Institutional Control

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Inadvertent Intruders

Institutional Control meets Inadvertent Intruder

Probabilistic Approaches for Evaluating Institutional Control and Inadvertent Human Intrusion for Radioactive Waste Disposal Performance Assessments

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Outline

- Background
- Perspectives
  - Conservatism
    - Stylized scenarios – consequence analysis
  - Technical defensibility – decision-based approach
  - Communication problems – risk perception
- Risk assessment – risk-informed IHI assessment
  - Site-specific and probabilistic
  - Elicitation
  - Examples

Background

- DOE regulations and guidance
  - 5820.2A followed by 435.1
  - Institutional Control period of 100 years
  - Inadvertent Human Intrusion (IHI) happens with probability = 1 for several default scenarios (construction, discovery and drilling) – essentially a "consequence analysis"
- NRC in draft 10 CFR 61 revision requires an IHI analysis, possibly following similar default (stylized) scenarios and "consequence analysis"
- IAEA appears to be moving in a similar direction (per Roger Seitz presentation), but perhaps with room to consider other options

Perspectives

- The “consequence analysis” could reasonably be used for exploration….
- ….but using it for decision making follows a conservative path
- IHI consequence analysis has been used to establish waste concentration limits (WCLs)
- This is not technically defensible
  - If the scenarios do not apply, why arbitrarily limit our ability to dispose of radioactive waste?

Perspectives – conservatism

- Conservatism is difficult to explain
  - For example, how do we explain modeling sand in a system dominated by clay?
  - How do we explain a groundwater pathway in a location where there is insufficient groundwater?
  - How do we explain modeling well drilling in a place where there is no groundwater?

It is ok to make conservative decisions, but it is not ok to make important decisions based on conservative models

A decision analysis approach is needed to properly, defensibly, account for these types of value judgments

Perspectives – risk scenarios

- The stylized scenarios do not always apply!
  - Consider NNSS – Mojave desert
  - Energy*Solutions* – groundwater is very saline
  - WCS – insufficient groundwater
- More generally, we have the technology to evaluate risk scenarios properly
- MOP and IHI should become one and the same, particularly after Institutional Control is lost
  - How do we manage to explain that MOP is offsite, but exposed to onsite concentrations (fence-man), and IHI is onsite but only exposed to waste inadvertently brought up from the subsurface?
- *Is there a better way?*

A Probabilistic Approach

- IHI should be evaluated site-specifically and probabilistically – LLW management examples:
  - WIPP
  - Sweden
- Many years ago, DOE/NV recognized this potential problem, and decided to address the probability of IHI for the NTS low-level radioactive waste management sites
- We went through the same steps that IAEA is following (per Roger's presentation), but arrived at a specific endpoint for our approach – *probabilistic expert elicitation*
- We completed this IHI elicitation project prior to release of NRC's expert elicitation guidance – NUREG-1563

Probabilistic Steps

- Probabilistic elicitation has 3 basic steps
  - Conditioning – sharing background information
  - Structuring – model building
  - Specification – probabilistic elicitation
- An elicitation project requires some other steps
  - Identification of suitable experts
  - Peer review
  - QA and documentation
  - Probability and elicitation training (inc. calibration and bias mitigation)
  - Feedback

We prefer group elicitation for some technical reasons, but can be challenging if experts disagree

Probability Training

- Discrete and continuous distributions
- Center and spread
- Independence and conditional probability
- Correlation
- Mutually exclusive and exhaustive events
- Disambiguity
- Quantile elicitation based on trade-offs

Elicitation Training

- Expert Elicitation is a science (and an art)
- There are many common biases that can be introduced if steps are not taken to avoid them:
- Motivational biases
  - Non-scientific influences that can affect opinion
  - Mitigation through openness and awareness
- Cognitive biases
  - Psychological effects that are “human nature”
  - Variety of mitigation techniques

Elicitation – Motivational Bias

- Expert bias – desire to appear expert
  - Make aware that uncertainty is expected
- Wishful thinking – having a stake in the outcome
  - Be open about benefits of useful results
- Approved numbers – difficulty deviating from them
  - Emphasize importance of conveying real targets
- Conservatism – choosing “conservative” numbers
  - Again, emphasize communication and understanding

Elicitation – Bias Mitigation

- For most motivational biases, openness and awareness are the primary mitigation strategies
- Choosing experts who are peers helps, as does the conditioning step of the elicitation process
- Another major strategy is to break the problem down into smaller, more manageable pieces
  - Scientific knowledge is typically better for more narrowly defined questions
  - By building model up from smaller pieces, there is less tendency to jump to a desired answer

Cognitive Biases

- Lack of clarity
- Anchoring
- Availability/coherence/vividness
- Overconfidence
- Implicit conditioning
  - These aspects of human perception are fairly predictable – be clear about the thinking process

Cognitive Bias Mitigation

- Introduce some simple games involving random chance
  - Introduce experts to probability and choices
  - Ask experts to make choices regarding simple betting options
    - Betting scenarios form the basis of most elicitations
  - Apply the “Almanac Game”
    - Demonstrates how difficult it is for experts to provide sufficient uncertainty in their estimates
    - Hence, trains the experts to think more broadly
    - Trains the experts to think in terms of scenarios that can drive more extreme possibilities

Quiz time – give 90% probability ranges for the following:

1. What is the (mean) distance from the earth to the moon (in miles)?
2. What is the population of Lithuania (CIA 2008 report)?
3. How long is the Amazon River (in miles)?
4. How many liver transplants were performed in the U.S. in 2002 (according to NIS)?
5. In what year was the Taj Mahal completed?
6. What is the area of Canada in square miles?
7. How many (earth) years does it take for Pluto to orbit the sun?
8. How many U.S. casualties were reported for World War I?
9. How deep (in feet below sea level) is the deepest point in the Arctic Ocean?
10. What is the liftoff weight of the [former] space shuttle (in pounds)?

Elicitation Examples

- Expert elicitation is not only possible, it usually meets with considerable success – it requires the right expertise to get defensible results – elicitors and elicitees
  - NTS IHI and IC (follows)
  - Mesa erosion in Los Alamos
    - Some later validation
  - Modeling stream water quality
  - Site characterization (Bayesian DQOs)

IHI and IC: Inextricably Linked

	Active Control	Passive Control	Loss of Memory
Societal control	Physical security at site, knowledge management, records, site markers	Knowledge management, records, site markers	No knowledge of hazardous nature of site
Design safety features	Depth of disposal, multi-barriers	Depth of disposal, multi-barriers	Depth of disposal, multi-barriers may be degrading
Implications for potential for HI	No inadvertent HI	Inadvertent HI extremely unlikely – safety case can justify exclusion of major HI scenarios	Inadvertent HI a possibility, may still be mitigated by enduring design features
Hazard of facility	Disposal inventory	Decaying inventory	Decay may be significant for near-surface, low-level waste facilities

NTS IHI and IC Example

- Concern that NTS WCLs were dependent on IHI scenarios that are unlikely to apply
- Desire to develop probabilistic estimate of IHI
- Link between IHI and IC required consideration of probability of IC as well

Why is the approach to IC so restrictive for LLW disposal??

- Is 100 years reasonable?
- Is perpetual control reasonable?
- Something in between?

Objective – optimize use of our limited radioactive waste disposal facilities

- Consider roles of Active & Passive controls

Why is the approach to IHI so restrictive for LLW disposal??

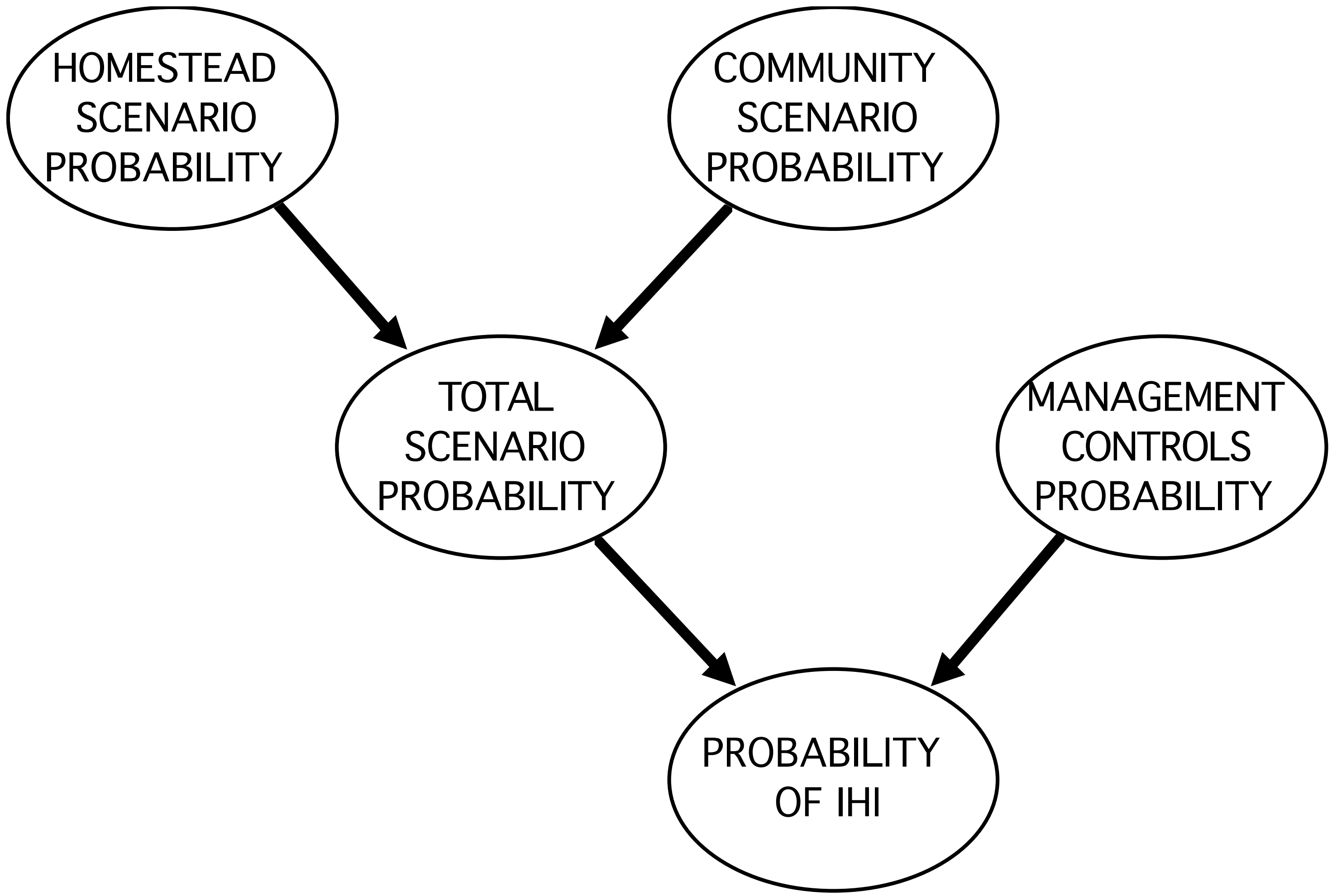
- Is evaluating the consequence of unlikely IHI scenarios reasonable?
- What is the difference between MOP and IHI?
- How far into the future should any of this be evaluated?

Objective – optimize use of our limited radioactive waste disposal facilities

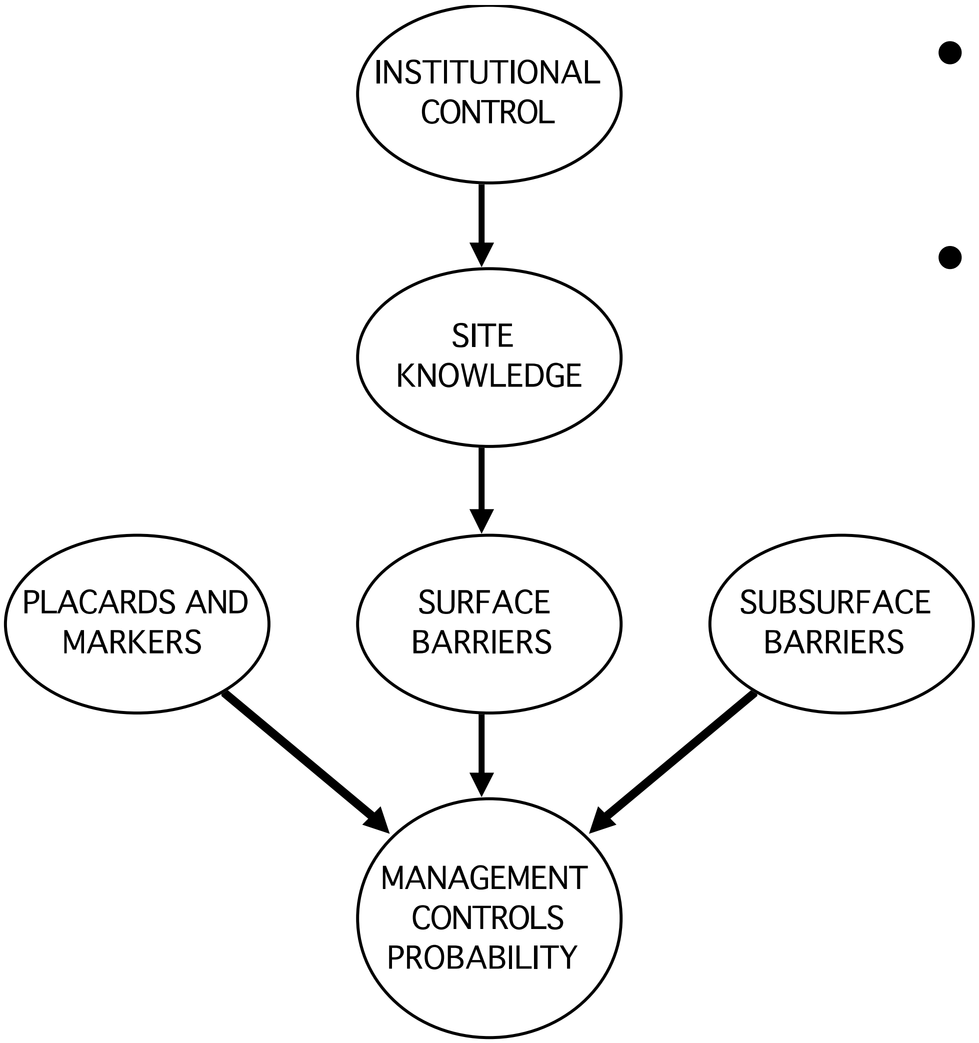
Pr(Inadvertent Human Intrusion)

- 10 Subject Matter Experts
  - Multiple disciplines
- Knew nothing about PA
  - Not constrained by DOE O 5820.2A
  - However, they got very close to mimicking the intent behind our regulations and guidance
- Goal – evaluate the P(IHI) from well-drilling
  - Homesteading scenario
  - Community scenarios
  - Institutional Controls

Influence Diagram



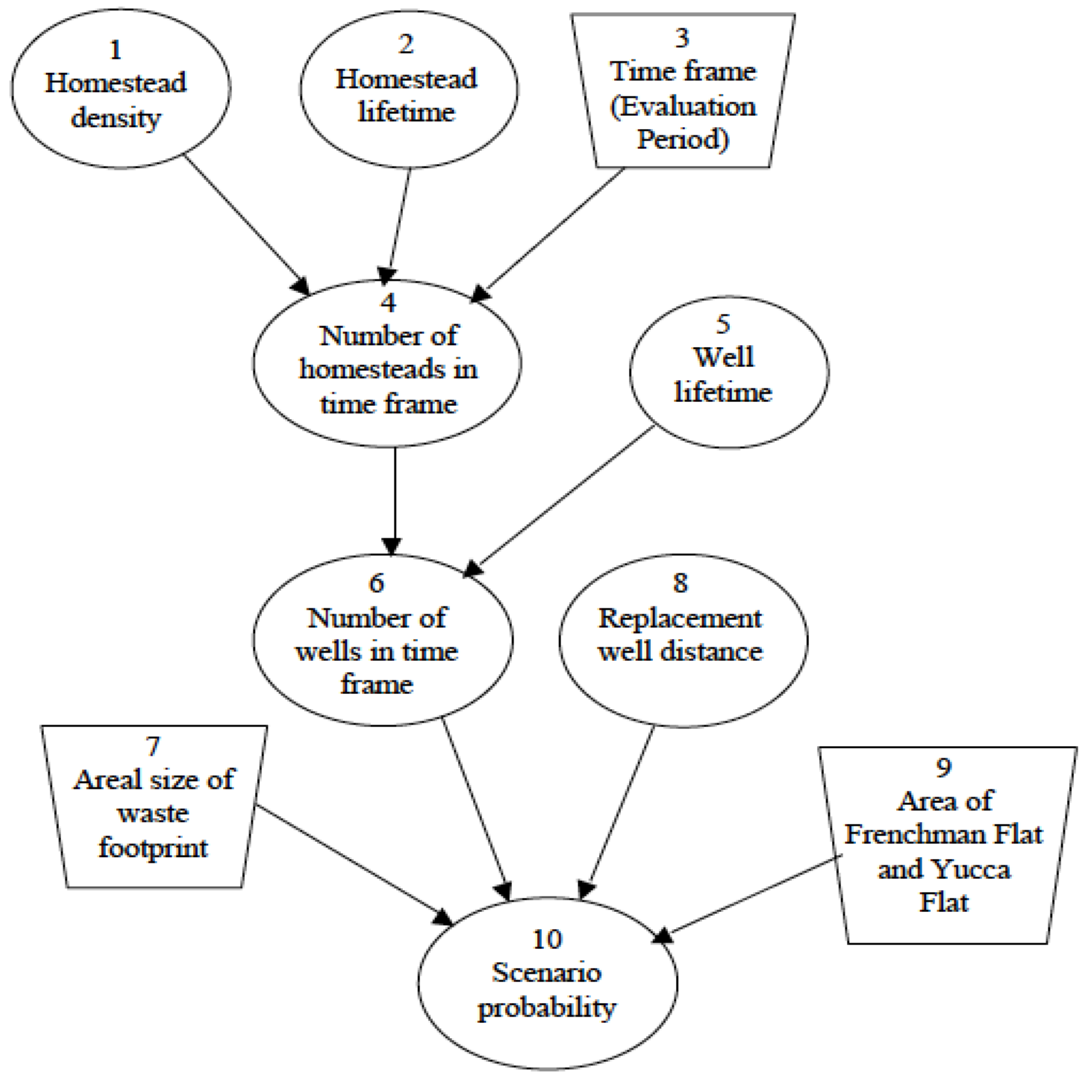
Management Controls Diagram



- Active controls
- Passive controls
  - Historical records
  - Signs
  - Engineered barriers

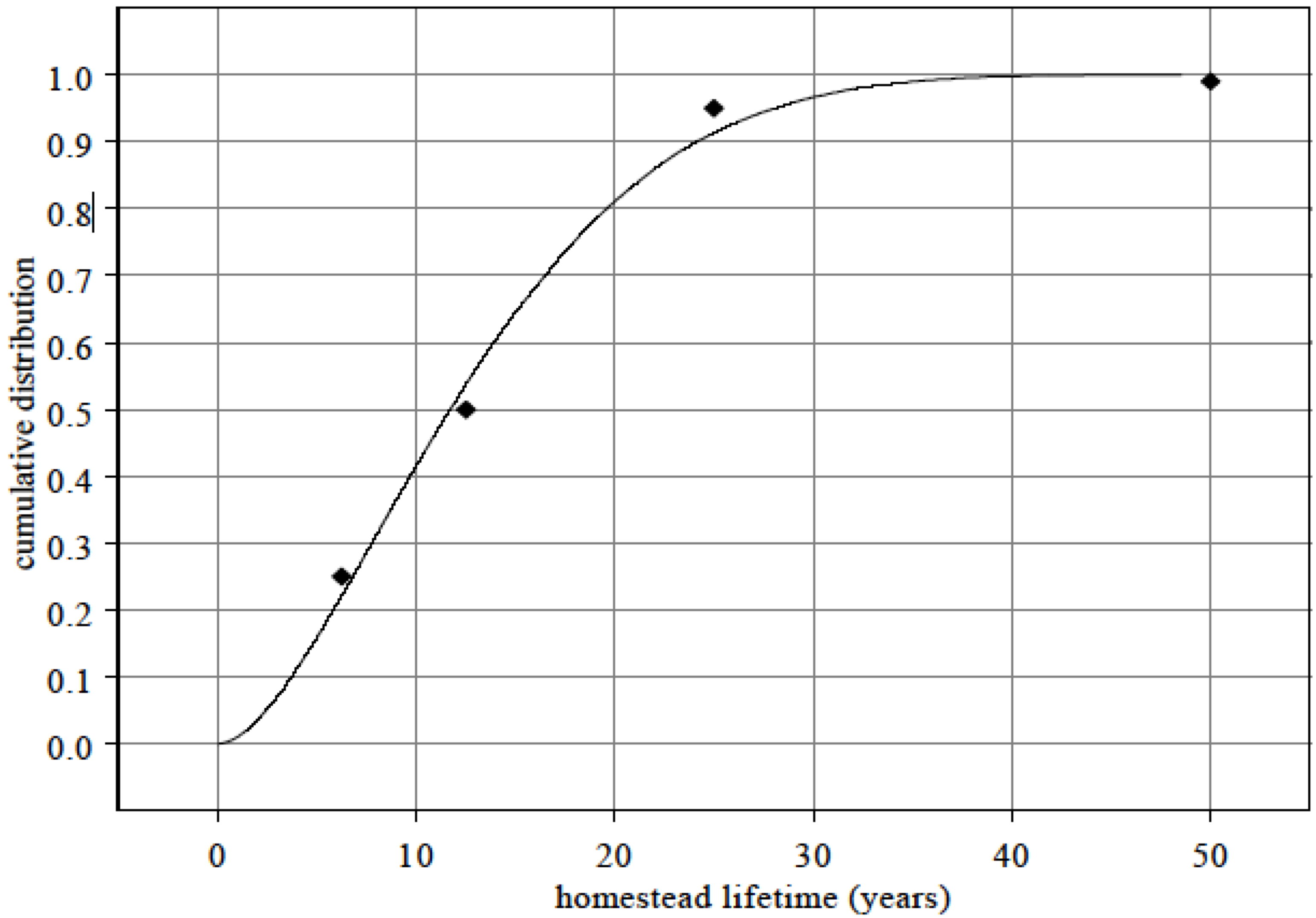
IHI – Well Drilling Scenarios

- Homesteading
- Community
  - Small community in Frenchman Flat or Yucca Flat
  - Urban expansion of Las Vegas into the alluvial valleys of the NTS
  - Small community in Mercury of Jackass Flats that puts homesteading pressure on Frenchman Flat or Yucca Flat

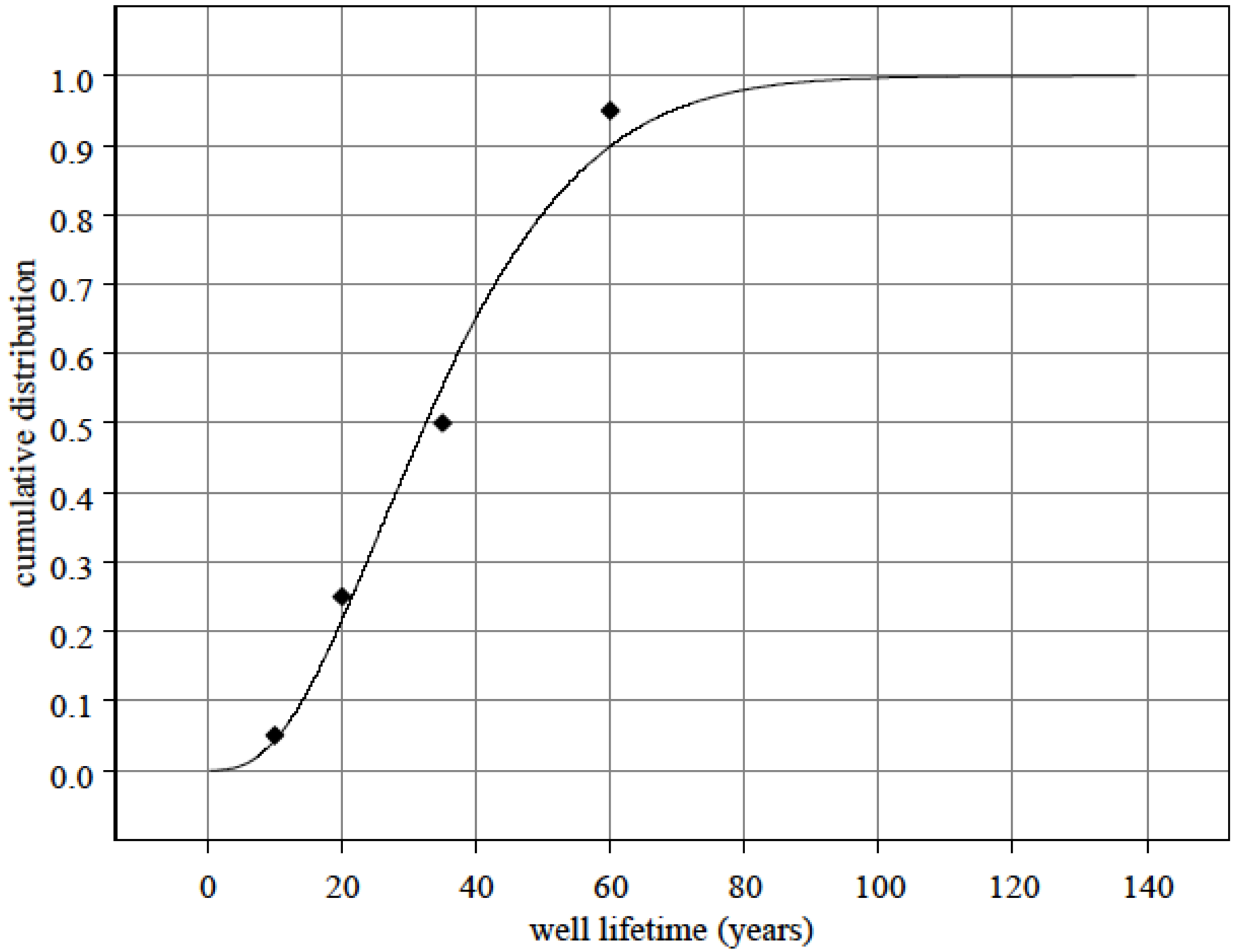


HOMESTEADER SCENARIO
for Frenchman Flat and Yucca Flat

Results – Homestead lifetime



Results – Well lifetime



Results – Pr(IHI – Homestead)

Summary Statistic	Total Number of Wells		Probability of IHI
	Primary	Replacement	
Minimum	10	0	0.000098
5%	17	1	0.00018
25%	21	2	0.00022
Median	24	3	0.00026
Average	**24**	**3**	**0.00026**
75%	27	4	0.00030
95%	33	6	0.00036
Maximum	46	12	0.00050

Similar results obtained for the 3 community scenarios – summed together for overall probability – dominated by the "Jackass Flats" scenario.

Results – Pr(IHI all scenarios)

Summary Statistic	Frenchman Flat	Yucca Flat
Minimum	0.032	0.0013
5%	0.059	0.0037
25%	0.084	0.0052
Median	0.11	0.0068
Average	**0.11**	**0.0069**
75%	0.14	0.0084
95%	0.16	0.010
Maximum	0.21	0.014

These estimates assume loss of all institutional controls from Time 0.

Additional effect of institutional controls applied next

Active Control

- Control will most likely be lost gradually, well within 10,000 years
- Control would be passed to other entities (e.g., the State or County)
- Gradual decline in perception of importance
- Political or economic instability
- Assessed a median value of 250 years with reasonable range of 50 – 1,000 years
- Corresponds to a mean of 300 years

Passive Control

- Defined as sufficient knowledge (oral or written history) to deter IHI
- Considered historical civilizations (e.g., pyramids vs Inca)
- Considered that far more knowledge has probably been lost than maintained over time
- Assessed a median value of 100 years with reasonable range of 50 – 500 years
    - On top of active control
- Corresponds to a mean of about 200 years

Results for Active Control

- Elicitation was performed for P(IHI) at NTS
- However, it could have broader applicability, at least as a reference point
  - Perhaps only for LLW
- Regulations allow consideration of 100 years of active institutional control
- Elicitation has a distribution with a mean of about 300 years
- 100 years is about the 20^{th} percentile of the distribution

Results for Passive Control

- US considers permanent passive institutional control, but requires analysis for the duration of the PA model
- Elicitation has a distribution with a mean of about 200 years

- There is some consistency with IAEA who suggest passive controls for tens or a few hundred years for LLW

Effectiveness of other IC Controls

- Engineered controls – Surface
  - Boulders and mounds – fairly effective at deterring siting a drill rig on top
- Engineered controls – Subsurface
  - Re-inforced concrete – fairly effective at stopping drilling
- Placards and Markers
  - Simple signage – probability of effectiveness decreased with time to about 0.1 at 10ky

Notes

- Active and passive institutional control results might be reasonably applicable to other sites – nothing was very specific to NTS for those factors
- Engineered factors are site-specific, and were not addressed completely – that is they were not taken credit for in any dose calculations
- IHI scenario are also site-specific
- Application of the elicitation results needs to be careful
    - Rote multiplication of dose by these probabilities might give “expected dose values”
    - But this does not address that a receptor (well driller) is either present or is not present
    - This can be addressed properly by modeling receptors specifically

Summary

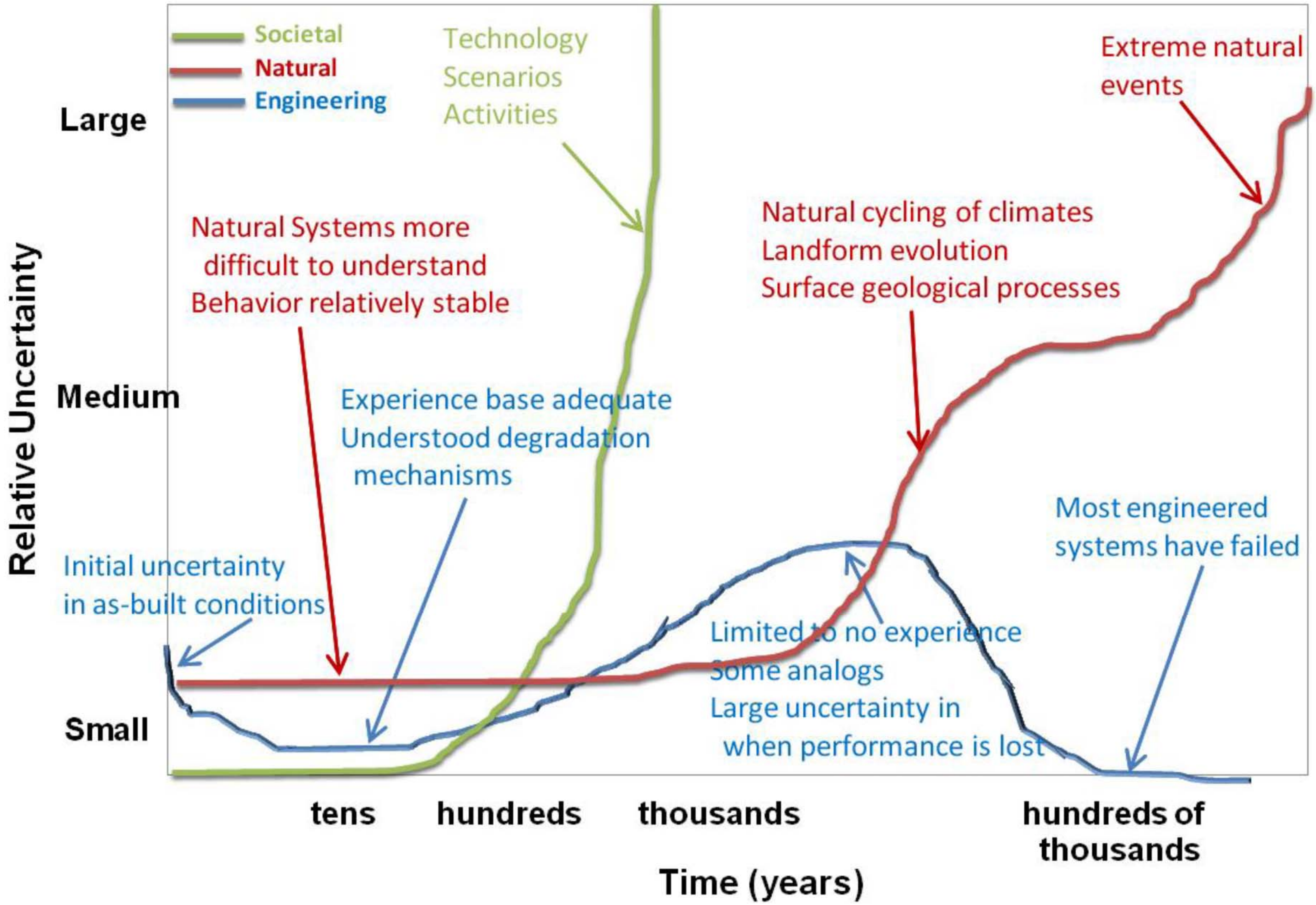
- Indications are that the elicitation was successful, despite this being a difficult problem
  - The experts formed a model that matched regulatory thinking, but without the benefit of that thinking
  - The results are reasonable in light of current policy that suggests a few hundred years of passive control is reasonable, so that credit could be taken but only to some extent
- Suggestion of about 300 years as a mean for active institutional control might also be reasonable
- Can always do the elicitation again for other specific conditions

Expert Elicitation Experiences

- We have performed expert elicitation on a wide variety of projects
- It requires a set of skills that include experts in facilitation, elicitation and statistics
    - Training in how to do elicitation is critical
    - Pre-conceived statistical models often don't apply – it is important to be able to adapt on the fly
    - Computer tools can help/support elicitation
- In our experience, experts are usually skeptical ahead of time, and surprised at the success and usefulness of the approach
- It works!

Other thoughts

- Risk assessment modeling into the long-term future is fraught with problems
  1. Lack of ability for humans to accurately/precisely predict the future
  2. Psychological, social, evolutionary, and technological changes over time
  3. Long-term physical changes in the Earth's systems
  4. Economic challenges to valuation of risks and benefits of policies
  5. Financial planning
- Perhaps IC lasts long enough that it covers a reasonable modeling timeframe?
- Revolving window with financing guarantees might be a better way to manage these facilities?



Types of Uncertainties and their Relative Magnitudes in the Near-Surface Disposal of Radioactive Waste, with Explanation of Contributing Processes and Events (from NRC 2011)

Quiz time – answers

1. What is the (mean) distance from the earth to the moon (in miles)? 238,857
2. What is the population of Lithuania (CIA 2008 report)? 3.57 million
3. How long is the Amazon River (in miles)? 3,912
4. How many liver transplants were performed in the U.S. in 2002 (according to NIS)? 5200
5. In what year was the Taj Mahal completed? 1643
6. What is the area of Canada in square miles? 3.8 million
7. How many (earth) years does it take for Pluto to orbit the sun? 248
8. How many U.S. casualties were reported for World War I? 300,041
9. How deep (in feet below sea level) is the deepest point in the Arctic Ocean? 17,900
10. What is the liftoff weight of the [former] space shuttle (in pounds)? 4.5 million

Advertent Intruder