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Comment on “Global risk of radioactive fallout after major nuclear reactor accidents” by J. Lelieveld et al. (2012)

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Answers to frequently asked questions about this article:

Q1. Why did you adopt the Chernobyl accident as a source of radioactivity in your model?

Chernobyl is the only INES 7 accident for which consensus exists about the emissions. The source estimate is consistent among different types of studies and with the available observations. We only used ^{131}I and ^{137}Cs sources from Chernobyl, as these isotopes are typically emitted from any type of nuclear reactor after a major accident. For the other reactors accounted for in our global model the emissions were scaled by their gross capacity to account for the different amounts of nuclear fuel.

Q2. Why didn't you adopt Fukushima as a source of radioactivity in your model?

The emissions from Fukushima are associated with much larger uncertainty than those of Chernobyl. Table 1 in our article presents a range of emissions based on the two references available at the time of publication, Chino et al. (2011) and Stohl et al. (2012). If the Fukushima emissions per reactor would be a factor of ten less than of Chernobyl, and if they would also be more representative for major accidents than Chernobyl, the calculated risk of contamination would decrease proportionally by a factor of ten.

Q3. Why were only Chernobyl and Fukushima considered in the estimate of the number of major accidents, and not less severe accidents such as Three Mile Island?

We concentrate on INES 7 events associated with the major release of radioactive material, which are by definition "major accidents" (INES is the International Nuclear Event Scale). Although the other accidents also released radioactivity, the amounts were much smaller (see Table 1 in our article). By leaving them out, we arrive at a more conservative estimate.

Q4. How is "contaminated" by radioactivity defined?

We adopt the deposition of $\geq 40\,\mathrm{kBq\,m^{-2}}$ as contaminated, following the definition given by the IAEA (2005). Note that this refers to deposition on the ground, not radiation doses (expressed in Sv). We applied the $\geq 40\,\mathrm{kBq\,m^{-2}}$ only to the deposition of ^{137}Cs, following the literature. However, IAEA (2005) defines contamination based on this threshold for all gamma and beta radiating substances. Thus this is a discrepancy in the literature that needs to be resolved. If we would apply this definition of IAEA (2005) strictly, we would have to add the deposition of substances such as ^{131}I and ^{134}Cs, which would increase the calculated risk of contamination accordingly.

Q5. Did you assume that emissions take place at the surface only?

In the model we emit the radioactive substances by introducing them into the surface layer of about 60 m depth. We assume that ^{131}I and ^{137}Cs are released gradually and not explosively or by large fires, which would increase the emission height. This assumption leads to a conservative estimate of long-distance transport. In general, the sensitivity to this assumption for the daytime convective boundary layer is small, but for the stable nighttime boundary layer this can be different.

Q6. Did you use information from non-peer reviewed publications in your model calculations?

We have used the list of reactors worldwide from Wikipedia, as referenced in our article. We have not yet been made aware of specific errors in this listing. From this list we only use two simple parameters, the geographical location and the gross capacity of the reactors, documented in the electronic Supplement. The source strength of radioactivity applied in our model calculations is based on peer-reviewed publications (about Chernobyl), including reports by the International Atomic Energy Agency.

Q7. Have risk assessments associated with major nuclear accidents been performed previously?

Yes, in different forms:

a. In 1990 the Nuclear Regulatory Committee (NRC, 1990) reported on the risk of severe nuclear accidents in the USA, associated with reactor core melts (we assume that "severe accident" qualifies as INES 7; the International Nuclear Event Scale was introduced later). The following was mentioned: "Of the plants analyzed thus far, most have an estimated likelihood of core melt of between 1 in 10 000 and 1 in 100 000 per plant year" (NRC, 1990). In the appendix of NRC (1990), which presents the overall risk estimate, only the number of 1 in 10 000 is included, being a factor of two larger than the previous estimate by the NRC (1975) of 1 in 20 000, and a factor of two smaller than our current estimate (1 in 5000). The conclusions of the NRC have had important influence worldwide on decisions to approve nuclear reactor technology. In Germany the National Risk Study on Nuclear Power Plants Phase A (GfR, 1980) and Phase B (GfR, 1990) adopted the basic methodology of the NRC and presented similar conclusions about the expected incidence of core melts.

b. There are published studies available that present methodologies to perform probabilistic risk assessments of contamination by selected nuclear reactor accidents (e.g., Baklanov and Mahura, 2004). However, none addresses the combined risk of multiple reactors worldwide.

Q8. How do your probability calculations compare with previous work?

a. The appendix of NRC (1990) presents the probability of a core melt of 1 in 10 000 per year, and the probability of containment failure 1 in 100. Based on the four INES 7 events that have actually occurred until 2011, we deduce a frequency of approximately 1 in 5000 per year, which we adopt as the statistically expected value. There are more sophisticated techniques that can be applied to address this, such as that applied by the NRC (1990), which arrived at an estimate of 1 in 10 000. This is only a factor of two different from our estimate of 1 in 5000. If we were to redo our calculations instead using the value directly from the NRC report, our results would decrease by a uniform factor of two everywhere in the deposition intensity and the risk of contamination. A study by Günther et al. (2011) estimates the probability of a core meltdown caused by a terrorist act to be 1 in 1000 per year (in Germany). If we were to apply this estimate uniformly (thus not even accounting for other risks) the calculated risk of contamination would increase by a factor of five.

b. The NRC (1990) also made further assumptions, such as the probability of containment being 99 %, which has not been borne out historically. In fact, the probability estimate of a major release of radioactivity by NRC (1990), being a combination of 1 in 10 000 and the 1 in 100 probability of containment, is 1 in 1 000 000. This is 200 times lower than our estimate of 1 in 5000. NRC (1990) furthermore assumed a 90 % probability for winds being in a “favorable direction” for evacuation, and a 90 % probability of not having an inversion layer, neither of which applies to our analysis of the overall deposition and the risk of contamination, which we integrate globally in all directions. Finally, NRC (1990) assumed a 10 % probability of evacuation failure, which is not relevant for computing the risk of ground contamination.

Q9. Are the factors leading to nuclear reactor accidents independent?

As mentioned in our article, these factors are not necessarily independent, though this was not considered by NRC (1990). For our calculations we consider the three core melts in Fukushima as independent because the reactor safety provisions must be independent. A common cause such as a tsunami or a terrorist act could as well affect reactors farther apart from each other, even in different countries. Nevertheless, if one chooses to treat Fukushima as one event, this would reduce the calculated risk of contamination by a factor of two.

Q10. Why are the model calculations performed over an entire year, considering that major accidents typically release radioactivity over a much shorter period?

By integrating the model calculated deposition over a year we capture the total contamination by ^{137}Cs over the range of meteorological conditions that might be encountered by an accidental release, which could occur at any time during the year. In reality the emission and deposition occur over a much shorter period. Based on sensitivity simulations we find that the accumulated risk of contamination over longer time periods (e.g., a year) is nearly the same as the average of the deposition that occurs when emissions take place only over one week, for all 52 weeks of the year. Thus, we can reduce our model simulation time by a factor of 52, which allows us to reasonably consider the entire set of currently active nuclear reactors worldwide.

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