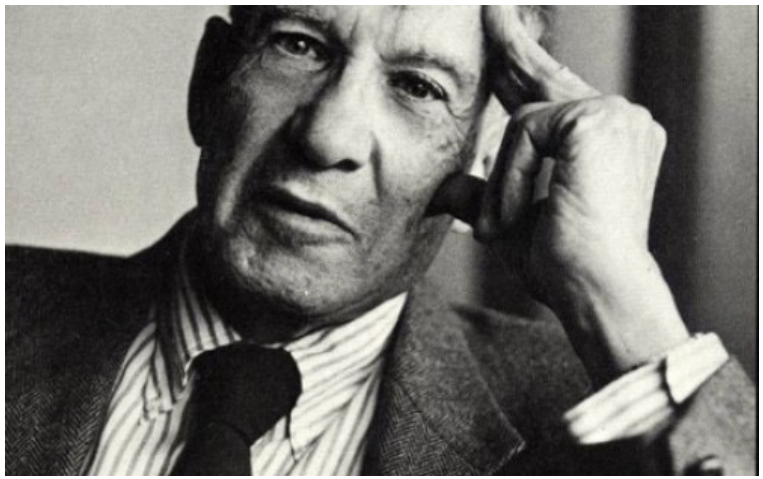
- ✓ Developed an industry-based consortium to address these issues.
- ✓ Developed significantly improved methods to identify and address hazards.
- ✓ Shared this information world-wide via books, reports and other documents.
- ✓ Offer technical conferences & networking opportunities.

Summary / Conclusions (continued)

Both communities have developed methods that would be of value to the other community.

- Chemical sector should consider adopting more robust screening criteria and root cause evaluation tools that are used in the nuclear sector.
- CCPS Library, such as the 20 Elements of Risk-Based Process Safety and LOPA could be potentially used in the nuclear industry.
- Formal or informal sharing of best practices of common interests.

Time for Self-Reflection



Peter Drucker

Don't tell me you had a wonderful meeting with me.
Tell me what you're going to do on Monday that's different.

Questions?

Thank you!