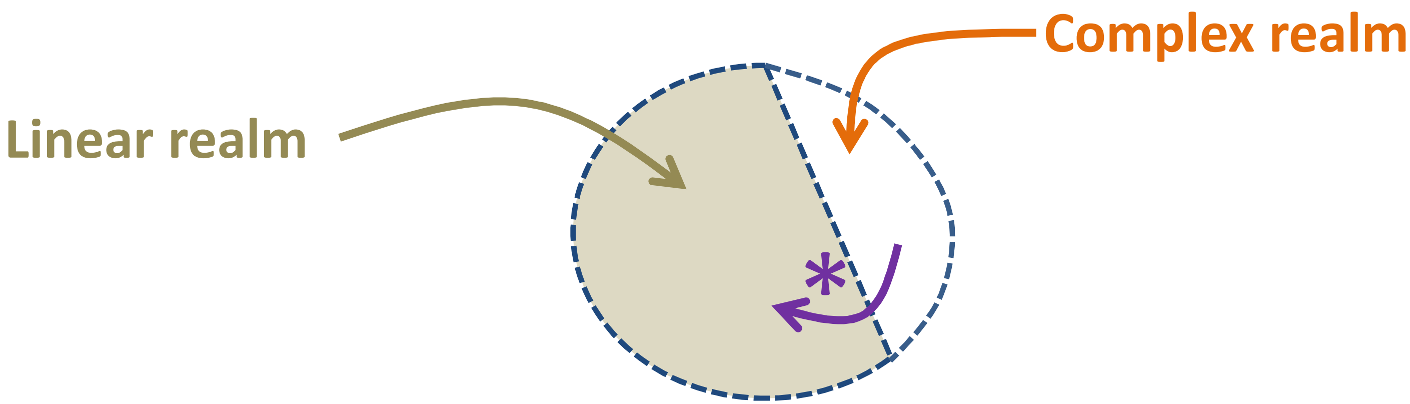
Complexity implies unknowable risk



***Cartesian tendency to ignore complexity and characterise systems as linear** ..then **make decisions/plans** as if model outputs were 'facts'.

e.g. 'Economic growth will be X% in 2014'

'X ppm atm C will lead to avg. 2^{o}C (+/- Y^{o}C) temp rise (Z% certainty)'

..instead of treating such 'predictions' with appropriate caution, **acknowledge system complexity**, that **possible outcomes** are **unknowable** & plan for imaginable worst case scenarios & **resilience**

Linear uncoupled systems ..and **risk**

Flip a fair coin 6 times; 6 independent (i.e. uncoupled) events

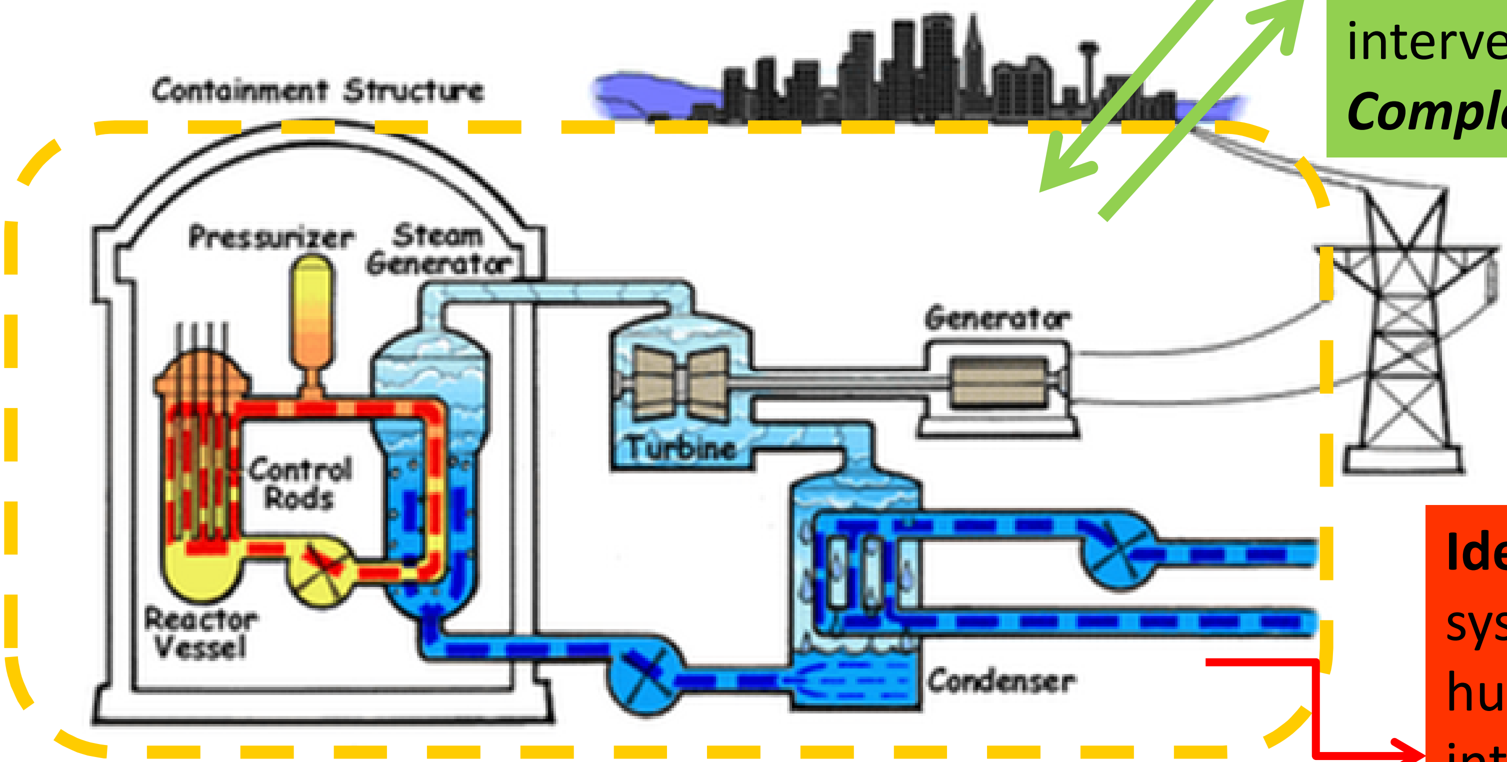
½ X ½ X ½ X ½ X ½ X ½

= 1/64 or a 1.56% chance for any combination

You keep my €2 after 6 flips ..but pay me €100 if I flip 6/6 harps?

<u>Complex tightly coupled</u> systems and <u>risk</u>

Nuclear power plants

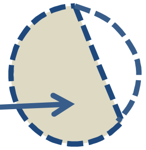


Real: An open system with human/natural intervention: ***Complex System***

Ideal: A closed system with no human/natural intervention: ***Linear System***

Complex tightly coupled systems and risk

Nuclear power plants

Linear probabilistic closed system approach:  Probable frequency of degraded core/ core melt accidents:

"The US Nuclear Regulatory Commission (NRC) specifies that reactor designs must meet a **1 in 10,000 year** core damage frequency, but modern designs exceed this. US utility requirements are **1 in 100,000 years**, the best currently operating plants are about **1 in 1 million** and those likely to be built in the next decade are almost **1 in 10 million**"

World Nuclear Association

Currently there are 433 Nuclear power plants globally with 65 in construction (Sept. '11). (European Nuclear Society)

1 in 10,000 years x 500 plants = 1 in 20 year core damage event globally (5%)
1 in 100,000 years = 1 in 200 years (0.5%), etc...

Complex tightly coupled systems and risk

Nuclear power plants; The Historic Reality

Five serious nuclear accidents (level 5 or greater) in 60 years production (ex 1951)

1. Mayak at Ozersk, Russia 1957 (level 6)
2. Windscale (now Sellafield), England 1957 (level 5)
3. Three Mile Island, USA, 1979 (level 5)
4. Chernobyl, Ukraine, 1986 (level 7)
5. Fukushima Daiichi, Japan, 2011 (level 7)

..5 serious accidents in 60 years represents an actual historic global annual risk of 1/12 or 8.3% per annum

A complex tightly coupled system: Fukushima

Fukushima I nuclear power plant, Japan
11 March 2011

World Nuclear Association:*

*"The **site licence** [for a nuclear power plant] **takes account of worst case flooding scenarios** as well as other possible natural disasters and, more recently, the possible effects of climate change.*

*...as an example, French Safety Rules criteria for river sites define the safe level as above a flood level likely to be reached with **one chance in one thousand years, plus 15%,** and similar regarding tides for coastal sites."*

*http://www.world-nuclear.org/info/inf06.html

A complex tightly coupled system: Fukushima

Fukushima I nuclear power plant, Japan
11 March 2011

Japanese Nuclear Safety Commission Guidelines (Jan 2011):

*"Even for a nuclear plant situated very close to **sea level**, the robust sealed containment structure around the reactor itself would **prevent** any **damage** to the nuclear part from a **tsunami**, though other parts of the plant might be damaged. **No radiological hazard would be likely**"*

A complex tightly coupled system: Fukushima

Fukushima I nuclear power plant, Japan
11 March 2011

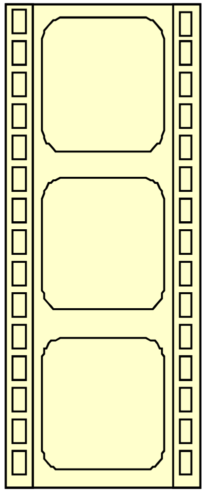
The reality:

Fukushima I was designed to withstand a **5.7m** high tsunami.

The March 2011 tsunami came ashore at a height of **14 metres**.

A complex tightly coupled system: Fukushima

See:



- **Fukushima Nuclear Reactor Problem Explained** (3:07)
http://www.youtube.com/watch?v=BdbitRlbLDc&feature=related

- **Fukushima Nuclear Accident - Part 1 of 3.mp4** (14:18) *(ex. 7.34)*
http://www.youtube.com/watch?v=dc-NMVq1W4s

A complex tightly coupled system: Fukushima

Nuclear power plant

multiple reactors (6)

beside the sea

large earthquake (9.0)

gravity fed isolation condenser (IC) switched off due to fast cooling by backup system

offsite power failure

high tsunami (14m)

diesel backup generators in basement

backup generators fail (flooding)

Backup battery power lasts 8 hrs

Emergency generator trucks (250km away) stuck in traffic/damaged roads

Reactor 1: IC valve closed: water boiling off core

Water level gauges reading incorrectly

exposed hot zirconium rods (1300°C) react with water to form H_2

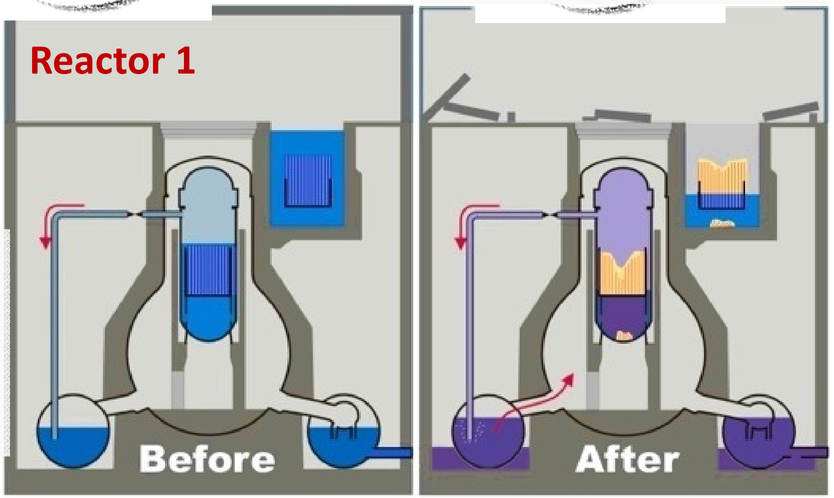
uranium core meltdown

Pressure rises above max op.

Vent: No power to open valves; radiation too high for manual

H_2 ignites, explosion

Radioactive hot zone; reactors 2,3,4 exposed; explode



A complex tightly coupled system: Fukushima

1950's & 1960's studies by US Atomic Energy Commission: Consequences of plant meltdown: 3,400-45,000 deaths - focus on **possible** outcomes of **worst case** failure. **But studies from 1970's** concentrated on **probability** of failure

Bulletin of the Atomic Scientists

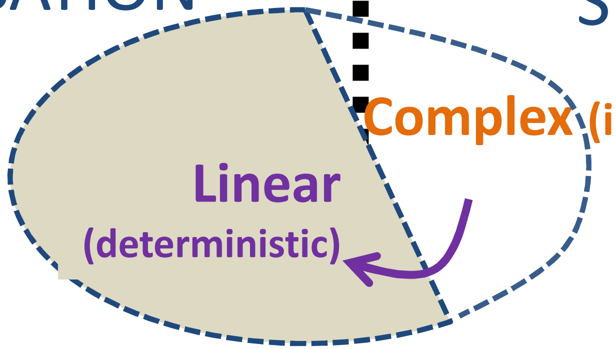
Fukushima, risk, and probability: Expect the unexpected

By Charles Perrow | 1 April 2011

"Currently our approach to risk is **'probabilistic,'** and the probability of a tsunami seriously damaging the Fukushima Daiichi plant was **extremely small**. But we should also consider a **worst-case approach** to risk: the **'possibilistic'** approach …things that never happened before are possible. Indeed, **they happen all the time**.
..consider this statement by Tsuneo Futami, a nuclear engineer who was the director of Fukushima Daiichi in the late 1990s: *'**We can only work on precedent**, and there was **no precedent**. When I headed the plant, the thought of a tsunami never crossed my mind.'"*

LINEAR SYSTEM CHARACTERISATION

RECOGNITION OF SYSTEM COMPLEXITY



"Overall, the likelihood of an accident and radiological release at a new nuclear plant is ***1600 times lower*** *than it was when the first reactors were built."*

World Nuclear News
'Risk statistics on energy'
3 September 2010

*"There will always be '****unknown unknowns'*** *whose discovery is painful. This is now recognised as 'the law of unintended consequences' or 'Murphy's Law'.* ***Systems that are designed in ignorance of this 'flipside' are fantasy, doomed to failure."***

Jerome Ravetz, 2006

Complex tightly coupled systems and risk

Charles Perrow: Normal Accidents

Accidents are inevitable (i.e. normal) in **complex and tightly coupled systems**.

Moreover, *"most normal accidents have a significant degree of* ***incomprehensibility****."*

Complex tightly coupled systems and risk

Charles Perrow: Normal Accidents

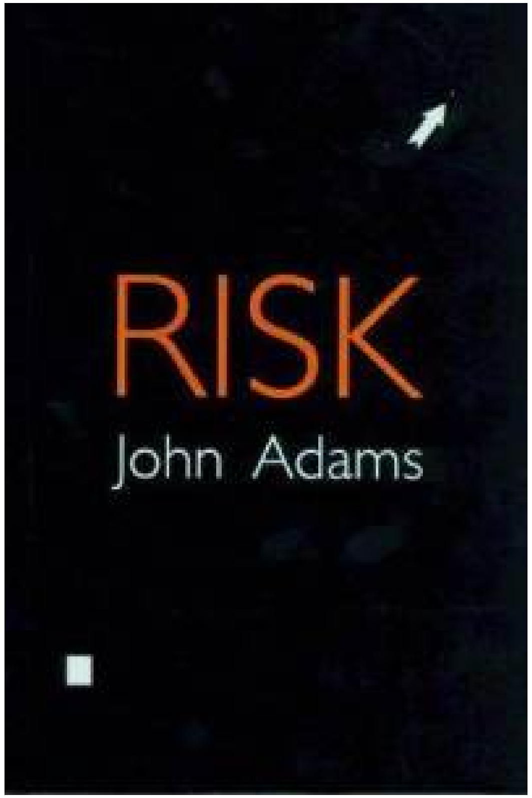
Accidents are inevitable (i.e. normal) in **complex and tightly coupled systems**.

Moreover, *"most normal accidents have a significant degree of **incomprehensibility**."*

Perrow proposes that some high risk systems are **'hopeless'** since (potentially catastrophic) risks outweigh benefits –these should be **abandoned**.

Others could be made **less risky** by **reducing tight coupling** and **interactive complexity** to improve benefit/risk ratio (e.g. chemical plants, aviation).

What is risk?



Traditionally, **risk** was defined in **'objective scientific'** terms (i.e. probabilistically, in the linear domain), including for complex systems.

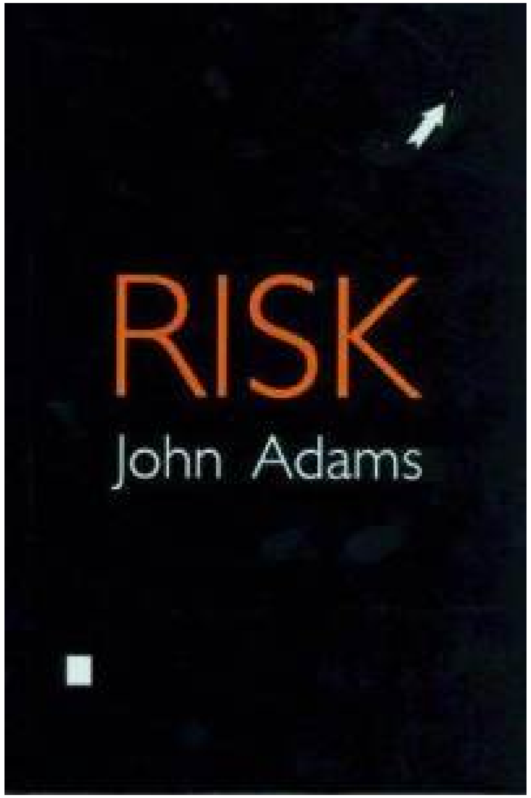
Once complexity is recognised however, one can see:

'Risk is culturally constructed.' (Adams, 1995)

e.g. **slipping and falling on ice** – risk is a function of **perceived danger** – it is based on (cultural) differences between e.g. children and elderly in how they perceive the world and respective levels of **vigilance** (i.e. subjective **perceptions of risk**).

Similarly, **risk perception** on a 'dangerous' bend will **vary** between young and experienced drivers, local and non-local drivers and 'expert' road engineers.
*who may base risk & inherent safety on 'objective' accident rates

What is risk?



Theory of Risk Compensation (Adams)

1. Everyone has **propensity** to take risks
2. This propensity **varies** between individuals
3. Propensity is influenced by **potential rewards**
4. **Perception of risk** is influenced by experiences of **accident losses** – of self and others
5. Individual risk taking represents outcome of balance between **perception** and **propensity** of/for risk
6. **Accident losses** are a function of **risks** taken

What is risk?

Risk is both inescapable and desirable.

A world **without risk** would be a world **without uncertainty** …and hence would be without **complexity, creativity, redundancy, emergence, evolution, agency, values, responsibility, conscience, ethics** and **entropy** (as per the 2nd law of thermodynamics).

'Without it we are mere predetermined automata' (Adams,1995)

What is risk?

<u>Risk is both inescapable - and desirable.</u>

A world **without risk** would be a world **without uncertainty** …and hence would be without **complexity, creativity, redundancy, emergence, evolution, agency, values, responsibility, conscience, ethics** and dynamic **open dissipative far from thermodynamic equilibrium systems**.

'Without it we are mere predetermined automata' (Adams,1995)