Regulating Nuclear Power in an Active Earth

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Successful Nuclear Power

- Nuclear power needs public support in democracies
- First Ingredient is a credible, independent regulator
- Second ingredient is set of strong, enforceable regulations

Importance of Independent Regulator

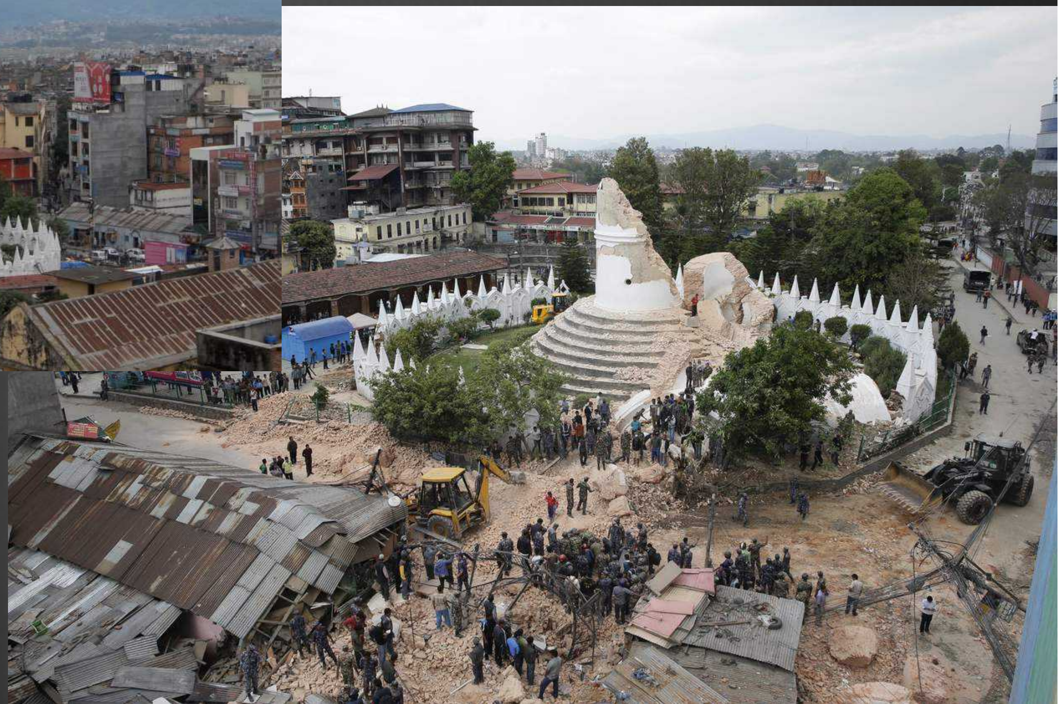
- No political or industry influence
- Well-funded
- Adequate technical expertise
- Full support of central government
- Real enforcement powers to shut down facilities
- No independent regulator: country at great risk in terms of economics and public health

Credible Regulator Essential

- No credible regulator – no public trust – no public support for nuclear power
- Public support lost when
  - Regulator is not *open* and *transparent*
  - Open – engages with public, industry, all interested parties
  - Transparent – makes all decisions in public and all documents available

Natural Hazards in Regulation of Operating Nuclear Reactors

- Earthquakes
- Volcanoes
- Floods
- Wind
  - Tornadoes
  - Typhoons
- Drought
- Heat/Cold
- Snow/Ice
- [Asteroids]



Floods

- Storm surge
  - Coastal
  - River/lake
- Tsunami
- River flooding
  - Storm event
  - Spring snow melt
- Seiche
- Dam break

Ft Calhoun Nuclear Power Plant, Nebraska, US, June, 2011

Wind

- Wind-generated missiles from tornados and typhoons
- Wind damage to structures

Tornado (water spout) photo from Maryland's Calvert Cliffs nuclear power Plant, US

Extreme Temperatures

- Heat
  - Loss of heat sink
    - Millstone unit 2, 2012
- Cold
  - Ice blocking water intake
    - Ice plug Millstone, 1996
- Snow/Ice
  - Strength of roofs/other structures
    - Chernobyl roof collapse in 2013

Collapsed portion of Chernobyl sarcophagus roof

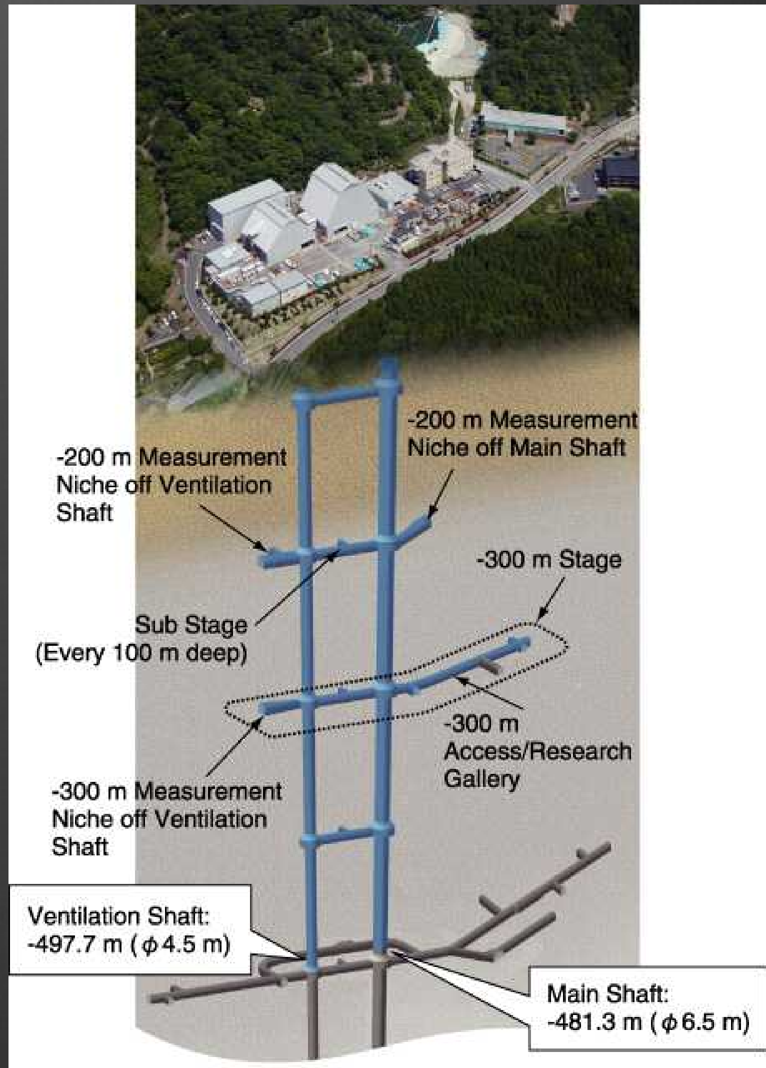
Earth Systems and Regulation of the "Back End" of the Fuel Cycle

- Similar considerations to operating reactors:
  - Spent fuel pools
  - Dry cask storage
  - Reprocessing facilities

- Additional considerations
  - Repository

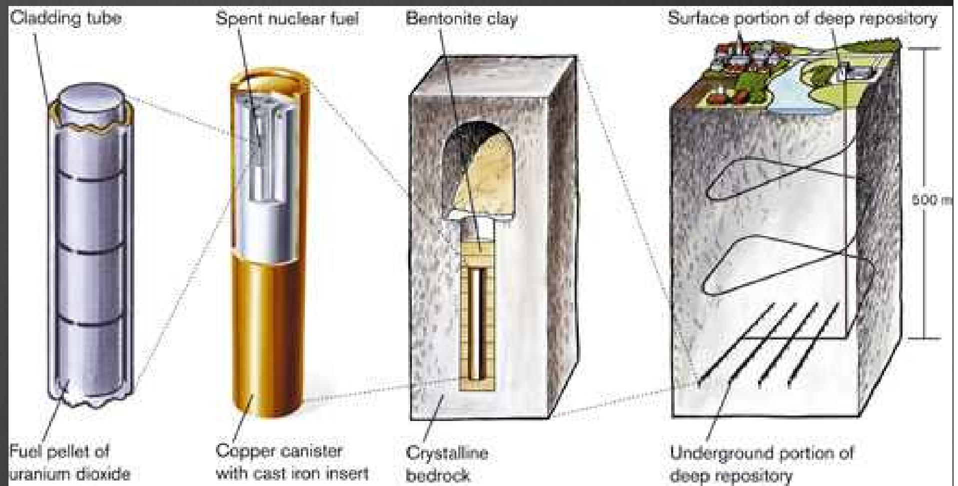
Deep Geologic Repositories

- Siting Considerations (from IAEA, 2003)
  - Long-term tectonic stability
    - Seismic issues – less shaking at depth than on surface
      - Mizunami experience
  - Excavatable rock



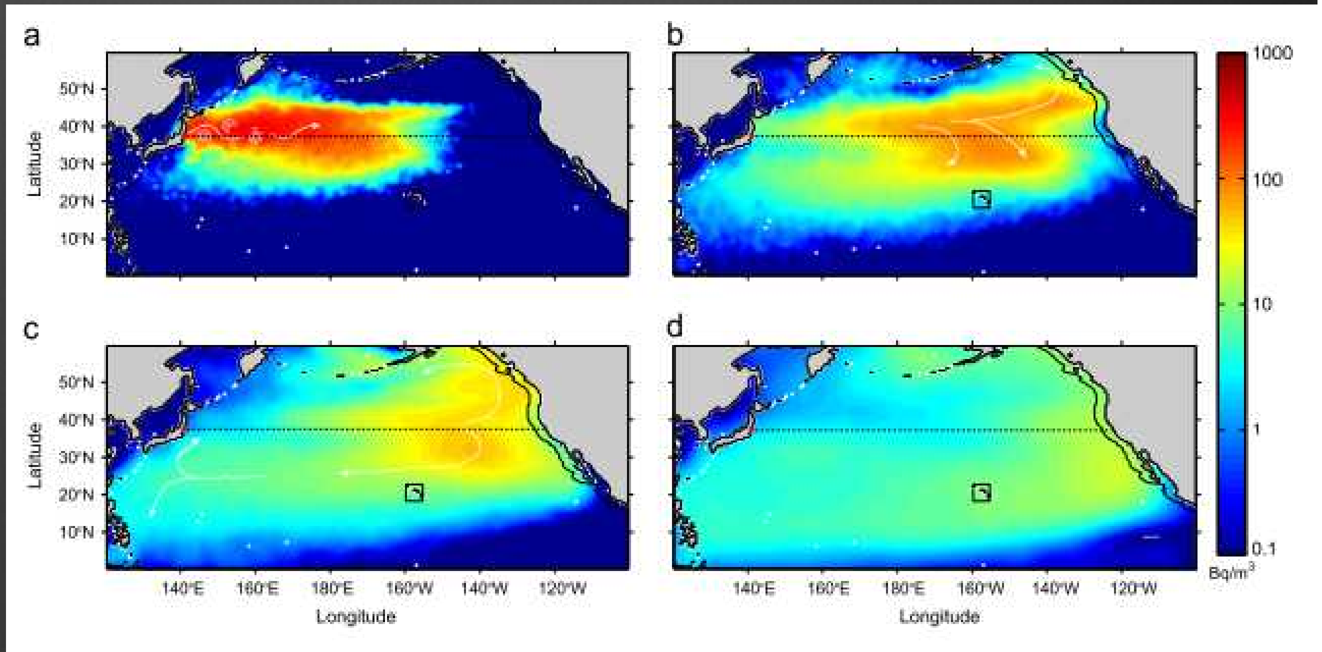
Deep Geologic Repositories

- Low-groundwater content and flow
- Stable geochemistry at depth
  - reducing environment
  - equilibrium between rock and water
- Also need
  - Deep site to avoid erosion
  - No potential for human intrusion



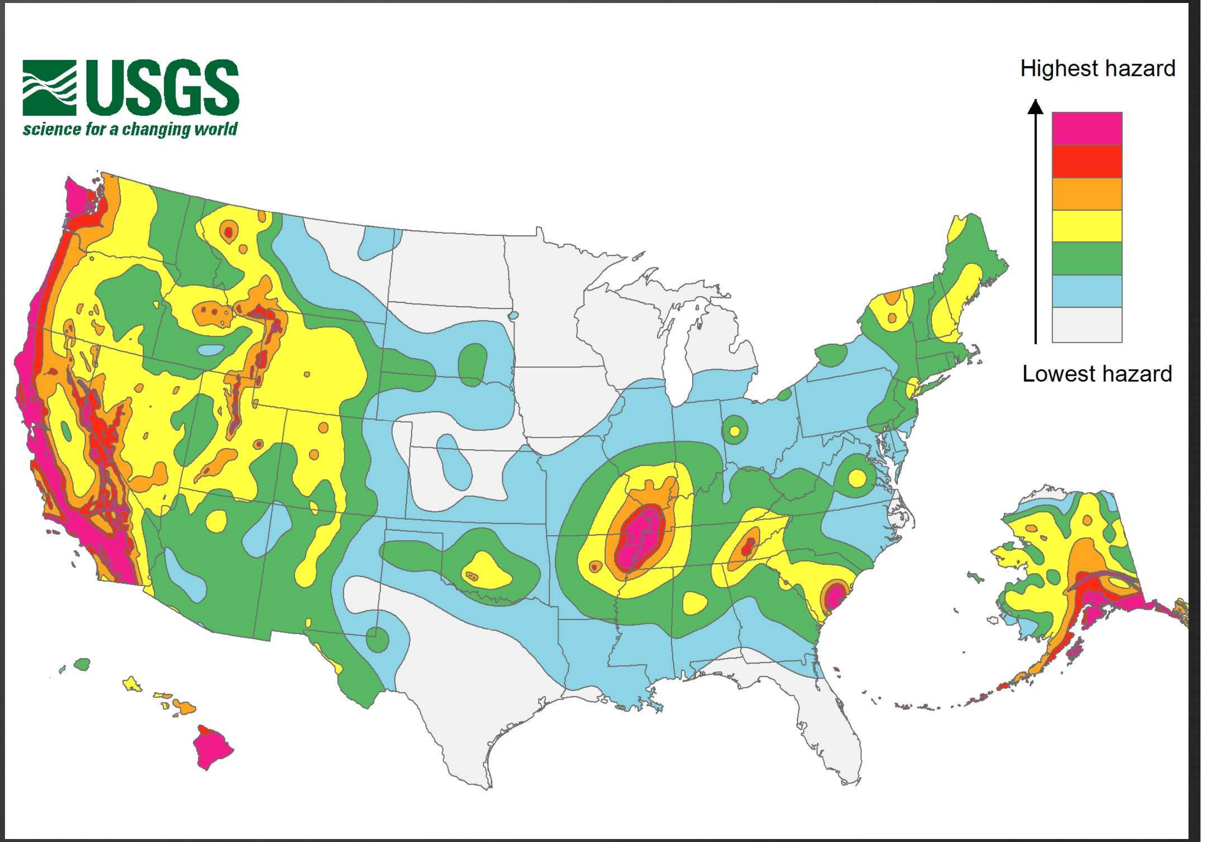
Earth Systems and Regulation of the "Back End" of the Fuel Cycle

- Accident aftermath – Fukushima
  - Groundwater infiltration
  - Groundwater contamination
  - Coastal contamination
  - Seawater/seabed contamination
  - Land contamination



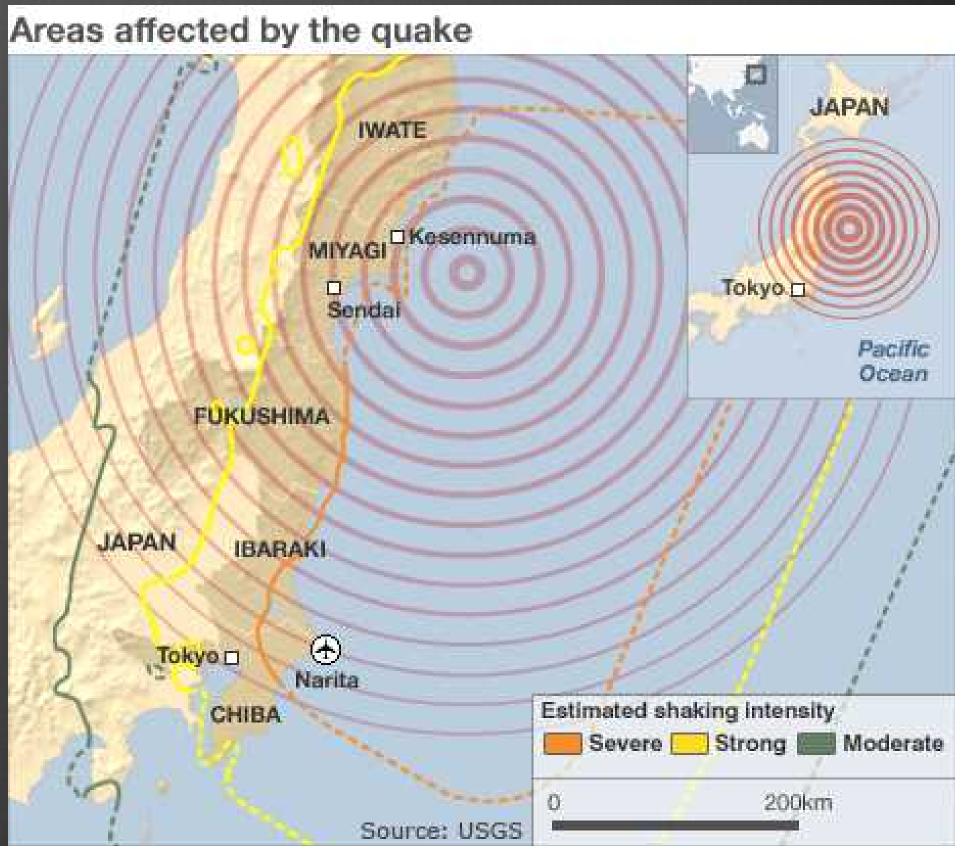
How to regulate for natural hazards

- Periodically review state of geologic knowledge
  - US NRC currently requiring reactors to reevaluate seismic and flooding hazard
  - US NRC considering requiring periodic reevaluations of these hazards
  - US NRC considering reevaluating other natural hazards



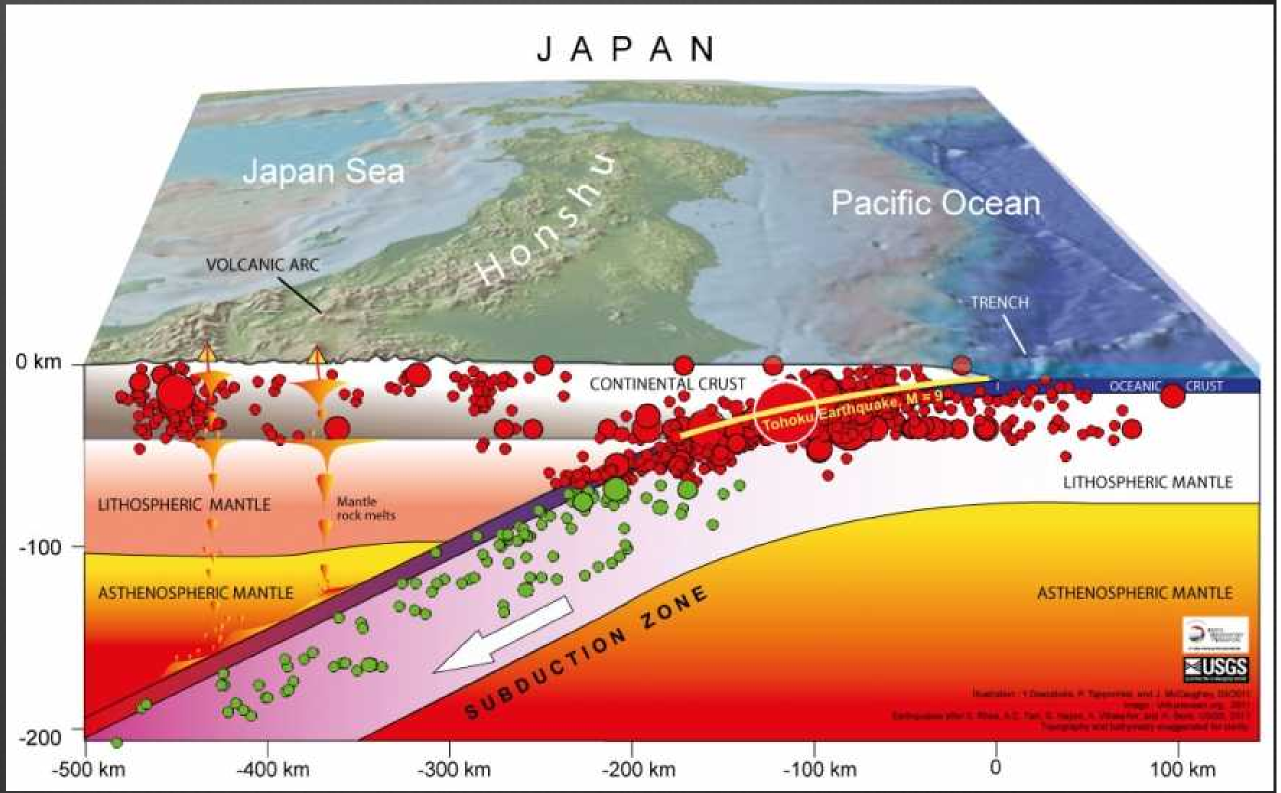
Considerations for Natural Hazards for Future Regulations

- Complex phenomena in complex systems
- Can be difficult or impossible to predict with accuracy in time and magnitude of events
- Propensity to normalize periods of quiet
- Risks can be severe
  - Fukushima example



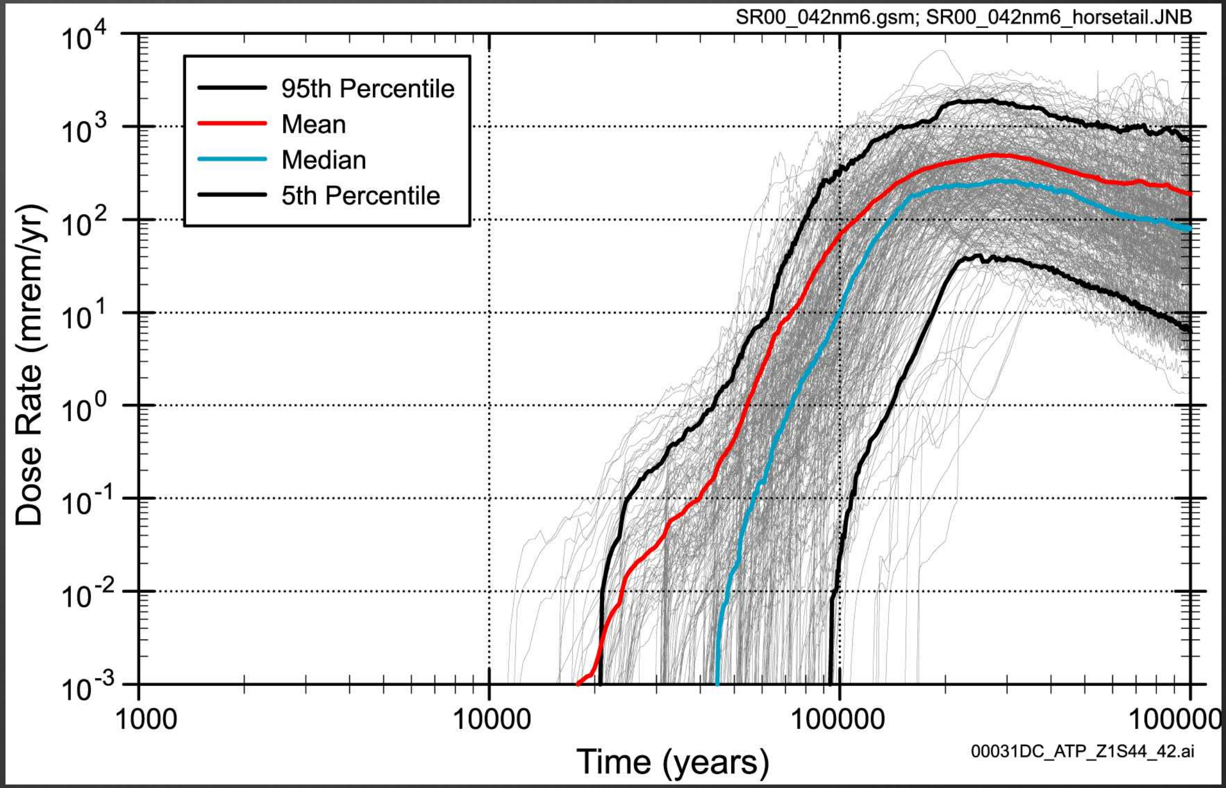
Geologic Knowledge Changes over Time

- Learn more over time
- Plate tectonic theory
  - Accepted in 1970s, after many plants built in US
- Examples
  - Seismology post–Sumatra earthquake
  - Tsunami risk in Japan



Considerations for Future Regulations

- Use of Probabilistic Risk Assessment
  - May provide some insights
  - Discounts low probability, high consequence events
    - (Fukushima)
  - Assumes periodicity of events that may not exist
  - Output only as good as the input
  - US NRC uses seismic PRA but not flooding PRA (yet)



Results of PRA for U.S. Energy Department's Yucca Mountain assessment

The Path Forward

- Grow trust in the regulator by making clear the independence of the regulator
- Treat natural hazards openly and transparently
- Use most current state of knowledge to establish regulations
- Use both probabilistic and deterministic methods
  - Be mindful of uncertainty in data and its consequences for our understanding of events
  - Err on the side of precaution
- Periodically revisit regulations based on new understanding of hazards

In conclusion: Credibility is key for trust