Solid-Tumor Mortality in the Vicinity of Uranium Cycle Facilities and Nuclear Power Plants in Spain

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To ascertain solid tumor mortality in towns near Spain's four nuclear power plants and four nuclear fuel facilities from 1975 to 1993, we conducted a mortality study based on 12,245 cancer deaths in 283 towns situated within a 30-km radius of the above installations. As nonexposed areas, we used 275 towns lying within a 50- to 100-km radius of each installation, matched by population size and sociodemographic characteristics (income level, proportion of active population engaged in farming, proportion of unemployed, percentage of illiteracy, and province). Using log-linear models, we examined relative risk for each area and trends in risk with increasing proximity to an installation. The results reveal a pattern of solid-tumor mortality in the vicinity of uranium cycle facilities, basically characterized by excess lung [relative risk (RR) 1.12, 95% confidence interval (CI), 1.02–1.25] and renal cancer mortality (RR 1.37, 95% CI, 1.07–1.76). Besides the effects of natural radiation, these results could well be evincing the influence on public health exerted by the environmental impact of mining. No such well-defined pattern appeared in the vicinity of nuclear power plants. Monitoring of cancer incidence and mortality is recommended in areas surrounding nuclear fuel facilities and nuclear power plants, and more specific studies are called for in areas adjacent to installations that have been fully operational for longer periods. In this regard, it is important to use dosimetric information in all future studies. *Key words*: environment, epidemiology, ionizing, mortality, neoplasms, nuclear facilities, radiation, uranium mines. *Environ Health Perspect* 109:721–729 (2001). [Online 11 July 2001]
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The report that appeared in late 1983 of a cluster of leukemias in young residents living near a nuclear fuel reprocessing plant in Sellafield, England, triggered a considerable amount of investigation into cancer incidence and mortality in areas near nuclear installations. The nuclear industry generates a great deal of social concern, exacerbated recently by the serious accidents that have affected nuclear power plants, such as that of Chernobyl in 1986, and uranium processing facilities, such as the one at Tokaimura in 1999.

Cancer incidence and mortality studies in areas near nuclear facilities have failed to eliminate doubts about possible adverse population effects attributable to routine operations, despite the fact that numerous studies performed in different countries have reported an absence of cancer risk in areas around nuclear fuel facilities and power plants (*1–4*). In the main, epidemiologic studies have targeted hematologic tumors and young age groups, and very few have sought to assess in depth the remaining malignant tumors. The concern voiced by society regarding the consequences of industry in its immediate vicinity has essentially focused on nuclear power plants. With respect to industries linked to uranium production, considerable effort has been made to ascertain the risk in cohorts of miners (*5–7*), and although the environmental impact of nearby uranium mines, particularly of uranium mill tailings (*8–10*), has been studied, the related public health consequences have received scant attention.

Spain currently has seven nuclear power plants, with a total of 10 reactors (nine fully operational and one being dismantled) and nine nuclear fuel facilities (three fully operational, one shut down, and five being dismantled). We therefore performed a cancer mortality study covering towns near nuclear power plants and fuel facilities. Death certificates were the only nationwide source of information on mortality in Spain on which a first analysis of this nature could be based.

In a previous study we reported the results for hematologic tumors (*11*). In this article we report the results of that study for solid tumors. The analysis presented here sought to quantify the relative risk of death in the vicinity of such installations; to ascertain said risk before and after the date on which these installations first came into operation; to study changes in risk according to subjects' relative proximity to the respective installations; and, given the descriptive and exploratory nature of this study, to provide further pointers for new research.

Materials and Methods

A more detailed description of the methodology may be found in a previous study (*11*). Here we present results on mortality caused by stomach cancer [*International Classification of Diseases-9* (ICD) 151] and colorectal (ICD 153–154), lung (ICD 162), bone (ICD 170), connective tissue (ICD 171), breast (in women, ICD 174), brain (ICD 191), thyroid (ICD 193), bladder (ICD 188), kidney (ICD 189), ovary (ICD 183), and all malignant tumors (ICD 140–208), in towns situated near nuclear facilities. We included towns near four nuclear power plants (NPP) with six reactors that had been operational from 1975 to 1993, and four nuclear fuel facilities (NFF) that had likewise been operational in the same period. With the exception of El Cabril, a nuclear waste storage facility (NWSF) built on the site of an abandoned uranium mine, the NFF are uranium-concentrate–processing facilities located in mining areas where the ore is extracted. The latency periods used were 10 years. This lag rules out the possibility of study for the areas surrounding the Ascó, Cofrentes, Trillo, and Juzbado facilities, since all these plants were inaugurated relatively recently.

Figure 1 shows the site and year of start-up of these installations. This was a spatial mortality study whose population base comprised inhabitants of towns neighboring the nuclear installations under review. For description and analysis, the area within a 30-km radius of any such installation was called the "exposed zone"; and towns (selected as outlined below) lying within a 50- to 100-km radius of the installation were called the "reference zone." With a Geographic Information System, we used the UTM (Universal Transversa Mercator projection) centroid coordinates for towns to measure the distance from the population centroids to the nuclear installations.

Follow-up took place from 1 January 1975 through 31 December 1993. For all four nuclear power plants, 184 towns within a 30-km radius and 178 within a 50- to 100-km radius were included in the study, matched by income level, number of inhabitants, proportion of the active population engaged in farming, proportion of unemployed, percentage of illiteracy, and province.

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We selected reference towns at random from among all those that met the matching conditions. For all four nuclear fuel facilities, 99 and 97 towns in the exposed and reference zones respectively were included in the study, matched as above. The study covered 513,248 persons in the exposed zone for all types of installations. We took sociodemographic data from the 1991 census (*12*) and information on income levels from the Spanish Market Yearbook (Anuario del Mercado Español) (*13*).

Data specific to this study were supplied on computer files by the National Statistics Institute (Instituto Nacional de Estadística, Madrid, Spain). Individual records were broken down by cause of death, sex, age group, year of death, and town of residence. Town-of-residence data for deceased persons are treated as confidential in Spain for towns having fewer than 10,000 inhabitants, so we obtained special permission from the National Statistics Institute for this study.

To obtain a population breakdown by sex, age, and year for towns included in the study, we referred to the 1981 population census, 1986 municipal roll, and 1991 census, as furnished by the National Statistics Institute. Relying on a log-linear polynomial regression model, we used interpolation to estimate annual municipal population figures for 1981–1991 (*14*). We extrapolated pre-1981 and post-1991 populations by adopting a linear procedure, allocating more weight to the nearest census year. With the annual population estimates for each town, we calculated person-years for each age band (0–4, 5–14, 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75+), sex, and period (1975–1978, 1979–1983, 1984–1988, 1989–1993), taking into account variables that had changed over time, such as operational start-up of reactors and installations.

We fitted log-linear models on the assumption that the number of deaths per stratum followed a Poisson distribution. In these models, observed cases were the dependent variable. As an external standard (*15*), we used concurrent Spanish cause-specific mortality rates, with expected cases computed by age, sex, and period for each town in the exposed and reference (control) zones. Expected cases were included as offset in the models. A term we called "exposure" (a radius of 30 km or less from the facility), was included as the independent variable. The regression coefficient of this exposure term gave us the logarithm of the ratio between the respective standard mortality ratios (SMRs) for the exposed and reference zones, which we called "relative risk" (RR). This estimator was adjusted for age, sex, period, and matching variables.

We fitted similar models to study the effect of distance on mortality. We constructed this variable by categorizing distances in the 0- to 30-km belt into five levels (consisting of circular sectors having equal surface areas), and using towns situated at a distance of 50–100 km as the reference level. Expressed in kilometers, the cut-off points for the intervals were 0–, 13.4–, 19.6–, 23.2–, 26.8–30, and 50–100. This was included in all models both as a categoric and as a continuous variable (in kilometers). Thus, it was possible, for the former, to estimate the effect for the respective distances and, for the latter, to ascertain the existence of radial effects (rise in RR with increasing proximity to an installation) and, by applying the likelihood ratio test, the statistical significance of such distance-induced effects. The test was also applied to the 0–30-km area with the reference area excluded. We included matching variables in this analysis to ensure control of possible gradients in these variables with proximity to the installation. Given the heterogeneity of the installations, we ran specific analyses on individual and a joint analysis on all installations.

We studied changes in risk by comparing the positions before and after the date on which nuclear power plants and fuel facilities first came into operation (start-up), taking latency periods into account. These periods were included in the assessment of risk before start-up. The statistical significance of this change was obtained following two criteria: fitting a model that compares the SMRs before versus after start-up only for the 0–30 km areas; and a likelihood ratio test, which evaluates the interaction term—exposure × plant operation—in regression models, also including reference areas. The former evaluates time trends in exposed areas in contrast with trends at the national level, and the latter evaluates time trend differences between exposed and unexposed areas (reference areas).

We calculated relative risk confidence intervals (CIs) using the standard errors of the parameters yielded by the model. We checked and corrected model results for overdispersion problems (*16*) using the robust methods recommended by Breslow, because these methods are insensitive to the form adopted by variance (*17*).

Results

The socioeconomic characteristics and contribution in terms of person-years of populations residing near nuclear installations are described elsewhere (*11*). According to the 1991 census, the study population in the 30-km belt totaled 204,672 and 308,576 for nuclear power plants and fuel facilities, respectively.

Tables 1 and 2 show the number of observed deaths, SMRs, for the reference zones and areas in a radius of 0–15 and 0–30 km of each installation, and the RRs and CIs yielded by comparison with the reference zones, for both sexes and across all age groups, for the different causes studied. Table 3 shows relative risk by distance from the respective installations, for tumors causing at least 10 deaths in the study period. The results of the pre- and poststart-up analysis appear in Table 4.

In the vicinity of the Sta M. de Garoña nuclear power plant (Burgos) (Table 1) an RR of 1.34 (95% CI, 1.06–1.70) was

Figure 1. Site and year of start-up of nuclear power plants and fuel facilities in Spain.

Table 1. Comparison of cause-specific mortality in areas within a 15- and 30-km radius of nuclear power plants against that in reference (control) towns lying within a radius of 50–100 km.

	Control		0–15 km		0–30 km		0–15 km		0–30 km	
Installation/cause	Obs	SMR[a]	Obs	SMR[a]	Obs	SMR[a]	RR[b]	95% CI	RR[b]	95% CI
All power plants										
Lung	551	0.740	96	0.688	690	0.692	0.947	0.750–1.195	0.929	0.791–1.090
Bones	28	0.956	7	1.289	38	0.966	1.355	0.590–3.112	0.967	0.593–1.577
Breast (women)	206	0.834	23	0.538	298	0.911	0.633	0.412–0.974	1.066	0.892–1.273
Brain	116	1.371	8	0.529	128	1.128	0.376	0.183–0.770	0.833	0.647–1.072
Thyroid	11	0.921	0	0.000	8	0.507	0.000	–	0.543	0.218–1.353
Bladder	142	0.800	21	0.619	197	0.835	0.788	0.498–1.246	1.028	0.829–1.276
Ovary	40	0.771	3	0.336	55	0.804	0.450	0.141–1.436	1.021	0.678–1.536
Connective tissue	10	0.655	3	1.120	24	1.180	1.970	0.536–7.243	1.903	0.908–3.986
Kidney	66	1.089	14	1.251	75	0.931	1.178	0.660–2.102	0.845	0.607–1.178
Stomach	460	1.088	86	1.076	612	1.085	0.989	0.761–1.285	1.019	0.879–1.182
Colorectal	360	0.880	67	0.883	483	0.892	0.995	0.766–1.293	1.010	0.881–1.158
All cancers	3,552	0.854	598	0.775	4,686	0.846	0.911	0.825–1.006	0.987	0.918–1.063
Zorita (1979–1993)										
Lung	128	0.621	35	0.644	145	0.647	1.038	0.683–1.577	1.042	0.814–1.332
Bones	7	0.804	2	0.874	7	0.741	1.087	0.227–5.205	0.922	0.324–2.620
Breast (women)	52	0.812	12	0.717	49	0.734	0.884	0.475–1.646	0.905	0.614–1.334
Brain	42	1.790	2	0.327	26	1.068	0.183	0.044–0.752	0.597	0.366–0.973
Thyroid	4	1.238	0	0.000	2	0.571	0.000	–	0.461	0.085–2.509
Bladder	35	0.690	8	0.600	47	0.825	0.870	0.404–1.871	1.195	0.773–1.848
Ovary	9	0.683	1	0.290	8	0.585	0.425	0.055–3.278	0.856	0.331–2.216
Connective tissue	0	0.000	2	1.993	6	1.484	–	–	–	–
Kidney	16	0.969	3	0.690	13	0.723	0.713	0.208–2.445	0.747	0.359–1.552
Stomach	145	1.174	36	1.099	161	1.167	0.936	0.648–1.351	0.994	0.785–1.259
Colorectal	91	0.810	31	1.046	117	0.943	1.291	0.859–1.940	1.164	0.886–1.531
All cancers	947	0.817	247	0.810	1,040	0.820	0.991	0.859–1.143	1.003	0.901–1.118
Garoña (1981–1993)										
Lung	208	0.762	16	0.410	234	0.613	0.538	0.324–0.894	0.805	0.668–0.970
Bones	11	0.990	0	0.000	7	0.460	0.000	–	0.465	0.180–1.199
Breast (women)	75	0.808	3	0.282	104	0.819	0.349	0.113–1.076	1.014	0.753–1.364
Brain	46	1.441	2	0.525	50	1.134	0.364	0.089–1.485	0.786	0.528–1.170
Thyroid	5	1.128	0	0.000	2	0.328	0.000	–	0.291	0.057–1.495
Bladder	55	0.854	5	0.503	64	0.717	0.590	0.238–1.458	0.839	0.586–1.203
Ovary	16	0.826	0	0.000	14	0.527	0.000	–	0.638	0.312–1.305
Connective tissue	7	1.235	1	1.495	6	0.776	1.211	0.149–9.814	0.628	0.212–1.865
Kidney	27	1.215	3	0.971	31	1.007	0.799	0.242–2.631	0.828	0.494–1.387
Stomach	170	1.082	38	1.667	314	1.448	1.541	1.057–2.247	1.338	1.055–1.698
Colorectal	111	0.739	13	0.609	161	0.778	0.823	0.464–1.461	1.053	0.827–1.341
All cancers	1,354	0.882	128	0.597	1,709	0.805	0.677	0.535–0.857	0.913	0.776–1.075
Vandellós (1982–1993)										
Lung	163	0.793	38	1.006	264	0.790	1.269	0.963–1.672	0.996	0.768–1.292
Bones	9	1.140	5	3.409	22	1.675	2.989	1.003–8.904	1.469	0.679–3.180
Breast (women)	65	0.937	7	0.549	131	1.156	0.586	0.277–1.240	1.233	0.889–1.711
Brain	22	0.949	4	0.909	46	1.175	0.958	0.330–2.780	1.239	0.593–2.587
Thyroid	2	0.609	0	0.000	4	0.763	0.000	–	1.254	0.230–6.842
Bladder	41	0.845	7	0.809	79	1.033	0.958	0.430–2.133	1.223	0.839–1.781
Ovary	10	0.685	1	0.378	29	1.227	0.551	0.071–4.290	1.792	0.879–3.653
Connective tissue	3	0.694	0	0.000	5	0.692	0.000	–	0.997	0.241–4.120
Kidney	18	1.077	8	2.638	26	0.968	2.450	1.066–5.633	0.899	0.493–1.638
Stomach	102	0.894	10	0.488	112	0.613	0.546	0.285–1.045	0.686	0.510–0.924
Colorectal	126	1.121	19	0.945	171	0.960	0.843	0.567–1.254	0.857	0.669–1.097
All cancers	980	0.858	187	0.901	1,656	0.900	1.050	0.925–1.193	1.049	0.946–1.163
Almaraz (1991–1993)										
Lung	52	0.863	7	0.823	47	0.824	0.953	0.384–2.368	0.954	0.619–1.469
Bones	1	0.631	0	0.000	2	1.296	0.000	–	2.054	0.189–22.370
Breast (women)	14	0.678	1	0.378	14	0.703	0.557	0.074–4.180	1.036	0.494–2.172
Brain	6	0.994	0	0.000	6	1.025	0.000	–	1.032	0.333–3.199
Bladder	11	0.788	1	0.502	7	0.528	0.638	0.085–4.795	0.670	0.260–1.726
Ovary	5	1.064	1	1.636	4	0.885	1.537	0.182–12.989	0.832	0.223–3.097
Connective tissue	0	0.000	0	0.000	7	5.215	–	–		
Kidney	5	0.969	0	0.000	5	1.016	0.000	–	1.048	0.303–3.620
Stomach	43	1.537	2	0.517	25	0.939	0.337	0.083–1.372	0.611	0.339–1.100
Colorectal	32	0.932	4	0.845	34	1.039	0.907	0.321–2.564	1.115	0.688–1.807
All cancers	271	0.843	36	0.812	281	0.917	0.964	0.693–1.340	1.087	0.894–1.322

Obs, Observed cases. Latency period of 10 years.
[a]SMR is the ratio of the number of deaths observed and expected at concurrent death rates in Spain. [b]RR compares the risk in study versus control areas. The RR for combined facilities is obtained from a regression model including the facilities as a factor, and differs from the simple ratio of the SMRs.

Table 2. Comparison of cause-specific mortality in areas within a 15- and 30-km radius of nuclear fuel facilities against that in reference (control) towns lying within a radius of 50–100 km.

	Control		0–15 km		0–30 km		0–15 km		0–30 km	
Installation/cause	Obs	SMR[a]	Obs	SMR[a]	Obs	SMR[a]	RR[b]	95% CI	RR[b]	95% CI
Nuclear fuel facilities										
Lung	1,429	0.895	379	0.915	1,424	1.022	1.123	0.953–1.324	1.124	1.015–1.246
Bones	51	0.685	18	0.918	66	1.017	1.209	0.699–2.091	1.512	1.048–2.182
Breast (women)	471	0.789	122	0.805	436	0.858	1.059	0.783–1.432	1.077	0.921–1.259
Brain	185	0.879	41	0.740	140	0.777	0.862	0.609–1.220	0.875	0.702–1.090
Thyroid	17	0.619	7	0.998	24	1.002	1.721	0.693–4.274	1.604	0.860–2.993
Bladder	331	0.887	56	0.581	251	0.760	0.707	0.531–0.943	0.837	0.690–1.015
Ovary	70	0.578	22	0.720	95	0.925	1.481	0.895–2.449	1.525	1.119–2.078
Connective tissue	38	1.100	4	0.452	20	0.684	0.462	0.163–1.313	0.608	0.353–1.046
Kidney	114	0.856	32	0.932	136	1.171	1.220	0.816–1.825	1.374	1.071–1.763
Stomach	892	0.892	225	0.869	752	0.849	0.930	0.782–1.105	0.963	0.865–1.073
Colorectal	667	0.733	199	0.853	677	0.847	1.205	0.989–1.470	1.153	1.009–1.317
All cancers	8,124	0.870	2,139	0.889	7,559	0.927	1.064	0.964–1.175	1.056	1.000–1.114
Andújar (1975–1993)										
Lung	686	0.768	291	0.927	670	0.954	1.207	1.000–1.456	1.242	1.056–1.461
Bones	39	0.821	15	0.899	39	1.039	1.095	0.604–1.984	1.265	0.813–1.970
Breast (women)	237	0.705	97	0.838	206	0.790	1.188	0.856–1.649	1.121	0.887–1.416
Brain	111	0.877	34	0.749	75	0.747	0.854	0.605–1.205	0.851	0.641–1.130
Thyroid	8	0.517	4	0.756	8	0.663	1.461	0.444–4.810	1.281	0.481–3.413
Bladder	160	0.759	42	0.583	113	0.688	0.768	0.581–1.015	0.906	0.718–1.145
Ovary	25	0.382	18	0.797	43	0.848	2.087	1.141–3.819	2.220	1.358–3.628
Connective tissue	16	0.868	4	0.606	10	0.683	0.698	0.234–2.082	0.787	0.359–1.722
Kidney	56	0.760	18	0.702	52	0.899	0.924	0.543–1.570	1.184	0.812–1.726
Stomach	524	0.858	174	0.836	377	0.791	0.975	0.805–1.180	0.922	0.792–1.073
Colorectal	342	0.672	138	0.795	320	0.806	1.183	0.904–1.549	1.200	0.966–1.491
All cancers	4,282	0.799	1,617	0.873	3,646	0.870	1.093	0.970–1.231	1.088	1.002–1.183
El Cabril[c] (1975–1993)										
Lung	259	1.124	–	–	351	1.210	–	–	1.077	0.858–1.351
Bones	5	0.410	–	–	15	0.979	–	–	2.389	0.870–6.557
Breast (women)	64	0.742	–	–	117	1.094	–	–	1.476	1.085–2.007
Brain	34	1.020	–	–	37	0.964	–	–	0.945	0.594–1.506
Thyroid	2	0.506	–	–	6	1.149	–	–	2.270	0.459–11.236
Bladder	55	1.035	–	–	73	1.010	–	–	0.976	0.661–1.442
Ovary	17	1.009	–	–	30	1.456	–	–	1.443	0.796–2.615
Connective tissue	5	1.018	–	–	9	1.618	–	–	1.590	0.533–4.744
Kidney	13	0.685	–	–	31	1.279	–	–	1.866	0.853–4.082
Stomach	100	0.651	–	–	161	0.763	–	–	1.171	0.911–1.505
Colorectal	93	0.720	–	–	152	0.874	–	–	1.214	0.940–1.567
All cancers	1,269	0.928	–	–	1,845	1.037	–	–	1.117	0.993–1.257
La Haba (1987–1993)										
Lung	421	1.141	49	0.842	336	1.103	0.738	0.553–0.984	0.967	0.835–1.120
Bones	7	0.578	1	0.553	10	1.044	0.957	0.118–7.764	1.806	0.691–4.718
Breast (women)	150	1.068	10	0.481	87	0.798	0.451	0.187–1.089	0.747	0.554–1.009
Brain	33	0.804	4	0.678	25	0.769	0.844	0.302–2.363	0.957	0.569–1.608
Thyroid	5	0.792	3	2.998	9	1.782	3.787	0.905–15.838	2.251	0.755–6.713
Bladder	98	1.174	7	0.497	54	0.777	0.424	0.158–1.134	0.662	0.396–1.104
Ovary	21	0.680	3	0.650	20	0.827	0.956	0.285–3.199	1.216	0.660–2.243
Connective tissue	16	1.781	0	0.000	1	0.143	0.000	–	0.080	0.011–0.602
Kidney	44	1.400	13	2.595	49	1.911	1.853	0.999–3.439	1.365	0.852–2.189
Stomach	183	0.983	31	1.021	162	1.070	1.038	0.709–1.519	1.088	0.881–1.344
Colorectal	184	0.874	43	1.248	163	0.954	1.428	1.025–1.989	1.091	0.870–1.369
All cancers	2,117	1.036	315	0.968	1,662	1.002	0.935	0.817–1.070	0.967	0.894–1.047
Ciudad Rodrigo (1989–1993)										
Lung	63	0.603	39	0.930	67	0.699	1.544	1.036–2.302	1.160	0.764–1.762
Bones	0	0.000	2	1.812	2	0.824	–	–	–	–
Breast (women)	20	0.586	15	1.005	26	0.819	1.716	0.879–3.351	1.398	0.781–2.505
Brain	7	0.725	3	0.732	3	0.341	1.010	0.262–3.894	0.471	0.122–1.820
Thyroid	2	1.162	0	0.000	1	0.621	0.000	–	0.534	0.048–5.879
Bladder	18	0.694	7	0.683	11	0.453	0.984	0.411–2.356	0.653	0.309–1.382
Ovary	7	0.893	1	0.297	2	0.277	0.332	0.042–2.646	0.310	0.065–1.492
Connective tissue	1	0.454	0	0.000	0	0.000	–	–	–	–
Kidney	1	0.110	1	0.271	4	0.475	2.463	0.154–39.367	4.314	0.496–37.546
Stomach	85	1.704	20	0.982	52	1.110	0.576	0.354–0.938	0.651	0.461–0.920
Colorectal	48	0.779	18	0.714	42	0.725	0.917	0.533–1.576	0.930	0.615–1.407
All cancers	456	0.809	207	0.898	406	0.774	1.109	0.885–1.391	0.956	0.745–1.226

Obs, Observed cases. Latency period of 10 years.
[a]SMR is the ratio of the number of deaths observed and expected at concurrent death rates in Spain. [b]RR compares the risk in study versus control areas. The RR for combined facilities is obtained from a regression model including the facilities as a factor, and differs from the simple ratio of the SMRs. [c]No towns within 15 km of the installation.

observed for stomach cancer, with the relative risk similar for men and women (data not shown). In Vandellós, excess renal and bone cancer was in evidence in the 15-km belt. For the Zorita area, six deaths occurred from connective tissue tumors, versus no deaths in the reference area. Four of these were men and two were women. Four of the cases resided in towns more than 19 km from the plant. Almaraz had somewhat similar conditions, with seven deaths from connective tissue tumors versus none in the reference area. Six of these cases were men and occurred in towns lying 26–30 km from the plant. Three people died before start-up (Table 4).

Overall, we observed no excess mortality for tumor sites as a whole in areas around nuclear power plants in Spain (Table 1). The highest relative risk was registered for connective tissue tumors (RR 1.90 95%; CI, 0.91–3.99), with 13 cases reported in the Almaraz and Zorita areas.

In the near-versus-far analysis of all fuel cycle facilities as a whole (Table 2), we detected statistically significant excess mortality for lung, bone, ovarian, renal, and colorectal cancer.

Examination of the results by facility showed excess cancer mortality of almost 9% in the area surrounding the Andújar plant. This excess was attributable to higher-than-expected lung, ovarian, and colorectal cancer mortality.

The El Cabril area registered a statistically significant excess breast cancer mortality among women (RR 1.48; 95% CI, 1.09–2.01). Comparison between the 15-km radius around the La Haba plant and the reference area showed a higher risk of colorectal cancer mortality (RR 1.43; 95% CI, 1.03–1.49), an RR of 1.85 (95% CI, 1.00–3.44) for renal cancer, and an RR of 3.79 (95% CI, 0.91–15.84) for thyroid cancer. Renal cancer registered an SMR that was almost 2 vis-à-vis the national reference and was statistically significant.

The most noteworthy finding in the Ciudad Rodrigo area was the higher risk of death from lung cancer observed for all towns nearest (0–15 km) the installation (RR 1.54; 95% CI, 1.04–2.30).

The RR point estimator for renal cancer exceeded 1 for all areas surrounding uranium cycle facilities. Overall, we observed excess

Table 3. Relative risks according to distance of population centroids from nuclear power plants and fuel facilities, with test for trend.

Reference > 50 km	Distance					*p*-Value for trend	
Installation/cause	26.8–30 km	23.2–26.7 km	19–23.1 km	13.4–18.9 km	0–13.3 km	Exposed area only	Exposed and reference areas
All power plants							
Lung	0.816	0.896	1.034	0.827	1.049	0.4881	0.0854
Bones	0.541	1.223	1.026	1.215	1.595	0.1210	0.6447
Breast (women)	0.965	1.108	1.233	1.008	0.721	0.3767	0.3594
Brain	0.870	0.415	0.912	0.993	0.427	0.1993	0.1802
Bladder	1.096	1.231	1.039	0.982	0.728	0.1612	0.8061
Ovary	0.844	1.345	0.961	1.527	0.521	0.7689	0.2773
Kidney	0.588	0.404	0.798	1.478	1.284	0.0065	0.2872
Stomach	1.042	0.980	0.992	1.074	1.004	0.9288	0.9314
Colorectal	1.129	0.917	0.992	0.916	1.010	0.3452	0.8983
All cancers	0.929	0.984	1.021	1.030	0.961	0.4573	0.2080
Zorita							
Lung	1.052	0.982	1.258	0.892	1.136	0.9719	0.8483
Breast (women)	1.008	0.633	0.938	0.649	0.981	0.9948	0.4642
Brain	0.893	0.000	0.599	1.556	0.194	0.2467	0.4857
Bladder	1.393	1.197	1.601	0.918	0.876	0.2522	0.5501
Kidney	0.296	0.737	0.678	3.150	0.549	0.3246	0.2937
Stomach	1.263	0.947	0.981	0.951	0.983	0.2101	0.5722
Colorectal	1.220	0.984	1.274	1.188	1.230	0.9011	0.1626
All cancers	0.978	0.973	1.094	1.046	1.013	0.7640	0.8231
Garoña							
Lung	0.559	0.854	0.957	0.905	0.727	0.0903	0.0631
Breast (women)	0.652	0.492	1.232	0.769	0.693	0.0787	0.3924
Brain	0.889	0.925	0.899	0.313	0.515	0.3521	0.2508
Bladder	0.615	0.665	0.505	0.970	0.611	0.9103	0.0128
Kidney	0.686	0.002	0.714	0.492	1.527	0.1577	0.2624
Stomach	1.215	1.455	1.206	1.643	1.749	0.0280	0.0036
Colorectal	1.092	1.772	1.087	0.714	0.829	0.1475	0.7998
All cancers	0.808	0.948	0.880	0.862	0.846	0.2270	0.0001
Vandellós							
Lung	0.904	1.067	1.104	1.058	1.315	0.5478	0.7494
Bones	0.808	3.519	1.632	3.054	3.622	0.0740	0.0432
Breast (women)	1.540	1.607	1.162	1.001	0.519	0.0296	0.3359
Brain	1.123	1.012	1.862	1.290	1.415	0.3156	0.6061
Bladder	1.407	1.733	1.085	0.907	0.952	0.5487	0.4473
Ovary	1.673	3.040	1.494	3.554	0.427	0.1842	0.6466
Kidney	0.463	0.193	0.555	0.839	2.039	0.0019	0.4970
Stomach	0.764	0.870	0.715	1.065	0.553	0.8251	0.0344
Colorectal	1.272	0.752	0.732	0.910	0.918	0.2919	0.7669
All cancers	1.068	1.106	1.068	1.139	1.044	0.7296	0.0849
Almaraz							
Lung	0.742	0.001	1.376	0.739	1.443	0.6561	0.4659
Breast (women)	1.629	3.496	1.174	0.785	0.766	0.3761	0.7295
Stomach	0.371	0.001	0.199	1.207	0.541	0.7098	0.0249
Colorectal	0.947	0.001	3.064	0.842	0.940	0.3765	0.6772
All cancers	0.988	0.378	1.393	1.055	1.102	0.3850	0.7145

continued, next page

cancer mortality (for all tumor sites as a whole) for fuel cycle facilities, in great measure reflecting excess lung cancer among men.

Analysis of mortality in relation to distance from any given installation yielded results that differed widely according to the radius of application of the statistical test used. Two different tests are included in Table 3: The first ascertains the statistical significance of the slope of relative risk solely in the exposed area, whereas the second addresses the entire study area. In Garoña, stomach cancer plotted a statistically significant gradient with both tests. Similarly, for bone cancer, there appears to be a risk gradient proportional to the proximity to Vandellós. For renal cancer in Garoña and Vandellós, the highest risks corresponded to the area closest to the installation, thus accounting for the statistical significance of the test for the exposed area in Vandellós and for the joint analysis of all four nuclear power plants (Table 3).

The different limitations of these two statistical tests can be observed better in Table 3, in which analysis of all fuel cycle facilities is displayed jointly. The statistical significance of the test covering the entire study area is in sharp contrast to the RR estimators for the different distances, in that these show no gradient with proximity to the installation. None of the statistical tests covering the entire study area were confirmed when applied to the 30-km radius. The El Cabril risk estimators for renal cancer were determined by the low number of cases in towns lying nearest the plant and the stringent stratification applied in the analysis. The greatest number of cases (22 of 31) occurred in the most distant towns (> 26 km), so that

Table 3 (*continued*).

Reference > 50 km	Distance					*p*-Value for trend	
Installation/Cause	26.8–30 km	23.2–26.7 km	19–23.1 km	13.4–18.9 km	0–13.3 km	Exposed area only	Exposed and reference areas
Nuclear fuel facilities							
Lung	1.077	1.164	1.073	1.172	1.113	0.6564	0.2313
Bones	1.953	1.487	1.276	1.816	1.233	0.2510	0.0353
Breast (women)	0.920	1.487	1.014	0.979	1.182	0.1435	0.7317
Brain	0.898	0.603	0.838	1.026	0.866	0.8540	0.1153
Thyroid	1.880	0.002	1.852	1.937	1.402	0.5036	0.1987
Bladder	0.744	1.090	0.778	1.026	0.713	0.6837	0.0098
Ovary	1.821	1.563	1.451	1.058	1.485	0.2658	0.0209
Kidney	1.434	2.113	1.210	1.327	1.317	0.3683	0.0066
Stomach	0.916	1.028	1.026	0.939	0.962	0.7711	0.7905
Colorectal	1.072	1.361	1.045	1.268	1.121	0.9606	0.0510
All cancers	1.010	1.139	1.014	1.073	1.073	0.3005	0.1819
Andújar							
Lung	1.060	1.361	1.254	1.415	1.106	0.7278	0.1446
Bones	2.189	2.329	0.966	1.721	1.484	0.4531	0.0852
Breast (women)	0.778	1.126	1.115	2.052	1.188	0.1533	0.4396
Brain	0.810	0.732	1.006	0.414	0.796	0.7472	0.2566
Bladder	1.096	0.952	0.907	1.536	0.792	0.5245	0.2361
Ovary	2.204	3.464	2.325	1.439	2.381	0.8357	0.0010
Kidney	2.013	2.013	1.054	0.437	1.019	0.0455	0.3409
Stomach	0.919	1.045	0.955	0.606	1.059	0.7610	0.7349
Colorectal	1.349	1.377	1.110	1.737	1.232	0.9096	0.0716
All cancers	1.026	1.127	1.091	1.277	1.087	0.3930	0.0305
El Cabril							
Lung	0.880	1.941	0.689	1.922	–	0.5973	0.6611
Bones	2.283	0.039	9.312	31.621	–	0.6478	0.0769
Breast (women)	1.276	6.283	1.694	3.320	–	0.8897	0.1916
Brain	0.940	1.027	0.892	1.481	–	0.5623	0.6127
Bladder	0.574	1.305	0.644	2.207	–	0.3417	0.0125
Ovary	1.702	3.376	0.169	1.186	–	0.2202	0.3496
Kidney	4.620	6.760	10.837	11.892	–	0.5855	0.0015
Stomach	0.898	1.848	0.957	2.806	–	0.1553	0.8829
Colorectal	0.996	2.060	1.234	1.487	–	0.5405	0.5016
All cancers	0.962	2.202	0.921	1.587	–	0.5087	0.9713
La Haba							
Lung	0.943	0.856	1.101	0.956	0.920	0.8782	0.4601
Bones	3.590	0.002	1.299	1.651	0.001	0.3149	0.1859
Breast (women)	0.817	0.728	1.048	0.648	0.768	0.6401	0.0188
Brain	0.396	0.003	0.906	1.094	1.136	0.2393	0.4265
Bladder	0.586	2.290	0.416	0.811	0.373	0.5640	0.1575
Ovary	1.807	0.010	2.611	0.919	1.068	0.3564	0.3906
Kidney	0.995	0.002	1.653	1.330	3.281	0.2138	0.0498
Stomach	0.921	1.402	1.364	1.010	1.130	0.9893	0.5535
Colorectal	1.002	0.001	1.042	1.198	1.260	0.2678	0.3414
All cancers	0.910	0.781	1.073	0.961	1.089	0.2641	0.3495
Ciudad Rodrigo							
Lung	0.714	0.582	1.851	1.334	1.493	0.0502	0.1446
Breast (women)	0.593	1.266	0.737	2.287	1.742	0.3510	0.1627
Bladder	0.000	1.090	1.007	0.000	0.799	0.6358	0.3950
Stomach	0.784	0.874	0.806	0.671	0.518	0.3541	0.0173
Colorectal	1.183	1.007	0.268	1.588	0.987	0.9753	0.9677
All cancers	0.889	0.974	1.029	0.964	1.061	0.9377	0.6539

Only tumor sites with 10 or more observed deaths are shown. Estimates have been adjusted for matching variables. The most distant towns (radius 50–100 km) are taken as reference.

Table 4. Estimated relative risk for study areas (0–30 km) before and after the date on which nuclear facilities first came into operation (before and after start-up).

	Before start-up		After start-up		After vs. before start-up		Trend differences
Installation/cause	Obs	SMR[a]	Obs	SMR	RR[b]	*p*-Value	*p*-Value[c]
Zorita		1975–1978[d]		1979–1993			
Lung	21	0.435	145	0.647	1.486	0.0893	0.9677
Bones	7	1.752	7	0.741	0.423	0.1070	0.7483
Breast (women)	9	0.576	49	0.734	1.274	0.5008	0.9585
Brain	8	1.135	26	1.068	0.942	0.8815	0.2386
Thyroid	0	0.000	2	0.571	–	0.7805	0.3726
Bladder	5	0.346	47	0.825	2.384	0.0617	0.1470
Ovary	1	0.472	8	0.585	1.240	0.8393	–[e]
Connective tissue	0	0.000	6	1.484	–	0.7687	–
Kidney	4	1.014	13	0.723	0.713	0.5540	0.1634
Stomach	67	1.159	161	1.167	1.008	0.9579	0.7370
Colorectal	27	0.791	117	0.943	1.192	0.4095	0.5082
All cancers	269	0.777	1,040	0.820	1.055	0.4310	0.4772
Garoña		1975–1980		1981–1993			
Lung	53	0.425	234	0.613	1.443	0.0158	0.4047
Bones	7	0.685	7	0.460	0.672	0.4566	0.6727
Breast (women)	35	0.760	104	0.819	1.077	0.7027	0.9374
Brain	22	0.982	50	1.134	1.154	0.5745	0.5616
Thyroid	0	0.000	2	0.328	–	0.6062	–
Bladder	20	0.620	64	0.717	1.156	0.5691	0.3785
Ovary	6	0.858	14	0.527	0.614	0.3179	0.1555
Connective tissue	1	0.560	6	0.776	1.386	0.7613	–
Kidney	4	0.396	31	1.007	2.544	0.0785	0.6044
Stomach	152	1.197	314	1.448	1.210	0.0539	0.0700
Colorectal	53	0.683	161	0.778	1.140	0.4070	0.4535
All cancers	632	0.743	1,709	0.805	1.084	0.0840	0.3868
Vandellós		1975–1981		1982–1993			
Lung	80	0.583	264	0.790	1.355	0.0173	0.7829
Bones	7	0.631	22	1.675	2.655	0.0232	0.2687
Breast (women)	20	0.399	131	1.156	2.893	0.0000	0.0028
Brain	28	1.085	46	1.175	1.083	0.7370	0.5890
Thyroid	2	0.815	4	0.763	0.936	0.9387	–
Bladder	26	0.753	79	1.033	1.372	0.1615	0.8312
Ovary	4	0.513	29	1.227	2.392	0.1003	0.0812
Connective tissue	2	0.935	5	0.692	0.740	0.7167	0.9176
Kidney	13	1.178	26	0.968	0.822	0.5613	0.1109
Stomach	80	0.608	112	0.613	1.009	0.9509	0.2727
Colorectal	64	0.792	171	0.960	1.213	0.1873	0.6208
All cancers	683	0.747	1,656	0.900	1.205	0.0000	0.7180
Almaraz		1975–1990		1991–1993			
Lung	244	1.075	47	0.824	0.766	0.0943	0.4455
Bones	10	0.738	2	1.296	1.757	0.4662	0.3927
Breast (women)	62	0.750	14	0.703	0.937	0.8265	0.6404
Brain	24	0.718	6	1.025	1.428	0.4354	0.4406
Thyroid	2	0.504	0	0.000	0.000	0.8094	–
Bladder	31	0.559	7	0.528	0.945	0.8918	0.4909
Ovary	13	0.849	4	0.885	1.043	0.9413	0.6632
Connective tissue	3	0.675	7	5.215	7.730	0.0030	–
Kidney	21	1.132	5	1.016	0.897	0.8276	0.9145
Stomach	216	1.261	25	0.939	0.744	0.1616	0.2143
Colorectal	104	0.793	34	1.039	1.311	0.1708	0.1766
All cancers	1,359	0.968	281	0.917	0.947	0.4010	0.3964
La Haba		1975–1986		1987–1993			
Lung	424	1.106	336	1.103	0.997	0.9769	0.7334
Bones	33	1.227	10	1.044	0.851	0.6533	0.4513
Breast (women)	136	0.923	87	0.798	0.865	0.2901	0.4998
Brain	54	0.834	25	0.769	0.922	0.7361	0.8611
Thyroid	2	0.289	9	1.782	6.173	0.0198	0.0364
Bladder	51	0.556	54	0.777	1.397	0.0866	0.2231
Ovary	19	0.741	20	0.827	1.116	0.7312	0.6459
Connective tissue	2	0.288	1	0.143	0.495	0.5651	0.4995
Kidney	30	0.969	49	1.911	1.973	0.0033	0.1476
Stomach	346	1.082	162	1.070	0.989	0.9054	0.3746
Colorectal	215	0.976	163	0.954	0.977	0.8264	0.9546
All cancers	2,301	0.937	1,662	1.002	1.069	0.0389	0.0727
Ciudad Rodrigo		1975–1988		1989–1993			
Lung	103	0.511	67	0.699	1.370	0.0451	0.1229
Bones	14	1.121	2	0.824	0.735	0.6840	–
Breast (women)	53	0.770	26	0.819	1.063	0.7993	0.7471
Brain	35	1.283	3	0.341	0.266	0.0256	0.0875
Thyroid	1	0.284	1	0.621	2.184	0.5807	0.7158
Bladder	28	0.525	11	0.453	0.863	0.6781	0.1765
Ovary	5	0.411	2	0.277	0.675	0.6383	0.5592
Connective tissue	1	0.297	0	0.000	0.000	0.7792	–
Kidney	17	1.050	4	0.475	0.453	0.1484	0.1459
Stomach	250	1.491	52	1.110	0.745	0.0530	0.0478
Colorectal	111	0.922	42	0.725	0.786	0.1842	0.5707
All cancers	1,052	0.821	406	0.774	0.942	0.3034	0.9700

Obs, observed deaths. [a]SMR is the ratio of the number of deaths observed and expected at concurrent death rates in Spain. [b]RR compares SMRs after versus before start-up in the exposed areas; *p*-value corresponds to the statistical significance of this RR. [c]Statistical significance for time trend differences between exposed and unexposed areas. [d]Years included. [e]No cases in the reference area.

estimates in the nearest sectors were made on the basis of 2, 4, and 3 deaths respectively and thus exhibit a very low degree of accuracy.

Analysis of nuclear power plants before and after start-up in Garoña showed an increase in stomach cancer after the plant began operating, though this increase was just on the limit of statistical significance (Table 4). In Vandellós, we observed a rise in breast cancer mortality in women after the plant's commissioning, and in Almaraz an increase of connective tissue cancer mortality. Regarding uranium cycle facilities, no statistically significant changes could be demonstrated for any of the tumors studied, except for thyroid cancer in the vicinity of La Haba.

In evaluating time trends, it is advisable to highlight the different results obtained by the two analyses proposed. Thus, lung cancer mortality showed a greater increase in the exposed areas of Garoña, Vandellós, and Zorita, compared with the national trend, and the same was true for renal cancer in La Haba. However, it would be risky to attribute these increases to the effect of the nuclear facilities, since the corresponding unexposed areas presented a similar pattern, as is suggested by the *p*-value in the last column of Table 4.

Discussion

Overall, the results of the study indicate a cancer mortality pattern in areas adjacent to uranium cycle facilities that is basically characterized by excess deaths due to renal and lung cancer [and leukemias (*11*)]. These results may well be evincing the influence exerted on public health by the environmental impact of mining activities and the effects of natural radiation.

In this exploratory study, we have sought to estimate risk of death for 11 different tumor sites in the vicinity of 8 installations. For many of these, we analyzed different areas and time periods, thereby allowing for numerous comparisons. The results must therefore be interpreted with caution, because some of the statistically significant mortality excesses or deficits found may be attributable to chance.

The validity of death-certificate diagnoses for investigating cancer is generally accepted (*2,3,18,19*). Except for Tarragona, none of the provinces studied are equipped with population-based cancer registries that would otherwise enable cancer incidence to be studied in these areas. In the calculation of person-years, interpolation and extrapolation techniques had to be employed. We applied these techniques in the same way to all provinces and towns included in the various studies. Hence, any possible deviations inherent in the estimates, will be equally present in all areas compared.

Specific methodologic problems are posed by investigation into relatively rare diseases in areas adjacent to sources of contamination. The importance of ascertaining disease-frequency and -distribution in other areas similar in size to those being studied has been stressed (*20*), which we followed in our design. In general, the areas compared in this study were rural. We matched reference towns to exposed towns by sociodemographic variables; the towns would thus indirectly maintain their comparability in diagnostic accuracy and accessibility to the health care system. Sociodemographic information for the entire study period was not available. However, bearing in mind the universal character of the Spanish National Health System, there would be no reason to suspect differential access to health care and diagnosis between exposed and reference areas.

In theoretical terms, comparison of SMRs is open to criticism in that, internally, the SMRs use different standard populations. Nevertheless, analysis based on comparison of mortality rates (rate ratios) via models that use person-years as offset and include age yielded equivalent results.

The study of the distance variable seeks to associate mortality with the nuclear installation as the putative source of contamination. Distance to the installation tends to be used as a surrogate variable for exposure in cases where dosimetric information or the radiologic history of an installation's environs is not forthcoming (*21,22*). Indeed in this respect the study is ecologic, in that individual levels of exposure are unknown and the inhabitants of any given town are thus implicitly assumed to have received similar exposures. There will inevitably be persons who have resided for part of their lives in exposed towns and then moved to nonexposed areas, and vice versa, which would produce nondifferential misclassification errors. Moreover, information is lacking on other risk factors associated with these tumors, such as smoking or exposure to chemical agents, although we sought to control for these partly by the town matching incorporated into the overall design.

In the Garoña area an unexpected, higher risk of stomach cancer was detected in both sexes, apparently linked to proximity to the nuclear power plant. Moreover, there was a parallel deficit in lung cancer mortality in this same area. This coincidence is reminiscent of the documented cancer mortality pattern in farmers (*23*) and could be interpreted as a design failure (matching by proportion of farmers) to control for this component. Yet it is strange that this should occur solely in the Garoña area and not in the surroundings of other installations. This, coupled with the fact that Garoña is situated in Burgos province—a province with the highest stomach cancer mortality in Spain—impels us to recommend an in-depth study. It would also be advisable to analyze bone and renal cancer incidence in the vicinity of Vandellós, because associated mortality proved higher than expected in towns lying nearest the plant, although admittedly this observation was based on very few cases.

The Zorita and Almaraz areas display an excess of cases of connective tissue cancer. Taking Spain as reference, the respective SMRs are 1.48 (95% CI, 0.55–3.23) for Zorita and 5.22 (95% CI, 2.09–10.75) for Almaraz. Nonetheless, the location of these cases (mostly residents of towns situated on the limits of the study area) and the fact that cases had already been reported in this sector before start-up (Table 4), leads us to think that the causes probably lie outside the Almaraz plant, although this result, too, would appear to call for closer study.

In the literature, it is difficult to find studies that have evaluated and published nonhematologic tumor incidence and/or mortality for areas neighboring NPP, and more difficult still for areas neighboring NFF. The standard practice is to group these under the heading of "other tumors" or "solid tumors," and the findings published for this umbrella group are generally negative. Consequently, the information to which we could turn to compare our results was very limited.

We should like to stress the differences in our results between the mortality patterns around NPP and those around NFF. In the vicinity of NFF, we detected an excess risk of cancer-related death of 5.6%. This excess is, in great part, determined by lung cancer mortality, which we observed exclusively in men (RR 1.14; 95% CI, 1.03–1.27) and has been detected in the Andújar and Ciudad Rodrigo areas. In the previous study, we reported a higher risk of leukemias in these same areas (*11*). To challenge the feasibility that tobacco use has any influence on this result—and given that smoking frequencies could not be included in the analysis—one could point to the fact that there was no parallel rise in bladder cancer mortality, a tumor likewise associated with cigarette smoking.

NFF are located in areas with uranium deposits, areas where mining operations are carried out and nuclear fuel is manufactured. A cytogenetic analysis showed a greater frequency of chromosomal aberrations and an abnormal DNA-repair response for a population residing near mines/uranium processing plants versus an unexposed population, though this was based on a small study (*24,25*).

Underlying the findings for areas near NFF are two phenomena: One concerns the lung-cancer–related deaths observed in men, which could be occupational in origin; this problem has been well documented (*26*) thanks to cohort studies covering miners in the uranium industry (*27*) and (underground) miners in general (*28*). The other phenomenon stems from environmental exposure to radon produced by the degradation of uranium-238 present in the soil of granite areas, and to natural radiation (an aspect that could not be controlled for in this study) and radioactive waste; and from the consequences of mining activities on the population (*24*). Arguably, each installation might have its own peculiarities, thus highlighting the limits on the ability of any generic radiobiologic-impact assessment to reflect the conditions of all uranium facilities (*10*).

In refining the ore to produce uranium concentrates, a great volume of hazardous waste is generated, known as tailings. These tailings are often dumped outdoors. Such waste contains most of the radionuclides that are produced by uranium degradation and continue to be radioactive for hundreds of years, plus variable quantities of other toxic substances, which are either present in the mineral (e.g., heavy metals) or used in extraction. Radionuclides and chemical toxics can be dispersed more easily from such dumps than they could from their original state in the ore, as a result of hydrologic and atmospheric processes (*29*), containment-dam disasters, and the possibility of improper use in the preparation of construction materials. Danger of contamination from tailings is heightened when dumps are abandoned following mine closure. To our knowledge, there is not one single site anywhere in the world in which a uranium mine has been satisfactorily cleaned.

Residential exposure to radon is an important cause of lung cancer in the general population (*7,26*). The interaction between radon exposure and smoking with regard to lung cancer exceeded additivity and approaches a multiplicative effect (*30*).

Similarly noteworthy is the higher risk of death due to renal cancer, a tumor that registers point effect indicators exceeding 1 for all NFF studied. Excess risk is higher in women (RR 1.81; 95% CI, 1.21–2.73) than in men (RR 1.16; 95% CI, 0.84–1.59). Although these results are difficult to interpret in environmental terms, renal toxicity is known to be the most adverse side effect of exposure to uranium (*31*). Dosimetric studies of radon exposure have shown that the kidney receives the second highest doses after the lung (*7*), and animal studies have shown that radon exposure can cause renal cancer (*32*). Furthermore, some results indicate that residence in the proximity of mill tailings raises the frequency of chromosomal aberrations and DNA-repair deficiencies (*29*).

In addition to lung cancer, exposure to radon has been associated with other types of tumors (*33–35*), though there are studies that conclude the contrary (*7*). International incidence of myeloid leukemia, renal cancer, and certain childhood cancers shows a significant correlation with radon exposure in the home (*33*). In one case–control study undertaken in Italy to evaluate the effect of radon levels, odds ratios of 2–3 were found for renal cancer, in tandem with a statistically significant dose–response relationship (*34*). The existence of a high risk for this tumor has also been reported for employees of the atomic weapons establishment (*35*).

Given the nature of our study, any comments that we might advance to explain these findings would, in part, be speculative. Nevertheless, we believe that besides the effects of natural radiation, the results for NFF could well be evincing the influence exerted on public health by the environmental impact of uranium mining. It is therefore essential that mechanisms be established to monitor the incidence of cancer in provinces in which these two types of facilities are found. We likewise recommend that besides nuclear power plants as such, all radiologic and environmental monitoring devices and systems deployed in areas adjacent to installations should also cover uranium cycle facilities and mill tailings, and that the ensuing measurements be made public. Design of any future studies will require dosimetric measurements for areas surrounding such facilities, efforts to reconstruct history of exposure, and an attempt to study the problem from a multidisciplinary point of view, using biologic exposure markers.

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