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Quantitative guidance on how best to respond to a big nuclear accident

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ABSTRACT

A review is made of the quantitative methods used in the NREFS project (Management of Nuclear Risks: Environmental, Financial and Safety) set up to consider how best to respond to a big nuclear accident. Those methods were: the Judgement- or J-value, optimal economic control and a combination of the computer codes PACE and COCO2 produced at Public Health England. The NREFS results show that the life expectancy lost through radiation exposure after a big nuclear accident can be kept small by the adoption of sensible countermeasures, while the downside risk is less severe than is widely perceived even in their absence. Nearly three quarters of the 116,000 members of the public relocated after the Chernobyl accident would have lost less than 9 months' life expectancy per person if they had remained in place, and only 6% would have lost more than 3 years of life expectancy. Neither figure is insignificant, but both are comparable with life expectancy differences resulting from the different day-to-day risks associated with living in different parts of the UK. It is clear in hindsight that too many people were relocated after both the Chernobyl and the Fukushima Daiichi accidents. Remediation methods can often be cost-effective, but relocation of large numbers following a big nuclear accident brings its own risks to health and well-being and should be used sparingly, a message coming from all three of the quantitative methods. There is a need to understand and hence demystify the effects of big nuclear accidents so that decision makers are not pressurised into instituting draconian measures after the accident that may do more harm than good.

1. Introduction

It is nearly 75 years since the world's first self-sustaining nuclear fission process was demonstrated at Stagg Field, Chicago, and nuclear power is now a significant component of the world's electricity supply. 435 nuclear power plants are operating worldwide, located in 30 countries, while 72 new nuclear plants are under construction in 15 countries. Nuclear power plants provided 12.3% of the world's electricity production in 2012, with 13 countries relying on nuclear energy to supply 25% or more of their total electricity (Nuclear Institute, 2014). However the severe reactor accident at Chernobyl in 1986 caused 335,000 members of the public to be relocated permanently away from their homes while 25 years later 160,000 people were instructed to relocate or moved away voluntarily after the accident at the Fukushima Daiichi nuclear power plant. These are huge numbers without industrial precedent, and raise the question of how far they were justified and, more generally, how should one cope with a big nuclear accident, should it occur in the future?

This question raised above formed the focus for the NREFS research project (Management of Nuclear Risks: Environmental, Financial and Safety). The project was sponsored by the Engineering and Physical Sciences Research Council (EPSRC) as part of the UK-India Civil Nuclear Power Collaboration, and involved 4 universities: City, University of London, Manchester University, The Open University and the University of Warwick. The author, who was Principal Investigator, was based at City, University of London throughout the duration of the NREFS project before taking up his current position with the Safety Systems Research Centre of the University of Bristol in 2015.

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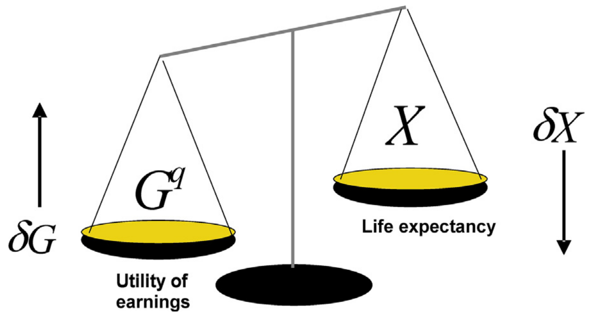

Fig. 1 – Balancing the utility of earnings against life expectancy.
(G^q is the (power) utility of earnings, G, where $q = 1 - \varepsilon$ in which ε is risk-aversion).

This paper reviews the methods used to generate answers to the questions raised above, and summarises the main findings first presented in outline form to the All-Party Parliamentary Group on Nuclear Energy on 11 March 2015 (NREFS, 2015). Three diverse methods point towards the conclusion that while big nuclear accidents are undoubtedly bad things, the radiation harm to the public is significantly less severe than is widely perceived, even in the worst cases. The fact that the downside risk is much less than is widely feared should reduce the pressure on decision makers. They should thus find themselves in a better position to take rational decisions as a result, and resist the temptation to institute draconian precautionary measures that may do more harm than good.

2. Methods of assessment

It is a requirement of Article 16.1 of the Convention on Nuclear Safety (International Atomic Energy Agency, 1994) that coping strategies for big nuclear accidents should be developed in advance, a stance that is reinforced by experience at both Chernobyl and Fukushima Daiichi. But any mitigation strategy adopted in practice will find itself in the spotlight of national and world opinion, and needs to be capable of rigorous justification, not only to experts in the field but also to politicians and the general public, who are widely presumed to have a particular fear of nuclear radiation, especially in the context of industrial nuclear power.

The use of subjective techniques to support mitigation strategies is immediately problematical, since judgements made by one group will almost inevitably clash with judgements made by another. This puts a premium on making the methods used for guidance and decision making in relation to such accidents as objective as possible, since these can offer the potential for wide acceptance.

Three quantitative methods were used in the NREFS project:

- the J- or Judgement-value method (Thomas et al., 2006a,b,c), which achieves objectivity and impartiality through balancing any future radiation-induced loss of life expectancy against the amount it is rational to spend on averting or reducing the exposure, as illustrated diagrammatically in Fig. 1. Appendix A summarises the J-value method, which was validated against pan-national data during the course of the project. It uses actuarial and economic parameters, all objectively measurable, to throw new light on the problems of relocation, food bans and remediation.
- optimal control, which follows the approach developed by Richard Bellman (Bellman, 1952, 1954, 1957). It was applied in the NREFS project to a model of the dynamic process of ground contamination after a major nuclear accident, with the model elements shown in diagrammatic form in Fig. 2. The extended system includes dynamic equations to describe the three broad countermeasures, food bans, remediation and population movement (relocation and repopulation), that constitute the control variables assumed available to the authorities.
- the combination of the Level 3 program, Probabilistic Accident Consequence Evaluation (PACE) described in Charnock et al. (2013) with version 2 of the Cost of Consequences computer program, COCO2 (Higgins et al., 2008). Both computer codes were developed at Public Health England (PHE).

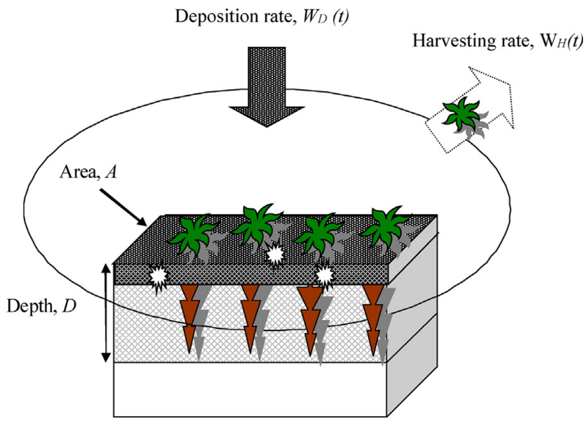

Fig. 2 – Showing radio-nuclide deposition, growth of vegetation and harvesting, either directly or via animal feeding.

Despite coming at the problem from diverse viewpoints, the three methods produced results that show significant commonality. Taken together, they reinforce the message that governments have tended to overreact if and when a bad nuclear reactor accident occurs, with the attendant offsite releases of radioactivity. Such an overreaction goes against the first and most fundamental of the three key principles of radiological protection, namely the Principle of Justification:

> "Any decision that alters the radiation exposure situation should do more good than harm" ICRP (2007).

Clearly the analyses of the Chernobyl and Fukushima Daiichi accidents have been made with the benefit of hindsight and there is no intention to blame the authorities for their responses in those cases. Nevertheless there are lessons to be learned from those accidents which should be applied in the management of a future big nuclear accident, should it occur.

3. Major findings of the NREFS project

3.1. *Relocation*

Relocation is taken to mean living away from a designated exclusion zone for a substantial time (many months or a year or more), after which return to the original location starts to become problematical. Staying away for a prolonged period will reduce both social and occupational ties to the original location and has been found to engender a general reluctance to return. It has a meaning distinct from 'evacuation', which is carried out in hours or over a day or two and is not expected to last for long, often for less than a week and not usually more than a month or so.