Responding after a big nuclear accident

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J-value website:
http://www.jvalue.co.uk/

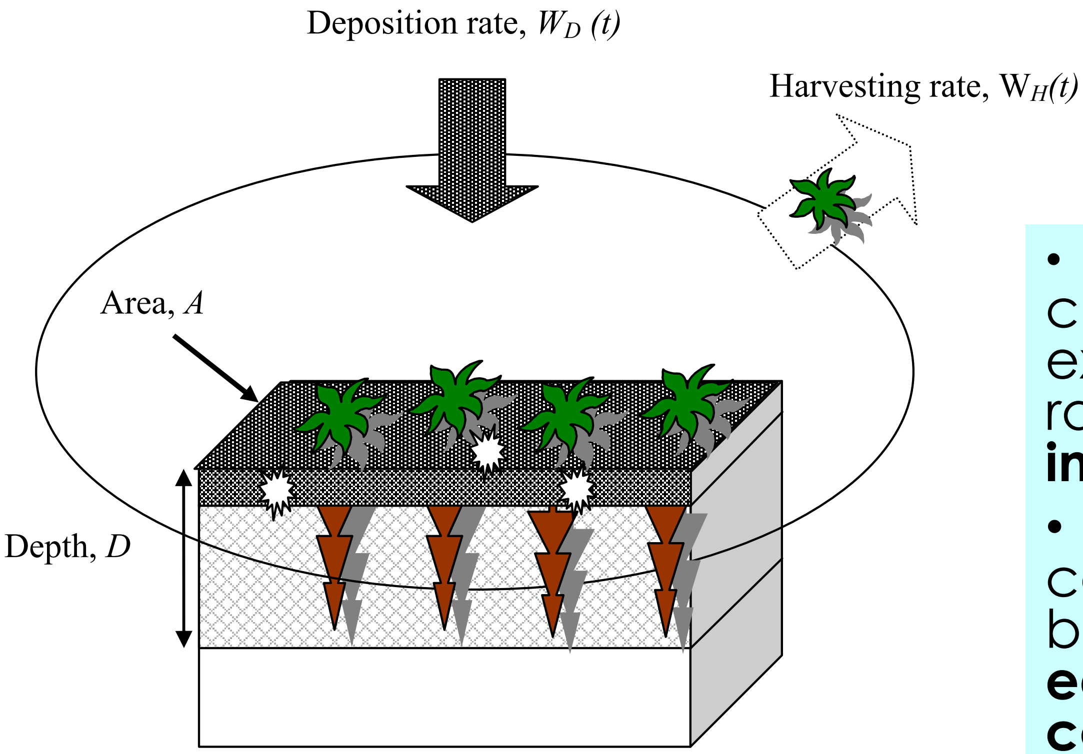
NREFS Special Issue on Coping wth a Big Nuclear Accident:
https://www.sciencedirect.com/journal/process-safety-and-environmental-protection/vol/112/part/PA

- Like all big, real-world problems, **managing the aftermath of a big nuclear accident** is multi-faceted, involving in this case
  - **science**: nuclear physics
  - **technology**: instrumentation and engineering
  - **medicine**: radiation and psychology
  - **logistics**
  - **economics**: a big nuclear accident currently costs $100+bn
  - the **general public**
  - the **media**
  - **politics**
- A **systems problem** par excellence.

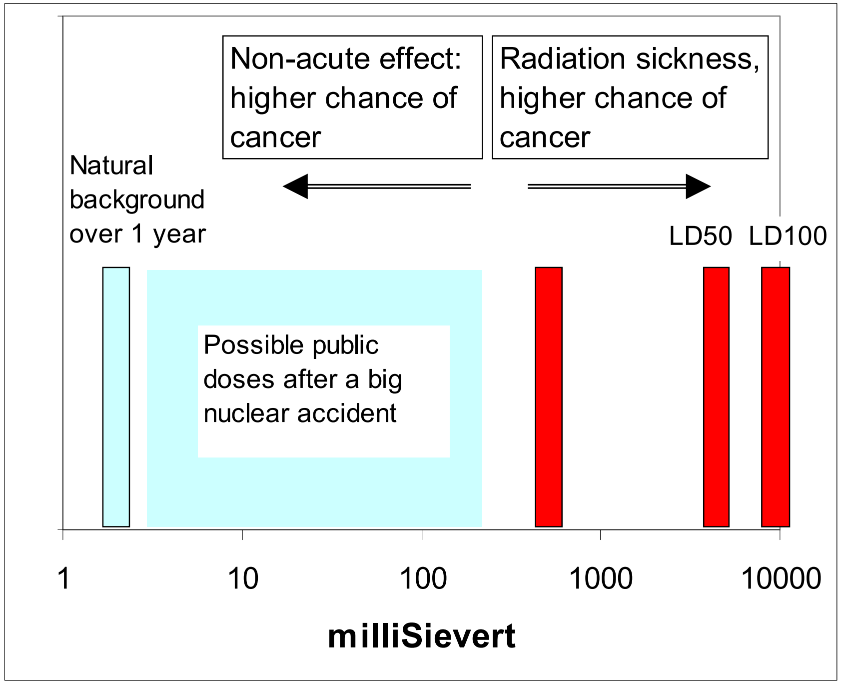
Basics: what is the **danger** from a **big nuclear reactor accident**?

1. A commercial nuclear reactor **cannot explode** like an atom bomb.
2. But heat production does **not** stop immediately after shutdown – it takes 24 hours to fall from 7% to 1% of full power, **210 MW → 30 MW** (thermal).
3. Big nuclear accidents happen when the cooling needed to take away the **nuclear decay heat** fails and the **core melts**.
4. The melting core will **penetrate its containing vessel** and **open up a path** between the **highly radioactive core** and the **outside world**.
5. Radioactive gases, vapours and gas-borne particulate matter will escape and **nuclear fallout** will be deposited around the plant.

Nuclear fallout: internal and external dose



- People living relatively close to the plant will be exposed to an **external** radiation dose and an **internal dose**,
- The internal dose will come initially from breathing and later from **eating radioactively contaminated produce,** either vegetables or meat, milk, cheese.



Danger to the public:
increased risk of cancer
after a big nuclear accident

But note that the dose is **falling away** rapidly over time

Falling dose rates over 70 y

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What are the policy options?

1. **Sheltering indoors** in the early stages of the accident: protects against breathing radioactive gases; protects against cloud shine and ground shine.
2. Distribution of **iodine tablets** – protects against thyroid cancer that might be induced by iodine-131 vapour (half-life 8 days).
3. **Temporary evacuation** – people will return to their homes within days. (This could be a precautionary measure possible while the extent of the problem is determined.)
4. **Relocation** - people are asked to abandon their homes for a long time or **for ever**.
5. Temporary **food bans** (which may last a very long time)
6. **Remediation**: urban decontamination, agricultural decontamination.

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The **NREFS Project**: Management of **N**uclear **R**isk Issues: **E**nvironmental, **F**inancial and **S**afety

- Sponsored by the Engineering and Physical Science Research Council as a contribution to the UK-India Civil Nuclear Power Collaboration.
- 4 UK universities, led by Philip Thomas as Principal Investigator. The work was completed during his time at the University of Bristol (2015 onwards):

CITY UNIVERSITY LONDON

MANCHESTER 1824 The University of Manchester

The Open University

THE UNIVERSITY OF WARWICK

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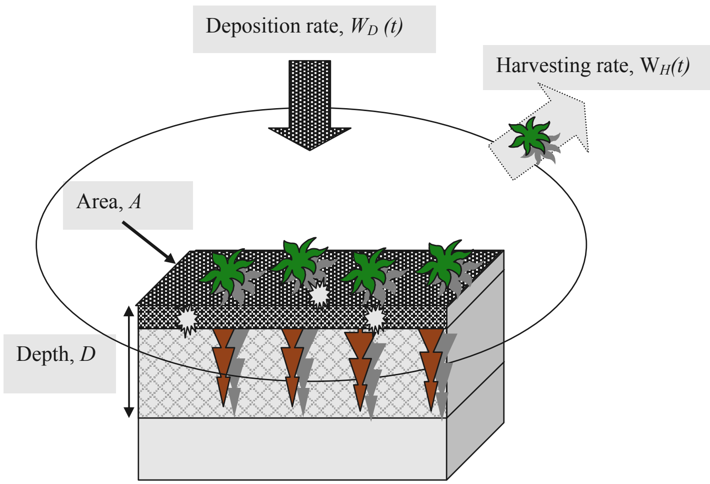
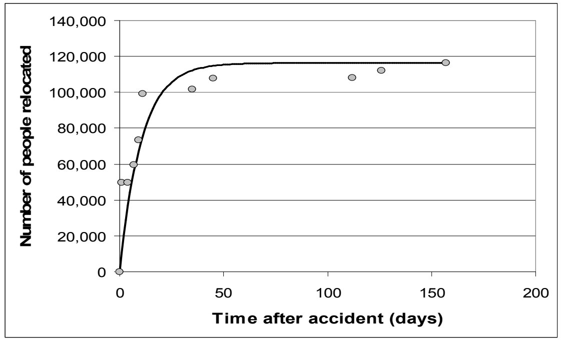
Method 1: **Optimal economic control** (including health effects) applied to **hundreds** of conceivable big nuclear accidents worldwide (*led by Manchester University*)

1st order Modelling



Modelling the deposition of fallout, its decay, and its contact with man.



Modelling the evacuation process (Chernobyl 1st evacuation shown).

£££

Modelling the economics

Finding the optimal strategies

Richard E. Bellman, 1920 - 1984

- Bellman's principle of optimality – the mathematics of "you cannot do better than the best".

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Optimal strategies found for a severe accident as bad as Fukushima Daiichi 2011

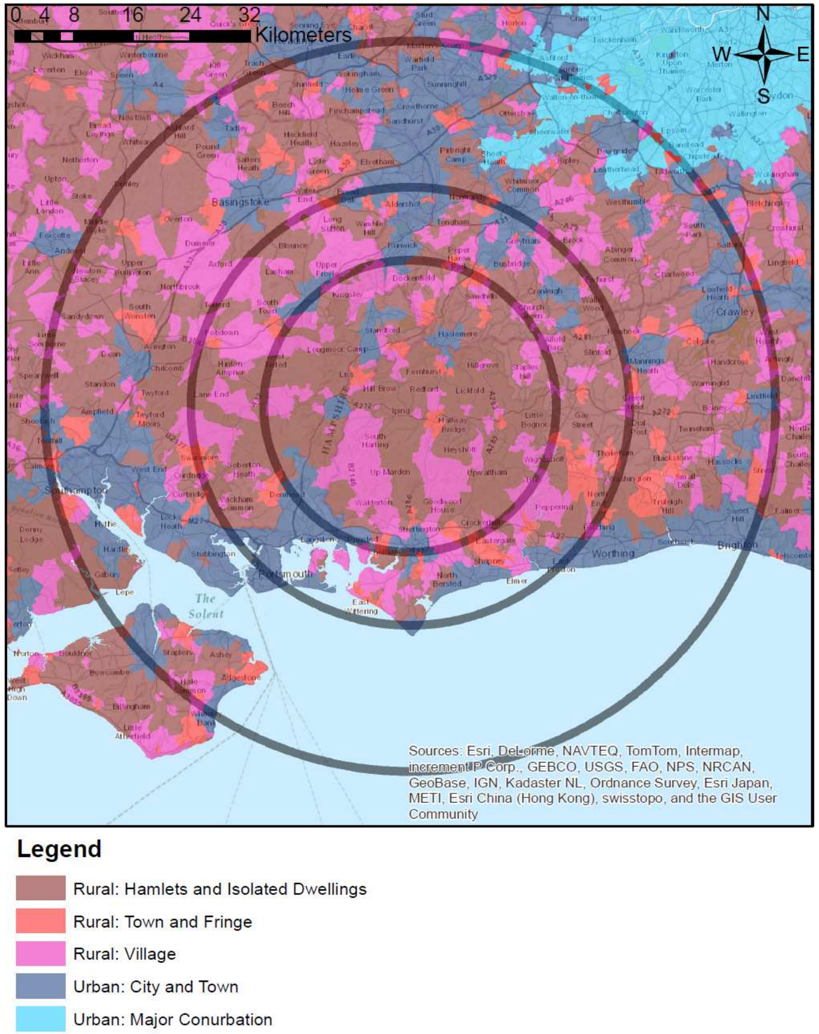
- Allowing for the different economic conditions around nuclear reactors worldwide, the **optimal strategy** for **84%** of the cases comprises:
  - early remediation
  - no food ban
  - partial relocation followed by **full repopulation**.
- For the remaining **16%** of the time **no relocation** at all is advised.
- Permanent relocation is advised in **less than 2%** of the cases in the sensitivity studies (which were **deliberately skewed** to **reduce** or **remove** the costs of moving).

Method 2. **Public Health England's nuclear accident consequence codes, PACE-COCO2**, applied to a big accident at a **fictional nuclear reactor** (*led by the Open University*).

- PACE: probabilistic accident consequence evaluation, which calculates **the spread of fallout** from a specified accident and radioactive release.
- COCO-2: cost of consequences, version 2, which calculates the **economic cost of the spread of fallout (including health costs)**.

Core melt accident at a fictional pressurised water reactor on the South Downs of England

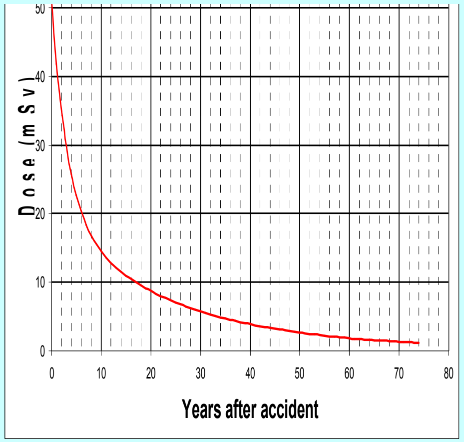
- **45 miles** from **Central London**
- **30 miles** from **Southampton**
- Release of fallout of the same order as **a single reactor** at **Fukushima** Daiichi.



Relocation

- The safe-return dose was set at **10 mSv** over the following year and applied after **3 months**.
- This is **half** the safe-return dose set by the Japanese authorities after Fukushima Daiichi.
- A dose of **10 mSv per year** for **50 years** continuously would reduce the life expectancy of people in the UK by **4 ½ months**.
- But the dose rate from an accident would fall to a very small fraction after 50 years. (See graph).
- The expected number of people needing relocation using this criterion is **620**.

Actual dose rates would fall with time



Method 3 **J-value** (J for Judgement) assessment applied to the **Chernobyl and Fukushima Daiichi** accidents (*led first from City, University of London then from the University of Bristol*)

- Chernobyl, 26th April 1986
- 28 near-immediate deaths amongst plant operators and firefighters, mostly from **acute radiation exposure**.
- 116,000 people relocated in 1986
- 220,000 relocated post 1990
- ~335,000 in total.
- cf. Bristol pop. 450,000

Principal policy response after Chernobyl: **mass relocation**

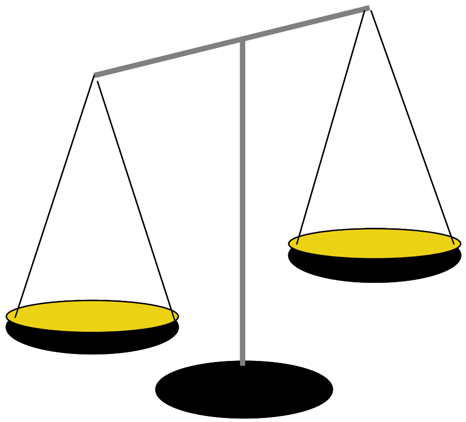
Principal policy response after Fukushima: **mass relocation**

- Fukushima Daiichi, 11 March, 2011
- **18,500** deaths caused by the **tsunami**
- No immediate radiation deaths
- **111,000** people told to leave their homes, **49,000** people self-evacuated.
- **85,000** people had not returned home 5 years later.
- 1,121 excess deaths in the evacuees in 2 years, attributed to "physical and mental exhaustion".

The Judgement- or J-value

- The J-value balances the **gain in life expectancy** that a safety measure brings against the **cost** of providing it.

You are spending too much if J is bigger than 1.0



Unique features:

(i) the balance is **objective**

(ii) the J-value has been **validated** against empirical data covering 90% of the world's nations.

Results: the J-value balance point for Chernobyl 1986

Results

- **116,000** people were moved away by the authorities in 1986, never to return.
- It was **sensible** to move out **only** those calculated to lose **8.7 months** of life expectancy or more because **J <= 1**.
- There were **31,000** such people.
- The remaining **85,000** would lose, on average, **3 months'** life expectancy by staying in their homes for ever, which is too small to warrant moving away.
- As a "sense check", the inhabitants of **London** are expected to lose **4 ½ months'** life expectancy **today** as a result of air pollution levels.

J-value analysis of Chernobyl 1990

Results

- A further **220,000** people were relocated by the Soviet authorities after 1990.
- The J-value was **2.9** for the **900 people** living on the **most contaminated** land.
- These worst-affected 900, who would have lost **3 months'** life expectancy, **should not** have been moved.
- **None** of the 220,000 should have been moved out.
- (The Soviet government was advised **not to move anyone** in 1990 by a **contemporaneous French study** it commissioned from the IAEA, but unfortunately it chose not to follow this advice.)

J-value analysis of Fukushima 2011

Results

- **111,000** people were moved out by the authorities.
- A further **49,000** self-evacuated making a total of **160,000**.
- **85,000** people had **not returned** to their homes after 5 years.
- The J-value was greater than 1.0 for even the **worst-affected** settlements, Tomioka Town and Okuma Town.
- **No-one** should have moved out.
- The loss of life expectancy in the worst affected settlement would have been **3 months** if everyone had stayed in their homes.

What about the disruption and dislocation?

- The J-value analysis just presented assumes that relocation removes the radiation risk and that its **only downside** is the **monetary cost of relocating**.
- But in fact the relocation at Fukushima is known to have caused **non-monetary costs**. Premature deaths among old people moved out : **1121 early deaths** after a year, **1656** after 3 years, **2202** by March 2018 (**Financial Times**, Japan Reconstruction Agency).
- And we know that mass relocation has a **devasting effect** more generally on those moved away **permanently** from their homes.

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Many relocated people think that they are doomed. This has its own internal logic

- Suppose that the relocated people come to see the **tens of billions** of dollars being spent on them **not as a way of protecting them from harm** but as **compensation** for the **damage inflicted on them**.
- Will they not now **back-calculate** the **extent of their harm** from the **vast expenditure** that they observe?
- Will they not conclude, **quite rationally**, that the likely harm they are facing is enormous?
- Will they not see themselves as **victims**, **almost certain to die young**?

A self-fulfilling prophecy

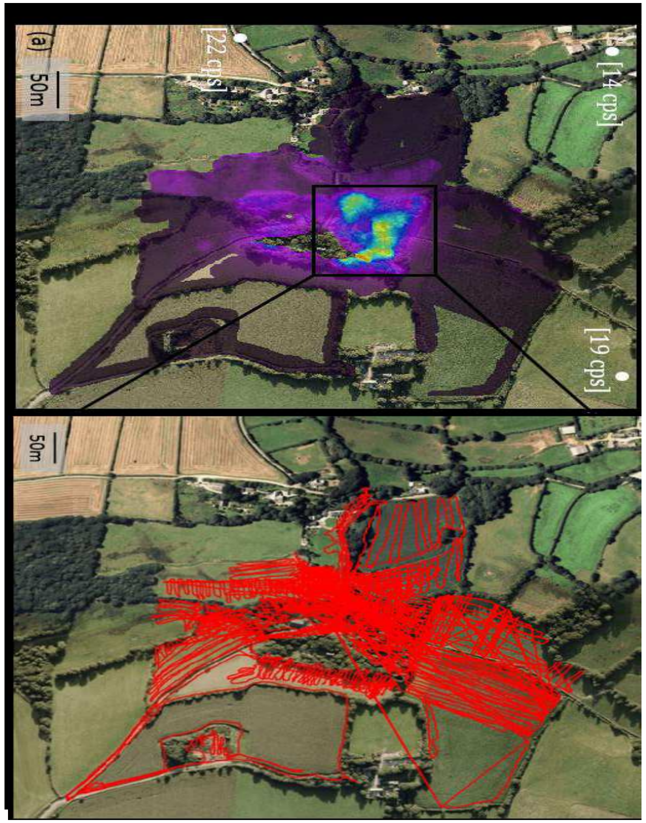
World Health Organisation (2005) on Chernobyl:

- “The designation of the affected population as 'victims' rather than 'survivors' has led them to perceive themselves as **helpless, weak** and **lacking control over their future**.
- “This, in turn, has led **either** to **over cautious behavior and exaggerated health concerns**, or **to reckless conduct**, such as consumption of mushrooms, berries and game from areas still designated as highly contaminated, overuse of alcohol and tobacco, and unprotected promiscuous sexual activity.”

The key instrumentation and software needed to support decision making

- The key measurements are the **initial radioactive contaminations (Bq/m^2)** across the area.
- These can be gathered **remotely** by **helicopter** or **drone**.
- Thereafter predictions of **dose profile**, l**oss of life expectancy** and **J-values** can be generated by software.

Radiation mapping using drones



Radiation map of contamination around the disused **South Terras uranium mine**, Cornwall, England

Flight path of the mapping drone

This technology could be made available at every nuclear power plant in the world.

The images are courtesy of Professor Tom Scott, of the South West Nuclear Hub, University of Bristol.

Conclusions

- The big lesson is **how small** the radiation damage has been to the members of the public from even the **biggest** nuclear reactor accidents.
- Most of the harm has come from what can now be seen to be **unjustified fear and worry** and from the **social disruption and dislocation** caused by relocation of hundreds of thousands of people.
- In the past, the **so-called solution** has become **the problem**.
- Remediation should be the watchword for any future big nuclear accidents **not** relocation.
- We should cope with any big nuclear accident in the future **more sensibly and effectively** than we have in the past.
- We will **protect the people better** and **save ourselves hundreds of billions of pounds** in the process.

See for further reference

- https://www.sciencedirect.com/journal/process-safety-and-environmental-protection/vol/112/part/PA
- https://southwestnuclearhub.ac.uk/research/case-studies/coping-with-a-big-nuclear-accident/
- https://theconversation.com/evacuating-a-nuclear-disaster-areas-is-usually-a-waste-of-time-and-money-says-study-87697
- https://www.thetimes.co.uk/article/nuclear-disaster-fallout-would-be-no-worse-than-living-in-london-706w9xc6h
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