Testing the PCSA Tool for a Pre-closure Safety Analysis of a Potential Yucca Mountain Repository

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2004 American Nuclear Society Annual Meeting
Pittsburgh, PA, June 15 to 17, 2004

OUTLINE

- **Background**
- **Potential Yucca Mountain Repository**
- **Pre-Closure Safety: regulatory requirements**
- **Pre-Closure Safety Analysis (PCSA) Tool**
- **Sensitivity Study: airborne release fractions, meteorological parameters, combined parameters, probabilistic approach, and event sequences, focusing on the spent nuclear fuel (SNF) performance**
- **Dose from Potential SNF Breaches**
- **Release Fraction: standards and guides**
- **Summary**

BACKGROUND

- **The NRC will decide if the DOE's license application for construction and operation of a geologic repository contains the necessary information to determine whether the repository can operate within the dose limits specified in 10 CFR Part 63.**

- **The NRC has been developing an independent capability to evaluate the DOE's license application.**

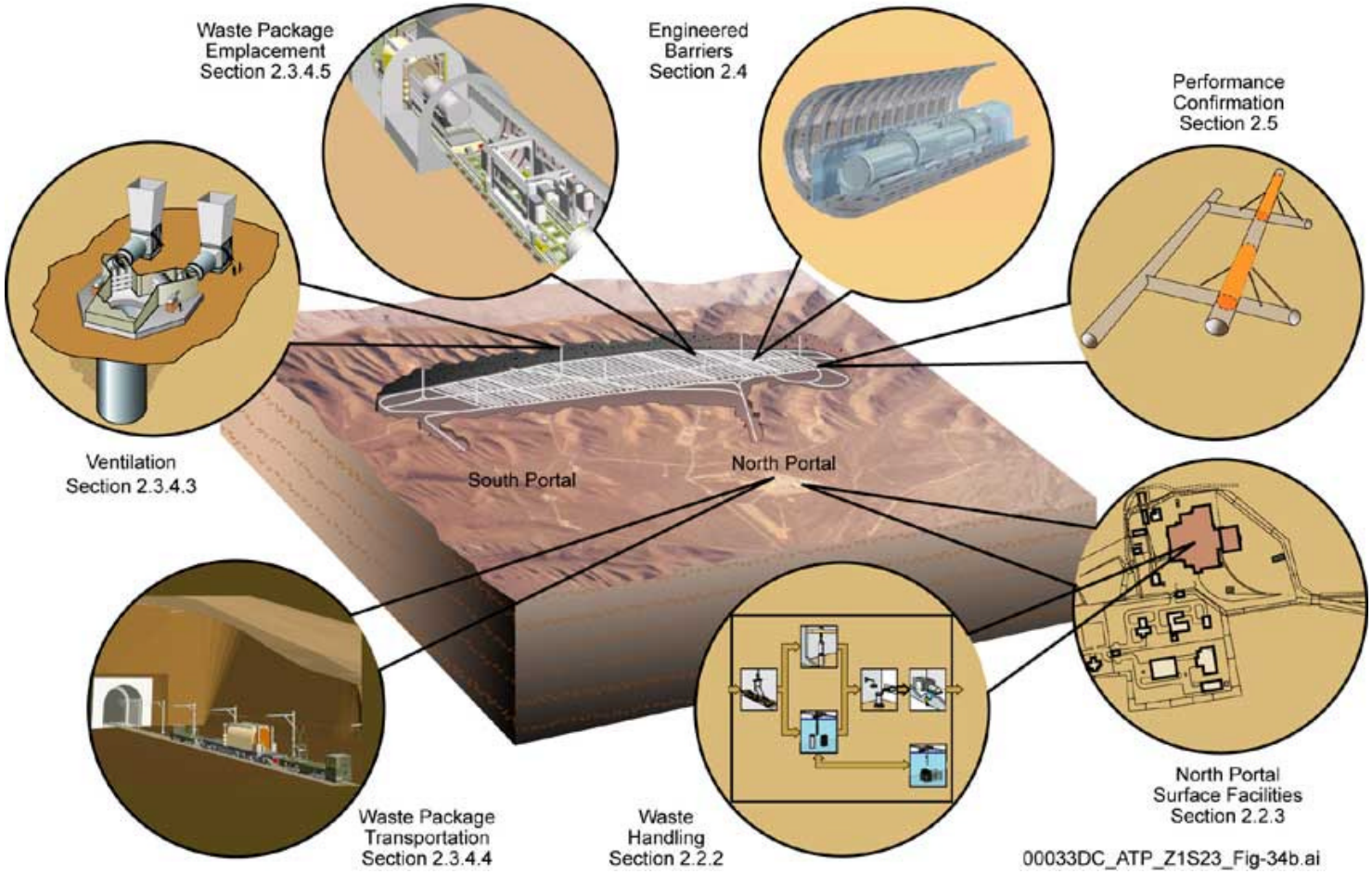
- **The pre-closure period is when the HLW will be packaged and emplaced before closure of repository.**

- **In order to systematically perform the review of pre-closure safety analysis (PCSA), a software program, named the "PCSA Tool," was developed by the Center for Nuclear Waste Regulatory Analyses (CNWRA).**

- **To establish bases for the licensing review of the pre-closure safety at the potential Yucca Mountain repository, PCSA Tool and sensitivity study examples will be described.**

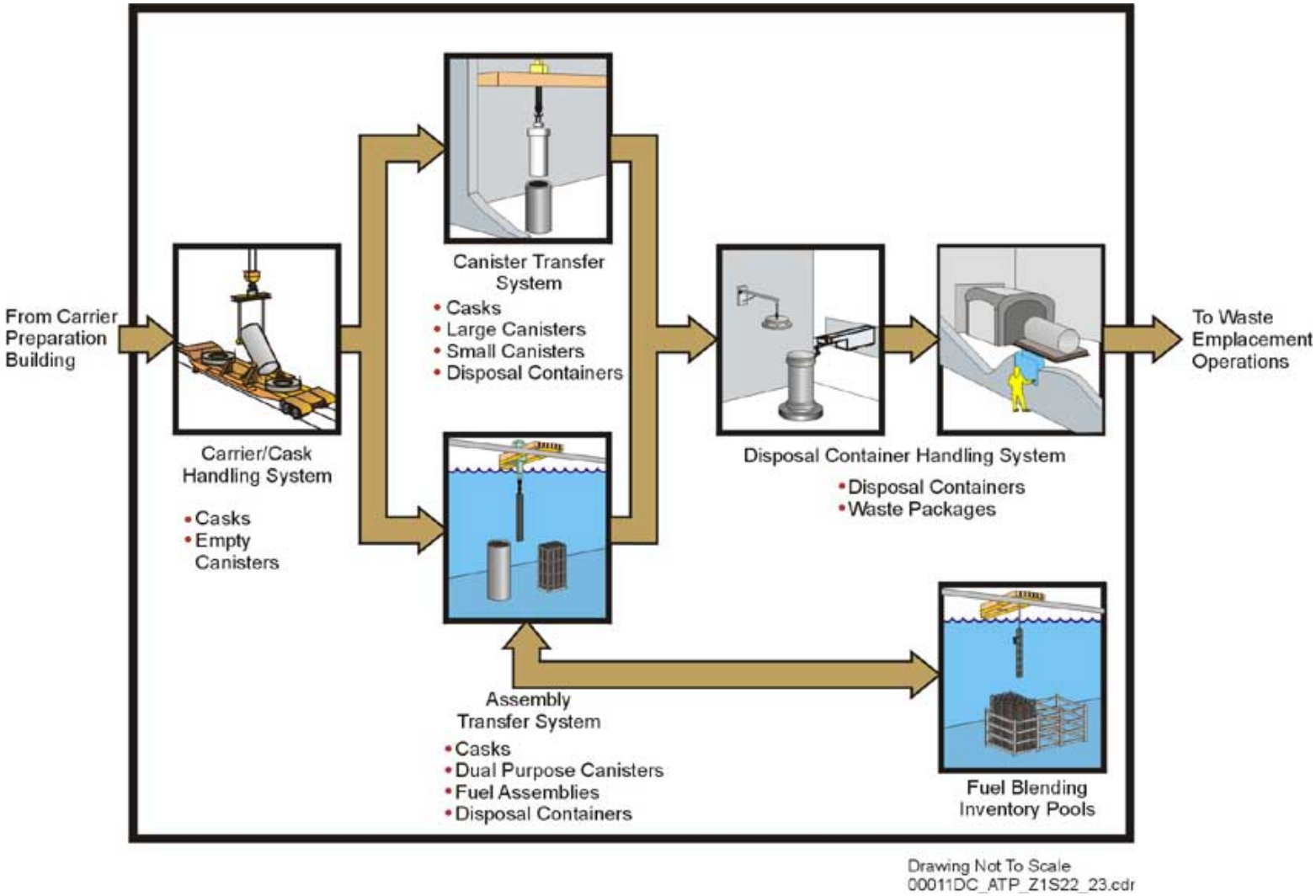
POTENTIAL YUCCA MOUNTAIN REPOSITORY

Potential Monitored Geologic Repository Facilities at Yucca Mountain (DOE, 2002): Pre-closure



POTENTIAL YUCCA MOUNTAIN REPOSITORY

Waste Handling Operations (DOE, 2002)



PRE-CLOSURE SAFETY:
regulatory dose requirements

(1) To the Public:

- **During normal operations and for Category 1 event sequences expected to occur one or more times during the pre-closure period, the annual total effective dose equivalent beyond the site boundary may not exceed 15 mrem/yr.**

- **Each Category 2 event sequence occurring at a chance of 1 in 10,000 once in the pre-closure period: limit of 5 rem/yr**

(2) To the Worker:

- **Annual limit of 5 rem from normal operations or Category 1 event sequences**

- **ALARA**

PCSA TOOL: Input Data for Safety Analysis

- **Functional Areas: the physical boundaries of facility operations**
- **System Description: information required for safety analysis in a functional area**

PCSA TOOL: Naturally Occurring and Human-induced Hazards and Initiating Events

- **Site-Specific Hazard Analysis Review: the naturally occurring events and human-induced events common to all functional areas in the facility**
- **Operational Hazard Analysis: events resulting from the facility operation for each functional area**
- **Initiating Events**

PCSA TOOL: Event Sequence Analysis

- **Event Scenarios: first identifying an initiating event from the site-specific and operational hazards analyses, then propagating through a series of potential safety-related systems/operations functions or failures to yield event sequence.**

- **Failure Rate Database: a comprehensive library of failure rates of equipment from actuarial data**

- **Event Frequency Analysis: event trees and fault trees are analyzed using the stand-alone software, SAPHIRE Version 6.70**

- **Event Sequence and Categorization: results from the event tree analysis (e.g., SAPHIRE)**

PCSA TOOL: Analysis of Consequence

- **Public Dose: point estimate or probabilistic calculations of public dose using RSAC**

- **Worker Dose: a stylized spreadsheet calculation to estimate dose to the facility workers, provisions for offline worker dose calculation.**

PCSA TOOL: Safety Assessment

- Integrate and analyze the results obtained in the various tasks for safety assessment

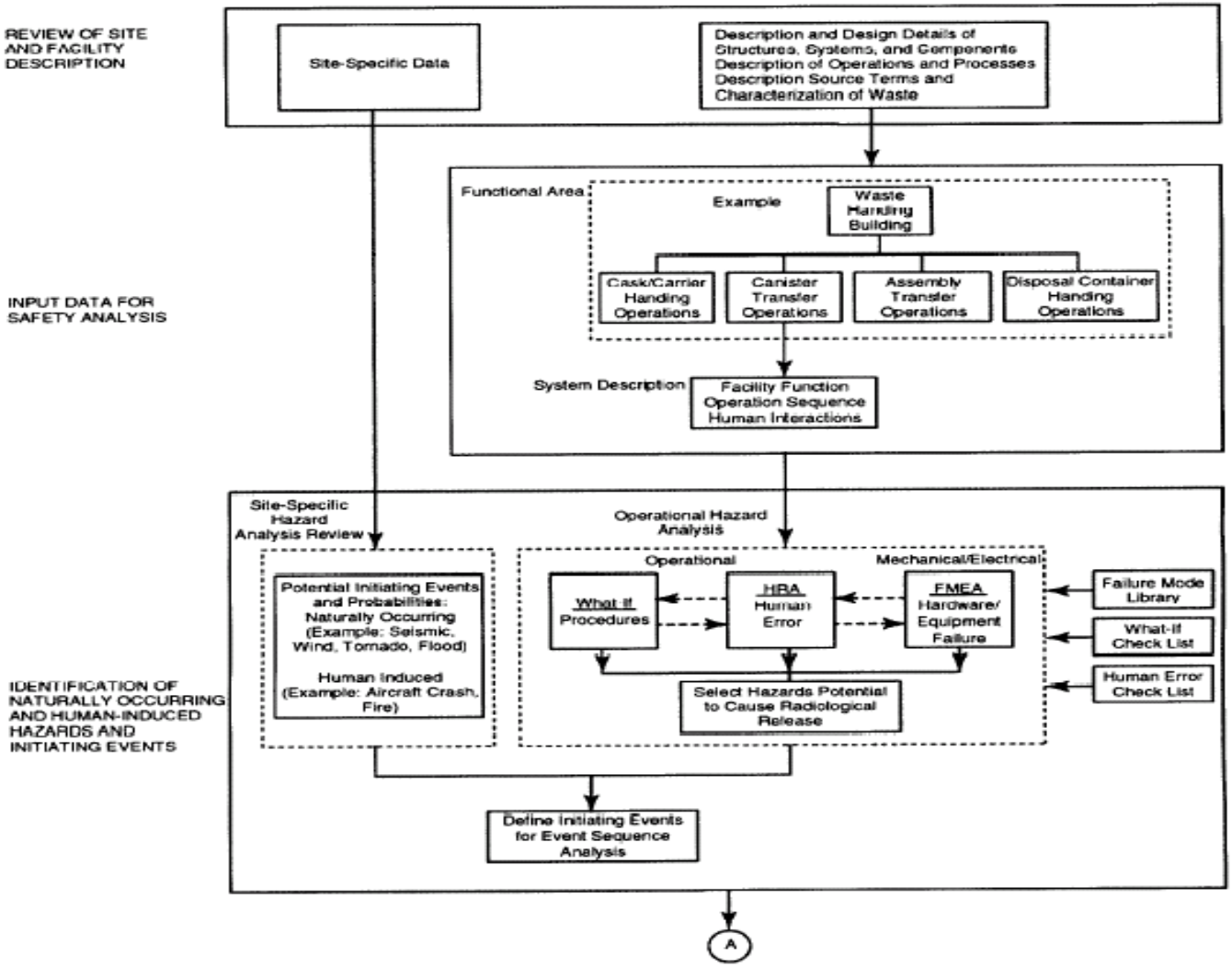
PCSA TOOL: Risk Assessment

- Evaluate aggregate risk from a potential repository during the pre-closure period

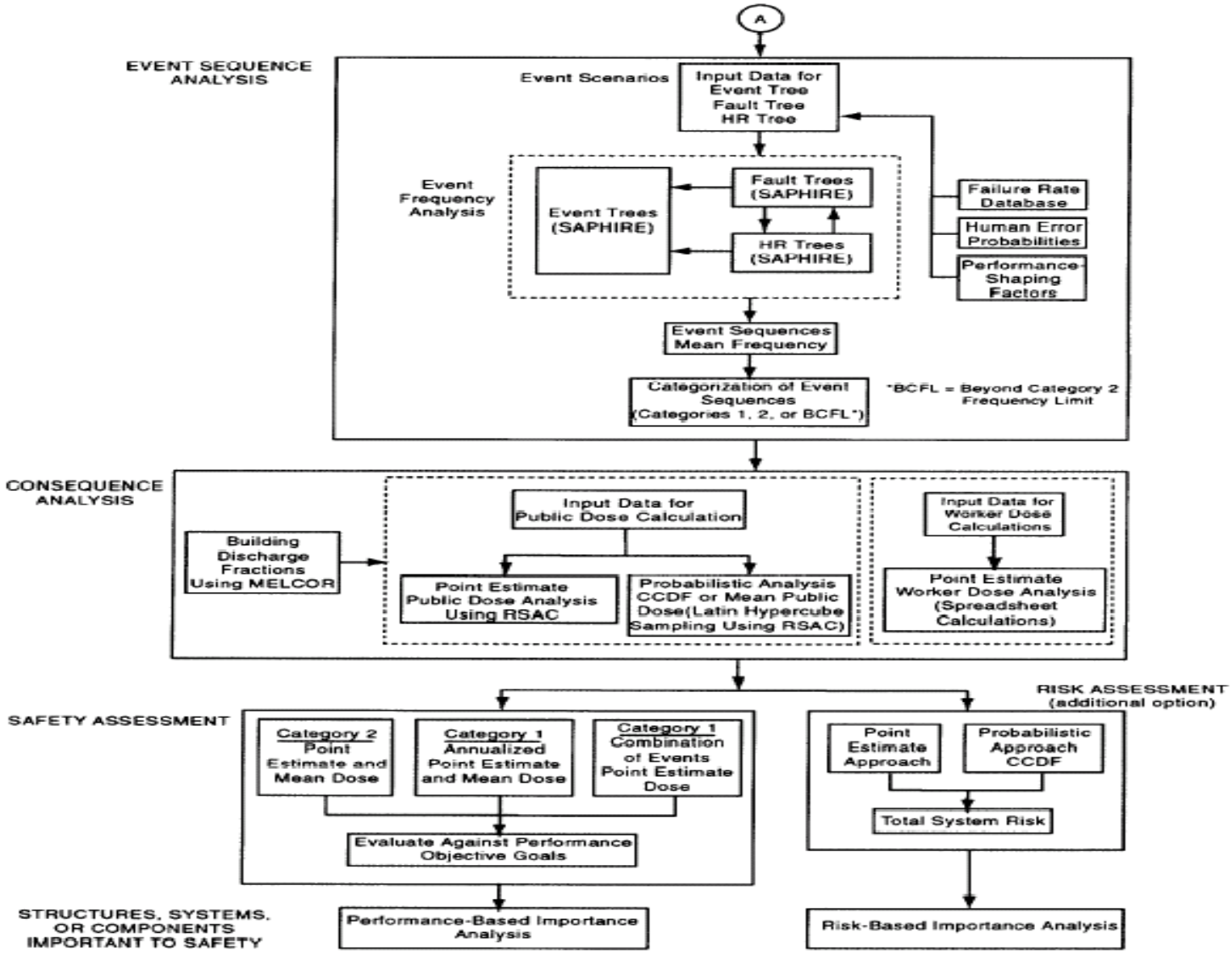
PCSA TOOL: Structure, Systems, and Components Important to Safety

- Identified using a performance-based importance analysis

PCSA TOOL


REVIEW OF SITE AND FACILITY DESCRIPTION
Site-Specific Data
Description and Design Details of Structures, Systems, and Components
Description of Operations and Processes
Description Source Terms and Characterization of Waste
INPUT DATA FOR SAFETY ANALYSIS
Functional Area
Example
Waste Handling Building
Cask/Carrier Handing Operations
Canister Transfer Operations
Assembly Transfer Operations
Disposal Container Handing Operations
System Description
Facility Function
Operation Sequence
Human Interactions
IDENTIFICATION OF NATURALLY OCCURRING AND HUMAN-INDUCED HAZARDS AND INITIATING EVENTS
Site-Specific Hazard Analysis Review
Potential Initiating Events and Probabilities:
Naturally Occurring (Example: Seismic, Wind, Tornado, Flood)
Human Induced (Example: Aircraft Crash, Fire)
Operational Hazard Analysis
Operational
Mechanical/Electrical
What If Procedures
HRA Human Error
FMEA Hardware/ Equipment Failure
Failure Mode Library
What-If Check List
Human Error Check List
Select Hazards Potential to Cause Radiological Release
Define Initiating Events for Event Sequence Analysis
A

PCSA TOOL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EVENT SEQUENCE ANALYSIS
Event Scenarios
Input Data for Event Tree Fault Tree HR Tree
Event Frequency Analysis
Event Trees (SAPHIRE)
Fault Trees (SAPHIRE)
HR Trees (SAPHIRE)
Failure Rate Database
Human Error Probabilities
Performance-Shaping Factors
Event Sequences Mean Frequency
Categorization of Event Sequences (Categories 1, 2, or BCFL*)
*BCFL = Beyond Category 2 Frequency Limit
CONSEQUENCE ANALYSIS
Building Discharge Fractions Using MELCOR
Input Data for Public Dose Calculation
Point Estimate Public Dose Analysis Using RSAC
Probabilistic Analysis CCDF or Mean Public Dose(Latin Hypercube Sampling Using RSAC)
Input Data for Worker Dose Calculations
Point Estimate Worker Dose Analysis (Spreadsheet Calculations)
SAFETY ASSESSMENT
Category 2 Point Estimate and Mean Dose
Category 1 Annualized Point Estimate and Mean Dose
Category 1 Combination of Events Point Estimate Dose
Evaluate Against Performance Objective Goals
RISK ASSESSMENT (additional option)
Point Estimate Approach
Probabilistic Approach CCDF
Total System Risk
STRUCTURES, SYSTEMS, OR COMPONENTS IMPORTANT TO SAFETY
Performance-Based Importance Analysis
Risk-Based Importance Analysis

SENSITIVITY STUDY

- Calculate dose to the public for the default case
- Calculate dose to the public for tests setting varying values of airborne release fractions, meteorological parameters, and other parameters, focusing on the SNF performance
- Assess the effects of combined parameters on the dose
- Calculate the dose using probabilistic distributions of parameter values
- Calculate the dose for event sequences

SENSITIVITY STUDY:

Airborne Release Fractions and HEPA Filtration Effectiveness

Radionuclides	Point-Estimates	
	Default Setting	Test Setting
H^{3}	0.30	1.0
Ru^{106}	1.5E-5	1.5E-4
I^{129}	0.10	1.0
$Cs^{134,135,137}$, Sr^{90}	2.3E-5	2.3E-4
Ar^{39}, Kr^{85}, $Rn^{219,220,222}$	0.40	1.0
Co^{60} Crud	0.15	1.0
All Others	2.0E-6	3.0E-5
HEPA Filtration Mitigation Factor for Particulates	0.0003	Inoperative (1.0)

SENSITIVITY STUDY:

Release Fraction/HEPA Filtration Effectiveness – Combined Dose Output

	BWR Dose [mrem]	PWR Dose [mrem]
Default	0.0301	0.0772
H^{3}	0.0510	0.1310
Ru^{106}	0.0301	0.0772
I^{129}	0.2180	0.560
$Cs^{134,135,137}$, Sr^{90}	0.0301	0.0772
Ar^{39}, Kr^{85}, $Rn^{219,220,222}$	0.0303	0.0778
Co^{60} Crud	0.0301	0.0772
All Others	0.0301	0.0773
All Release Fractions Set to 1 HEPA at default	1.04	2.84
All Release Fractions at default, HEPA Filtration Inoperative	0.0624	0.103

SENSITIVITY STUDY:

Other Selected Parameters

- **Mixing Layer Height: lowering by 95 % from 1420 m [4659 ft] to 71 m [233 ft] increased the dose by ~18 %**
- **Weather class from 6 to 5: decreased the dose by ~48%.**
- **HEPA mitigation factor from 0.0003 to 0.01 increased the dose by ~101%.**
- **Particulates Leak Path Factor to Ventilation System: increasing from 0.002 to 0.02, very small effect**
- **Air density: increasing from 1.29×10^3 to 1.42×10^3 g/m^3 [$(8.05 - 8.87) \times 10^{-2}$ lb/ft^3], very small dose effect**
- **Stack Release Height: lowering from 40 m [131 ft] to zero increased the dose by ~ 10 %**
- **Maximizing the fraction of stored annual forage and eliminating the fraction of fresh annual forage increased the dose by ~9%. The opposite case increased the dose by ~8%**

SENSITIVITY STUDY

- **Two Parameters**

  - Sum: down wind distance and HEPA mitigation factor, down wind distance and mixing layer height, weather class and mixing layer height, weather class and HEPA mitigation factor, mixing layer height and HEPA mitigation factor

  - Positive (increased) Effect: downwind distance and weather class

- **Three Parameters: similar to sum of two parameters**

  - (mixing layer height, downwind distance, HEPA mitigation factor)

  - (weather class, mixing layer height, down wind distance)

  - (weather class, mixing layer height, HEPA mitigation factor)

  - (weather class, downwind distance, HEPA mitigation factor)

SENSITIVITY STUDY
Probabilistic Approach

- **Test of the number of realizations for the default case and the operation of HEPA Filter**

- **Each percentile, mean, and max approach the convergent values as the number of realizations increases.**

- **The maximum value for the default input parameters increase – when all parameters set to the values that result in the worst values.**

SENSITIVITY STUDY

Event Sequences

- **Example of Scenarios (NUREG/CR 6672, NRC, 2000):**

- **Collision without fire accidents**
- **Collision with fire accidents that cause the cask to leak**
- **Collision with fire accidents that cause the cask to leak by puncture**
- **Fire accidents**

Highest Values of Release Fractions Calculated Given the Test Scenarios

- **$Cs^{134,135,137}$ 9.8×10^{-4}**
- **Particulates 2.4×10^{-5}**
- **Crud 7.4×10^{-2}**
- **Ru^{106} 1.1×10^{-4}**

- **Preliminary Preclosure Safety Assessment for Monitored geologic Repository, Site Recommendation (CRWMS, DOE, 2000): Release Fractions, ~ 0.3, for Category 1 and 2 DBE**

- **Standard Review Plan for Transportation Packages for Spent Nuclear Fuel (NUREG-1617, NRC, 2000): Release Fractions, < 0.3, for hypothetical accidents**

SENSITIVITY STUDY
Event Sequences

RSAC Modifications: under study

- **Stack Release Height (dimension): 40 (default) to 0 (test) increased the combined dose by ~9.8%**

- **Mixing Layer Height (m): 1420 [4659 ft] to 71 [233 ft] increased the combined dose by ~18%.**

DOSE FROM POTENTIAL BREACHES OF SPENT NULEAR FUEL (SNF) ASSEMBLIES

- **Example Event Scenarios**

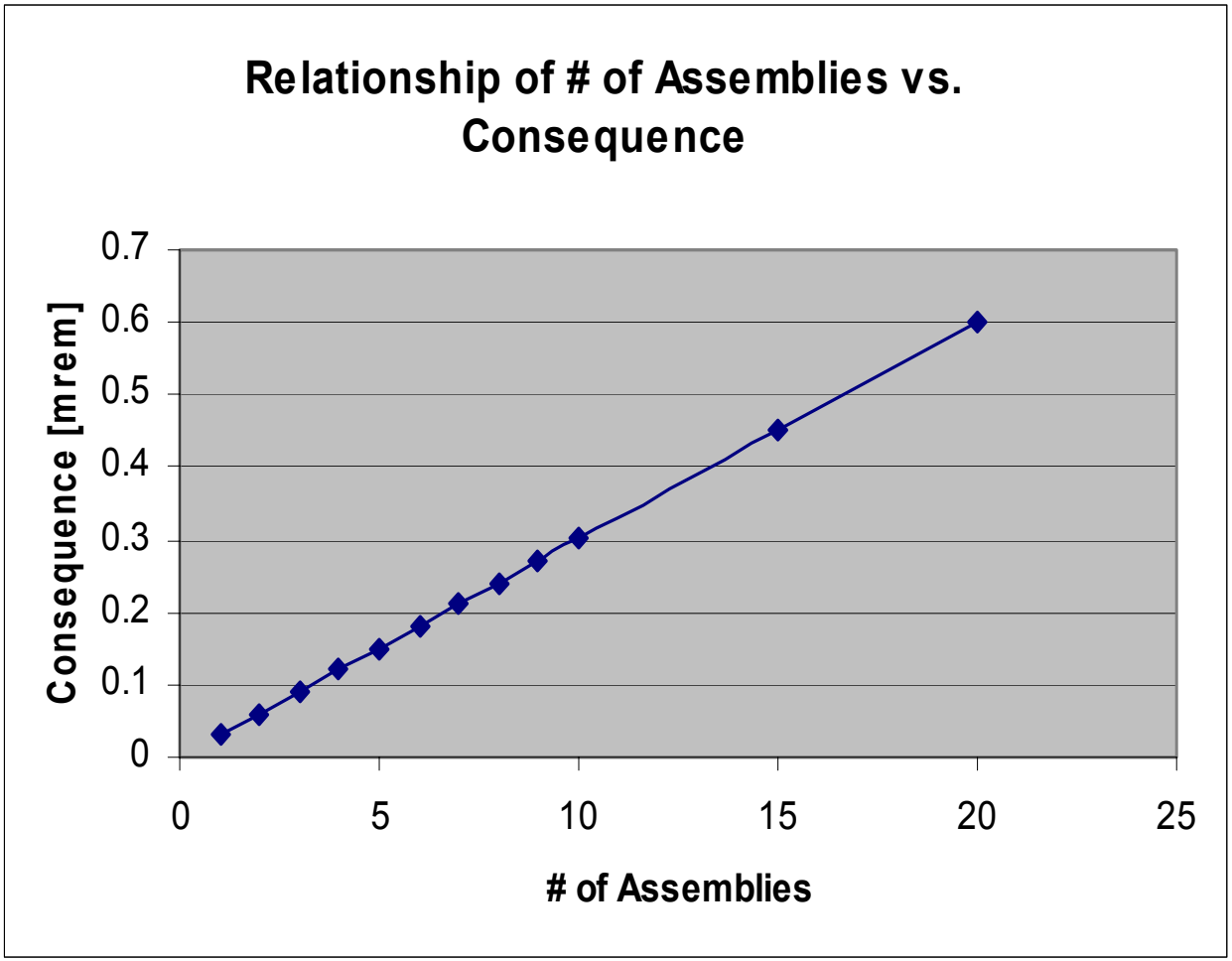
  - ATM (Assembly Transfer Machine) drops SFA (Spent Fuel Assembly) on transportation cask: 2 PWR

  - Drop of Canister onto transportation cask due to failure of bridge crane: 21 PWR

  - Drop unsealed waste package and tip-over while lifting onto welding turntable: 44 BWR

  - 18x68: maximum 2x9 array rack in staging area

DOSE FROM POTENTIAL BREACHES OF SNF ASSEMBLIES (Example)



RELEASE FRACTION: Standards and Guides

- **NUREG/CR-6672 (NRC, 2000):**

  - Derived Equations to Represent Effects of different Scenario Conditions on the Release Fraction

  - For a Collision Only Scenario: fraction of rods involved in the impact, fraction of rod contents released to the cask interior, fraction of radioisotopes deposited onto the cask interior, atmospheric and internal pressures of the cask

- **ANSI/ANS 5.10 (ANS, 1988):**

  - Derived from a Series of Experiments Involving Explosions, Thermal Stresses, and Mechanical Stresses

  - May Need Some Further Consideration to Obtain a Release Fraction Resulting from a Non-listed Event Scenario.

RELEASE FRACTION: Standards and Guides

- **NRC SFPO ISG 5 REV. 1 (NRC, 1998):**

  - Through Research of Fuel Accident Scenarios, Release Fractions Guidance Value at Least Used to Determine Compliance with 10 CFR 72 at independent Fuel Storage Facilities

  - Values are the highest among three standards and guides (e.g., noble gases ~ 0.3, volatiles ~ 2E-4, fuel fines ~ 3E-5, crud ~ 0.15). The current study values are at or above these.

- **Other Variations**

SUMMARY

- **Background on the pre-closure safety of the potential Yucca Mountain repository are presented.**
- **PCSA Tool is summarized.**
- **A sensitivity study of PCSA Tool was conducted with default values for the point estimate consequence analyses on the release fraction, HEPA Filter, and meteorological parameters, focusing on the SNF performance.**
- **Some investigations with the probabilistic approach calculation and on event sequences were performed. The study was also conducted under some accident conditions.**
- **The relationship between the number of spent nuclear fuel assemblies breached and potential public dose was investigated.**
- **Existing standards and guides for non-reactor facilities are discussed with respect to the present sensitivity analyses.**

Disclaimer: The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geologic repository Yucca Mountain

REFERENCES

- American Nuclear Society, Airborne Release Fraction at Non-Reactor Nuclear Facilities, ANS/ANE-5.10, LaGrange Park, 1998
- Civilian Radioactive Waste Management System (CRWMS), Management & Operating Contractor, Preliminary Preclosure Safety Assessment for Monitored Geologic Repository, Site Recommendation, 2000
- U.S. Department of Energy, Yucca Mountain Science and Engineering Report, DOE/RW-0539-1, 2002
- U.S. Nuclear Regulatory Commission, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, NUREG-1617, 2000
- U.S. Nuclear Regulatory Commission, Reexamination of Spent Fuel Shipment Risk Estimates, NUREG/CR-6672, Washington, D.C. 2000
- U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, Interim Staff Guidance – 5, Revision 1, Washington, D. C., 1998

POTENTIAL YUCCA MOUNTAIN REPOSITORY
View Looking Down Exploratory Studies Facility (DOE, 2002)

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