Screening of Other External Hazards in Generation III+ and Generation IV Nuclear Power Plants

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Topics

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Introduction & Background

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Current & Next-Generation operating reactors are required to address risks from all hazards, operating states, and sources of radioactive material.

Screening criteria – Gen II plants

CDF of less than 1.0E-06/year

OR

hazard has a mean frequency less than 1.0E-05/year and a CCDP less than 1.0E-01.

Introduction & Background (Cont.)

- Screening criteria – Gen III+ plants
  - 1.0E-06/year CDF criteria is modified to 1.0E-08/year
    - Effort required to screen based on this criteria is more challenging.

Example Hazard Screening for Solar Flares

Example Screening Hazard – Solar Flares

Destabilize and damage transformers, I&C, and DI&C

Discretized into 3 bins:

Low magnitude – regular occurrence with negligible effects.

Moderate magnitude – non-recoverable LOOP with CDF contribution being the product of the LOOP CCDP and the solar flare frequency.

Large magnitude – assumed to be capable of damaging I&C systems.

Frequency exceeding the observed maximum energy can be estimated to be ~ 1E-03

Combining the moderate and large magnitude impacts challenges the screening criteria.

Example Screening for Meteorite & Satellite Strike

Example Screening Hazard – Meteorite / Satellite Strike

Table 1: Frequency of Impact for Various Size Ranges	
Diameter of Object (m)	**Frequency of Impact (per year)**
Greater than 1500	7.07E-07
1250 to 1500	3.79E-07
1000 to 1250	7.51E-07
900 to 1000	5.17E-07
800 to 900	7.52E-07
700 to 800	1.15E-06
600 to 700	1.86E-06
500 to 600	3.28E-06
400 to 500	6.49E-06
300 to 400	1.54E-05
200 to 300	4.99E-05
100 to 200	3.34E-04
75 to 100	4.02E-04
50 to 75	1.30E-03
25 to 50	8.73E-03
10 to 25	8.29E-02
3 to 10	1.50E+00

- The frequency per year of impacts was calculated using the following equation:

$$\boldsymbol{Frequency\ of\ Impact}\ (>\boldsymbol{L}) = \mathbf{1.8368} * \mathbf{10}^{-\mathbf{6}} * \boldsymbol{L}_{\boldsymbol{km}}^{-\mathbf{2.354}}$$

- Total Frequency of impacts is 1.6 per year.

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Example Screening Hazard – Meteorite / Satellite Strike

Table 2: Adjusted Impact Frequency for Various Size Ranges		
Diameter of Object (m)	**Radius of Damage (km)**	**Adjusted Frequency of Impact (per year)**
Greater than 1500	1350(1)	7.94E-09(2)
1250 to 1500	400	3.74E-10
1000 to 1250	340	5.34E-10
900 to 1000	270	2.32E-10
800 to 900	240	2.67E-10
700 to 800	215	3.27E-10
600 to 700	185	3.92E-10
500 to 600	160	5.17E-10
400 to 500	135	7.28E-10
300 to 400	110	1.15E-09
200 to 300	80	1.97E-09
100 to 200	50	5.14E-09
75 to 100	26	1.67E-09
50 to 75	22	3.89E-09
25 to 50	24	3.10E-08
10 to 25	1(3)	5.11E-10
3 to 10	1(3)	9.25E-09

Note (1): For objects greater than 1500 m, a size of 5000 m was used to identify the radius of damage.

Note (2): Meteorites of this size are associated with planet-wide impacts. Therefore, the "damage area" is the entire Earth, and an "adjusted" frequency which diminishes the impact frequency by the ratio of the "damage area" to the surface area of the Earth may be optimistic for this case.

Note (3): A conservative 1km radius of damage was set since these sizes only cause direct hit damage.

- The frequency of impact can be adjusted based on the area affected by the impact relative to the surface area of the Earth. This is generally where you would screen a Gen II plant.
- A "Radius of Damage" was calculated using an impact simulator to examine different consequences of an impact (Ejecta, Air Burst, Seismic Effects, etc.).
- The bounding consequence was estimated to be the wind speed caused by an impact. A conservative windspeed of 100 mph was used for damage to occur at a site.
- This lowers the frequency overall (Total Frequency of ~ 6E-08 per year), but still requires additional refinement to fully screen.

Consideration of Volcano Super-Eruption

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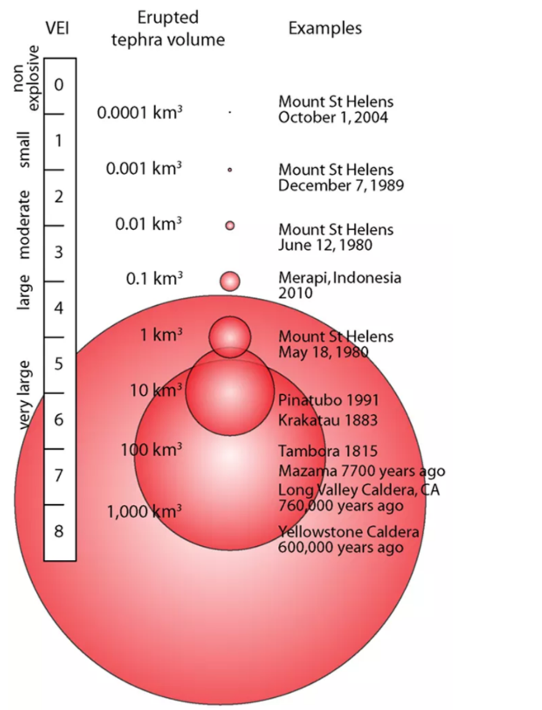
- Volcanic super-eruption – highest measurable type of eruption (Volcanic Explosivity Index of 8).
  - 1,000 cm^3 of volcanic material.
  - Pyroclastic flows reach up to tens of thousands of km^2.
  - Within 60 miles, impact would be catastrophic.



[3]

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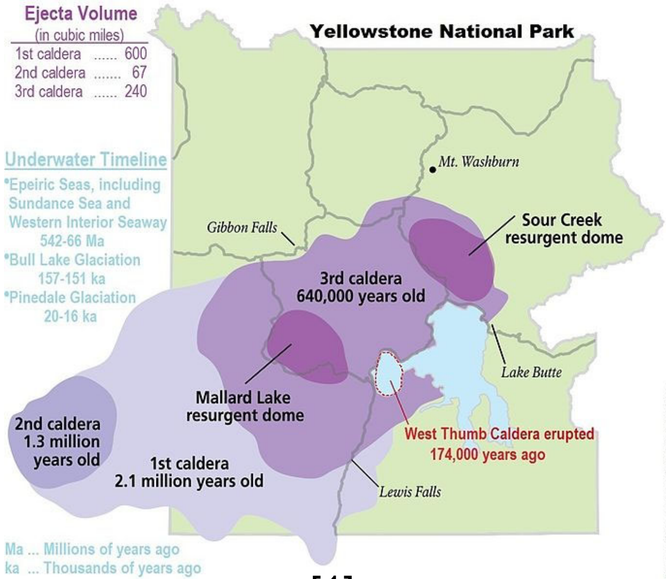
Consideration of Volcano Super-Eruption (Cont.)

- Yellowstone Caldera
    - VEI-8 eruption – 1 in 730,000 years or 1.4E-06/year
        - NOT less than 1.0E-08/year

[2]



ADAPTED WITH PERMISSION FROM *WINDOWS INTO THE EARTH* BY ROBERT SMITH AND LEE J. SIEGEL, 2000.
Henry Heasler and Cheryl Jaworowski, US NPS, 2013.

[1]

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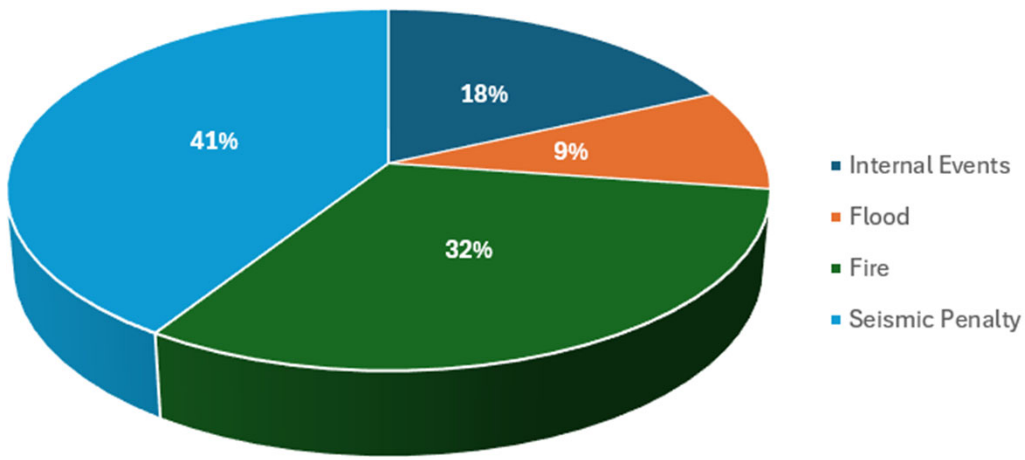
Proposed Approach for Addressing Very Low-Frequency Hazards

Proposed Approach for Addressing Very Low-Frequency Hazards

CDF Values

- Internal Events: 4E-07
- Flood: 2E-07
- Fire: 7E-07
- Seismic Penalty: 9E-07
- Total: 2.2E-06



Proposed Approach – Option 1

Potentially more beneficial to examine impact on total CDF as opposed to just internal events CDF.	Additional screening criterion based on all-hazards risk. Less than or equal to 2E-08/year (~1% of the all-hazards risk)
Consistent with how certain risk-informed applications (e.g. 50.69) evaluate multiple hazards via integrated risk importance measures.	Weighting importance measures against each of the hazards in a PRA.
Plant response for low frequency other external hazard initiating events likely doesn't differ from already modeled hazards.	Overall contribution to CDF relatively low compared to other hazards in a detailed PRA model.

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Proposed Approach – Option 2

Risk-Informing Design

- Can only be realistically completed against a devastating event with reasonable potential to mitigate.
- If CCDP=1, minimal risk-insights would be obtained.
- Event is likely to cause complete devastation.

NRC Quantitative Health Objectives (QHOs):

- *"The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1%) of the sum of prompt fatality risks resulting from other accident to which members of the U.S. population are generally exposed."*

- *"The risk to the population in the area of nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1%) of the sum of cancer fatality risks resulting from all other causes."*

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Proposed Approach – Option 3

Unlikely to gain significant risk insights from continent or Earth-wide population devastating events.

World ending events require detailed consideration to support quantitative screening using next-generation screening criteria.

Proposed that these be screened from the assessment.

- Meteorites over 1.5 km – global risk of fatal consequences.

Plant consequences are negligible regarding public health and safety if the world population is itself devastated from the event.

Conclusion

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Solution needs to be further developed, but this paper provides several paths forward to investigate

Need input from many organizations in nuclear industry

Overall intent of screening criteria and PRA development may need to be further refined

Continue to focus on risk-informed design

Q&A

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Image References

[1] Geology of Yellowstone National Park: Volcanoes

[2] Yellowstone National Park: How to Plan Your Adventure – Earth Trekkers

[3] Volcanic Explosivity Index - Volcanoes, Craters & Lava Flows (U.S. National Park Service)