

# Critical facilities and earthquakes: managing risk of operational failure

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# Critical facilities

- Failure causes loss disproportionate to damage
  - Hospitals, data centers, operational centers...
- Failure results from red tag or equipment failure
- Mitigation measures
  - Strengthening: reduce  $p$ , site failure probability
  - Backup facility: reduce  $P$ , operational failure prob
- Backup facility
  - Cold to hot; normal operations can take place there
  - Located far enough from primary to avoid common-cause failure
  - Not too far to allow personnel exchange
- This presentation: is  $P$  low enough?



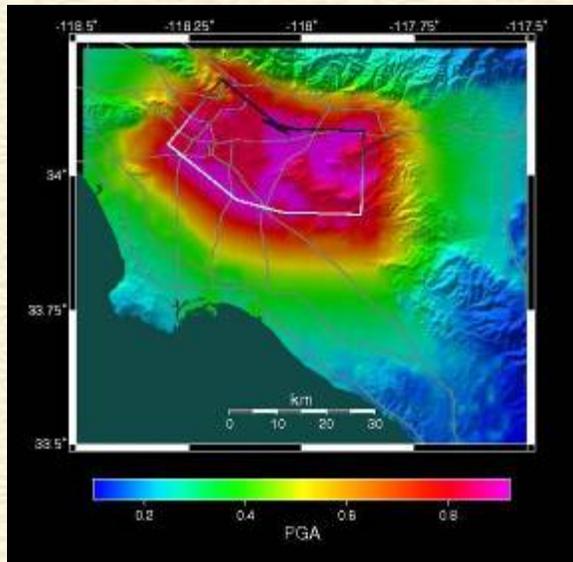
# Decision-making information

- Let's calculate  $P(t)$ : prob. simultaneous operational failure at 2 sites in time  $t$
- Question: is  $P(t)$  “low enough?”
  - 😊 Yes! Bonuses for everyone!
  - 😐 No, but can be made so by strengthening, or
  - 😞 No; have to relocate the backup
- $P(t)$  depends on
  - **Hazard**: how strongly and frequently both sites shake
  - **Fragility**: failure prob. each site as function of shaking

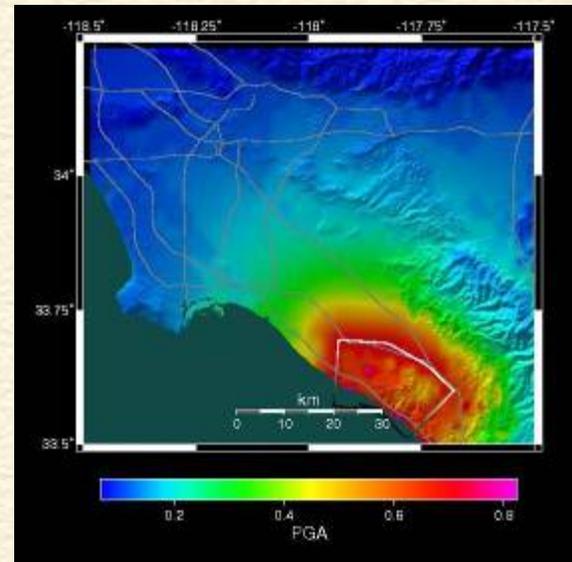


# How do we calculate hazard?

Hypothesize earthquake ruptures, estimate their annual frequency, and calculate probabilistic shaking at each site



shaking in quake 1 at site 1  
shaking in quake 1 at site 2  
frequency of quake 1

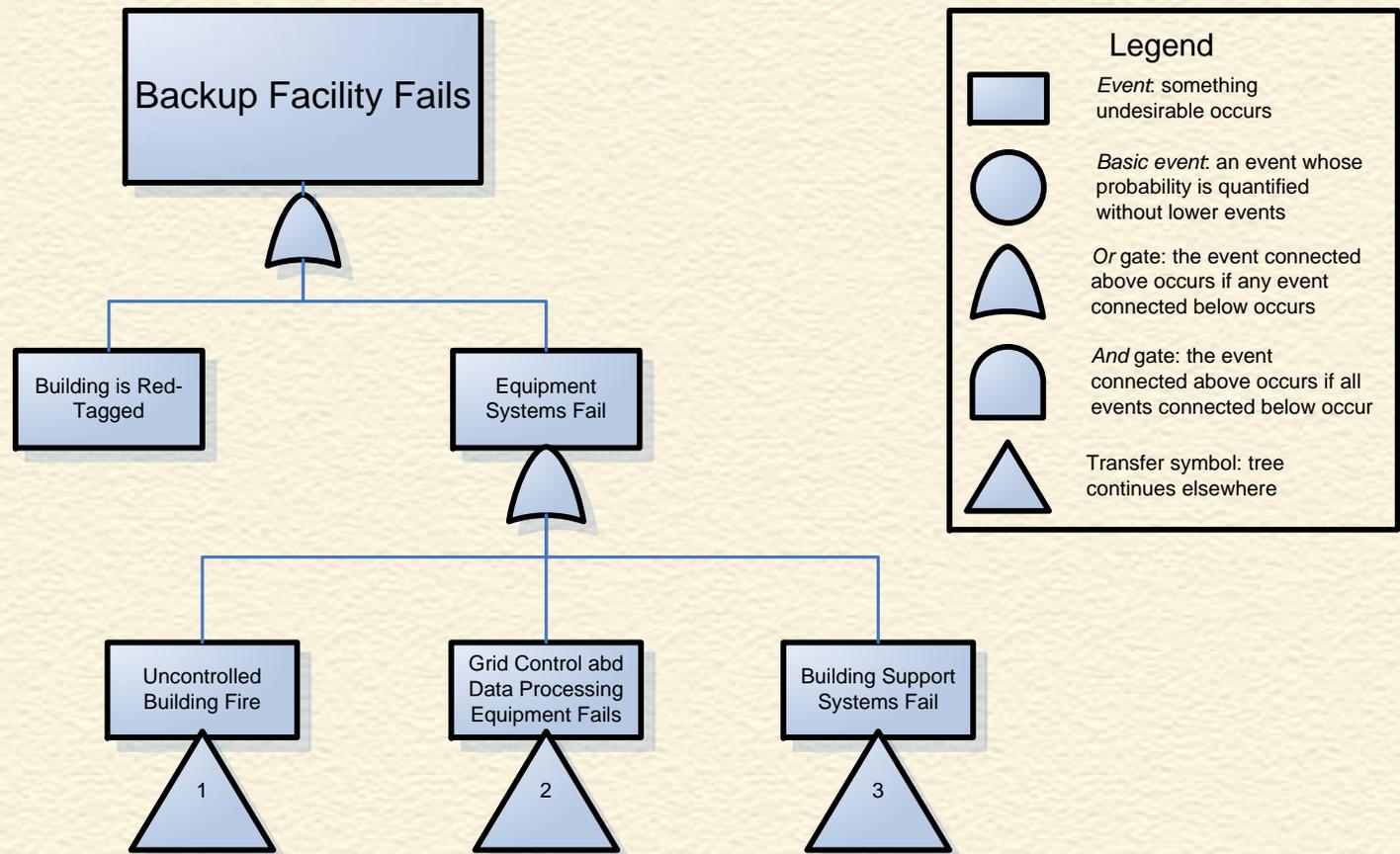


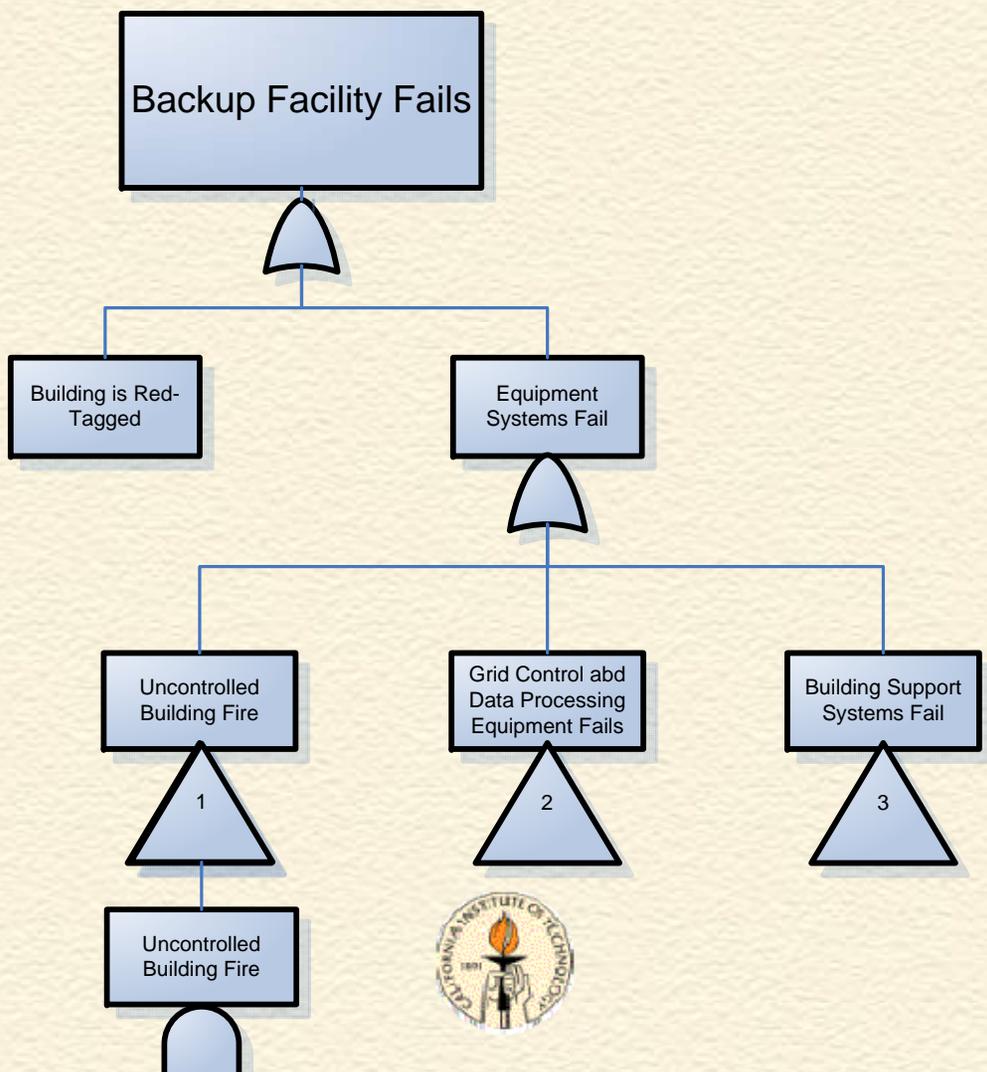
shaking in quake 2 at site 1  
shaking in quake 2 at site 2  
frequency of quake 2

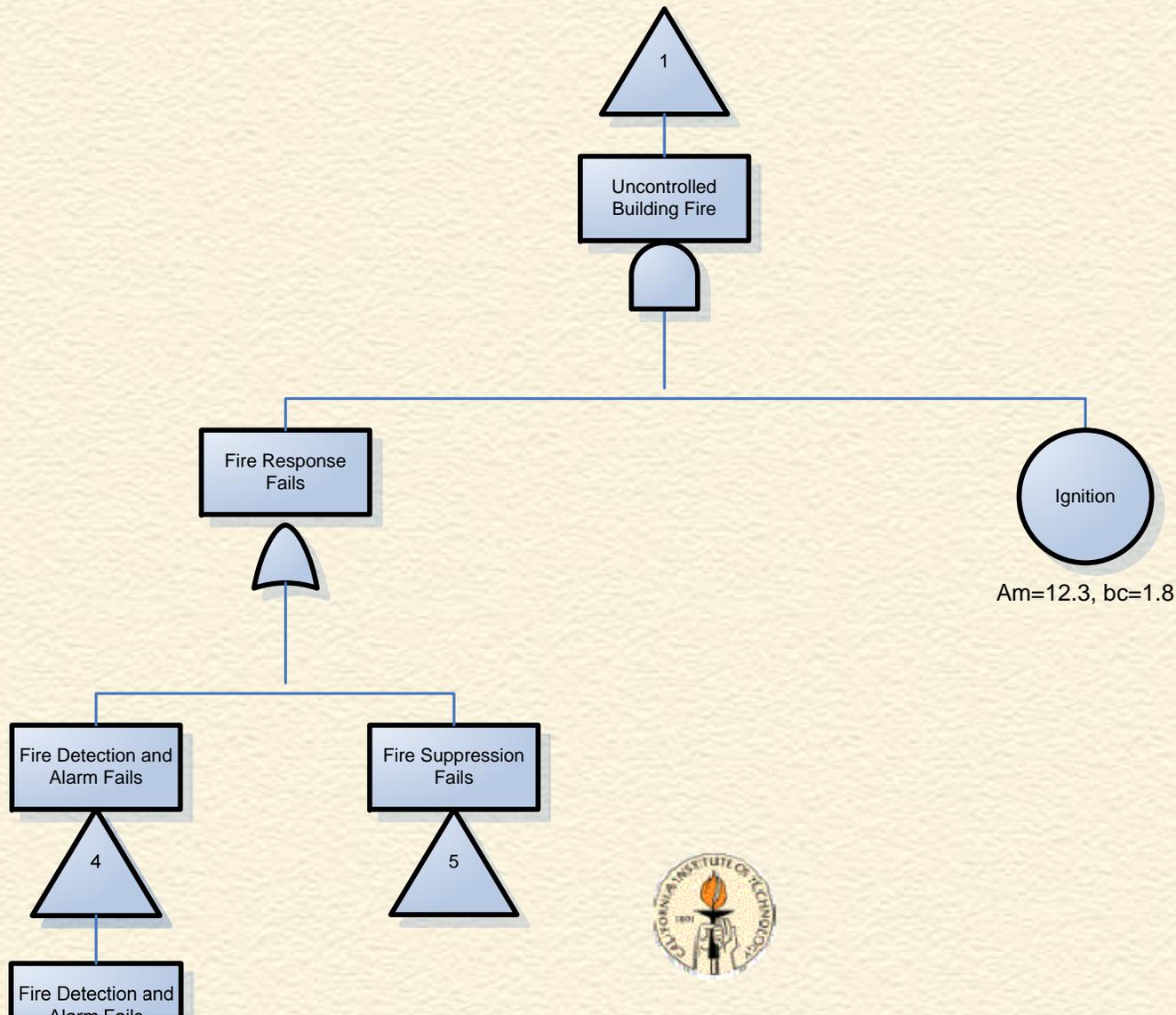
etc.



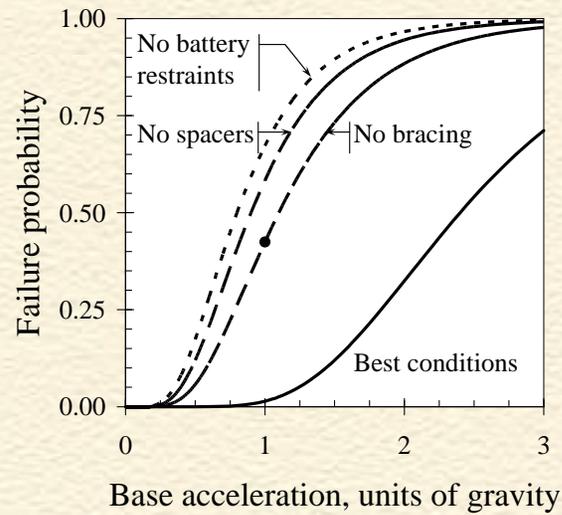
# How do we calculate fragility?







# Basic events failure probabilities



# All the math you'll see here

- Start with basic events and “and” and “or” gates

$$p_{A \text{ and } B} = p_A \times p_B$$

$$p_{C \text{ or } D} = 1 - (1 - p_C) \times (1 - p_D)$$

- Repeat until reach the top event

$p_1$  = combine *and* and *or* math, calculate vs intensity

$p_2$  = similar combination for site 2

- Now calc  $P(t)$ , prob. simultaneous operational failure at 2 sites in time  $t$

$$L = \sum_n [f(\text{quake } n) \times p_1(\text{quake } n) \times p_2(\text{quake } n)]$$

$$P(t) = 1 - \exp(-L \times t)$$



# Implementation

- A SoCal utility
  - Ops center
  - Data center
  - Backup 1 hr away
- Puente Hills thrust fault was a concern
  - Quick qualitative check: one event *could* strongly shake all 3 facilities
  - So management needed quantitative risk: what was  $P(t = 5 \text{ yr})$ ?



# Hazard analysis: USGS/SCEC OpenSHA app

“IM\_EventSetCalc.jar” produces:

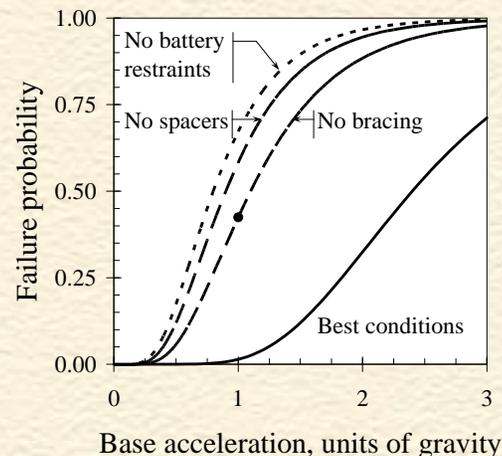
- A database of intensity measure levels
  - ... mean and variance
- for an arbitrary list of intensity measure types,
  - ... e.g., PGA, Sa(0.2 sec), Sa(1.0 sec)
- using any intensity measure relationships,
  - ... e.g., BJF97, CB03, & Sadigh et al. 1997
- at any sites of interests
  - ... e.g., ops center, data center, and backup.



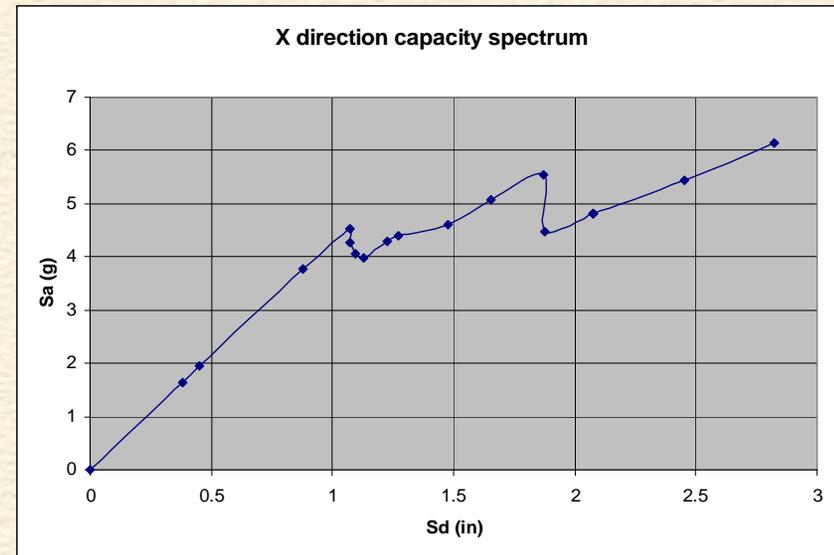
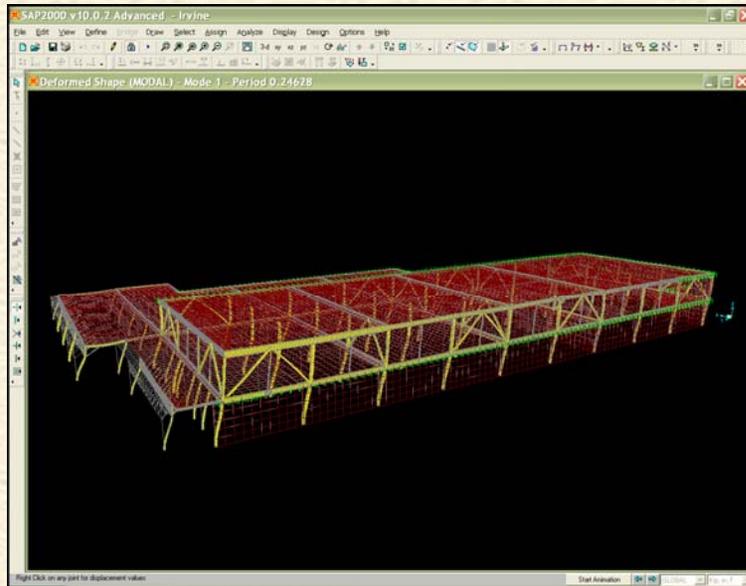
# Caltech fragility analysis

## Equipment fragilities:

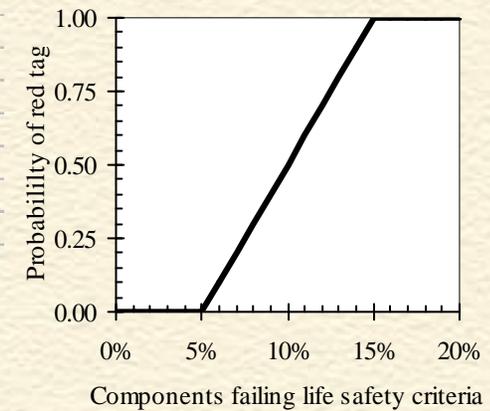
- Examine ~150 components for condition, config., redundancy
- 1,000 photos
- 1999 MCEER atlas for fragility parameters



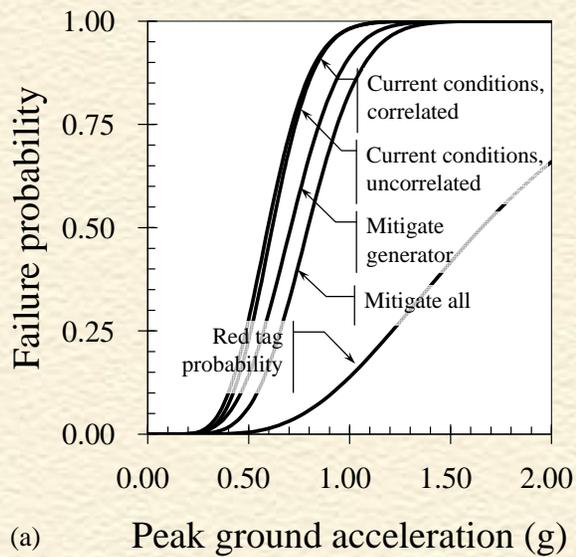
# Red-tag fragilities



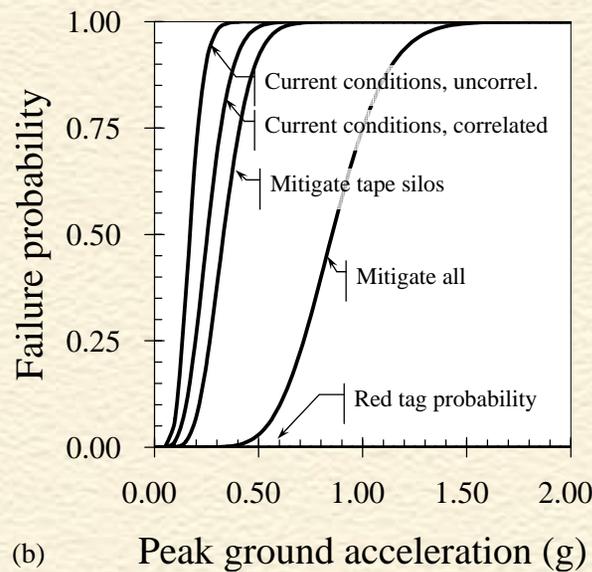
Step	Teff	Beff	Sd (in)	Sa (g)	< IO	IO to LSL	LS to CP	> CP
0	0.154	0.050	0.000	0.000	248	0	0	0
1	0.154	0.050	0.379	1.643	248	0	0	0
2	0.154	0.050	0.448	1.939	248	0	0	0
3	0.154	0.051	0.879	3.781	246	2	0	0
4	0.156	0.058	1.072	4.516	243	3	1	1
8	0.157	0.069	1.075	4.272	243	3	1	1
10	0.158	0.069	1.094	4.061	243	2	1	2



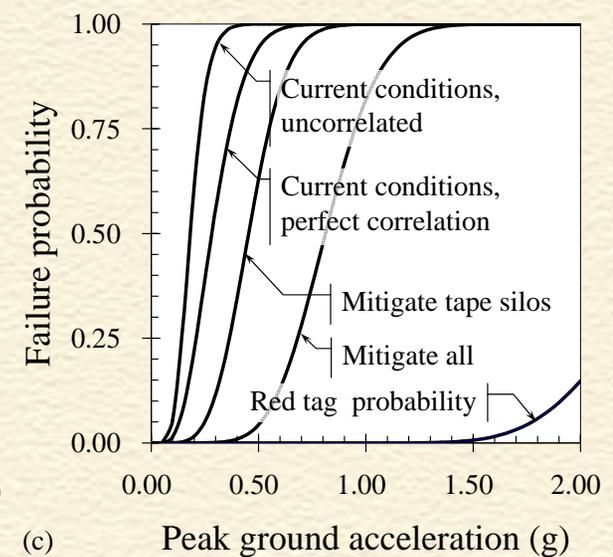
# Ops, data, and backup fragilities



Operations



Data processing



Backup site



# Failure probability next 5 years

	<b>As-is</b>	<b>Fix these weak links...</b>	<b>Get</b>
Operations	0.8%	Generator equipment	0.3%
Data facility	5.5%	Tape silos	0.2%
Backup facility	3.2%	Generator equipment, fans, EQSL, computers, raised access floors, tape silos	0.1%
Ops & backup	0.1%		$\sim 10^{-6}$
Data & backup	0.4%		$\sim 10^{-6}$



# Conclusions

- Red-tagging wasn't the problem
- Equipment was
- Most equipment had been secured
- Unsecured equipment was critical,  $P(t)$  too high
- $P(t)$  low enough after fixing equipment, 😐
- Utility is fixing the weak links, not relocating



# What's new here

- Hazard analysis using IM\_EventSetCalc.jar
  - Captures correlated shaking at distant sites
  - Arbitrary number of intensity measures, attenuations, sites
  - Inter- and intra-event variability in ground motion
- Fragility analysis using of fault trees
  - For data centers with MCEER empirical fragility dataset
  - Considering red tag, equipment failure, and off-site utility failure

## **Bottom line: fully probabilistic risk analysis**

- Simultaneous operational failure of 2+ distant facilities
- Considering both red-tagging and equipment damage
- Broad empirical basis for equipment failure
- State-of-the-art fault tree analysis
- 1.2 million scenarios



# Questions

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# Supporting material



## Relating FEMA 356 criteria to ATC-20 tag color

- FEMA 356: various life-safety criteria for structural components
- ATC-20: “Severe conditions *endangering the overall building* are grounds for an Unsafe posting. Localized Severe and overall Moderate conditions may allow a Restricted Use [yellow tag] posting.”

