NEA/CSNI Workshop on Safety Assessment of Fuel Cycle Facilities –
Regulatory Approaches and Industry Perspectives
Toronto, Canada, 27-29 September 2011

Risk-informing Safety Reviews of Fuel Cycle Facilities: An Example Application

Presentation by:
Felix E. Gonzalez , Risk and Reliability Engineer
U.S. Nuclear Regulatory Commission

Authors:
V. Mubay; M. Yue; R. Bari: Brookhaven National Laboratory
W. Mukaddam; G. Good: Cambridge Chemical Technologies, Inc.
M. A. Azarm: Information Systems Laboratories, Inc.
F. Gonzalez: U.S. Nuclear Regulatory Commission

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Agenda

- Introduction and Purpose of Study
- Risk Assessment Considerations and Limitations
- Qualitative Risk Assessment
- Quantitative Risk Assessment
- Conclusion

Introduction

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- Focus of paper is in the analysis methodology
- Hazard of concern: explosions due to nitration oxidation reactions (NOR) in solvent extraction technology

Purpose of Review

- Plutonium Uranium Recovery by Extraction (PUREX) process uses solvent extraction
- Solvent or Liquid-liquid extraction consist in removing compounds from two immiscible liquids (aqueous and organic phases)

Figure: Solvent Extraction Column Example

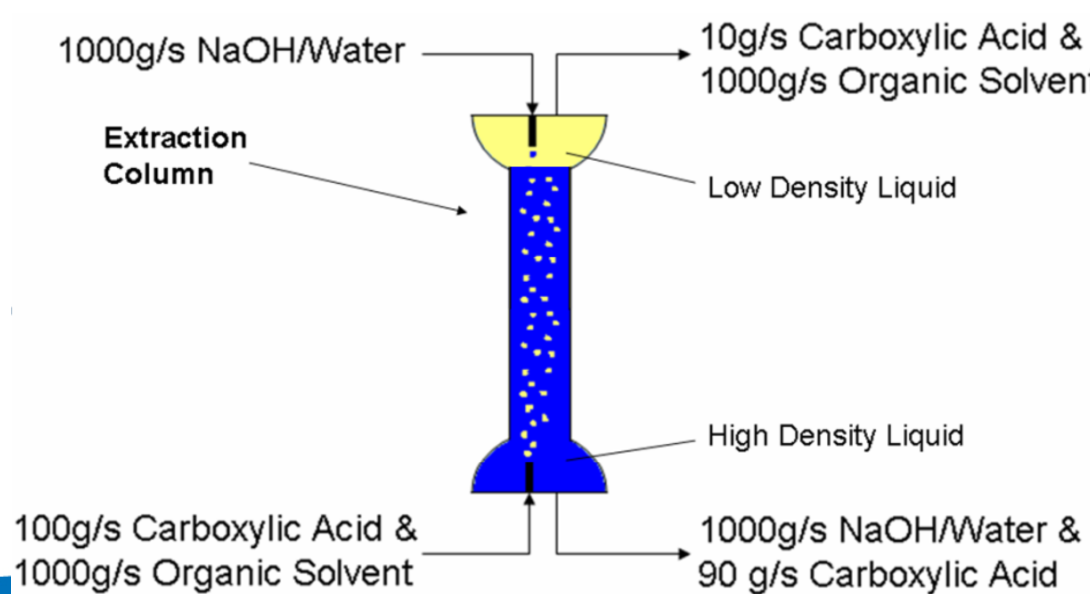

Figure by Felix Gonzalez

Conditions for NOR

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- Temperature above 120oC
- High concentration of Nitric Acid
- Mass of tributyl phosphate (TBP) present
- Lack of pressure equalization system

Risk Assessment Considerations and Limitations

- Limited scope PRA:
  - Generic risk due to external hazards were excluded from the analysis
  - Failures of heat transfer strategy in low temperature process vessels were not considered in the analysis
  - Semi-empirical model for the tributyl phosphate (TBP)-nitrate reactions based on thermal decomposition alone

Risk Assessment Considerations and Limitations

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- Quantitative analysis end state: annual probability of transport of TBP into process equipment with conditions that could promote NOR
- Consequence of NOR was assumed to be high for the facility worker
- Safety controls should be in place to reduce the likelihood of occurrence of the event to highly unlikely
- Consequence analysis was not performed

Qualitative Assessment

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- Screen and prioritize resources to processes of highest risk.

- Factors that may contribute to possibility of NOR:
  - Contact of organic and aqueous phase
  - Potential of TBP transfer
  - Heat sources
  - Heat balance

Process vessels in the table were identified as higher risks and selected for further evaluation in the Quantitative Risk Assessment

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Process Vessel	Safety Strategy	Success Criteria
Evaporator: natural recirculation thermo-siphon type boiler	Evaporative Cooling	- Maintain hot water system temperature below 122°C - Maintain minimum aqueous phase to TBP ratio - Maintain maximum TBP layer depth - Maintain maximum process solution temperature - Adequately vented system
Collection Tank	Evaporative Cooling	- Maintain tank temperature below 80°C - Maintain minimum aqueous phase to TBP ratio - Maintain maximum TBP layer depth - Maintain maximum process solution temperature - Adequately vented system - Tank flush once every six months
Evaporator: natural circulation thermo-siphon evaporator	TBP Prevention	- Prevent transfer of TBP to evaporator

Quantitative Assessment

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- Quantitative evaluation using accident sequence delineation (event trees and fault trees)
- Quantification using SAPHIRE code.
- Point Frequency of conditions that could promote NOR was calculated
- Uncertainty (5th and 95th percentile)

Evaporator 1

- Upset conditions:
  - Normal TBP accumulation
  - Upset accumulation of TBP (Failure of process upstream barriers)
- Initiating Events:
  - Loss of temperature control
  - Heat exchanger tube rupture

Evaporator 1

- Dominant cut-sets:
  - Failure or ineffectiveness of density controls
  - Failure of sampling
  - failure diluents wash column
  - Malfunction of pulse extraction column

Simplified Event tree for condition 1: normal accumulation of TBP

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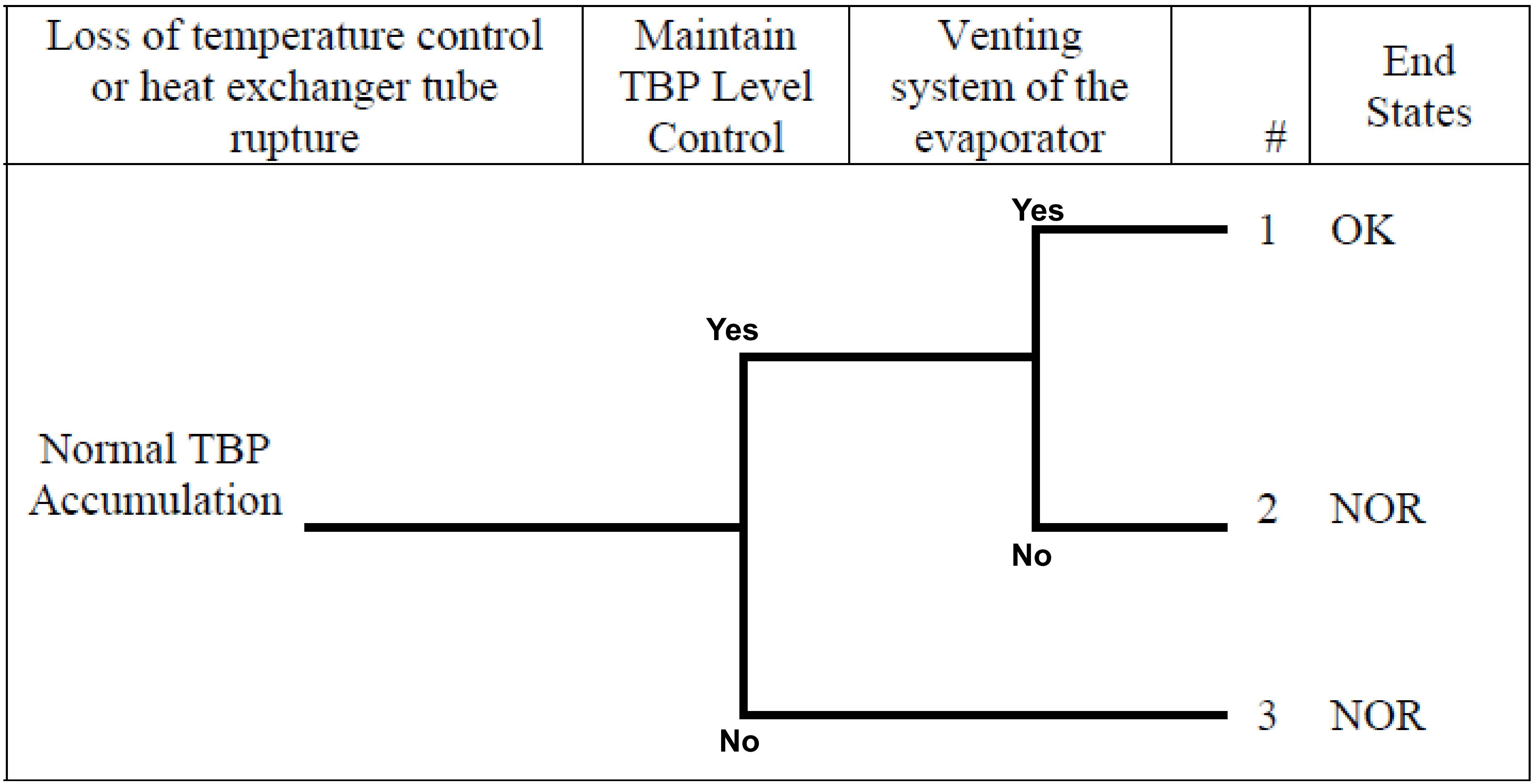
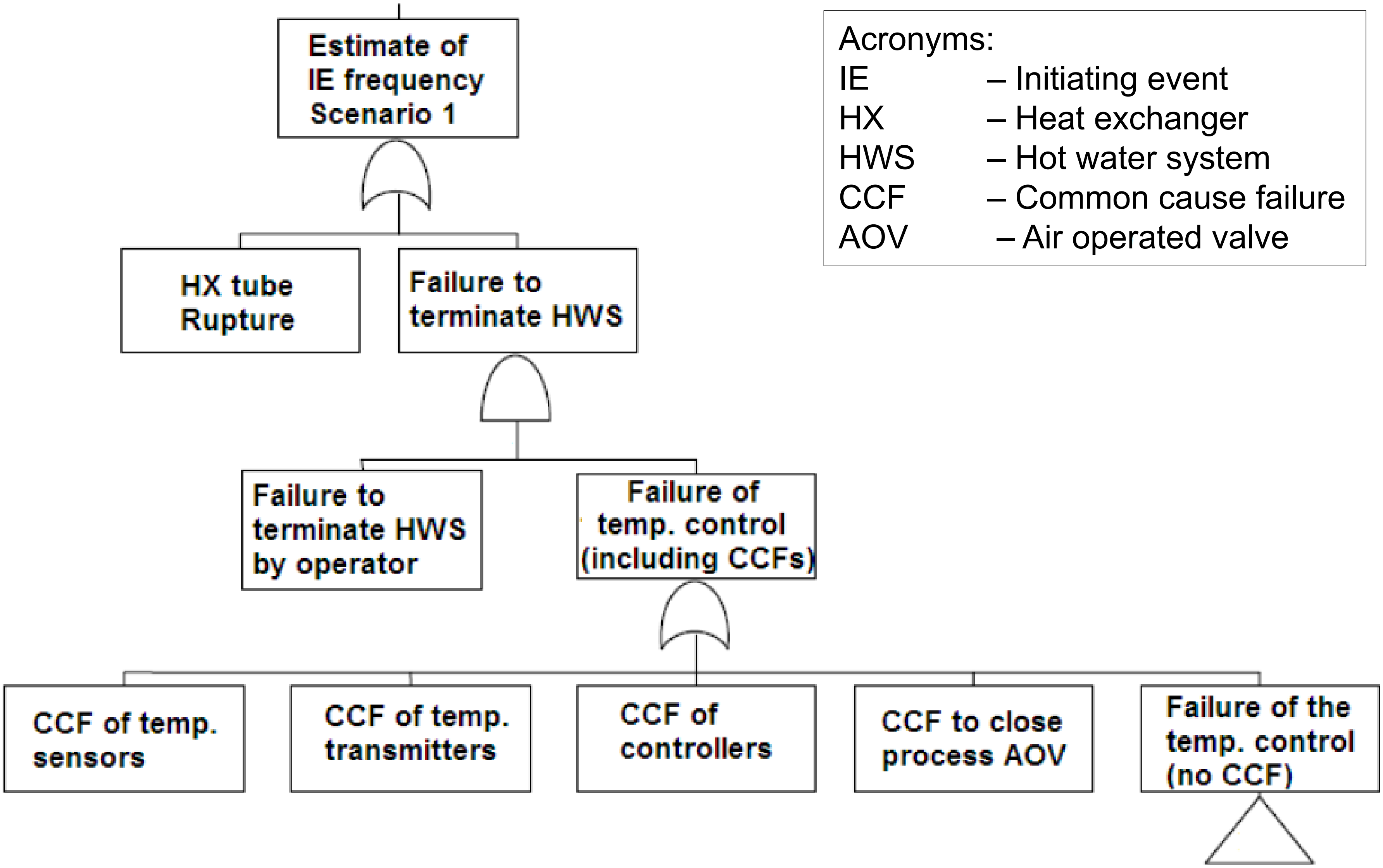


Simplified Fault Tree of Initiating Event frequency of Scenario 1



Acronyms:

IE	– Initiating event
HX	– Heat exchanger
HWS	– Hot water system
CCF	– Common cause failure
AOV	– Air operated valve

Concentrate collection tank

- Upset conditions:
  - Excessive accumulation of TBP
  - Large transfer of TBP

- Initiating Events:
  - Loss of cooling or mixing
  - Failure of spray mixing
  - Loss of mixing

Concentrate Collection Tank

- Dominant cut-sets:
  - Plugging of HEPA filters
  - Operator failure to recognize level alarm and take proper action

Evaporator 2

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- Upset conditions:
  - Accumulation of TBP
- Initiating Events:
  - Mechanical entrainment
  - Process malfunction leading to a relative large transfer of solvent

Evaporator 2

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- Dominant cut-sets:
  - Operational failure of passive systems to separate organic from the aqueous phase
  - Failure of the diluents wash columns
  - Failure of the air lift to stop solution transfer to the evaporator unit

Conclusion

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- PRA methods and tools can be successfully applied to model accident sequences in fuel cycle facilities
- Identify items of higher concern
- Identify vulnerabilities that may arise from combination of equipment failures and human errors
- Challenges:
  - Sparse data (equipment human reliability data)

Questions?

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