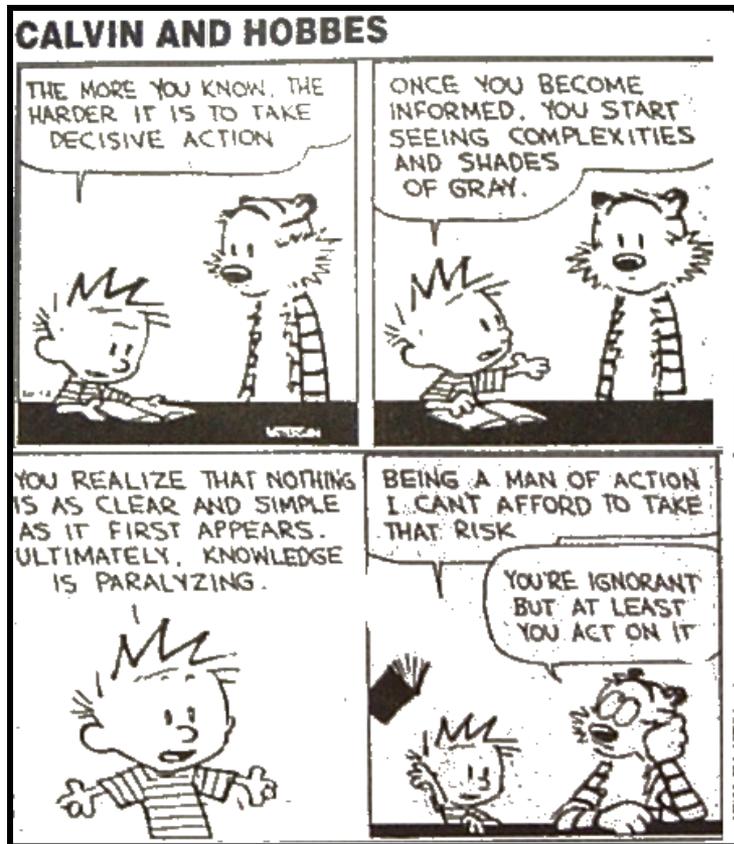


# Maritime Risk: Challenges in Risk Assessment



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Marine Board Meeting

Washington, DC

9 November 2016

# Introduction

- Risk is inherent in most any activity
  - What is really known? Engineered and natural systems
  - 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?

# Risk Management

- What can you affect?
  - Reduce the probability of having an accident (initiating event)
  - Given an accident, reduce the damages that occur (oil outflow, fire, or radioactive release)
  - Given damage, reduce the consequences (damage to health, environment, economy)
- What can you change/improve?
  - Engineering design
  - Procedures (life-cycle perspective)
  - Organizational norms/culture

# “Better” Methods/Analytics

- What happens to your ability to make decisions when ...
  - Adding detail and complexity?
  - Adding multiple outcome dimensions?
  - Adding uncertainty?
- Using uncertain results to justify your conclusions and/or recommendations
  - Trust me ... I’m 95% sure, that the 95<sup>th</sup> percentile adult would have a 95% chance of surviving the 95<sup>th</sup> percentile fire.
  - What could go wrong?
  - Public/policy makers don’t like uncertainty
  - Hiding uncertainty has its risks (manslaughter & 2009 Italian earthquake)

"Doctors say he has a fifty-fifty chance of living, even though there's only a ten percent chance of that."

***Capt. Ed Hocken, The Naked Gun***

# Approaches to Risk Management

- Study accidents
  - Wait until something goes wrong before fixing a problem
  - Expensive way to collect data, but don't waste the opportunity (Macondo dispersant use)
  - How do you identify the actual "cause" of the accident?
- Learn from near misses
- Conduct "experiments"
  - Can be very expensive
  - What do you tell those in the "control" group?
- Model the system
  - How do you get the necessary data?
  - We've never had an accident like that ... so it's impossible?
  - Expert opinion (BBNs and 1,000s of distributions, elicitation, disagreement)
  - Model/analytical complexity results in over confidence?
  - "Black Swan" or bad analysis?
- Research question: What percent of design and procedure updates are initiated from each category?
  - How does it vary within and across industry (aviation, nuclear power)?



*"Then we've agreed that all the evidence isn't in, and that even if all the evidence were in, it still wouldn't be definitive."*



# Waiting for an Accident Has Its Limitations

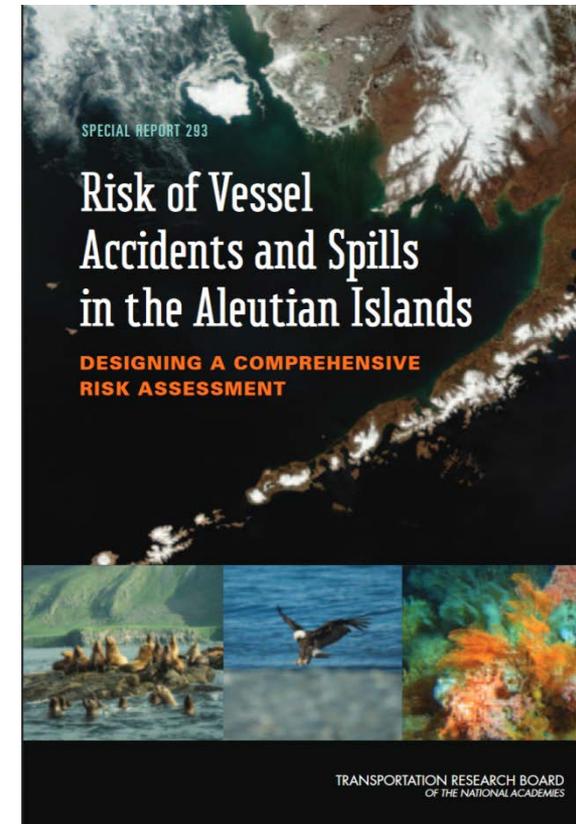
- Closing the barn door after the horse got out?
- Was that only a coincident or really a cause of the accident?
  - Fishing boat collision and civilians onboard USS GREENVILLE
- Once in the Press, the Public will want answers and solutions.
  - Challenger
- How much should be spent to prevent another accident from happening?
  - Seton Hall college dorm fire

# System's Life-Cycle Perspective

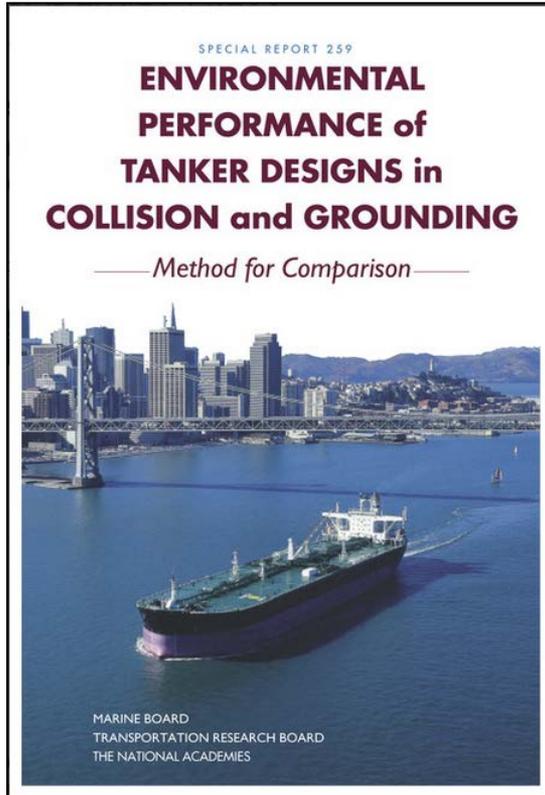
- Origin of risk and opportunity to mitigate
  - Design
  - Construction
  - Training
  - Operations/procedures
  - Maintenance
  - Upgrades
  - Retirement
- Cascading failures across phases
  - Initial weakness occurred early in the life
  - Problem unidentified and/or correction not implemented
  - Band-Aid or cure: Design problems “solved” by risk redefinition or training/operational restrictions or engineering upgrades?
  - Role of regulations
- “Build-in” resilience given future uncertainties
  - Real options (paying now for future decision/correction points)
  - More uncertainty ... more option value

# Designing a Risk Assessment

- **Traffic study:** Characterize the existing fleet and traffic and the quantities of hazardous cargoes moved. Project growth and changes over a 25-year study period.
- **Spill baseline study:** Develop an oil spill baseline on the basis of projected movements of oil and hazardous materials and estimated spill rates and frequencies. The projection should provide an understanding of the most important hazards
- **Identification of high-risk accidents:** Identify the hazardous substances, representative spill sizes, and locations of spills associated with the highest-risk accidents.
- **Consequence analysis:** For representative high-risk accidents, perform a high-level spill trajectory and fate analysis to gain an understanding of the relative impacts of spill size, type, and location.
- **Accident scenario and causality study:** Determine representative accident scenarios to develop probabilities for their principal causes and associated consequences.



# Comparing Tanker Designs



## Structural Damage and Oil Outflow Calculation

- Collect data on collision and grounding accidents
- Develop distributions of accident factors
- Generate accident scenarios
- Calculate structural damage
- Determine oil outflow

## Design Evaluation

- Calculate differences in consequence metrics
- Analyze designs

## Consequence Assessment

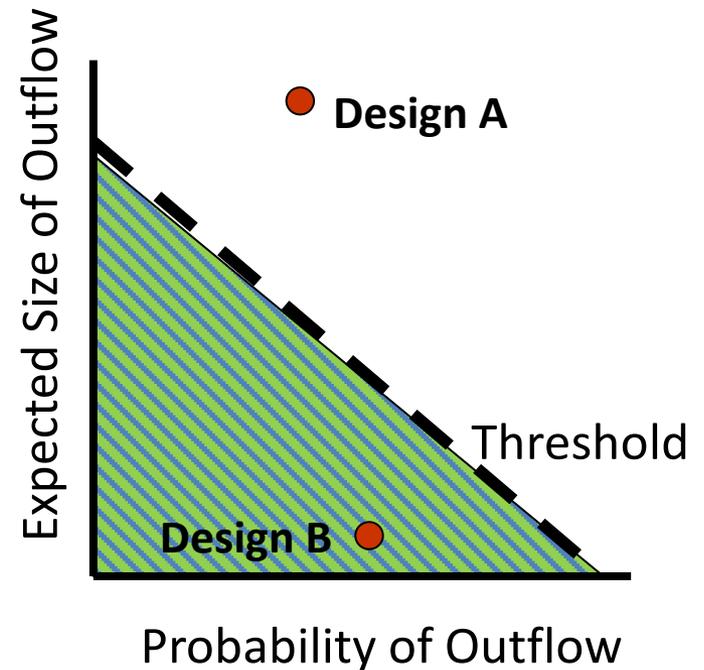
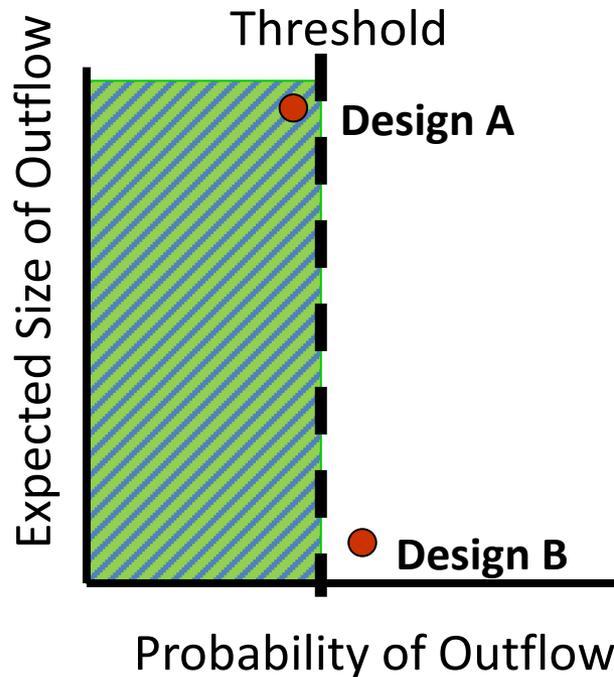
- Model oil fate and transport
- Simulate environmental conditions
- Select impact measures
- Develop consequence metric (ratio based)

# 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?
- Best models/analysis with wrong metric ...



# OPA 90: Equivalently Safe 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**
- Clearly state a trade-off between metrics?**

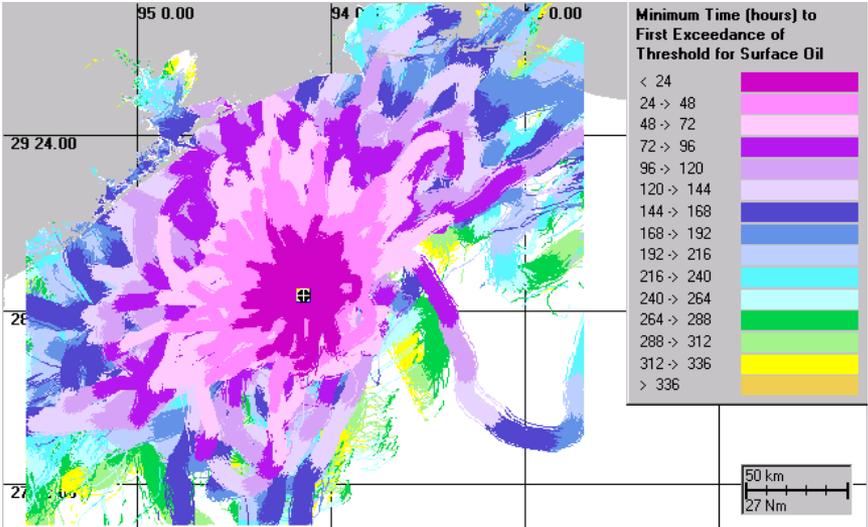
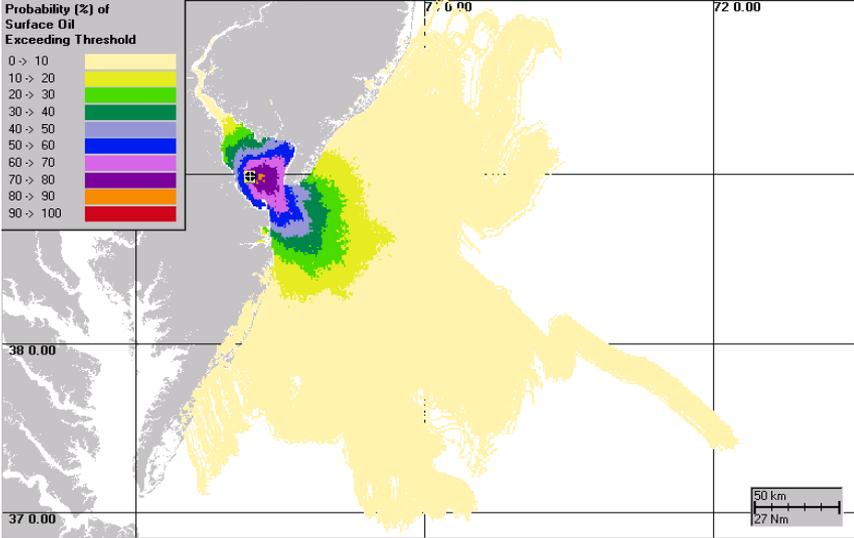
# Oil Spill Impact

## Spill Variables (Uncertainties)

- Location
- Weather
- Amount
- Type

## Impact Criteria

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

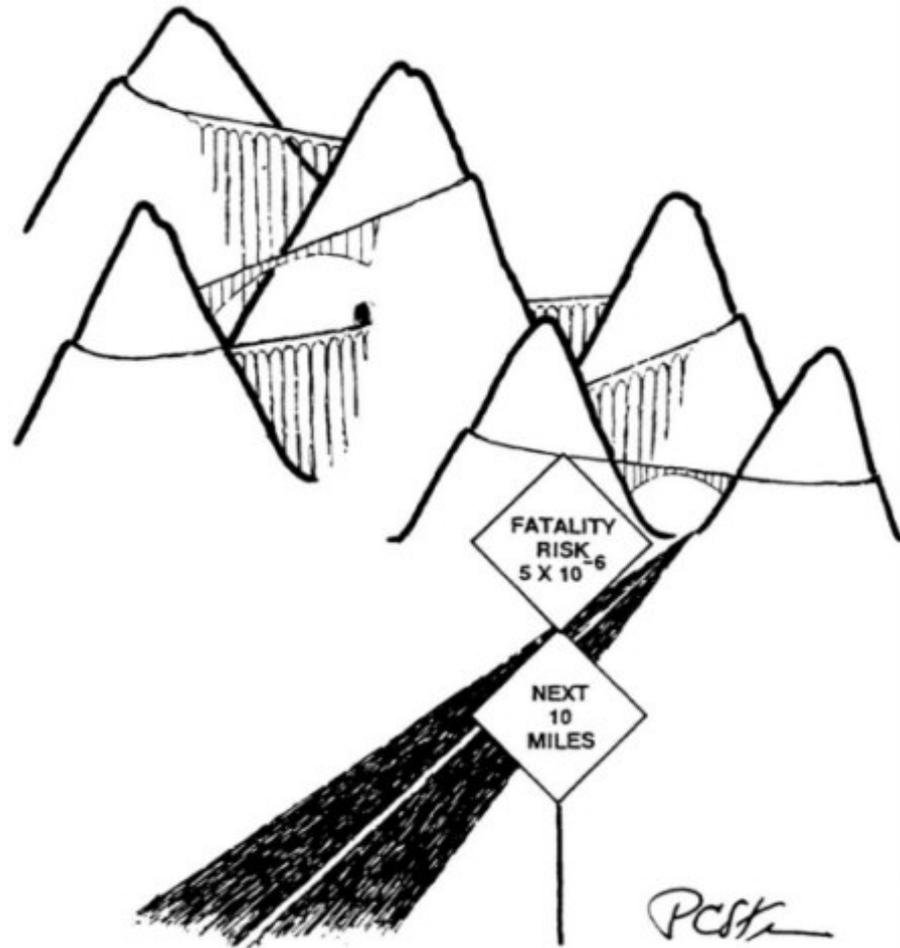


# What Do You Do with the Results?



Mischa Richter The New Yorker Magazine

# Just Because You Can Do the Calculation ...



SOURCE: Courtesy of Paul Stern

- Extract the “relevant” information
  - Make it germane to the decision context
- What is the “correct” warning?
  - “Sharp Curves Next 10 Miles”
- Is the  $10^{-6}$  risk calculation
  - Necessary?
  - Helpful?
  - Accurate?
  - Same for all drivers and conditions?
  - Uncertain?
  - Counterproductive?

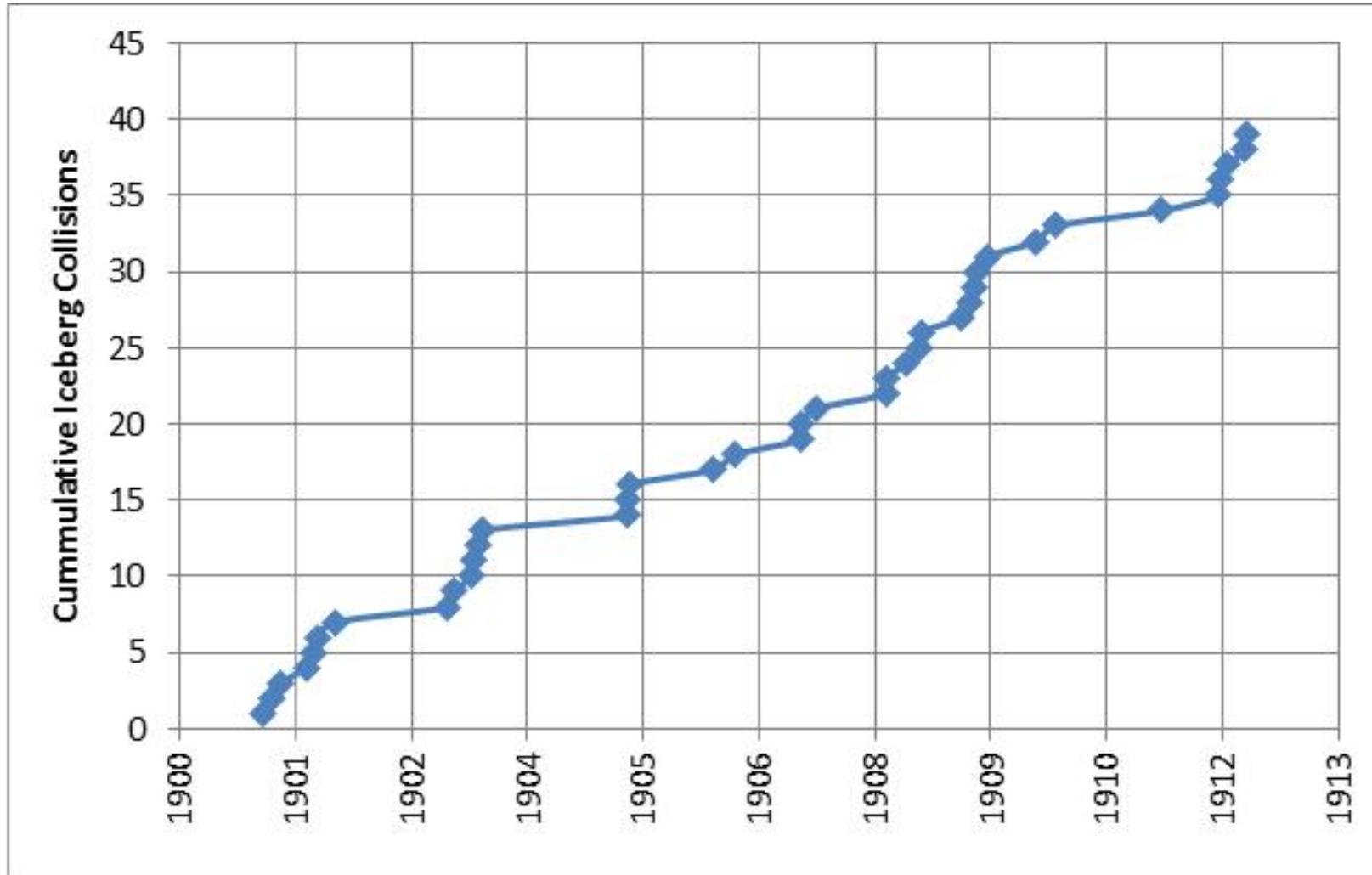
# Study Accidents: Lessons Learned from the Titanic

- Maiden voyage, early April 1912
- “Practically unsinkable” design
  - Watertight bulkheads
  - Could withstand the flooding of up to four compartments
- High-speed impact with iceberg around midnight
- Sank in 2 hours and 40 minutes
- Industrial norm ...

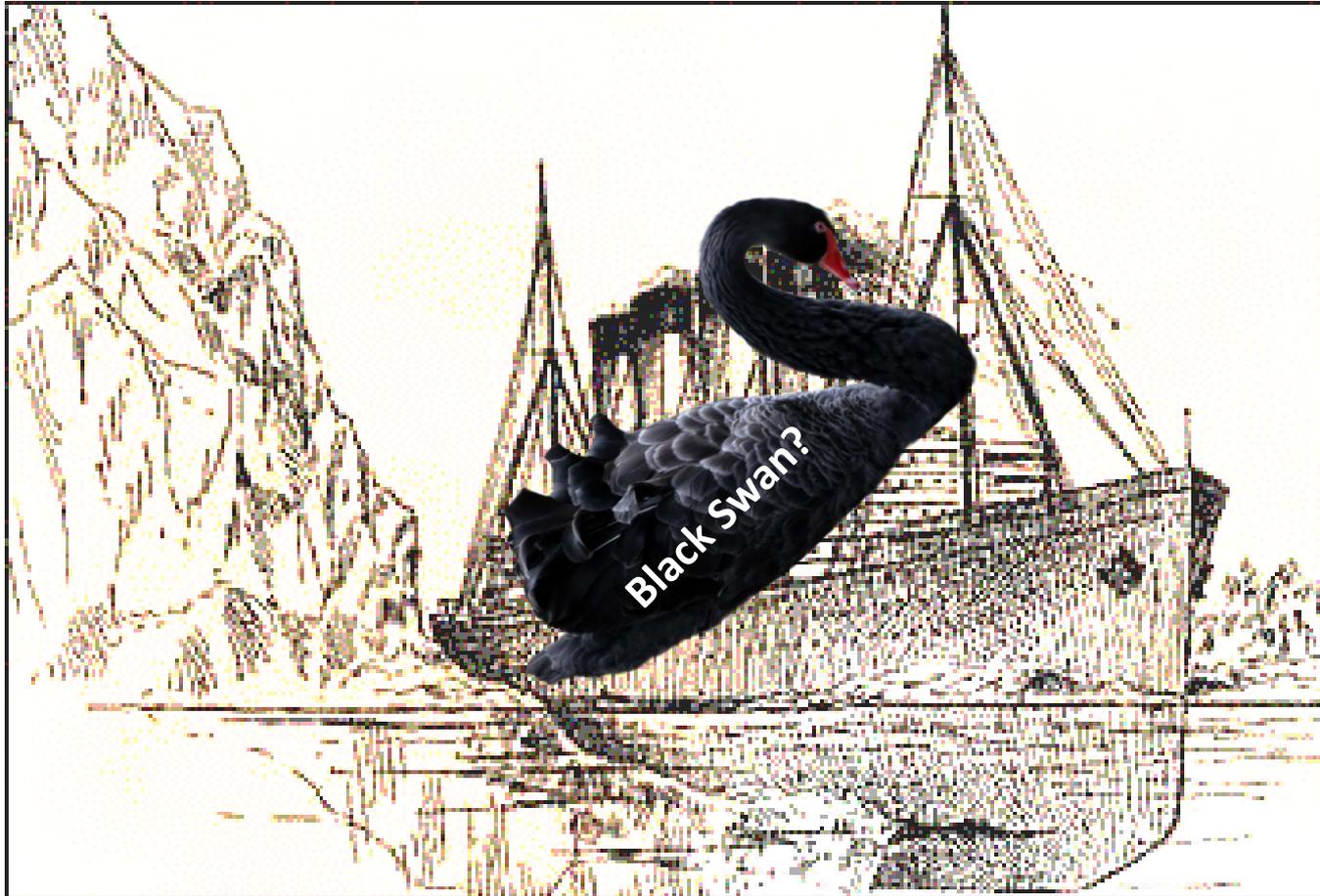
*“I cannot imagine any condition which would cause a ship to founder. I cannot conceive of any vital disaster happening to this vessel. Modern ship building has gone beyond that.”*

Captain Edward J. Smith, 1907

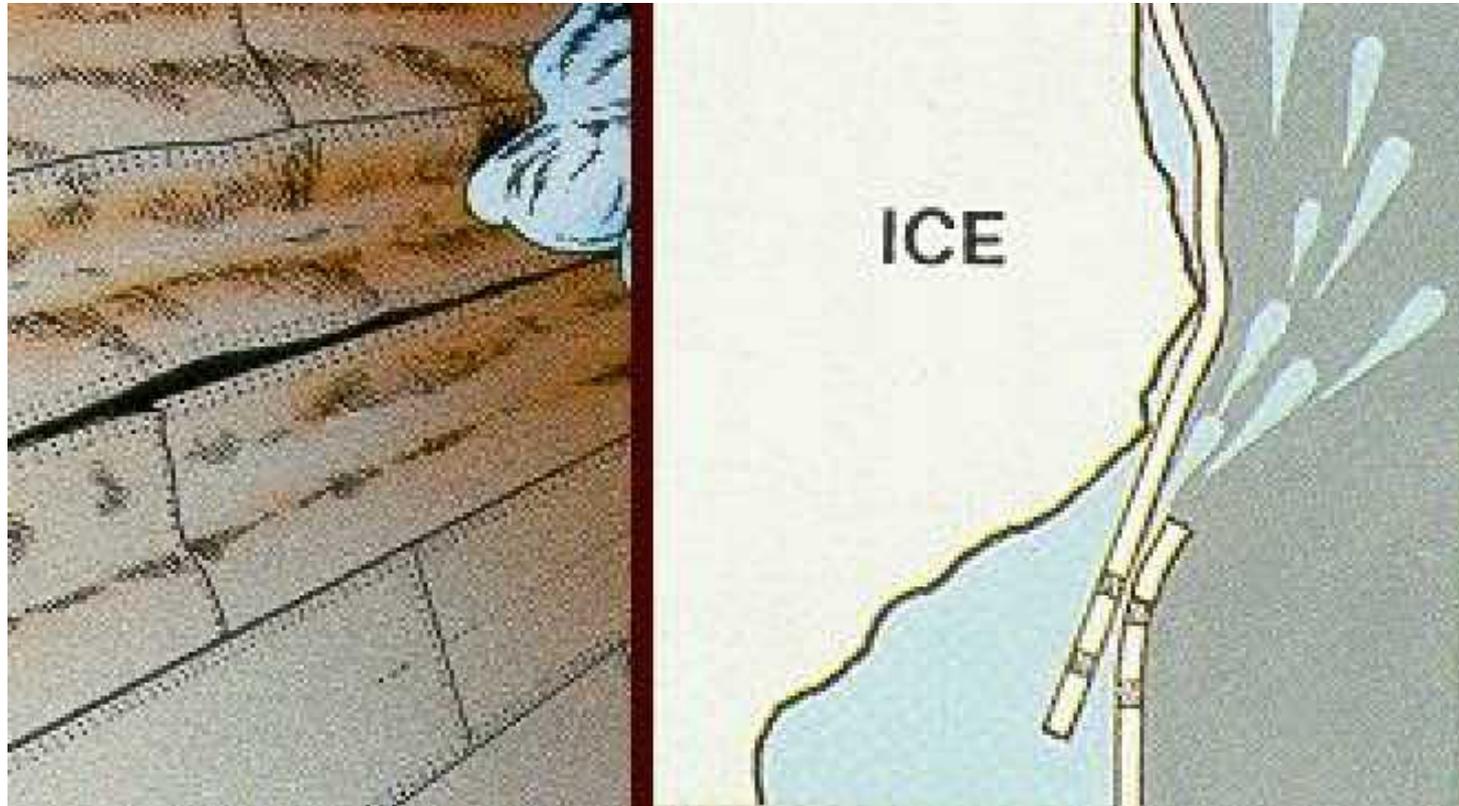
# No Data? Near Miss?



# Long Glancing Blow below the Waterline

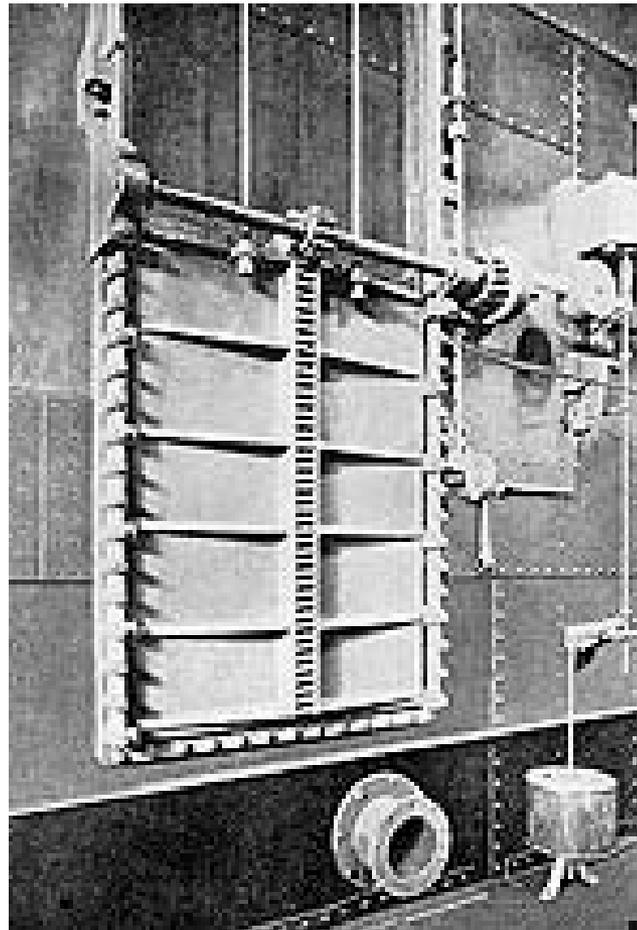


# Plates Buckled and Rivets Popped



300 feet long, but only an inch wide!  
Total area of hole is only 24 square feet

# Automatic Watertight Doors

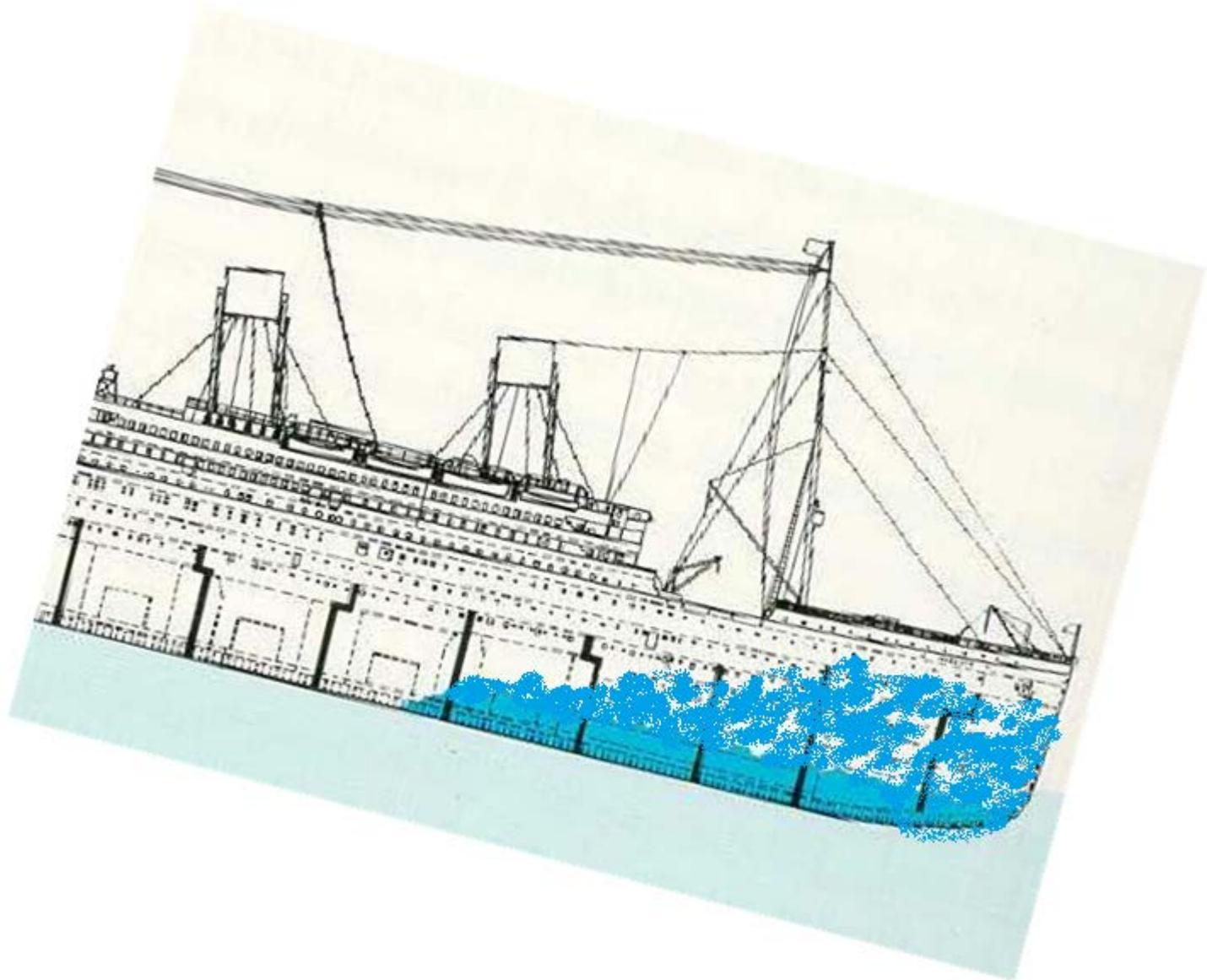


Automatic closing sensor

# Trade-off with Passenger Comfort



# Watertight Bulkheads Went Only So Far

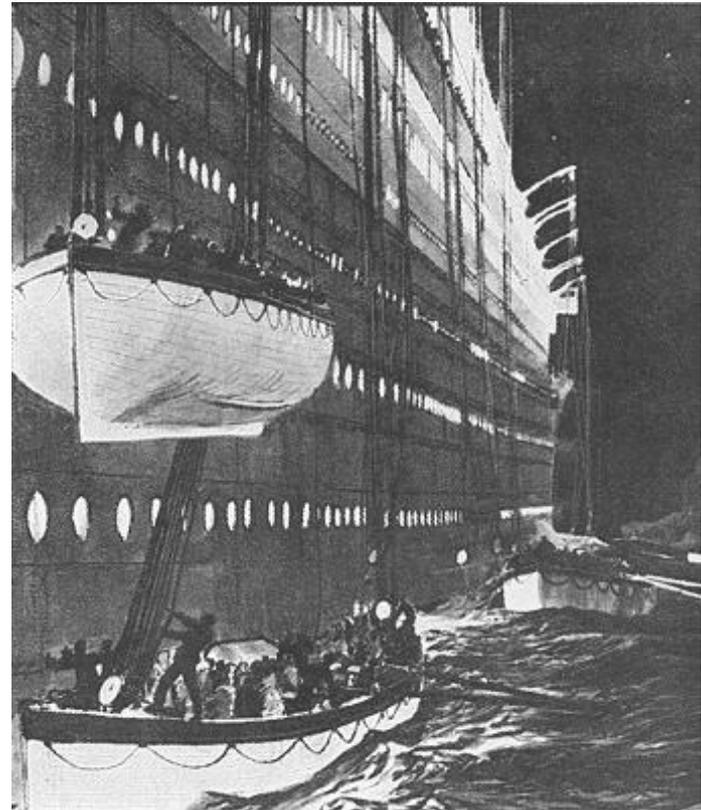


# Lifeboats

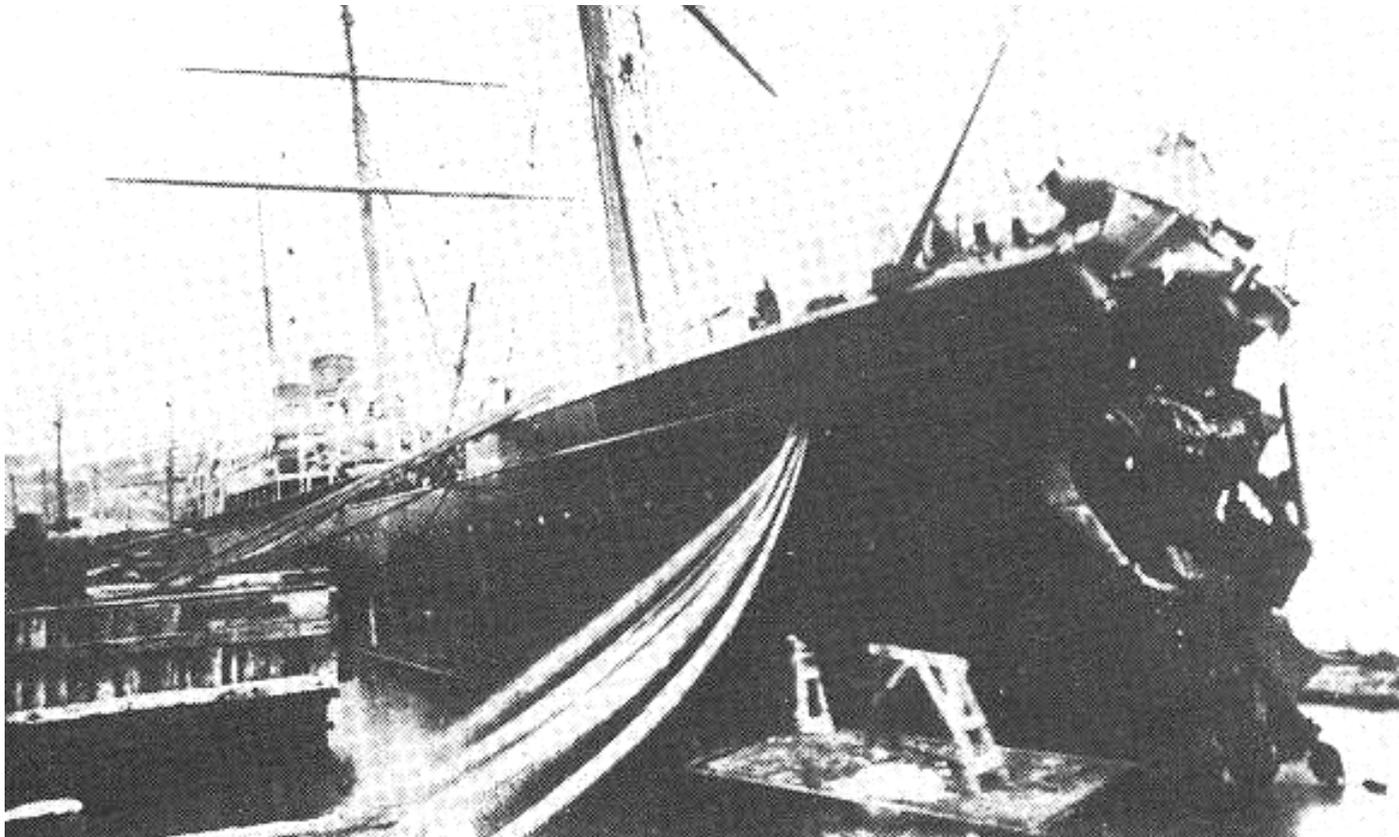
Took up valuable deck space



How hard could it be?



# A Better Way to Hit an Iceberg?



# Risk Management after the Sinking

- Ship design
  - Double hull
  - Watertight compartments, not bulkheads
- Onboard procedures
  - Wireless (new technology)
  - Binoculars in the Crow's Nest
- Industry-wide procedures
  - New lifeboat regulations (based on passengers not tonnage)
  - Iceberg patrols and tracking
- Industry-wide culture
  - Luxury - Safety tradeoff
  - Speed - Safety tradeoff

**What was knowable before the accident?**

# Change in the Culture

CITY EDITION EXTRA **The Globe** CITY EDITION EXTRA  
AND *Commercial Advertiser* 1877  
NEW YORK'S OLDEST NEWSPAPER.

THIRTIETH YEAR. NEW YORK, FRIDAY, APRIL 19, 1912. ONE CENT.

## TITANIC INQUIRY ON; LOSS OF 1,595 LIVES DUE TO SPEED MANIA

**Last Hours of the Giant Liner Filled With Unprecedented Scenes of Self-Sacrifice and Heroism---Astor Put His Wife in the Boat and Then Made Way for a Woman---Mr. and Mrs. Straus, the One Refusing to Be Saved Without the Other, Went Down Clasped in Each Other's Arms---Band Played "Nearer, My God, to Thee," as Ship Sank.**

**SENATORS OPEN INVESTIGATION AT THE WALDORF**

J. Bruce Lunsay, Managing Director of the White Star Line, on Hand to Testify as to Why Titanic Was Going at Full Speed When Crash Came - Vice-President Franklin Will Be Asked to Explain Bulletins Disproved by Event.

There was nothing to conceal. From the very first, were taken in the boats to help man moment the steved, the iceberg until the arrival those, as jumped overboard and were picked up few passengers in New York, the story of the afterward.

The hero was discovered before the Titanic struck it. He was the last man to be seen on the ship.

Some considered the lowering of boats unnecessary.

**HOW HEDGER STRAUB DIED**

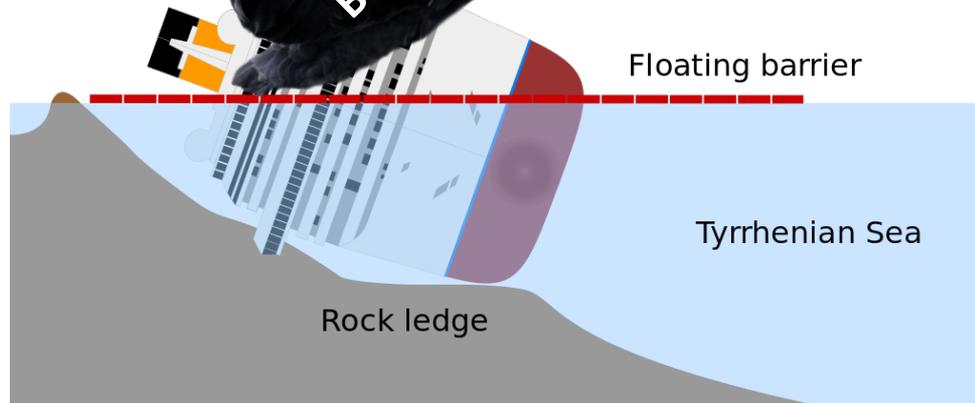
Mr. Straus stood on Deck D. He was held at the side of the ship as it struck the iceberg.

The International Conference for the Safety of Life at Sea (SOLAS) approves the following resolution:

***“When ice is reported on or near his course, the Master of every vessel is bound to proceed at night at a moderate speed or to alter his course, so as to go well clear of the danger zone.”***

# Costa Concordia

13 January 2012

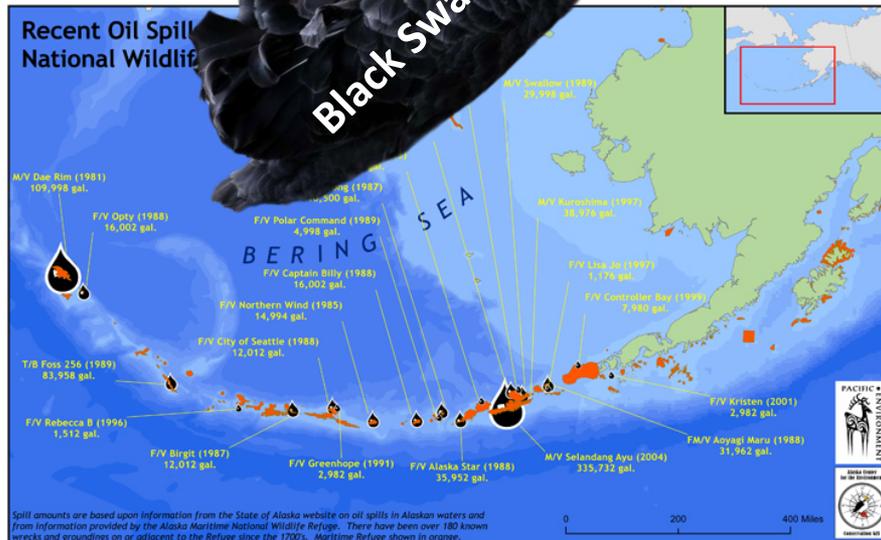


# Selendang Ayu

8 December 2004



<http://blog.netscraps.com/machine-of-war-the-selendang-ayu-alaska.html>



[http://blog.oceanconservancy.org/wp-content/uploads/2014/05/akmnr\\_spills.jpg](http://blog.oceanconservancy.org/wp-content/uploads/2014/05/akmnr_spills.jpg)

# Back-up Generators in the Basement

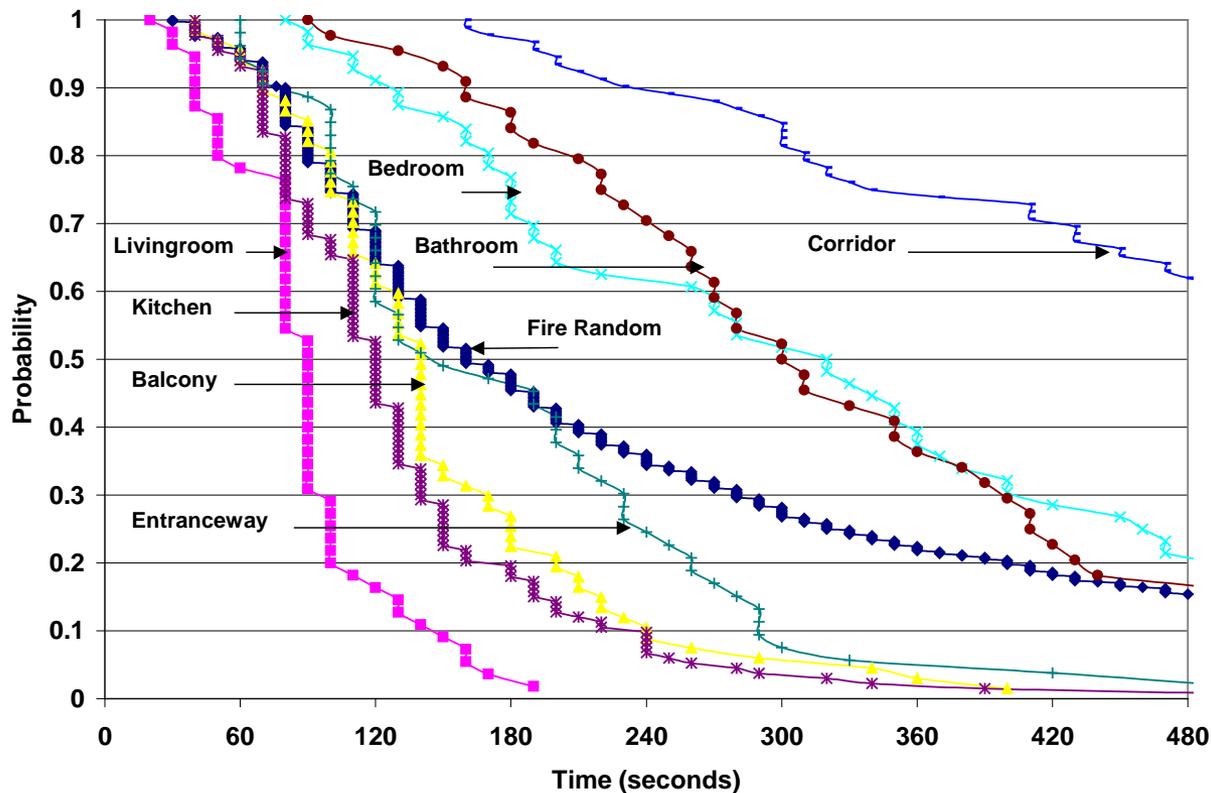


Build a sea wall  
around your nuclear  
power plant



# 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



# Quantifying Risks Has Benefits

- What is the value of reducing uncertainty?
- What risk mitigation options should be considered
- Benefit-cost analysis
  - Valuing life, environment, property
  - Explicit trade-offs of difficult to value endpoints
  - Environmental impact of Exxon Valdez
- But ... GIGO
  - How good is the model/data?

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

## Opportunity Costs per Statistical Life Saved

<b>Regulation</b>	<b>Year</b>	<b>Agency</b>	<b>Cost/Life Saved (millions)</b>
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

# Why Do Methods Get Used?

- Add recommendations/requirements that mandate/suggest a method/approach (e.g., a BBN or CBA)?
  - How determined? Updated?
  - Not all approaches are created equal (AHP)
  - How many research teams are qualified to complete an analysis (Buzzards Bay study)?
- The art of matching approach to problem
  - One size does not fit all
  - Only having a hammer, makes everything look like a nail
- Does the rule prohibit non-specified approaches?
- What is the minimum effort needed to qualify as completing an approach?
  - Who decides?
  - Fully burden cost of fuel (energy)

# 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?

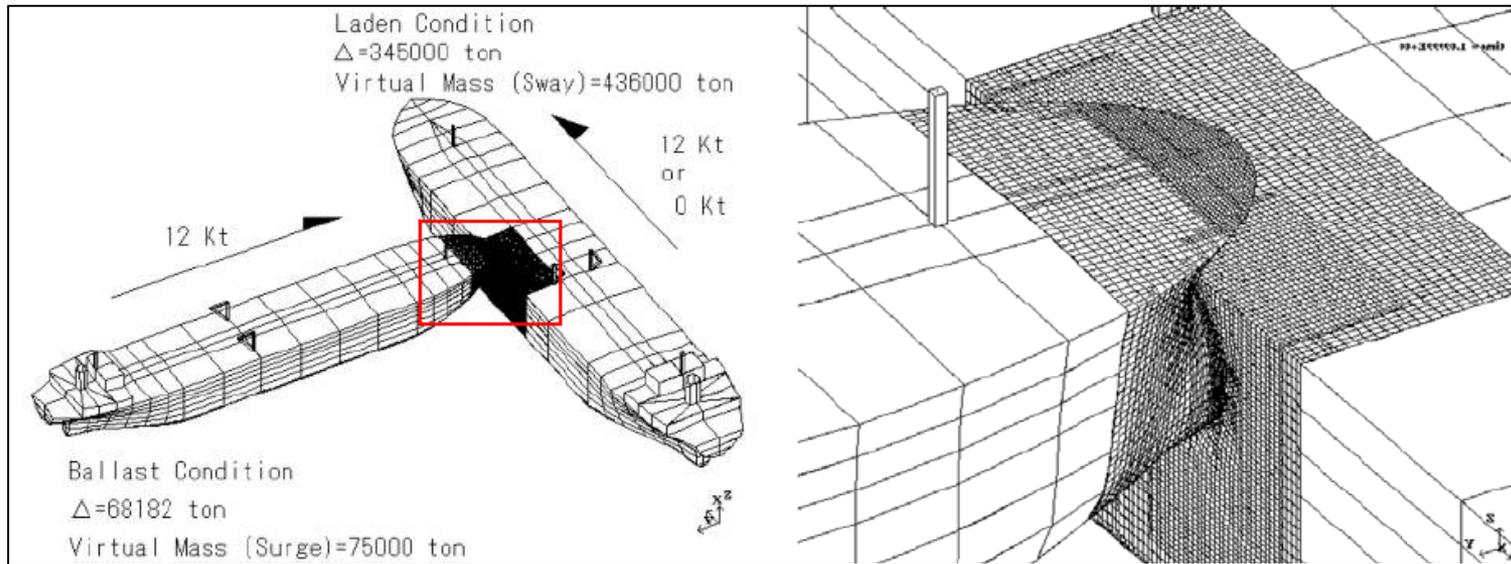
# Conclusions

- Lots of value in well-done risk assessments
  - You can't control risk until you understand it
  - Other sectors have but no one is perfect
- Risk analyses and the public are strange bedfellows
  - Social media
  - How much risk aversion is rational?
  - Who pays? Who benefits? When? How?
  - How are “black swan” losers compensated/penalized?
- Poorly done risk analysis ... what could go wrong?
  - I've done a study and used probabilities ...

**Those darn unintended consequences!**



- Accidents
- Learning from/collecting data
- Safety culture
- Better modelling more uncertainty
  - Making decisions using results
- Macondo dispersant usage
  - 65 million gallons dispersant for 175 million gallons of spilled oil
- Probabilistic regulation
- How bad is marine industry compared to others
  - Nuclear
  - NASA
  - Getting the politicians, bureaucrats to accept the recommendations of uncertain analysis
- Black swans
- New technologies
- Climate change, arctic sea ice



Proceedings of COBEM 2011 21st Brazilian Congress of Mechanical Engineering

# How Many Lifeboats?



# 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.”

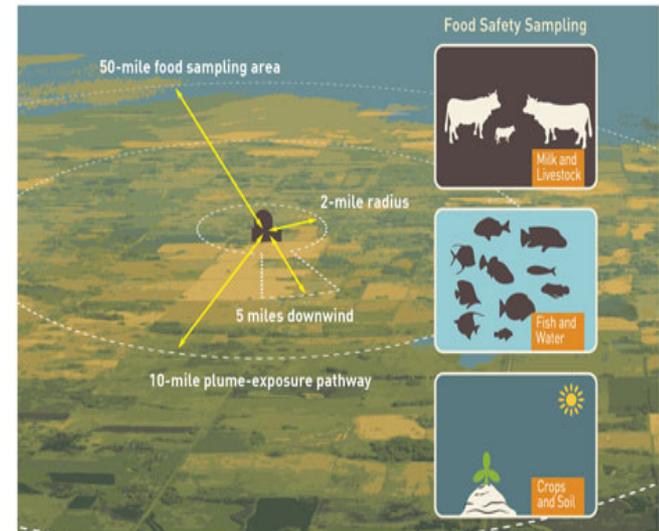
NUREG-2150, April 2012

# 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

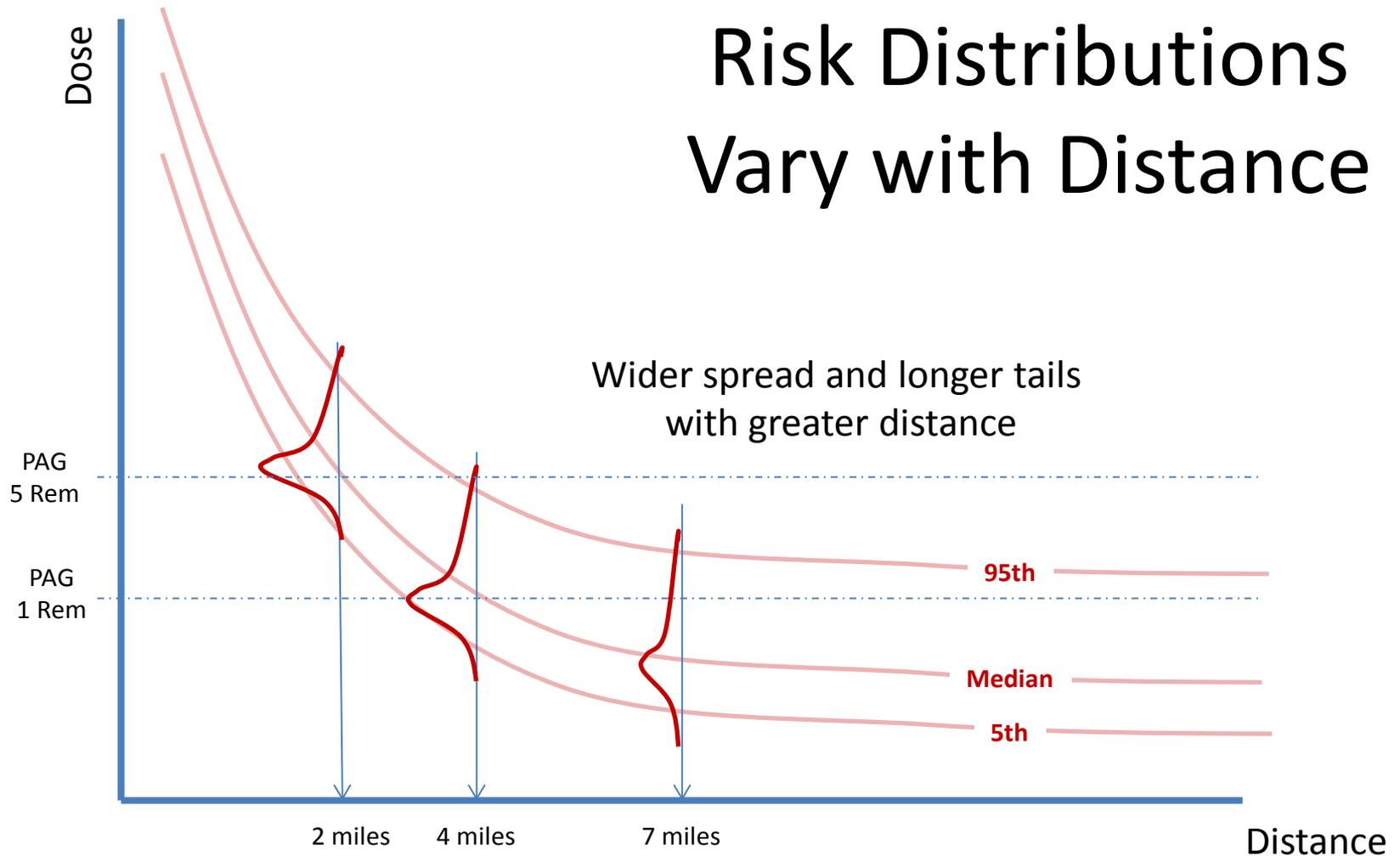
Use PRA-determined distance to be 95% sure that no one outside the zone gets more than 1 REM given an event

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?**