Cost of Major Accidents: an introduction

Marco Cometto, Marc Deffrennes, Jan Horst Keppler

OECD Nuclear Energy Agency
Division of Nuclear Development

International Workshop on "The Full Costs of Electricity Provision", Paris, 20 January 2016

Introduction

First attempts to study and quantify economic losses of major accidents were initiated in the early 90's, after the accident in Chernobyl (1986).

ExternE (EU, 1995) – first attempt to quantify externalities associated with major accidents in the energy chain:

- ExternE (1995) limited to accidents in the nuclear and oil and gas fuel cycles
- NewExt (2004) extended analysis on major accidents in the non-nuclear fuel chain.

Nuclear accidents are **different** from other generation technologies:

- Geographic scale of the consequences.
- May impact a large fraction of an economy → well beyond contaminated areas.
- Time dimension – impact can last for a very long-time.
- Frequency/probability of a major accident.
- Fatality rate (immediate and delayed) is comparably much lower.

Large range of estimates: ORNL (1993): 0.06-0.08 $/MWh, ExternE (1995) 0.002-0.1 ECU/MWh, NewExt (2004) negl.-0.006 €/MWh, IER (2013) 0.23 €/MWh, D'Haeseleer (2013) 0.3-3 €/MWh, Matsuo (2015) 300 JPY/MWh (≈2.3 €/MWh).

The NEA Study on economic losses due to nuclear accidents

In 2013 the NEA undertook a study to estimate the potential losses due to nuclear accidents (publication expected in 2016).

The project is overseen and directed by an Ad-Hoc Expert group.

Main objectives of the NEA study:

- Conduct an **appraisal of existing studies** and data on radiological consequences and economic costs of severe nuclear accidents that have occurred in the civil nuclear industry (TMI, Chernobyl and Fukushima).
- **Develop a methodology on assessments of losses** associated with severe nuclear accidents, including definition of cost elements, their characterisation and relative order of importance.
- Develop a **scenario analysis** on the basis of the defined methodology and perform reviews, e.g. to assess the cost drivers, provide orders of magnitude of estimates and their sensitivity to initial conditions.
- Review existing **liability regimes** in OECD countries.

Methodology: characterisation of impacts

- Impacts of nuclear accidents are of very different natures, with different degrees of firmness.
- Different approaches and perspectives in analysing the cost of nuclear accidents.
- All impacts from a nuclear accident should be considered and accounted for:
  - Not all costs can be quantified *a-priori* (qualitative or scenario-based estimates).
  - Difficulties in avoiding double counting.

Loss category		Loss type	Perspective		
			Accident preparedness and mgmt.	Potential liabilities and compensation	Total social cost
On-site	People	Radiological exposure to personnel	✔		✔
On-site	People	Accident management - on-site	✔		✔
On-site	Property/Business	Loss of nuclear power assets			✔
On-site	Property/Business	Incremental operational costs and additional expenses for long-term recovery			✔
Off-site	People	Radiological exposure to public	✔	✔	✔
Off-site	People	Accident management - off-site	✔	✔	✔
Off-site	People	Loss of individuals' earnings		✔	✔
Off-site	People	Cost of countermeasures: evacuation and relocation	✔	✔	✔
Off-site	People	Psychological effects on individuals	✔	✔	✔
Off-site	Property/Business	Cost of countermeasures: decontamination	✔	✔	✔
Off-site	Property/Business	Agricultural losses (including land losses)	✔	✔	✔
Off-site	Property/Business	Private property and non-agricultural land losses	✔	✔	✔
Off-site	Property/Business	Public property and environment losses		✔	✔
Off-site	Property/Business	Direct impact on local business profits	✔	✔	✔
Off-site	Property/Business	Macro impacts/indirect business losses			✔
Off-site	Property/ Business	Effect on the electricity generation mix and impact on electricity generation costs			✔

Methodology: key elements

General

- Some losses are **quantifiable**, others can only be treated **qualitatively or by scenarios.**
- Estimates of physical and economic damage should be presented separately.
- All cost estimates should be presented with the associated **uncertainties and probabilities.**
- **No single-figure estimate** for losses due to nuclear accidents. The group decided not to sum the cost categories, but provide and analyse each value separately.
  An exception is in the cost-benefit analysis where a figure of merit is needed.

Technical aspects

- "Monetary valuation of human life": experts agreed using willingness-to-pay (WTP) approach.
- Discounting of cash flows: 3% real will be used ("social discount rate").
- Risk aversion will be discussed, but not explicitly integrated in the cost estimates.
- Health effects: **both LNT and linear-with-threshold models** will be applied, without making a specific recommendation on the model to be used.

Cost of historical accidents: Some examples

Three very different accidents:

TMI: Containment and filtering was effective.

Very limited, delayed radioactivity releases (I, noble gases), no long-term contamination

Chernobyl: No containment, immediate release of large amounts of radioactivity.

Evacuation and emergency countermeasures were ineffective.

Fukushima: Delayed releases of large radioactivity amounts (8% of I, 20% of Cs vs Chernobyl)

Evacuation and emergency countermeasures significantly reduced doses.

Assessing the cost of a nuclear accident is **challenging**, even in an *ex-post* perspective.

- Some costs will arise and be known only several decades after the accident (health effects, on-site costs relative to waste management and decommissioning).
- Presence of interrelated events (earthquake, tsunami and nuclear accident in Fukushima, or dissolution of the former Soviet Union in Chernobyl) make the attribution of losses challenging.
- In the case of Chernobyl, no market price to value the loss of some goods and services.
- Compensation to victims is often the only data available, but might not always correspond to real losses.

Cost of historical accidents: Health-related impacts (1/2)

Direct health-related effects are not the main cost driver for nuclear accidents.

The application of appropriate countermeasures can effectively reduce the dose to the population (ex. Fukushima vs. Chernobyl accident).

TMI

- ✓ Doses to the population were very low, well below threshold for deterministic effects.
- ✓ No evidence of any health effect in the long term for the population.

Chernobyl

- ❖ 3+28 immediate deaths among those hospitalized with Acute Radiation Syndrome.
- ❖ Substantial increase in thyroid cancer incidence for those exposed as children (6800 cases). Thyroid cancer rate has increased among recovery workers and population living in contaminated areas.
- ❖ Some correlation between dose rate and incidence of leukemia.
- ❖ At the moment weak or no incidence of other health effects has been observed.

Fukushima

- ➢ No immediate deaths or early acute effects have been observed.
- ➢ The estimated risk for specific cancers has increased for a certain subset of the population in the Fukushima Prefecture (thyroid cancer in infants).
- ➢ Predicted radiological risk for the general population are low or very low and "*no observable increase in cancer rate is expected among exposed members of the public*" .

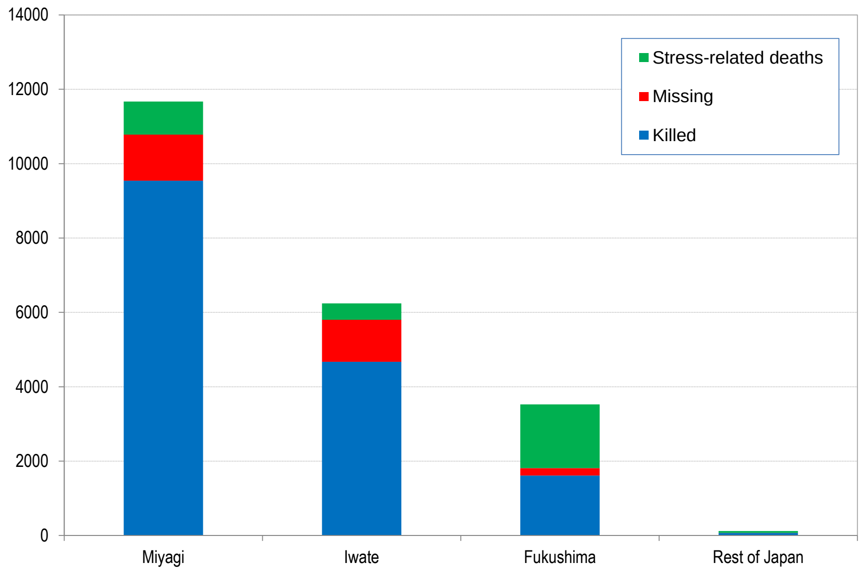
Cost of historical accidents: Health-related impacts (2/2)

Psychological and stress-related effects constituted the primary health impact in all 3 major accidents.

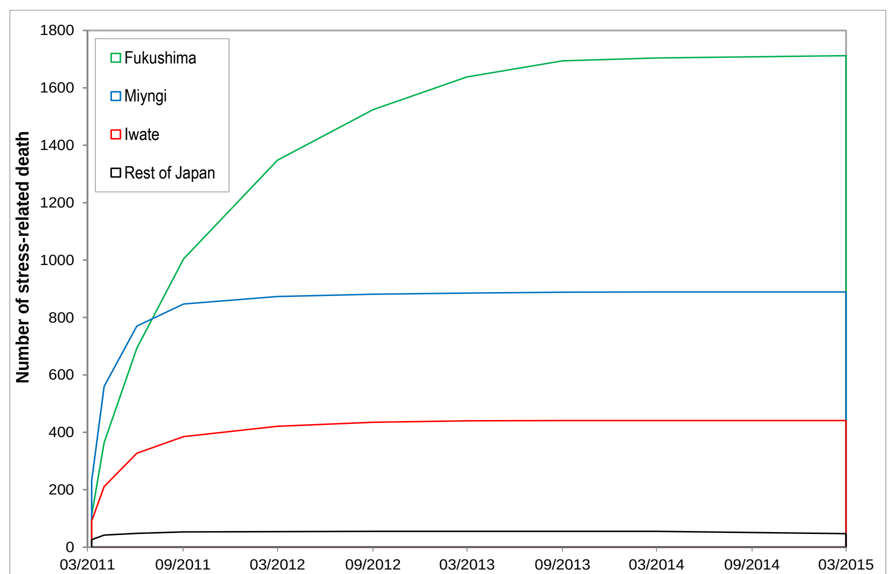
Causes are the trauma of the accident, of evacuation and relocation processes, as well as the disruption of living conditions.

More than 3000 people might have died from stress-related illnesses following the great east Japanese earthquake, tsunami and nuclear disaster.

No causally link to a single cause is possible, but the incidence in the Fukushima prefecture is much higher than in Iwate and Miyagi, and temporal pattern is different.



Source: National Police Agency of Japan Emergency Disaster Countermeasures Headquarters, 10 July 2015
www.npa.go.jp/archive/keibi/biki/higaijokyo_e.pdf



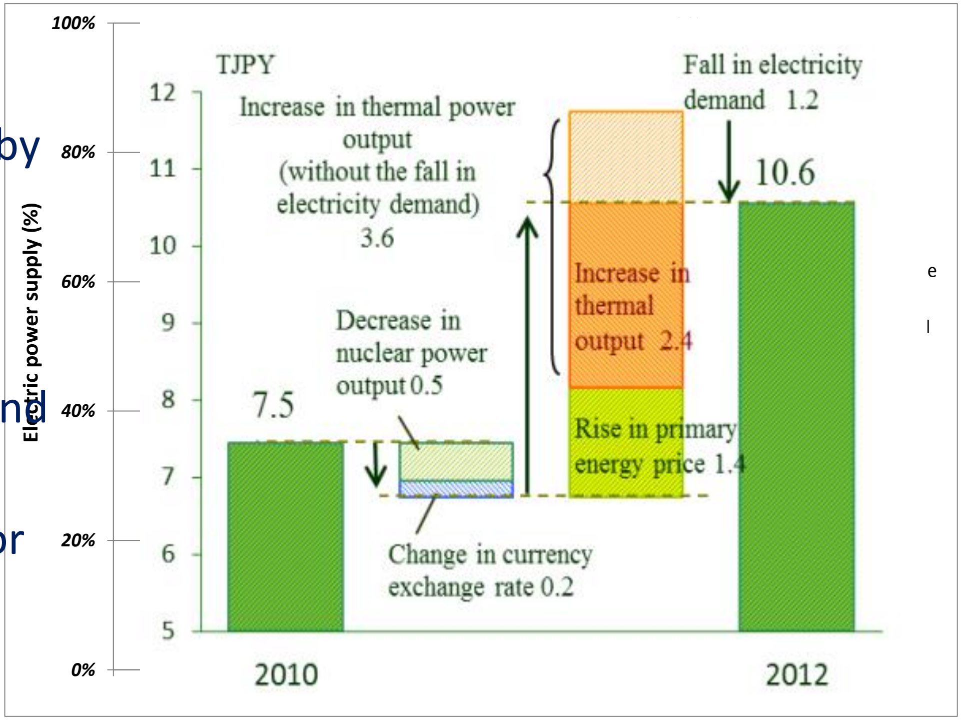
Source: Reconstruction Agency, Japan

Cost of historical accidents: Impact on the generation mix

The earthquake, tsunami and Fukushima accident had a large impact on the electricity infrastructure of Japan, in the short- and mid-term.

- In May 2011 only 17 NPP were on-line, and most NPP have not been permitted to resume operation after outages.
- Severe electricity shortages, restrictions in peak demand and rolling blackouts in 2011.

- Increase in Load factors of oil and gas PP.
- Higher gas and oil prices.
- Cost of electricity generation has increased by 40% in 2012 wrt. 2010 (≈ 40 bn USD).
- Cost increase would have been higher if no reduction in demand.
- Increase in electricity prices for customers and industry (+20% and 30%, 2013 wrt. 2010).
- Large impact on the balance sheet of 8 major utilities in Japan.
- Increase in the CO_2 emissions.



In TMI and Chernobyl, the impact on generation capacity were much more limited.

Cost of historical accidents: Main economic cost drivers

Victim compensation

- ✓ A priority was to ensure quick and appropriate compensation for accident's damages.
- ✓ More than 2.3 million applications from individuals and businesses, for a total of 5 trillion JPY (≈ 42 bn USD) in 2015, expected to total over 7 trn JPY (≈60 bn USD).
- ✓ 1/3 compensation paid to individuals, 40% to legal entities (earning lost), while the rest covers loss and reduction in property value
- ✓ Half of the compensation to individuals was dedicated to mental anguish.

Decontamination

- ❑ First estimate of decommissioning and on-site clean-up costs: 1 trn JPY (8 bn USD).
- ❖ Japanese Gvt has set an ambitious goal of 1 mSV/y for long-term off-site dose level.
- ❖ Definitive figures will be available only when decontamination is completed and will strongly depend on decontamination technics used and decontamination levels.
- ❖ Total Gvt budget is of about 2 trn JPY (16 bn USD) the first 5 years after the accident.
- ❖ Studies indicate a range of 1-5 trn JPY depending on scenario and technology.

Tourism

- ➢ Large short-term effect (-28% in term of arrivals in 2011 wrt. 2010).
- ➢ Tourism industry has recovered quickly and long-term impact was lower than forecasted. However the large fluctuations of JPY have contributed to these trends.
- ➢ Locally, large loss of international visitors, compensated by increase in visitors for work and business (+40% wtr pre-accidental levels).

Quantitative analysis

Quantitative analysis of economic impacts associated with a severe nuclear accident:

- 3 different scenarios (large early, limited and delayed, controlled and filtered releases).
- Three sites (one inland and two coastal sites)
- Analysis performed in 2 OECD countries.

Detailed stochastic modelling of dispersion of radioactive materiel

Large variability of **physical consequences** (and hence economic) :

- Choice of the site
- Prevailing weather conditions at the moment of the accident

Large variability of **health consequences** depending on the dose response function:

- The application of a threshold of 0.1 mSv reduces the incidence of cancers by (13.3%, 39% and >80% for the 3 accidents); reductions using a 1.5 mSv value (37%, 61% and >80%).

Large variability of indirect economic **consequences** (to be calculated based on separate scenarios).

➡ *A-priori* estimates are bound by a large uncertainty band

Probabilities

Estimation of the probability of severe nuclear accidents with large releases is a key component for evaluating the external cost of nuclear accidents.

Severe accidents frequency is strongly plant- and site-specific.

Three approaches to evaluate probabilities have been followed in the literature:

1) Based on historical nuclear accidents
   - Few events, which makes the statistical analysis problematic.
   - Does not adequately reflect technical progress of existing and new NPPs.
2) Based on IAEA safety targets:
   - Existing reactors [< 10^{-4} CDF, < 10^{-5} LERF], New reactors [< 10^{-5} CDF, elimination LERF].
   - Based on targets and not on plant performances.
3) Based on the analysis of Probabilistic Safety Assessments

The **NEA CSNI/WGRISK** chair proposed to use the following ranges, based on **expert opinion** and **analysis of Level 1 and 2 PSAs** in OECD member countries.

- Core melt accidents with limited radioactive releases **[10^{-4} to 10^{-6}]** events/year.
- Core melt accidents with large radioactive releases **[10^{-5} to 10^{-7}]** events/year.

Conclusion

Nuclear accidents have specific characteristics compared with other energy and their quantitative estimation is particularly challenging.

Long-term contamination is a key determinant of economic losses.

Government decisions have a key role in determining the economic losses of nuclear accidents (application emergency countermeasures, choices of intervention levels, impact on demand for products from contaminated areas).

- How to deal with the uncertainty intrinsic in cost estimates?
- What is the best way to reflect probability ranges?
- Should risk aversion be integrated and how?
- Is there a coherent approach to compare nuclear accidents with those of other energy sources.

Thank you
For your attention