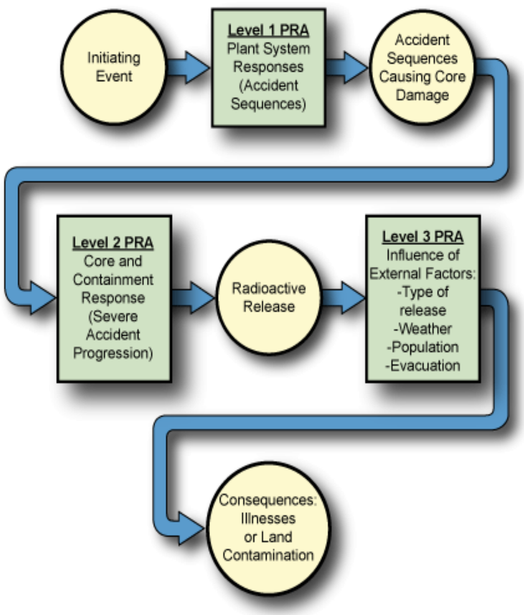

EARLY LESSONS LEARNED FROM RISK APPLICATIONS ON DOE NONREACTOR NUCLEAR FACILITIES

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2012 Department of Energy Facility Contractors Group (EFCOG) Safety Analysis Workshop

Santa Fe, New Mexico – May 9, 2012

Overview of Discussion

- **Draft PRA Standard and DOE Nuclear Safety Policy**
- **PRA Applications**
  - NUREG-1150 LWR Plants
  - DWPF and 1990s Probabilistic Safety Assessment
  - WTP and Current-day Quantitative Risk Analysis of Hydrogen Events
- **Comparison of Methods**
- **Applicable Software and Data**
- **DWPF and Safety Goal Quantitative Safety Objectives**
- **WTP and Preliminary Results**
- **Initial Use of DOE Draft PRA Standard**
- **Insights and Recommendations**

DNFSB Recommendation 2009-1

- **Risk Assessment Methodologies at Defense Nuclear Facilities**
  - Published in July 2009
- **Recognized Quantitative Risk Assessment used throughout complex, engineering systems**
  - NRC: WASH-1400 – 1975; NUREG 1150 – 1990
  - Risk-informed Regulatory applications since mid-1990s
  - NASA application& Chemical Processing Industry
- **Increasing use in DOE Complex was not viewed as objectionable in itself**
- **Board's concern was use of**
  - QRA methods without having in place a clear policy and set of procedures to govern the application of these methods at facilities that perform work ranging from assembly and disassembly of nuclear weapons to nuclear waste processing and storage operations."

DOE Draft PRA Standard (December 2010) - 1

- **Part of DOE Implementation Plan on Defense Nuclear Facilities Safety Board (DNFSB) Recommendation 2009-1**
- **Purpose - Provides guidance and criteria for a standard approach to utilization of probabilistic risk assessments (PRAs) in nuclear safety applications.**
- **Discusses Applicability and Scope**
- **Directed mostly toward the planning of a PRA application**
  - Covers key elements in the development of a PRA Plan, including: (1) planning; (2) approach; (3) results, conclusions, and uses; (4) quality assurance and peer review plans
  - Summarizes performance of the PRA, its documentation, quality assurance and peer review, and peer review results
  - Section 5 describes some potential ways that PRAs can be used to supplement DOE's semi-quantitative hazard and accident analysis process

1. Evaluating Alternative Compliance Approaches
2. Supporting the USQ Process (PISA Process)
3. Supplementing the Traditional Safety Methods
4. Evaluating Changes to DOE Safety Requirements

DOE Draft PRA Standard (December 2010) - 2

- **Appendices provide references for guidance on planning, performing, and applying PRAs for risk-informed decisionmaking**
- References from PRA applications at DOE facilities, chemical and process industries, aerospace industry, and the commercial nuclear power industry
- **Representative examples include:**
- U.S. NRC, Regulatory Guide 1.174, *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis*
- ASME/ANS RA-Sa-2009, *Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications*, Addendum A to RA-S-2008.
- NASA/SP-2010-576, *NASA Risk-Informed Decision Making Handbook*.

- **Topical references for :**
- Standards for PRA and Risk-Informed Decision Making
- Guidance for Risk-Informed Decision Making
- Non-Reactor PRA Applications
- Guidance for PRA Peer Reviews
- Guidance for PRA Methodology
- PRA Methods for Special Topics (Fault Tree Analysis, Database Development and Analysis, Common Cause Failure Analysis, Human Reliability Analysis, Internal Flooding PRA, Internal Fire PRA, External Event Screening, Aircraft Crash Analysis, Seismic PRA, External Flooding PRA, High Winds PRA, Expert Elicitation, Probabilistic Treatment of Phenomena, and Quantification and Treatment of Uncertainties)

Revision to *DOE Nuclear Safety Policy*, DOE P 420.1 (2-08-2011) - 1

- **As stated in *Technical Basis for U.S. DOE Nuclear Safety Policy, DOE Policy 420.1 (July 2011)*, includes five high-level commitments that defines necessary and sufficient actions:**

1. **Establish and implement nuclear safety requirements that utilize national consensus (or other government) standards or applicable regulations in accordance with DOE's process for developing and implementing rules, directives and technical standards.**
2. **Implement core functions and guiding principles of the Integrated Safety Management (ISM).**
3. **Use a safety management approach that includes minimizing use of hazardous material, and establishing controls that provide defense-in-depth.**
4. **Allow appropriate use of quantitative and probabilistic risk assessments (PRA) to support nuclear safety decisions.**
5. **Establish safety goals related to worker and public risk from DOE nuclear facility operations.**

- **Consistent with SEN 35-91 but reflects DOE adoption of ISM**

Revision to *DOE Nuclear Safety Policy*, DOE P 420.1 (2-08-2011) - 2

- Having Safety Goal to conduct operations such that
  (a) Individual members of the public be provided a level of protection from the consequences of DOE operations such that individuals bear no significant additional risk to life and health to which members of the general population are normally exposed, and
  (b) DOE workers' health and safety are protected to levels consistent with or better than that achieved for workers in similar industries.

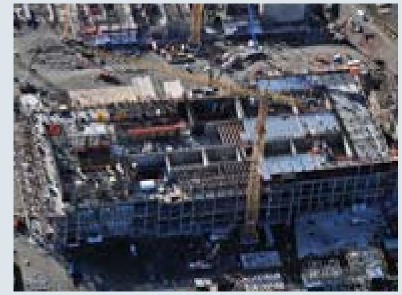
- Two quantitative safety objectives (QSOs) or "aiming points" in support of the Safety Goal that guide the development of DOE's nuclear safety requirements and standards
  – **Acute risk:** The risk to an average individual in the vicinity of a DOE nuclear facility for prompt fatalities that might result from accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatalities resulting from other accidents to which members of the population are generally exposed. For evaluation purposes, individuals assumed are assumed to be located within one mile of the site boundary.
  – **Latent risk:** The risk to the population in the area of a DOE nuclear facility for cancer fatalities that might result from operations should not exceed one-tenth of one percent (0.1%) of the sum of all cancer fatality risks resulting from all other causes. For evaluation purposes, individuals are assumed to be located within 10 miles of the site boundary.

- Same as those established for nuclear power plants by the Nuclear Regulatory Commission (NRC) **Acute: 5E-07 per year** / **Latent: 2E-06 per year**

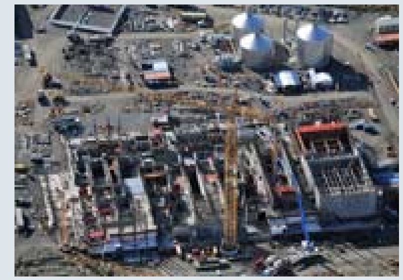
Hanford Tank Waste Treatment and Immobilization Plant

- **WTP will process the majority of the 56 million gallons of radioactive waste stored at Hanford, separating it into high and low activity fractions and vitrifying it**
- **Four major, integrated nuclear facilities – Pretreatment, High-Level Waste, Low-Activity Waste and Analytical Laboratory**
- **Over 60% complete**
- **Construction to be completed in 2016 and full operations in 2022**
- **Waste processed at WTP will be capable of producing detonable mixtures of hydrogen and oxidizers in vessels and piping**
- **Initiated QRA project for hydrogen events project in 2009 to inform final piping design**
    - Not a surrogate for DOE-STD-3009 safety analysis

PTF



HLW



LAW

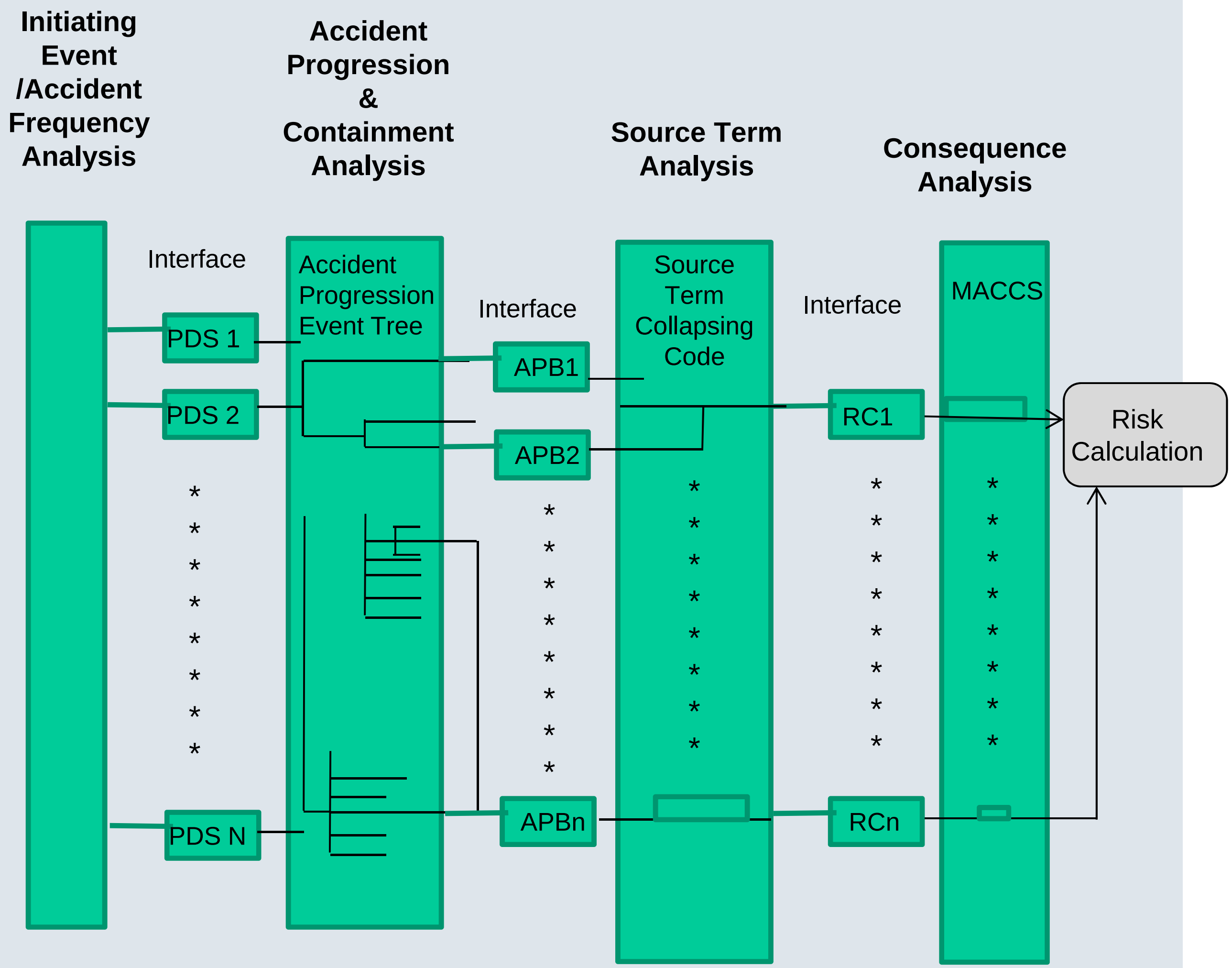
LAB

Overview of Defense Waste Processing Facility & PSA

- **DWPF (42,000 ft^2 facility) receives, treats, and immobilizes alkaline slurries of aqueous high level waste from SRS tank farms in a durable, borosilicate glass**
- **In operation since 1996**
- **Ultimately, plan to fill 7,557 canisters (about halfway complete by end of January 2012)**
- **About 36 million gallons of liquid nuclear wastes are stored in 49 underground carbon-steel tanks to be processed**
- **Pre-operational PSA performed with best information available 1993-1995**
  - "Snapshot" of anticipated operations
  - Does not mirror operations after 16 y
  - Not maintained beyond publication and not applied to Safety Basis

NUREG-1150 Probabilistic Safety Assessment

- **Full-Level 3, reactor-style PSAs standard set by NUREG-1150 study (1990)**
- **Five operating LWRs evaluated from initiating event through to quantification of risk and NRC safety goals**
  - Grand Gulf/BWR
  - Peach Bottom/BWR
  - Sequoyah/PWR
  - Surry/PWR
  - Zion/PWR
- **Four-step, probabilistic risk analysis**



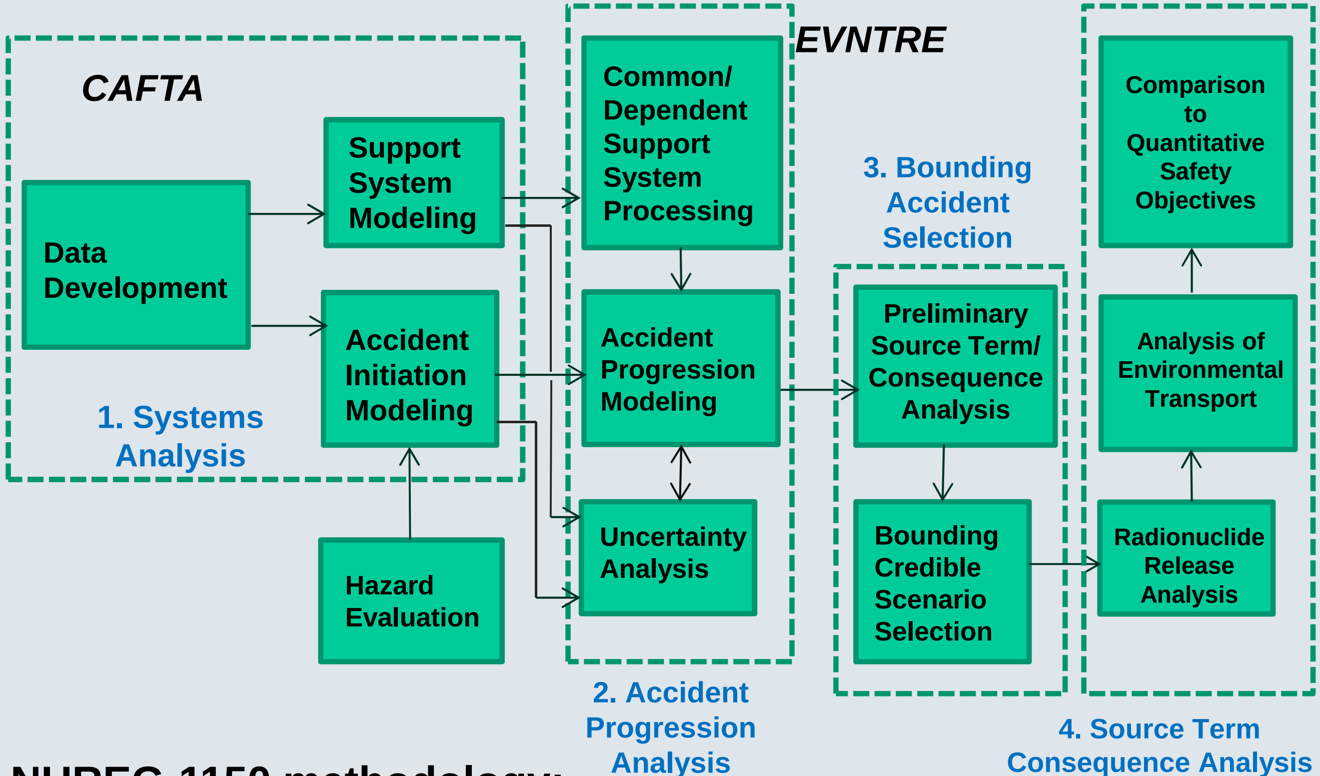
Key Differences: Commercial Nuclear Power Plant (NPP) PRA Compared to PSA & QRA Studies

Characteristic	Risk Study		
	NUREG-1150 PRA Study	DWPF PSA Study	WTP QRA of Hydrogen Events
Nuclear Facility/Mode	**Nuclear Power Plant/ Steady-State, Continuous Operation**	**Waste Processing, Nuclear, Nonreactor/ Batch Operation**	**Waste Processing, Nuclear, Nonreactor/ Batch Operation**
Facility Design	**Standardized PWR and BWR designs; (multiple containment types)**	**Unique design; confinement system**	**Unique design; confinement system**
PRA type	**Radiological Risk; Plant-specific**	**Radiological Risk; Facility-specific**	**QRA of hydrogen events; Piping route specific**
PRA timing "snapshot" PRA performed & Year of Operation/Start up	Operating plants; Published in 1990: 1. Grand Gulf 1 (BWR-6) - 1985 2. Peach Bottom 2 (BWR-4) – 1974 3. Sequoyah 1 (4-loop PWR) – 1981 4. Surry 1 (3-loop PWR) – 1972 5. Zion 1 (4-loop PWR) - 1973	• Pre-operational • PSA performed in 1993-1994 • Startup in 1996	• Pre-operational • Design of the plant to be complete by 2013 • Construction to be completed in 2016, along with start-up of plant systems • All facilities and systems to be fully operational in 2019
Operational modes	**Severe accidents; internal & external initiating events**	**Design basis events; Normal operation Internal & external initiating events,**	**Design basis events; Normal operation Internal & external initiating events,**
Risk metrics	**Acute fatality and latent cancer fatality risks; others; Safety Goal Compliance**	**Acute fatality and latent cancer fatality risks; others; Safety Goal Compliance**	**Frequency-Severity curves for different hydrogen event types**
Risk output format	**Complementary cumulative distribution functions (CCDFs);Safety goal risks @ mean level**	**Complementary cumulative distribution functions (CCDFs); Safety goal risks @mean level**	**Complementary cumulative distribution functions (CCDFs); design based on load at the 95th percentile**

NUREG-1150/DWPF PSA/WTP QRA – Software & Data

Characteristic	Risk Study		
	NUREG-1150 PRA Study	DWPF PSA Study	WTP QRA of Hydrogen Events
Fault tree software	CAFTA V1.7 and successor versions	CAFTA, V2.2	CAFTA V5.4
Equipment reliability data	• NUREG/CR-2300 • NUREG/CR-4550, • NUREG-4780 • Others	• WSRC-TR-93-262 • SRS Fault Tree Data Bank • IEEE 500-1984	• NUREG/CR-6928; • WSRC-TR-93-262, Rev. 1;
Human reliability data	• NUREG/CR-4772 (Swain et al.)	• NUREG/CR-1278 (earlier Swain et al.)	• WSRC-TR-93-581 • Others
Common cause failures	• NUREG/CR-4780	• NUREG/CR-4780 • NUREG/CR-5460	• NUREG/CR-5485
Event tree software	EVNTRE	EVNTRE	Gas Pocket and Event Progression Logic Model Custom-developed
Event tree data	• Extensive testing program • Integrated model calculations	• Preliminary Hazards Analysis • Precursors to DOE-HDBK-3010	• Extensive multiyear, multisite testing program • WTP-specific

DWPF PSA Followed Majority of NUREG-1150 Methodology



<u>Similar to NUREG-1150 methodology</u>:

1. Systems Analysis (CAFTA models)
2. Accident Progression
3. Source Term Binning
4. Consequence Analysis & QSO Quantification

- In principle, could extended to nonradioactive (chemical) plant analysis & consequences
- Considered full range of Internal and External events
- Demonstrated comprehensive uncertainty analysis

DWPF/Pre-operational Snapshot – Individual Risk Worker and Public

Components to Individual Risk	Individual Worker (LCF/y)	Individual Public (LCF/y)
Normal	1.3E-07	4.0E-08
External Events	9.9E-08	4.7E-09
Internal Events	5.9E-09	4.2E-10
Total	2.4E-07	4.5E-08
QSO	2.0E-06	2.0E-06

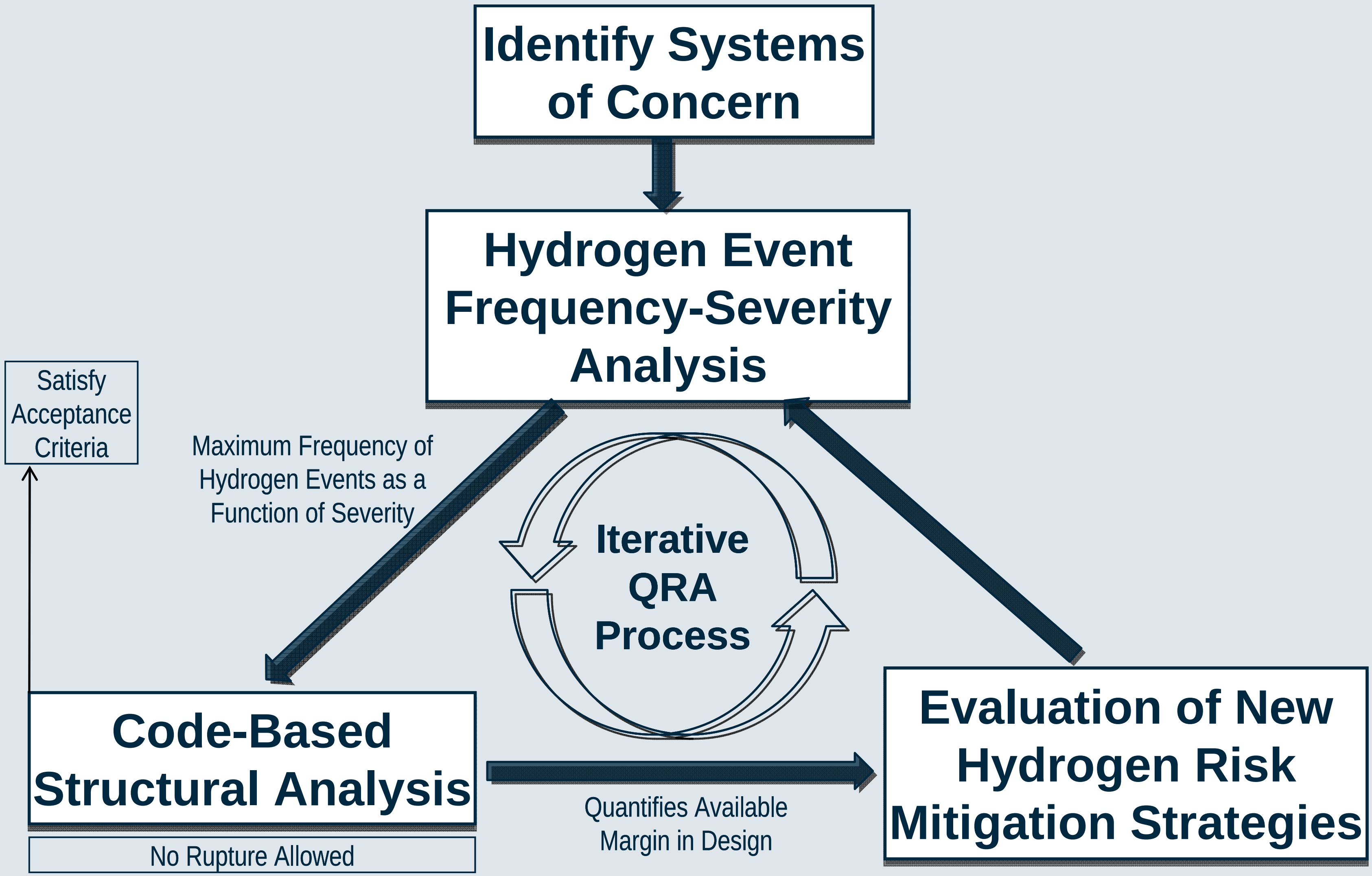
Hanford Tank Waste Treatment & Immobilization Plant (WTP) QRA

- **NRC issued Information Notice 2002-15, "Hydrogen Combustion Events in Foreign BWR Piping," describing catastrophic failures of high-pressure BWR process piping attributed to the accumulation of hydrogen ga**
- **While WTP Vessels designed to prevent detonable amounts of hydrogen**
  - Piping not originally designed with such protection
- **Waste produces hydrogen and oxidants due to radiolytic decomposition, and radiolytic and thermolytic decomposition of organic components**
- **Hydrogen and oxidants can accumulate in stagnant regions of piping when waste containing systems stop flowing**
  - Normal process evolutions
  - Faulted condition or accident events (e.g., loss of power, seismic event, etc.)
- **Hydrogen accumulation in sufficient quantities in piping systems could cause damage if ignition occurred**
- **QRA Suggested in late 2008 to guide late stages of piping design**

Quantitative Risk Analysis

- Quantitative Risk Analysis (QRA) used to evaluate the potential frequency and severity of postulated hydrogen events at WTP
- Provides technical basis for weighting the severity of a postulated hydrogen event with its associated frequency
- Uses Monte Carlo simulation to permit evaluation based on appropriate uncertainty/variation in input parameter and their distribution
- Uses hydrogen event types to define pressure time history of structural loads for use in code-based structural analysis
- Provides an integrated treatment of both the design, operational frequency analysis and phenomenological model (governing physics) of hydrogen events

Iterative QRA Process

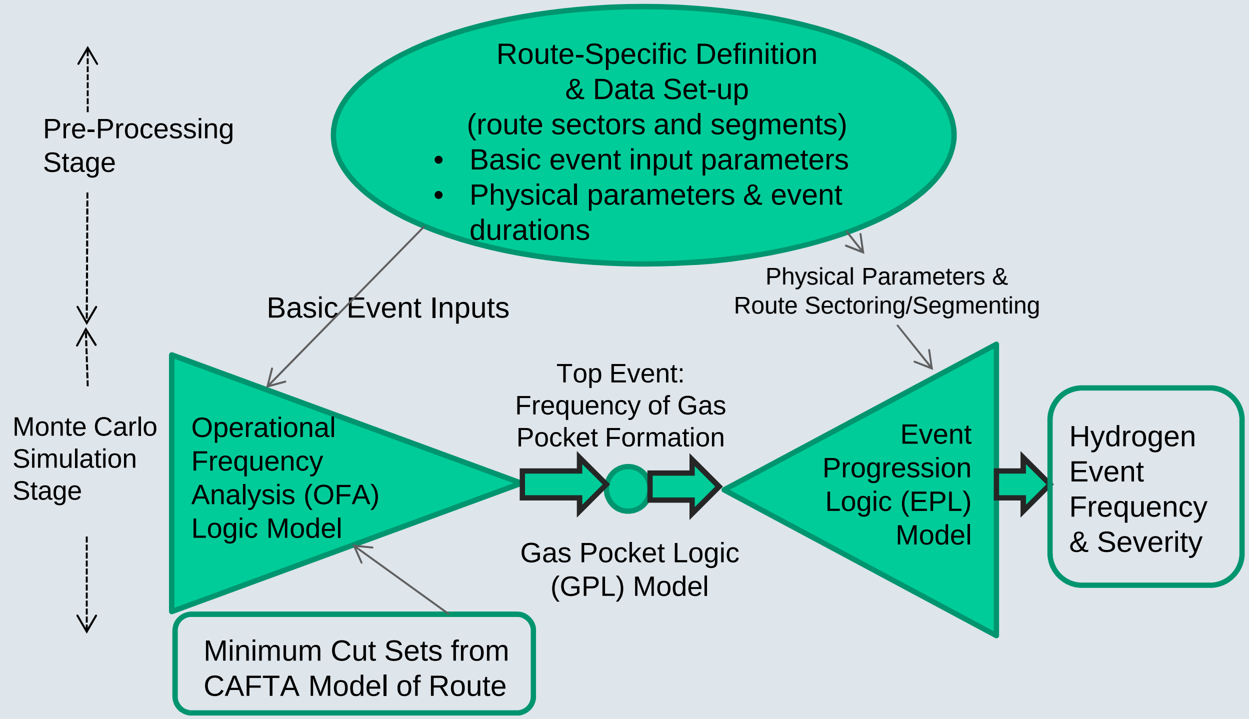


QRA Methodology – *Event Frequency-Severity Analysis*

Structure for hydrogen event frequency-severity analysis

- **Pre-processing** of plant / operational data and definition of required user inputs / assumptions
- **Probabilistic frequency analysis and event progression** with Monte Carlo simulation
  - **Operational Frequency Analysis (OFA):** Quantifies frequency of conditions that can support gas pocket formation
  - **Gas Pocket Formation (GPF) Model**: Quantifies realistic gas pocket parameters (e.g., size, composition, $p_{initial}$)
  - **Event Progression Logic (EPL) Model**: Evaluates event progression logic to quantify event type and severity
- **Post-processing** of MC simulation results and risk aggregation

QRA of Selected Piping Systems in WTP



- **Software applied is identical to full PRAs – e.g., CAFTA, EVNTRE, Crystal Ball**
- **FTA uses standard industry data – e.g., IEEE Gold Book, FTA, and applicable plant and system data**

Faulted Conditions Leading to Gas Pocket Formation

- **OFA models route-level and plant-level conditions leading to gas pocket formation**
- **Route-level sources of gas pocket formation**
  - Interrupted waste transfer operations
  - Completed waste transfer but interrupted flush or other hydrogen event mitigation
  - Gas accumulation in instrumentation or access points in the piping system
- **Plant-level conditions that could lead to gas pocket formation**
  - Internal fires and seismic events
  - Loss-of-offsite power (LOSP); Seismically-induced LOSP
  - Ashfall effects
  - Failure in a support system or an integrated control network failure

Tailoring the OFA Model for Each Route

OFA Model contains all potential route configurations

Route-specific and segment-specific information entered into Basic Event (BE) table

Operations, Engineering, & Nuclear Safety representatives review and agree with BE table inputs

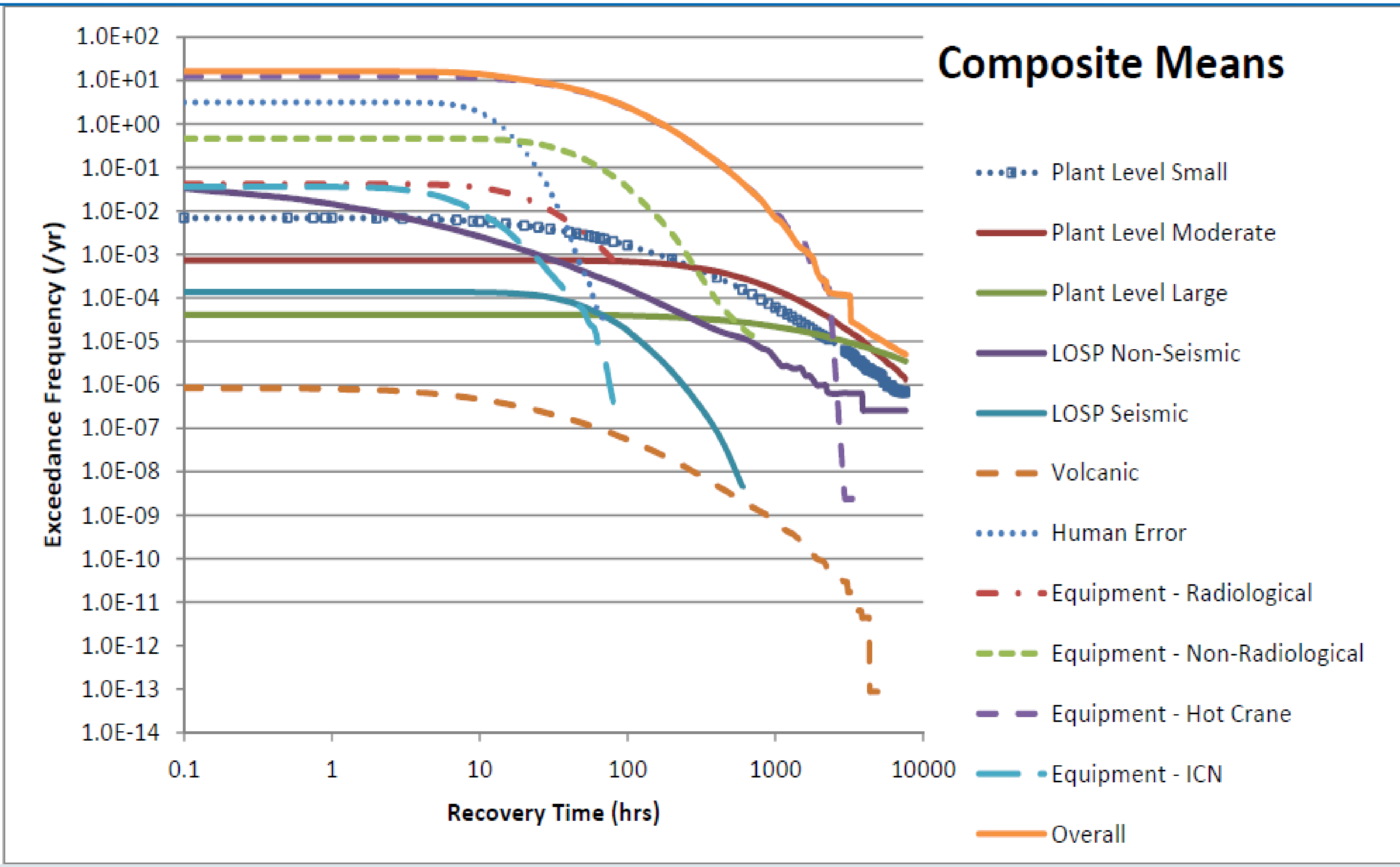
The BE table inputs turn parts of the OFA logic model ON and OFF and to produce a route-specific cutset

Multi-disciplinary/functional team to review model inputs also reviews model outputs

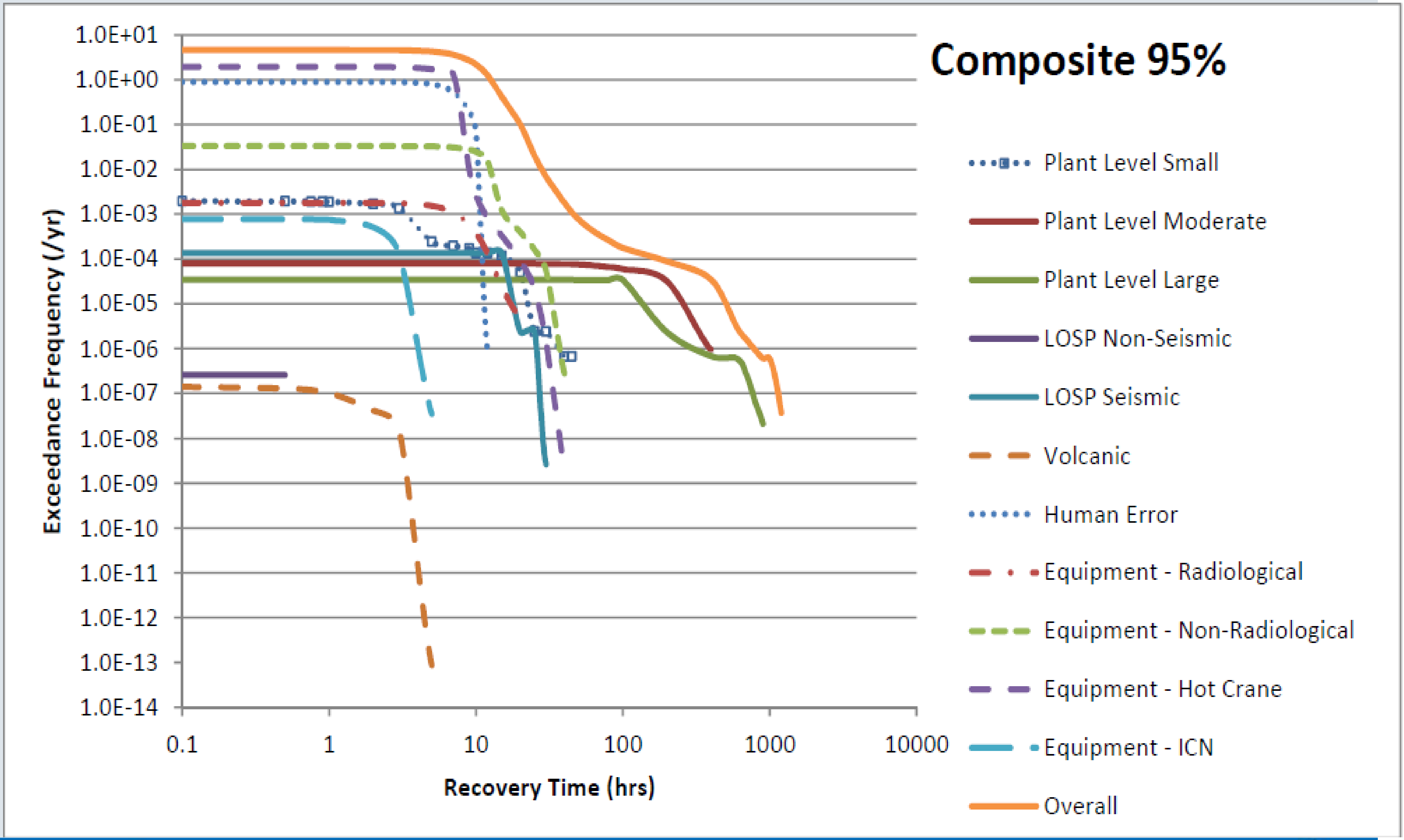
Current (Preliminary) Results

- **QRA allows relative understanding of risk – operational/normal compared to accident-initiated conditions & basis for prioritization by resolving leading sources of risk**
- **Operational risk and faulted condition risk comparison Routes with dead legs are being reexamined for dead leg placement and location, and whether their monitoring & sampling functions could be met otherwise**
- **Route-level accident conditions are much more likely to result in gas pocket formation than plant-level events**
- **Over 90% of the recovery time distribution risk is from piping route initiated accident conditions**
  - Several AOV failures are being explored for follow-up alternatives to reduce or eliminate the vulnerabilities
- **Updated, more complete picture to be provided by Mike Wentink & Ryan Jones - Risk Applications Panel Thursday, May 10th**

Representative Results: Recovery Time/1



Representative Results: Recovery Time/2



DOE Draft PRA Standard

- **DOE Risk Assessment Standard (December 2010)**
  - ➢ Weighted toward planning aspects and thus was not available prior to QRA initiation
  - ➢ Useful in assessing performance, documentation, developing risk metrics, quality assurance, and planning peer review.
  - ➢ Also led to early planning on uncertainty analysis, compliance with ASME/ANS PRA standard, etc.
  - ➢ Useful set of use nuclear, chemical and other high-hazard methods/data sources
- **Would benefit from risk applications "Examples" section**
  - ➢ Technical examples (ranging from simple to more complex)
  - ➢ Process or regulatory examples
- **Standard highlighted needed for robust peer review process and carefully choosing risk metrics especially in nontraditional applications**

Overarching Insights from the PSA and QRA Studies

- **Risk applications can complement traditional safety applications**
  - 1990s Pre-operational DWPF PSA radiological risk
  - Current-day WTP QRA for risk-informing design
- **Nuclear reactor based methods and software are extendable to safety applications for nonreactor risk applications**
  - Use of FTs and ETs, and consequence methods are straightforward
  - CAFTA, EVNTRE, and other software (e.g., MACCS2, GENII) can be applied
- **Provides clearer, more systematic basis to identify design and operational vulnerabilities and prioritize resolution than would be from deterministic analysis alone**
  - Yields a relative ranking basis for preventing and/or mitigating certain accident conditions
  - Relative risk values are often more useful than the absolute risk values
    - If the latter used to inform decision-making then strongly suggest uncertainty analysis be performed (or quantification of retained margin)

Quantitative Safety Objectives and Recommendations

- **Identifies design improvement opportunities**
- **Nonreactor nuclear facility risk tends to have appreciable contribution from normal anticipated operations**
- **Nonreactor nuclear risks and quantitative safety objectives**
  - ➢ **Acute individual fatality risks are for all intents and purposes, zero**
  - ➢ **Latent individual fatality risks are much lower than QSO (2.0E-06/year)**
- **Recommend augmenting DOE Risk Application Standard with risk application examples as separate appendix or as a standalone guide**
- **Recommend re-establishing DOE-applicable failure dataset**
  - ➢ **Current nuclear industry data sources are not always applicable to DOE nuclear facilities**
    - ▪ **Spectrum of nuclear and chemical environments**
    - ▪ **Change with operating history**
  - ➢ **Older data sources have not been maintained and updated**
  - ➢ **Suggest both human and equipment reliability data source upgrades**

Back-up Information

- Acknowledgments
- QRA Reviews
- Generic OFA FT
- HRA Methods Reports

Acknowledgments

- PSA - DWPF – Jackie East + Others
- QRA – WTP – Ryan Jones, Jean Collin, David Gross (DEI)
- Sarah Lachmann, Bechtel National, Inc.
- Carl Benhardt, Hank Ford, Mike Hitchler - URS
- Operations, Design, Engineering – BNI

QRA Peer Reviews

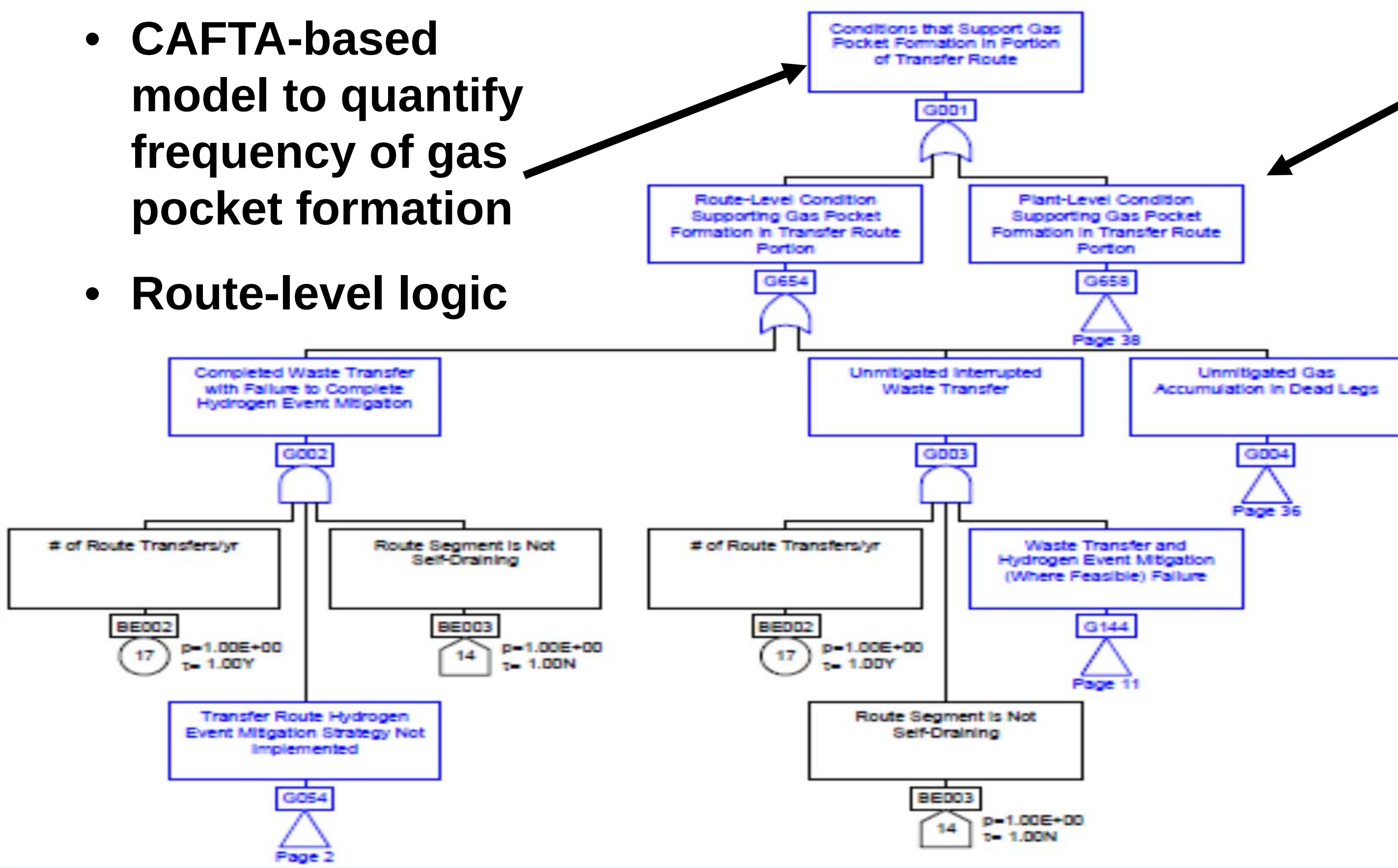
- **DOE Health Safety & Security (O'Brien)**
- **Brookhaven National Laboratory (Bari)**
- **Independent Review Team (Mattson)**
  - Three Teams (QRA, Gas Phenomenology, and Structural)
- **QRA Peer Review Team (Mattson)**

OFA – “Level 1” of the QRA

← Route-level events → ← **Plant-level events** →

- **CAFTA-based model to quantify frequency of gas pocket formation**
- **Route-level logic**

Logic accounts for plant-level events



Human Reliability Data Sources

- **WSRC-TR-93-581, "Savannah River Site, Human Error Data Base Development for Nonreactor Nuclear Facilities (U)", February 1994.**
  - Based on a number of other sources
  - Used SRS data where available
  - Primary source for analyses
  - Sometimes additional shaping factors are required
- **NUREG/CR-1278, "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Applications", August 1983**
  - Provides base human reliability failure probabilities and shaping factors
  - Used as source to evaluate situations that are not adequately by the SRS Human Error Data Base