Predicting the global health consequences of the Chernobyl accident
Methodology of the European Committee on Radiation Risk

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1. Introduction

There have been a number of calculations and predictions of the health consequences of the Chernobyl accident exposures. These range from virtually none (The UN Chernobyl Forum) through 60,000 excess cancer deaths (Fairlie and Sumner 2006) to 1.8 million cancers (Rosalie Bertell 2006) and include the prediction of between 900,000 and 1.4 million deaths in the last 25 years made recently by Alexey Yablokov (Yablokov 2011) in Berlin and widely covered in the media. In view of the recent and ongoing local and global contamination being produced by the Fukushima nuclear power station meltdown in Japan and the 25th anniversary of the 1986 Chernobyl accident it would seem of interest to revisit the various calculations and to employ the ECRR2010 approach to predicting the cancer yield and other ill health, and at the same time, check the results against other epidemiological approaches to obtaining the correct result for exposures to the radionuclides emitted from an accident involving a nuclear reactor.

Some predictions are given in Table 1 including the results of the present analysis.

Table 1. Predictions of the health outcome of exposures to radioactive contamination for the Chernobyl accident.

Prediction/ analysis	Number	Note
Gofman J. W 1990	970,500	Excess Fatal cancers, calculated from Cs-137 deposition doses and Gofman's risk factor of 0.28/Sv; worldwide
IAEA/WHO 2005	9000	Excess All cancers using ICRP risk factor 0.05/Sv; worldwide
Fairlie Sumner TORCH report 2006	30,000-60,000	Excess All fatal cancers worldwide; ICRP model assumptions and collective doses
Greenpeace 2006	93,000	Excess mortality solid cancers and leucosis 1986-2056 all countries
Bertell Rosalie (ECRR2006)	899600 to 1,787,000	Excess Fatal cancers worldwide; not clear on method
Yablokov 2011	900,000 to 1.4 million	Excess deaths in 25 years only. Comparing increases in deaths in differentially contaminated populations of Europe.
This analysis based on contamination	489,500	Excess Cancer incidence in 10 years following the exposure based on Tondel epidemiology
This analysis based on dose	Between 740,000 and 1.48 million	Cancer incidence in 50 years; global; based on ECRR 2010 absolute risk model and assumptions of internal fraction
This analysis based on contamination	2.45 million	Cancer incidence in 50 years based on Tondel epidemiology

2. The data and assumptions

There are several sources of data for the contamination available but many of them disagree slightly with each other. In general, the percentage of the Chernobyl reactor contents which was released has been increased from the first estimates of 5% to between 50% and even 95%. Gofman's calculation was based upon total Cs-137 releases of 1,990,000 Curies i.e. 7.3 x 10^{16} Bq (73 PBq) and this is not very different from the value given in the latest UNSCEAR 2008 report (published 2011) of 85PBq. Early assessments were of less. Sumner et al 1987 gave 38PBq Cs-137. I do not propose to employ a source term for the calculations but base them on two kinds of input. The first is the effective first year dose to an individual in a defined national population. The second is the mean area contamination by Caesium-137. I obtain these data from the following sources:

1. UNESCO 1995
2. UNSCEAR 2011

The UNESCO (Savchenko) data are given as average first year committee effective doses from the Chernobyl accident to populations of different countries (Fig 1). Where Savchenko has not listed a country I have gone to UNSCEAR 2011. By employing maps of contamination given in IAEA, UN and many other publications, I have adjusted the contamination levels in one or two countries where the UNSCEAR 2011 data seems incorrect, notably Poland. I have used the Handbook of Radiological Protection and the USA EPA FGR12 Part 2 tables and graphs to convert between Cs-137 contamination on the ground and dose rate. I have assumed that internal dose is 1/3rd of external dose from this source, where the absolute ECRR 2010 method requires this. This is based on ratios of internal and external doses given in UNSCEAR 2008. I have taken the first year dose as the effective dose from Chernobyl exposure. I have used the mean ECRR2010 hazard factor of 300 for internal exposures.

I calculate the cancer yield in two ways. First I employ the ECRR2010 method. Then second, as a check, I employ the results of the epidemiological study of cancer in Northern Sweden by Tondel et al 2004 who found a 11% increase in cancer for each 100kBq/m^2 Cs-137 contamination. It should be noted in all these calculations that they do not assume that the cancer is caused by the Cs-137 exposure but that the latter is a flag for a range of harmful radionuclides. The ECRR hazard factor 300 for this range of harmful radionuclides is based upon the regression analysis of cumulative committed effective dose from Strontium-90 on increases in cancer in populations differentially exposed to global weapons fallout (Busby 1994, 1995, ECRR2003, ECRR2010). One such correlation is shown in Fig 2.

The numbers of cancers generated by the Tondel method assumed that the all person all cancer rate per year was 450/100,000 (various sources including CIFC, SEER and national cancer registries).

3. Results

Results are given in Table 2. It should be noted that the assumptions of 1/3 of the internal exposure carrying a weighting of 300 is based on nuclear atmospheric test fallout in the 1960s and other similar spectra of contamination radionuclides. In addition, the factor is based on exposure to Sr-90. The ratio of Sr-90 to Cs-137 in fallout is far greater in weapons fallout than in the distant Chernobyl contamination. The Chernobyl exposures generally had a greater particulate and uranium contamination and therefore are likely to carry a greater hazard weighting. A factor of about 400 is necessary to explain the infant leukemias after Chernobyl (Busby 2009)

Fig 1 Mean doses from Chernobyl fallout to some countries (from Savchenko/ UNESCO 1995).

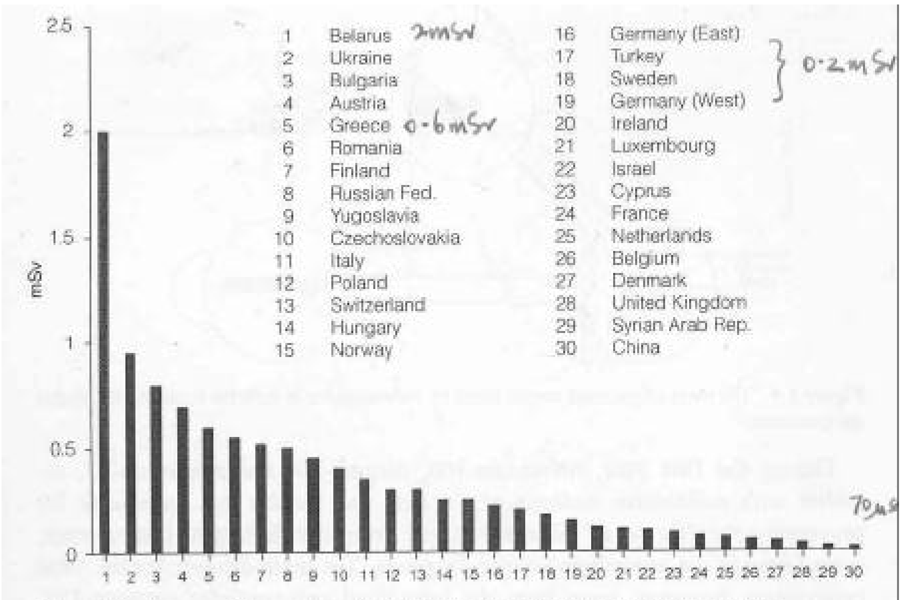

Figure 1.3 Average first-year committed effective doses from the Chernobyl accident

Fig 2 Cumulative dose from Strontium 90 1954 to 1974 plotted against age standardised excess all cancers in Wales 20 years later (Busby 2006)

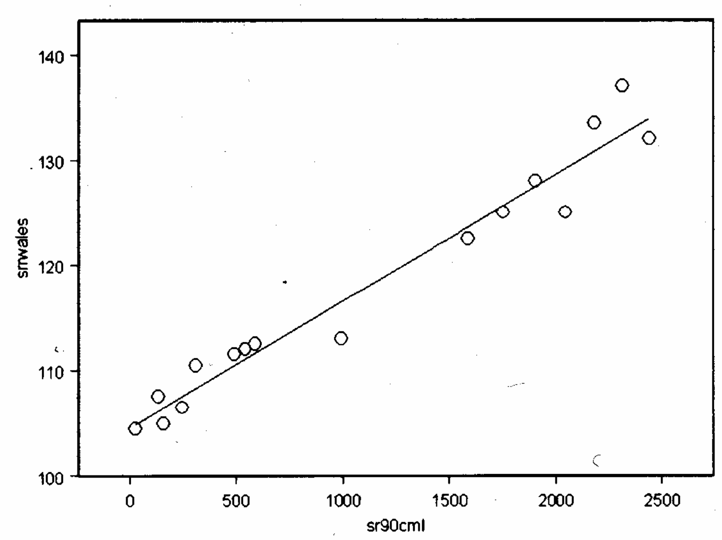

Fig 1.5.2 Cumulative dose in Wales from Strontium-90 in weapons fallout (μSv, microSieverts) 1954-1974 lagged by 20 years and plotted against Standardised Registration Ratios for all cancer 1974-1994 averaged over both sexes.

Table 2. Absolute cancer (incidence, numbers) yield following exposures from the Chernobyl accident contamination in countries of the world with data on immediate area contamination, population and committed dose (from UNESCO 1995, UNSCEAR 2011)

Country	**Population Millions**	**Committed dose (mSv)**	**Mean Cs-137 Contamin. kBq/m^2**	**10yr cancer yield Tondel**	**50yr cancer yield ECRR2010**
Albania	2.5	0.35	12.3	1526	4,385
Austria	7.6	0.7	24.6	9282	26,666
Belgium	10.1	0.06	2.0	1017	2923
Bulgaria	8.6	0.8	27.9	11904	34,198
Cyprus	0.75	0.08	2.9	105	303
Czech Rep.	10.3	1.16	41.1	21029	60415
Canada	22.1	0.011	0.41	450	1293
China	1221	0.011	0.41	24863	71430
Denmark	5.3	0.05	1.85	478	1375
Estonia	1.53	0.3	0.85	811	2360
Finland	4.8	0.58	18.1	4299	12350
France	54.5	0.076	2.67	7216	20731
Germany	78.5	0.18	6.16	23808	68400
Greece	9.7	0.59	21.0	10069	28929
Hungary	10.6	0.25	9.0	4747	13637
Ireland	3.1	0.11	4.11	631	1812
Italy	56.2	0.35	12.3	34319	98596
Israel	5.55	0.1	3.7	1015	2918
Japan	119.5	0.011	0.4	2432	13976
S Korea	3.4	0.011	0.4	690	1982
Latvia	2.5	0.3	10.69	1331	3823
Lithuania	3.7	0.3	10.69	1966	5648
Luxembourg	0.35	0.1	3.7	64	184
Netherlands	14.4	0.07	2.46	1758	5052
Norway	4.13	0.25	9.0	1849	5313
Poland	36.9	0.3	10.7	19529	56105
Romania	22.9	0.6	20	22671	68013
Russian Rep	148.1	0.49	17.4	128160	368186
Slovakia	5.3	0.1	3.6	955	2865
Slovenia	1.9	0.46	16	1571	4713
Spain	38.2	0.001	0.5	113	400
Sweden	8.3	0.57	20	8212	24600
Switzerland	6.5	0.34	12	3861	11583
Syria	14.1	0.02	0.9	577	1659
Turkey	48	0.14	5	11880	47520
UK	56	0.04	1.4	3689	11461
USA	235	0.011	0.4	4783	13742
Ukraine	50.7	0.95	33	83594	240157
Belarus	9.9	2.0	70	34460	99000
Total				491,794	1,438,703

4. Discussion

The results obtained by the two methods I have used compare well with each other. The ECRR 50 year cancer yield is about three times the value for the 10 year excess found by Tondel et al 2004 in Sweden, based on Cs-137 contamination. However, the cancers caused by the Chernobyl accident are likely to show in the first ten or 15 years and then reduce in number. The yield of about 1.4 million cancers worldwide also agrees quite well with the calculations of John Gofman, with Rosalie Bertell and also with Alexey Yablokov. The ECRR method used was developed in 2003, before Tondel et al published the results of their study of cancer in Sweden. Yet the ECRR 2003 method predicted what they found with a fair degree of accuracy. It should be noted that Tondel et al found an 11% increase in cancer at contamination levels of $100kBqm^{-2}$ and at this level the annual external doses from the Caesium are about 3mSv, around natural background, and should not have cause any increase in cancer. It was not, of course, these external doses that caused the damage, but internal exposures to radioactive substances that were also there at the time, substances which carried enhanced hazard from a number of biophysical and biochemical sources discussed in ECRR2003 and ECRR2010.

It should be noted that this study has focused only on cancer. ECRR2010 also predicts significant harm from a wide range of conditions and causes of death, including heart disease, strokes, diabetes, congenital illness in children, infant mortality and loss of fertility as a result of damage to sperm and ova. In general it is now clear that radiation causes a general loss of lifespan through premature ageing and therefore, as in the areas heavily contaminated from Chernobyl, the overall increases in cancer predicted here on a linear basis may be truncated at higher doses by competing causes of early death.

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5. Conclusions

Two separate methods have been employed to calculate the global cancer yield of the Chernobyl accident. The results show between approximately 492,000 and 1.4 million incident cancers in the 10 years and 50 years following exposure. These results agree rather well with earlier estimates by Gofman (1990), Bertell (2006) and epidemiological approaches to deaths using real data by Yablokov (2011) but are much greater than those published by the World Health Organisation and the International Atomic Energy Agency or by Fairlie and Sumner 2006.

The agreement between the ECRR2003 method employed and real data on cancer from ex Soviet Union areas contaminated by Chernobyl, from weapons fallout and Sweden after Chernobyl suggests that the current approach to modelling radiation risk based on the ICRP dependence on the external exposures of the Japan A-Bomb survivor cohorts is erroneous (Lesvos Declaration 2009). The matter has significant implications for policy in the case of Fukushima.

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Appendix

The ECRR Biological Equivalent Dose **B** in bioSieverts in tissue **T** resulting from exposures **E** of quality **R** is:

$$B_{T,E} = \Sigma_R N_E H_{T,R}$$

Where N is the hazard enhancement weighting factor for J different biophysical (e.g. Auger emitters, 2nd event, particulates) and K different biochemical (e.g. DNA affinity) hazard enhancements for internal irradiation and

$$N_E = \Sigma_E W_J W_K$$

The cancer incidence yield is then

$$C = B_{T,E}\, \alpha\, P$$

or

$$C = \alpha\, P\, \Sigma_R N_E H_{T,R}$$

Where P is the population exposed to dose B and α is the absolute cancer risk factor per bioSievert ECRR which is 0.1