Collecting reliability data and building of databases for PRA the PLG way

AESJ

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USA Data Collection

- WASH 1400
- NUREG/CR 1363
- GCR
- IEEE Std. 500-1984
- Reliability & Availability Data System (RADS)
- CCF: NUREG/CR-4780
- INL: Licensee Event Reports (LERS) and Event Notifications
- INPO: Licensee equipment failure reports
- NRC: Analyzes the INL and INPO data and results published annually on the NRC website. The data is primarily used to support the NRC's standardized plant analysis risk (SPAR) models but also provides generic industry average values for use by the industry in their individual PSA models.

The PLG Generic Database

- Evolved from Data Collection Efforts in Late 1970’s and Early 1980’s
- First Published in 1989
- Includes Data for
  - Initiators
  - Failure Rates
  - Maintenance Outages
  - Common Cause Parameters
  - Human Error Rates

Data analysis the PLG way

- Representation of Failure Parameters
- Bayesian Updating (1-stage, 2 stage)
- Operations of Distributions
- The PLG Generic Database
- CCF Parameter Estimation
- Maintenance Unavailability

Data analysis the “PLG” way

- Representation of Failure Parameters
- **Bayesian 2 stage Updating**
- Operations of Distributions
- The PLG Generic Database
- CCF Parameter Estimation
- Maintenance Unavailability

Two-Stage Bayesian Updates: incorporates site specific data with general data

Thomas Bayes (c. 1702 – April 17, 1761)

Why Two-Stage Updates?

- Incorporate evidence from multiple plants and prior generic estimates into one generic prior.
- Repeatable approach to synthesis of data.
- First stage output represents plant-to-plant variability of the data parameter, $\Phi(\lambda)$;

  e.g., plant may be good or bad performer.
- Second stage incorporates evidence from single plant performance (same as one-stage update).

Statistical Thinking

- The standard statistical view of probability is the so-called frequentist approach.

- whereby the likelihood λ of an uncertain event A, λ(A), is defined by the frequency of that event based on previous observations.

- For example, in the USA 50.9% of all babies born are girls; suppose then that we are interested in the event A: 'a randomly selected baby is a girl'.

- According to the frequentist approach λ(A)=0.509.

Bayesian Thinking

- The statistical approach for defining the likelihood of an uncertain event is fine if, and only if:
  - we have been able to record accurate information about many past instances of the event;
  - the number of times this type of event occurs approaches ∞
  - and we believe that future events will be EXACTLY like past events.
- Bayesian probability is a formalism that allows us to reason about beliefs **under conditions of uncertainty**.
- For a future failure event, nobody can state with any certainty whether or not it is it will happen and when.
- Different NPPs may have different factors that might effect the likelihood and timing of failures.

Why don't I like the statistical approach?

- Fundamental difference in the between the Bayesian and statistical approach
- Most frequentists accept failure rates based on an arbitrarily chosen value (conventionally >= 95%), such as the HCLPF value for SSCs.
- This tells us nothing about the probability of SSC failure … is 94% chance of failure OK, 93%?
- The frequentist conclusion is restricted to the data at hand, it doesn't take into account previous, or future, valuable information.

Why do I like Bayesian Methods?

1. **All types of information are used.**
2. The use of judgment is visible and explicit.
3. With weak evidence, the prior dominates results.
4. With strong evidence, results insensitive to prior (dominated by evidence).
5. Successive updating gives same result as one-step updating with consistent evidence

Bayes' Theorem

- True Bayesians actually consider conditional probabilities as more basic than joint probabilities . It is easy to define P(A|B) without reference to the joint probability P(A,B). To see this note that we can rearrange the conditional probability formula to get:

- P(A|B) P(B) = P(A,B)

by symmetry:

- P(B|A) P(A) = P(A,B)

- It follows that:

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}$$

- which is the so-called ***Bayes' Rule.***

Bayes' Theorem Interpretation

$P(A|B) = P(A)\, P(B|A)/P(B)$

A $\rightarrow$ The frequency of some event takes on a specific value.

B $\rightarrow$ The accumulation of evidence about the frequency of the event.

P(A) $\rightarrow$ Probability of A prior to knowing evidence B **("The Prior").**

P(B|A) $\rightarrow$ Probability of observing evidence B given A; i.e., given the event frequency takes on a specific value **("The Likelihood").**

P(B) $\rightarrow$ Probability of observing evidence B summed over all possible values of event A; i.e. a normalization factor.

P(A|B) $\rightarrow$ Probability of A after, or given knowledge of, the evidence of event B **("The Posterior").**

Types of Generic Information Available

- **Type 1:** Failure Data from Operating Experience at N Plants

  $E_1 \equiv \{ < k_i, T_i > ; i = 1, \ldots, N \}$ (the data for the plant should not be incorporated into the first stage of the analysis. The use of these data in the first stage leads to a "double counting" of the evidence in the second stage.)

- **Type 2:** Failure Rate Estimates or Distributions in M Generic Data Sources

  $E_2 \equiv \{ \lambda_i ; i = 1, \ldots, M \}$

Two-Stage Bayes' Updating

First Stage: Incorporate Related Evidence

1. Collect plant-specific evidence for 'N' plants $\{E_1 = K_i, T_i), i = 1, 2, \ldots, N\} = \langle E_1,N \rangle$.
2. Expert opinion distributions can be incorporated as additional plant evidence weighted by assigned range factor $\{E_2 = \lambda_i, i = 1,2,\ldots,M\} = \langle E_2,M \rangle$.

Two-Stage Bayes' Updating *(Continued)*

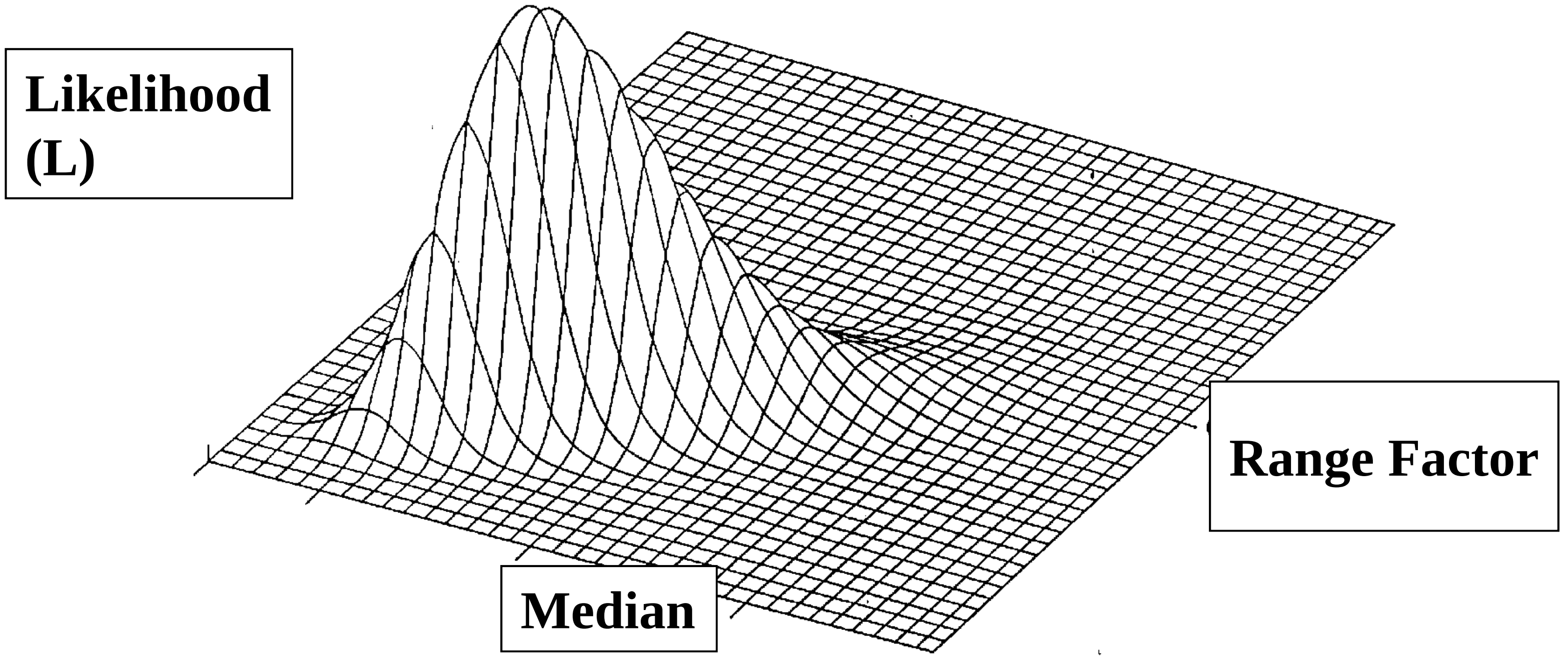
3. Define family of N, equally likely lognormal distributions to characterize the plant to plant variability.
   A. Use discrete grid to represent uncertainty in the two parameters of the "True" lognormal distribution;
   i.e., θ, where θ represents a specific median and range factor pair, and $P_0(\theta|E_0)$= constant; i.e., each lognormal initially equally weighted.
   B. Each lognormal distribution represents the probability that λ_i is the true value, given θ; $\Phi(\lambda_i|\theta)$.

Two-Stage Bayes' Updating *(Continued)*

4. Compute Poisson Likelihood of the Evidence
   A. Apply Poisson model for likelihood of each E_k set over the entire range of λ_i ; i.e., $L(E_k| \lambda_i)$.
   B. For a given lognormal distribution, $\Phi(\lambda_i|\theta)$, integrate the likelihood of the evidence, E_k, over the entire range of λ. In discrete form: $L(E_k|\theta) = \Sigma_{all\ \lambda i}\ [\Phi(\lambda_i|\theta)^* L(E_k| \lambda_i)]$
   C. Take product of likelihoods for each evidence set, E_k, to obtain likelihood as function of θ; i.e.,

$$L(E_1|\theta,E_o) = \Pi_k\ [L(E_k|\theta)]$$

Likelihood of Evidence Sets for Each Curve of Distribution Family



Two-Stage Bayes' Updating *(Continued)*

5. Apply Bayes' Theorem to obtain new weights for the θ distributions; i.e., $P(\theta|E_o,E_1)$.
6. Combine Posterior of lognormal family of distributions, $P(\theta|E_o,E_1)$.
   A. Apply probability distribution merge function.
   B. Compute "Expected Distribution", $\Phi(\lambda_i)$, by summing over distribution weighted probabilities, $P(\theta|E_o,E_1)$, of each lognormal at each value λ_i.
   C. Resulting distribution is not assumed to be any specific shape (represented as 100 Bin DPD).
7. Apply second-stage Bayes' update in usual way to incorporate plant-specific evidence.

$$\phi(\lambda_j | E_2) = \frac{\phi(\lambda_j)\, L(E_2 | \lambda_j)}{\sum_{i=1}^{N} \phi(\lambda_i) L(E_2 | \lambda_i)}$$

Motor-Operated Valve MOV-1 Failure on Demand Stage 1 Data

Source	Data			
	Number of Failures	**Number of Demands**	**Estimate**	**Assigned Range Factor**
<u>TYPE 1</u>				
Plant A	10	1.65E+3		
Plant B	14	1.13E+4		
Plant C	7	1.73E+3		
Plant D	42	6.72E+3		
Plant E	3	1.26E+3		
Plant F	31	9.72E+3		
<u>TYPE 2</u>				
Wash-1400			1.00E-3	5
NUREG/CR-1363			5.60E-3	3
GCR			1.00E-3	10

Stage 1: Prior

Distribution

Name: MOVFO1 | Date: 27 NOV 2014 11:59 | F/M Duration: F | Units: DEMANDS | Scale: LOG10

Description: MOTOR OPERATED VALVE - FAIL TO OPERATE ON DEMAND

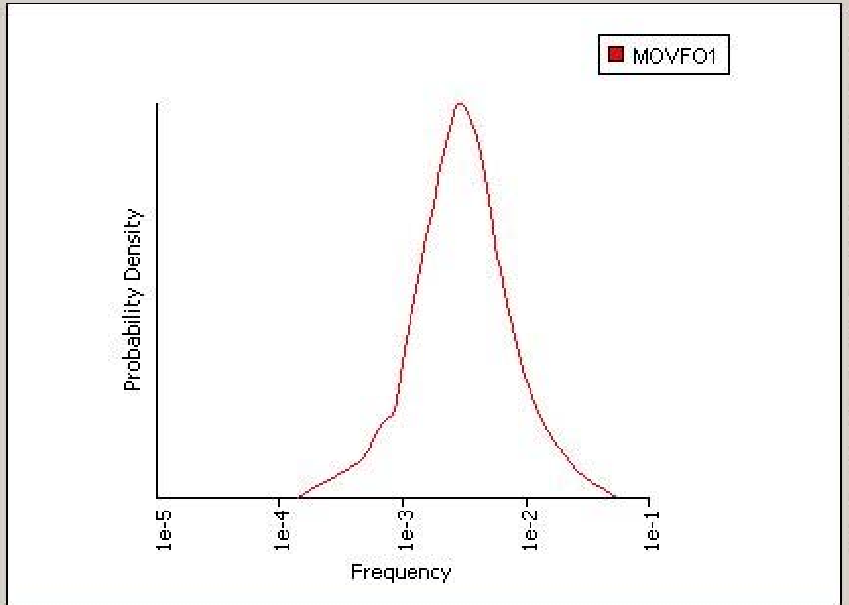
Perform Bayesian Update

Stats

Mean:	4.43E-03
5th Percentile:	4.40E-04
Median:	2.41E-03
95th Percentile:	9.43E-03
Range Factor:	4.63E+00

Notes

Two-Stage Prior



Bin	Value	Probability	Cumulative
1	1.78E-04	4.56E-003	4.56E-003
2	2.83E-04	1.36E-002	1.81E-002
3	4.90E-04	2.14E-002	3.95E-002
4	6.93E-04	2.81E-002	6.76E-002
5	8.49E-04	1.62E-002	8.39E-002
6	9.49E-04	1.75E-002	1.01E-001
7	1.22E-03	1.01E-001	2.02E-001
8	1.73E-03	1.10E-001	3.12E-001
9	2.24E-03	1.05E-001	4.17E-001
10	2.74E-03	9.34E-002	5.11E-001
11	3.24E-03	7.89E-002	5.89E-001
12	3.74E-03	6.49E-002	6.54E-001
13	4.47E-03	9.55E-002	7.50E-001
14	5.48E-03	6.33E-002	8.13E-001
15	6.48E-03	4.31E-002	8.56E-001
16	7.48E-03	3.02E-002	8.86E-001
17	8.49E-03	2.19E-002	9.08E-001
18	1.34E-02	7.22E-002	9.80E-001
19	2.83E-02	1.48E-002	9.95E-001
20	4.47E-02	4.72E-003	1.00E+000

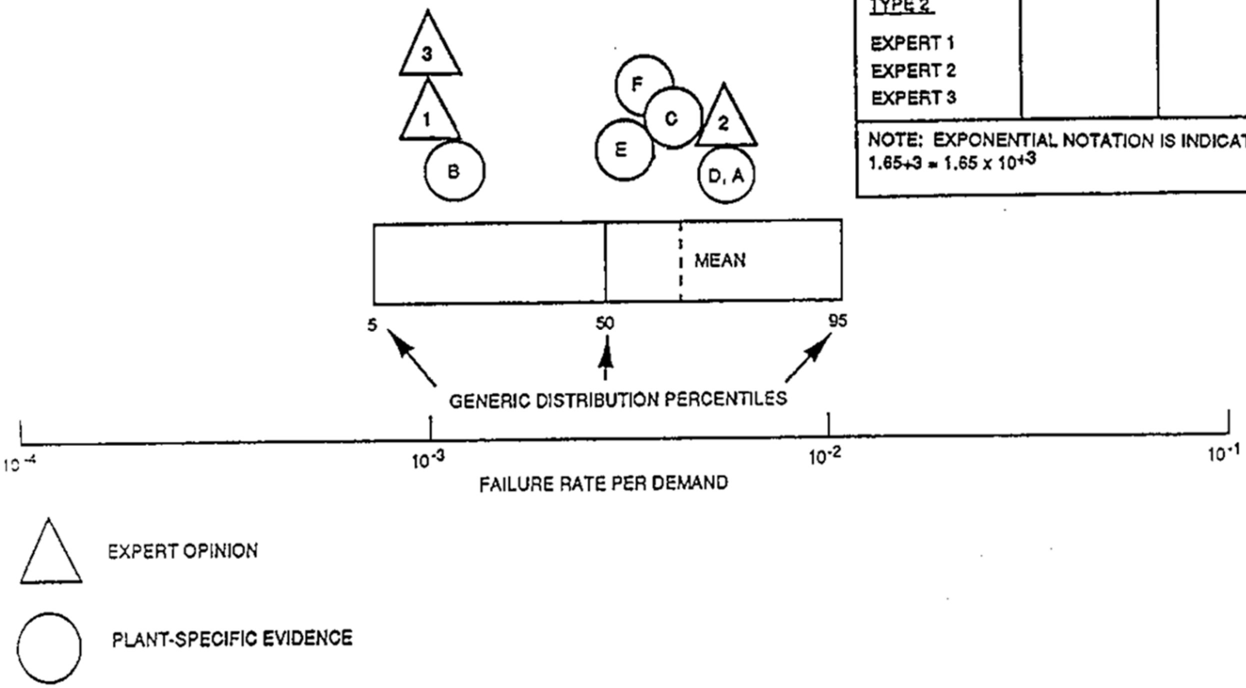
(•) Log 10 ( ) Linear (•) Density ( ) Cumulative

Save Graph | Report | Exit | Save

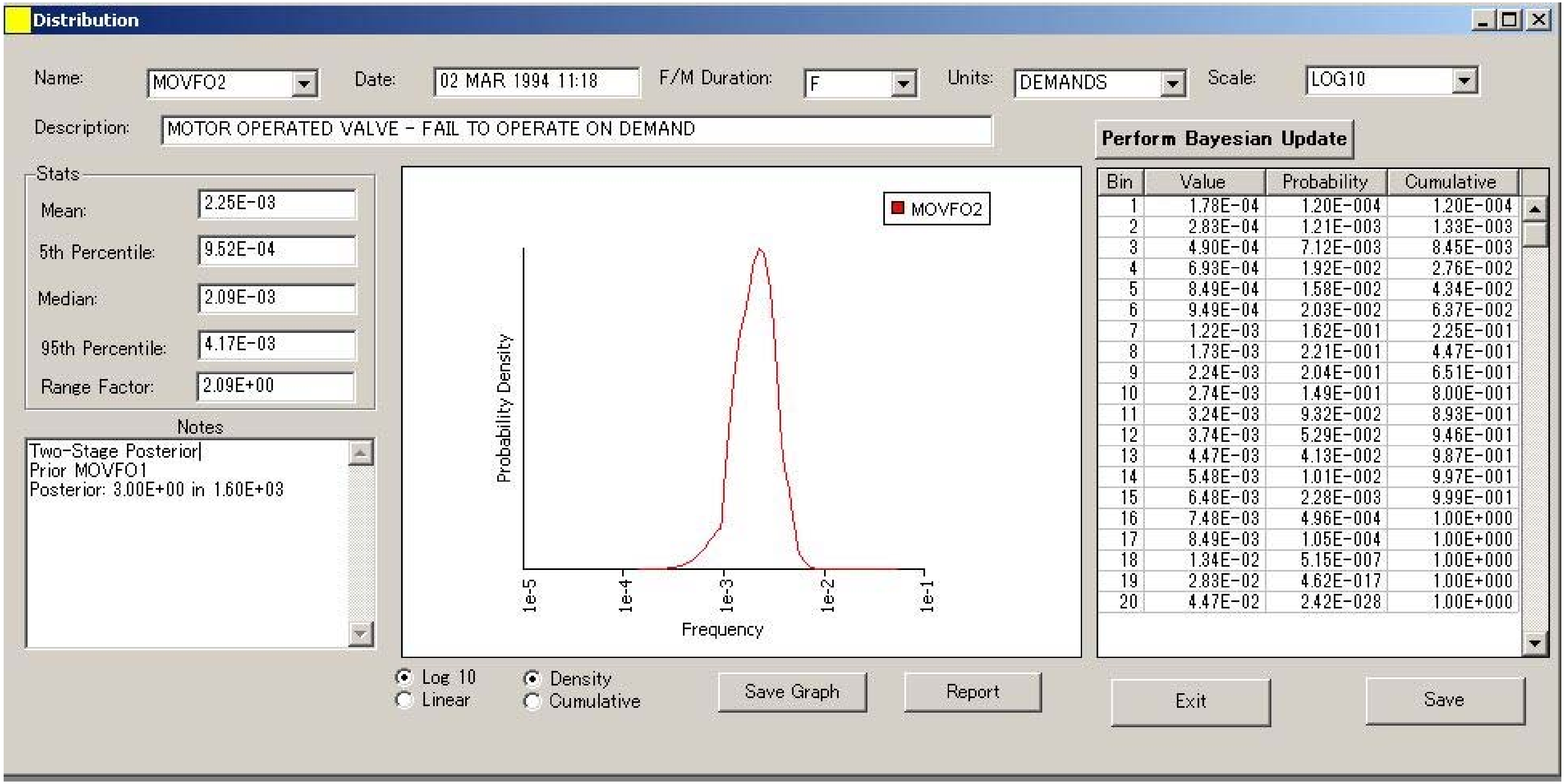
Comparison of Generic Distribution with Evidence

EVIDENCE COLLECTED FOR FAILURE RATE				
SOURCE	DATA			
	NUMBER OF FAILURES	NUMBER OF DEMANDS	ESTIMATE	ASSIGNED RANGE FACTOR
TYPE 1				
PLANT A	10	1.65+3		
PLANT B	14	1.13+4		
PLANT C	7	1.73+3		
PLANT D	42	6.72+3		
PLANT E	3	1.26+3		
PLANT F	31	9.72+3		
TYPE 2				
EXPERT 1			1.00-3	5
EXPERT 2			5.60-3	3
EXPERT 3			1.00-3	10

NOTE: EXPONENTIAL NOTATION IS INDICATED IN ABBREVIATED FORM; e.g., 1.65+3 = $1.65 \times 10^{+3}$

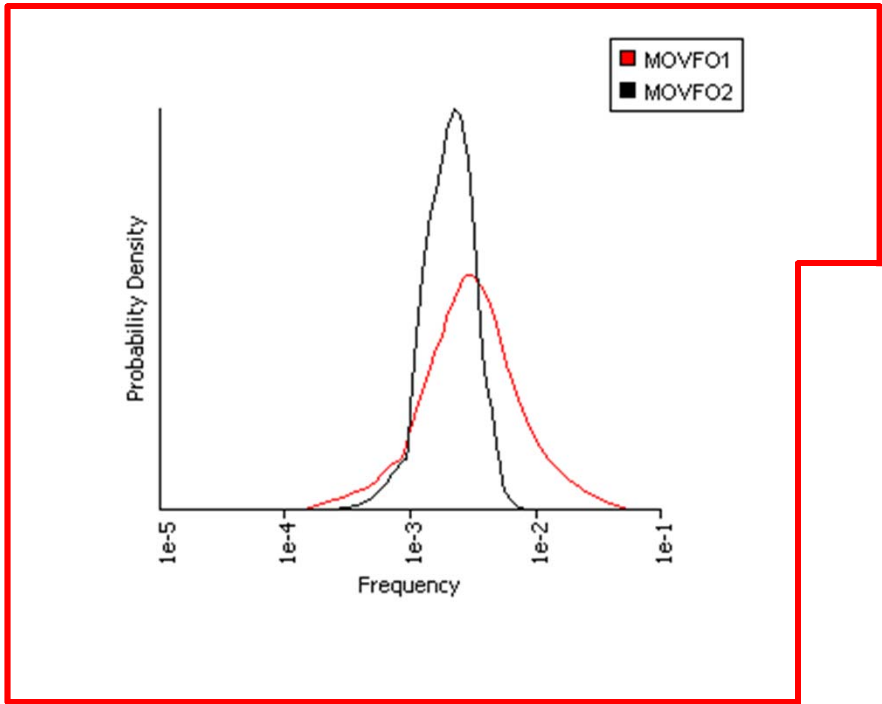


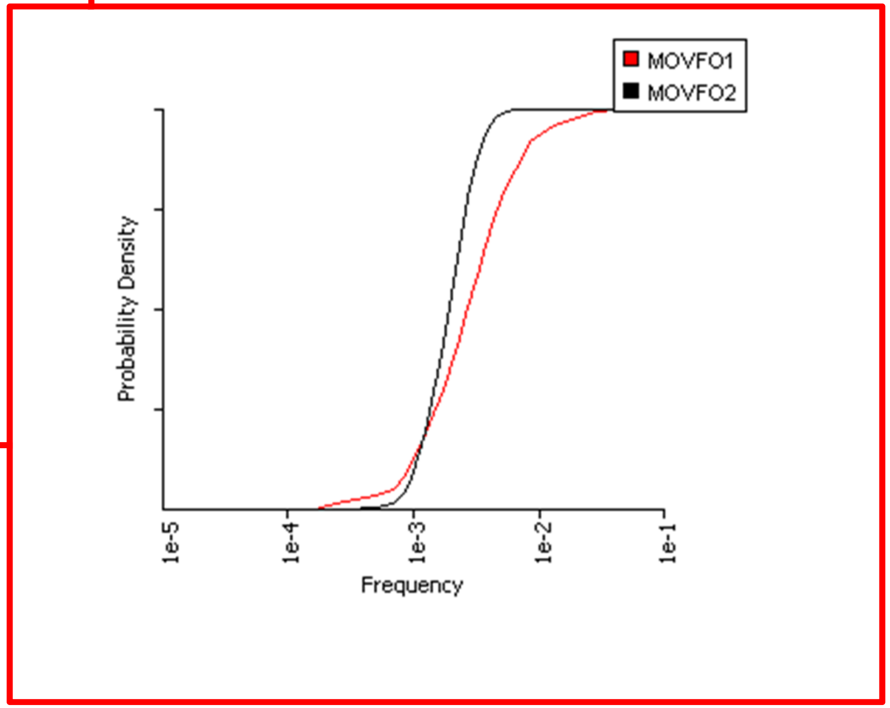
Stage 2: Posterior



3 failures in 1,600 demands

Comparison of Stage 1 and Stage 2





Creating J-SQUG: Using Earthquake Data the PLG Way

An experience-based approach using all available data and common sense to re-engineer the seismic analysis and design of nuclear plants, help with restarts, and reduce costs

SQUG History
(Seismic Qualification Utility Group)

- In the early 1980s EPRI with EQE began sponsoring investigations of electric power facilities and industrial sites subjected to strong earthquake shaking.
- The purpose of the post-earthquake investigation program was to provide useful information for the nuclear power industry for the seismic qualification of critical equipment in power plants.
- The intent was to observe the typical causes of earthquake damage to equipment representative of NPP safety systems.
- And to analyze equipment that appeared susceptible to earthquake damage, versus equipment that did not, and the threshold intensity of ground shaking resulting in equipment damage.

Some two dozen categories of standard mechanical, electrical and electronic equipment were defined that covered most components of safety systems in nuclear plants:

Mechanical Equipment					
Horizontal Pumps	Vertical Pumps	Air Compressors	Fans	Engine-Generators	Overhead Cranes
Air Handlers	Tanks	Motor-Operated Valves	Fluid-Operated Valves	Motor-Generators	

Electrical Equipment		
Transformers (<15 Kilovolt)	Medium Voltage Switchgear (<15 Kilovolt)	Low Voltage Switchgear (<500 Volt)
Motor Control Centers	Panelboards	Battery Racks

Electronic Equipment			
Control & Instrument Panels	Instrument Racks	Sensors	Rectifiers & Inverters

Interconnections		
Piping & Tubing	Conduit & Cable Tray	Duct

SQUG Insights

- It was discovered that these categories of equipment are found in power and industrial facilities throughout the world.
- There are a limited number of principal manufacturers, so many of the same models of equipment are found at multiple sites and multiple industries; NOT JUST NPPs.
- Control and instrumentation has evolved from pneumatic to analog-electronic to digital-electronic systems.

We should make SQUG in Japan

And we should

(1) Develop a realistic assessment method;
(2) Improve the accuracy of response analyses;
(3) Improve the accuracy and realism of fragility evaluations;
(4) Reduce uncertainties.

And includes:

(1) Building a realistic fragility assessment technique based on experience
(2) Checking SPRA against experienced damage and success data – how do the experiences at Onagawa and KK and other plants compare with current SPRA?
(3) Assessing successful building/structures behavior in very strong ground motion. How does that change current conservative analyses and assumptions
(4) Building realistic fragility assessment techniques for equipment, piping and other systems, etc.
(5) And build the J-SQUG Database

The Right Balance and the Right Lessons

The needed strategy is so obvious…
Not only what went wrong at Fukushima, but also what went right at Onagawa and elsewhere!

Summary of the Strategy

- The proposed new strategy brings **common sense, experience, and reality** back to the seismic design of nuclear facilities and the resolution of safety issues
- We have the tools to design and build safe plants, as shown by the three Onagawa units and other plants in the earthquake of 2011
- These tools have to be reassessed and updated with our experience and observations from the real world to re-engineer the industry's practices and the restart of plants at lower costs while increasing safety

Summary of the Strategy (Cont.)

- Re-engineering should include (1) hazard analysis for earthquake and tsunami and (2) PRA, analysis, design, and (3) regulatory practices

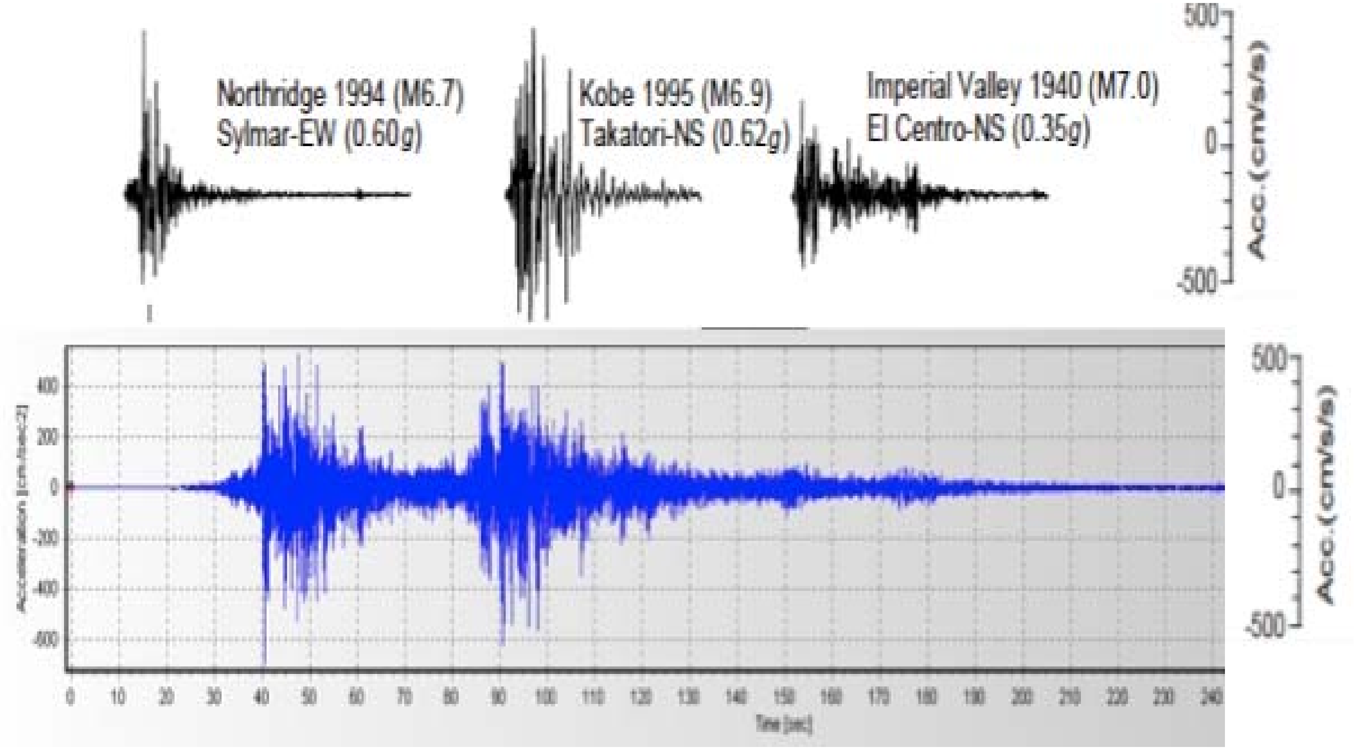
- Re-engineering must bring back common sense, experience, and realism to the earthquake design and reassessment of new and operating facilities supported by real-world data, including data from recent mega-earthquakes and not just high-acceleration small earthquakes

- This can also only be accomplished if FEPC, JANSI, the NRRC, and the NRA all address the issues together. **Academic and international support are vital**

- SQUG was a similar major project. Its organization and successful resolution of a difficult and costly earthquake issue serves as a model for resolving current seismic issues in Japan
- **<u>We must make the SQUG of Japan</u>**

Are We Using Real Ground Motion Data?

Comparison of Onagawa NPS and Nearby 3/11 Ground Motion



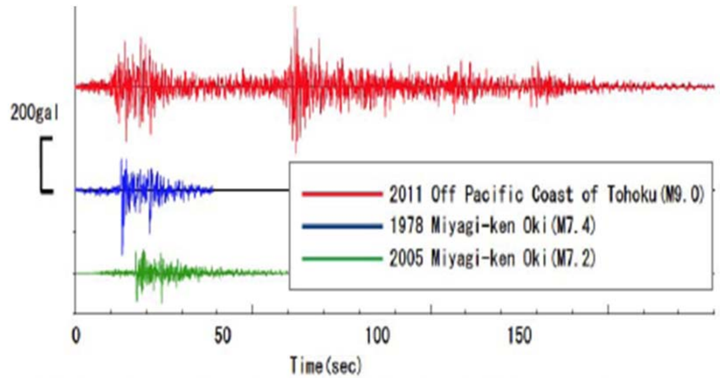


Fig.2 Comparison of Observed Acceleration Waveforms (NS Direction) at Sumitomo Building near Sendai Station for 3 earthquakes

Are You Using Response Spectrum Analysis Properly?

This is a Test

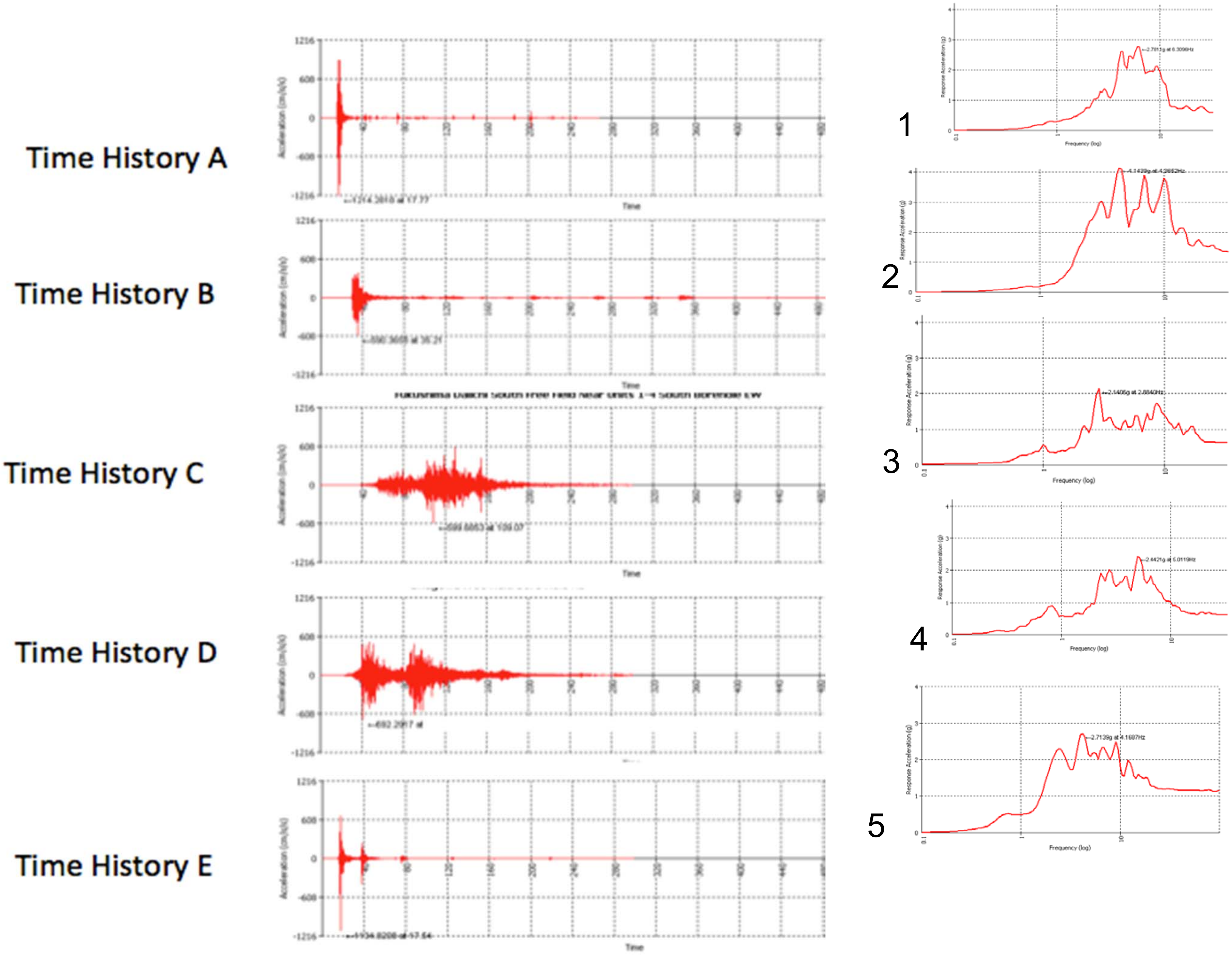
Look carefully at these recent earthquakes in Japan.
Now, match their spectra, time histories, and their locations!

Here are the 4 earthquakes:

1. M 5.8 2013 Tochigi
2. M 6.1 2004 Rumoi in Hokkaido
3. M 6.8 2007 Chuetsu in Niigata
4. M 9.0 2011 Great Eastern Japan

And here are 5 records and their spectra from them:

1. Onagawa NPS: closest plant to Great Japan on 3/11
2. Fukushima Daiichi NPS: Farther away than Onagawa on 3/11
3. Hokkaido: Station HDKO02 on 12/2004 Rumoi
4. Kashiwazaki Kariwa NPS: 2007 Chuetsu
5. Tochigi: Station TOGH07 on 2/13

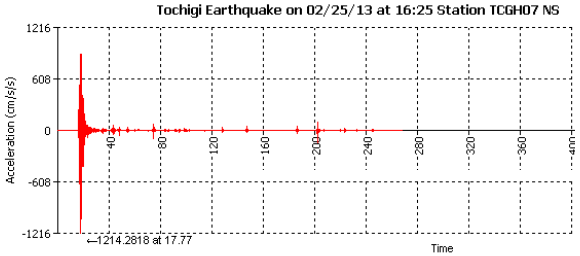


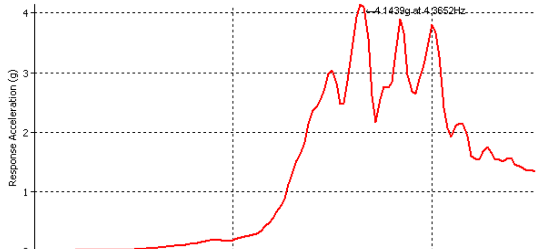
Time History A
Time History B
Time History C
Time History D
Time History E
1
2
3
4
5
Time
Frequency (log)

Our 1950s Tools and Habits Are Badly Out of Date: Response Spectra & PGA Do Not Capture the Correct Energy of Ground Motion and **Underestimate Capacities** of Structures, Equipment, etc.

Perhaps CAV is a better tool?

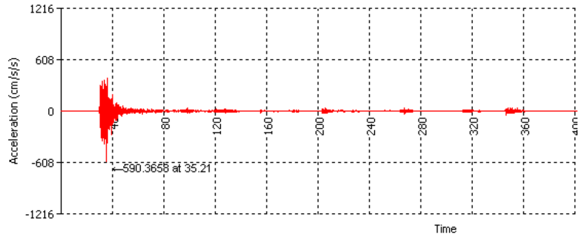
2013Tochigi
M_w5.8

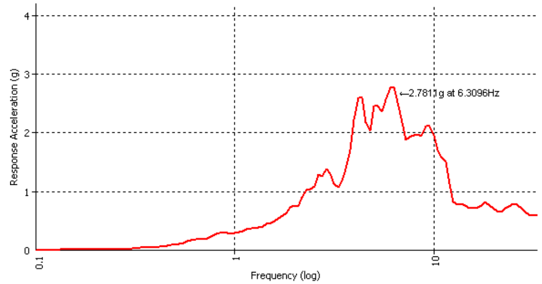




CAV_{max} = 1.4

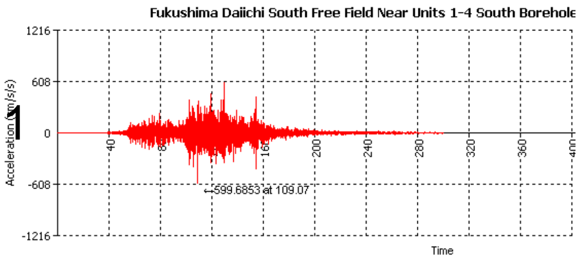
2007 KKariwa
M_w6.8

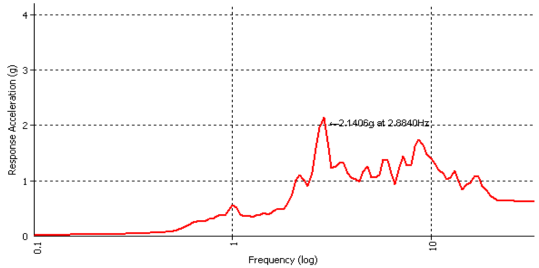




CAV_{max} = 5.2

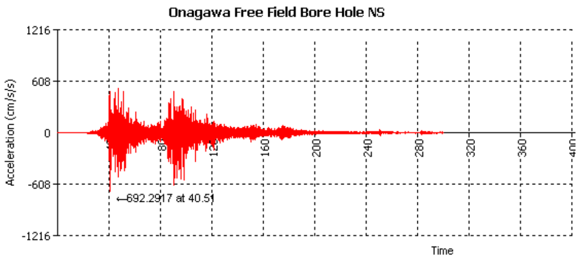
2013 Fukushima 1
M_w9.0

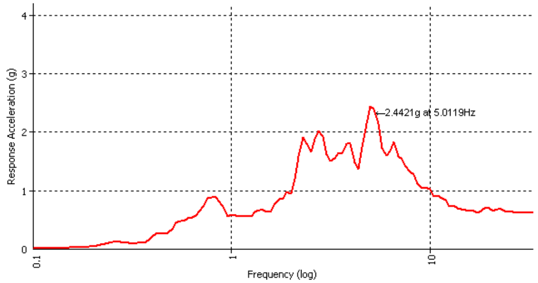




CAV_{max} = 8.5

2013
Onagawa
M_w9.0





CAV_{max} = 8.3

Are These the Right Tools?

- Is the Response Spectrum Method the right tool for analysis today?
  Maybe not

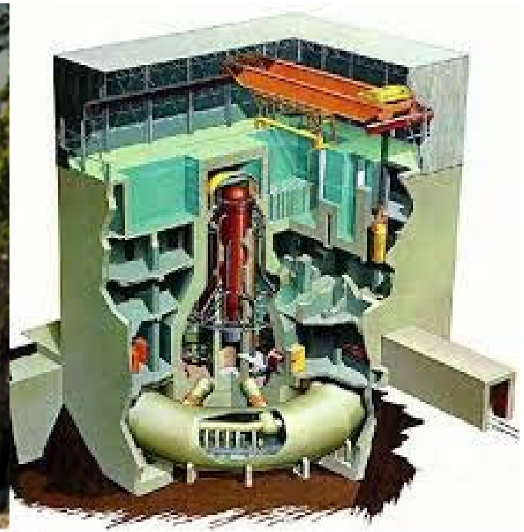
- Are PGA and RSM the right tools for SPRA?
  Maybe not

- Should they be updated/replaced?
  Maybe (it has been +50 years)

- Are you getting reasonable and accurate results in your analyses using these tools (including SPRA)?
  No, we are not

- Is there better technology that will give realistic results?
  This is what our workshop at PSAM14 is about

What do we predict for the M9.0 earthquake that happened at Onagawa NPS using current procedures?



- Standard SPRA procedures applied to Onagawa predict Success Probability for Reactor De-Pressurization and Long-Term Cooling of:
  - **18% per unit, using current average SPRA in the USA**
  - **57% per unit, using current EPRI/SQUG EQ Data**
- Both of the above numbers (18% & 57%) are far too conservative -- the 3 operating units shut down successfully (100%)
  - **100 % per unit in the actual M9.0 earthquake**

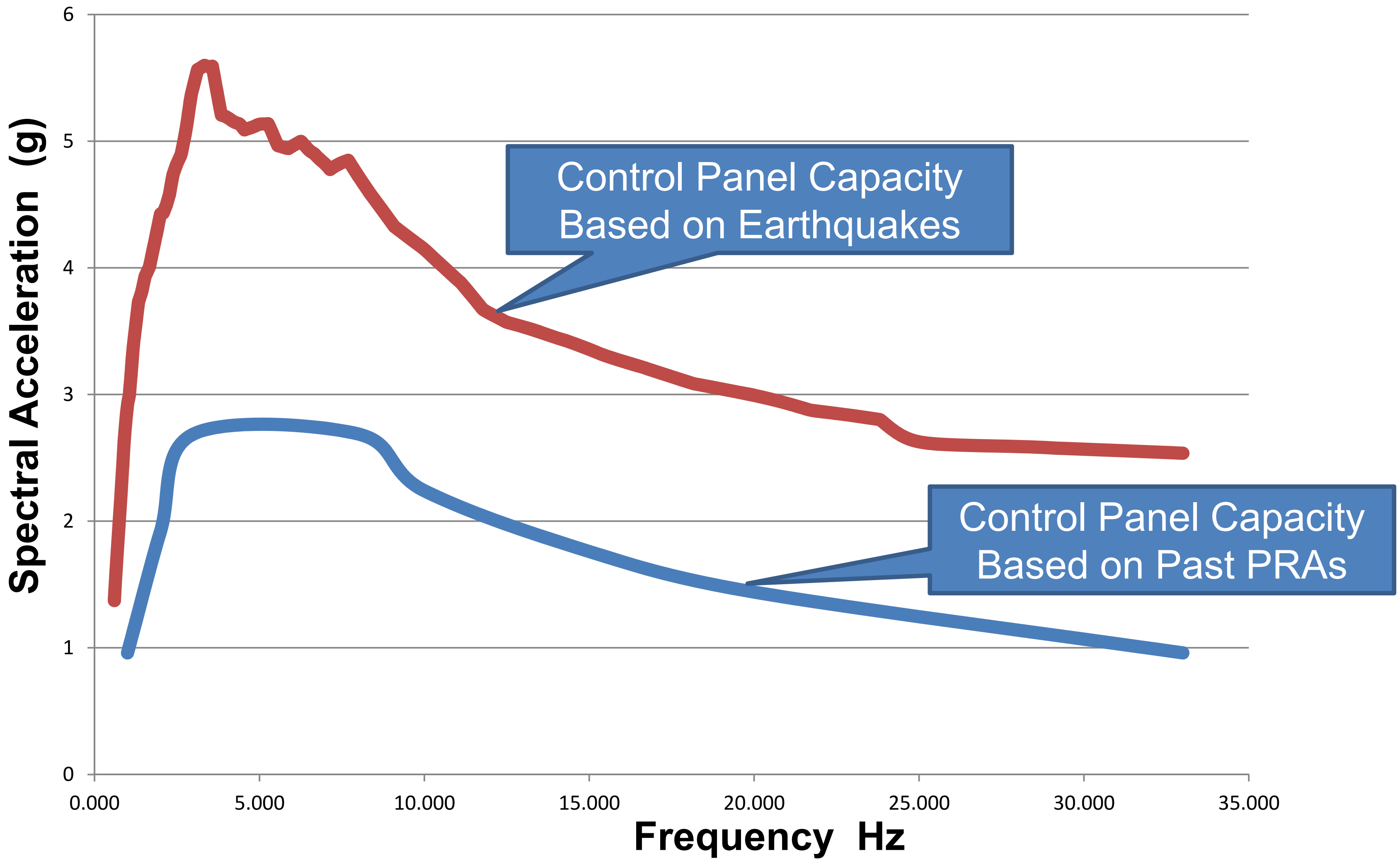
Summary of Results

- Seismic fragilities are based on old data and do not reflect Japan realities.
- We have lots of new data that is not reflected in SPRA - the 3.11 earthquake, the KK earthquake, Rumoi, and similar Japan, Chile, California, and other earthquakes.
- SPRAs and margin assessments (SMAs) are often **excessively conservative. A major reason is that they were developed originally for the low-seismic regions of the USA, not Japan!**
- More specifically, today's seismic fragilities reflect the much lower seismic risk situation in most of the USA, which is quite different from Japan and less consequential to SPRA results.
- Today's fragilities contribute to over-estimates of the probability of:
  - Damage to critical components,
  - Core damage (CDF),
  - Uncontrolled off-site release (LERF) following an earthquake
- The proper application of actual experience from earthquakes (both failure and success) in estimating fragilities (especially the new data and past unused data) results in more realistic results.

Partial Summary of Building Amplification Measurements in Nuclear Plants Collected to Date

Data Point of Building Amplification	ZPA/PGA	Ln(ZPA/PGA)
Tohoku Earthquake of 3/11/2011: Onagawa Free-Field to Unit 1 Control Room	0.79g/0.64g = 1.23	0.21
Tohoku Earthquake of 3/11/2011: Onagawa Free-Field to Unit 2 Control Room	0.83g/0,64g = 1.30	0.26
Tohoku Earthquake of 3/11/2011: Onagawa Free-Field to Unit 3 Control Room	1.1g/0.64g = 1.72	0.54
Miyagi Earthquake of 6/12/1978: Daiichi Free-field to Reactor Operating Floor	0.15/0.13g = 1.15	0.14
Niigata Earthquake of 7/16/2007: Kashiwazaki Free-Field to Unit 5 Operating Floor	0.61g/0.40g = 1.53	0.42
Niigata Earthquake of 7/16/2007: Kashiwazaki Free-Field to Unit 6 Operating Floor	0.57g/0.40g = 1.43	0.35
Niigata Earthquake of 7/16/2007: Kashiwazaki Free-Field to Unit 7 Operating Floor	0.41g/0.40g = 1.03	0.03
Mineral Virginia Earthquake: North Anna Free-Field to reactor Operating Floor	0.33g/0.23g = 1.43	0.34
Average	**1.35**	**0.29**
Standard Deviation	**0.22**	**0.16**

Problem: Equipment capacity too low & ground motion too high
Solution: Records and observations from actual earthquakes
Equipment in this example: Control Panels



Update the Existing Fragility Curves Bayesian Style with Earthquake Data:

Conceptual example using Bayes' Theorem to update an analytic fragility curve with earthquake data.

$$P(A \mid B) = \frac{P(B \mid A) \cdot P(A)}{P(B)}$$

STRUCTURAL FRAGILITY MODEL

$$P_f(\lambda) = f(\lambda; \mathbf{\Theta}) \text{ where } \mathbf{\Theta} = [\theta_1, \theta_2, \ldots]^T$$

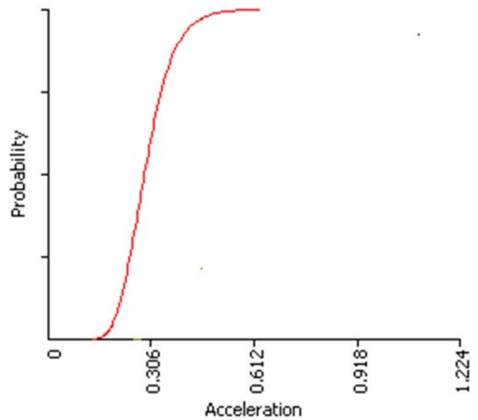
$$\text{"Prior" knowledge of } \mathbf{\Theta} = f'_{\mathbf{\Theta}}(\theta_1, \theta_2 \ldots)$$

$$\text{Observed Data, } \mathbf{y} = [y_1, y_2 \ldots y_m]^T$$

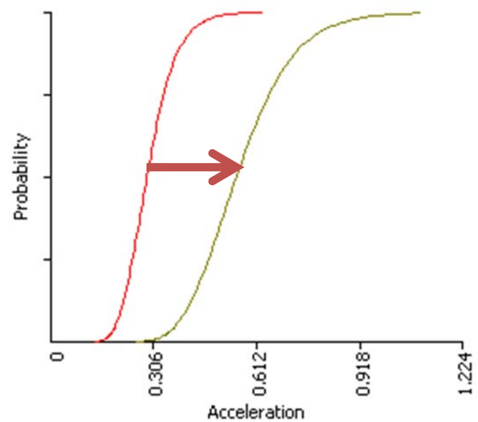
From Bayes' Theorem ...

$$f''_{\mathbf{\Theta}}(\theta_1, \theta_2 \ldots \mid \mathbf{y}) = \frac{P(\mathbf{y} \mid \theta_1, \theta_2 \ldots) f'_{\mathbf{\Theta}}(\theta_1, \theta_2 \ldots)}{P(\mathbf{y})}$$

"Posterior" or updated pdf of $\mathbf{\Theta}$

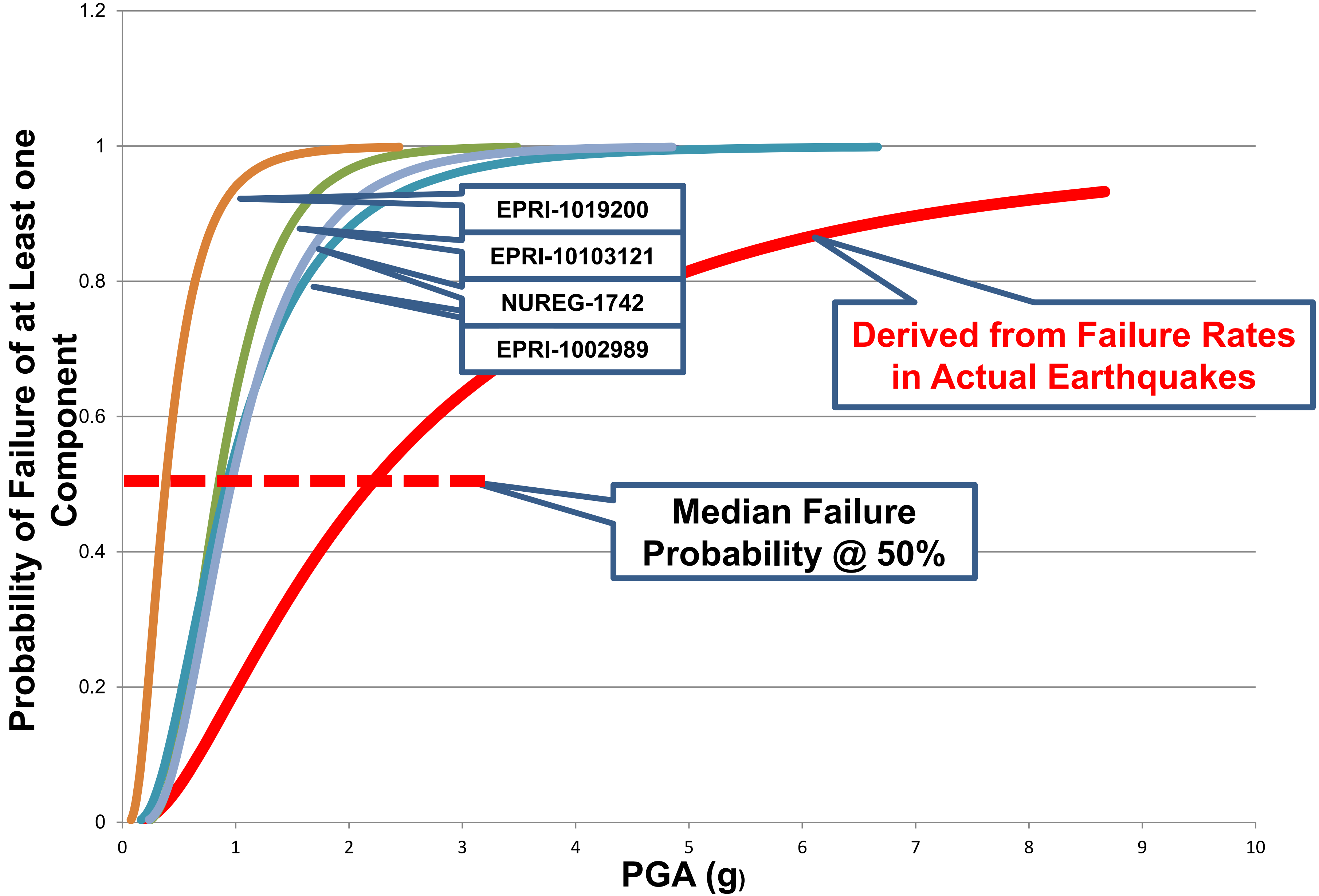


Bayesian Update



Thanks to Yamaguchi-sensei

Example of Current Seismic Fragility Functions for I&C Panels
(Failure of a single Panel-Mounted Component)



Update the Fragilities

- Standard fragilities for equipment, using current practice show HCLPF of 1.8g and a median spectral capacity (MSC) of 4.8g

- We compute the following values when using up-to-date experience data (a few examples):
  - AOVs: HCLPF of 4.4g and MSC of 10.2g
  - MOVs: HCLPF of 14g and MSC of 32g
  - Heat Exchangers: HCLPF of 1.7g and MSC of 23g

- The differences are substantial; the “PGAs” are unrealistic as they likely do not exist

From current work in Europe

SPRA, Fragilities, Margins….. and the Use of Real Data
Correlation of Failure in SPRA for 4 Equipment Categories
Factor ρ_2 vs. Total Failure Probability Q_t --- It is not 0 or 1.0. The implication for most items is that there is little to no correlation

Summary for All 4 Equipment Categories:
Estimates for Correlation of Multiple Failure

Category	Strong Motion	Factor ρ_2	
Live Tank Circuit Breakers	**.49**	**0.90**	**ρ_2 approaches 1.0 as Q_t approaches 50%**
Engine Generators	**.24**	**0.57**	**The estimate of ρ_2 applies to the higher estimate of Q_t**
Large Vertical Tanks	**.102**	**0.29**	**Includes both anchored and unanchored tanks**
I & C Panels	**.038**	**0.077**	**"Failure" is defined as loss of any device, out of many, in a panel**

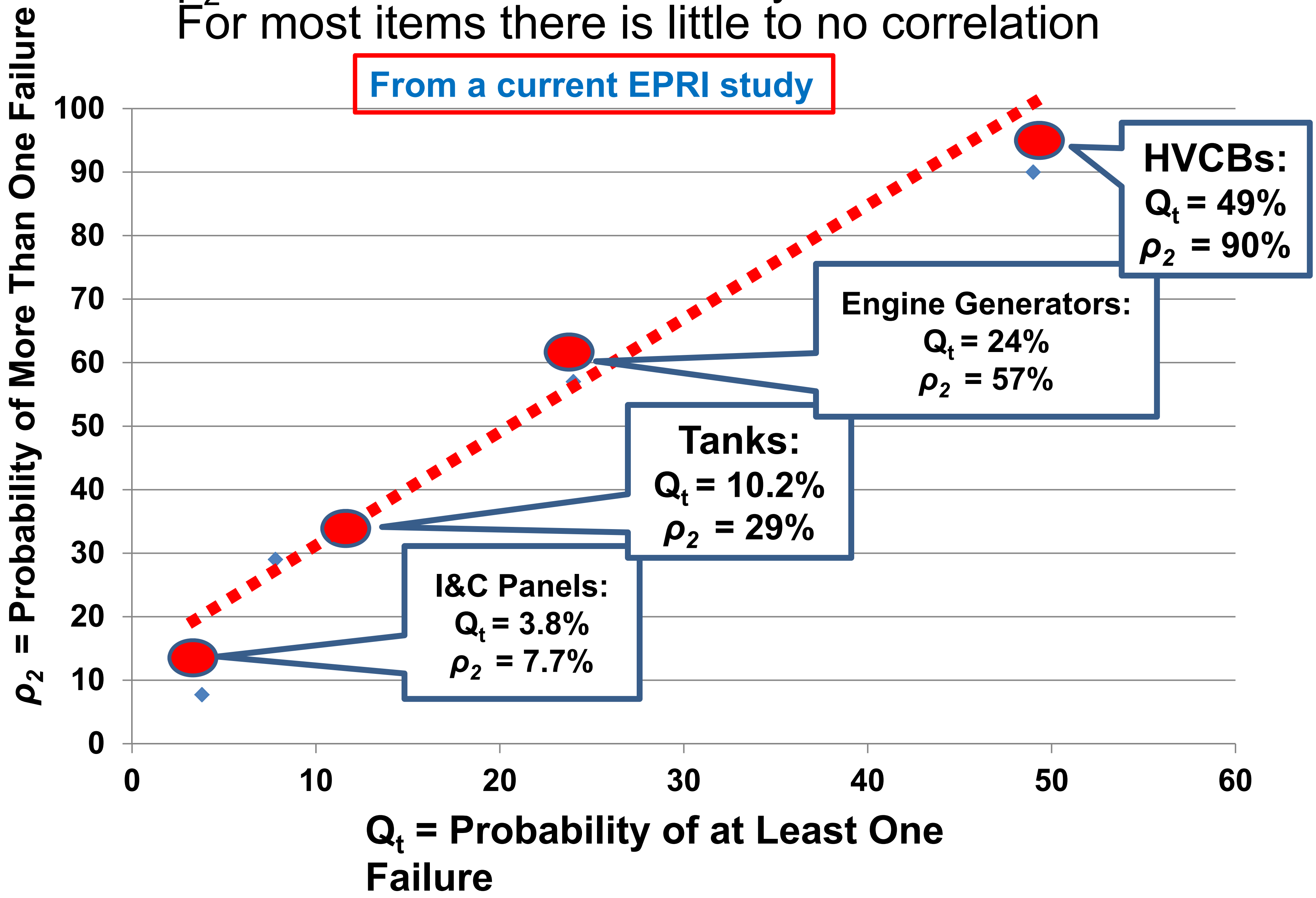
Q_t = Probability of at Least One Failure
ρ_2 = Probability of More Than One Failure

From a current EPRI study

SPRA, Fragilities, Margins….. and the Use of Real Data

Correlation of Failure in SPRA for 4 Equipment Categories

Factor ρ_2 vs. Total Failure Probability Qt. It is not 0 or 1.0. For most items there is little to no correlation



Overview of the Proposed New Industry Strategy

- The industry has the tools to design and build safe plants, as illustrated by the three Onagawa units in the 2011 M9 Japan earthquake and other plants and earthquakes. These tools have to be reassessed and realigned with what has been observed in the real world.

- Bring back engineering judgment, common sense, and real world experience (especially from Japan) to the earthquake engineering of nuclear plants and re-engineer some of the practice to get back to reality.

- This can be accomplished through a joint industry & regulator effort (like the original SQUG project) by involving all of the key players: FEPCO, JANSI, Universities, NRRC, and NRA. It should also be led by Japan – that is where the best data come from.

A proposed specific project for Japan to help restarts

1. Review one or more existing specific SPRAs to estimate the reduction in CDF and LERF using:
   - Data from Japan, etc., to develop realistic estimates of amplification of ground motion to upper floors
   - Actual earthquake failures & successes for the leading risk contributors to update fragilities

2. Review seismic work at sites which have been given a SSE goal of 2.0g, including:
   - GMRS (hazard curves)
   - Seismic analysis of the structures, floor spectra, etc.
   - SPRA to determine where the biggest conservatism are, are they contributors to CDF/LERF, and where to focus further efforts

Bayesian update of fragilities (equipment, structures)

Correlations of failures

Other critical likely conservatisms

So what does all this mean?

- We have several measures of earthquake intensity which we try to use as the silver bullet of damage indicating parameters:
  - PGA
  - Max SA
  - Response Spectra
  - CAV
  - Shindo (I_{JMA})
  - Arias
- To understand which measurements, under what conditions including distance from fault, soil structure, elevation, etc., are the best indicators means that we must …

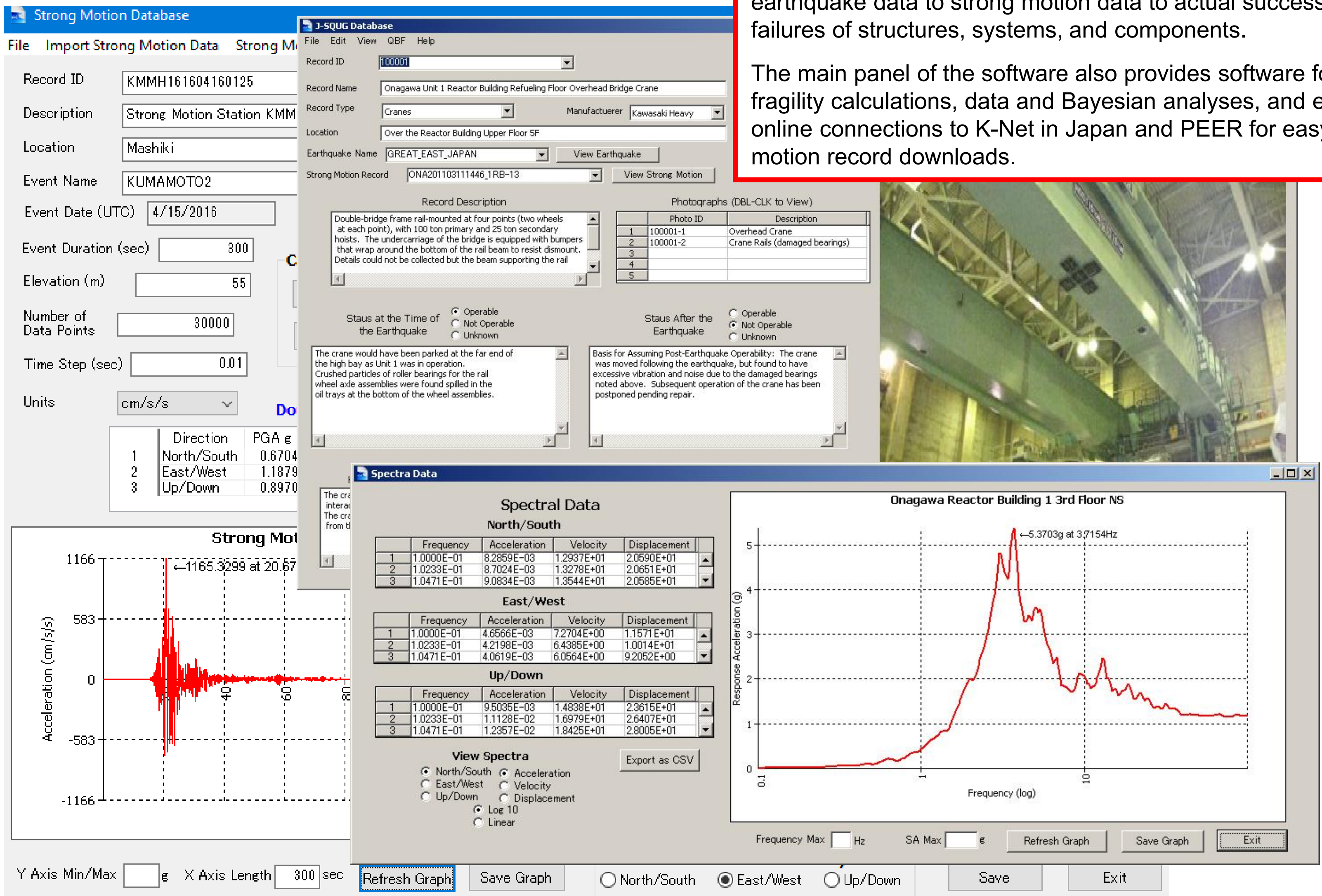
Create an the J-SQUG Database

- The database must include both SSC successes and failures.
- It must be a threaded database which links:
  - an earthquake catalog;
  - strong motion records;
  - site information, like soil structure, distance from a fault …;
  - and structure, system, and component success and failures.
- Only in this way can we make proper judgments about which measures to use in a specific NPP location.
- We must use Bayes' Theorem to update fragilities with earthquake data.
- It should appropriate data from all over the world.

Shakeman: a 100% working J-SQUG Database

SHAKEMAN is a 100% working software prototype to link earthquake data to strong motion data to actual success and failures of structures, systems, and components.

The main panel of the software also provides software for fragility calculations, data and Bayesian analyses, and easy online connections to K-Net in Japan and PEER for easy strong motion record downloads.



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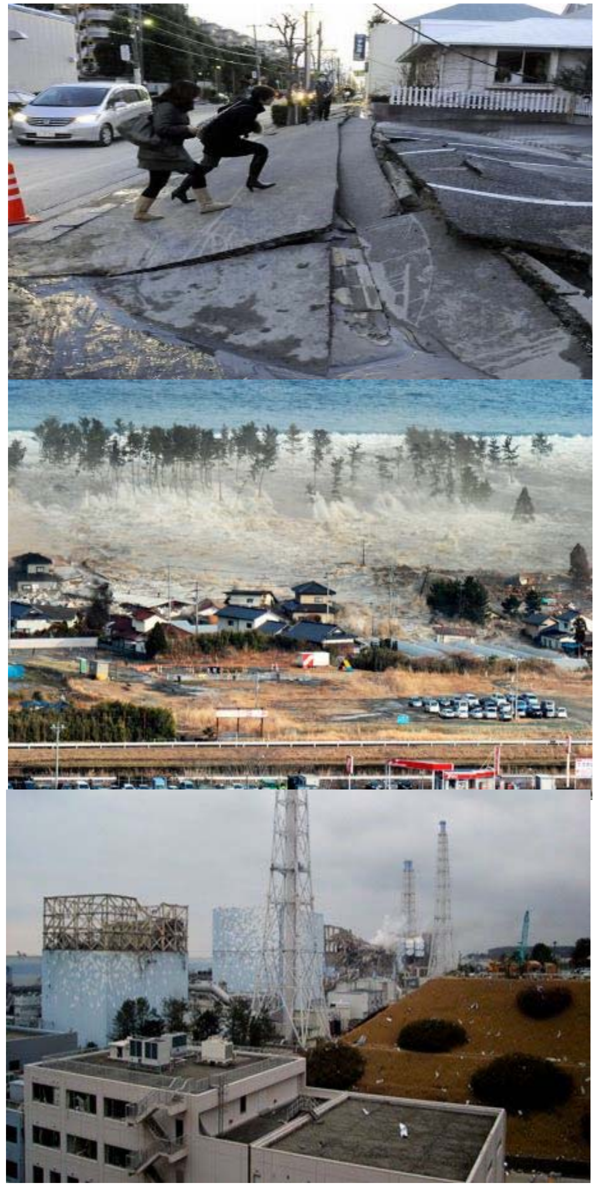

"Such an event is probable because many things should happen contrary to probability."

-- Agathon as quoted in Aristotle's Poetics