Managing Beyond Design Basis Accidents

Current Capability at
U.S. Nuclear Power Plants

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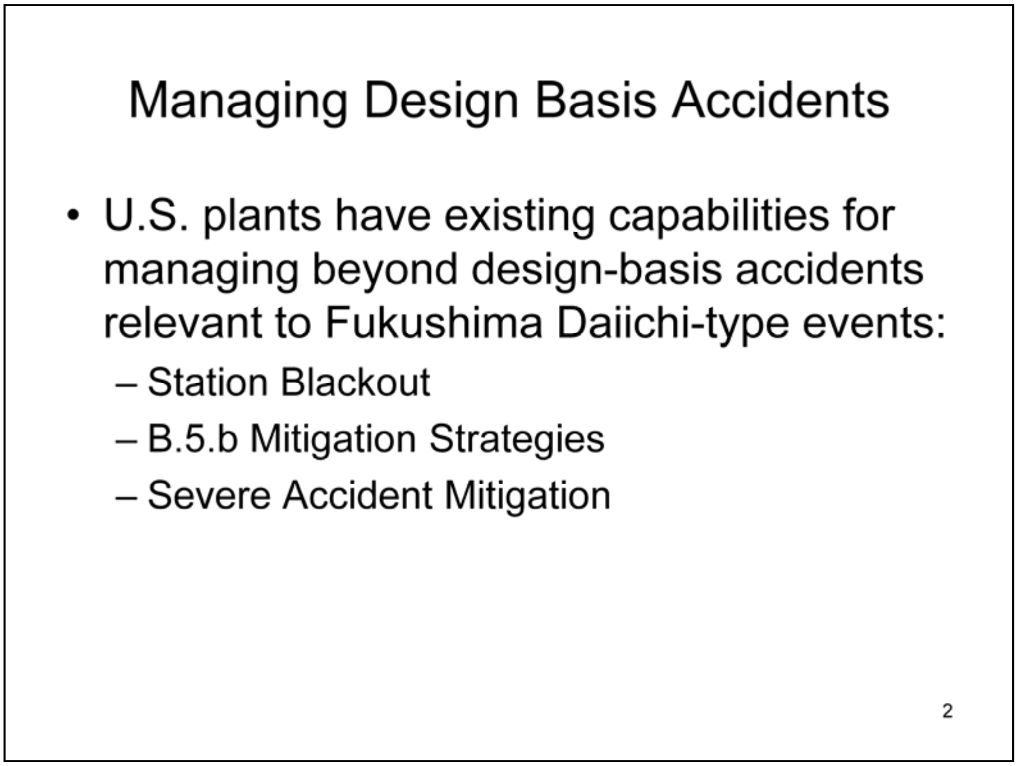
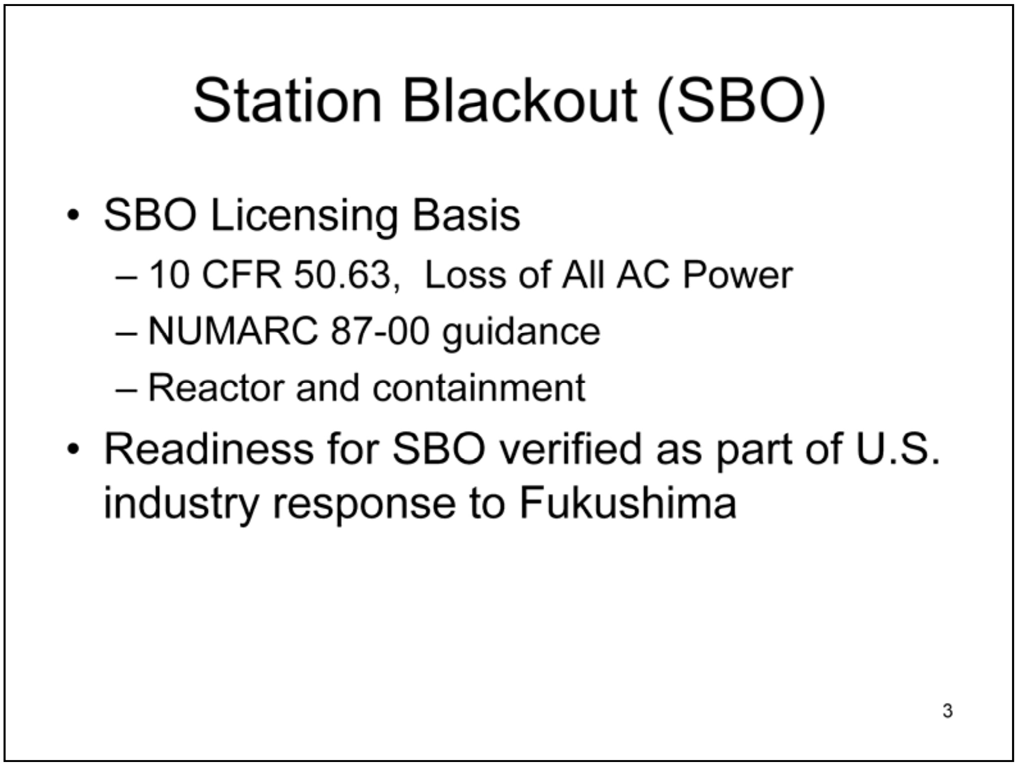


- Will discuss each of these with respect to:
    - The current Licensing basis
    - How they stack up against the Fukushima-Daiichi events
    - And, what upgrades or additional capabilities may be needed

- B.5.b mitigation strategies relate to Security events. Will discuss in detail in later slides.



- The Station Blackout rule and guidance address a loss of all AC power due to loss of offsite power (e.g., due to severe weather) and concurrent random failure of the emergency AC sources.
- SFP cooling was not included in SBO scope-- the typical time-to-boil in the SFP is longer than the SBO coping time requirements.

- Readiness verified for procedures, personnel, and equipment

- SBO Licensing Basis assumptions on next slide

Station Blackout (SBO)

- SBO Licensing Basis assumptions
  - Initiated from normal full power operation
  - Loss of offsite power to all units on site
  - SBO on at least one unit*
  - Maximum RCS leakage + shaft seal failures
  - No random accidents, events or failures
  - Must maintain decay heat removal, core covered, and containment integrity

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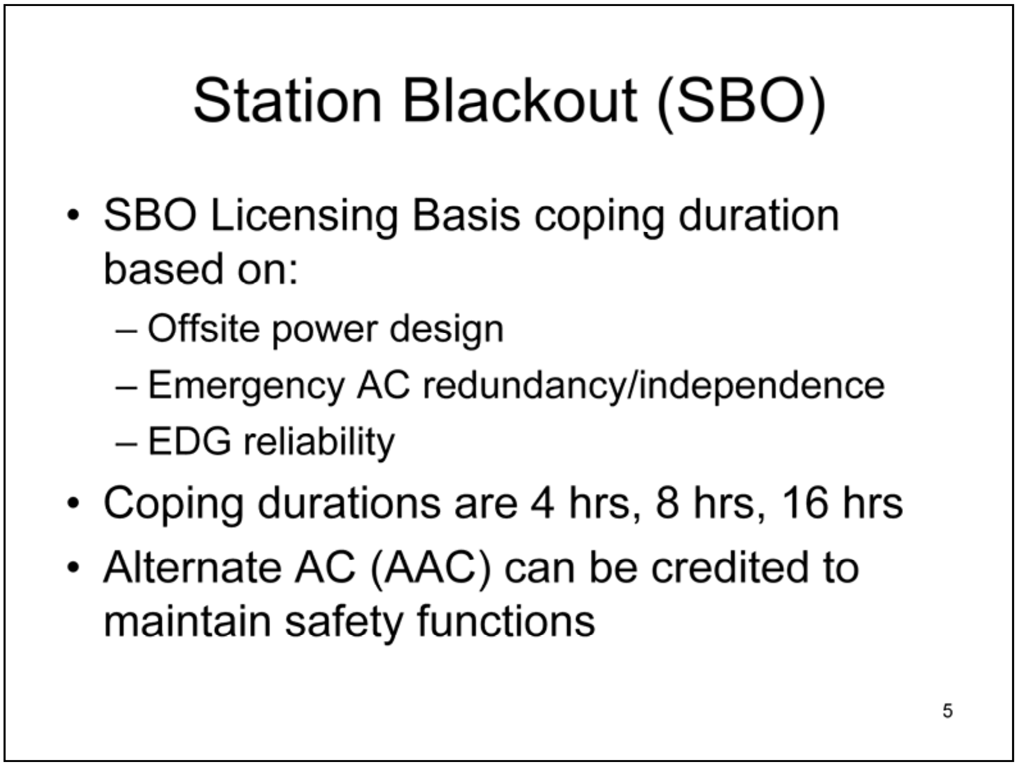
- The SBO License Basis differ significantly from the Fukushima-Daiichi event.
  - Some units were already shutdown—their steam driven decay heat removal systems (RCIS, TDAFW) were unavailable.
  - SBO occurred on multiple units. Power and essential auxiliaries (e.g., HVAC) could not be recovered in Units 1-4 by cross-tying from another unit.
  - DC power was also degraded or lost due to flooding.
  - RCS leakage was actual vs. maximum possible. Will return to this point in Slide 6.



- These coping durations are significantly shorter than the SBO experienced at Fukushima Daiichi. Will return to this point in Slide 6.

- AAC typically required to:
  - Maintain batteries for coping duration > design discharge (typ 4 hrs)
  - Maintain RCS pump shaft seal cooling for continued seal integrity
  - Provide RCS makeup or suppression pool cooling.
  - Maintain habitability of control room and electronics

- AAC would have been unavailable at Fukushima Daiichi due to damage by the earthquake and tsunami, or unavailability of the plant electrical switchgear (due to flooding).

- Without AAC or B.5.b mitigation strategies, typical coping duration <u>under licensing basis assumptions</u> would be between 4 and 8 hours (due to assumed RCS leakage or suppression pool heat up).

Station Blackout (SBO)

- SBO for Fukushima-type events
  - All units affected
  - AC and DC power lost
  - Actual RCS leakage
- Coping duration beyond battery capacity by use of:
  - B.5.b strategies
  - Portable generators
  - High temperature pump seals

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- Loss of AC and DC power is addressed at U.S. plants by B.5.b strategies.
  - Will discuss B.5.b in the next section of this presentation.
- It is possible to maintain the plant in a safe condition from remote shutdown locations outside the control room. Some U.S. plants use portable generators to power essential instrumentation at remote shutdown panels (this modification resulted in a 30% reduction in CDF at San Onofre). An alternative indication method is to read out the instrument loops at the containment penetration terminals.
- SBO coping duration at PWRs (and BWRs without RCIC) is limited by RCS leakage.
  - Over 4 hours, can lose about 1/3 of RCS water inventory. This leakage can be significantly reduced by retrofit of high temperature seals (qualified by test/evaluation—no change in elastomer properties).
  - With high temperature seals, the expected RCS leakage during SBO is controlled bleed-off flow (~ 1-2 gpm per pump) vs. leakage rate with elastomer failure ($\geq$ 25 gpm per pump), reducing leakage by a factor of 10.

B.5.b Overview

- B.5.b requires mitigation of wide spread damage from fire or explosion
  - Requirement of 2002 NRC Security Order
  - NRC Phase 1 guidance in 2005
  - NEI 06-12 Phase 2 & 3 guidance in 2006
  - Phase 2 &3 implementation in 2007
- Readiness for B.5.b verified as part of U.S. industry response to Fukushima

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- B.5.b is the section of the 2002 NRC Security Order that addresses damage from fire or explosion, such as could occur from impact of large commercial aircraft.

- NEI 06-12 guidance based on insights from plant-specific assessments of U.S. plants that considered spatial separation of redundant safety systems for a range of threats per 2005 RAMCAP (Risk Assessment and Mitigation for Critical Asset Protection).

- 10 CFR 50.54(hh) incorporated B.5.b into the regulations in 2009

- Readiness includes procedures, personnel, equipment and offsite support agreements. A concurrent seismic or flooding event is <u>not</u> assumed for B.5.b, but U.S. plants are looking at storing their B.5.b equipment in protected locations following the events at Fukushima Daiichi.

- NEI 06-12 has been decontrolled, but other details of B.5.b strategies are currently *Security Related Information* (information that would reasonably be useful in planning an attack against a facility).

B.5.b Spent Fuel Pool

- Assumes: damage to normal cooling and makeup systems
- Strategies
  - – Internal makeup
  - – External makeup
  - – External spray
  - – Leakage control
  - – Site-specific strategies

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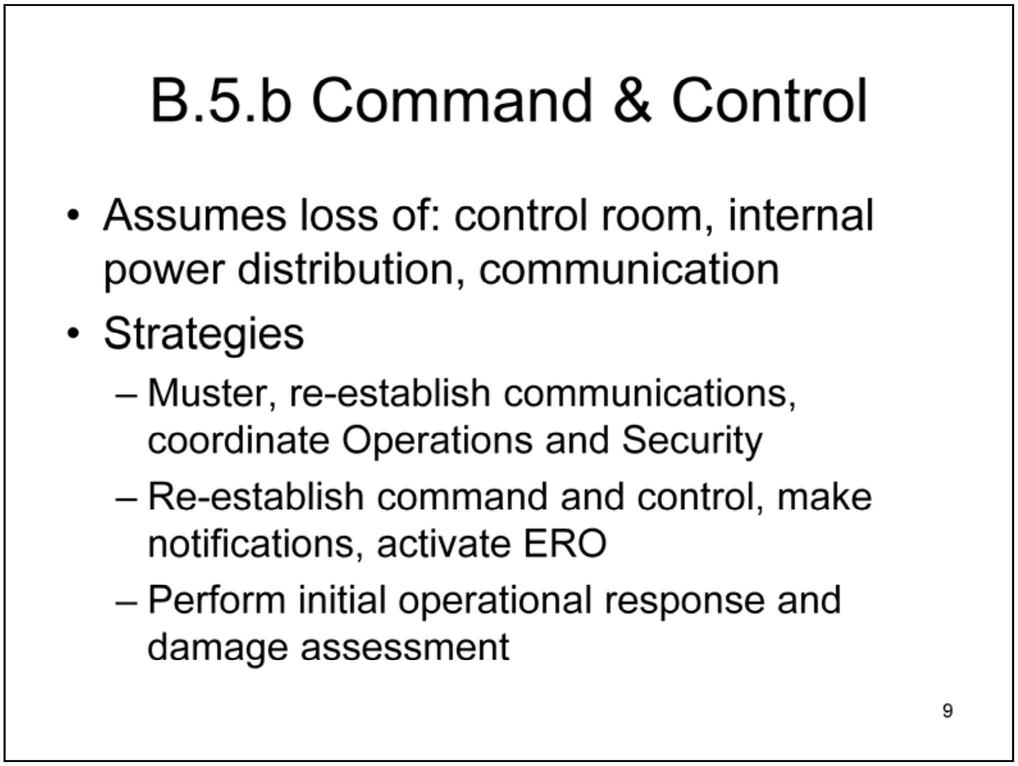
- These B.5.b mitigation strategies use manual operation and portable equipment (pumps, hoses, DC power supplies, etc.) from outside the assumed damage footprint.
- U.S. plants with reinforced concrete containment structures over their spent fuel pools were required to be able to spray the pool both from inside the building as well the building itself from outside.
- These B.5.b strategies would have addressed the SFP issues at Fukushima Daiichi, if:
  - The associated B.5.b equipment stored on site was protected from damage by the earthquake and tsunami *(U.S. plants are currently looking at upgrading their storage)*, and
  - There was enough water and fuel to implement the strategies for the SBO duration at Fukushima Daiichi *(the guidance only requires 12 hours, although many U.S. plants have much more than this)*, and
  - Enough B.5.b equipment was available for all of the affected units and SFPs. *(The guidance only requires one equipment set, although many U.S. plants already have multi-unit capability.)*
- As part of B.5.b Phase 1, plants were also required to optimize their spent fuel pool loading patterns with respect to withstanding loss of cooling and makeup water. This would certainly have helped at Fukushima Daiichi.



- These strategies cover the circumstance of damage without prior warning.

    - The alternate means of communication needed to implement these strategies would have been of benefit following the loss of all AC and DC power at Fukushima Daiichi.

    - Most of the other Command & Control strategies are not relevant to a Fukushima Daiichi event.

B.5.b Reactor & Containment

- Assumes: damage to normal systems and loss of internal power distribution
- Strategies
  - Inject water
  - Makeup to tanks
  - Manually depressurize
  - Manually operate heat removal
  - Flood containment
  - External spray

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- These B.5.b mitigation strategies use manual operation and portable equipment (pumps, hoses, DC supplies, etc.) from outside the assumed damage footprint.

- There are additional site-specific and BWR-specific strategies.

- These B.5.b strategies would have addressed the reactor and containment issues at Fukushima Daiichi, if:
  - The associated B.5.b equipment stored on site was protected from damage by the earthquake and tsunami *(U.S. plants are currently looking at upgrading their storage)*, and
  - There was enough water and fuel to implement the strategies for the SBO duration at Fukushima Daiichi *(the guidance only requires 12 hours, although many U.S. plants have much more than this)*, and
  - Enough B.5.b equipment was available for all of the affected units and SFPs. *(The guidance only requires one equipment set, although many U.S. plants already have multi-unit capability.)*

- These B.5.b strategies do not specifically address shutdown conditions.

Severe Accident Management

- Overview
  - Severe Accident issue 1988-1989
  - NUMARC guidelines 1991-1992
  - EPRI SAM-G technical basis report 1992
  - Vendor-specific guidelines 1995
  - Plant-specific SAM-Gs 1998
- Readiness for SAM-G verified as part of U.S. industry response to Fukushima

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- SAM-G concerns the reactor and containment. It does not address spent fuel pool problems.

SAM-G Phase 1 and Phase 2

- Entry based on safety functions not met
- RCS/Core diagnosed/verified as
  - Badly Damaged (BD)
  - Ex-vessel (EX)
- Containment diagnosed/verified as
  - Bypassed (B)
  - Impaired (I)
  - Closed and Cooled (CC)
  - Challenged (CH)

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- Badly Damaged = based on REPCET, RV water level, RCS pressure, containment pressure
- Ex-Vessel = BD + high containment rad monitor readings and rapid increase in excore detector readings
- Bypassed = LOCA outside containment (including unisolated SGTR)
- Impaired = unplanned decrease in containment pressure with hi outside rad
- Closed and Cooled = pressure $\leq$ design and not challenged
- Challenged = pressure > design

SAM-G Phase 3

- Priorities based on diagnosis
- Candidate High Level Actions (CHLAs):

Inject into RCS	Inject into S/Gs
Vent the RCS	Depressurize S/Gs
Depressurize RCS	Restart RCPs
Spray into containment	Spray FW into containment
Operate containment ECUs	Operate H2 recombiners
Flood reactor cavity	Flood auxiliary buildings
Spray outside of containment	Spray auxiliary buildings

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- Candidate high level actions are selected and prioritized based on the verified diagnosis from Phase 1 and 2.
- Some of these strategies would be unavailable with a loss of AC and DC power.
- Many of these strategies overlap with B.5.b capabilities.

SAM-G Phase 4

- Applies when information insufficient to diagnose plant conditions
- Based on sound engineering judgement
- Requires declaring 10 CFR 50.54(x) & (y)
- Uses same CHLAs as Phase 3
- Priorities based on most recently failed safety functions

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- Phase 4 includes situations like those at Fukushima Daiichi, in which all control room instrumentation was lost when AC and DC power were disabled or depleted (batteries).

- Declaration of 50.54(x) & (y) means that (with Senior Reactor Operator approval) the operators can take any reasonable actions necessary in an emergency that are immediately needed to protect public health and safety--prior permission from outside officials would <u>not</u> be needed.

Conclusions

- U.S. plants have existing capabilities for managing beyond design basis accidents:
  - Station Blackout per 10 CFR 50.63
  - B.5.b strategies per 10 CFR 50.54(hh)
  - Severe Accident Management Guidelines
- With some upgrades, these capabilities could reduce the consequences of a Fukushima Daiichi type event.

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- SBO
  - Existing coping durations without AC power would need to be extended, for example by back-fitting high temperature RCS pump seals and portable generator-powered remote shutdown panels. [PWRs with these features and turbine-driven decay heat removal can have expected coping durations of more than 24 hours.]
  - AAC capability (both generators and the plant’s switchgear) would need to be protected against natural phenomena (including seismic and beyond design basis flooding).
- B.5.b
  - Would have addressed loss of both AC and DC power, and spent fuel cooling, <u>if</u> the equipment was protected from the initiating events, and there were enough fuel, water and equipment sets available.
  - Other strategies may be needed for units already shutdown.
- SAMG
  - Would have addressed beyond design basis conditions encountered.
  - Declaration of 10 CFR 50.54(x) would have allowed actions immediately needed for public health & safety without outside approval