Lecture: Nuclear accidents.

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Environmental Economics

Introduction

- Nuclear accidents such as Chernobyl or Fukushima are examples of slow-moving but persistent disasters.
- Slow-moving because, unlike say earthquakes or industrial explosions, typically the accident unfolds over a timescale which allows most local residents and workers to abandon the affected area safely.
- The disasters are persistent because of the nature of radioactive materials released which often have half-lives that are significant compared to the typical life spans of humans.
- The purpose of this lecture is,
  - To introduce you to the problems involved with valuing the economic costs of slow-moving disasters with persistent effects
  - To show some of the available data on the economic effects of major nuclear accidents.

Introduction

- Major nuclear accidents are rare events.
- Two ‘7’ on the International Atomic Energy Authority’s event scale for accidents (Chernobyl, Fukushima dai-ichi)
- 6 event was the Kyshtym disaster at Mayak in the Soviet Union, in 1957.
- 3 accidents labelled 5, including the Three Mile Island (TMI) accident in the USA and the 1957 Windscale Fire in the UK
- There is very little work done on the economic valuation of nuclear accidents. The key problem with existing works are:
  - many lost benefits lost are estimated using the cost of damaged or abandoned assets.
  - some lost benefits are measured twice – by the cost of the damaged assets and by the cost of their replacement.
  - many costs are in fact transfers
  - many costs remain unestimated – this particularly applies to health and labour market costs.

Background

- There are 3 types of ionizing radiation.
- Directly ionizing particles.
  - Alpha particles are helium nuclei and consist of two protons and two neutrons. They therefore carry a positive charge.
  - Beta particles are electrons and therefore carry a negative charge.
- Indirectly ionizing particles. Neutrons
- High energy photons, such as gamma an x-rays are the third type of ionizing radiation. Again, they are indirectly ionizing.

Background

- Radio-nuclides.All atoms of a given element have the same number of protons, but different isotopes have different numbers of neutrons in the nucleus.
- Isotopes differ in their atomic mass and may also differ in their stability.
- Unstable isotopes may lose energy by emitting ionizing particles spontaneously. Isotopes have different patterns of decay.
  - For instance, Iodine-131 (i.e. Iodine with an atomic mass of 131), decays to Xenon-131 by gamma and beta particle emission. Meanwhile, uranium-238 normally decays by emitting an alpha particle.

Background

- **Becquerels**. A becquerel is defined as the radioactive decay of 1 nucleus per second. The units are therefore 1/seconds. A giga becquerel is 10^9 becquerels. A tera Becquerel (TBq) is 10^{12} Becquerels.
- **Sieverts** are a measure of biological dose. The units are joules per kg. A millisievert is 1/1000 of a sievert (written as mSv). A microsievert is one millionth of a sievert (or μ Sv).
- The equivalent dose for an organism is defined by,

$$E = \sum_T W_T \sum_R W_R D_{RT}$$

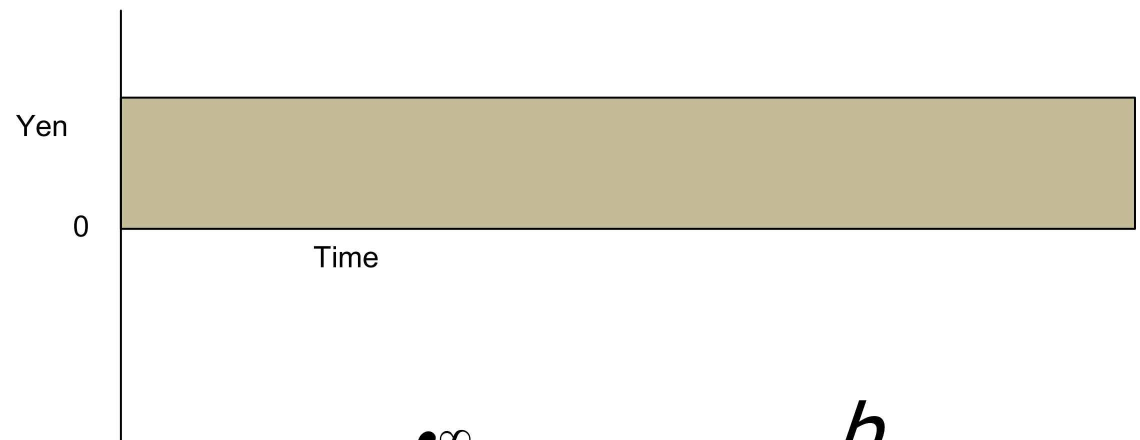
- Where WT is the proportion of tissue type T (in a kg of body mass), WR is the weighting factor for different types of radiation, R and measures the relative damage caused by each type, while DRT is the absorbed dose of radiation type R in tissue type T.
- WR varies considerably according to the type of radiation. For instance, electrons and photons have a weight of 1, while alpha particles have a weight of 20.

Background - Half-life.

- Radioactive decay is stochastic.
- The half-life of an isotope is the length of time after which the rate of decay has fallen by 50%.
- Iodine-131, for instance has a half life of 8 days. This means that after 64 days, say, the rate of radioactivity has fallen by $\frac{1}{2}^8$ = 1/256 of its original level.
- In nuclear reactor accidents, commonly released radionuclides include iodine-131 (half life of approximately 8 days), caesium-134 (2 years), caesium-137 (half life of 30 years), strontium-90 (half-life of 29 years).

Economic costs

- Cost = value of the benefits lost from destroyed or damaged assets + costs of adaptation and mitigation – benefits from adaptation and mitigation + spillover costs
- Example: lost benefits of b per unit of time forever, discounted at rate r.



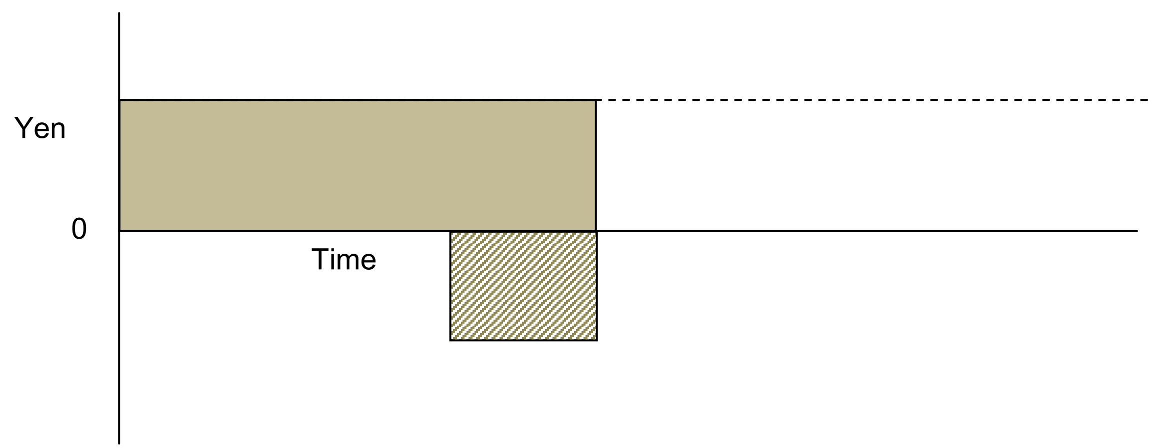
$$\int_0^\infty be^{-rt}\,dt = \frac{b}{r}$$

Economic costs

- Example: lost benefits of b per unit of time until T when the asset is replaced, discounted at rate r. E.g. destroyed housing rebuilt elsewhere.

$$\int_0^T b(t)e^{-rt}dt + \int_{T-x}^T c(t)e^{-rt}dt = \frac{b}{r}\left(1 - e^{-rT}\right) + \frac{c}{r}\left(e^{-r(T-x)} - e^{-rT}\right)$$

- Example: construction starts at time T-x at a cost per unit time of c



Economic costs ***Human capital.***

- The major damage to human capital is in 3 forms:
  - Mortality – either at the time of the accident or subsequently perhaps by radiation-induced cancer.
  - Morbidity – reduced health or quality of life. E.g. due to a non-fatal cancer. Morbidity also includes psychiatric conditions such as anxiety or depression
  - Stigma - the negative reaction of other people to experience of exposure to radiation
- Within economic valuation, the most common approach to costing mortality is based on the value of a statistical life (VSL).

Economic costs ***Human capital.***

- Within economic valuation, the most common approach to costing mortality is based on the value of a statistical life (VSL).
- For income y and risk of dying of 1-p, find the reduction in income w that a person is willing to pay for a risk reduction of Δ

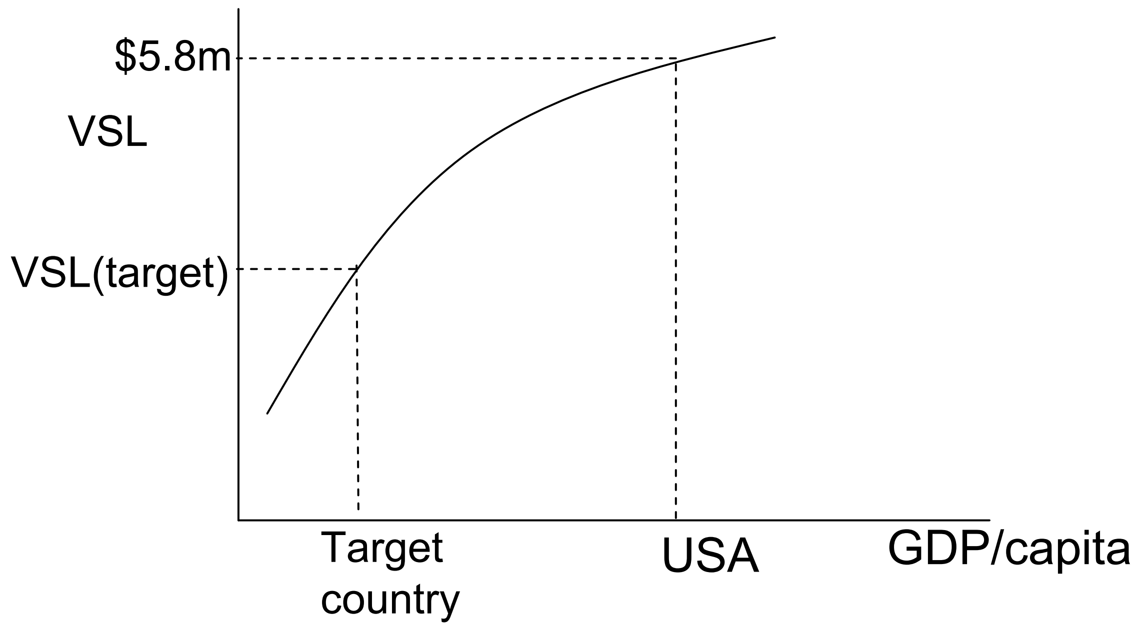
$$pu(y) = (p + \Delta)u(y - w)$$

- So,

$$\frac{dw}{d\Delta} = \frac{u(y - w)}{u'(y - w)p}$$

Economic costs ***Human capital.***

- In the US a figure of $5.8m is the standard used in public policy by the Federal Government.
- Viscusi and Aldy, 2003, use a meta-analysis across countries to calculate income elasticities for wtp to save a statistical life.
- Their preferred figure is 0.51. This can be used to estimate vsl for other countries or eras.



VSL

- Direct estimates can be made as well:
- Kenshi Itaoka et al, 2006 estimate ex ante wtp for reductions in the risks of death from nuclear accidents in Japan.
- The figure below was translated into English by the authors).
- A professional survey firm was used to deliver questionnaires to a random sample of 1500 Tokyo residents and 1000 Gifu residents.

	Attributes	Current situation	Program 7	Program 8
Break-down of effects of Nuclear power sector	(a) Annual probability of a severe accident	30 / 1 million	30 / 1 million [No change]	30 / 1 million [No change]
	(b) Lives lost if a severe accident happens	4000 persons	1500 persons [2500-person reduction]	1500 persons [2500-person reduction]
Nuclear power sector	(c) Lives lost per year Calculatedby(a)*(b)=(c)	0.12 person	0.05 person [0.07-person reduction]	0.05 person [0.07-person reduction]
Thermal power sector	(d) Lives lost per year	1000 persons	990 persons [10-person reduction]	998 persons [2-person reduction]
Total reduction of lives lost per year		0	10.07-person reduction	2.07-person reduction
More tax per household per year (Costs for new public policies)		0	8000 yen	2000 yen
Which one of these three options would you vote for?				

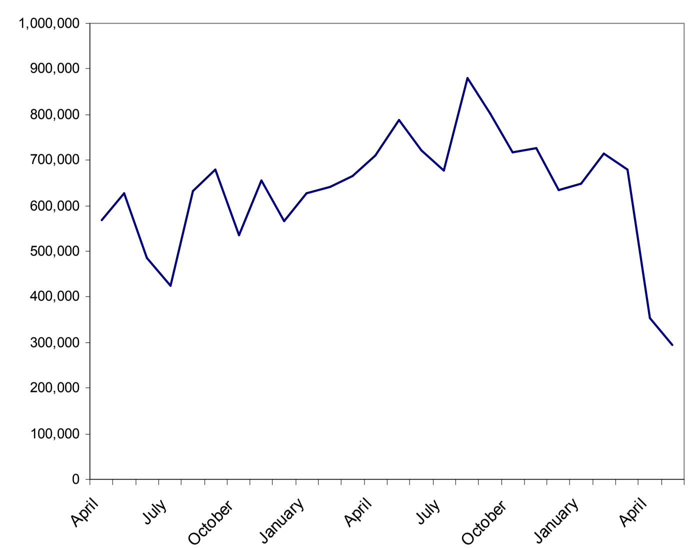
PRODUCT: (a) × (b) → (c)

SUM: (c) + (d) → Total reduction of lives lost per year

1000 yen per year = About 80 yen per month

Spillovers and Macroeconomic effects.

- Accidents can have consequences throughout the economy.
  - Supply chain effects.
  - Uncertainty shock (see Bloom, 2009, for example for a general discussion of an uncertainty shock).
  - Domestic confidence.
  - Overseas demand. Fear of contamination and fear of contaminated products can lead to a drop in export demand. For instance, tourist numbers coming to Japan dropped sharply after the earthquake and nuclear accident on 11th March 2011 and have been slow to recover (see inset).

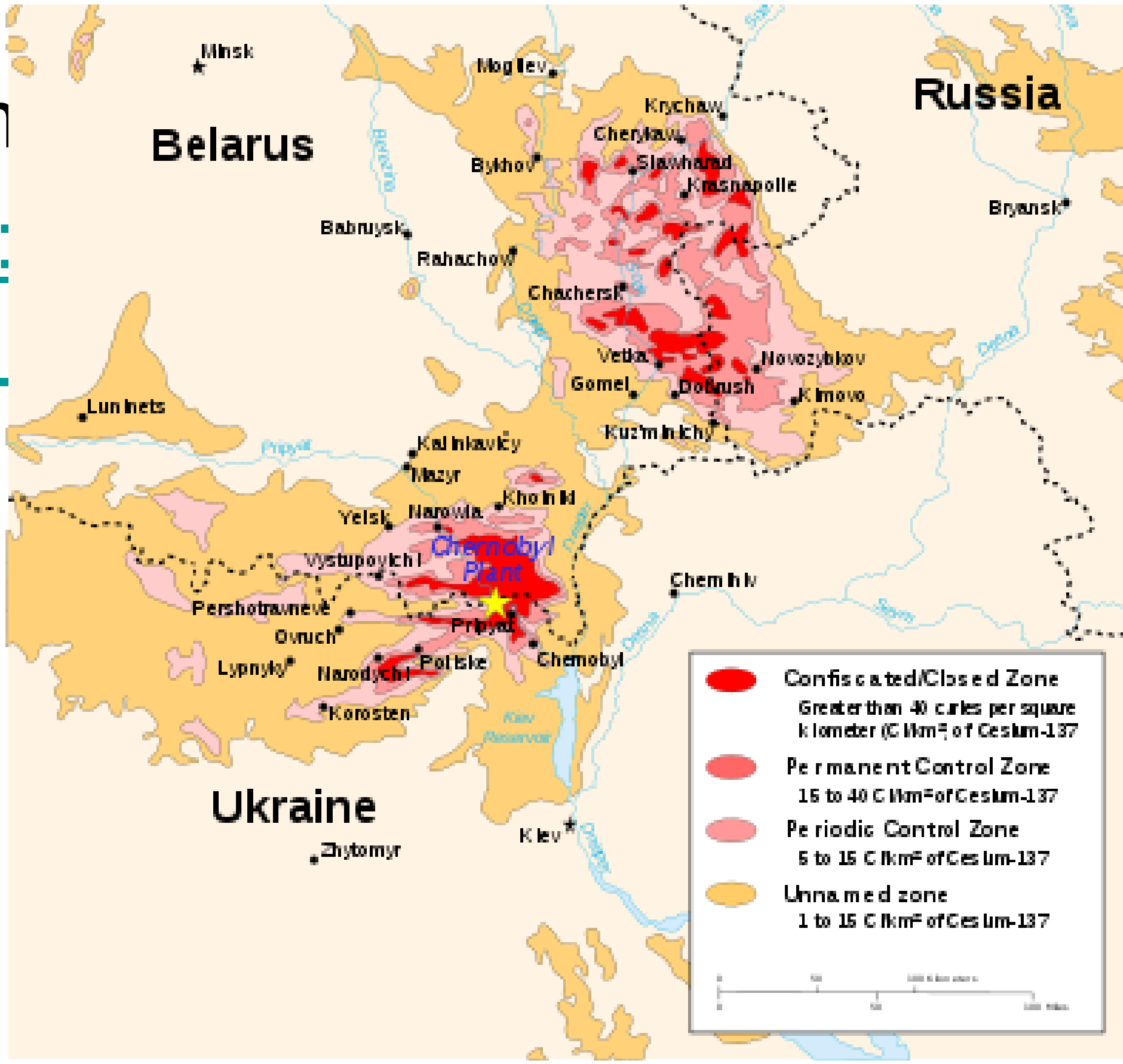


Chernobyl, 1986.

- The largest civilian accident to-date
- 25th April 1986 in what is now Ukraine.
- During a planned experiment on the reactor, there was a sudden and unanticipated power surge. In response workers attempted an emergency shut-down of the plant, but this led to a further sharp rise in power output and sequence of violent explosions which released a large amount of radioactive material into the atmosphere.
- Once exposed to the air, the graphite in the reactor vessel caught fire and over several days fire released plumes of smoke which drifted over much of the local area and then across large parts of northern Europe.

Map of caesium deposition

- Anin
- http: /tcherno byl_



Former-USSR health impact

- 200 people were hospitalized for acute radiation exposure
- 31 people died, most of them fire-fighters.
- Approximately 115,000 people were eventually evacuated from the immediate area,
- A 30km exclusion zone was established and another 220,000 people were eventually resettled
- Thyroid cancer cases amongst children shot up in the 10 years after the accident. Approximately 6,848 cases in total and 10 deaths were reported in the 3 countries by 2005 for children under aged 18. The overwhelming majority of these cases were in 1991-1995
- Estimates for the long-term mortality impacts are extremely varied. Apart from ideological biases there are several sources for this variation, including
  - Poor data.
  - Incomplete life histories.
  - Assignment of causes.
  - Theoretical model. threshold model, versus linear models of risk.
- (WHO, 2005 or Chernobyl Forum, 2006) estimates a total of 4,000 excess deaths from the accident out of a considered population of 600,000.
- TORCH report, an unofficial investigation sponsored by a Green Party Euro-MP considered a much larger population, across the whole of Europe and proposed that excess deaths would be between 30,000 and 60,000.

Former-USSR health impact

- If we use the Viscusi elasticity of 5.1m
- And a 1993 figure for Ukrainian GDP per capita
- And ignore differences in the timing of deaths.
- $7.1bn estimate of ‘cost’ of 4,000 lives
- $105bn estimate for 60,000 lives.

- These figures will ignore morbidity costs.

Non health impact

Table 5.2: Agricultural land, forest, enterprises and resources removed from service

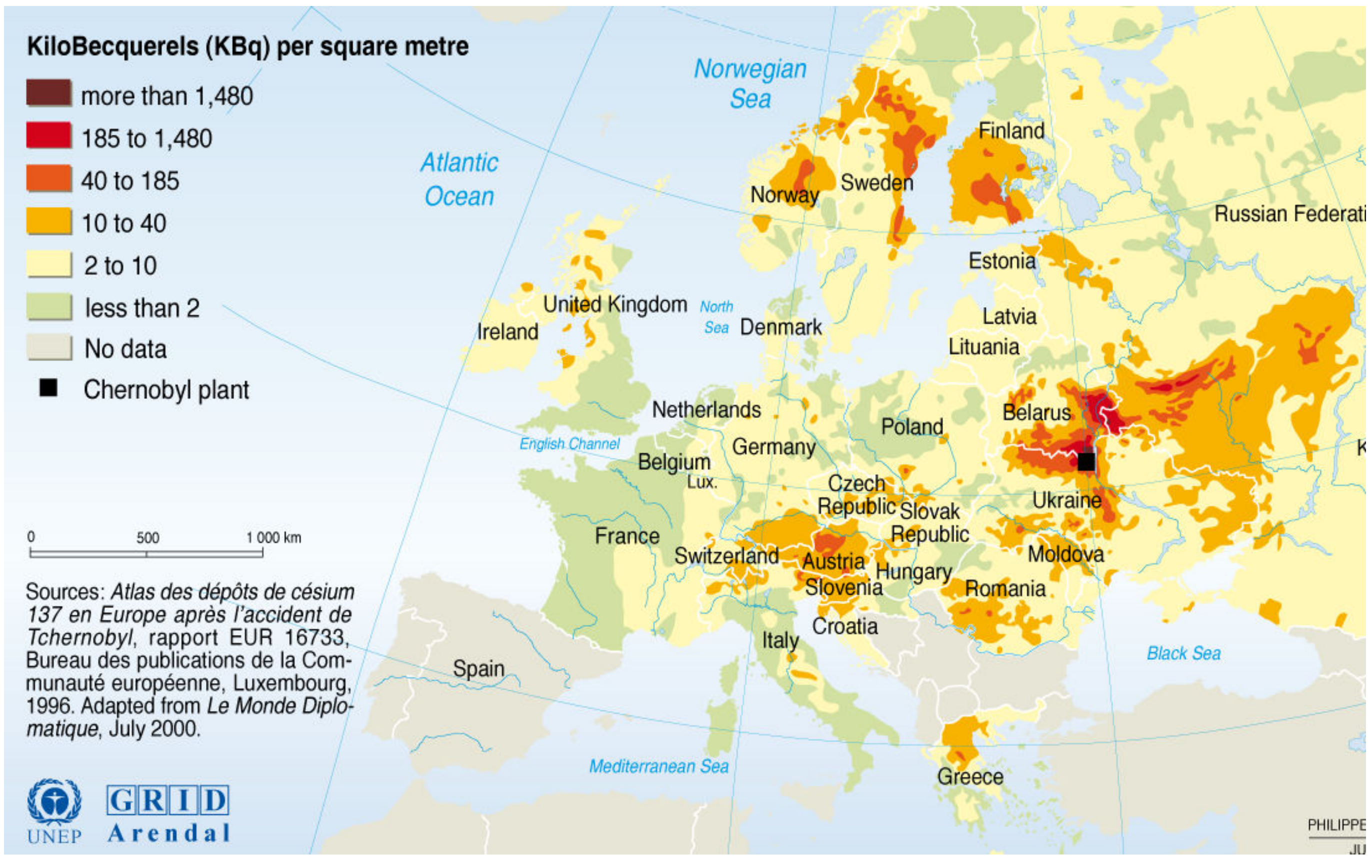
	Belarus	Russia	Ukraine	Total
Agricultural land (hectaires)	264,000	17,100	512,000	**784,320**
Forest (hectaires)	200,000	2,200	492,000	**694,200**
Agricultural and forest enterprises	54	8	20	**82**
Factories, transport and service enterprises	9	0	13	**22**
Raw material deposits	22	0	0	**22**

Non health impact

- Ukrainian government estimate of cost of destroyed assets: $1.3bn
- The major problems with this approach:
  - many costs are omitted (e.g. health costs)
  - lost asset are valued by their construction costs or equivalent and not by the value of lost benefits.
  - historical costs are used in some cases.
  - there are no on-going costs in the calculation.
- A UN-sponsored report put the accumulated costs at $235bn for Byelorussia over a period of 30 years.
- A figure of $148bn for 1986-2000 for Ukraine is quoted in the same source (UN, 2002). (no figure for Russia)
- However, most of these ‘costs’ are financial payments to household living in the three main affected countries (Chernobyl Forum, 2006).
  - i.e. they are transfer payments.

Outside USSR impact

- Caesium-137 deposits



Outside USSR impact

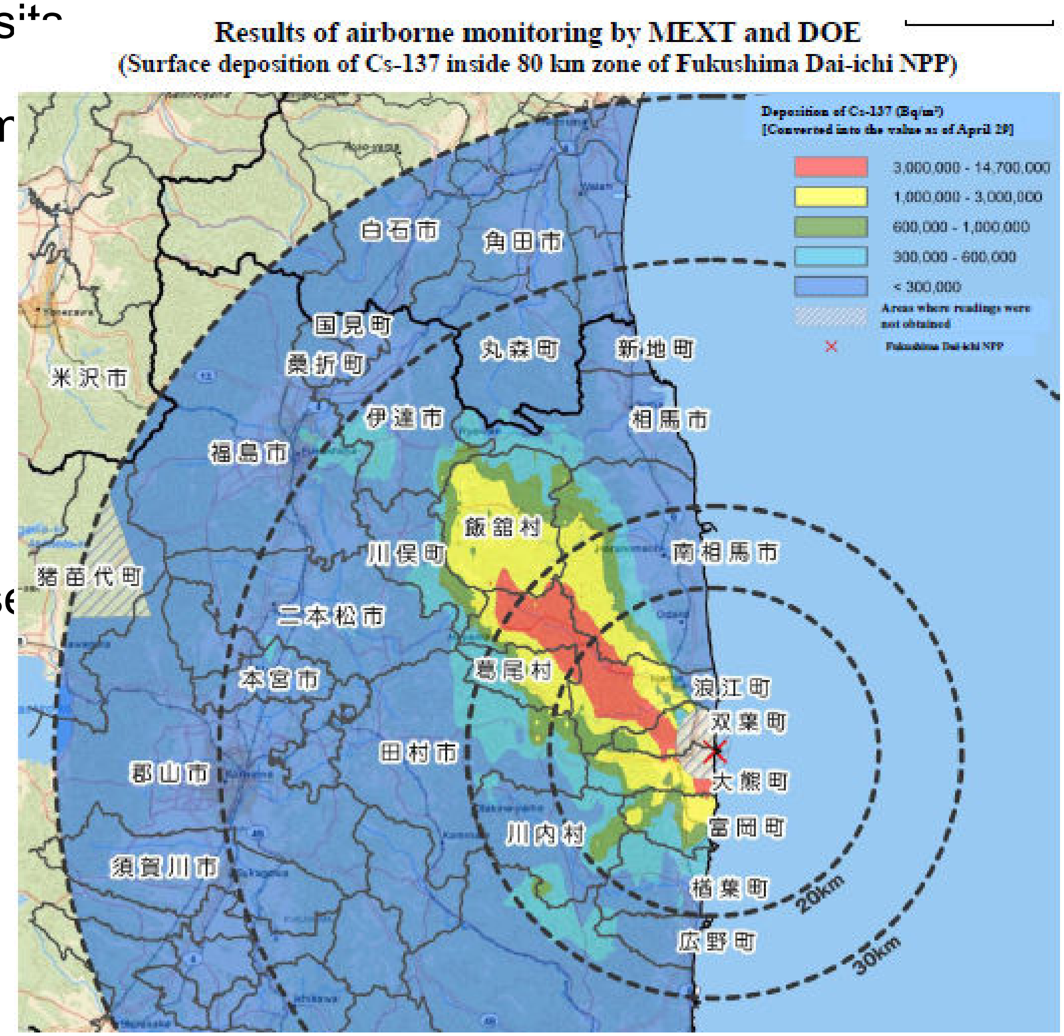
- Restrictions on foodstuffs

Foodstuff	*Country*	*Restrictions*
Reindeer, Boar, Freshwater fish, berries	Sweden	>1500 Bq/kg banned from market; refunding system for producers
Game (including wild boar and deer), mushroom	Germany,	Refund system, banned from market
Game	Norway	
Sheep	UK	Testing system for specific upland areas. Refund system for producers
Source: UK Defra; Germany: Ministry of the Environment.		

- Still in place!
- Tondel et al, 2004, controversially estimates that 849 cancer cases in Sweden were attributable to the event,
- Almond et al, 2009, examine the impact on health and educational achievement for Swedish children who were in utero at the time of the accident. For children who were at 8-25 weeks of gestation they find a significant negative effect on maths scores at aged 16 and predict a lifetime reduction in wages of approximately 3% for the most affected group.

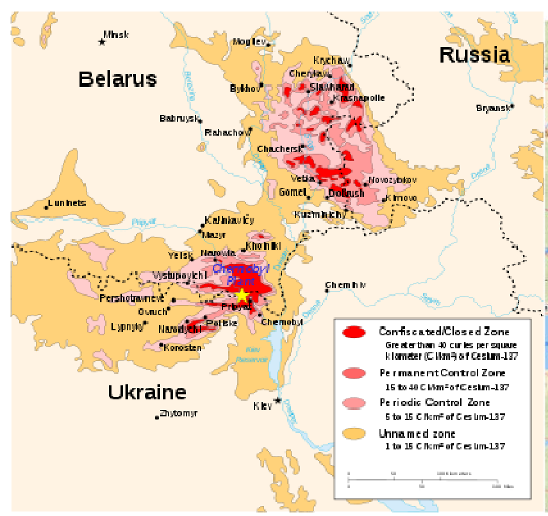
Fukushima

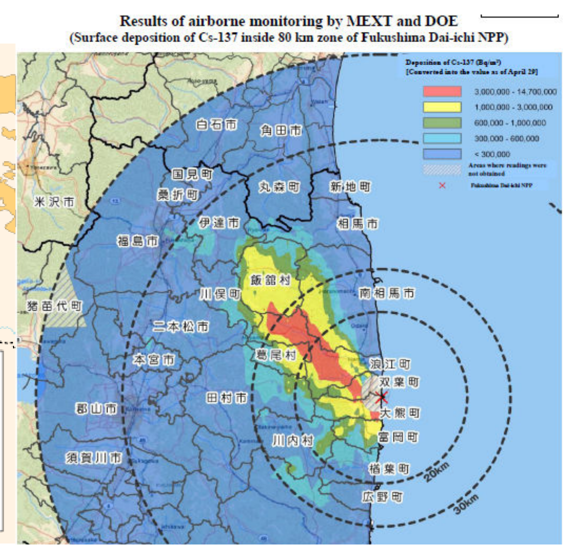
- Map shows, caesium-137 depos on land
- Evacuation has been more prom at Fukushima
- Exposure of the workforce has been significantly lower
- More widespread monitoring
- Quicker action on milk consumption
- But incomplete restrictions on marketing of foodstuffs.
- One key difference is the releas of significant volumes of contaminated water into the adjacent sea.



Fukushima

- Convert: 15 Curies per km^2 contour in the first map is equivalent to 555,000Bq/m^2
- Thus the green, yellow and orange shaded areas in the Fukushima map all represent higher concentrations of Caesium-137 than the Permanent control zone in the Chernobyl map.
- The orange and some portion of the yellow shaded areas in Fukushima represent higher concentrations of Caesium-137 than the excluded zone in the Chernobyl map.





Summing up.

1. Why is it useful to have economic cost figures for major nuclear accidents?
    1. To consider the value of precautions against accidents
    2. Comparison with other sources of risk
    3. As a guide for insurance markets
    4. For cost benefit analysis of post-accident interventions such as,
        1. Food protection measures
        2. Soil remediation
        3. Cancer screening and treatment services
2. The current data from past major events is very poor quality and does not provide a clear guide for Fukushima.
    1. For instance we don’t have any good guide to the relative sizes of health and non-health costs
    2. Little cost-benefit evidence on food protection measures.
    3. No macro data.