

Risk Analysis in Engineering and Public Policy

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Introduction

- Risk is inherent in most any activity
 - What is really known?
 - Add human behavior to mix
 - Regardless, decisions must be made.
- Simple definition of risk
 - Risk = Probability X Consequence
- Possible problems?
 - It equates a rare event with relatively high consequences with a more common event with relatively modest consequences.
 - It equates risk with expected outcome potentially obscuring information that is of interest to the decision-maker.
 - Risk must be understood before it can be mitigated.
 - Need a better definition to provide insights.

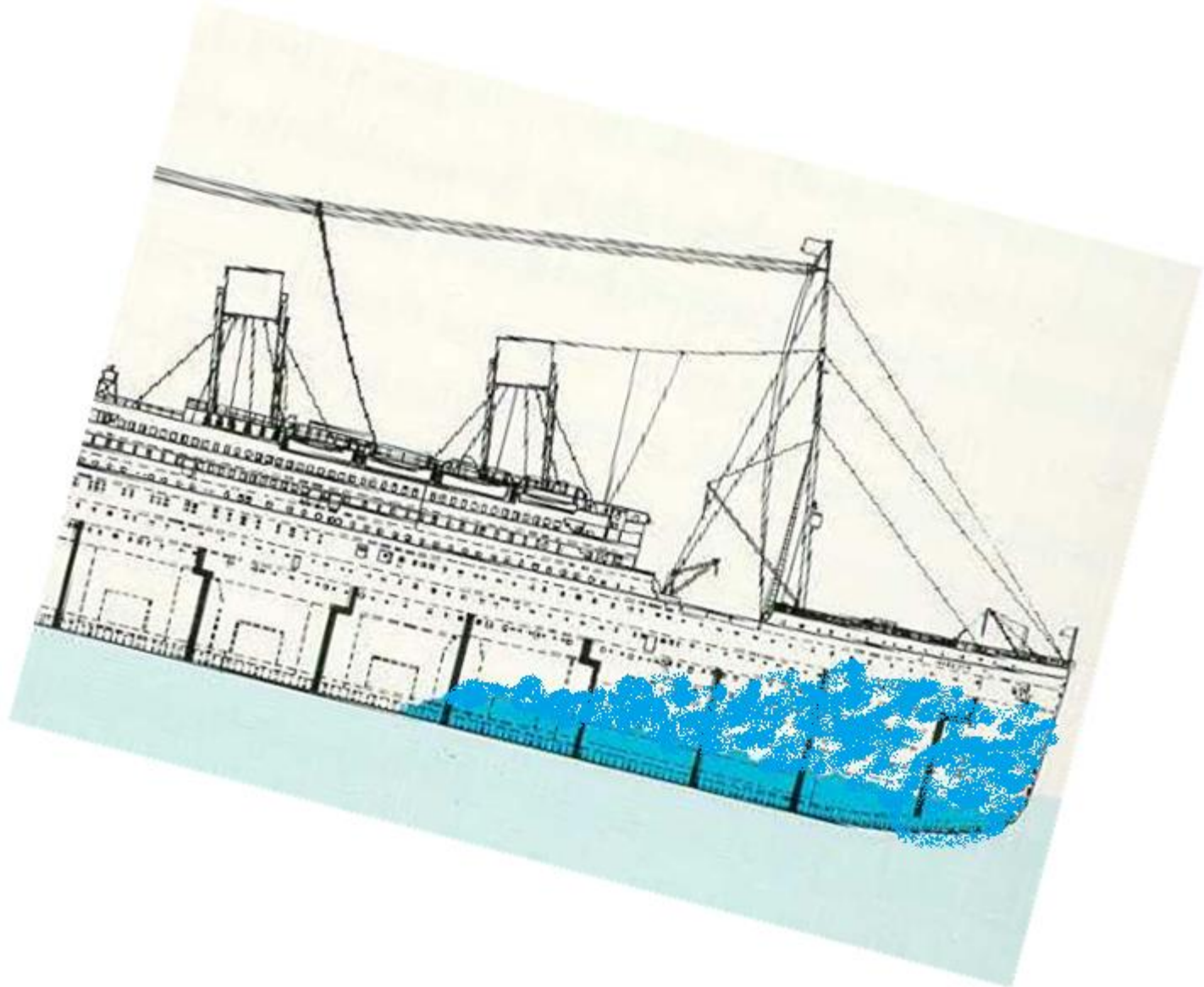
A Broader Definition of Risk

- Stan Kaplan & John Garrick's landmark paper, "On the Quantitative Definition of Risk," was the first paper published in the first issue of the Journal of the Society for Risk Analysis.
- Risk is the set of triplets: $R = \{(s_i, p_i, x_i)\}$
 - s_i What can happen (initiating event)?
 - p_i How likely is it to happen?
 - x_i If it does happen, what are the consequences?
- Risk is multidimensional with many possible damage measures.
- Risks include costs and benefits
- Nature, mechanical systems, and human/societal events
 - What's knowable and what's reducible?

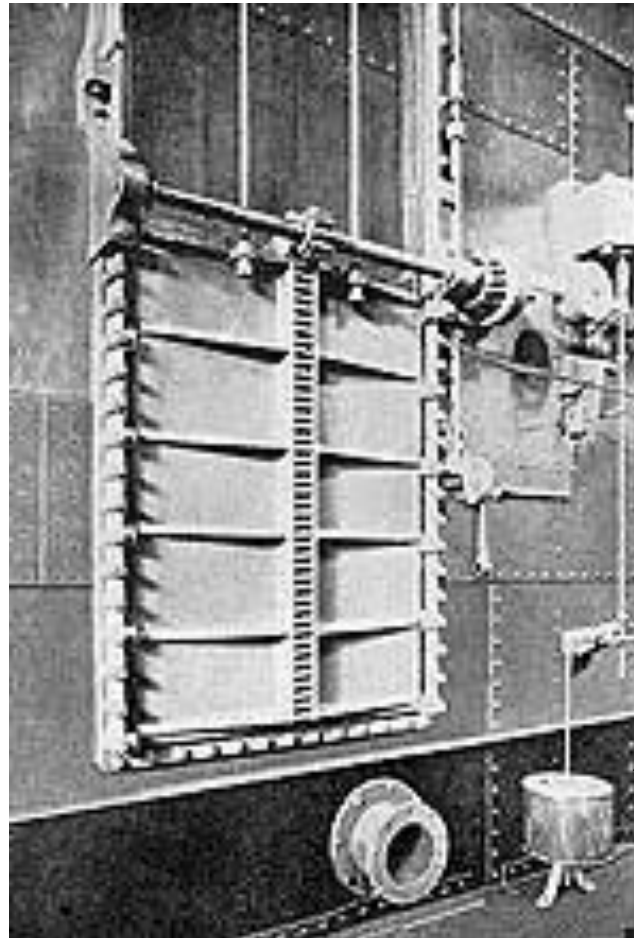
Reduce Risk

- Reduce the likelihood of the IE “and eliminate” the consequences
 - Slow down and give the lookouts binoculars to look for icebergs
 - Design water-tight doors for the lower decks of your ship up to and over the waterline

Watertight Bulkheads Went Only So Far



Automatic Watertight Doors



Automatic closing sensor

Trade-off with Passenger Comfort



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 - Build a sea wall around your nuclear power plant

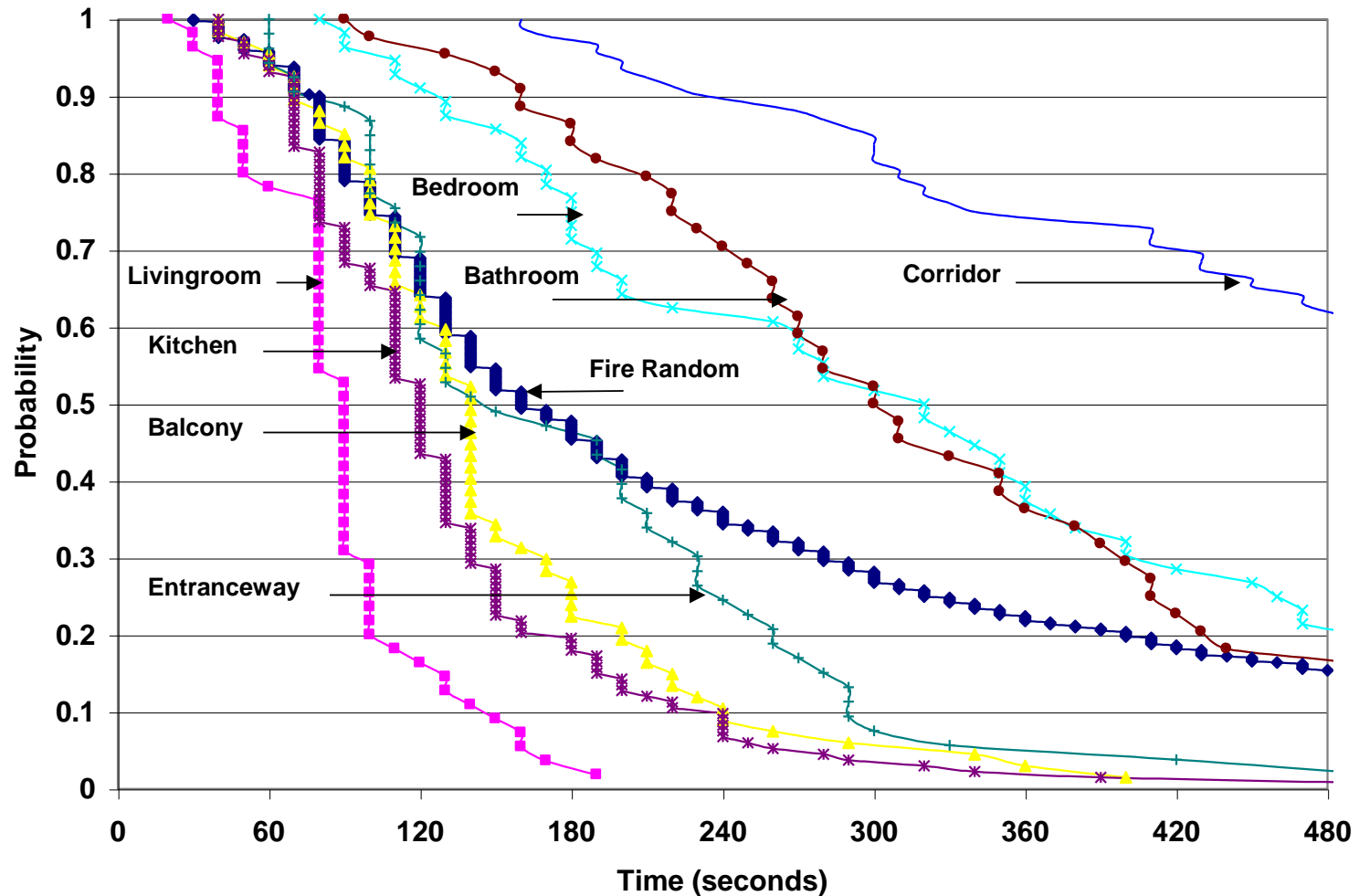
Back-up Generators in the Basement



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 - Build a sea wall around your nuclear power plant
- Prescriptive or performance-based standards
 - Fire code (e.g., must have fire doors, fire sprinklers) or performance-based standards that include human behavior

Time to Untenability in the Living Room Given Fire-starting Location



Reduce Risk

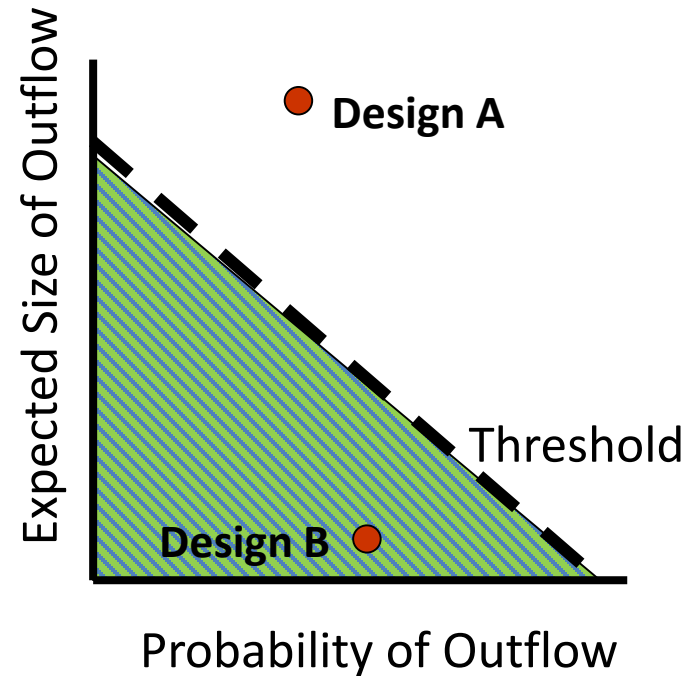
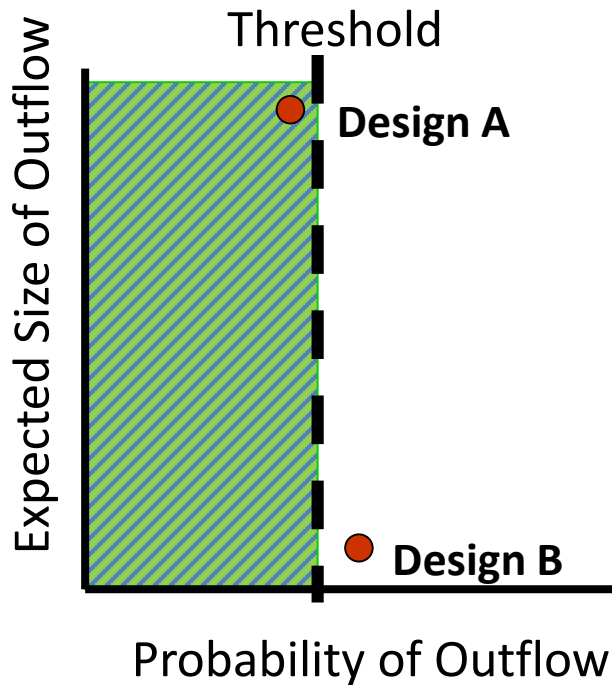
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 - Double hull oil tankers or “equivalently safe”

What's the Metric of Interest?

- Probability of leak given initiating event?
- Amount of oil in the water?
- Environmental damage given oil in the water?
- Worst case spill?
- What is worse: ten 1,000 barrel spills or one 10,000 barrel spill?
- Multiple dimensions?



Equivalent in What Sense?



Which is better? A design that:

- Leaks rarely, but when it does, leaks a lot**
- Leaks more often but on average, not very much**

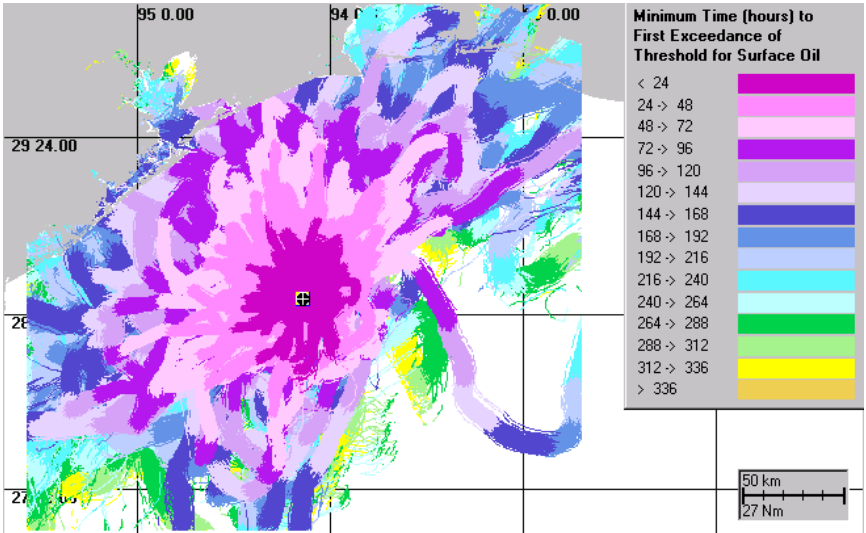
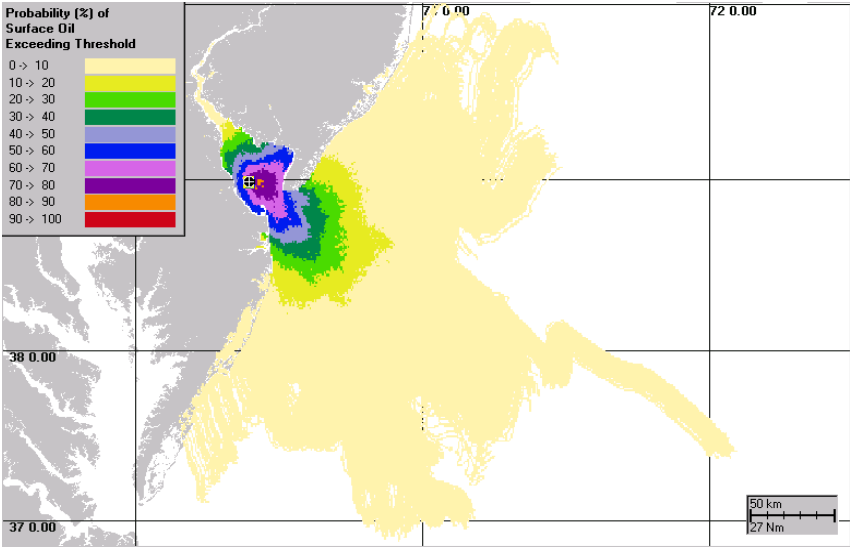
Oil Spill Impact

Spill Variables

- Location
- Weather
- Amount
- Type

Impact Criteria

- Water column/Threshold
- Surface/Threshold
- Shore/Threshold
- Clean-up/Third Party Damage



Acknowledge or Bound the Risk

- Given what we don't know, how safe is safe enough?
 - Really want to be sure
- Cancer risk from chemicals
 - Mouse-to-human models
 - Extrapolating cancers risks from large doses in mice to small doses in humans
 - Extrapolate based on weight differences (2,000) *or* ...?
 - Large uncertainties handled through safety margins (10 to 100-fold factors)
 - Adding a margin of safety?

Nuclear Power Plants

- The poster child for probabilistic risk assessments (PRA)
- Extensive fault trees to find the potential initiating events and opportunities for risk reduction
 - Common mode failures (Tsunamis ...)
 - Combinations of events
- Likelihood of initiating events and outcomes
- Pushing for risk-informed, performance-based regulations
 - Deterministic versus risk-based approaches
- No magic bullet solution

NRC Risk Management Task Force

“To develop a strategic vision and options for adopting a more comprehensive and holistic risk-informed, performance-based regulatory approach for reactors, materials, waste, fuel cycle, and transportation that would continue to ensure the safe and secure use of nuclear material.”

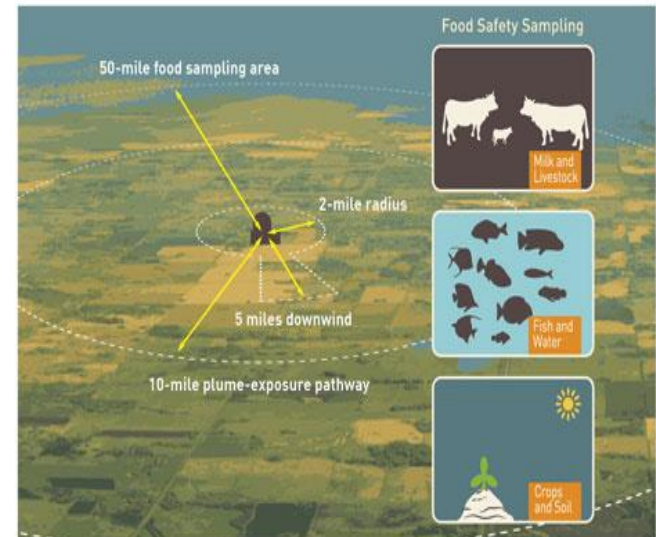
NUREG-2150, April 2012

Emergency Planning Zones (EPZ) around Nuclear Plants

- Inside the EPZ, emergency services and radiation mitigation options must be made available
- A 1975 study set a 10-mile standard for all plants
- But new reactors designs (SMRs) that are smaller and safer. Do they get smaller EPZs?
- Choice ...
 - 10-mile distance
 - Worst-case distance
 - “Scalable” EPZ

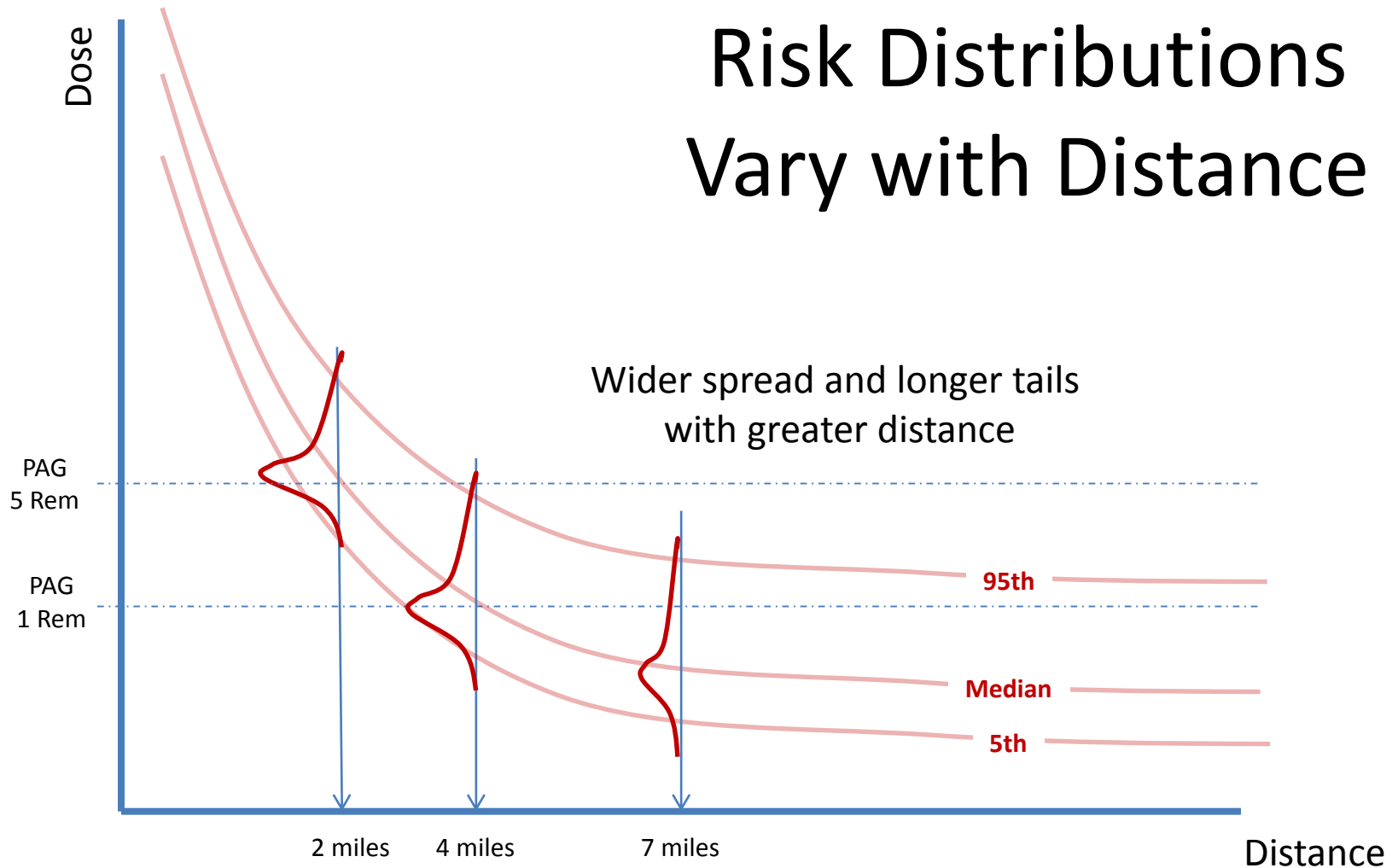
Use PRA-determined distance to be 95% sure that no one outside the zone gets more than 1 REM given an event

Emergency Planning Zones



Note: A 2-mile ring around the plant is identified for evacuation, along with a 5-mile zone downwind of the projected release path.

Risk Distributions Vary with Distance



**How well are the distributions understood?
Uncertainty about uncertainties?**

Not All Risk-Mitigation Schemes (*i.e.*, Regulations) Are Created Equal

Opportunity Costs per Statistical Life Saved

Regulation	Year	Agency	Cost/Life Saved (millions)
Childproof Lighters	1993	CPSC	\$0.10
Unvented Space Heaters	1980	CPSC	\$0.20
Food Labeling Regulations	1993	FDA	\$0.40
Passive Restraints/Belts	1984	NHTSA	\$0.50
Reflective Devices for Heavy Trucks	1999	NHTSA	\$0.90
Seat Cushion Flammability	1984	FAA	\$1.00
Floor Emergency Lighting	1984	FAA	\$1.20
Low-Altitude Windshear	1988	FAA	\$1.80
Children's Sleepwear Flammability	1973	CPSC	\$2.20
Hazard Communication	1983	OSHA-S	\$3.10
Roadway Worker Protection	1997	FRA	\$7.10
Asbestos	1986	OSHA-H	\$66.00
DES (Cattlefeed)	1979	FDA	\$170.00
Sewage Sludge Disposal	1993	EPA	\$530.00
Hazardous Waste: Solids Dioxin	1986	EPA	\$560.00
Drinking Water: Phase II	1992	EPA	\$19,000.00
Formaldehyde	1987	OSHA-H	\$78,000.00
Solid Waste Disposal Facility Criteria	1991	EPA	\$100,000.00

Example for Sharing Spectrum

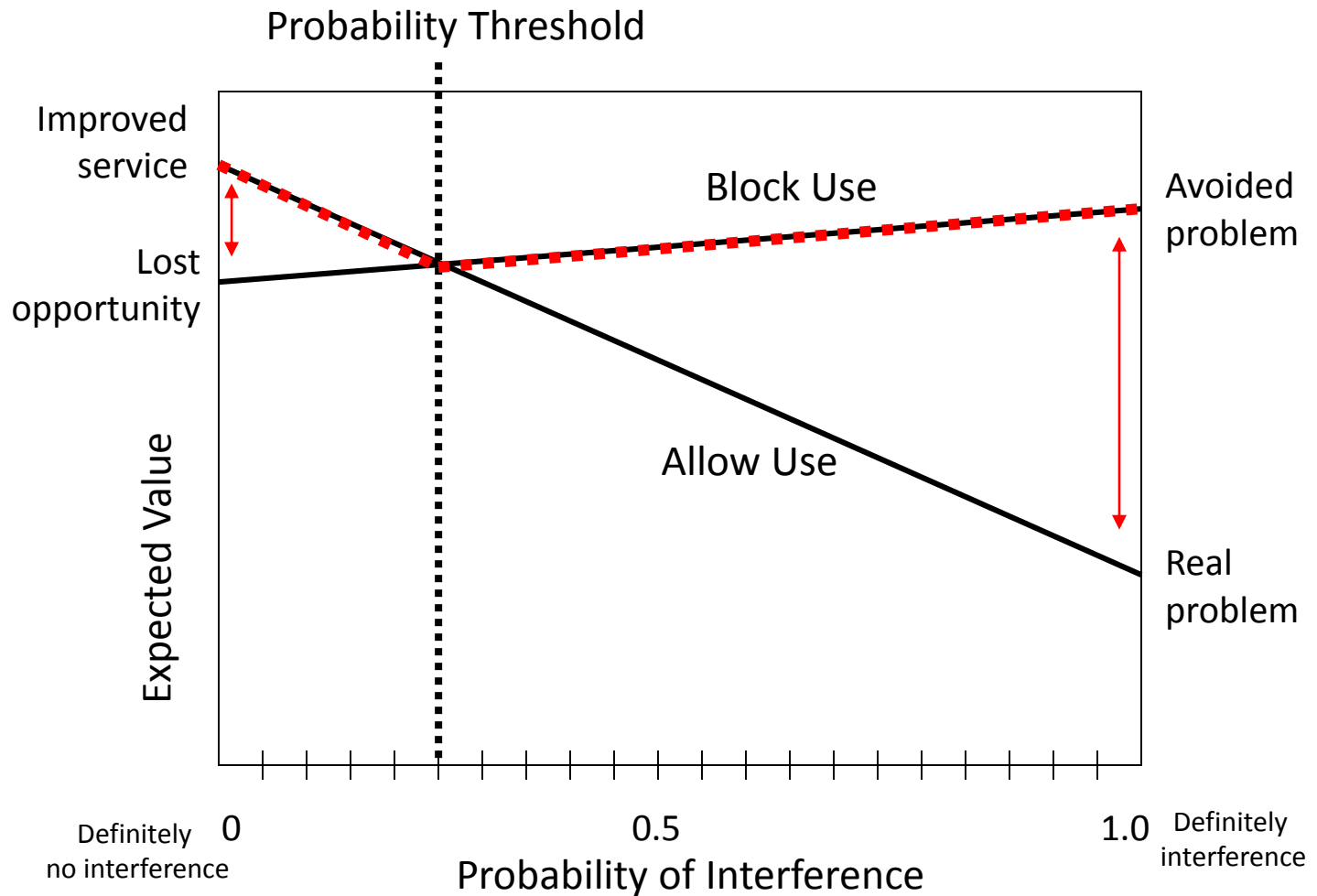
- Proposal to share spectrum for geographically sparse users
- Interference likelihood uncertain
- Determining the threshold probability for interference
- Calculate “expected utility” for all four outcomes

	No Interference	Interference
Allow Sharing	Improved service	Real problem
Block Sharing	Missed opportunity	Avoided major problems

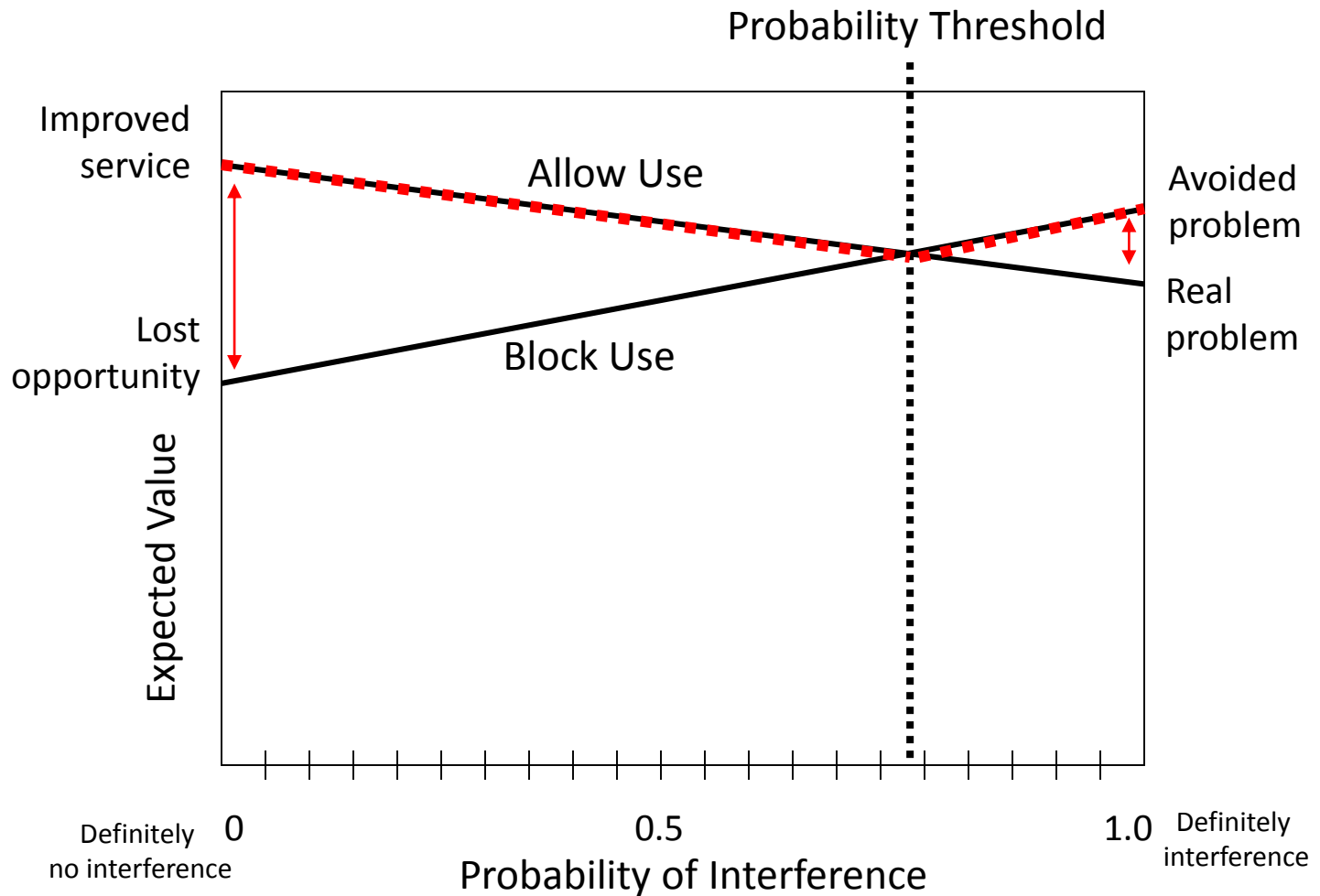
What Comparisons Can Be Made?

- Compare the outcomes
 - Best outcome: Allow Use/No Interference
 - Lost opportunity: Block Use/No Interference
 - Avoided problem: Block Use/Interference
 - Worst outcome: Allow Use/Interference
- For each pair of outcomes
 - Which is better?
 - How much better?
- Between pairs
 - How different are the differences?
- The difference of the differences determines the threshold probability

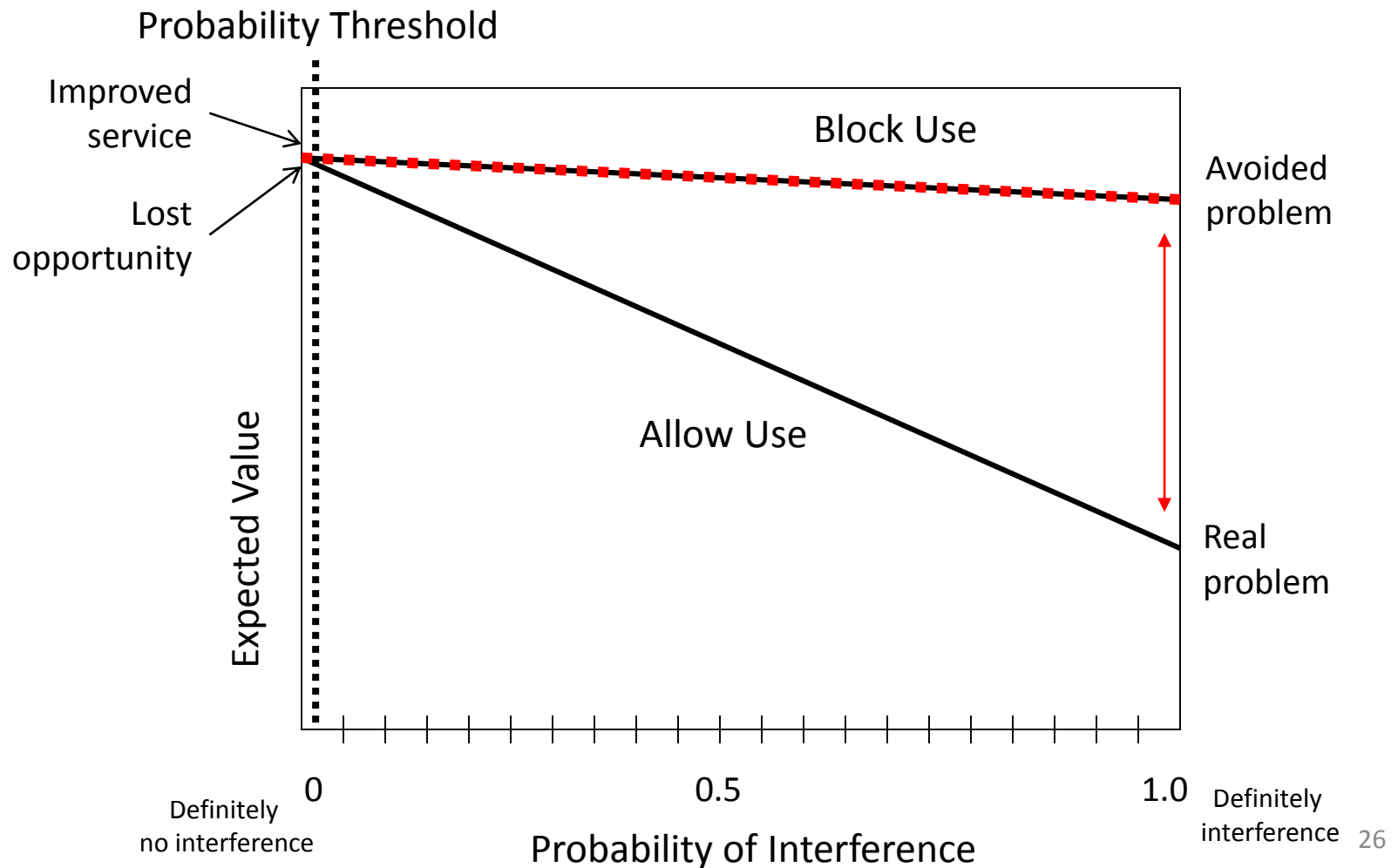
Determine the Threshold Probability



Determine the Threshold Probability



Precautionary Situation (LightSquared?)



Conclusions

- Embrace risk
 - It's there, exploit it
 - Other sectors of the economy have
- Risk and regulation are strange bedfellows
 - How much risk aversion is rational
 - Who pays? Who benefits? When? How?
 - How are bad-luck losers compensated (if at all)?
- Poorly done risk analysis ... what could go wrong?

Those darn unintended consequences!