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Natural external hazards, uncertainty and probability of exceedance hazard curves

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17th September 2015

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- Using a simple risk model to explore special features of natural hazards
  - Defining hazard across broad initiating frequencies range, rather than one discrete frequency
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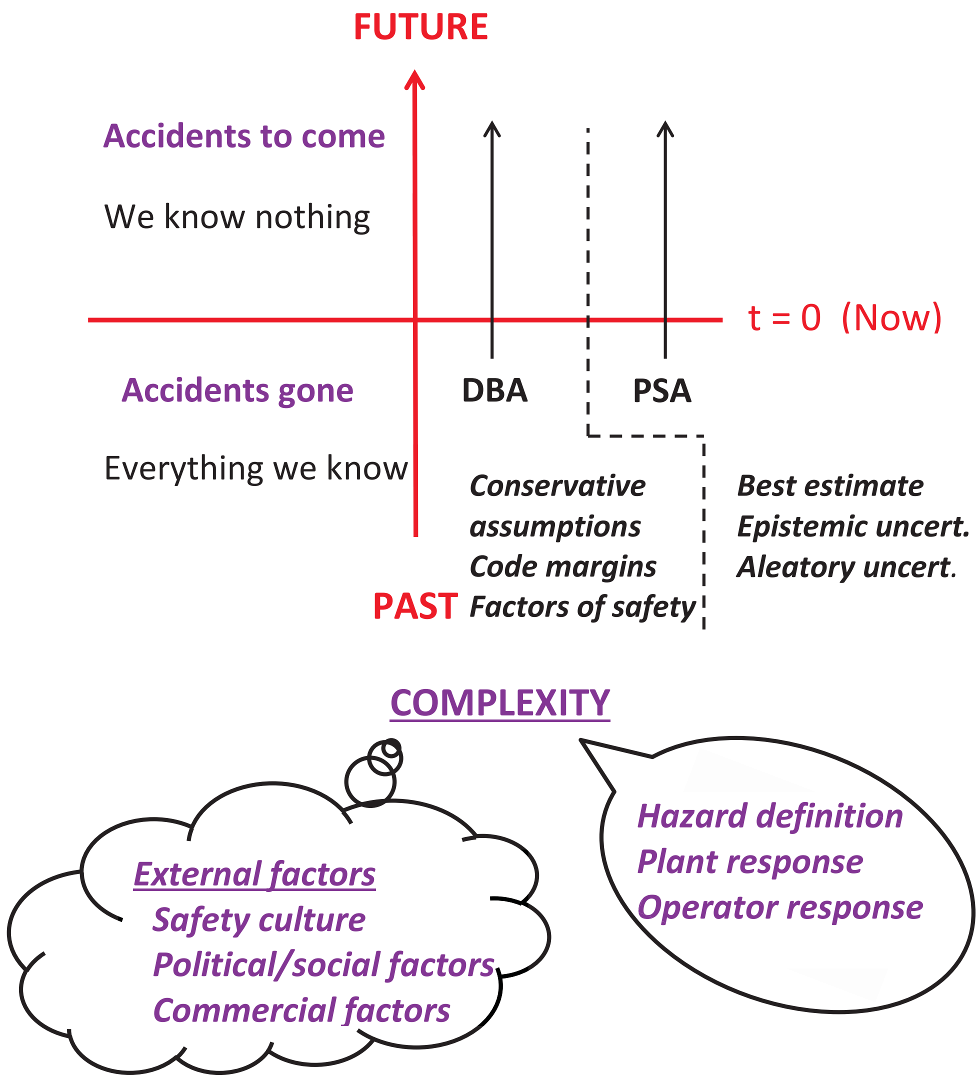
- Final thought!

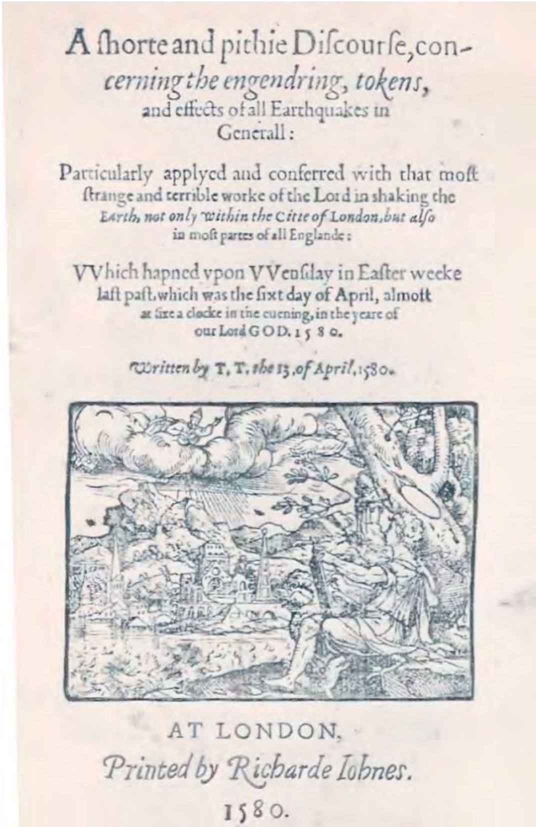
Origin of uncertainty



Characteristics of natural external hazards

- Realised over a broad range of magnitudes/severities
- Complex physics
- Driven by conservation of energy on a planetary scale, modified by regional and very local effects
- Large uncertainties in ability to predict at site-specific scales and very low probabilities – 10^{-4}/yr and less
- Describing natural hazards
  - Hazard curve: Probability of exceedance v. hazard magnitude/severity
  - Plus more detailed descriptions for design purposes
- Quality of data
  - Instrumental (good / ~50yrs), Scientific, quantitative
  - historical (medium-poor / ~1000 yr, - drives seismic hazard at 10^{-4}/yr
    - Historical newspaper accounts, church records etc
    - Transcribed by interpretation into quantitative data
  - Geological (poor–very poor / ~ MA), Scientific, qualitative

Historical seismicity data - UK



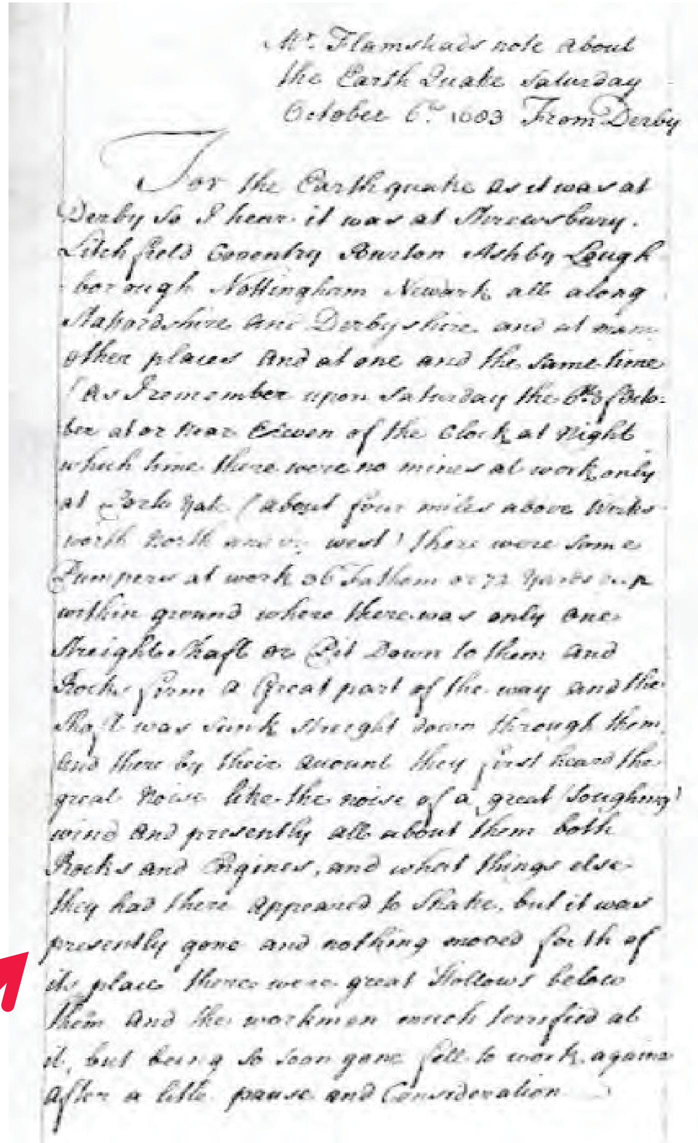
A ſhorte and pithie Diſcourſe, concerning the engendring, tokens, and effects of all Earthquakes in Generall:

Particularly applyed and conferred with that moſt ſtrange and terrible worke of the Lord in ſhaking the Earth, not only within the Citie of London, but alſo in moſt partes of all Englande:

VVhich hapned vpon VVenſday in Eaſter weeke laſt paſt, which was the ſixt day of April, almoſt at ſixe a clocke in the euening, in the yeare of our Lord GOD. 1580.

Written by T. T. the 13. of April. 1580.

AT LONDON,
Printed by Richarde Iohnes.
1580.



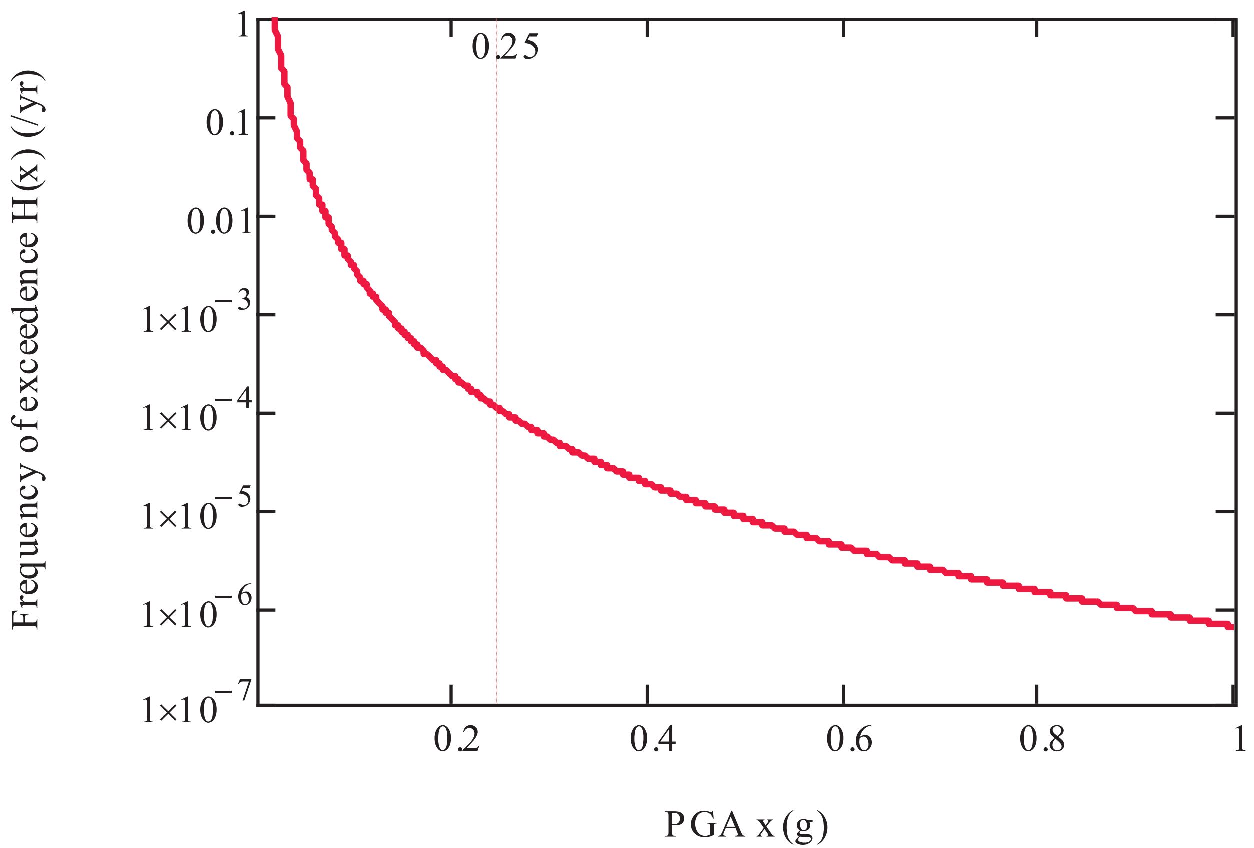
Mr. Flamsteads note about
the Earth Quake Saturday
October 6th 1683 From Derby

For the Earthquake as it was at
Derby so I hear it was at Shrewsbury.
Litchfield Coventry Burton Ashby Lough
borough Nottingham Newark all along
Staffordshire and Derbyshire and at many
other places and at one and the same time
(as I remember upon Saturday the 6th of Octo
ber at or near Eleven of the Clock at Night
which time there were no mines at work only
at Yorke gate (about four miles above Wirks
worth North and by west) there were some
Pumpers at work 36 fathom or 72 yards deep
within ground where there was only one
Straight shaft or Pit down to them and
Rocks from a great part of the way and the
shaft was sunk streight down through them
and there by their account they first heard the
great Noise like the noise of a great Soughing
wind and presently all about them both
Rocks and Engines, and what things else
they had there appeared to shake, but it was
presently gone and nothing moved forth of
the place there were great Hollows below
them and the workmen much terrified at
it, but being so soon gone fell to work again
after a little pause and consideration

This was one of the largest and most damaging British earthquakes 6 April 1580

Letter referring to earthquake in Derbyshire, 6 October 1603

Typical hazard curve - seismic



Prob. of exceedance – seismic hazard

- A point on the hazard curve: "Probability of exceedance" v. "X" means (using X = 0.25g as an example)
  - Prob ($x > 0.25g$) = 10^{-4}/yr, or Prob ($0.25g < x < \infty$) = 10^{-4}/yr
  - Where ∞ is a hazard magnitude for which plant has effectively no withstand capability and/or max. earthquake the geology can support
- If Design Basis is x_{DB} defined at 10^{-4}/yr hazard level
  - Why is x_{DB} normally defined as:= 0.25g = x_{min} ?
  - Why not x_{DB} defined as:= mean (x) ?
- Exceedance probability hazard curves have implications for:
  - Importance of having a conservative plant design at Design Basis
  - Importance of Beyond Design Basis analysis
  - Ability of designers to control hazard induced plant risk

Plant risk from natural hazards

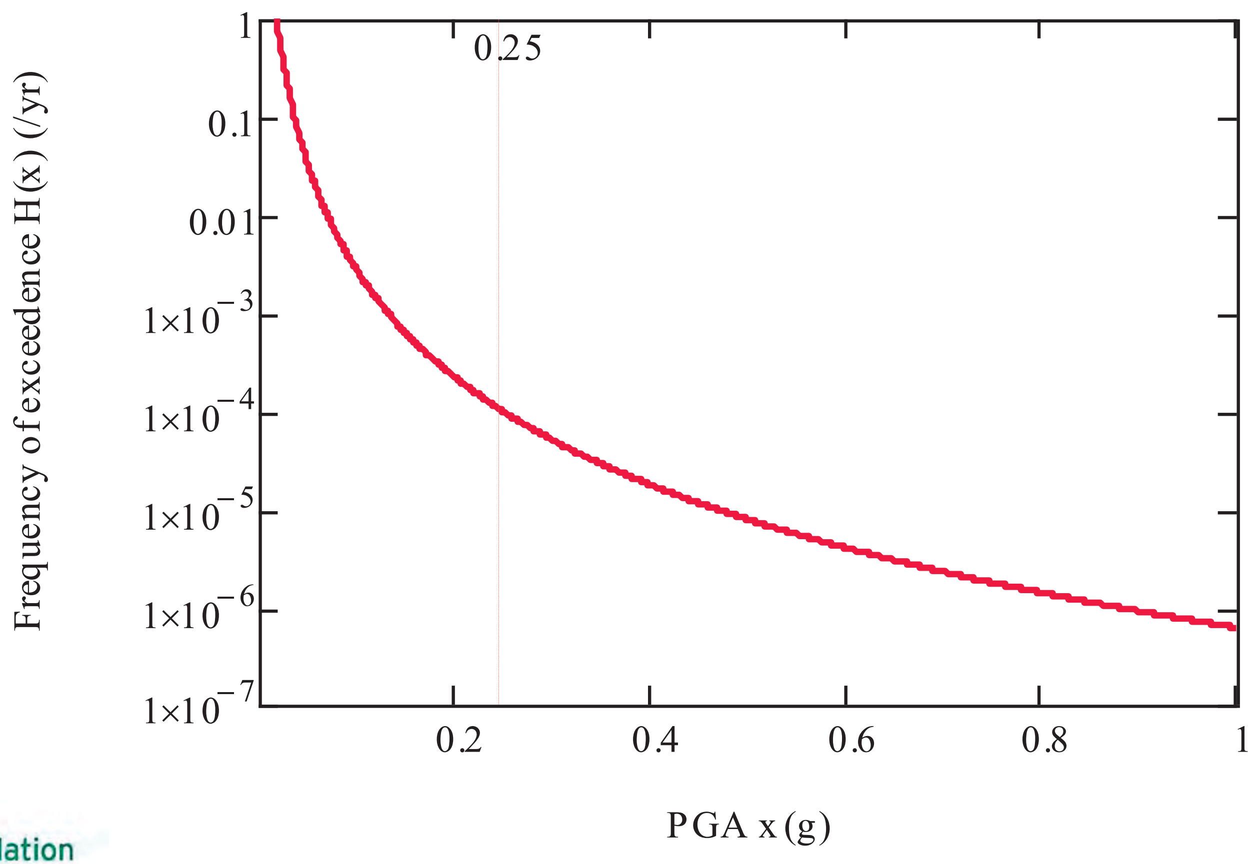
- Need to define hazard initiated faults and their sequences of plant failures
  - Normal to neglect explicit representation of dose consequences
- Assume fault is protected by one or more Lines of Protection (LoP)
- Need probabilistic (or frequency) hazard and fragility functions
- Hazard functions are simple inverse decreasing curves
  - But defining equations are complex
- Nuclear plant fragilities have only been developed in detail for seismic hazard
  - Fukushima event has prompted research into fragilities for other natural hazards

Simple seismic risk example – seismic hazard

- Hazard model: Kennedy Power Law model: H(0.25g) = 10^{-4}/yr

$$H(x) = 6.113.10^{-7} \, . \, x^{-3.677}$$

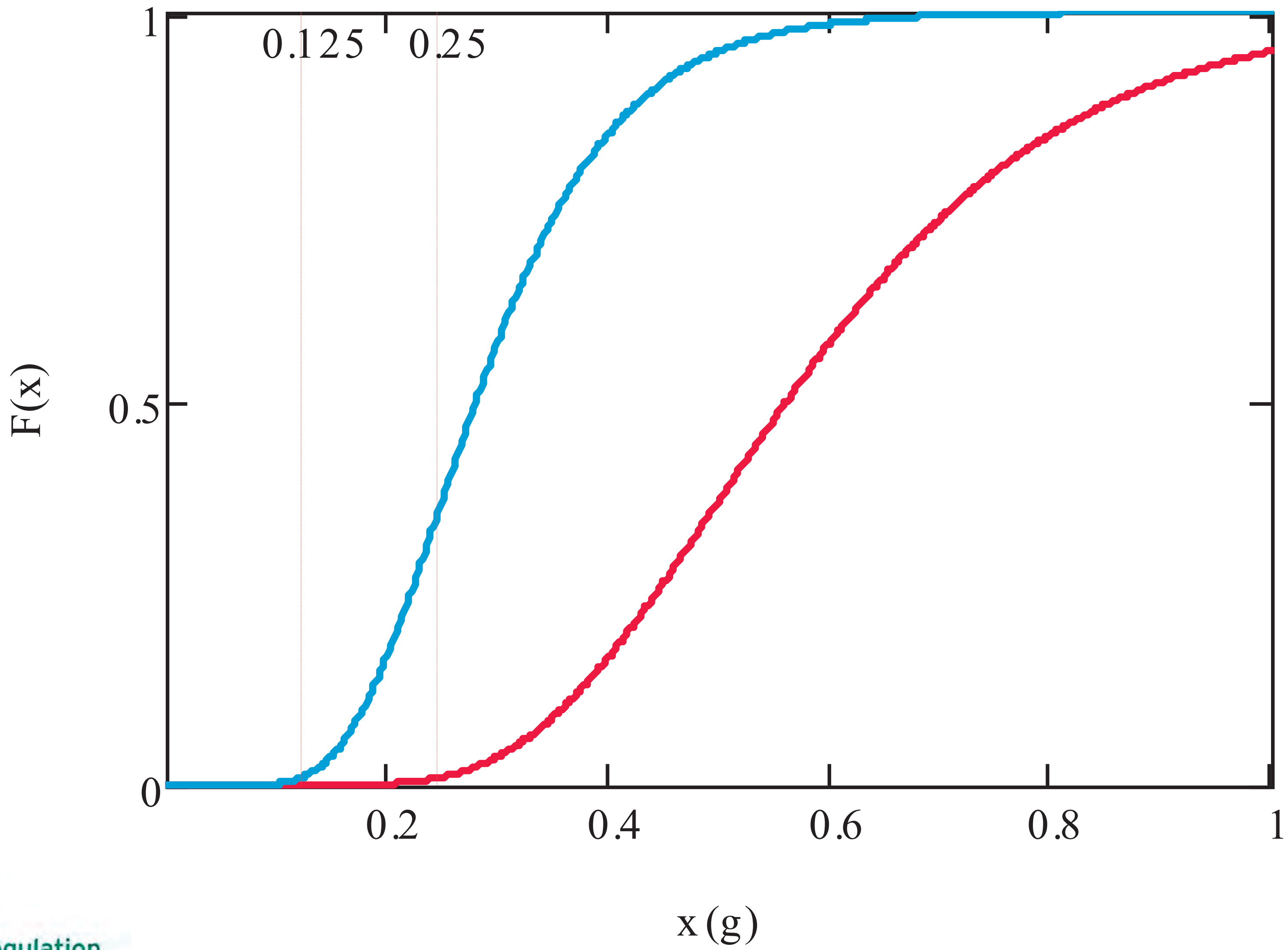
  - Note: this is a frequency of exceedance model



Seismic fragility model

- Fragility model: Lognormal single uncertainty parameter model
  - Note: This is a probability model
  - Applies to a given fault, mitigated by a LoP with known mode of failure
  - Needs only 2 parameters to define for each LoP
    - Median ***x*** & log. standard deviation ***β***
- ***This is a simplified model compared to those normally used in seismic PSA***

Seismic fragility curves



Seismic design basis and High Confidence of Low Probability of Failure (HCLPF)

- For single param. uncertainty fragility model: HCLPF ≈ $x_{1\%}$
- Set Design Basis (DB) to this value: $x_{DB} = x_{1\%}$
- Representative plant data assumed as below

Line of protection	$x_{1\%} = x_{DB}$	β	Median x	$H(x_{DB})$
A	**0.25g**	**0.35**	**0.565**	10^{-4}/yr
B	**0.125g**	**0.35**	**0.283**	1.3×10^{-3}/yr

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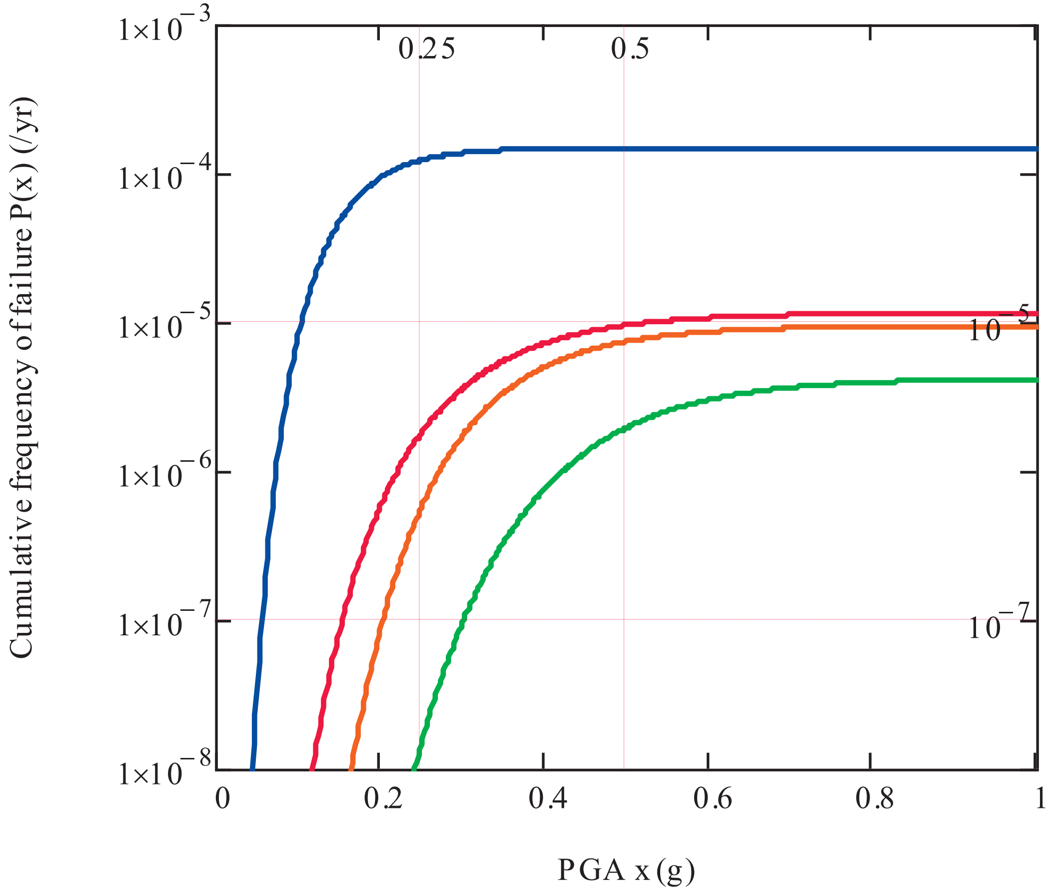
Seismic risk model

- Risk Model: Standard model derived from reliability theory
  - Calculates $P(\infty)$: Frequency of plant failure for given fault

$$P(\infty) = \int_0^\infty H(x) \cdot f(x) \cdot dx = \int_0^\infty h(x) \cdot F(x) \cdot dx$$

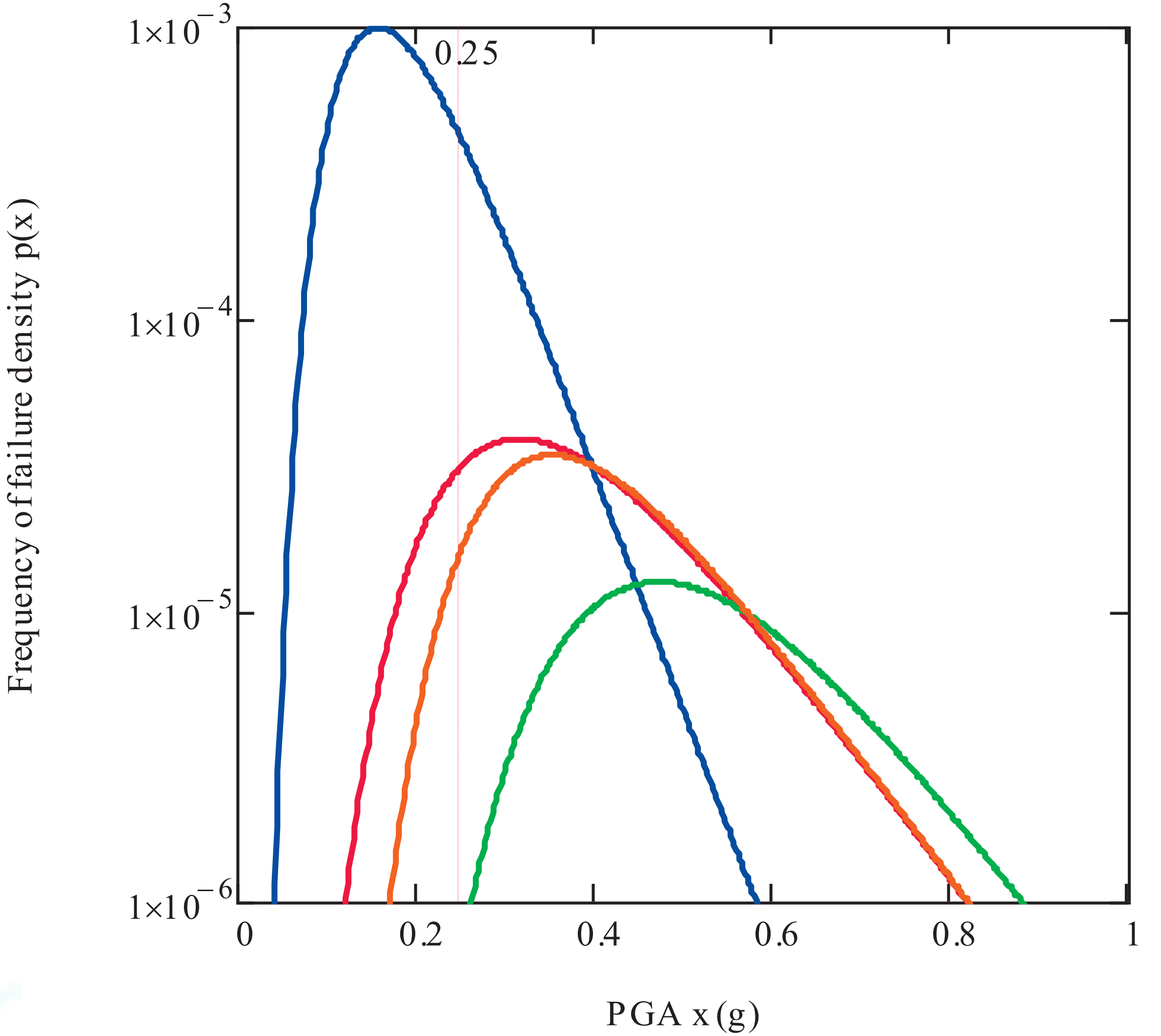
Risk results #1

$P_A(\infty)$	$P_B(\infty)$	$P_{A \cap A}(\infty)$	$P_{A \cap B}(\infty)$
1.1 x 10^{-5}/yr	1.5 x 10^{-4}/yr	4.1 x 10^{-6}/yr	9.4 x 10^{-6}/yr



Risk results #2

- Most of the risk arises at just beyond the Design Basis



Deductions – Single LoP & effect of hazard curve

- Line A alone:
  - Gives about an order of magnitude of protection over the DB exceedance frequency.
    - Note: for exceedance frequency (and prob.) hazard curves
    - (10^{-4}/yr design basis) x (10^{-2} failure per demand) ≠ (10^{-6}/yr plant failure frequency)
    - Most of the failure frequency occurs just beyond the design basis
    - Saturates at about twice x_{DB} ~ 0.5g, or 2 x DB or ~ 10^{-5}/yr
    - Therefore: BDB value should be ~ 10^{-5}/yr
- Line B alone:
  - Same applies but significantly worse – as expected

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Deductions – Two LoP & common-cause effect

- Lines A ∩ A:
  - Adding a second independent LoP of equal reliability reduces *P*(∞) by factor of ~ 2.7 to 4.10^{-6}/yr
    - **NOT*****:*** ***P_A*** x ***P_A*** $\sim 10^{-5} \times 10^{-5} \sim 10^{-10}$/yr
  - This is due to ***common-cause*** nature of hazard
- Lines A ∩ B:
  - Adding a second independent LoP of significantly lower reliability provides very little improvement to overall plant failure frequency
  - This is because the ***common-cause*** nature of the hazard affects both LoPs and advantage from Line *B* fades to ~ 0 by 0.25g

Saturation risk and overall plant risk

- **At 10^{-5}/y:** hazard subject to increasingly large uncertainties
  - Majority of failure frequency accrued by 10^{-5}/yr hazard level
  - Useful BDB region for natural hazards is 10^{-4}/yr → 10^{-5}/yr
- **Beyond 10^{-5}/yr**: increasingly approaching *Severe Accident* territory
- Target 8, large release for single class of hazard BSO is 10^{-7}/yr
  - Overall station risk ~ 10^{-6}/yr for new builds
- Very large uncertainties in hazard analyses at these very low exceedance probabilities
  - **Precautionary Approach** - Can major release occur at these very low probability hazard levels?
    - Seismic hazard in UK → max. up to ~**1g**!
  - If so, hazard could dominate overall station risk

Final thought!

- An enigmatic quote from two anthropologists on society's approach to risk:

  "Can we know the risks we face, now or in the future? No, we cannot; but yes we must act as if we do."

  From: Douglas & Wildavsky, Risk and Culture (1982)

- Thank you