MULTI-AGENCY FEDERAL WORKSHOP
Probabilistic Flood Hazard Assessment

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Combined Events in External Flooding Evaluation for Nuclear Power Plants

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Combined Events in External Flooding Evaluation for Nuclear Power Plants

- Combined Events as part of Design Basis Flood Determination
- New Plants – Early Site Permit/Combined Operating License
- Operating Plants Flood Reevaluation – Fukushima Response
- Deterministic Approach
- Regulatory and Industry Guidance
- Combined Events Criteria
- Considerations for Probabilistic/Risk-Informed Approach

Combined Events in External Flooding Evaluation for Nuclear Plants

- ANSI/ANS 2.8-1992 “Determining Design Basis Flooding at Power Reactor Sites”
- NUREG/CR-7046 “Design-Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America”
- IAEA Safety Standard SSG-18 “Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations”

Combined Events in External Flooding Evaluation for Nuclear Plants

ANSI/ANS 2.8-1992

- No single flood-causing event is adequate as a design flood base for power reactors.
- Dependency - In any combination of flood-causing events, distinction between dependent and independent events is not sharp.
- Time sequential meteorological events, for example, are only partially and not invariably dependent and their magnitudes are only partially and not invariably dependent also. Seismic and meteorological events are independent. [Combined events can be independent, dependent or causal]
- Acceptable Probability – less than 1×10^{-6} is an acceptable goal

Combined Events in External Flooding Evaluation for Nuclear Plants

NUREG/CR-7046

- Because of their extreme nature, probable maximum events from two separate phenomena should not be combined unless they are clearly dependent or result from a common cause.
- For example, seismic events should not be combined with precipitation events.
- Exception: PMF and PMH for relatively small drainage basins in regions where the PMP may result from a hypothetical and maximized hurricane event.
- Wind waves effects are almost always combined with other flood-causing mechanisms.

Combined Events in External Flooding Screening of Flooding Mechanisms

Flooding Mechanism	Site Location			
	Coastal + Riverine	Coastal	Riverine	Others
Local Intense Precipitation	X	X	X	X
River and Stream Flooding	X	NA	X	NA
Dam Failure	X (upstream dams)	NA	X (upstream dams)	NA
Storm Surge	X	X	NA	NA
Seiche	X	X	X (onsite pond)	X (onsite pond)
Tsunami	X	X	X (landslide potential)	NA
Ice	C	C	C	C
Wind Wave Actions	X	X	X	X

NA = Not Applicable; C=Cold Region

Combined Events Criteria Applicable to Open Coast/Riverine Sites

- **Precipitation Flooding**

Event Combination	Alternative I	Alternative II	Alternative III
Primary Event	PMP	Probable Maximum Snowpack	Snow Season PMP
Antecedent or Subsequent Event	Lesser of 40% PMP or 500-year Rain		
Coincidental Event		100-year Snow Season Rain	100-year Snowpack
Base Flow	Mean Monthly	Mean Monthly	Mean Monthly
Wind Wave*	2-year wind	2-year wind	2-year wind

* In critical direction

Combined Events Criteria Applicable to Open Coast/Riverine Sites

- **Storm Surge Flooding**

Event Combination	Alternative I	Alternative II	Alternative III	Alternative IV*
Primary Event	Surge & Seiche from worst regional hurricane or windstorm	25-year Surge and Seiche	Probable Maximum Surge and Seiche	Surge from PMH
Coincidental Event	Lesser of 1/2 PMF or 500-year flood	PMF	25-year Flood	PMF
Antecedent Sea Level**	10% high tide	10% high tide	10% high tide	10% high tide
Wind Wave	Attendant	Attendant	Attendant	Attendant

* in hurricane area and Drainage Area <300 mi^2

** include sea level rise

Combined Events Criteria Applicable to Open Coast/Riverine Sites

- Seismic Dam Failure Flooding

Event Combination	Alternative I	Alternative II
Seismic Event*	SSE coincidental with flood peak	OBE coincidental with flood peak
Coincidental Event	25-year Flood	Lesser of ½ PMF or 500-year Flood
Wind Wave	2-year wind speed in critical direction	2-year wind speed in critical direction

*Seismic SSE and OBE events in deterministic analysis vs exceedance probabilities from PSHA

Combined Events Criteria Applicable to Open Coast/Riverine Sites

- Tsunami Flooding

Event Combination	Shore Location	Streamside (Alternatives I, II, III, IV)
Tsunami	PMT Runup	I Runup from PMT Bore II Runup from Worst Observed Tsunami Bore III Runup from SSE Tsunami Bore IV Runup from OBE Tsunami Bore
Antecedent or Concurrent	10% High Tide	I 25-year Flood II PMF III Mean Monthly Baseflow + SSE Dam Break Flood IV 25-year Flood + OBE Dam Break Flood
Wind Wave		I – IV 2-year wind speed in critical direction

Combined Events Criteria Applicable to Open Coast/Riverine Sites

- **Other Site Specific Combined Events**

  Potential Breach of Large Onsite Basin due to PMSS, PMF or Dam Break Flood Wave

Combined Events in External Flooding Deterministic Approach

- PMF
  - PMP from NOAA HMRs
  - HEC-HMS Rainfall-Runoff Model; HEC-RAS for Flood Level Routing
  - Unit Hydrographs calibrated with 2 to 4 Largest Historical Storms
  - Peaking and Reduced Lag of Unit Hydrographs
  - Maximize Precipitation Depth over Basin
  - Back to Back Storms (40% PMP or 500-year Rain) with 3 to 5 days Interval: Zero Initial Loss, Bankfull
  - Sensitivity on Surface Roughness, Rainfall Loss Rate
  - Basin Areas from 300 sq. miles to 20,000 miles
  - 2-year wind – setup and wave runup
  - Gridded runoff model considered

Combined Events in External Flooding Deterministic Approach

- Dam Break Flooding
  - ½ PMP from NOAA HMRs; 25-year or 500-year rain from NOAA Atlas or TP
  - Breach Models (Wahl, USBR, Froehlich, FERC)
  - HEC-RAS for Flood Wave Routing
  - Sensitivity – Surface Roughness
  - Upstream Dams - 1 to over 60
  - Onsite Cooling Ponds
  - Basin Areas up to 20,000 sq. miles
  - 2-year wind – setup and wave runup

Combined Events in External Flooding Deterministic Approach

- Storm Surge Flooding
  - PMH parameters from NOAA NWS 23
  - Maximize Surge Level by varying hurricane tracks
  - 10% Exceedance High Tide from NOAA tide data
  - Sea Level Rise included – 100-year projection
  - SLOSH or ADCIRC
  - Sensitivity – Forward Speed, Radius of Maximum Wind
  - Attendance wind-wave runup

Combined Events in External Flooding Deterministic Approach

- Tsunami Flooding
  - PMT Seismic or Submarine Landslides
  - Literature Review for Source Identification and Characterization
  - Establish Conservative Initial Wave Form
  - 10% Exceedance High Tide from NOAA tide data
  - Sea Level Rise included – 100-year projection
  - MOST (East Break Slump); FUNWAVE and NHWave (Cape Fear, Florida Escarpment and Great Bahamas Bank), Delft3D (1755 Lisbon)
  - Sensitivity – Initial Wave Height and Shape, Surface Roughness in Inundation Phase

Combined Events in External Flooding Probabilistic Approach - Considerations

- Individual or Combined Hazard Curve
- Dependence among Combining Events
- Associated Hazards besides Flooding Levels
  - Flooding Duration, Time of Arrival
  - Hydrostatic and Hydrodynamic Forces
  - Debris, Scouring, Waterborne Missiles
- NUREG/CR-7046 "individual, worst-case flood hazards may result from different flooding mechanisms. Therefore, it may not be appropriate to focus on a single "design-basis flood;" rather, the design should consider the worst-case hazards resulting from all appropriate combined-effects floods that are relevant.."

Combined Events in External Flooding Probabilistic Approach - Considerations

- Acceptance Criteria: $1x10^{-4}$ – $1x10^{-6}$ (?)
- Combine deterministic and probabilistic approaches?
- Improvement on the uncertainties
- How will the quantified uncertainties be incorporated into Risk Assessment?
- New Guidance and Standard (ANS 2.31, ANS 2.8,?)
- Level of Effort