

The health outcome of the Fukushima catastrophe
Initial analysis from risk model of the
European Committee on Radiation Risk ECRR

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Assumptions and methodology

The radiation risk model of the European Committee on Radiation Risk is described in ECRR2010. It differs from the model currently employed by radiation protection agencies which are based on the recommendations of the International Commission on Radiological Protection ICRP. The latter (ICRP) model deals with radiation exposure from all sources in the same way, as if it were external to the body, and generally averages the dose to the body as if it were uniform across tissues more massive than 1 kilogram. The ICRP model then takes this dose and multiplies it by a risk factor for cancer linearly based on the cancer yield at high acute doses of the Japanese survivor populations of Hiroshima and Nagasaki who have been studied since 1952. This method cannot apply to internal doses from radioactive substances, called radionuclides, which have been inhaled or ingested in food or water. This is because these substances have varying affinities for DNA and different parts of the body and can deliver very high energy to local tissue. The ICRP method cannot either be applied to inhaled or ingested hot particles, which are solid but microscopic and can lodge in tissue delivering high doses to local cells. There is a great deal of evidence that exposure to internal radionuclides is up to 1000 times more harmful than the ICRP model concludes.

The ECRR risk model deals with this issue by adding hazard enhancement weighting factor to the doses calculated for internal radionuclide or particle exposures.

Collective Dose

Up until recently the ICRP model employed a system known as *collective dose*. This enabled calculation of the cancer yield following an exposure to a known population of some given dose. The individual dose to a representative individual was calculated and that was then multiplied by the population at risk. This gave the collective dose. This number could then be multiplied by the cancer risk factor to obtain the cancer yield. The ICRP abandoned this method, although it is quite a sensible approach. The reason was that (a) it was felt to be politically embarrassing and (b) the ICRP risk model was conceded to be strictly invalid for internal exposures since the uncertainty was as high as 500-fold or more for certain internal radionuclide exposures. This followed many studies of the effects of the Chernobyl Catastrophe which showed much higher cancer yields than had been predicted by the ICRP model.

Calculating risk by the ECRR method.

In order to properly apply the ECRR risk model to the Fukushima catastrophe it is necessary to know:

1. the doses from each of the radionuclides emitted or some way of assessing these
2. the population exposed

Since information about the concentrations of the different radionuclides which are contaminating the areas near the plant are not yet available, a strictly formal application of the ECRR model is not yet possible.

However it is possible to make some assumptions which will give a reasonable idea of the health consequences of the exposures based on the ECRR approach.

There are two approaches to approximating internal dose which both give approximately the same result. I can calculate the area contamination on the basis of

the gamma radiation dose rate. I can also employ the reports of the International Atomic Energy Agency IAEA of contamination level at various distances from the release point. I will then assume generally that the internal ICRP dose is equal to the external reported dose, or that obtained by calculating the dose rate over an infinite flat plane contaminated with the isotope Cs-137. This can be done using the USA EPA FGR12 Part 2 or the graph of the HRP 1971 shown below in Fig 1.

Fig 1 Exposure rate over a plane source which can be used to determine either the source contamination level given the dose rate or the dose rate given the source contamination. (HRP 1971). Conversion factors: One Curie Ci = 37GBq or 37×10^9 Becquerel. Can assume that 1 Roentgen = 1 Rem = 10mSv.

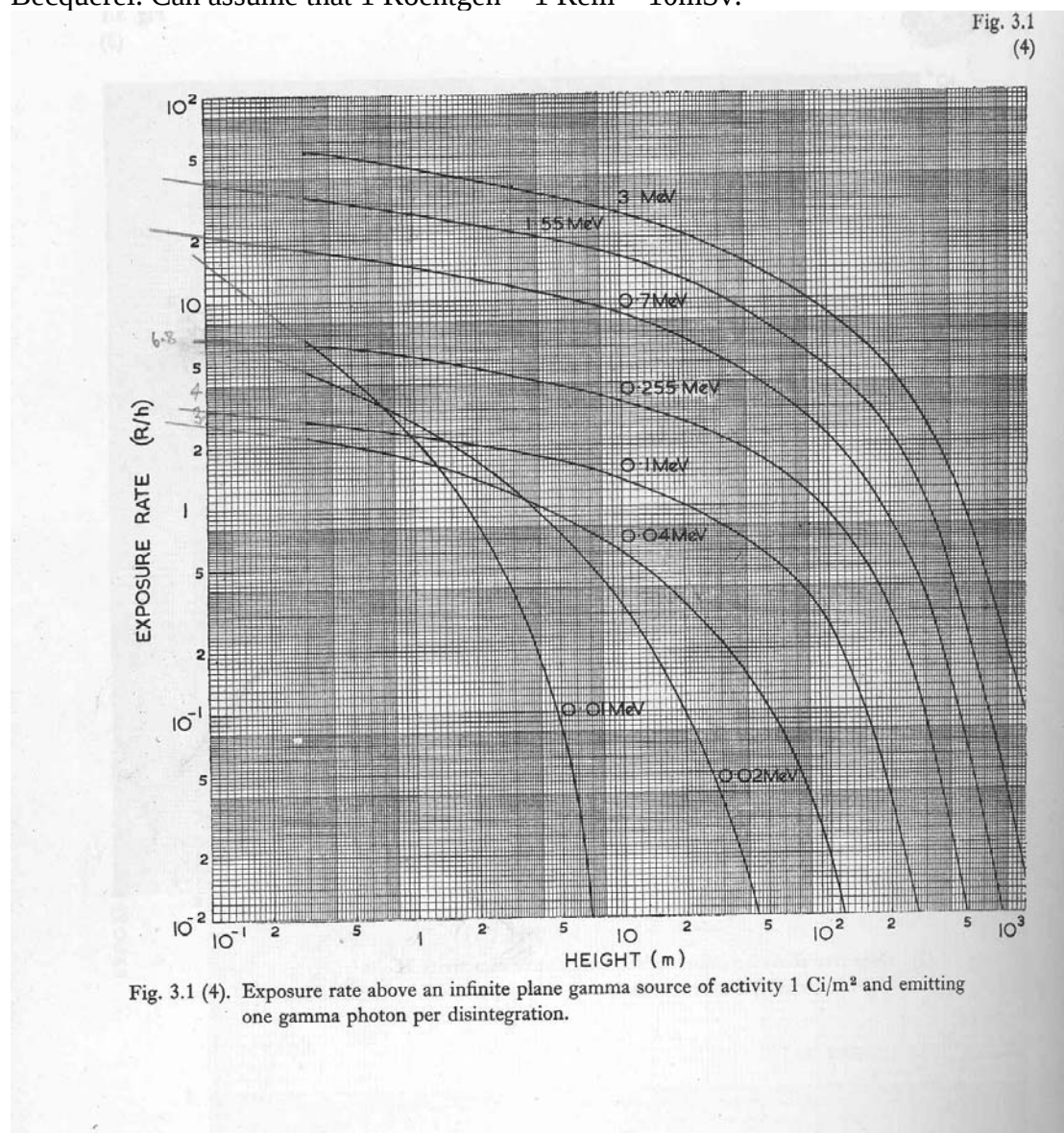


Table 1 shows the contamination in Bqm^{-2} (Becquerels per square metre) from a flat uniformly contaminated plane with material emitting one photon of energy 660keV (0.66Mev) approximately the energy of a Caesium-137 emission. The Iodine-131 emission is of lower energy, 365keV and so the contamination would be higher if this energy were used for the calculation.

Table 1. Contamination of surface based on gamma dose rate 1 metre above ground (or gamma dose rate based on contamination of surface. Assumes photon energy of 660keV (Cs-137).

Gamma dose rate $\mu\text{Sv/h}$	Surface contamination MBqm^{-2}
1	0.308
5	1.54
10	3.08
20	6.16
50	15.4
100	30.8
1000 (1mSv/h)	308
10,000 (10mSv/h)	3080 (3.08 GBq)

This method was applied to the results of the study of Tondel et al 2004 in Sweden who found 11% increase for 100kBqm^{-2} surface contamination. It almost exactly predicted what these researchers found. These researchers carried out regressions to correlate cancer increases with area contamination by Cs-137 and other radionuclides from Chernobyl. The error factor relating the ICRP risk model, which employs external radiation, was upwards of 600-fold. Of course, this was an external dose rate based on contamination that was used by Tondel et al and it was obtained from the Swedish authorities i.e. the contamination was measured, not the external dose rate. In the case of Fukushima, there are dose rate measurements reported but also some surface contamination reports from the IAEA. We now briefly address the contamination and dose rates reported up to 30th March.

Radiation exposure near Fukushima

There are a number of sources of information, but for the purposes of this study we employ the official data from the Japanese MEXT Ministry (www.mext.go.jp/english/radioactivity_level/detail/1303986.htm) and from the IAEA bulletins. The data from MEXT is reported for areas near the Fukushima plant and also for other prefectures. The MEXT map showing measured dose rates near the Fukushima plant for 16/17 March is reproduced in Fig 2. This is an example and includes my handwritten values for dose rates copied from the March 16 and 17th bulletins. Means and standard deviations for dose rate values from the reports from March 16th to March 29th are given in Table 2 for different distance zones. As in the case of Chernobyl, the contamination is not uniform and the measurements are also patchy.

The measurements of surface contamination have been reported by the IAEA in various bulletins. Their results are given in Table 3.

Fig 2 External dose rates in Fukushima prefecture March 16/17th 2011 $\mu\text{Sv/h}$

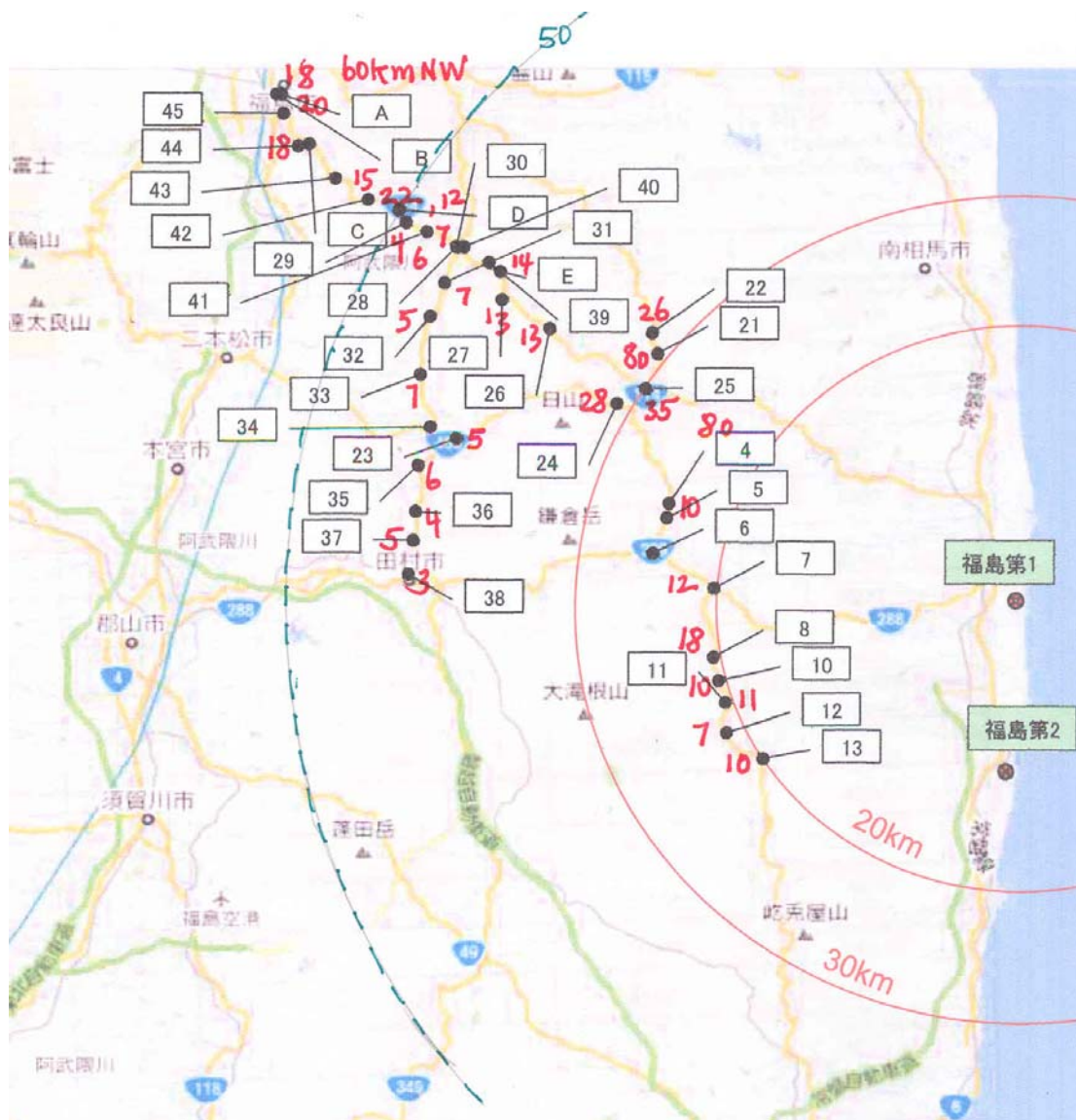


Table 2 Mean dose rates $\mu\text{Sv/h}$ and mean contamination (MBq m^{-2}) reported from 16th to 29th March 2011 at various distances from the nuclear site at Fukushima (Soma). SD is standard deviation; N is number of readings. Data from MEXT. (www.mext.jp)

Distances	Mean rate measured $\mu\text{Sv/h}$	SD	N	MBq m^{-2} contamination deduced
0-20km 16/17 March	14.3	19.9	17	4.4
20-30km 16/17 March	11.9	18.8	39	3.7
30-50km 16/17 March	15.1	5.9	9	4.7
30-50km 29 March	6.42	9.7	18	1.9
50-70km 29 March	1.6	1.0	3	0.9

Table 3 Surface beta gamma contamination, gamma dose rates in statements from 16th March to 29th March from the International Atomic Energy Agency, IAEA

IAEA bulletin date	Area/ contam/ dose	Statement
17 th March	30km	In some locations at around 30 km from the Fukushima plant, the dose rates rose significantly in the last 24 hours (in one location from 80 to 170 microsievert per hour and in another from 26 to 95 microsievert per hour). But this was not the case at all locations at this distance from the plants. Dose rates to the north-west of the nuclear power plants, were observed in the range 3 to 170 microsievert per hour, with the higher levels observed around 30 km from the plant. Dose rates in other directions are in the 1 to 5 microsievert per hour range.
20 th March	150km/ Tokyo	The IAEA radiation monitoring team took additional measurements yesterday between Tokyo and locations up to 150 km from the Fukushima site. Dose rates were typically a few microsieverts per hour compared to a typical background level of around 0.1 microsieverts per hour.
21 March	200km 2-160µSv/h 0.2-0.9MBq	As I reported yesterday, the IAEA radiation monitoring team took measurements at distances from 56 to 200 km from the Fukushima nuclear power plant. At two locations in Fukushima Prefecture gamma dose rate and beta-gamma contamination measurements have been repeated. These measurements showed high beta-gamma contamination levels. The dose-rate results ranged from 2-160 microsieverts per hour, which compares to a typical natural background level of around 0.1 microsieverts per hour. High levels of beta-gamma contamination have been measured between 16-58 km from the plant. Available results show contamination ranging from 0.2-0.9 MBq per square metre.
22 March	68km 0.8-9.1µSv/h 0.08-0.9MBq	The IAEA took measurements at additional locations between 35 to 68 km from the Fukushima plant. The dose-rate results ranged from 0.8 to 9.1 microsieverts per hour. The beta-gamma contamination measurements ranged from 0.08 to 0.9 MBq per square metre.
23 March	30-73km 0.2-6.9µSv/h 0.02-0.6MBq	The IAEA radiation monitoring team took additional measurements at distances from 30 to 73 km from the Fukushima nuclear power plant. Results from gamma dose-rate measurements in air ranged from 0.2 to 6.9 microsievert per hour. The beta-gamma contamination measurements ranged from 0.02 to 0.6 Megabecquerel per square metre.
24 March	34-73km 0.6-6.9µSv/h 0.04-0.4MBq	The IAEA radiation monitoring team made additional measurements at distances from 21 to 73 km from the Fukushima nuclear power plant. At distances between 34 and 73 km, in a westerly direction from the site, the dose rate ranged from 0.6 to 6.9 microsievert per hour. At the same locations, results of beta-gamma contamination measurements ranged from 0.04 to 0.4 Megabecquerel per square metre. At distances between 30 and 32

	30-32km NW 16-59 μ Sv/h 3.8-4.9MBq	kilometers from the Fukushima Nuclear Power Plant, in a north westerly direction from the site, dose rates between 16 and 59 microsievert per hour were measured. At these locations, the results of beta-gamma contamination measurements ranged from 3.8 to 4.9 Megabecquerel per square metre. At a location of 21 km from the Fukushima site, where a dose rate of 115 microsieverts per hour was measured, the beta-gamma contamination level could not be determined.
27 th March	30-41km 0.9-17 μ Sv/h	The second team made additional measurements at distances of 30 to 41 km from the Fukushima nuclear power plant. At these locations, the dose rates ranged from 0.9 to 17 microsievert per hour. At the same locations, results of beta-gamma contamination measurements ranged from 0.03 to 3.1 Megabecquerel per square metre.

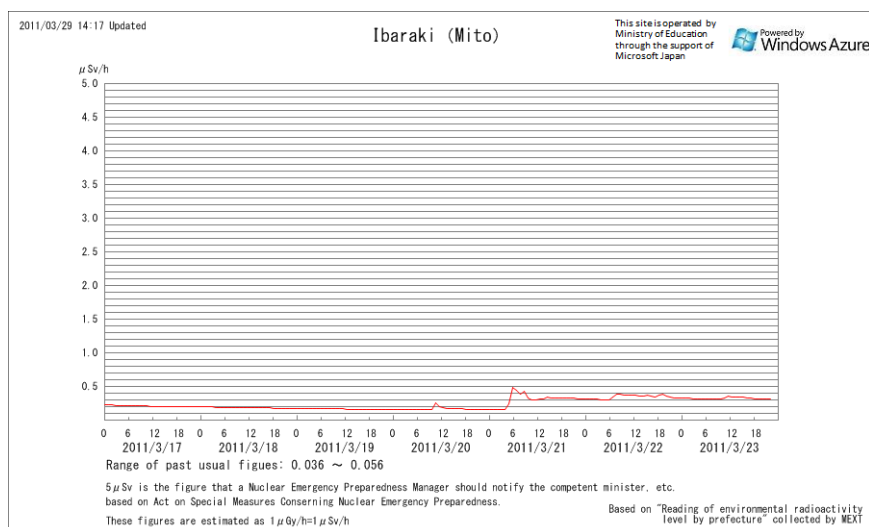
Exposure in Prefectures

Values of exposures in prefectures is also available from the MEXT Ministry website in the form of graphs of dose rate. These have been reduced to mean dose rates and are given in Table 4 for prefectures local to the catastrophe. An example for Ibaraki Prefecture is give in Fig 3.

Table 4 Rates of exposure in selected prefectures from 16th to 29th March with deduced surface contamination. Background is assumed to be 0.04 μ Sv/h

Prefecture	Dose rate μ Sv/h	Deduced surface contamination kBq/m^{-2}
Ibaraki	0.35	95
Yamagata	0.1	18
Tochigi	0.2	50
Tokyo	0.1	18
Gunma	0.1	18
Saitama	0.1	18

Fig 3. Dose rates in Ibaraki prefecture as displayed on MEXT website



Comparison of the IAEA statements and the MEXT measurements with our calculations of area contamination show that all the measurements and calculations roughly agree though the contamination levels deduced from the dose rates are much higher than those reported by the IAEA. I will assume that the method can be used to determine the area contamination for those areas where no surface contamination levels have been reported. I will employ the Tondel et al 2004 published regression coefficient of 11% increase in cancer (all cancers) per $100\text{kBq}\cdot\text{m}^{-2}$ to predict the 10-year cancer yield. I will assume for the calculation that the exposure is for 365 days. To establish the total cancer increase we will require the populations involved.

Populations

Using data from the Japanese census, it is possible to establish the approximate populations at risk. Fig 2 shows the population density in areas defined by a 100km and 200km radius. Assuming mean population densities given by the shadings the population at risk can be calculated using mass planimetry (cutting out with scissors and weighing on a chemical balance) Results are given in Table 4

Fig 4 Population density, Japan Prefectures 2005

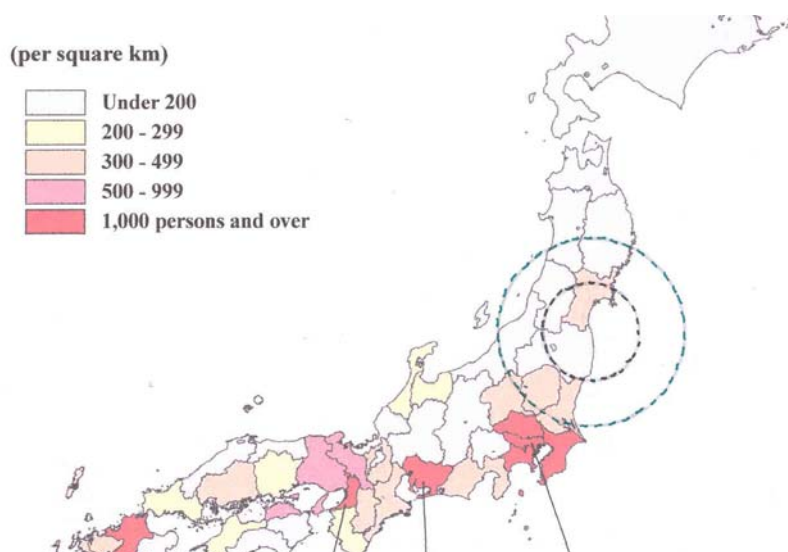


Table 5 Populations and areas within 100 and 200km rings for the purposes of calculating collective doses and cancer increases.

Locality	Population
100km radius land area	3,338,900
100 - 200km radius land annulus	7,874,600

Cancer excess in 100km population

This is an extremely conservative set of assumptions. On the basis of the measurements and arguments above, I assume the 100km radius is contaminated uniformly to 600kBq m^{-2} . The dose associated with this level of contamination is $2\text{ }\mu\text{Sv/h}$. Assuming that no one moves away and that the contamination remains at this level, using the Tondel et al 2004 regression coefficient of 11% cancer increase per 100kBq m^{-2} and assuming the same spectrum of radionuclides and pathways for exposure the cancer increase in the 100km population is 66% and these cancers will be manifest in the next ten years.

The cancer rate for all malignancies in the Japanese population is 462 per 100,000 per year. Therefore the annual number of cancers in the 3,388,900 population of the 100km radius is 15,656. In ten years there will be 156,560 cancers normally if this 2005 rate is maintained plus an extra 66% of this number diagnosed from Fukushima **that is 103,329 extra cancers due to the Fukushima exposures.**

The annual dose from this contamination can be calculated in mSv. If we assume 365 days and 24 hour a day exposures then for $2\text{ }\mu\text{Sv/h}$ the annual dose is 17mSv. The population is 3,338,900 so the collective dose is 56,761 person Sieverts. The ICRP absolute cancer risk factor is 0.05 per Sievert. Thus the ICRP **predicts 2838 extra cancers in this population from the Fukushima fallout.**

Given that the ICRP predicted excess cancers will probably appear in the next 10 years, they will not be measurable above the normal rate unless they are rare cancers. Examples are leukaemia in children or thyroid cancer.

The ECRR absolute risk method cannot be formally used unless we know the individual radionuclide exposures. However it can be used if we approximate that 1/3 of the dose is internal and that 1/3 of the internal dose carries a weighting of 300 (which was the overall weighting factor obtained from the weapons test fallout spectrum of radionuclides epidemiology). Then the annual internal dose is 5.6mSv and 1/3 of this is 1.9mSv which we weight at 300. The total ECRR dose is thus 575mSvECRR. The collective dose is then $3,338,900 \times 575 \times 10^{-3}$ to give 1,919,867 person Sieverts and a **lifetime (50 year) cancer yield of 191,986 extra cancers** assuming the ECRR risk factor of 0.1 per Sievert ECRR. Given the different time frames, these numbers obtained from the Tondel et al 2004 regression and the ECRR absolute model based on the atmospheric test cancer yields in Wales and England are in reasonable agreement.

The three predictions are given in Table 5

Table 5. The predicted cancer increases in the 100km zone near the Fukushima site

Model	Cancer yield	Note, assumptions
ICRP	2838	In 50 years, based on collective doses at exposure of 2 μ Sv/h for one year
ECRR Tondel	103,329	In ten years following the catastrophe, based on surface contamination only
ECRR absolute	191,986	In 50 years, based on collective doses at exposure of 2 μSv/h for one year; probably half of these expressed in the first ten years.

Cancer excess in 200km annulus population

The methods employed above may be extended to the 200km annulus if the contamination levels are known. Presently no data is available of contamination in these areas although dose rates are available. NOAA Computer modelling carried out by us and published on the internet (www.llrc.org) and elsewhere suggest that the plumes from the catastrophe have travelled south over the highly populated areas shown in Fig4. Dose rates have been published for these areas and from these dose rates it can be assumed that significant exposures have occurred. From Table 4 and Fig 3 we can assume that the exposures are of the order of 1 μ Sv/h with associated contamination levels. Therefore the methods employed for the 100km area may be extended to the 200km area. The population is, however much greater at 7,874,600. The results are given in Table 6.

Table 6. The predicted cancer increases in the 100-200km zone near the Fukushima site

Model	Cancer yield	Note, assumptions
ICRP	3320	In 50 years, based on collective doses at exposure of 2 $\mu\text{Sv/h}$ for one year
ECRR Tondel	120,894	In ten years following the catastrophe, based on surface contamination only
ECRR absolute	224,623	In 50 years, based on collective doses at exposure of 2 $\mu\text{Sv/h}$ for one year; probably half of these expressed in the first ten years.

Other areas and some caveats.

First, it should be clear that the surface contamination calculated from the gamma dose rates is twice to three times the highest level referred to by the IAEA in their bulletins. It is clear that the authorities do not reveal the full picture: something which also occurred following Chernobyl. I note that the IAEA stated that the maximum level was 0.9MBq m^{-2} . Was this because above 1MBq there would have had to have been some consequent action? The lower IAEA level has been used for the cancer risk calculation where the Tondel method was employed and the conservative low dose of 2 $\mu\text{Sv/h}$ for the absolute risk methods. But it is clear that the doses are much higher than this in the 100km zone, mostly between 6 and 14 $\mu\text{Sv/h}$. They are particularly high to the North West out to 60km. Again, this is about twice to three times the dose rate we have used. Therefore the overall cancer yield is likely to also be twice to three times as high. But there is a problem. The ECRR risk model assumed a biphasic dose response relationship, and so there is linearity of risk only over the low dose region.

For the high exposures modelled here there will be significant saturation, that is the proportionate cancer risk will fall as the dose increases. This is for a number of reasons but partly because there will be competing causes of early death.

Second, it must be understood that unlike ICRP, the ECRR model does not only model cancer. Studies of populations exposed internally show that a wide spectrum of diseases and conditions follow; these include heart disease, diabetes, and all the normal conditions and illnesses that contribute to mortality and morbidity. In addition, studies of nuclear Test veterans, Chernobyl-affected populations and those exposed to Uranium show us that alarming increases in congenital disease in children and grandchildren are to be expected. The ECRR2010 report should be studied for details.

Third, these predictions are based on the assumption that the population will remain in the 100km zone for one year. If they are evacuated inside one month, the yield will be much less, though not in proportion to the period of exposure since it is clear that the initial exposures were high and with weathering and decays the exposures will become less as time goes on.

The predictions for other areas can be scaled according to the exposures given in Table 4. It must be understood that although the doses and assumed contamination is

lower in these prefectures, the populations are enormous, and therefore the cancer and health detriment yield will also be very great.

Finally, all these predictions are based on the assumption that the spectrum of internal exposures is the same as weapons test fallout (ECRR Absolute) or Chernobyl Sweden (Tondel). There may be more uranium and/or plutonium in the Fukushima spectrum and this may affect the risk by increasing it. They are also based on the contamination reports to date and will have to be altered when the more accurate reports become available or if there is more contamination.

Conclusions and recommendations

- 1. The ECRR risk model has been applied to the 3 million people living in the 100km radius of the Fukushima catastrophe. Assuming these people remain living there for one year the number of excess cancers predicted by the method is approximately 200,000 in the next 50 years with 100,000 being diagnosed in the next 10 years. If they are evacuated immediately, the number will fall by a significant amount. For those 7 million living between 100km and 200km from the site, the predicted number of cancers is slightly greater with 220,000 extra cancers in the next 50 years and about 100,000 being expressed in the next ten years. These predictions are based on the ECRR risk model and also the findings of cancer risk on Sweden after the Chernobyl accident.**
- 2. The ICRP model predicts 2838 extra cancers in the 100km population. The eventual yield will therefore be another test of the two risk models.**
- 3. Calculations based on official gamma dose rates published by the Japanese Ministry MEXT can be used to back calculate surface contamination at the positions of the measurements using accepted scientific methods. The results show that the IAEA reports have significantly under reported the contamination levels**
- 4. It is recommended that urgent attention is given to making isotope specific ground contamination measurements.**
- 5. It is recommended that populations living within the 100km zone to the North West of the site are immediately evacuated and the zone is made an exclusion zone.**
- 6. The ICRP risk model should be abandoned and all political decisions should be made on the basis of the recommendations of the European Committee on Radiation Risk www.euradcom.org This is the conclusion of the eminent radiation risk experts who signed the 2009 Lesvos Declaration**
- 7. Investigation and legal sanctions should be brought against those who knowingly held back data from the public**
- 8. Investigation and legal sanctions should be brought against those minimising the health effects of this event in the media.**

References

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