U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

USNRC Proposed Approach to Developing an Integrated Site PRA Model

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BACKGROUND AND PROBLEM DEFINITION

USNRC Site Level 3 PRA Project Objectives

- Develop a contemporary Level 3 PRA that:
  - Reflects technical advances since NUREG-1150 study.
  - Addresses risk contributors not previously considered.
- Extract new risk insights to:
  - Enhance regulatory decision making.
  - Help focus limited resources on issues most directly related to USNRC's mission to protect public health and safety.
- Enhance USNRC staff's PRA capability and expertise.
- Improve documentation to make PRA information more accessible, retrievable, and understandable.
- Obtain insight into the technical feasibility and cost of developing new Level 3 PRAs.

Integrated Site PRA Element Objectives

- Estimate integrated site risk for the Vogtle Electric Generating Plant (VEGP) site.
- Identify and characterize significant contributors to integrated site risk for the VEGP site.

Integrated Site Risk Definition: Element 1

- Integrated
  - Accident scenarios ***initiated by internal hazards*** (internal events, internal floods, internal fires) ***and external hazards*** (seismic event, high winds, and other external hazards).
  - Accident scenarios ***initiated during all modes of operation.***
  - Accident scenarios ***involving at least one major radiological source on the site***.

Integrated Site Risk Definition: Element 2

- Site
  - A collection of co-located sources of radiological materials that pose a major hazard to public health and safety.
  - For the VEGP site:
    - Two operating reactor units (Unit 1 and Unit 2).
    - Two spent fuel pools, one for each operating reactor unit (Unit 1 and Unit 2).
    - One dry cask storage facility.

Integrated Site Risk Definition: Element 3

- Risk
  - ***Risk triplet*** framework $R_{TOTAL} = \{< s_i, f_i, \boldsymbol{c}_i >\} \forall_i$
    - Accident scenarios (s_i)
    - Accident scenario frequencies (f_i)
    - Accident scenario conditional consequences ($\boldsymbol{c}_i$)
  - Two broad categories of accident scenarios:
    - **Single-source:** Modeled in single-source PRA inputs
    - **Multi-source:** Modeled in Integrated Site PRA
      - ***Independent:*** Concurrent accidents occur randomly.
      - ***Dependent:*** Concurrent accident occur due to coupling between co-located radiological sources.

PROPOSED APPROACH TO INTEGRATED SITE PRA

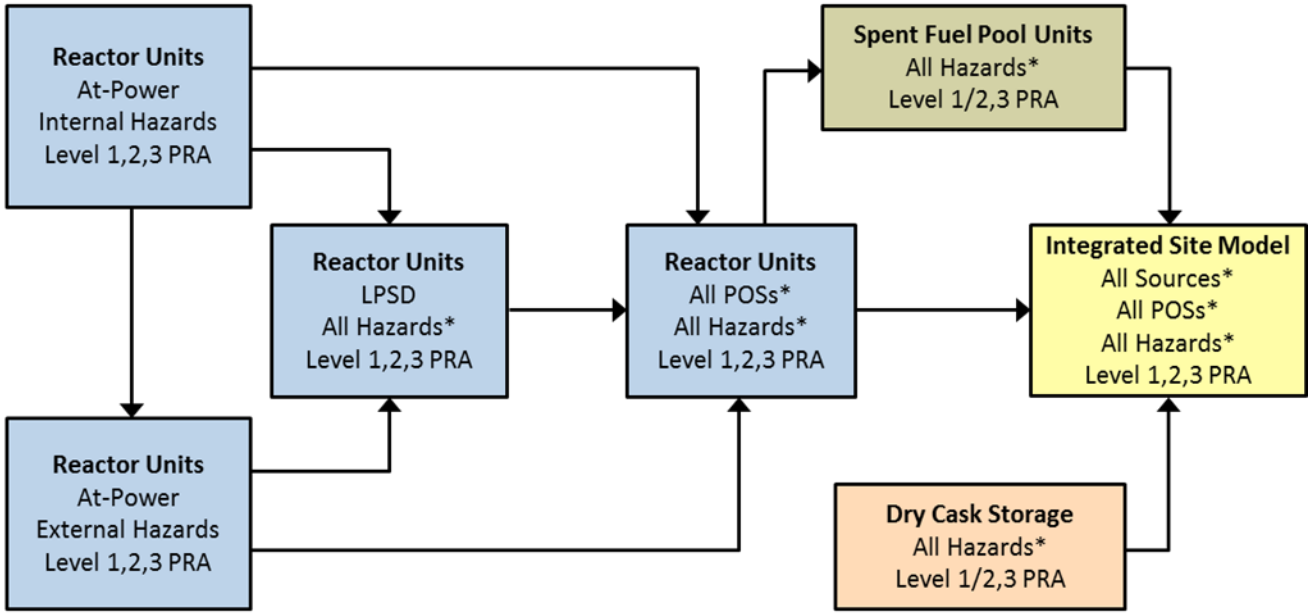
Motivation

- There are many possible approaches.
- Purely deductive approaches can make problem intractable and focus resources on factors that may not be important.
- Logically combining full accident sequences from single-source PRA models is not feasible using existing analytical tools.
- A focused approach that makes informed approximations to obtain useful insights is thus needed.

Key Assumptions

- Multi-source accident scenarios can be constructed by logically combining accident scenarios from the single-source PRA models and eliminating logically impossible scenarios.
- Single-source PRA model risk insights can be used to prioritize selection of multi-source accident scenarios.
- Inter-source dependencies will likely be dominant contributors to integrated site risk.

Inputs and Interrelationships

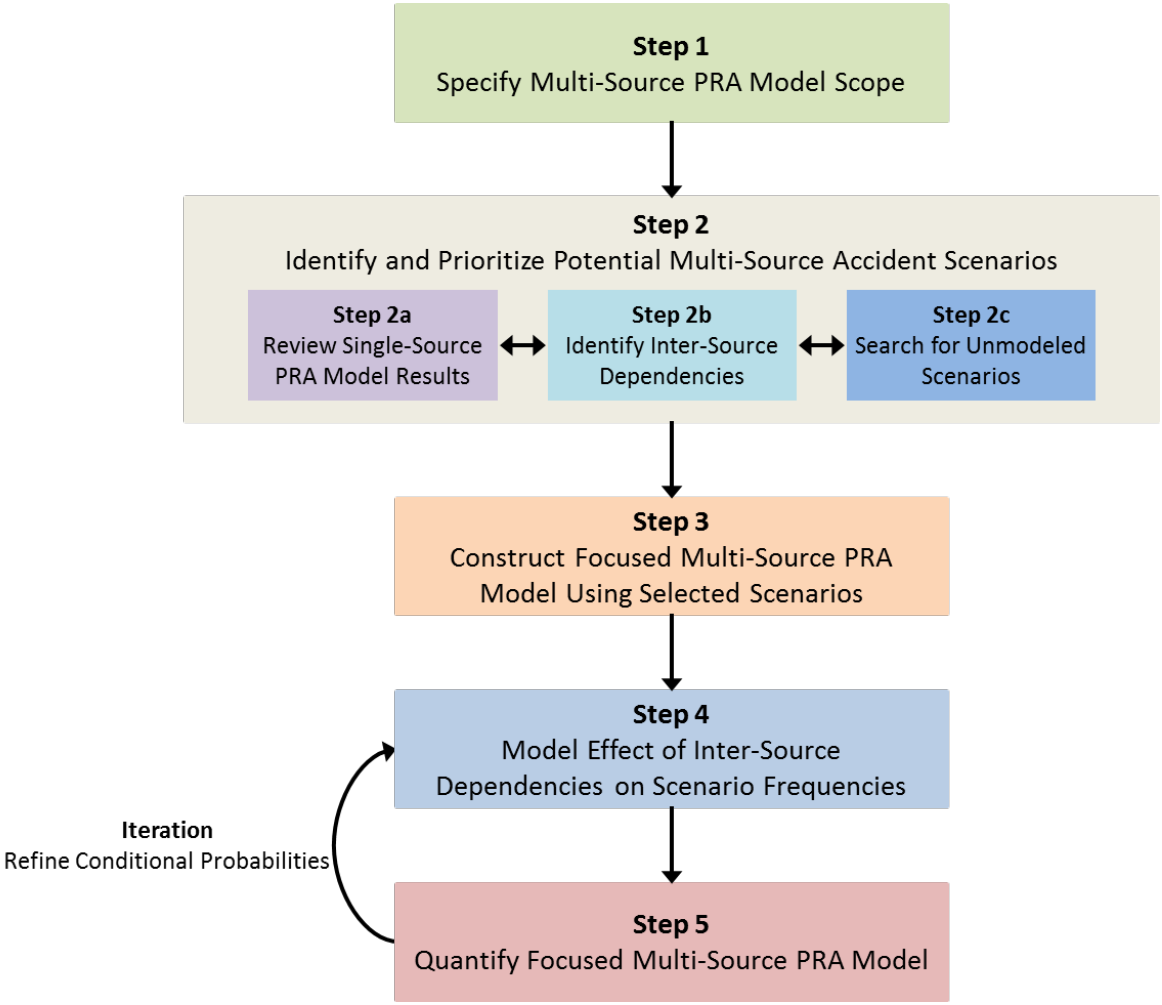


Acronyms

LPSD:	Low-Power and Shutdown
POS:	Plant Operating State
PRA:	Probabilistic Risk Assessment

* **NOTE:** The term "all" in this context means all factors (sources, POSs, or hazards) selected for inclusion in the scope of the project and individual PRAs that provide input to the integrated site PRA task. It does not mean that all possible factors are included within the scope of each PRA.

Overview of Approach



1. Specify Multi-Source PRA Model Scope

PRA Scope Element	Scoping Options
Radiological Sources	Operating Reactor Units (Unit 1 & Unit 2)
	Operating Reactor Spent Fuel Pools (Unit 1 & Unit 2)
	Dry Cask Storage Facility
Plant Operating States (POSs)	At-Power
	Low-Power and Shutdown (LPSD)
Initiating Event Hazard Groups	Internal Hazards (Internal Events, Floods, and Fires)
	External Hazards
PRA End States	Level 1: Nuclear Fuel Damage
	Level 2: Radiological Release Categories
	Level 3: Offsite Radiological Consequences

2a. Review Single-Source PRA Results

- End state significant accident scenarios
  - Combined contribution ≥ 95% OR individual contribution ≥ 1% to total end state frequency.*
  - Number depends on end state risk profile.
    - End states with a concentrated risk profile have a limited number of significant accident scenarios to evaluate for inclusion in multi-source PRA model.
    - End states with a diffuse risk profile can have tens of thousands of significant accident scenarios and thus may require approaches that group accident scenarios based on specified attributes (e.g., same initiator, similar functional failures).
- End state significant basic events
  - Fussell-Vesely (F-V) > 0.005.*
    - Fractional contribution to total end state frequency of scenarios that include event of interest.
  - Risk Achievement Worth (RAW) > 2.*
    - Factor by which total end state frequency increases if event of interest is assumed to occur with 100% probability.

* **NOTE:** These criteria are consistent with definitions specified in the ASME/ANS *Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications*.

2b. Identify Inter-Source Dependencies

- Existence of potential inter-source dependency determines whether a single-source accident scenario is selected for inclusion in the multi-source PRA model.
  - Dependencies of interest are scenario-related causal links between basic events.
- Literature review on multi-source PRAs and operational experience involving multi-source events led to identification of five broad dependency categories.
- Categorization scheme is coupled with review of single-source PRA model results to identify accident scenarios that will be included in the multi-source PRA model.

2b. Identify Inter-Source Dependencies

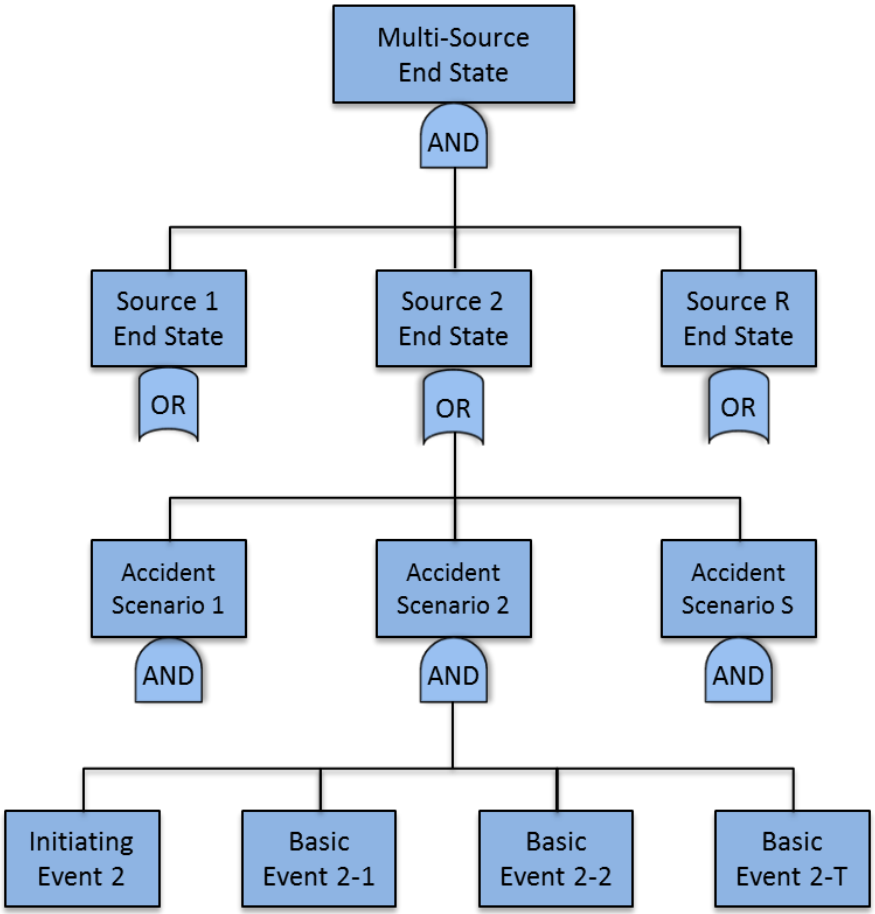
Category	Definition	Example(s)
Initiating events		
• Common initiators	Initiators that simultaneously challenge multiple radiological sources.	Loss of shared electrical grid or ultimate heat sink.
• Consequential initiators	Initiators that arise from events involving another radiological source.	Transient in one reactor unit causes loss of offsite power to another unit.
Shared Structures, Systems, Components (SSCs)	SSCs that support multiple radiological sources under various conditions.	Electrical power sources that can swing between radiological sources.
Common-Cause Failure (CCF) Events	Dependent failures of SSCs across multiple radiological sources due to a shared cause that are not otherwise explicitly modeled.	Failure of similar components installed in each unit due to a shared defect.
Phenomenological Dependencies	Arise from exposure of multiple SSCs to shared phenomenological or environmental conditions.	Failure of components in multiple radiological sources due to shared environmental conditions (e.g. temperature, moisture, or radiation levels) that exceed capacity.
Human or Organizational Dependencies	Dependencies between operator actions associated with multiple radiological sources that can arise from multiple causes, including shared organizational factors.	Shared training, procedures, or command and control structure cause recovery actions taken in response to an accident affecting one radiological source to be dependent upon those taken in response to an accident affecting another radiological source.

2c. Search for Unmodeled Scenarios

- Revisit accident scenarios screened out of single-source PRA models.
  - Screening criteria may not be appropriate for Integrated Site PRA.
- Search for accident scenarios that may not have been considered in single-source PRA models.
  - A combination of strategies and tools should be used to provide assurance that important contributors are not missed.

3. Construct Multi-Source PRA Model

- Top-level AND gates combine end states for selected radiological sources.
- Mid-level OR gates combine selected accident scenarios for each selected radiological source.
- Bottom-level AND gates combine basic events for each selected accident scenario for each selected radiological source.



4. Model Inter-Source Dependency Effects

- Approach depends on event of interest.
- For site-level events in each single-source PRA model that represent same event across all radiological sources:
  - Ensure same event applies to all modeled radiological sources to ensure proper structure and quantification of minimal cut sets for multi-source end states of interest.
- For other dependent events:
  - Screening analysis
    - Assume complete inter-source dependence for modeled dependent events (i.e., conditional probability of dependent event in co-located sources is 1.0 given event occurrence in one source).
  - Iteration
    - Iteratively refine conditional probability estimates for dependent events that are significant contributors to multi-source end state frequency.

5. Quantify Multi-Source PRA Model

- Select multi-source end states of interest.
- Specify probability truncation level.
- Account for modeled inter-source dependencies using post-processing rules.
- Results of interest:
  - Significant multi-source accident scenarios.
  - Significant basic event importance measures.

Pilot Applications

- Purposes*
  - Evaluate technical feasibility of implementing the focused approach using existing analytical tools.
  - Identify potential barriers to implementation.
- Scope
  - Reactor, At-Power, Internal Events, Level 1 PRA
  - Reactor, At-Power, Internal Events and Floods, Level 2 PRA
  - Reactor, At-Power, Seismic Events, Level 1 PRA
- Key finding
  - For scoping options addressed in the pilot applications, available technology with workarounds can be used to efficiently develop a focused Integrated Site PRA model based on risk insights from single-source models.

* **NOTE:** No attempt was made to comprehensively identify, characterize, and model inter-source dependencies for each pilot application. Since the main purpose was to evaluate the technical feasibility of the focused approach using existing analytical tools, only a limited set of inter-source dependencies was considered.

QUESTION AND ANSWER SESSION

Acronyms and Abbreviations

ASME	American Society of Mechanical Engineers
ANS	American Nuclear Society
CCF	Common-Cause Failure
F-V	Fussell-Vesely
LOOP	Loss Of Offsite Power
LPSD	Low-Power and Shutdown
POS	Plant Operating State
PRA	Probabilistic Risk Assessment
RAW	Risk Achievement Worth
SAPHIRE	Systems Analysis Programs for Hands-on Integrated Reliability Evaluations
SSC	Structure, System, Component
VEGP	Vogtle Electric Generating Plant