MUPSA Aggregation and Safety Goals Consideration

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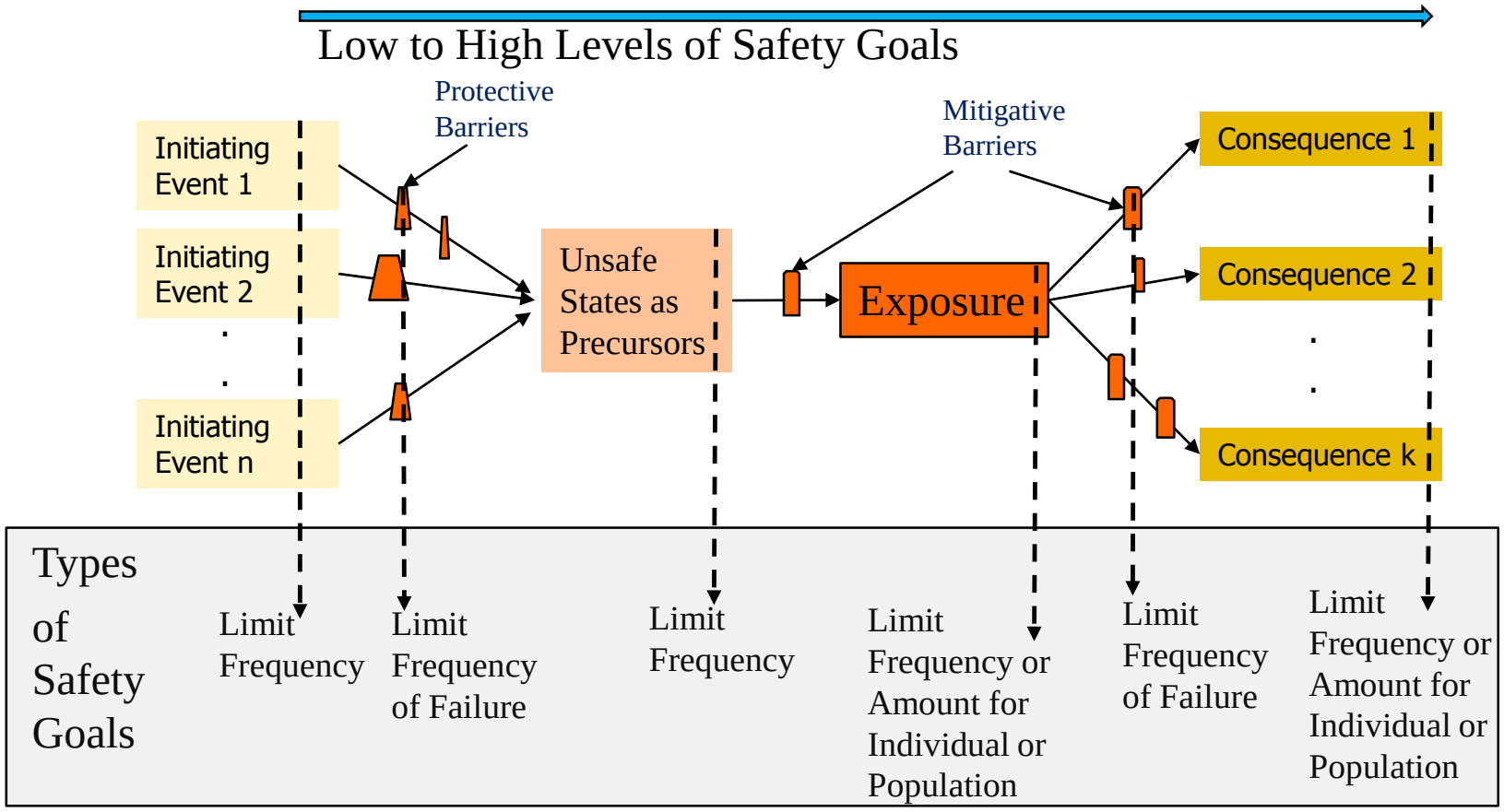
Topics

- Safety Goals (MUPSA Implications)
- Risk Metric Aggregation (Relation to Safety Goals and Issues)
- Conclusions

Safety Goals: Purpose

- Set for a nuclear facility or a site by the regulator
- They are in form of policy or requirements meant to collectively address the question of "how safe is safe enough?" by defining risk levels considered as de-minimis and thus acceptable or tolerable
- The burden of conformance is on the vendor, owner and operator
- They provide a simple means of risk communication with the public and other stakeholders

Levels and Types of Safety Goals



CLASSES OF SAFETY GOALS

- Place site-level limits (absolute or relative) on:

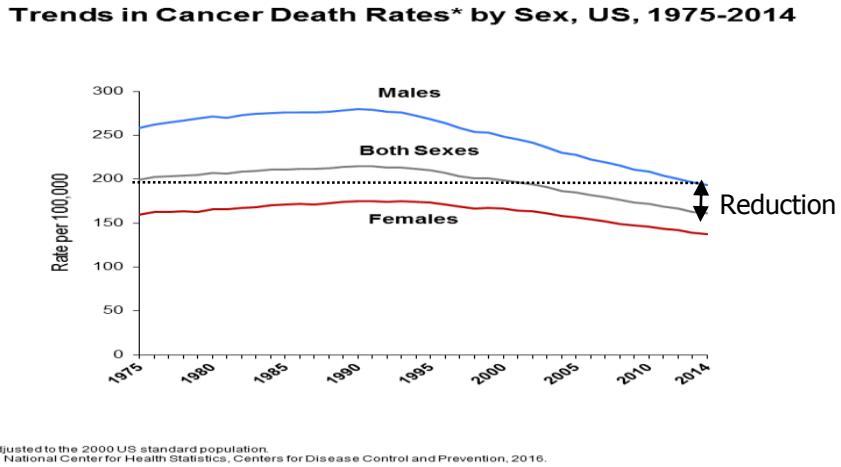
1. Frequency Limits: On a risk metric, a surrogate risk metric, individual or population prompt or latent fatalities (American Example)
2. Exposure Limits: On cumulative, maximum rate, or duration of the radioactive release. (Canadian SG Example)
3. Consequence Limits: Individual early or latent fatalities, population early or delayed fatalities, population displacement and economic losses
4. Minimum Performance Level: Barriers such as systems, human processes that prevent, protect or mitigate accidents
5. Combinations of above

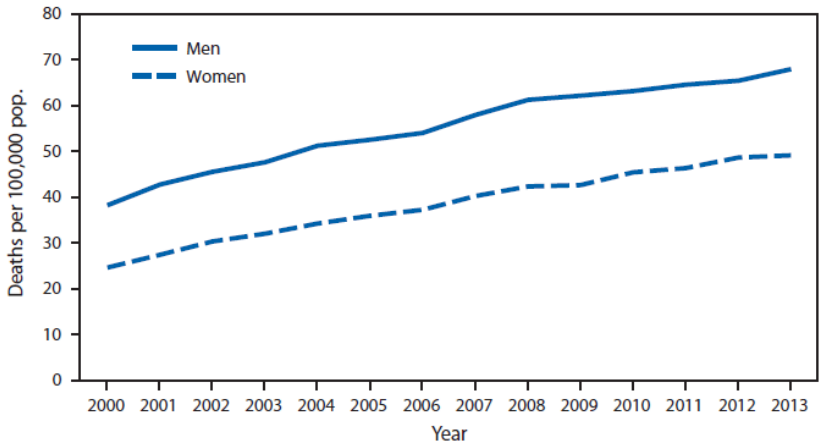
U.S. SAFETY GOALS (QHOs)

- Quantitative health objectives, applicable to a site:
  - 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 percent) of the sum of prompt fatality risks resulting from other accidents to which member, of the U.S. population are generally expose
  - The risk to the population in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes.

Relative Goals

U.S. SAFETY GOALS (Cont.)





Cancers

Accidental

Quantitative Prompt Fatality SG in 1986: $(35/100,000)*(0.1\%)=3.5x10^{-7}$ / person

Quantitative Prompt Fatality SF in 2016: $(43/100,000)*(0.1\%)=4.3x10^{-7}$ /person

Quantitative Latent Cancer SG in 2016:

$(172/100,00000)*\ 0.1\% = 1.72x10^{-6}$/Person Vs. $2.40x10^{-6}$/Person in mid-1980's

- Prompt fatality goal remains more restrictive than the latent cancer fatality goal
- Surrogates for these QHOS: 10^{-4}(CDF), 10^{-6}(LRF), and 10^{-5} (LERF)

Examples of Quantitative SGs

Canadian Existing SGs (single-unit basis)

1. Small Release Frequency (SRF)

A release to the environment of > 10^{15} Becquerel of $^{131}I < 10^{-4}$ /Yr.

2. Large Release Frequency (LRF)

A release to the environment of > 10^{14} Becquerel of $^{137}Cs < 10^{-5}$ /Yr.

3. CDF < 10^{-5} /R-Yr.

Canadian Proposed Multi-Unit SGs??

Large Off-Site Release from a Site

Total release from the site exceeding X (Becquerel) of Y (radionuclide) < Z / site-yr.; where, X does not require extensive long-term relocation of the local population.

Site CDF

Aggregate frequencies of CD from one more reactors on the site < Z / site-yr.

British SG

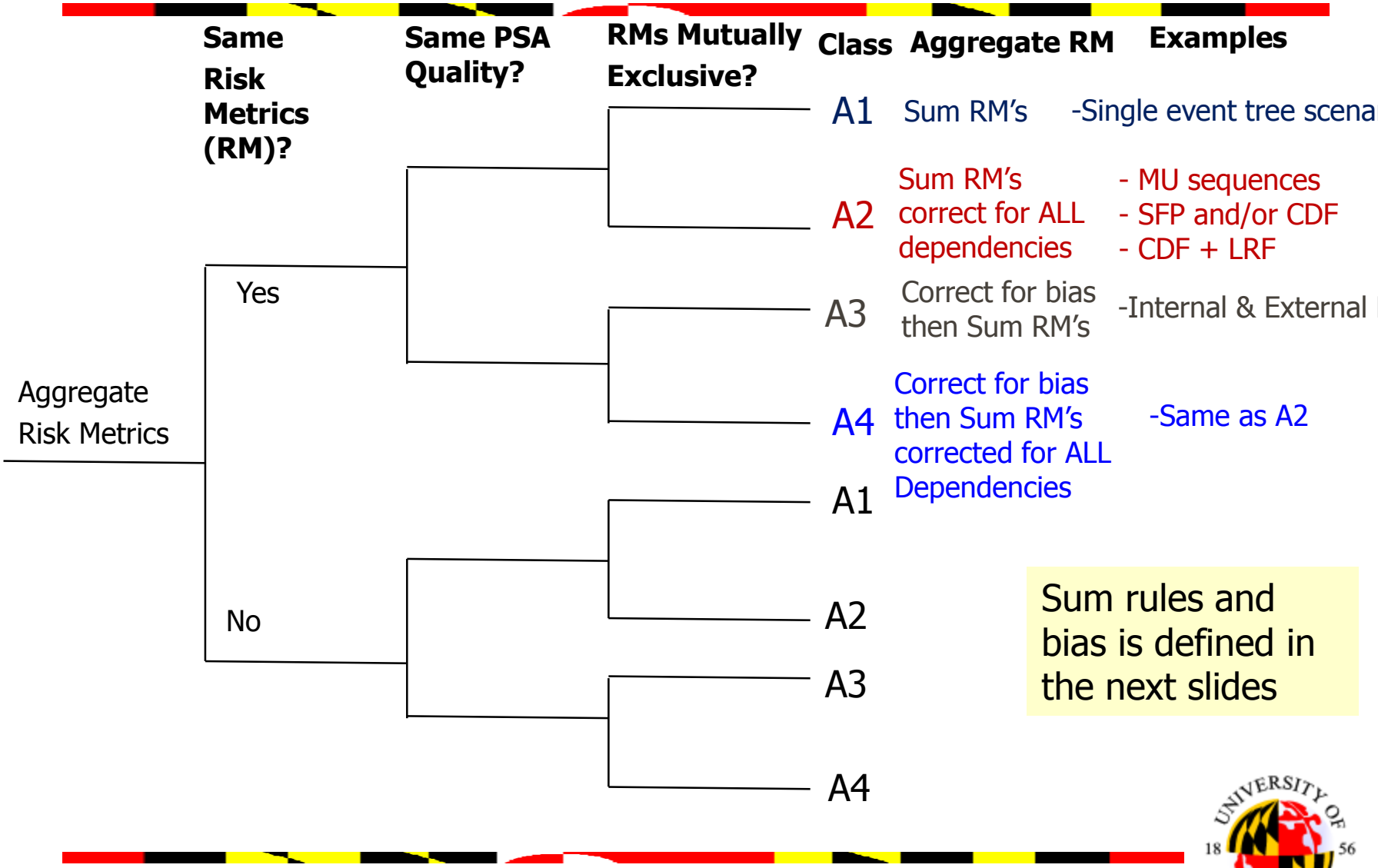
Societal Goal: HSE considers >50 deaths as intolerable if frequency > 1-in-5000 years

Absolute Goals

Why Aggregation?

- Risk Aggregation is the process of combining the amount of exposure, consequence, likelihood or frequency of various risk metrics (RM) into a single metric for comparison to safety goals or for overall risk management
- Probabilistically the combined metric is a random variable representing the same metric (such as CD of one or more units) or dissimilar metrics (CD or spent fuel damage)
- For now, I present probabilistic aggregation of likelihood or frequency of events, exposures or consequences
- Aggregation of RMs from multi-units, multi-source, multi-hazards, and multi-phases may be needed to show conformance to safety goals or other requirements

Probabilistic Aggregation Classes



Sum rules and bias is defined in the next slides

Sum of RM Metrics: Applicable to Multi-Units

- *If Mutually Exclusive Risk Metrics :*
  - ✓ $P\left(U_{i=1}^{n} RM^{(i)}\right) = \Sigma_{i \le n} P\left(RM^{(i)}\right)$

- *Otherwise for multi-units or non-mutually exclusive events including sum of CDF of one unit but LRF of another then:*
  - ✓ $P\left(U_{i=1}^{n} RM^{(i)}\right) = \Sigma_{i \le n} P\left(RM^{(i)}\right) - \Sigma_{i1<i2} P\left(RM^{(i1)} \cap\right.$

Correct for Causal and Common Cause Dependencies

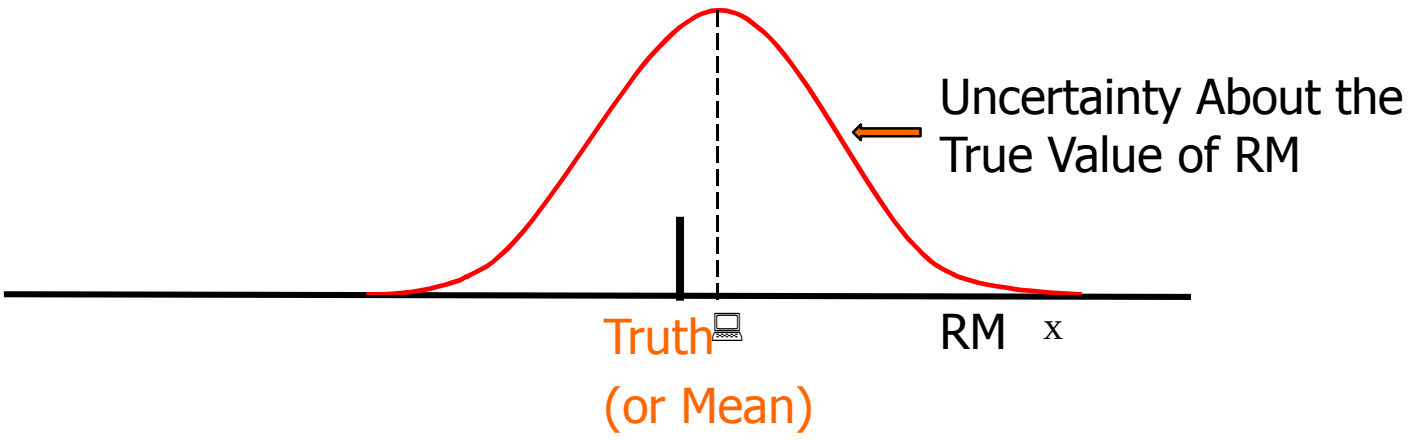
Risk Metric Uncertainties

- Consider the uncertainty about the "true" value of a RM or about its "mean" value
- If we are not generating the true or mean value of a RM then the metric is only a "risk reference"
- When comparing RMs to safety goals sometimes we need to aggregate "true" or "mean" values
- Even when dealing with vastly different levels of uncertainties about a risk metric (e.g. CD from internal and external events) we still can aggregate!
- If we have introduced "bias" in the true or mean value of a RM, it should be corrected before aggregation

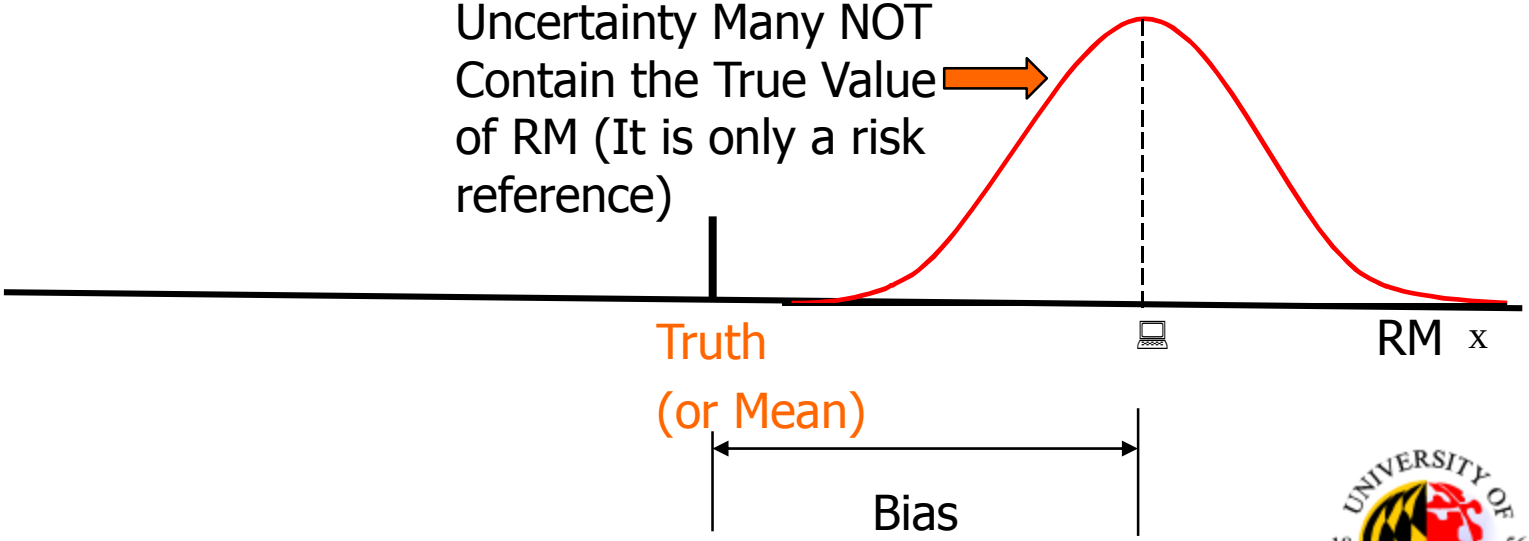
What is Bias in RMs?

- Bias in RMs is introduced by
  - Conservatism
  - Approximations
  - Scope Limitation
  - Simplifications
  - Team Experience / Level of Quality Controls / Adherence to Standards
  - Unconventional PSA Method
- Bias is not uncertainty!
- Sometimes amount of bias may be assessed by expert elicitation
- If expert elicitation not possible then aggregation not advised
  - If comparison to safety goals needed, then the PSA should be corrected
  - If used to identify risk contributors or for other risk-informed activities then neither bias correction nor aggregation is needed

Uncertainty vs. Bias



When Biased Uncertainty Many NOT Contain the True Value of RM (It is only a risk reference)



Estimation of Bias by Expert Elicitation

- Similar to estimating unknown events, bias may be treated as a random variable to be estimated by multiple expert aggregation
- Bias may be treated as a multiplicative error factor, F, that corrects the uncertainty distribution's scale
- For example, F may described by the lognormal distribution

$$\frac{P(RM_i^t)}{P(RM_i^e)} = F_i; \;\; F_i \sim LN(b_i, s_i)$$

Estimation of Bias by Expert Elicitation (Cont.)

Likelihood of n equally capable expert bias estimations, F_i :

$$L(F_i|b_i,s_i)=\prod_{k=1}^{n}\frac{1}{\sqrt{2\pi}}\frac{1}{F_i^k s_i}e^{-\frac{\left[\ln\left(F_i^k\right)-b_i\right]^2}{2s_i^2}}$$

Clemen and Winkle[1] propose adjustments to include credibility weights of each expert, w_i, ranging from 0 (not credible) to 1 (fully credible).

$$L(F_i|b_i,s_i)=\frac{1}{\tau}\prod_{k=1}^{n}\frac{1}{\sqrt{2\pi}}\frac{1}{F_i^k s_i}e^{-\frac{\left[\left(ln\left(F_i^k\right)\right)^{w_i}-b_i\right]^2}{2s_i^2}}$$

Normalization factor τ should be computed based on the values of w_i to preserve the characteristic of L(.) as a probability

16 "Combining Probability Distributions from Experts in Risk Analysis, Robert T. Clemen and Robert L. Winkler, *Risk Analysis, Vol. 19, No. 2, 1999"*

Estimation of Bias by Expert Elicitation (Cont.)

$$\pi_1\left(b_i, s_i | \ all\ F_i^k\right) = \frac{L(F_i|b_i, s_i)\pi_0(b_i, s_i)}{\iint_{b_i,s_i} L(F_i|b_i, s_i)\pi_0(b_i, s_i)db_i ds_i}$$

where $\pi_1(.)$ is the posterior and $\pi_0(.)$ is the prior joint distributions of the parameters of the lognormal distribution of F

Once the posterior values of b_i, s_i are known, then the true probability distribution function of values of the risk metric of interest would be

$$P(RM_i^t) = F_i \times P(RM_i^e).$$

Moving Forward: Developing a Report on Safety Goals

- Discuss each class of safety goals including when they are most appropriate for application to a site (Pros and Cons in MUPSA applications)
- Discuss their relevance when applied to MUPSA RMs
- MUPSA risk metrics and surrogates available
- Examples of current SGs
- Some examples of comparison of MUPSA RMs to SGs in different countries
- Discuss issues with aggregation
- Considerations needed when aggregating MUPSA RMs to compare with SGs

Questions?