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Socio-technical management of big nuclear accidents

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The NREFS Project: Management of Nuclear Risk Issues: Environmental, Financial and Safety (www.nrefs.org.uk)

- Sponsored by the Engineering and Physical Science Research Council as part of the UK-India Civil Nuclear Power Collaboration.
- 4 UK universities, led by Philip Thomas (formerly at City University) as principal investigator:

The stand-out message from NREFS is that nuclear power is a lot less harmful than many fear **even when it goes badly wrong**.

- Three diverse methods concurred on this conclusion:
  - The Judgement- or J-value
  - Optimal economic control
  - Public Health England's Level-3 Probabilistic Safety Assessment code “PACE®” coupled to an economic costing model “COCO-2”

To judge how much to spend on safety, we need to value **human life**. But how?

Q. What benefit is conferred when a safety measure **"saves"** a person's life?

A. The benefit is the **restoration of that person's life to come**.

- **Problem**: we cannot predict how long anyone is going to live.
- **BUT** actuarial tables give us the **expected life to come** for a person of a **given age** and a **given gender**.
- We can value **life expectancy** – the average life to come for someone of a given age and gender.

Historic Interim Life Tables, United Kingdom

Period expectation of life
Based on data for the years 2005-2007

Age	Males				
x	m_x	q_x	l_x	d_x	e_x
0	0.005504	0.005489	100000.0	548.9	77.16
1	0.000402	0.000402	99451.1	40.0	76.59
2	0.000259	0.000259	99411.1	25.7	75.62
3	0.000180	0.000180	99385.4	17.9	74.64
4	0.000131	0.000131	99367.5	13.0	73.65
5	0.000120	0.000120	99354.5	11.9	72.66
6	0.000121	0.000121	99342.6	12.1	71.67
7	0.000093	0.000093	99330.5	9.3	70.68
8	0.000115	0.000115	99321.2	11.4	69.69
9	0.000118	0.000118	99309.8	11.7	68.69
10	0.000104	0.000104	99298.1	10.3	67.70
11	0.000135	0.000135	99287.8	13.4	66.71
12	0.000143	0.000143	99274.4	14.2	65.72
13	0.000179	0.000179	99260.2	17.8	64.73
14	0.000196	0.000196	99242.4	19.5	63.74
15	0.000254	0.000254	99222.9	25.2	62.75

The Life Quality Index

- So we choose to value **life expectancy** – the average life to come for someone of a given age and gender.
- This figure is used in the **J-value**, which is based on the **Life Quality Index,** Q:

$$Q = G^{1-\varepsilon} X_d$$

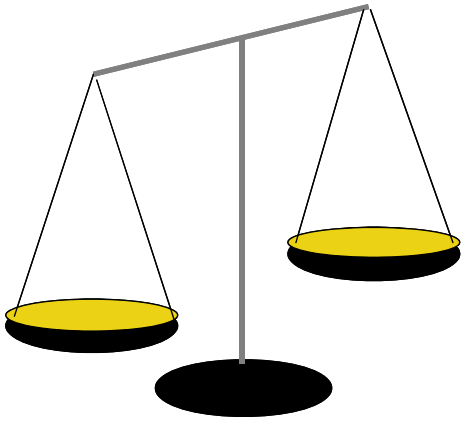
where X_d is the (discounted) **life expectancy** and ε is the **risk - aversion**. Population averages are used for X_d and ε.

G is taken to be the GDP per head for ethical reasons.

Life quality is maintained when

$$\frac{\delta Q}{Q} = 0$$

$$= \frac{\delta X_d}{X_d} + (1-\varepsilon)\frac{\delta G}{G}$$



which calls for a **balance** between extra life expectancy, δX_d, and loss of disposable income, δG.

The J-value

- The Judgement- or J-value is simply the ratio of the **amount actually spent** on protection to the **maximum that is reasonable** (defined by $\delta Q = 0$).
- Hence $J = 1.0$ corresponds to the limiting condition where the actual expenditure on protection is justified by the gain in discounted life expectancy.

Life expectancy after Chernobyl 1986, the **world's worst nuclear accident**

- Life expectancy in Ukraine and Belarus in 1986:
  - 67 years at birth.
  - **37** years is the population-average life expectancy
- 116,000 relocated 1986. If **left in place**:
  - **85,500** would have lost **8.7 months** or less (**3 months** on average)
  - worst affected **6,800** would have lost **3 years** or more; their average dose would induce a loss of **5.6 yr**

Initial comparison

- UK:
  - **3¼ yr** lost by moving from Harrow, North London to Manchester (**6½** yr at birth)
  - **8.6 yr** difference in life expectancy between baby boys born in Kensington & Chelsea and Blackpool.
  - **4½** months lost by Londoners to air pollution

J-value comparison for the 1986 relocation of **116,000** from Ukraine, Belarus + Russia

- The J-value would suggest relocating
  - **31,000** - those who would lose more than 8.7 months if left in place.
  - **72,500** based on the 95th percentile heuristic. It is assumed here that the 31,000 **cannot be identified**, and **precautions that exceed what is needed by 19 out of 20 people** in towns and villages **are applied to all**.

1990 relocation of **220,000** from Ukraine, Belarus + Russia

- J-value: **relocate no-one**.
- 1990 – 1992 EU study (at USSR's request): **relocate no-one**. (*Conclusions not taken up by USSR and did not come to general public notice.*)
- J-value conclusion on **335,000** total numbers moved from their homes in the 1986 and 1990 mass relocations: only between **9%** and **22%** justifiable.

2011 relocation of **160,000** from around Fukushima Daiichi

"The future existence of Japan as a whole was at stake. Something on that scale, an evacuation of 50 million, it would have been like a losing a huge war."

Former PM Naoto Kan,
The Daily Telegraph,
5 March 2016

- J-value: **no-one** should have been relocated.

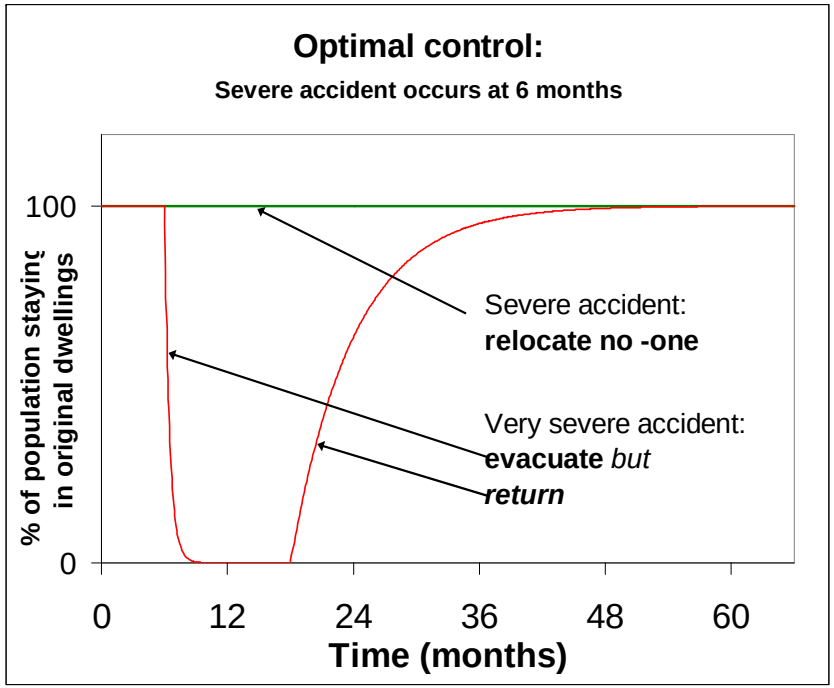
Similar message from other two techniques: **use relocation sparingly if at all.**

PACE/ COCO-2 model of a **fictional reactor** in southern England

- Severe accident equivalent to the accident at one of the 4 Fukushima Daiichi reactors:
- Relocate permanently just **600** people.

Optimal economic control

- Severe accident: relocate **no-one**
- Very severe accident: evacuate but **return** after typically 12 months



Conclusions

- For policy makers:
  - All 3 quantitative methods suggest that **relocation should be used sparingly** after a big nuclear accident.
- For socio-economic research
  - Radiation harm can be **calculated** as the **change in life expectancy**.
  - The **J-value** uses **economics** and **actuarial science** to give **objective advice** on protecting humans and the environment.
  - Presenting the **J-value** and the related statistic of **change of life expectancy** may provide people with a **simple yet fully scientific** way of **understanding nuclear risks**.
  - This last proposition needs to be **tested formally**.