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OPINION

Opinion on "Worldwide health effects of the Fukushima Daiichi nuclear accident" by J. E. Ten Hoeve and M. Z. Jacobson, *Energy Environ. Sci.*, 2012, 5, DOI: 10.1039/c2ee22019a

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What struck me first on reading the Ten Hoeve–Jacobson (T–J) paper was how small the consequences of the radiation release from the Fukushima reactor accident are projected to be compared to the devastation wrought by the giant earthquake and tsunami that struck Japan on March 11, 2011. The quake and tsunami left 20 000 people dead, over a million buildings damaged and a huge number of homeless. This paper concludes that there will eventually be a 15-130-1100 fatalities (130 is the mean value and the other numbers are upper and lower bounds) from the radiation released from reactor failures in what is regarded as the second worst nuclear accident in the history of nuclear power. It made me wonder what the consequences might have been had Japan never used any nuclear power. My rough analysis finds that health effects, including mortality, would have been much worse with fossil fuel used to generate the same amount of electricity as was nuclear generated. This conclusion will surely draw fire since it flies in the face of what many believe, and of new policy directions some propose for Japan and Germany.

To answer my question requires an analysis of health effects from electricity generation using other fuels. There is only one comprehensive analysis that I know of and it is for conditions in Europe.[1] The regulations and required emission controls are those of the European Union and the population at risk is Europe. There are certainly differences between Europe and Japan in population density, prevailing wind, *etc.*, but simply assuming them to be comparable is the best I can do. T–J also calculate what might happen if the same radiation release occurred at the Diablo Canyon nuclear plant in California. And I will use that to give some idea of how things might vary in different geographic areas.

Another complication is that Krewitt *et al.* calculate what they call years of life lost per unit of electricity generation (Terawatt hours or TW h in their paper) for different fuels including all emissions. This is the shortening of life summed over the population at risk. For nuclear they include radiation from radon release from uranium mine tailings as well as from normal plant operations. In T–J premature deaths from all radiation released in the accident are calculated. To put these two studies on an equal footing, I convert the T–J number to years of life lost by subtracting the Japanese median age (45 years) from the Japanese life expectancy (82 years) and multiply this by the T–J mortalities. The T–J central value is then $130 \times 37 = 4810$ years of life lost overall from the Fukushima disaster which should be an upper limit since cancers typically take 20 years to develop. The Krewitt *et al.* years of life lost per TW h of electrical output are coal = 138, gas = 42, and nuclear = 25 excluding nuclear accidents. The accident gets included from the T–J paper.

Total electricity generation over the operating lifetimes from all the reactors at the Fukushima complex is given by the World Nuclear Association[2] as 898 TW h and for all reactors in Japan as 6097 TW h. Table 1 below gives the results. The first three rows are the Krewitt *et al.* estimates as given in their paper, scaled to the total electrical output of Fukushima, and scaled to the output of all reactors in Japan. The fourth row gives the T–J estimate scaled down to 1 TW h for comparison purposes and then as it is given in the paper, while the last row is the total mortality from nuclear.

It seems clear that considering only the electricity generated by the Fukushima plant, nuclear is much less damaging to health than coal and somewhat better that gas even after including the accident. If nuclear power had never been deployed in Japan the effects on the public would have much worse. The same conclusion would most likely result in a study of morbidity, but it is less clear to me how to compare the Kerwitt *et al.* and the T–J numbers.

T–J gives their mortality estimate for the same release at the Diablo Canyon plant as 11-160-1600. These values are roughly 25% larger than their Fukushima estimates indicating that the result is not too sensitive to details of geography.

There have been two other nuclear accidents, Three Mile Island (TMI) and Chernobyl. Radiation offsite from TMI was negligible and so were health impacts.

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Table 1 A comparison of years of life that would have been lost had electricity generated by nuclear been generated by coal or gas fuels

Fuel	**1 TW h**	**898 TW h**	**6097 TW h**
Coal	**138**	**124 000**	**840 000**
Gas	**42**	**38 000**	**260 000**
Nuclear – normal operations	*25*	*22 000*	*153 000*
T–J Fukushima meltdown	*5.4*	*4800*	*4800*
Total nuclear	**30**	**26 800**	**157 800**

T–J compares the radioactivity releases of Chernobyl and Fukushima and notes that Chernobyl had a much larger release of radiation than Fukushima,[3] perhaps as much as ten times, from a Russian reactor that had no containment and was known to have a range of operations in which it was unstable. From the table above, scaling the T–J number up by a factor of ten, Fukushima if it had released as much as Chernobyl would have mortality from the accident less than coal and more than gas considering generation at the Fukushima plant alone, and comparable to gas and less than coal considering all the nuclear electricity generated in Japan. Of course there are other issues such as land contamination, but the obvious conclusion is that nuclear power is better for your health than other choices, a conclusion that may come as a surprise to many.

I have a few comments on the paper itself. It is a first rate job and uses source of radioactivity measurements that have not been used before to get a very good picture of the geographic distribution of radiation, a very good idea.

The authors use the linear-no-threshold (LNT) model in their analysis. Many argue that the LNT model overestimates the consequences of exposure to low levels of radiation, and most of the mortality and morbidity cases in most analyses come from low doses. I agree with the authors' choice. The LNT model is what UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) and the U.S. BEIR (Biological Effects of Ionizing Radiation) committees use. The basis of LNT calculations comes from the high radiation doses received by the residents of Hiroshima and Nagasaki where the effects of radiation can be clearly distinguished statistically from the natural occurrence of cancer. At low levels the change in cancer incidence is small and cannot be clearly separated from the natural cancer background. However, there is no agreement among the critics as to what the threshold should be, and, until there is, use of the LNT assumption should give an upper bound to the biological effects.

The T–J comparison to the results of the same radioactivity release at the California Diablo Canyon power plant is interesting and useful. They estimate that the same release as at Fukushima would give mortalities 25% larger than from Fukushima which to me is close enough to the Fukushima numbers to say that there is little difference despite the difference in prevailing winds and population distribution. I also think there is too much editorializing about accident potential at Diablo Canyon which makes the paper sound a bit like an anti-nuclear piece instead of the very good analysis that it is. The U.S. Nuclear Regulatory Commission has already required that the emergency power systems, spent fuel pool monitoring, and pressure relief systems at all U.S. reactors be upgraded.

References

1 W. Krewitt, *et al.*, *Risk Anal.*, 1998, **18**(4), 377.

2 http://world-nuclear.org/NuclearDatabase/rdResults.aspx?id=27569.

3 Best reference is the UNSCEAR 2000 report appendix J; www.unscear.org/unscear/en/chernobyl.html.