3
Sellafield and the Irish Sea

The sea has always been regarded by coastal and seafaring peoples as the ideal place for dumping their waste and this is, of course, a very reasonable and proper attitude. Almost everything that is put into the sea is either diluted to insignificant concentrations or broken down by physical and biological action or stored harmlessly on the sea bed. Most of the objects that do ultimately find their way to the shore are harmless and are a considerable source of pleasure to children.

Mr H.J Dunster, United Kingdom Atomic Energy Authority,
(Proceedings of the International Conference
on the Peaceful Uses of Atomic Energy, Geneva 1958)

It is hard to imagine how the phenomenon of Sellafield came to be an accepted part of life on Earth. In my mind's eye, I see some alien sociologists, studying our history and trying to piece together the origins of the place, and the mind-states of those who developed the technology, studied the effects of the materials being used and then permitted the operation. They would probably fail, as I have, and as Marylyn Robinson, the American novelist has, in her work *Mother Country,* which I strongly recommend. She has come close in that book to an understanding of part of the reason how it has been countenanced. She sees Sellafield, and its cavalier daily release of poison to the Irish Sea, to the people who live nearby and to the planet and its unsuspecting inhabitants, as an extension of the male-dominated class culture of England. To her, the separation of the poor from the human race by the rich which occurs England's vertical class structure, is a separation of humanity and rights, similar, perhaps, to the separation in Germany during the Third Reich. of the Jews, Slavs and other *untermenschen*. Therefore it is a simple matter, when you need atom bombs to secure your power and wealth, to place the poison factory as far away as possible from where you live so that the harm is only to the poor people, fisherfolk, farmers and their families, who were unfortunate enough to live in such a marginal area. Of course, I now learn that this is exactly what happened. The original death factory was just south of Oxford at Harwell: this is where the research into the radiation and bombs began in the war years. At that time, the radioactive waste went into the Thames at Sutton Courtenay (as some still does). But when the quantities of radioactivity began to rise in London drinking water, the public health people began to complain. Although they were fobbed off or sacked (evidence released under the 30 year rule) the great and the good began to feel uneasy at the prospect of having to drink the Tritium and eat Plutonium with their dinner.

The first suggestion was for building a (very long) pipe to send the waste to the Bristol Channel, but the physical pressures in the pipe would have to be very high to pump it over the hills, so that was abandoned. Then someone suggested Trawsfynydd lake in Wales. Build the factory there and tip the poison in the lake: why not? Only sheep and Welsh people live there. However, luckily for the Welsh (although the plan was not forgotten: a nuclear power station was sited there later in 1966), the quantities of material involved were very large and at the time of the decision, the British Nylon Spinners plant at Windscale became available. This began the nightmare for the people of Cumbria, and the coastal populations of Wales, Ireland, Lancashire, the Solway Firth and eventually everyone in the UK, even the inhabitants of the East coast of England, facing the North Sea, and the people living in Scandinavia.

As we shall see later, the material released by Sellafield since the start of operations in 1952, has caused the deaths or countless numbers of people. Instead of remaining politely in the Irish Sea, it has been thrown back on the land, as the soldiers of the sea might throw back a smoking grenade. Plutonium from Sellafield has drifted over the British Isles and Ireland in the seaspray, an evil invisible mist carrying illness and death, penetrating all living creatures, to be found in the dust from Barmouth in Gwynedd to Bexleyheath in Kent. I will outline the evidence for this and the mechanisms, but first let us take a look at the place.

3.1 Radioactive discharges from Sellafield to the Irish Sea

The nuclear reprocessing facility at Sellafield, formerly Windscale, in West Cumbria has operated since 1952, extracting plutonium from spent nuclear fuel and discharging radioactive waste. In the period 1952-95, 1.35PBq of alpha and 115 PBq of beta-emitting man-made radioisotopes have been reported discharged to the Irish Sea. The trend in releases over the period relevant to this study is given in Figure 3.1.1

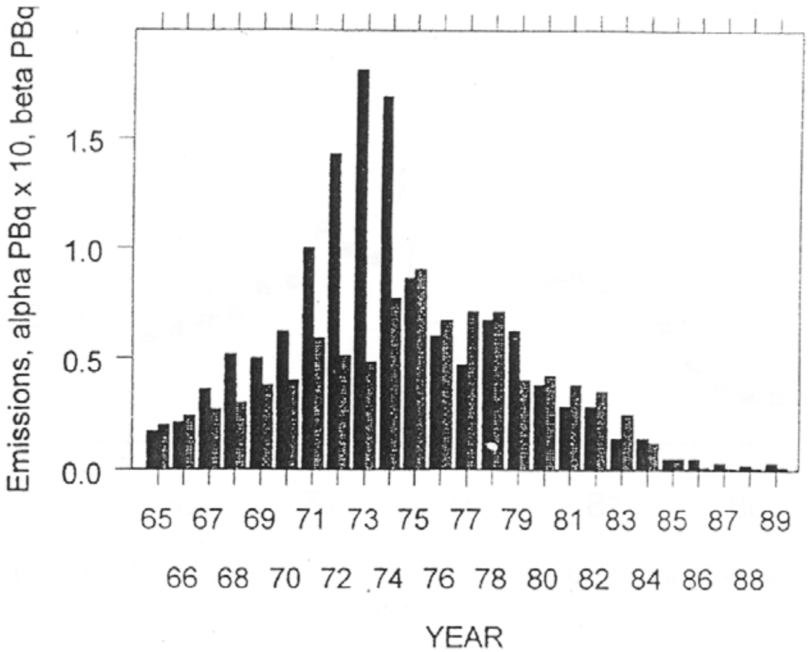


Figure 3.1.1 Trend in releases of alpha and beta emitting radioisotopes to the Irish Sea from Sellafield **(***Source:* MAFF , FoE, 1993).

In the early days of its operation the issue of pollution from the Windscale plant was raised as a cause of concern. Most of the poison ends up in the sea, either directly from the pipeline, or following washout from the atmosphere and runoff into rivers and streams. Most finds its way to the sea eventually. The justification for releasing liquid radioactive waste into the Irish Sea was that the sea would provide an infinite dilution and dispersion route for radioactive waste, as Dunster argued in 1958. Since that time, a huge body of evidence has accumulated that clearly demonstrates that a considerable quantity of long-lived man-made radioisotopes has come ashore and is contaminating beaches, estuaries, sea, air and water. The stuff is picked up from the contaminated mud by wave action and pitched into the air. Particles of various sizes, mostly too small to be visible, but seriously radioactive, are dispersed over enormous distances. The most studied of these isotopes is Plutonium-239, an alpha emitter with a half-life of 24,000 years, but many other fission product and reprocessing isotopes contaminate the Irish Sea and the littoral. The plutonium contamination exists as micron and sub-micron-diameter oxide particles, PuO_2. This material is glassy, virtually insoluble, and as a speck of dust, a mote in a sunbeam, is both invisible and infinitely mobile. In addition, huge quantities of Uranium isotopes have been thrown into the Irish Sea. Other poisons like the alpha emitter Americium-241 and the beta emitters, Caesium-137 and Strontium-90 float about and are washed up. The list of horrible substances is very large and each isotope has their own biophysical or biochemical characteristic, concentrating in particular tissue or dispersing in the environment through different specific mechanisms.

Radioisotopes from Sellafield may be distinguished from radioisotopes from other sources by measuring isotopic ratios using various sophisticated techniques. The technology for these measurements is now so awesome that we are able to measure vanishingly small amounts. For example, I am a member of the UK Ministry of Defence Depleted Uranium Board where we are engaged in arranging measurements of Uranium Isotopes in the urine of Persian Gulf War veterans at concentrations of a few nanograms (one thousand millionth of a gram) per litre.

Measurements of Plutonium 239 and Caesium-137 made in Wales after the Chernobyl contamination of the Welsh uplands showed that most of the radiation in silt in estuaries and along the coast had the characteristic fingerprint of Sellafield. It was only at the inland head of estuaries that the situation reversed and Chernobyl isotope ratios became seen (Assinder *et al.*,1994). After the material was released from the outfall pipe at Sellafield, it moved away and became dispersed through the Irish Sea and further afield by various mechanisms depending on the reactivity, chemical identity or physical form of the specific substance. The material in the silt in Cumbria has been moving slowly across the Irish Sea to Ireland. The finer particles of silt pick up the plutonium and other isotopes and swirl around the Irish Sea by tidal action to be precipitated in areas where the tidal energy is low, like bays and river estuaries and tidal slacks. Contamination resulting from releases from Sellafield could be found on the coast of North Wales, at the MAFF measuring point of Cemlyn Bay on the Isle of Anglesey about one year after their releases (see Figure 3.1.2)

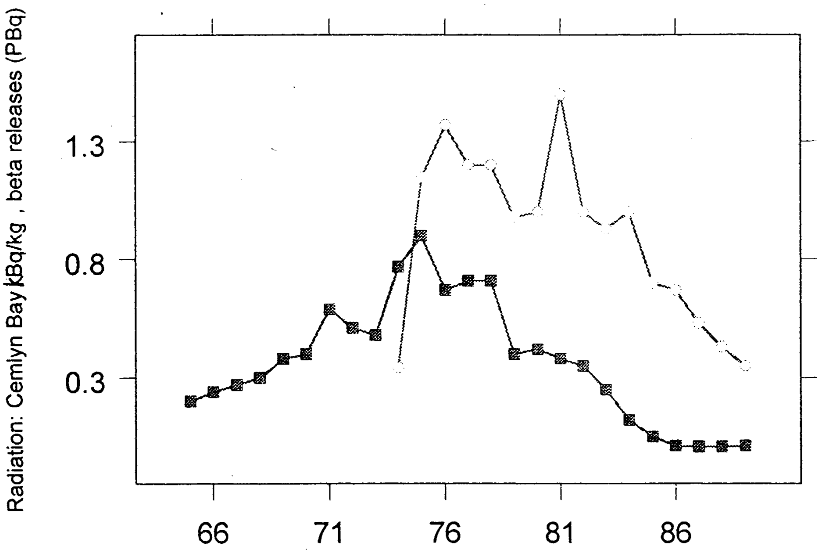


Figure 3.1.2. Trend in Caesium-137 in silt in Cemlyn Bay, North Wales (circles) and trend in total beta emissions to Irish Sea (mainly Cs-137) from Sellafield (squares) **(***Source: MAFF).*

By the mid 1980s Plutonium from Sellafield was being mapped by scientists from Harwell to parts of England and Wales more than 150 miles from the Irish Sea as I show in Fig 3.1.3. (Cawse and Horrill, 1986). Since this first grassland survey of plutonium, a number of other researchers have discovered that the concentrations in soil and grass in middle England have been mysteriously increasing. For example, in the late 1990s, there were public concerns about increases in leukaemia rates in the districts of Newbury and Reading in Berkshire and South Oxfordshire. These are the County Districts containing the Atomic Energy Research Establishment site at Harwell and the Atomic Weapons Establishment sites at Aldermaston and Burghfield. All these sites release radioisotopes, including plutonium, to the environment. In addition, there was a concern about an atomic bomb fire which had apparently occurred at the USAF Greenham Common airbase in 1959 (check). I discovered that these nuclear site County Districts had the highest leukaemia mortality rates for children and with Molly had written this up in a research note for the *British Medical Journal* in 1997. (Busby and Scott Cato, 1997). Newbury Council responded by funding a £300,000 study of Uranium and Plutonium in the vicinity of the Greenham Airbase, and this was undertaken jointly by the Scottish Universities Research Reactor Centre (SURRC) and the Southampton Oceanographic Centre. The measurements showed a significantly large increase in the concentrations of Plutonium from those given by the 1986 Cawse and Horrill report from Harwell. Whilst the latter showed levels of about 0.02-0.07 Bequerels per kilogram, Dr Ian Croudace at Southampton was finding more than 100-times this, between 0.5 and 10 Bq/kg in samples some considerable distance from Aldermaston. Croudace has been unable to square his high readings with the earlier Cawse and Horrill readings, although he has tried hard in his reports to imply that the plutonium he found is from weapons fallout, the other possible source. The Atomic Weapons Establishment at Aldermaston measures radioactivity and its annual reports list extraordinarily high levels of radioactivity in dust collected on filters placed as far away as Basingstoke and Reading. Routine measurements of dust in filters near to and remote from the Aldermaston site in West Berkshire show that alpha activity in some dusts is as high as 2500Bq/kg and beta activity as high as 60,000 Bq/ kg. (AWE, 1992, 1993, 1994, 1995). These levels exceed the threshold level of 400Bq/kg defining low-level radioactive waste under the Radioactive Substances Act 1993. I return to this in al later Chapter.

By the mid 1990s, Plutonium was being found in children’s teeth over the whole of the United Kingdom (Figure 3.1.4) (Priest *et al.*, 1997) I came across this research when, in 1998, I had begun research with colleagues in *Green Audit* in support of an Irish court case against British Nuclear Fuels begun by four people living in Dundalk, County Louth. We were attempting to discover what effect, if any, Irish Sea contamination might be having on health. To look at correlations with cancer effects in Ireland or Wales we needed to examine relative concentrations of radioisotopes on the coast, look at routes of exposure and ask certain questions. Having read the paper by Nick Priest et al., one question was, how did plutonium from Sellafield become incorporated into children's teeth from parts of England and Wales over 200 miles distant from the plant and in a pattern that appears to vary monotonically with distance? This led to other questions. Where in the Irish Sea were the highest levels found? Was there any evidence which cast light on the route from Sellafield to the children's teeth? It turned out that answers to all of these questions existed and had been ignored or actively suppressed by the UK radiation risk establishment. Indeed, in the course of the Irish Sea research I accidentally learned that the UK Department of Health were worried and had jointly, with BNFL, funded the scientist who discovered the trend in plutonium in children's teeth to carry out a larger and more searching enquiry into the source of the plutonium. This was to be a confidential study to establish for certain that the plutonium isotope ratios pointed unequivocally to Sellafield as the source. But I will now turn to the answer to the question of how the plutonium came to be in the teeth.

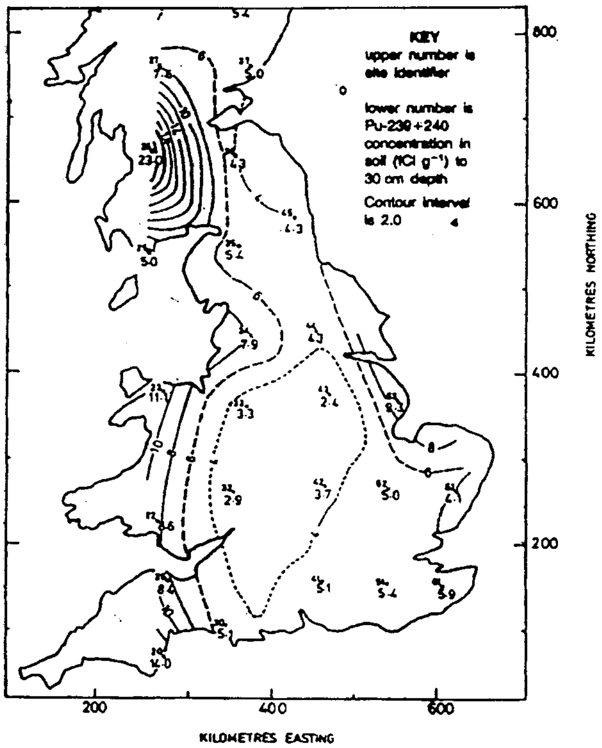


Figure 3.1.3. Plutonium in grassland and soil over England and Wales, 1977 (*Source:* Cawse and Horrill, 1986)

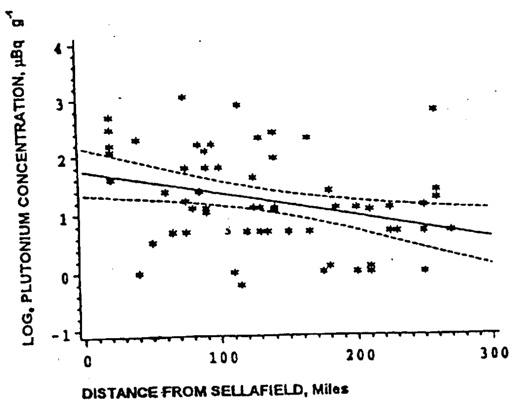


Figure 3.1.4. Concentration of Plutonium in children's teeth by distance from Sellafield in the whole of the United Kingdom (*Source*: Priest *et al.*,1997)

3.2 Routes of Contamination and Levels of Exposure

First it is worth getting the amounts of radioactivity released by Sellafield in perspective. There is an enormous amount of radiation involved. For example, the largest injection of radioactive pollution into the global environment has been from atmospheric weapons tests which occurred in the post war period and which culminated in massive megaton bomb tests in the period 1959-1963 when Kennedy and Kruschev signed the Test Ban Treaty. If we are looking for radiation effects in cancer and other diseases then this was the primary source prior to 1970 and it is this that represents the main cause of the present cancer epidemic, as I argued in *Wings of Death.* But although the bomb test fallout quantities were large overall, in terms of concentration in the Irish Sea they were dwarfed by the releases from Sellafield. In Table 3.2.1 I compare the alpha emitters Plutonium and Americium-241 from bomb fallout deposition per unit area with the releases of the same isotopes from Sellafield which I have diluted uniformly into the Irish Sea. As far as the people living near the Irish Sea are concerned, the reprocessing waste is more than 50 times greater. In terms of all the plutonium released to the world, Sellafield is in a class of its own. All the weapons fallout plutonium to the entire planet Earth has been about 11 PBq (11 x 10^{15} Bq). Sellafield has released about one eighth of all this Plutonium to what is effectively a small shallow pond, surrounded by people living in coastal towns and villages.

Table 3.2.1 Plutonium 239+240 and Americium-241 (alpha emitters) released to the Irish sea from Sellafield up to 1990 and 1999 compared with total weapons fallout deposition in the UK

Area (sq.m x 10^{-9}); source	**Total deposited up to 1990 (TBq)**
UK (244); fallout	20.2
Irish Sea (57); Sellafield	1350-2250

*Based on 83Bq/m^2 Pu239+240 plus Am-241 given in UNSCEAR 1993 and *estimates from Green et al 1993 and Kershaw et al. 1999*

The highest concentrations of pollution are naturally found very near Sellafield itself. However, the fall-off in concentration with distance by sea does not follow the inverse-square-law pattern expected, nor any pattern that might have been modelled. Although there are many complexities, in general, it turns out that the radioisotopes attach themselves to fine silt particles by a process known as adsorption, and it is the movement and re-distribution of these fine silt particles by the water circulation in the Irish Sea that determines the coastal distribution of radiation in mud, silt and sand. (Assinder, 1983, Assinder *et al.*,1994, 1997; Hamilton, 1998).

Professor Murdo Baxter directed the 1989 Department of the Environment and Scottish Universities joint study of the redistribution of

Sellafield radioactivity in the Irish Sea (Baxter, 1989). This report to the DoE concludes:

On the Irish Sea bed, artificial nuclide concentrations are variable primarily as a function only of sediment type or grain size rather than distance from source.

This may explain the common finding that levels of radioactivity in inter-tidal regions are highest in areas of low tidal flow or water movement, so-called low-energy zones. These include, harbours, tidal inlets and estuaries. The reason is that slack water conditions permit the fine particles to precipitate, and these fine particles are brought up river estuaries where their concentrations are highest at the inland end of the estuary (Assinder *et al.,*1994,1997). In addition to this, hot spots, small areas of intertidal mud where radiation detectors begin to chatter, have been found on the coast of Ireland, north Wales and in the Cumbria, Lancashire and Solway regions (FoE, 1993). Janine Allis Smith, who operates the Cumbrians Opposed to a Radioactive Environment, CORE tells me of a Japanese scientist who had been to the Chernobyl exclusion zone to study radiation effects and had visited her. It seems he went for a walk along the coast with a Geiger Counter and was astonished at the levels of radioactivity which he said were comparable to the Chernobyl areas he had visited.

Concentrations of isotopes in sediment and marine biological samples from fish and crustacean to seaweeds have been measured since the 1970s by the Ministry of Agriculture, Fisheries and Food (MAFF), now CEFAS. In Ireland, the Radiological Protection Institute (RPII) measure radionuclide concentrations from time to time and make reports. In Wales, there are results available that suggest that the concentrations of Sellafield isotopes in silt are about twice as high on the north coast than the west coast, although concentrations in the river estuaries are comparable (Garland *et al.*, 1989). All the studies and data support Murdo Baxter's conclusions about particle size and also suggest that on the East coast of Ireland, river estuaries like the Boyne at Drogheda, and the muddy inlets at Dundalk Bay and Carlingford Lough where there are slack tide or low energy conditions are similarly contaminated. Measurements are also made by MAFF in Northern Ireland show that in Carlingford Lough and Oldmill Bay, levels of plutonium 239+240 are comparable with those in North Wales, and for the same reason. The reason for this distribution is, as Murdo Baxter stated, due to the tidal energy conditions at the places where rthe isotopes accumulate. Therefore it is of some interest to examine the general circulation of the Irish Sea, and in particular its tides.

3.3 Circulation in the Irish Sea

Measurement of the concentration of Caesium-137 in filtered water in the Irish Sea has enabled MAFF to draw maps which show the relative levels of this isotope. Such a map for the year 1989 confirms that there was appreciable transfer of material to the coast of north Wales and Ireland (Figure 3.3.1). It should be borne in mind that this map does not indicate the relative concentration of nuclides in silt, but merely acts as an indication of the general circulation involved. Although there are limited numbers of measurements available that indicate the levels of isotopes in silt on the coast of Wales and Ireland, MAFF have measured Caesium-137 and Plutonium 239 + 240 in Carlingford Lough in Northern Ireland and also Cemlyn Bay on the northern tip of the Isle of Anglesey in North Wales since 1988. Cemlyn Bay sediments are almost exclusively from Sellafield and readings of Caesium-137 at Cemlyn Bay were made back to 1970. The trend in Caesium and Plutonium isotopes roughly correlate and so it may be reasonable to a first approximation to use Caesium in silt as an indicator for all isotopes, including Plutonium-239 + 240 in silt.

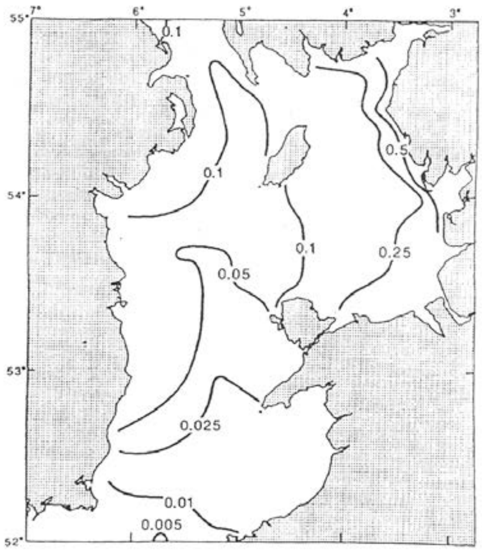


Figure 3.3.1 Caesium-137 in filtered seawater in the Irish Sea, 1989 **(**Source: MAFF).

Table 3.3.1ows the trends in silt concentrations in Carlingford Lough, Ireland after 1988 and in Cemlyn Bay, north Wales, over most of the period of the major releases. Also shown is the concentration for some years of the isotope Americium-241, which acts as a marker for the isotope

Plutonium-241 and may indicate the approximate amount of Plutonium 239 in those years when no measurements were made.

Examination of results of these surveys indicates that the distribution of Sellafield isotopes on the coasts of the Irish Sea lag the discharge by about a year and depend upon particle size and upon the tidal flow rates or energy of the sea conditions at the point of interest. The tidal circulation is of great importance for the coast of the Irish Republic, since it turns out that there is a very large and continually maintained area of slack water off the north-eastern coast, from Dundalk Bay to Carlingford. This is the place where the south-going, anti-clockwise tidal stream meets the north-going, clockwise stream, and this results in a very large area where fine silt and mud precipitates out. It is where fine silt particles containing large quantities of radionuclides can precipitate, and measurements made by RPII show that this process does indeed occur. These muddy silty areas extend into Dundalk Bay where there are large offshore drying mud-flats (see Plate3) and silty mud comes up the river Boyne and Carlingford Lough with the tide (Plate 10) Admiralty tidal stream maps show that there is always slack water, with no tidal flow off the north-eastern coast of the Irish Republic (Admiralty Hydrography Office, 1992) and I show such a map in Fig 3.3.2

Table 3.3.1 Trends in concentration of Sellafield isotopes in mud: North Wales (Cemlyn) and Carlingford Lough, Ireland, (Bq/kg)

Year	Carlingford Cs-137	Carlingford Pu-239+240	Cemlyn Bay Cs-137	Cemlyn Bay Pu-239 + 240	Cemlyn Bay Am-241
1970					
1971	-	-	207	Not listed	-
1972-3	-	-	362	Not listed	-
1974	-	-	344	Not listed	-
1975	-	-	1150	Not listed	-
1976	-	-	1400	Not listed	-
1977	-	-	1200	42	-
1978	-	-	1200	44	-
1979	-	-	950	44	-
1980	-	-	1000	56	-
1981	-	-	1500	Not listed	92
1982	-	-	1000	Not listed	54
1983	-	-	930	78	88
1984	-	-	1000	84	88
1985	-	-	700	58	76
1986	-	-	670	47	58
1988	224	15	430	41	53
1989	240	15	350	39	52
1990	160	13	320	48	71
1991	170	16	250	39	54
1992	-	-	-	-	-
1993	180	14	270	39	55
1994	Not listed	13	220	30	46
1995	120	13	180	23	33
1996	110	14	150	22	31
1997	100	13	170	23	32

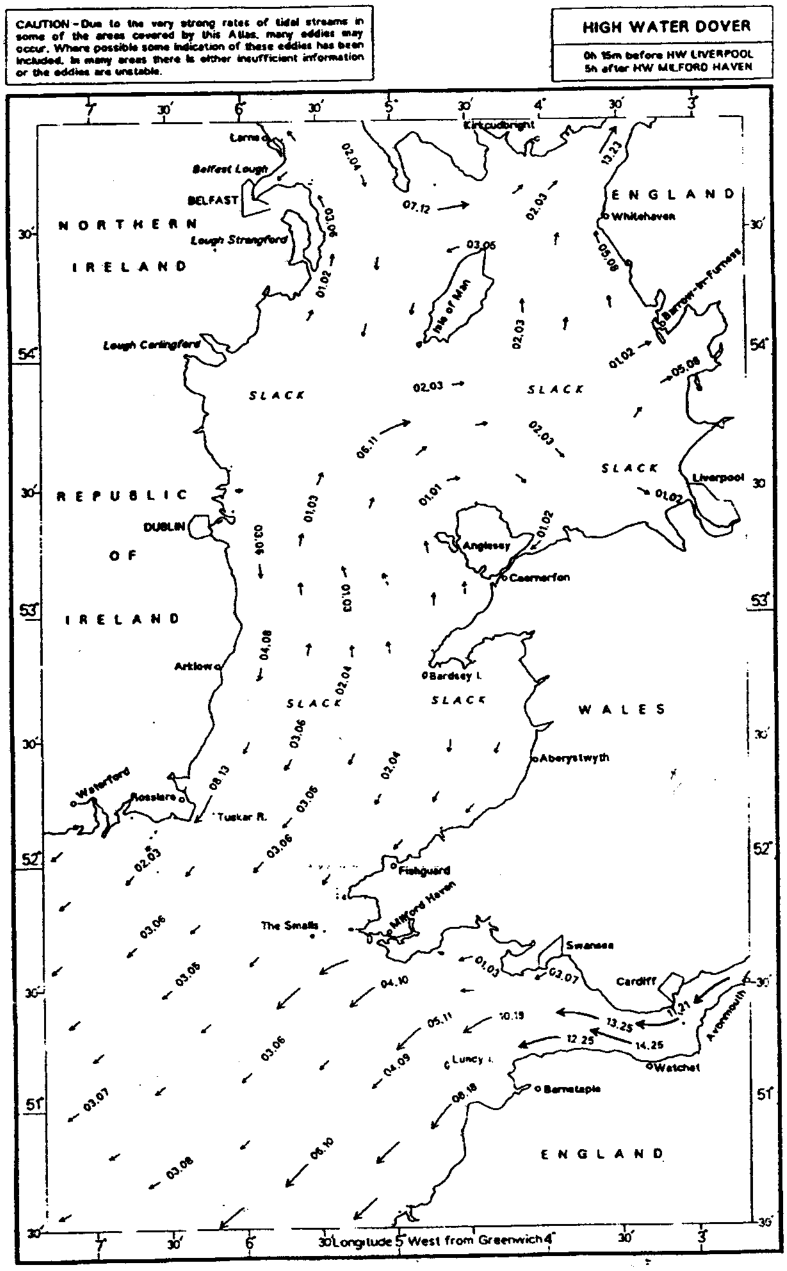


Fig 3.3.2. Admiralty tidal stream atlas picture of tidal flows at High Water Carlingford. There is slack water in Dundalk Bay (NE Ireland) at every state of the tide.

The behaviour of plutonium in silt in the Irish sea over the last 20 years has recently been re-examined by Kershaw *et al.* (1`999) and the results are interesting. Fig.3.3.3 and 3.3.4 shows the slow movement of Plutonium 239 away from Sellafield and towards the shores of Ireland and Wales over the period 1978 to 1995. A wave of Plutonium-239, a fearfully toxic element with a half life of 24,000 years, is moving slowly towards Ireland and Wales. By 1983 the 1kBq/m^2 isoline had reached the Welsh coast at Llandudno and the Irish coast at Warren Point. A dense band of Plutonium contamination released to the sea at Sellafield is creeping towards the shores of Wales and Ireland.

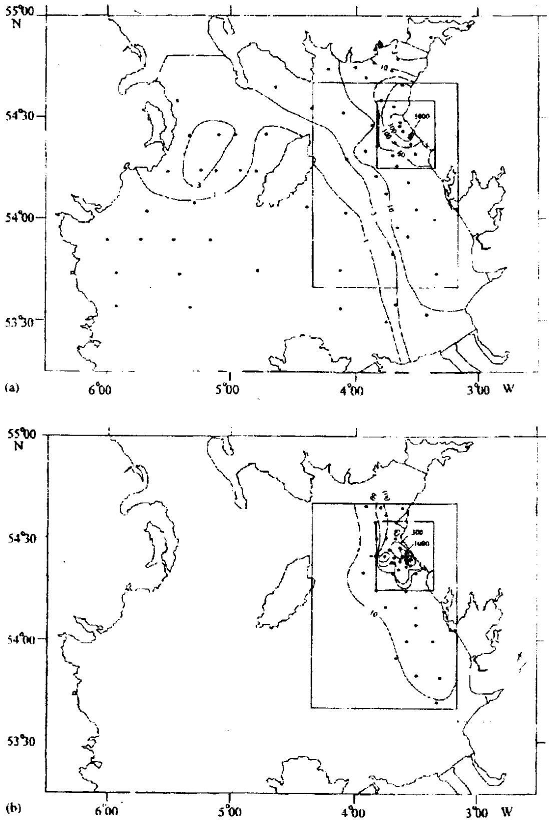


Fig 3.3.3 Movement of plutonium in sediment in the Irish sea. (kBq/m^2 Upper, 1978 and lower 1983. (*Source:* Kershaw *et al.* 1999)

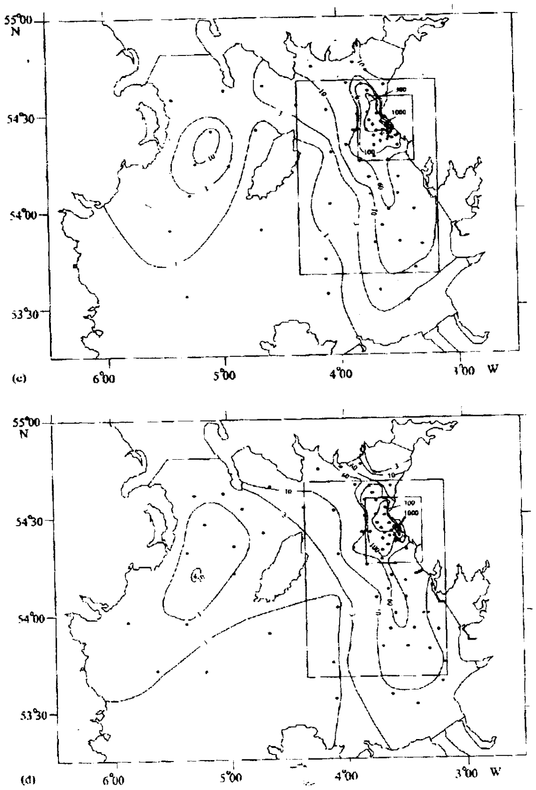


Fig 3.3.4 Movement of plutonium in sediment in the Irish sea. (kBq/m^2 Upper, 1988 and lower 1995. (*Source:* Kershaw *et al.* 1999)

In addition to the slow movement of Plutonium away from Sellafield, Kershaw *et al.* (1999) noticed something even more curious. The total inventory of Plutonium in the Irish sea did not correspond to the amount released from Sellafield. In the words of Kershaw *et al.:*

A budget of Plutonium-alpha and 241-Americium has been estimated based on published observations in three main compartments: water column, sub-tidal and intertidal sediments. This amounts to . . . . 60-61% of the decay corrected reported discharge.

In other words, about 40% of the Plutonium and Americium had disappeared. Where had it gone? Perhaps we should look on the shore, inside people and their teeth. But before we do this, because later I will describe the effects on cancer rates in Wales, we must look more closely at the shores of Wales.

3.4 Intertidal Sediments in Wales

In Wales, measurements of radioisotopes in intertidal sediment were made by the Harwell team of Garland *et al.* in 1989. This report measured artificial radioactivity in coastal seawater, in seaspray, in beach sand and sediment. In the abstract the authors state:

The results show low but measurable concentrations of plutonium isotopes, Am-241 and Cs-137 in samples from the north coast. Concentrations were even lower in samples from the west and south coasts and many samples were below the detection limit. Sea-to-land transfer was seen in measurements of plutonium isotopes and Am-241 in sea spray, air, and in material deposited from the air close to the north coast. The results show that the radiation dose to the population due to the actinides and Cs-137 in the coastal environment is a small fraction of the recognised limit.

The report is an extensive one. For our purposes, its findings may be briefly summarised:

- Levels of plutonium-239+240 were greatest in intertidal sediment in the north of Wales.
- On the north coast of Wales, 80 per cent of the plutonium and other isotopes were in the coastal strip between the northern entrance to the Menai Strait and the town of Bangor, and Great Ormes Head and the town of Llandudno. The largest deposit was in the offshore drying bank known as the Lavan Sands, lying between the north-eastern entrance to the Menai Strait and the western entrance to the River Conway estuary.
- A moderate concentration of plutonium, about one fifth of the Lavan Sands concentration existed over the whole of the northern coastal intertidal region from the north of Anglesey to the mouth of the Dee, taking in the towns and areas of Amlwch and Beaumaris on Anglesey and Colwyn Bay, Abergele, Rhyl and Prestatyn. The levels in the River Dee estuary (Mostyn Bank) were comparable with those on the Lavan Sands. The main area affected here is Flint and Holywell.
- South of Anglesey levels were lower and in Cardigan Bay levels were about one tenth of those on the north coast, except for estuaries of rivers like the Teifi and Dyfi where the low tidal energy increases the levels in the silt.
- Sea-to-land transfer of plutonium occurred and the isotopes were measured in air, seaspray and on the ground in a pattern showing rapid fall-off in the first kilometer and at concentrations which correlated with the levels in the intertidal sediment.

Very large amounts were involved. For example, the quantity present in the Lavan Sands mud-bank represents about 100 times the inventory of the cooling water lake at Trawsfynydd nuclear power station, also in Wales. This lake was recently the subject of a study by the National Radiological Protection Board (Carey *et al.* 1996) in which they explicitly stated that to minimise health risks to the (small) local population the water levels should not be allowed to fall and expose the radioactive isotopes in the sediment. These isotopes are largely the same ones that exist in the Lavan Sands but at one hundreth the concentration and quantity. Yet the Lavan Sands, and indeed, the entire coast of north Wales, is uncovered on every tide and subject to the energy and power of the wind and waves. Living close by are large populations of moderate sized coastal towns and holiday resorts. Table 3.4.1 below gives levels of Plutonium and Americium-241 in samples measured by Garland *et al.* (1989), confirming that the plutonium does not fall off with distance from the source, but according to some other process. As far as coastal populations are concerned, hoever, there is a major source of risk. The material does not stay in the sediment: it comes ashore.

3.5 Sea-to-Land Transfer of Radioisotopes

It has become apparent that the radioisotopes in silt and sand are associated with particles. This is particularly true of the alpha emitters. Thus exposure from inhalation of dust is not a molecular transfer, as eating a Caesium-contaminated fish might be, but involves the total transfer of what is effectively a tiny radioactive hot particle from the environment to the inside of the person exposed. As I pointed out in an earlier section, such a particle may deliver a very high dose to adjacent tissue. Alpha emitters are notoriously difficult to measure. This is because the range in air of an alpha particle is a few centimetres. A Geiger counter is therefore useless because the particles do not penetrate the window glass even if the detector is placed next to the source. We have to use scintillation counters, devices that rely of the energy of the alpha emission causing a special chemical in solution or embedded in very thin plastic foil to emit a spark of light which is subsequently amplified and measured. Such devices are horribly expensive. Thanks to the Irish State on the one hand and the Goldsmith Foundation on the other, we have two of these machines which we have used to measure alpha and beta activity in silts around the Irish Sea.

Table 3.4.1 Plutonium in intertidal sediment in Wales , 1989 (Garland *et al.* 1989)

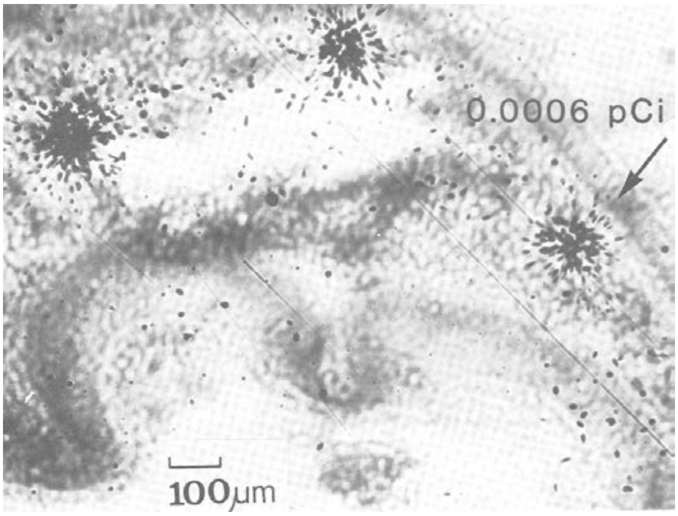
Sample area	**Distance from Sellafield**	**Pu-239+240 (Bq/m^2)**
Lleyn peninsula SE	*227*	*120*
Lleyn peninsula SW	*189*	*300*
Lleyn peninsula NW	*181*	*260*
Caernarfon Bay	*177*	*160*
Foryd Bay	*156*	*720*
Traeth malynog	*154*	*800*
Llanddwyn bay	*169*	*2100*
Malltreath sands	*165*	*1160*
Aberffraw bay	*154*	*1520*
Rhosneigr	*147*	*570*
Cymryan bay	*144*	*500*
Anglesey NW	*141*	*200*
Dulas/Lligwy bay	*125*	*350*
Red Wharf bay W	*131*	*2270*
RedWharf bay E	*130*	*770*
Beaumaris	*134*	*520*
Menai Strait	*148*	*1570*
Lavan sands W	*136*	*780*
Lavan sands E	*135*	*12400*
Conwy sands S	*128*	*770*
Conwy sands N	*125*	*4200*
Ormes bay	*123*	*1840*
Rhos on sea	*123*	*4700*
Colwyn Bay	*125*	*2300*
Abergele	*123*	*3200*
Kinmel Bay	*122*	*2700*
Prestatyn	*119*	*1800*
Point of Air	*118*	*1700*
Dee estuary	*130*	*14500*

But there is another and much cheaper way. Eric Hamilton (1998), used to work at NRPB. In the 1980s began to use a novel method for measuring alpha activity which involved the discovery by Dennis Henshaw of Bristol University of an alpha-particle-detecting plastic called CR-39.

I have also used this magic material. What we do is to place a piece of the plastic next to the source for a measured period, take it away and develop it using 4N potassium hydroxide at 70degrees. This etches out tiny track holes in the plastic which we count under a microscope (see Fig 3.9). The number of tracks per unit area give a measure of the activity. It is even possible to perturb the tracks in a magnetic field, or examine their shape or multiplicity, to obtain the energy or identity of the isotope. Hamilton used this technique and also normal X-ray film to examine `hot particles' in silt in Cumbria which have an average diameter of 70 μm and a mass of 2 μg. He found the average specific activity of such particles to be 706,000 Bq/kg and each particle had average activity of 0.0014 Bq. This represents a decay every 12 minutes into a volume of tissue defined by the alpha particle range of about 0.1mm. If such a particle is immobilised within tissue for any length of time the resultant dose to the adjacent cells is enormously high. Hamilton's method (and one we have also used for samples from Wales and Ireland) involves cutting a mud core by hammering a piece of plastic drainpipe into the intertidal sediment to a depth of about 18 inches in an accretion zone, a place where the mud has been undisturbed, close to the high water mark. The surrounding mud is then dug out and the core removed. It is then frozen at -18degrees and cut longitudinally with a saw to give two half-cylinders. These are then dried under vacuum and placed alongside a piece of CR39 which we purchase from Prof. Henshaw's TASTRAK company in Bristol. This is then developed and examined under a 400X metallurgical microscope. After retirement from NRPB, Hamilton has argued at some length that the sediment contamination represents a serious source of risk and in 1999 published a frightening autoradiograph of a half-core taken from the estuary of the Esk near Ravenglass, showing the presence of hot particles in the sediment (Fig3.5.2).

Hamilton's core shows the presence of large hot particles and though these are serious hazards, they are relatively stationary. In addition, even of they were to be resuspended and inhaled, they would not pass the lung. I am much more concerned with the effects of micron and sub micron sized material which are much more mobile and widely dispersed. According to a recent NRPB report, plutonium in the environment is in the form of particles whose size ranges from sub-micron to 5 microns in diameter, but with the mean size being about 0.5-1micron. Such particles are extremely resistant to natural destruction and are virtually insoluble, only being dissolved with difficulty in strong acid (Wilkins *et al.*, 1996). Post-mortem analysis of children from the Chernobyl-affected territories of the former Soviet Union found these plutonium particles in lymph nodes, and such particles have also been found in the lymphatic system of animals grazing near the Nevada test site in the USA (Wilkins *et al.*, 1996). Eakins *et al.* (1984) measured plutonium in sheep faeces from St Bees in Cumbria, near Sellafield, across the whole of northern England to Whitby on the eastern coast. They showed that the levels fell of rapidly with distance up to about 20 km and then stabilised. A typical result is shown in Figure 3.5.3. This pattern is most easily explained by models involving the dispersion of larger precipitating particles and smaller continuously airborne aerosol particles. The hot particles get into the marine life and can therefore be transferred to anything that eats sucg creatures. Fig 3.5.1 shows a CR39 track developed from a cross section of a edible mussel.

Fig 3.5.1 Hot particle from Sellafield detected in the intestine of an edible mussel from Ravenglass using CR39 (Source: Hamilton and Clifton 1980)



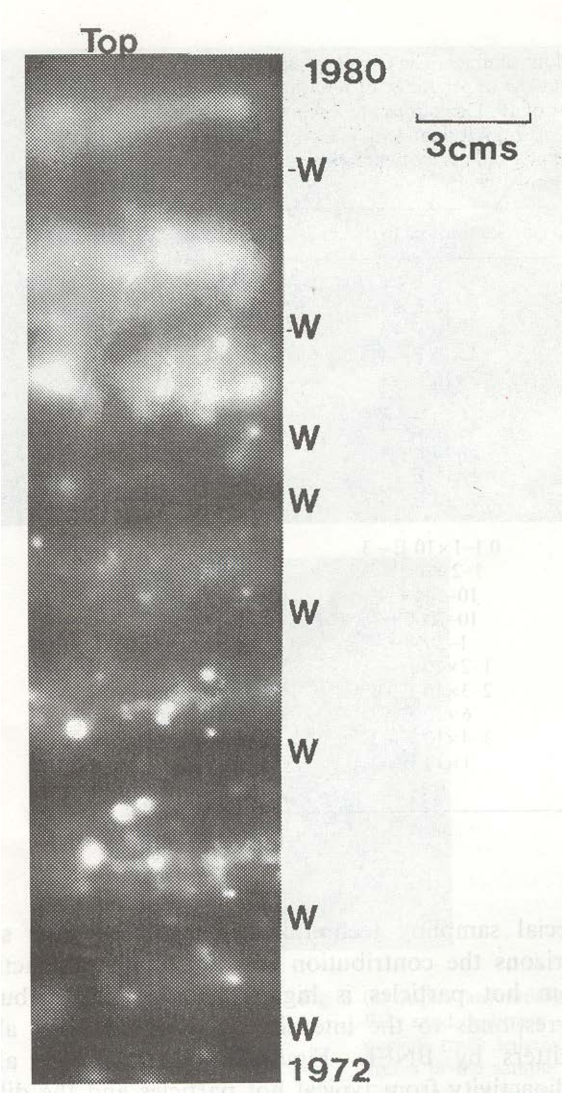


Fig 3.5.2 Beta gamma autoradiograph of a sandy Esk estuarine core sampled in September 1980 using Kodak Industrex C No Screen X-fray filmn. The white zones show deposition of the radioisotopes during the summer, the black zones that in the winter where the mud is stirred up by gales and the material does not sediment. (Hamilton1998)

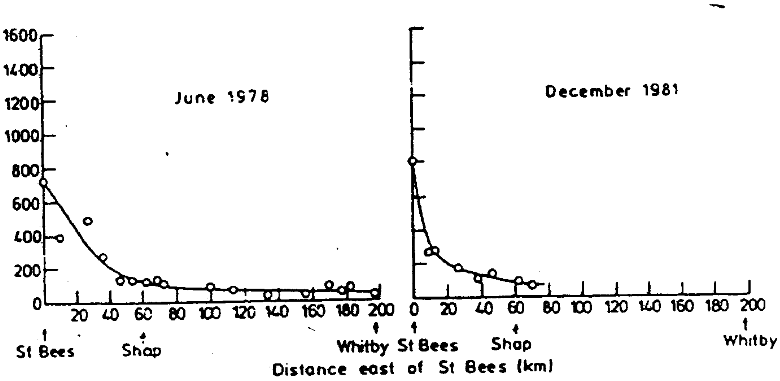


Figure 3.5.3 Concentration of Plutonium-239 in sheep faeces by distance from St Bees in Cumbria.*Source:* Eakins *et al.*, 1984.

The Welsh Office commissioned a radiological survey of Wales in 1984, and results showed Plutonium contamination of sheep droppings up to 10 km from the Irish Sea coast (Cawse *et al.*,1988). The isotopic signatures confirmed the origin of the Plutonium as the Sellafield plant. The study by Garland *et al.* 1989 also detected Plutonium sea-to-land transfer. If particles can contaminate sheep then clearly people must also be at risk. Supporting evidence that this is the case comes from measurements made on cadavers in the UK. Plutonium levels in post-mortem tissue seem to be highest in the tracheo-bronchial lymph nodes and highest in Cumbrian residents and occupationally exposed workers in Cumbria, relative to other UK citizens. Some results from a report by Popplewell of the NRPB are given in Table 3.5.1

Table 3.5.1. Plutonium in various organs at post-mortem, from members of the public and from occupationally exposed workers living in Cumbria. (mBq/kg; numbers of cases are in brackets) (Source Popplewell 1986)

Tissue	**Occupationally exposed (Cumbria)**	**Members of public (Cumbria)**	**Members of public (elsewhere UK)**
Rib	130, 360, 94	9 (10)	6 (43)
Femur	132, 250, 100	5.4 (11)	3.6 (35)
Liver	91, 400, 83	49 (10)	26 (47)
Lung	940, 1140, 120	6.8 (11)	1.9 (47)
Tracheo-bronchial lymph nodes	450, 73300, 1600	35 (12)	10 (37)

Source: Popplewell, 1986.

The parameters of sea-to-land transfer were investigated by Eakins and Lally of Harwell in the early 1980s (Eakins and Lally, 1984). They were able to show that 95 per cent of the plutonium precipitated inside about one kilometre from the sea and thereafter the trend in plutonium in air was flat. Thus there was always a residual level of plutonium which remained across the whole of their sampling transect, up to 10km inland. This result is shown in Fig.3.5.4 In addition, in 1993 a Harwell team investigated the mechanism of seaspray enrichment (McKay *et al.* 1993). They showed that enrichment occurred by the scavenging of silt particles by rising bubbles which produce particulate rich droplets on bursting at the surface.

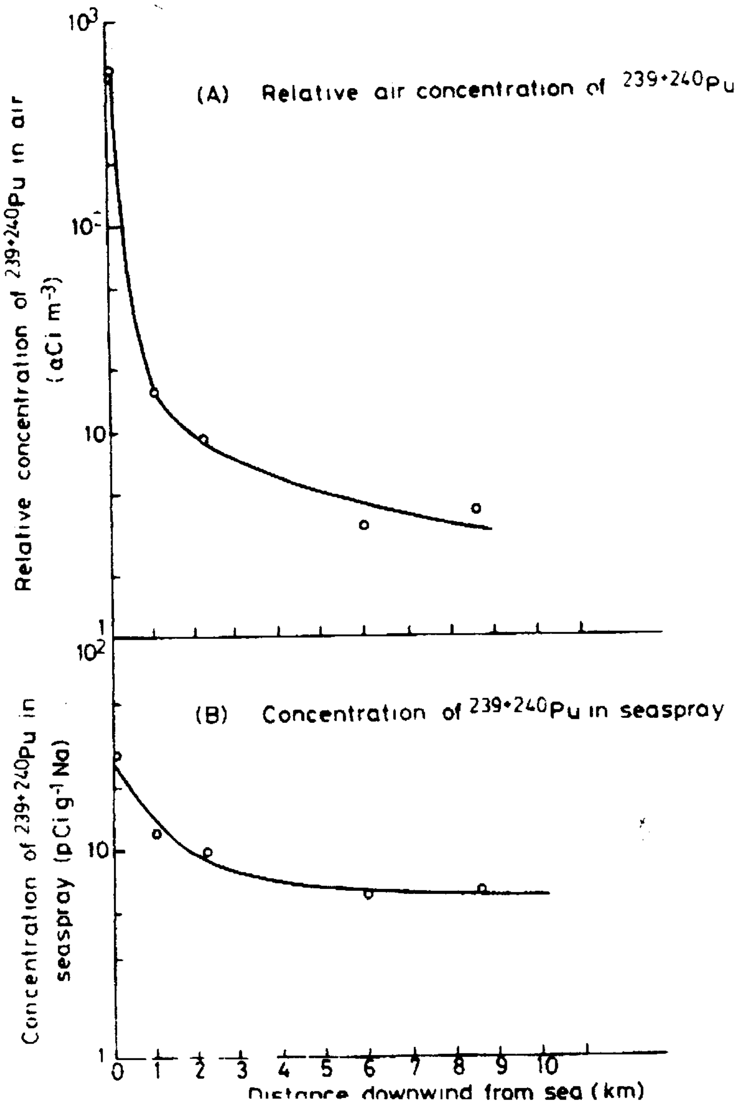


Fig 3.5.4 Penetration of plutonium and seaspray inland. (*Source:* Eakins and Lally, 1984)

It is clear from comparing the two graphs in Fig 3.5.4 that it is the seaspray that carries the plutonium inland. A recent report from the UK government's Airborne Particle Research Group (APEG, 1999) relates that up to 30 per cent of PM10 particles in the UK originate from the sea. This is probably the answer to the question of the concentration of plutonium in children's teeth and also the origin of the radioactive dust in middle England. The penetration inland of material from the sea has been known for some time prior to the period of main discharges to the sea from the Sellafield plant.

The map shown in Fig 3.5.5 shows penetration of seaspray in the United States. Compare it with that of Fig 3.1.3. showing plutonium in grassland in the UK.

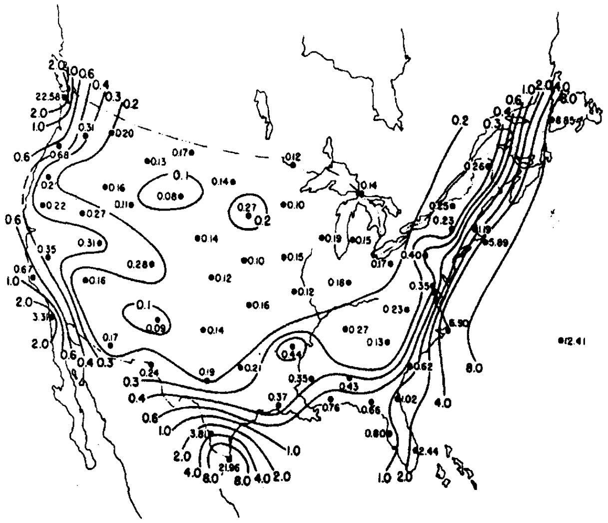


Fig 3.13 Seaspray penetration inland in the US (*Source:* Junge, 1963)

Although the prevailing wind over the Irish Sea is south-westerly, easterly winds do occur, and the sea-to-land transfer of radioactive particulates would also occur on the Irish eastern coast under these conditions. The Irish Radiological Protection Institute measure radioactivity in air at a number of stations on the east and west coasts of Ireland. In their 1993 report there are tables of gross beta activity in airborne dust measured monthly. I have reduced the tables to give annual mean values for 1990-3 for two locations chosen to represent the west coast, namely Galway, and the east coast nearest to the mud flats, namely Clonskeagh. These results are given in Table 3.5.2 It is clear that levels of radioactivity are twice as high in dust on the east coast than the west. We would expect the higher value to be on the west coast because of higher rainfall: this is what occurs in England and Wales. In fact, as I shall show both cancer rates and radioactivity in dust in Ireland are higher in the east.

The question we need to ask is: what is the speciation of the dust in the Clonskeagh filters? What size are the particles, and what is the specific activity, what isotopes are present and where do they originate? This question remains open.

Table 3.5.2 *Gross beta activity in airborne dust in Galway and Clonskeagh, Dublin (annual mean value: mBq/cu:metre)*

Year	**Galway (SD)**	**Clonskeagh (SD)**
1990	0.40 (0.27)	0.76 (0.26)
1991	0.17 (0.06)	0.50 (0.15)
1992	0.22 (0.13)	0.51 (0.46)
1993	0.39 (0.19)	0.42 (0.22)
1990-3 av.	0.26 (0.2)	0.56 (0.3)

Mean differences are statistically significant at the p = .04 level; 95% Confidence Interval = .022<x<.483mBq/cu:m (Source: RPII, 1993).

3.6. Exposure Routes

How has all this been permitted by the authorities? First we must realise that the risk model for internal exposure is wrong, as I outlined in the previous chapter. But second, because it is absorbed dose that is calculated, the main exposures of interest, and on which the limits are set, are believed to be from standing on the sea shore or handling fishing equipment. Internal doses are mean doses from eating fish or shellfish. These doses are estimated by the radiological protection agencies and they use their method to protect members of the public that depends upon *ab initio* modelling of exposure. The choice of a 'critical group' of people who are those most likely to be exposed according to the model. This method is utilised by both the IRPI and the NRPB. These models rely heavily on averaging dose to tissues and the main exposure groups chosen as critical in the case of exposure to Irish Sea contamination were, in 1974:

- Fishermen exposed to beta/gamma radiation from fish flesh
- Fishermen exposed to beta/gamma dose to whole body from estuarine sediment.
- Porphyra laverbread eaters, because of the high beta dose to Gastric tract from the isotopes (mainly the beta emitter Ruthenium-106) in the seaweed used to make the lavabread..

Ireland has a significant inshore fishing industry with small boats operating in inshore waters, including the Irish sea. By 1993, in Ireland, internal dose had become of greater concern than external dose, because of the far greater number of people eating contaminated seafood and critical groups had been extended to eaters of shellfish, fish and prawns. The calculation of exposure dose follows the crude averaging methods of ICRP 60 (ICRP, 1990) which I have criticised for not taking account of anisotropies of dose either temporally or microscopically. Thus the radioactivity in the fish or shellfish is assumed to transfer to the whole body or organ in the human body which is being considered. Because of this, the ingestion of hot particles, either by inhalation or ingestion does not carry any risk, since decay energy is diluted out into the mass of tissue of the body. In reality, of course, the multiple decays of a particle trapped in tissue will give a massive dose to the adjacent tissue. In fact, many shellfish contain hot particles which may be transferred to the human gut as we see in the autoradiograph of a mussel from the Irish Sea shown in Fig 3.5.1. What happened when a shellfish like this is eaten? Can the particles get across the intestine of the person eating the shellfish? What if the particle is trapped in the colon?

3.6 Summary

In this chapter I have looked at the operation at Sellafield purely from the point of view of its releases to the Irish Sea. This is because it is here that I made the first discovery of the immediate effects of internal radiation exposure from man-made fission-products, effects which I will be describing. The ethical basis of the operation at Sellafield is that of cost-benefit analysis. The benefit in this exchange accrues to the rich and powerful, the cost to those who live near the plant or near the coast. In the case of Ireland, there is no benefit whatever, only cost. I will return to the matter of the ethical underpinning of the nuclear project later, but here I merely want to finish this account by summarising what we need to know about Sellafield in order to understand what follows. Sellafield is a huge nuclear fuel reprocessing plant that takes in spent radioactive fuel from nuclear power stations in the UK and elsewhere in the world. By chemical processes the plant extracts the Plutonium from these fuels for manufacturing atom bombs, and more recently as a feedstock for a new and largely untested and dangerous nuclear fuel called MOX. Part of this process involves the production of large quantities of radioactive waste. Significantly large quantities of this waste, including the alpha emitters Plutonium 239, Plutonium-240 and Americium-241 and the beta emitters Caesium-137 and Strontium-90 are discharged to the Irish Sea through a pipe. Releases are also made to the atmosphere by chimney, but a large proportion of these aerial emissions also end up in the sea. In terms of the alpha emitters, the quantities are very large comparable with all the fallout from weapons testing.

In terms of density or concentration, the material represents a much large risk to people living near the Irish Sea than weapons fallout. The dispersion of the material is affected by tidal energy: specifically, radioactive material is concentrated on the shores of the Irish Sea in areas of low tidal energy and particle size. These highlight areas like estuaries and coastal inlets and coastal mudflats which dry at low tide. There is sufficient evidence to show that the contaminated sediment in such areas becomes resuspended by wave action and is driven inland. Radioactive particles of plutonium and other isotopes can be found in the air near the coast, and although the smallest particles have been crossing the entire country, the highest levels of aerosol concentration are in a narrow coastal strip, maybe 1km deep. These levels of exposure are very low, when assessed as absorbed dose, but there are plausible biological and mechanistic arguments to suggest that such an averaging approach is unsafe. If this were so, and these particulate internal exposures carried enhanced hazard for cell mutation and cancer, then looking at the trend in cancer with distance from the sea, might be expected to show a cancer trend effect. In Part II, Chapter 5 onwards which follow, I pursue this line of enquiry using data for Wales and Ireland.

5
The Irish Sea Part I. Cancer in Wales 1974-89

5.1. Wales

In *Wings of Death*, in 1995, I predicted a cancer epidemic in England. At the time, it was being argued by the government that there were no increases in cancer in real terms. The basis of my argument was the increase in cancer Wales which began in the late 1970s and which national data showed to accurately follow the cumulative dose to the Welsh population from Strontium-90. The graphs are shown in Fig 5.1.1 below.

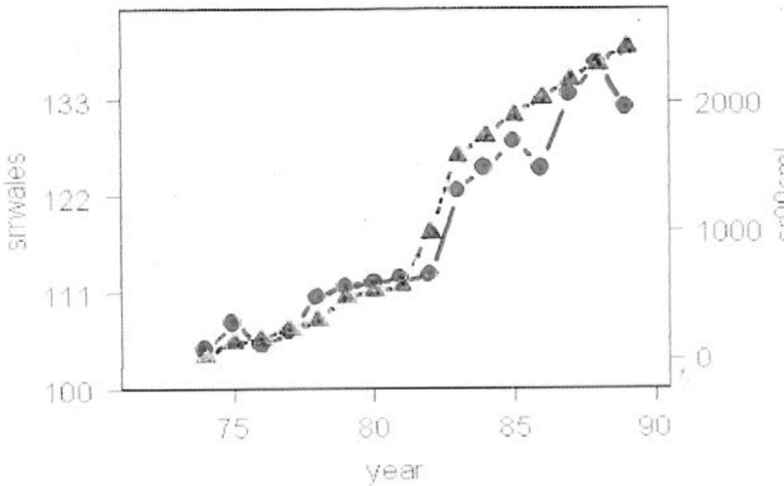


Fig 5.1 Cancer in Wales (circles, SRR, all malignancies M+F) and Strontium-90 cumulative dose (microSieverts) twenty years earlier (Busby BNES).

Of course, there was not just Strontium-90. There was Caesium-137, Barium-140, Iodine-131, Ruthenium-106, Plutonium-239, on and on and on, a list that includes a host of new radioactive substances capable of being incorporated into human tissue and causing genetic damage to cells. The reason for the higher levels of radioactivity in Wales was rainfall. Wales has three times the rainfall of England and the levels measured in the milk and the food by the Ministry of Agriculture (MAFF) were two to three times higher than in England. But this was not the only radioactivity in Wales. There was also the material that fell with the rain after the Windscale fire in 1957. There was also the material from Sellafield washed up on the coast. There were three questions. Were the increases in cancer shown by the national aggregated data in *Wings of Death* uniformly spaced over Wales in the disaggregated small area data? If not, then where would the highest levels of cancer be found, if radioactivity were the cause? Finally, what would be the effect of living near the contaminated coast, if any?

Sellafield released material over the whole period covered by the data at a much greater level than there had ever been before or since. There were huge discharges which increased from the beginning of the period and peaked towards 1979. If there was a 1-year lag between the contamination leaving the pipeline and fetching up on the coast of Wales then allowing a few years for the start of the clinical expression of cancer from this source, and walking into the problem like the TV detective Columbo with a naïve air of ingenuous bewilderment, we could expect two things. First, there should be higher levels of cancer near the coast in the north which was closer to Sellafield. Second, the trend in cancer risk over the period should increase more rapidly near the coast than further away. At the beginning we didn't know what we should find, and at that time, we didn't know either about the concentration of the material in estuarine and intertidal sediment, nor did we know anything about the trend in air concentration away from the coast. We found all that out later when we were trying to explain the initially curious results. Originally, we thought that the highest levels of cancer would be in the areas of highest rainfall, but that there might be some coastal effect from Sellafield superimposed on this and increasing over the period.

The idea was to look at the small area distribution of cancer in all of Wales over the period 1974-89 and this is what we did. Some of these results can get a bit technical. Don't bother to try and follow it all if it gives you a headache. The gist is clear.

5.2 The data and the exercise

Between 1974 and 1995, when they were closed down, Wales Cancer Registry collected details of all cancer cases in Wales by address at the time of diagnosis, sex, age at diagnosis and site of cancer (or what I shall call, cancer type). For historic reasons to do with the population divisions of the country and for purposes of statistical analysis, the numbers of cases were aggregated to small areas called Areas of Residence (AOR). These areas varied widely in area but each consisted of a small number of census wards. Appendix B lists the names of all the AOR's in Wales with their 1981 population. In 1998, we began research for the Irish Court case, which is still running, *Short and Others vs.BNFL.* The idea was to examine cancer incidence risk by distance from the Irish Sea and also look for any changes there might be over the period 1974 to 1989, the period covered by the data. We had all the different cancers. We had all the age groups. The most difficult part at the beginning was converting the text-based files we were given into a form that could be sorted on the computer. Because they were too large for EXCEL, we had to use SPSS for this procedure. The first file we were given was a compressed datafile named *A-2218.exe* which had been extracted from the mainframe computer at the Welsh Office by Susan

Frost on 25th May 1995. It had an on-board unpacking program but when it unpacked it was too large for any program we had on the computer we had then: they promptly locked up. As you will see later on, this turned out to be valuable, since I asked for the file to be split into two and Wales Cancer Registry sent me the divided file on a separate disk. Unfortunately this was also too big. By late 1996, Wales Cancer Registry had been closed down. However, the Welsh Office cancer data collection was now being carried out by the Statistics Division and I phoned Heather McGrane, who was part of this operation, and asked if I could have a different version of the cancer files and one which was updated as far as possible. She was helpful and organised to send me a complete set of the data back to 1974. This was extracted using a different method by Hugh Warren from the mainframe computer on 12th June 1996. This file included the latest data year 1990 and was labelled *A-2883.*

We had to wait until 1998 to start examining all this. The Irish State bought us a bigger PC, a Gateway 2000 (a machine which is still running) and they also paid for software which enabled us to begin organising and analysing the data. In addition we obtained two secondhand backup 486 machines which were used by the data processing assistants.

Ecological analysis

The basic method we used to investigate the hypothesis that exposure to radioactive discharges had caused excess cancer on the Irish Sea coast of Wales is termed by epidemiologists, ‘ecological’. It cannot, even after a discovery of a very strong association, prove a causal relation, but may provide supporting evidence, strong negative evidence or, on the other hand, may generate new hypotheses. The best form of such analysis would be the comparison of radioactive exposure levels for the isotopes of interest, perhaps measured as doses, with subsequent levels of cancer. However, here we had only the measured levels of radioactive pollution in the intertidal sediment for certain points on the Welsh coast and data on activity levels of man-made radioisotopes in soil. We could also identify the coastal populations and our initial hypothesis, as described below, was merely that such people have a higher risk of cancer than those living inland.

The most useful form of cancer incidence data would be postcoded cases, so that an accurate mapping of cases to distance bands from the coast could be compared with populations in such bands. Post coding only began in the middle of the period we were examining and anyway, the data we had been given was not postcoded. So in practice, we were constrained to examining the smallest areas that cases are coded to by the Wales Cancer Registry database, the AOR. In any event, the ability to usefully examine case numbers would depend upon having suitable population data. What we were essentially doing was comparing observed rates with expected rates. To generate rates for an area we needed the population of that area.

Hypothesis

The hypothesis being tested was that coastal populations are at greater risk of cancer than inland populations. The null hypothesis, that there is no difference, was tested using a chi-square statistic where numbers of cases were greater than 50 and cumulative Poisson probability where the numbers were smaller. The trend with distance from the sea and also trends in time in distance bands were examined using a Relative Risk based on the England and Wales populations for 1979. This is because this population was used as a base for trend by the Office for Populations, Census and Surveys, OPCS in the annual publications Cancer Statistics Series MB1 and because we had used this base year in other analyses and publications, notably in *Wings of Death*. It also enabled us to examine trends in time relative to data from England and Ireland.

In addition, certain other statistical procedures were used to analyse the data and these will be described in due course.

Populations and Areas of Residence

The best available source of population data for small areas is the decennial census, and so we were forced to identify the smallest area we could examine with the smallest census unit. In this case, however, the AORs used by the Welsh Office for health administrative purposes were slightly larger than these. They varied in area and population but these populations could be obtained by aggregating 1981 census wards.

This resulted in a 1981 population for the AORs. It was this population, and its distribution by 5-year age group, that was used to approximate the population for each year from 1974 to 1989. Cancer incidence generally increases exponentially with age and so it was necessary to allow for the ageing of the population between 1974 and 1989. This is a problem, however, for ward level data, since population data from the 1991 census was based on new wards due to boundary changes, which occurred between the 1981 and 1991 censuses. Normally, the best method to allow for changing population demography is to generate a trend line between the 10-year census populations. Because of the boundary changes, this was not possible. However, we were able to use the larger areas in Wales to examine the level of error that was introduced by using the 1981 census figures alone and show that for Wales, for the summation of effects from the whole age range, the alteration in population from 1974 to 1981 exactly balances that from 1981 to 1989 and that the error was negligible. This is shown in Table 5.2.1. below. It had also been possible, in the case of some of the AORs, because of minimal changes in the ward boundaries, to examine the effect of the changing populations. Such analyses confirmed that the 1981 populations were a suitable approximation for the population at risk over the whole period. Table 6.1 also shows the change in expected numbers of 'all malignancies' in Bangor, north Wales, based on 1981 and 1991 populations although this comparison has to be considered with caution owing to slight changes in the ward boundaries between the two years.

Census figures were obtained from the Office of National Statistics (ONS), Titchfield, Hants and also on floppy disk from the Statistics Division of the Welsh Office. Areas of Residence maps were generated using County maps of the 1981 wards supplied by the Cartography Division of the Welsh Office who also kindly supplied 1991 ward boundary maps. A digitized map of the AORs was produced using the program EPIMAP. This map is used throughout for presentation of geographical data and also as a coloured descriptor of disease rates or pollution. The basic map of AORs in the study area used is given in Appendix B and Plate 4 of *Wolves of Water* (2006).

Table 5.1 Variation in expected numbers of 'all malignancy' based on 1979 England and Wales rates using 1974, 1981 and 1989 estimated populations for Wales. *(Source: Welsh Office Statistics Department*)

Population	**Expected number 'All Malignancies'**
[a]All Wales 1974 only	10879
[a]All Wales 1981 only	11522
[a]All Wales 1989 only	12284
[b]Population at risk: all Wales 1974-89	185203 by linear interpolation
[c]Population at risk: all Wales 1974-89	184352 by approximation on 1981 population
Bangor MB 1981 census year only	47.07
Bangor town wards 1991 census	46.20

[a] Based on Welsh Office figures (Welsh Office 1994); [b] Summation of annual totals produced by linear interpolation between the data years.; [c] 11522 x 16 years

Distance from sea, SEADIST

Our identification of population distance from the sea was similarly constrained by the data. What we did is to calculate approximate centroids of population for each AOR and to use these as the distance from the sea labelled SEADIST in our working files. The centroids of population were obtained by the following method. The main centres of population in an AOR were identified on a map and a line was drawn between the two largest. A point was positioned on this line such that the distance from the two ends was in proportion to the relative populations. This point and its calculated virtual population was then used as a centre of population in a subsequent similar exercise involving the third centre of population. The process was repeated until the centroid was obtained. In practice, the centroids for most AORs were easily determined since there was only one centre of population, usually a large town. In the case of the coastal towns within 1km or less of the sea there could be no error. Centroids of population for AORs in Gwynedd had been published by the Wales Cancer Registry in their 1994 Report on Trawsfynydd Nuclear Power Station (Welsh Office, 1994). This paper is discussed later but the centroids given in that publication substantially agreed with those obtained by the method outlined. Distance from the sea was measured from the map in any direction to the nearest sea coast.

Origin of cancer data

The Wales Cancer Registry Database (which I will refer to as WCR1) was obtained in 1995 (see above). An account of the acquisition of WCR1 and an entirely separate layout of the same data including the year l990 which was given to us by the Statistics Division of the Welsh Office in 1996 (which I call WCR2) is also discussed, above and later in the book. It is the data from WCR1 which was used throughout the study as the primary source. However, WCR2 has been extracted and coded for the age groups 0-4, 5-9, 10-14 and 15-19 in order to provide a check for the childhood cancer analysis. Both these databases were provided as text files extracted from the Welsh Office mainframe computer. The text files were separately compressed using different compression routines at an interval of one year. They were extracted in the Welsh Office from the SPSS datafile on the Welsh Office computer by two different people, using different routines, working a year apart. The first pages of the text files of WCR1 and WCR2 are reproduced in Appendix B together with pages of data from the two separate databases referring to a case of childhood cancer in Bangor. This is to illustrate the point that the two databases may be used as a check upon each other to show that at the point that they were handed over to us, except for certain anomalies relating to leukemia which will be discussed later, they largely agreed with each other.

Software and routines

The data supplied by the Welsh Office, WCR1, was decompressed using the on-board routine supplied and then imported into MS Word 6 for preliminary examination or comparison with WCR2. This text file was stripped of initial text lines and imported into MS EXCEL or Mathsoft AXUM. The EXCEL files were then filtered into cancer site files for each year but containing columns for each 5-year age group which were then exported to SPSS or S-PLUS programs and saved as SPSS and S-PLUS files. Population data were reconfigured to AORs using the disk versions of the 1981 census ward populations supplied by the Statistics Division of the Welsh Office and imported to EXCEL. The aggregations of AORs in terms of their constituent wards was a problem at first. Initially, the new cancer registry that replaced WCR in 1997, the Wales Cancer Intelligence and Surveillance Unit (WCISU) was approached for assistance, but they had no idea what the makeup of the AORs was, and still don't know. I had to contact ONS in Titchfield and eventually they supplied me with two separate files that enabled me to collect the constituent wards of the AORs together. It turned out that the AORs were based on 1974 local government boundaries whose constituent wards were largely unchanged by the 1981 census. Using these populations, expected numbers of cases were then generated within these files by applying the age-related incidence rates for the cancer site in question recorded in the OPCS 1979 cancer incidence Volume (OPCS, 1994). The expected numbers for each AOR were then exported to the relevant SPSS and S-PLUS cancer site file for final analysis. In order to examine the effects of the various possible casual parameters, e.g. rainfall, deprivation etc. dummy variables relating to the AORs (a dummy variable is an indicator of some categorical description e.g. near the coast = 1, remote from coast = 0) together with data on Plutonium pollution, rainfall, socio-economic descriptors etc. were imported or coded into the SPSS and S-PLUS master area files. Finally, following the analysis of these files, any AORs with significant excess cancer risk were checked against the separate text file WCR2.

Area chosen for study

The area of Wales chosen for the study is rural mid and north Wales north of a parallel drawn through St David's Head. We also initially looked at a study area which was slightly larger and which included Pembrokeshire and Carmarthen in the South and Wrexham in the North. The justification for reducing the area was that the OPCS classification of the County Districts containing the Areas of Residence (AORs) should be uniform in order to exclude, as much as possible, confounding causes of cancer from industrial pollutants. The final AORs included in the study area were thus all those classified by OPCS as 'Type I (Rural Areas)' and all 'Type V (Mining and Industrial Areas)' were excluded. In addition, the AORs south of St David's Head which included the areas near Milford Haven and Llanelli were excluded for two reasons. The first was that there is considerable petrochemical pollution associated with the refinery at Milford and the chemical and steel factories in the area. The second was that measured Sellafield radioactivity concentrations were very low in the Bristol Channel and South Wales silts and effects from the Bristol Channel nuclear sites may have confounded any results. A map showing the AORs with their names is given in Appendix B Figure 1 and the AORs with their total populations in Appendix B Table 1.

Method

For each AOR in the study area, the expected number of cancer cases in each sex and 5-year age group was calculated by multiplying the 1981 census population in each sex and 5-year age group by the rate for that cancer site published for the 1979 population of England and Wales. This provided the expected number of annual cases of that cancer for any aggregate group of persons in the AOR. In general, for all ages, the sex and 5-year groups were then summed to give the total expected numbers and this was multiplied by the appropriate number of years to give the total expected number of cases, termed 'E'. The Relative Risk RR was then obtained by calculating the ratio Observed/ Expected or O/E. For some sites, a socio-economically adjusted Relative Risk was also considered. This was obtained by adjusting the expected number of cases by a factor derived from the Carstairs Index of Deprivation as described below.

Having calculated Relative Risks for any site, population age group or period the next stage was to examine the data for trend with distance from the sea. This was initially done by generating a scatterplot of Relative Risk by distance from the sea, or RR by SEADIST. There is a problem, however, in interpreting such a plot or in using the RRs for each AOR as individual data points in any regression analysis to examine casues. This is due to the widely different population sizes in the different AORs. Some of the rural AORs in Powys have very small populations. This lead to a much larger scatter of values for RRs in these areas, especially for low incidence cancer types and for children where the natural rates are very small. This could have resulted in one such AOR having a single case by chance but causing a very high RR and the resultant scatterplot or regression would thus convey undue weight to this point value. The problem is discussed in Elliott *et al* (1992) where a number of solutions are suggested, including the method of Bayesian smoothing. We adopted a different approach. Scatterplots may be weighted by the size of the AOR to produce what is called a 'bubble plot' . In such a plot the size of the data point represents the weight to be ascribed to it. Thus an area with a large population has a larger bubble and the eye is led to see the relationship between cancer risk and SEADIST.

Besides the graphical use of 'bubble plots', to analyse the relationship qualitatively we also decided to overcome the problem in two other ways. The first was by aggregating AORs into grouped bands at different distances from the sea with approximately the same number of AORs. For the high incidence all ages analyses, seven such bands were used. The distances were not linearly defined since the main purpose was to establish sufficiently large populations in each band to reduce the variance in Relative Risk. The following distance (km) bands were used:

Group I	0~SEADIST<0.8
Group 2	0.9<SEADIST~2
Group 3	2. l<SEADIST<5
Group 4	5.1 <SEADIST<11
Group 5	11.1 <SEADIST<20
Group 6	21<SEADIST<40
Group 7	SEADIST>41

In addition, for comparison, RR values were computed for three other groups;

- All study area
- All South Wales
- All Wales

Population data, averages and mean values of SEADIST and number of aggregate AORs for the groups are given in Appendix B.

The second way of examining the effect of SEADIST and also other possible explanatory variables was by regression analysis. Professor Diggle of Lancaster University, and expert in this area, suggested using as a general equation of trend the following:

$$\text{Relative Risk} = Ae^{\alpha S + \beta D + \dots}$$

or

$$\ln(RR) = \alpha S + \beta D + \dots + \text{constant}$$

where for each AOR, RR is relative risk, S is SEADIST, D is deprivation, and other covariates can be examined. The basic regression on SEADIST and the p-value of the t- statistic for the coefficient α answers the question of whether there is a significant trend away from the coast although it constrains the answer to an assumption that the form of the relationship over the whole range of distance is logarithmic (and see the arguments about regression in Chapter 5). In order to overcome the problem that small areas carry equivalent weighting with large population areas, the values of RR were population-weighted by the expectation values. Inclusion of socio-economic deprivation coefficients in the equation of risk enabled this factor to be examined. However, as already noted, there are problems of interpretation with a multiple regression approach, which increase with the number of covariates in the equation. There are also statistical pitfalls associated with autocorrelation, heteroscedasticity and multi-collinearity. Furthermore, regression and correlation only measure association. Interpretation depends on inputs of other factors, areas of knowledge and causal mechanisms. One important area where the results must be considered with caution is that of illness and socio-economic deprivation. This has already been considered in Chapter 5 and in order to make certain that deprivation was not at the base of the effects we discovered in Wales, a number of different techniques and indicators were used.

Socio-economic deprivation

In an attempt to resolve the problem of standardising for deprivation, we obtained two sets of deprivation indices (see Appendix C for details). First, we contacted the Small Areas Health Statistics Unit (SAHSU) at Imperial College, London. Their deputy director, Dr Jarup, agreed to supply us with Carstairs scores for the 1991 Welsh census wards but was unable to help over the problem of devising a standardisation routine. He suggested using the cancer rates in all the AORs in the whole of the study area to obtain a correlation which would enable us to devise a standardising factor. Second, we discussed the same problem with the statistical division of the Welsh Office and they supplied copies of 1981 ward-level maps together with a list of values for deprivation in the 1981 wards calculated using a more comprehensive deprivation index, the Welsh Index of Socio-economic Conditions.

Our final procedure was to calculate two different deprivation indices for the AORs in the study area using the 1991 Carstairs index ward-level data for wards which approximated to those boundaries in 1981 wards. The ward data was a population-weighted aggregate of these 1991 wards approximating in boundary to the 1981 AOR boundary. These values were coded as CARSTAIRS. The Welsh Index of Socio-Economic Conditions was a population weighted aggregate to the exact AOR level and was coded as DEP1. We then ran simple linear regressions between the Relative Risks and deprivation scores as suggested by Jarup.

In a second approach, which I prefer as it seems more rational, we examined the relation between cancer incidence and the Carstairs index found by Carstairs herself in Scotland, and generated standardisation factors for the main cancer sites we examined. They were applied to certain cancer sites to see if the magnitude of any effect could explain all or part of the results. The effect of deprivation on cancer trends can be teased out in another way. We know, for example that lung cancer has a strong positive relationship with deprivation. The more deprived, the greater the lung cancer: this is what is universally found. On the other hand, leukaemia and breast cancer operate in the opposite direction. So if there is a sharp excess of lung cancer in a small area (over the national average) and also an excess of leukaemia and breast cancer, then the primary reason cannot be deprivation.

5.3 Results

In the following pages I will show the results of this exercise. Each pair if pages represents the results we obtained for each of the main cancer types we examined, first in adults of all ages then in children. For some of these a coloured map of relative risk over the larger study area is displayed in the Plate Section. These maps have to be approached with caution since in many of the large rural areas, there are very few people and so a high RR may not be statistically significant and is probably a chance finding. This is unlikely to be true for the towns and the more populated areas. In each results section I show a bubble plot of risk for the cancer in all the AORs in the study area by distance from the sea. This is followed by a table of risk in each of the aggregated bands and in Wales and South Wales. These values are then plotted and a local regression LOESS line fitted to examine any underlying associations between risk and distance from the sea. I then plot the trend in cancer over the period 1974-1989 for aggregated groups at three distances from the sea, in order to examine whether there has been an increase in cancer close to the sea relative to groups far from the sea. Finally, for each cancer I give a summary of the results of regression analysis on the various possible confounding causes which we examined. At the end of this section, I look separately at the confounding causes and describe them in greater detail.

5.3.1 Adults: all malignancies

The most common malignancies in men are lung, skin, prostate, bladder, stomach and colo-rectal (large bowel) cancer. In women the common cancers are breast, skin, lung, colorectal and stomach cancer. . Lung cancer accounts for 22 per cent of male cancers whereas female breast cancer accounts for 22 percent of cancer in women, one in 12 now develop it at some time in their lives. In examining the trends in cancer in Wales by distance from the sea, we were anxious to examine all cancers aggregated together because the increase in real terms of all cancers had been already shown to follow the increase in cumulative doses from weapons fallout Strontium-90. The hypothesis was that genetic damage introduced by the weapons fallout had led to an increase in all cancers some twenty years later. But of course there are some very large question marks over such a hypothesis. Different cancers develop with different lag times; in putting all the cancers together we are looking at the sum of many effects, but these effects are mainly driven by the high incidence rate cancers like lung and breast etc which probably do have roughly similar development period from initial exposure The results for Wales from 1974-89 show that there was a significant sea-coast effect with significantly higher rates of cancer in the 0-2km group of areas (Table 5.3.1.1, Fig 5.3.1.1 and Fig 5.3.1.2). In addition the levels of cancer in this coastal population were higher than in industrial south Wales or Wales as a whole and that the overall increases which were found in Wales as a whole increased most rapidly in this coastal group, particularly after Chernobyl in 1986 (Fig 5.3.1.3).

This result was the first of many that showed a very sharp increase in cancer close to the coast. From Table 5.3.1.1 we can deduce that over the 16 year period, about 3000 people in the 0-0.8km plus 1000 people in the 0.8-2km strip developed cancer because the lived in these coastal strips rather than living inland in the rest of Wales. Thus a total of about 4000 extra cancers in the 16 year period can be traced to the effects of the Irish Sea coast. Using the average incidence to mortality ratio for all cancer this implies a cancer death toll of about 2700 in this sixteen year period. These increases were distributed amongst most (but not all) the cancer types.

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5.3.2 All leukemias in adults ICD 204-208

Lukemias are a diverse group of malignancies arising from the precursor cells of blood cells and tissue white blood cells. They have been associated with ionizing radiation exposure since the beginning of the radiation age but acute lymphoblastic and acute myeloid leukaemia, diseases which account for the major part of childhood cancers have been connected to exposure more than the chronic leukemias which are essentially diseases of older people. Indeed, it was the increase in childhood leukaemia at Sellafield in the 1980s that rekindled the concerns about the effects of nuclear pollution and led to the formation of the varios committees and organisations that have been responsible for the cover ups that I am addressing.

Leukemia was a major and early feature of the Hiroshima survivors study and various other external radiation studies which have been used to assess radiation risk. Rates in Wales, which are higher than in England, have been rising consistently since 1982 and more sharply since the Chernobyl accident in 1986 (Welsh Office 1994, WCISU 2003). The lag between exposure and expression of the disease varies with the size of the exposure, and as I argue elsewhere, there is always an immediate response also. The distribution of leukaemia in adults (i.e. all ages) with where they live in Wales and its trend over the period 1974-1989 should be a pointer to the cause of the disease. As with the all malignancies category results for Wales from 1974-89 show that there was a significant sea-coast effect on leukaemia with significantly higher rates in the 0-5km group of areas (Table 5.3.2.1, Fig 5.3.2.2 and Table 5.3.2.2). As with all malignancies the levels of leukemia in this coastal population were higher than in industrial south Wales or Wales as a whole and that the overall increases which were found in Wales as a whole increased most rapidly in this coastal group, particularly after Chernobyl in 1986 (Fig 5.3.2.2). The trend in development of the disease by distance from the sea over time shows graphically how the effect is driven by proximity to the sea (Fig 5.3.2.2) where we see that there is little change over the period 1974-89 in leukaemia in adults in the people living more than 5km from the sea yet in those living in areas less than 0.8km, the risk doubles over the period from about 1.2 in 1974 to 2.4 in 1988. If we assume a lag of about 5-8 years then this result directs the cause of the sea coast effect to an exposure which is linked to leukaemia and one which involves events in the period 1975-1983. The effect seems to be driven by coastal towns and small areas on the north Wales coast. Thus the AORs of these towns, close to the highest measured levels of radioactivity from Sellafield trapped in the in the coastal and estuarine sediments are significantly high compared with inland town areas as I show in Table 5.3.2.3 below.

Table 5.3.2.3 SRRs for all ages leukaemia incidence 1974-89 in north Wales coastal town AORs compared with some comparable inland town AORs

Coastal Areas	**O/E = RR**	**Inland Areas**	**Relative Risk**

74CA Bangor	37/15.9 = 2.44***	71GA Denbigh	15/12.3= 1.2
71CC Colwyn Bay	67/48 = 1.4 ***	76AA Brecknock	12/8.4 = 1.5
71JA Prestatyn	51/30.8 = 1.7 ***	76AA Builth Wells	2/2.6= 0.8
71JC Rhyl	65/36.7 = 1.8***	3 Newtown AORs	11/21.3= 0.5
71CA Abergele	53/26.6 = 2.0 ***	76CG Welshpool	13/9.9 = 1.3
1.374AE Llandudno	51/33.6 = 1.5***	76ET Rhayader	8/6.31 = 1.2
74AG Llanfairfech'n	11/5.7 = 1.9	76EC Llandrindod	7/6.2=1.1
71EA Flint	32/19 = 1.7**	76CB Llanidloes	6/4 = 1.5
All coastal above	367/216.3 = 1.7***	All inland above	74/71.1 = 1.04

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5.3.3 Breast cancer in women

Breast cancer is the most common cancer occurring in women and has received the greatest attention as to its cause, since the disease began to increase rapidly in the mid 1970s and is now at epidemic levels. Unlike lung cancer, but like leukaemia, the trend with Social Class is negative, i.e. there is higher risk in high Social Class. Breast cancer rates are higher in Wales than in England and highest in North Wales. In 1995 and 1996 I analysed the age profile changes over the period of the increases in the mid 1970s. I concluded (Busby 1995,1997) that there was a cohort effect which identified women who were progressing through puberty at the peak of the weapons fallout as most at risk. These women would have been aged between 40 and 54 in 1980.

Because there was more than twice the fallout in Wales, especially north Wales, we would expect the onset of the overall national increase to begin in Wales, which it did and we should expect north Wales to be most affected, which it is. We might also expect highest levels of fallout Strontium and other isotopes to be washed to the sea and result in exposure near the coast, and also to be augmented with material (including Plutonium, Uranium, Caesium and Strontium) from Sellafield. Therefore it would not be unexpected for there to be a sea-coast effect, and indeed, the results show that this is exactly what there is. However, there is also an increase in incidence in areas between 50 and 50km from the sea, a result which is also found in other cancer studied. Results for Wales from 1974-89 show that there was a significant sea-coast effect on breast cancer with significantly higher rates in the 0-5km group of areas (Table 5.3.3.1, Fig 5.3.3.1 and Fig 5.3.3.2). As with all malignancies the levels of breast cancer in this coastal population were higher than in industrial south Wales or Wales as a whole. The trend in development of the disease by distance from the sea over time shows graphically how the effect is driven by proximity to the sea (Fig 5.3.3.2) where we see that there is little change over the period 1974-89 in the people living more than 5km from the sea yet in those living in areas less than 0.8km, the risk doubles over the period from about 1.2 in 1974 to 2.4 in 1988. If we assume a lag of about 5-8 years then this result directs the cause of the sea coast effect to an exposure which is linked to leukaemia and one which involves events in the period 1975- 1983. Regression results show a high level of significance for the seacoast effect ($p = 0.0002$) and for no other covariant, including deprivation.

Again, risks are high in the north Wales coastal towns e.g. Bangor (O/E = 120/79; RR = 1.52), Caernarfon (O/E, 98/66; RR = 1.5), Conwy (O/E = 194/109, RR = 1.8), Prestatyn (O/E = 231/154, RR = 1.5), Rhyl (O/E = 280/187, RR = 1.5) and Menai Bridge (38/21, RR = 1.8).

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5.3.4 Lung cancer

Lung cancer is the most commonly occurring cancer. Since a great deal of epidemiological work in the post war period it has become associated with cigarette smoking and following health education the reduction in smoking had begun to reduce the levels of lung cancer in men (though not in women) over the period of these results. Because of its lnk with smoking, the disease shows a strong association with Social Class, with almost a doubling of risk between the highest and lowest Social Class, and it is this link that drives the general positive association of all malignancy with Social Class such that the lowest Social Class have the highest cancer risk. However, the results of this study indicate very strongly that lung cancer in Wales is determined by where you live rather than by what you do. Rather than declining slightly after 1980, as the disease was in England, in the coastal groups in Wales it was increasing. Results for Wales from 1974-89 show that there was a significant sea-coast effect on lung cancer with significantly higher rates in the 0-5km group of areas (Table 5.3.4.1, Fig 5.3.4.2 and Table 5.3.4.2). In general, in the inland part of study area the risks were significantly lower than in England but they increased sharply near the coast. This is clear from the map shown in Plate 4. Levels were highest in Bangor (O/E = 189/142, RR = 1.33) and Caernarfon ()/E = 168/118, RR = 1.4). Compare the inland towns of Newtown (O/E = 106/195, RR = 0.5) and Welshpool (O/E = 82/91, RR = 0.9). Logarithmic regression showed a very significant association with sea-distance (p = 0.003), with Plutonium in Air (p = 0.04) and with Carstairs deprivation (p = 0.001) though not with the Welsh Office Deprivation DEP1 (p = 0.14).I conclude that these results suggest that the generally clean air of the region result is low levels of lung cancer relative to England and Wales, but that inhaled radioactive material from the sea causes an increase in the disease in the coastal areas close to the pollution. The Carstairs association may show that deprivation is also a component, but if this is so, the lack of association with the DEP1 covariant is puzzling. This sea coast effect in lung cancer was the first time we found such an interesting result. However, we were to find this lung cancer sea coast effect in most of the mortality studies we did, as I shall describe later in the book.

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5.3.5 Colon cancer in adults

Cancer of the colon (colorectal cancer) is the second most common cancer after lung cancer in the UK. It accounts of about 12 percent of all cancers in Wales with few cases at ages below 40 and rates in women being slightly higher than rates in men in Wales. Like other cancers, the rates are higher in north Wales and also highest close to the coast. There is a clear sea coast effect in colon cancer as can be seen by the results in Fig 5.3.5.1 (bubble plot, loess plot) and Table 5.3.5.1 which gives the data on distance groups and risks. Fig 5.3.5.2 shows the trend by distance over time, Table 5.3.5.2 gives statistics of comparisons of the coastal and inland groups by 5km break, and a summary. Risks are driven mainly, as usual, by the coastal towns e.g. Bangor (O/E = 113/56, RR = 2.0) Caernarfon (O/E 71/46, RR = 1.53) but there are also high risks in some inland towns e.g. Denbigh (O/E = 82/45, RR = 1.8). Regression (Table 5.3.5.3) shows significant association with SEADIST (p = 0.001) and also AIRPU (p = 0.0002), but there is no association with deprivation (p = 0.2).

Colon cancer is associated with meat eating (ref) and presumably therefore the exposure of cells in the large intestine to mutagenic materials. These would be higher in coastal population is they ate local food, including meat, seafood (shellfish) and vegetables which are contaminated with resuspended contaminated sediment.

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5.3.6 Prostate

Cancer of the prostate is a common cancer in men accounting for 9 percent of all new registrations in Wales. It has been increasing in Wales since 1974 when data was first being collated. It also has been associated with working in the nuclear industry among those who are contaminated with internal fission-product isotopes (Beral et al ref). This led to my associating the increases in prostate cancer in Wales with the weapons fallout in 1997 (Busby 1997 ref check), drawing a comment from the nuclear industry that such a conclusion would demand an enhancement of radiation risk over that which was assumed by a factor of about 1000-fold (Atkinson). Although prostate cancer has increased sharply in Wales, the distribution of by distance from the sea is not as clear cut as with the other common cancers, as the results show. Fig 5.3.6.1 shows the basic results as a bubble plot and the loess plot and the table of distances and risks. Fig 5.3.6.2 shows the trend by distance over time, Table 5.3.6.2 shows the regression results and the summary. The lack of clear cut association with sea coast in the case of prostate cancer is also found in the mortality studies and requires an explanation, which as yet, I cannot supply. Prostate cancer has a very long lag time and so it seems that the increases probably relate to events which occurred before the peaks in weapons fallout as well as to later exposures, and this may be part of the explanation for the less clear correlation. Nevertheless, there is a weak association as the regression results show ($p = 0.02$). In a multiple regression on 5 covariates, the only significant association was with SEADIST and AIRPU (the plutonium in air function).

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5.3.7 Oesophageal cancer, thyroid cancer, cervical and stomach cancer

Cancer of the oesophagus has increased over the period in Wales, particularly in men. It is one of the four main gastrointestinal cancers with stomach, colorectal and pancreas that make up 23 percent of cancer in Wales, but oesophageal cancer makes up only 2 percent. Since it was increasing over the period, it was of interest to see if it also exhibited a sea coast effect, and indeed it did do so as can be seen by the bubble plot and loess results given in Fig 5.3.7.1. However, although the levels are high close to the coast, they also increase in the more remote inland areas so the regression results do not show a significant effect.

Stomach cancer which now accounts for about 6 percent of all cancers has been falling nationally over the period 1974-89, possible due to the development of anti-ulcer drugs in the anti-H(2) histamine series like ranitidine and cimetidine (e.g.Zantac). These were drugs that I did some research on when at Wellcome. Other possible causes for the decline in stomach cancer is the use of antibiotics which are capable of (often as a side effect) decreasing levels of the types of bacteria which are associated with the inflammation of the stomach that increases the likelihood of the disease. Although the levels were falling in Wales, the levels were highest in north Wales where there was still a sea-coast effect on the risks na dnote the interesting trend over the period, with a bump in the coastal groups some ten years after the Sellafield peaks (Fig 5.3.7.2 Levels were significantly high in Caernarfon (o/e = 82/40, RR = 2.10) and Bangor (O/E = 90/48, RR = 1.9) and in other coastal areas.

Thyroid cancer results are interesting, see Fig 5.3.7.4

The highest levels might be expected to follow radioiodine exposure. If this were from weapons fallout then the high levels seen in the mountainous areas can be explained. Care should be exercised though as it is a very rare disease and the numbers are small. The cervical cancer seems to be highest in the wider coastal strip (0-10km) but the multiple regression results showed a positive effect of deprivation with no seadist effect but a p-value for Carstairs of 0.03, which is in agreement with the literature oon the association.

Fig5.3.7.3 and Fig 5.3.7.4 show the bubble plot and the loess plot. Table 5.3.7.1 gives the data. Levels were significantly high in Caernarfon (o/e = 82/40, RR = 2.10) and Bangor (O/E = 90/48, RR = 1.9) and in other coastal areas. The trend over the period is given in Fig. 6.7.3.5 and the statistical comparisons of coastal vs inland areas in Table 5.3.6.2. Regression and other results for stomach and oesophagus are collected in Table 5.3.7.3

5.3.8 Other cancers in adults

In addition to the cancers in adults which I have listed, we also examined the area distribution of some other cancers which we felt might be of interest from a radiological viewpoint. These were brain, thyroid, cervix uteri and pleura. For these, the results were either equivocal with regard to a sea coast effect or else there was definitely not one. Results are summarised below in Table 5.3.8.1

Table 5.3.8.1 Risk Effects by area in cancer of brain, cervix uteri, thyroid, pleura in Wales 1974-89.

Cancer	**Seacoast effect cut at 5km?**	**O/E (RR) <0.8) km**	**Regression p value on SEADIST**	**Regression p value on DEP1**
Brain	0.92 Not significant	158/112 (1.4)	0.58	0.80
Cervix	1.0 NS	305/158 (1.9)	0.2	0.8
Thyroid	0.97 NS	47/36.6 (1.3)	0.3	0.47
Pleura	1.5 Not significant	12/19.7 (0.6)	0.14	0.4

6
The Irish Sea Part II. Childhood cancer in Wales and other relevant studies

6.1 Introduction

Childhood cancer, although rare, is the third most common cause of death in the age-group 0-14. There are major differences in tumour type and primary sites in childhood cancer compared with adult cancer. In England and Wales, leukemia is the commonest childhood cancer, responsible for a third of all cases, with a preponderance of acute lymphoblastic leukemia, which peaks in the age-group 0-4. The two other main types of childhood cancer are brain tumours and lymphomas. Table 6.1.1 shows the distribution of these cancers in England and Wales in the 0-14 year old group between 1971 and 1980 (Draper, 1995).

The risk agencies and the nuclear industry have always concentrated on leukemia as the main indicator of radiation damage to populations, despite the clear evidence that ionising radiation causes increase in all cancer types. The Gardner study of Seascale showed a three-fold excess of non-leukemia cancer in children as well as the ten-fold leukemia and lymphoma excess (Gardner *et al*., 1990). Leukemia was the basis of the legal action regarding radiation effects from Sellafield (Reay and Hope *vs.* BNFL, 1993) and was bound to be an important consideration in the litigation for which the present results were obtained for.

As a result of the Hiroshima and other studies leukemia in children, had come to be firmly associated with radiation exposure by the late 1960s and so when, in 1983, a cluster of childhood leukemia was discovered near the Sellafield plant, with relative risk of about ten times the national average, public concern was that the plant emissions were the cause of the illness. The risk agencies argued then, and continue to argue, that their risk factors, obtained by linear extrapolation from the yield in the Hiroshima survivors, could not predict the effect, and therefore that there must be some other cause (COMARE, 1996). Shortly after this, studies were published that showed excess risk in children near the reprocessing plant at Dounreay of eight times the national average (Heasman, 1986). This was followed by the discovery of a significant, though modest excess near the atomic weapons factories at Aldermaston and Burghfield (Roman, 1993, Busby and Scott Cato, 1997). More recently, the French reprocessing plant at Cap de la Hague has been the focus of studies showing excess childhood leukemia risk associated with both playing on the beach and also eating shellfish (Viel, 1994, 1997).

Since Chernobyl, there have been reports of leukemia increases in the affected territories (Savchenko, 1995; Nestorenko, 1997) and also reports of no stepwise leukemia increases in the entire aggregated European population (Parkin *et al*. 1996). However, I had drawn attention to increases in childhood leukemia in Wales and Scotland after Chernobyl at the House of \Commons symposium we organised (Busby 1996a, 1998a)

And in particular, Molly and I recently been argued that risk factors adopted by the I C R P (and used by the UK National Radiological Protection Board) fail to predict the significant 3.3-fold excess leukemia incidence in those infants (age 0-1) in Scotland and Wales exposed *in utero* or with fathers whose sperm was exposed before conception. (Busby and Scott Cato, 2000)

The error involved is of the order of hundreds of times, a number that is sufficient to explain the Sellafield leukemia cluster and also those at other nuclear sites. Similar increases in infant leukemia after Chernobyl have been reported from Greece (Petridou *et al.*, 1997), the USA (Mangano, 1997), Germany (Michaelis *et al.*,1997) and in a preliminary report from Scotland (Gibson *et al.*, 1988).

Table 6.1.1 Distribution of the main childhood cancer types in England and Wales

Type	Numbers (% total)	Crude rate per 100,000
All cases	11,479	10.3
Leukemias	3857 (33.6)	3.47
Brain and spinal	2685 (23.3)	2.42
Lymphomas	1314 (11.4)	1.16
All other sites	3623 (31.7)	3.25

Source: Draper, 1995.

For childhood cancers we will report here the results obtained in the original, slightly larger study area which we began looking at in 1997, since there was no significant difference in the trend in childhood cancer between this and the restricted area which we used for the adult cancers The results we obtained for leukaemia in children in our initial study of the Wales Cancer Registry first database (A2218.exe) gave rise to enormous controversy when I first reported it in 1998. It showed a very high rate of child leukaemia in north Wales and was picked up by the BBC who made a half hour TV documentary called *Sea of Troubles.* This drew attention to the high levels of leukaemia and also other cancers in adults in the coastal areas of mid and north Wales and resulted in the Welsh Office calling in COMARE. It also switched on a searchlight which illuminated the earlier questions over cancer incidence in Wales and the closure of the Wales Cancer Registry just after they released to us the small area data. It began a fight over the truth of the cancer increases in Wales which continues to the present day. I will devote some space to these arguments in Part III but here I will present the results of the studies into childhood cancer in the area.

6.2 All cancers in children ages 0-4 and 0-14

Results by distance from the Irish Sea are given for the whole period in Table 6.2.1 and in the bubble plot Fig 6.2.1. The trend over the whole period was interesting: whilst there was a sea coast effect throughout the period, it became significantly high in the last thirds between 1984 and 1988 by which time the relative risk in the coastal strip <0.8km was 3.6 with 17 cases observed and 4.8 expected; p = 0.0000 Fig 6.2.2 shows this effect graphically. The effect existed but was less obvious in the 0-14year olds where over the whole period 1974-89 there were 56 cases of cancer observed and 40.9 expected (RR= 1.4, p = 0.01). By 1984-88 the 0-0.8km coastal strip had 22 cases observed and 12.8 expected (RR = 1.7, p = 0.01). So the effect was driven, as with the Sellafield children, by the 0-4year olds. The trend over the whole period was interesting: whilst there was a sea coast effect throughout the period, it became significantly high in the last thirds between 1984 and 1988 by which time the relative risk in the coastal strip <0.8km was 3.6 with 17 cases observed and 4.8 expected; p = 0.0000 Fig 6.2.2 shows this effect graphically in the sets of points for 19884-88 added to the LOESS graph. Tables for the three periods 1974-78, 1979-83 and 1984-88 are shown in Fig 6.2.1

Childhood maligs results Page 1

Table 6.2.1 and in the bubble plot Fig 6.2.1.

6.3 Leukemia

The Wales Cancer registry data for childhood leukaemia caused us a great deal of difficulty from the beginning. The first set of files we were sent (the A2218 exe files) contained separate columns for all leukaemia to those that were listed as ICD 204-208, the code for all leukaemia. I took this to mean that there were separate listings in the database for child leukaemia and in the initial analysis added the two columns of leukaemia data together. This was because there was no overlap. If a case appeared as 'all leukemia' it did not appear as 204-208. I return to this issue later in the book. But as far as the results were concerned, we reported results for two separate analyses. The first was the analysis of the Wales cancer Registry first file A2218.exe which I call WCR1. The second was the analysis of the second Wales Cancer Registry A2283.exe (WCR2) file which I obtained from the Statistics division of the Welsh Office after the registry had been closed down.

The result that caused all the trouble was the leukemia incidence in the 0-4s indicated by the WCR1. This is shown in Fig 6.3.1 Also is shown the same analysis but this time using the WCR2 file. Fig 6.3.1 also shows the plot of risk by distance from the sea over the whole period for the two databases. The sea coast effect is present in both datasets but the numbers of cases are far greater in the WCR1 dataset. I will return to the controversy about these numbers in Part III. Initially, when the arguments over the issue of the two files came to a head following the BBC it was agreed by the new cancer registry, the Wales Cancer Intelligence and Surveillance Unit (WCISU) that the WCR2 data was accurate. This second file shows a sea coast effect which increases in the second half of the period 1982-90. Cutting the coastal groups at 2km we find that over the whole period 1974-90 the relative risk was 1.5 ($p = 0.004$) and in the second half, 1982-90 this increased to 2.9 ($p = .001$). So even in the agreed dataset, without the extra cases tabulated in the first dataset, there is a significant sea coast effect on child leukaemia. Childhood leukemias are very rare, so a single case in an area might give a high relative risk and yet be a chance finding. However we can look to see areas where there are multiple cases over the period. We find that these areas are all the same coastal towns in north Wales that showed the high levels of adult cancer. Fig 6.3.1 also shows AORs in the study area with more than one case of child leukemia 0-4 and the calculated relative risk.

This is page 1 of the child leukaemia tables

Table 6.3.1 In Table 6.3.2

Tables and graphs

This is page 2 of the child leukemias
Fig 6.3.1 shows the plot of risk by distance from the sea over the whole period for the two databases *1*.

Include 6.3.3. from the earlier page

6.4 Brain tumours, lymphomas and cancer of the eye.

Brain tumours represent the second most common childhood cancer. In England and Wales about 13% of all tumours were brain tumours. The incidence has been increasing steadily in England and Wa;les between 1962 and 1991 with the greatest increases (50%) in the 0-4 age group. About half of these are fatal. Cook Mozzafari found excess brain tumours around nuclear installations in 1987 (1987).

We found a significant excess of brain tumours in children 0-4, 0-9 and 0-14 in the coastal groups with the excess driven by the usual coastal towns with contaminated beaches and local sediments. Fig 6.4.1 shows data for the 0-4 age group by distance from the sea. In the Table I show the analysis for the 0-9 age group. The effect was not significant in the 0-14s suggesting that it was driven by exposure occurring in the middle of the period of study (which is when Sellafield releases became significant).

I also give results for the coastal towns and compare 11 coastal towns with 11 inland towns. These results show high risk from brain tumours as well as leukemia in the coastal towns, at levels which approach those found at Seascale near Sellafield in the 1980s. Since non Hodgkin lymphoma NHL was also a feature of the Seascale cluster, we looked at NHL in Wales. The numbers are very small and so we had to split the area into three sections cut at 2km, 11km and greater than 11km. When we did this, we found a significant excess (RR = 2.73, p = 0.06) in the coastal 2km strip. This effect was not there for all lymphomas combined.

Because the well described genetic eye cancer retinoblastoma is associated with Sellafield pollution, as I have described earlier, we also examined the few cases of eye cancer in the 0-4 year olds over the period. Although the numbers were very low, there were higher risks in the coastal areas in the north of Wales. Out of the 10 cases in the entire study area over the 16 year period, four cases were in coastal AORs Flint, Llandudno, Pwllelli and Valley on Anglesey. The coastal effect was not statistically significant for eye cancer in the 0-4s.

Tables: Page 1 of the brain 0-4s etc.
Table 6.4.1 shows data for the 0-4 age group by distance from the sea. In Table 6.4.2 I show the analysis for the 0-9 age group.

Page 2 of the brain 0-4s and the lymphomas

6.5 Trawsfynydd and Wylfa Study (Welsh Office,1994b)

The results found by us were electrifying in their significance. For they showed that the operation of Sellafield had resulted not only in local effects at Seascale, but also deaths along the shores of the Irish Sea. The implications for the authorities were immense and so they moved swiftly to counter the accusation implicit in the results. Of course they must have known that there was such an effect when they rapidly closed the Wales Cancer Registry after the cat was out of the bag in 1995. But interestingly, and useful to our position was the fact that there was earlier data that showed the existence of the same sea coast effect which we had uncovered. This was, ironically enough, contained in a report intended to exonerate the nuclear industry. This first study to investigate cancer incidence in Wales in terms of possible causes was undertaken in 1994 by the Wales Cancer Registry. It followed the 1992 General election and our 1992 Non-Violent Direct Action against Trawsfynydd nuclear power station and its subsequent closure. The direct action was undertaken in conjunction with the publication of the books *Low Level Radiation from the Nuclear Industry: Biological Consequences*. and its Welsh language translation *Pelydriad Level Isaf o'r Diwidiant Niwcliar: yr Canliniadau Biolegol* (Busby 1992). This book argued that cancer in Wales was largely determined by low-level radiation exposure and focused partly on the radioisotopic pollution of the lake at Trawsfynydd nuclear power station.

The Wales Cancer Registry study (Welsh Office,1994b) published in May 1994 was entitled 'Investigation of Incidence of Cancer around Wylfa and Trawsfynydd Nuclear Installations, 1974-1986 A-EMJ-28'. There was no author listed, but in 1998, the present director of the Wales Cancer Intelligence and Surveillance Unit, Dr John Steward, admitted to me at our first meeting in Cardiff that he had been the main author of the report. Later, he retracted this admission.

For full details of the report and a critical review of its methods and results refer to the original report and to Busby, 1994b. Briefly, the finding was that there was no significant excess cancer risk which fell off continuously with distance from either Trawsfynydd or from Wylfa nuclear power stations.

The analysis for risk near a putative point source used the method of Stone (Stone 1988). This is a statistical procedure in which continuous fall-off of relative risk in annular aggregates of wards at increasing distances from a single point source of pollution is used as confirmation that there is a problem. The method itself is subject to criticism (Busby 1995). Its use in the Welsh Office paper was spurious since there were two sources of risk, Wylfa and Trawsfynydd. Therefore, if there was an increase in risk near each site due to radiation, risk would increase as the wards distant from one site approached the second site and the Stone procedure would signal no effect, even if there was one. However, the importance of the study is that the same Area of Residence (AOR) cancer incidence data for Gwynedd was used, together with centroids of population for seven groups of cancers, for the period 1974-86.

All leukemias were among the cancers analysed. Results were presented together with a map of the AORs and their centroids of population. In Busby 1994b, which reviewed the analysis, it was observed that cancer incidence relative risks shown in the report increased close to the shores of the Irish Sea. The numbers of cases of the seven groups of cancers tabulated in the results section of WCR,1994, agree closely with the data contained in the two files WCR1 and WCR2, with the exception of the contested child leukemia data. The 'all leukemia'--all ages' totals given in the Trawsfynydd study can easily be shown to demonstrate the sea-coast effect. A plot of Relative Risk for 'All Leukemia--all ages' in the areas of Gwynedd and western Clwyd reported in WCR, 1994 with distance from the sea, obtained from the WCR,1994 map is given in Figure 6.5.1. Both the effect of the proximity to the Irish sea and also the effect of Trawsfynydd power station are clearly visible. Because the cancer sites chosen for the study were small incidence sites, it was not possible to effect the same analysis for the other sites or more restricted age groups. However, in the case of the leukemias, the WCR,1994 study shows a result very similar to the general finding, that is, increasing risk close to the coast.

The study is valuable evidence because it shows that already in 1994 Wales Cancer Registry data showed the existence of a coastal effect on. leukemia. The Trawsfynydd study was a demonstrably flawed attempt to exonerate the nuclear industry sites at Wylfa and Trawsfynydd from causing increases in cancer in their neighbourhood. That the author of the study is Dr John Steward, Director of the WCISU, the organisation set up to take over from the Wales cancer Registry was our first evidence of Dr Steward's sympathies. However as I will relate in Part III Steward later denied ever having been involved in the report and my enquiries to the Welsh Office met with the statement that the report was produced by 'Wales Cancer Registry', and no individual author would be named.

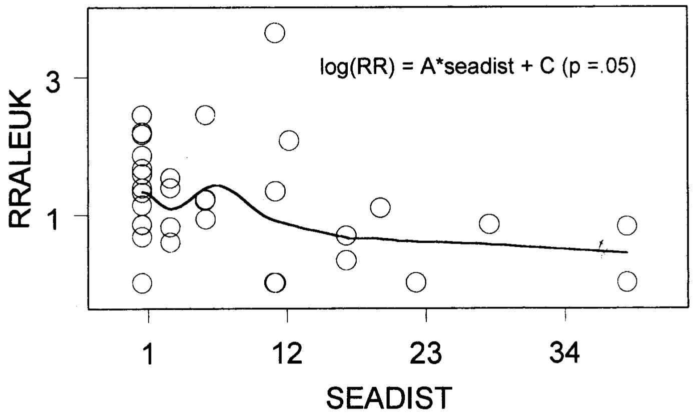

Figure 6.5.1 Scatter plot and local regression of Relative Risk of all leukemia in all age groups by distance from Irish sea. Data from Wales Cancer Registry Study of cancer near Trawsfynydd and Wylfa nuclear sites, WCR, 1994. The peak in the line represents wards around Trawsfynydd.

6.6 Other possible reasons for the effects found in the Wales data.

The hypothesis at the beginning of this study of cancer risk in Wales was that radioactive man-made isotopes had been released from Sellafield under license and had migrated to the coast of Wales and caused increased exposure to coastal populations which resulted in increases in cancer. Finding higher levels of cancer near the coast might however have been due to other confounding factors and these needed to be examined.

The first possibility was radioactivity from global weapons fallout in grassland and soil throughout Wales, ignoring the materials that had been washed to the sea and had become fixed in estuary sediment. These substances were measured by teams from Harwell in 1984, and again in 1986, following Chernobyl. (Welsh Office,1988) Tables and maps of concentrations of Strontium-90, Caesium-137 and Plutonium-239+240 in Wales are thus available. The fallout from weapons testing correlated with rainfall. Rain in Wales washes much of the particulate fallout to the rivers and thence to the estuaries of these rivers, many of which empty to the Irish sea. The east and south flowing rivers, draining the eastern parts of the Cambrian mountains, take a circuitous path to empty to the Severn estuary and Bristol Channel (Wye, Usk and Severn) and part of the fallout isotope burden will have taken this route to the sea. The ecological correlation with cancer risk may be modelled from the rainfall data and from the fallout data itself. We calculated and coded two variables, PLUTO, plutonium in soil from the Welsh Office Harwell report (Welsh Office, 1988) and RAIN (rainfall maps from the Metereological Office , Bracknell). Both were coded to the AORs by map superposition and geometrical square averaging . A map of PLUTO is shown in Fig 7.6.1 while a colour map of rainfall, purchased from the Metereological Office from which we coded the RAIN covariate by AOR is shown in Plate X.

Of course, the Irish Sea coast in Wales thus has inputs from weapons fallout and Chernobyl as well as from Sellafield, and the various proportions of these in the silt in parts of north Wales have been determined by Assinder *et al.* (Assinder *et al.*1994). In general, Assinder found that the weapons fallout/ Chernobyl fallout predominated at the inshore end of estuaries whereas the Sellafield radiation contributed most to the seaward end of estuaries and in the coastal sediment. Measurements made by the Harwell teams (Garland *at al.* 1989) show that 80% of the Sellafield radioactivity in Wales is in silt between the Menai Strait and Llandudno together with material trapped in the Dee estuary. The highest concentration was near the town of Bangor. The remaining 20% is distributed along the shores of West Wales with higher concentrations if the silt of estuaries of the rivers. This material and its concentration was coded to the coastal AORs and labelled SEAPU.

The sea-to-land transfer of radioactivity from Sellafield was discussed in Chapter 3. Several studies of plutonium in air concentrations by distance from the Irish Sea show a quite specific type of behaviour. There is a very rapid increase in concentration close to the sea, in the 0-1km range of distance, with a sharp flattening out in concentration from 5km to 200km. This suggests the existence of two ranges of particle behaviour based on the mass of the particle with larger particles dropping out under the influence of gravity in the first 1000m. Using data from various sources, but based largely of the work of Eakins and Lally (1984) we derived an empirical relation between plutonium in air and distance from the sea. This is coded to the AORs as the variable AIRPU.

Data was available on the levels in Wales of the natural radioactive gas Radon-222. This variable was coded to the AORs as RADON.

In addition to the variables already described, I used two socioeconomic variables DEP1 and CARSTAIRS. A list of the variables which were coded and considered is given below in Table 6.6.1.1

Table 6.6.1 Descriptive regression variables coded to each AOR and investigated for correlation with distance from Irish Sea and cancer risk in this study.

Variable name	**Description**	**Origin**
SEADIST	Distance from Irish sea (km)	mapping (see text)
RAIN	Average rainfall 1960-1995 (mm)	Metereological Office

PLUTO	Activity of Plutonium in soil (Bq/kg)	Harwell (Cawse *et al.*1988)
SEAPU	Activity of Plutonium in intertidal sediment. (kBq/kg)	Harwell (Garland *et al.* 1989)
AIRPU	Activity of Plutonium in air (nBq/cu:m)	Harwell (Eakins and Lally, 1984)
RADON	Activity of Radon in dwellings (Bq/cu:m)	NRPB 1999
DEP1	Welsh Index of Socioeconomic Deprivation (see text)	Welsh Office 1981
CARSTAIRS	Carstairs Index of Socioeconomic Deprivation (see text)	Census 1991, Small Area Health Statistics Unit

Results for each of the variables will be given below.

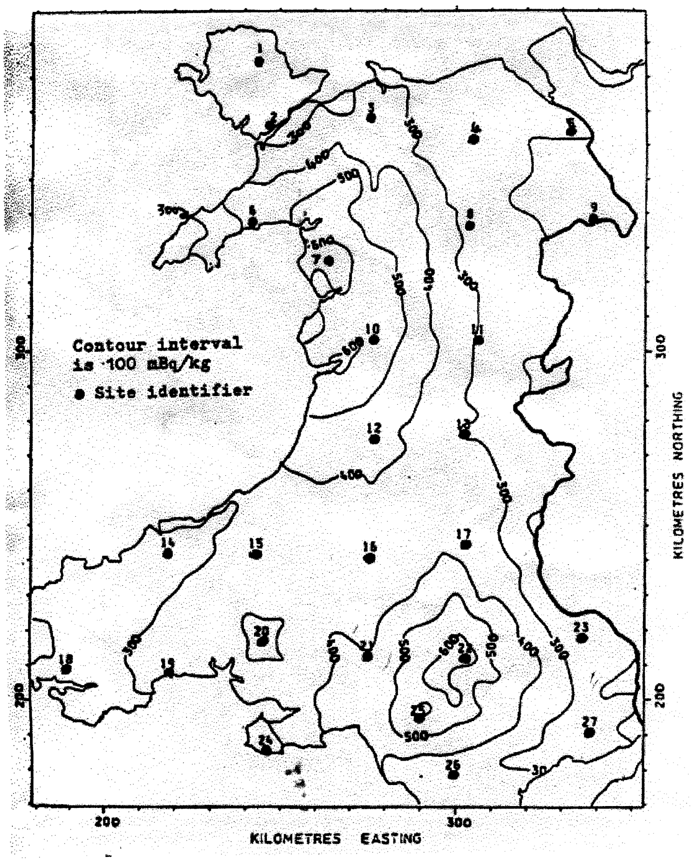

Fig 6.6.1.1. Map of plutonium in soil (Bq/kg) in Welsh AORs (*Source:* Welsh Office, 1988)

6.6.2 Rainfall

The variation of average rainfall with distance from the coast is given below in Fig 6.6.2.1 None of the simple two covariate or multiple log regressions gave significant association for any cancer risk and RAIN.

6.6.3 Plutonium in soil.

It had been hypothesised that increased risk might be associated with increased levels of plutonium in soil. The relation with distance from the sea is given in Fig 6.6.3.1 below suggests that this simple relationship is unlikely and indeed no cancer risk regression results gave any significant beta coefficient for such an association. However, the averaging process that led to the construction of the plutonium maps could not show differences on a small scale and thus could not distinguish elevated levels of isotopes in river valleys. There was a significant and moderate rural/urban split in cancer risk in the whole of the study area but mostly in the eastern low-risk areas where most of the towns are built on rivers e.g Builth Wells on the Wye.

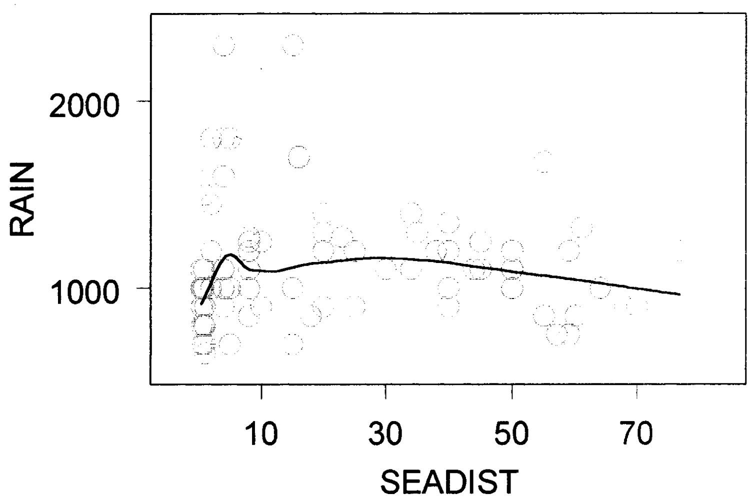

Fig 6.6.2.1 LOESS fit of RAIN (mm annual precipitation) coded into the AORs with distance from Irish Sea in study area (source: Met Office).

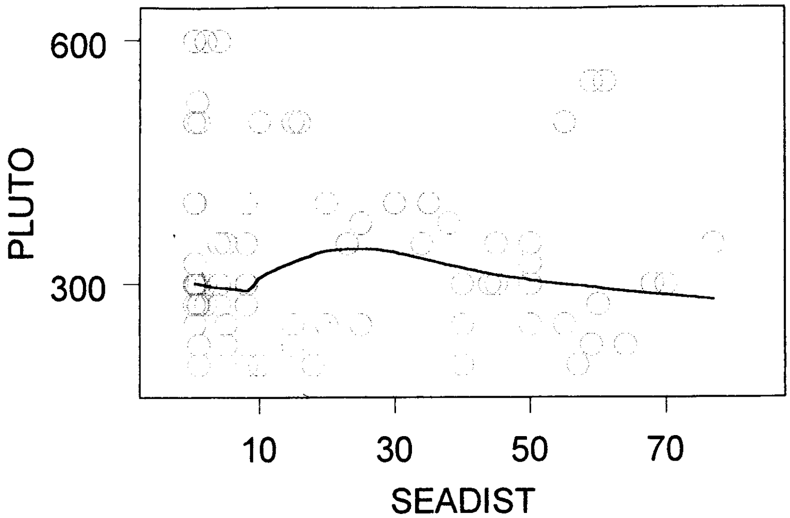

Fig 6.6.3.1 LOESS fit of PLUTO, plutonium in soil (mBq/kg) on distance from sea in study area. Note highest levels in mountains, following rainfall.

6.6.4 SEAPU

The plutonium concentration in intertidal sediment was mapped on the basis of measurements made by Harwell (Garland *et al.*, 1989). This map is shown in Plate 7. Coastal AORs were coded for the levels indicated on the map which were either measured or extrapolated linearly from measurements made by this Harwell study. The higher levels of cancer, particularly childhood cancer, were generally associated with the AORs in the north where the value of SEAPU was high, e.g. Bangor to Llandudno and Colwyn Bay to Flint. Indeed, it was possible to show that there was a correlation between the value of SEAPU for these coastal areas and the relative risk of cancer of most types. A scatterplot of relative risk for adult all malignancy, leukemia and colon cancer by SEAPU is given in Fig 6.6.4.1 In the case of some cancer types, e.g. colon cancer and leukemia, the correlation was statistically significant at the $p<0.05$ level.

In the overall regression of weighted relative risk of the cancer sites investigated in all the 94 AORs in the study area, the beta coefficients for SEAPU were not statistically significant. This was because the value was only defined for about a quarter of the total AORs. Nevertheless, the discovery that the highest cancer relative risks were on the coast and in the north enables the secondary analysis using the SEAPU variable and this points to the source of the high relative risk in the existence of high levels of Sellafield radioactivity, modelled here as plutonium, in the coastal or estuarine sediment.

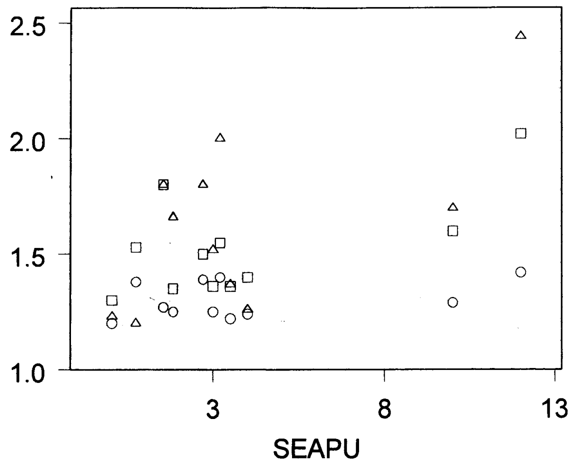

Fig. 6.6.4.1 Relative Risk of all malignancy (circles) colon cancer (squares) and all leukemia (triangles) by SEAPU, concentration of plutonium in intertidal sediment (kBq/kg).(*from Garland et al., 1989)*

6.6.5 AIRPU

The sea-to-land transfer of radioactive material from the Irish Sea has been measured (see Chapter 2). In order to examine the effect of such transfer, the concentrations in air with distance from the sea measured by Eakins and Lally in Cumbria (Eakins and Lally, 1984) were converted into a general

function to describe the fall-off of air concentration with distance from the sea. This function was obtained by mathematically fitting the empirical result and generating a trend curve. Values of plutonium in air at different distances on this sea distance trend line were then assigned to the AORs on the basis of their SEADIST value.
We modelled the trend in AIRPU by distance from the Irish Sea using the empirical measurements of Eakins and Lally as a basis. This function was then used as acovariate in the multiple regressions for cancer risk.

In the logarithmic regression of cancer risk in the study area, AIRPU was generally a highly significant covariate, and often more significant than SEADIST. This was because of the sharp increase both in cancer risk and in plutonium in air in the 0-5km coastal region. For example, in the case of all leukemias, all ages, AIRPU correlated with Relative Risk with a p value of 0.001. Fig 6.6.5.1 shows the trend in AIRPU with distance from the sea.in the coastal region upo to 10km.

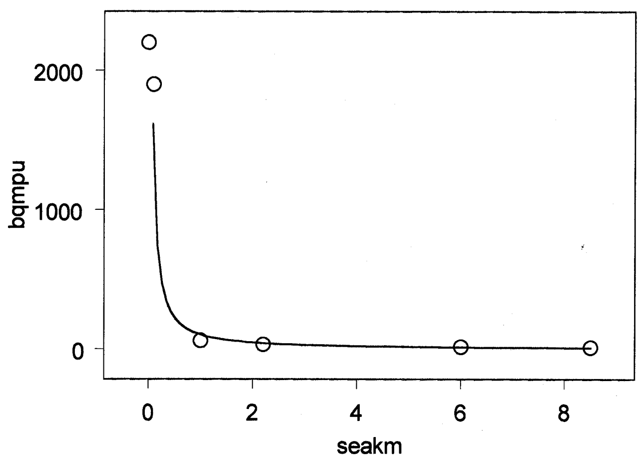

Fig 6.6.5.1 AIRPU trend with distance from sea, based on empirical measurements by Eakins and Lally 1984.

6.6.6 RADON

There has been considerable concern over exposure to the radioactive alpha emitting gas Radon-222, which is a daughter product of the decay of naturally occurring Radium-226, the fifth daughter of Uranium-238.(see e.g. BEIR V, 1988)

This gas seeps through Uranium containing rocks in granite areas and becomes concentrated in homes, particularly those modern homes, with low ventilation rates. The main concern is that radon may cause lung cancer and evidence for this comes from Uranium miners, although these are also exposed to solid radioactive dusts. Wales is not considered to be a high radon area, like Devon and Cornwall, nevertheless, the NRPB, at great expense, have mapped Radon concentrations in homes in Wales and recently (2000) published a Radon map. This is reproduced in Plate 8.

In view of the risk that is believed to exist between Radon exposure and cancer, particularly lung cancer, we coded the NRPB map to the AORs and examined the data for correlation. There are no cases of correlation between Radon levels and any cancer type in the study area. Indeed, the areas of highest risk, Bangor to Llandudno in the north have the lowest levels of Radon in Wales. Fig 6.6.6 below shows the levels of Radon (% of homes above action level of 400Bq/m^3) in AORs by distance from the sea. Fig 6.6.6.1 also shows a bubble plot of lung cancer risk versus radon level. The relation, if there is one, is negative: this is because the high radon levels are remote from the sea and therefore carry lower risk.

Fig. 6.6.8 Lung Cancer Relative Risk vs. Radon levels in AORs 1974-1989

6.6.7 Deprivation DEP1

The DEP1 deprivation index was described in Chapter 4. None of the cancer Relative Risks could be correlated with DEP1. The DEP1 index is one-sided, unlike the CARSTAIRS index. That means it does not have a negative range: populations are described as being undeprived or having varying levels of deprivation. Thus the greater part of the population of the study area, particularly those in the eastern region of Powys, were described by DEP1 as being undeprived. Their low levels of cancer were not able to weight any regression line in favour of a significant correlation. The pattern that emerged in the results was one in which deprivation had no effect on cancer rates in Wales. This is clear in the marked difference between cancer rates in the north of Wales compared with the socioeconomically deprived south of Wales. The variation of DEP1 and SEADIST in the study area is shown below in Fig 6.6.7.1 There is clearly little difference in DEP 1 with distance from the sea.

DEP1 is believed to be a more comprehensive and appropriate index than the more simple CARSTAIRS index and indeed the values of DEP1 were calculated for the exact ward aggregates of the AORs used in this study by the Welsh Office in 1981. This is explored further in the analysis of the results for CARSTAIRS below.

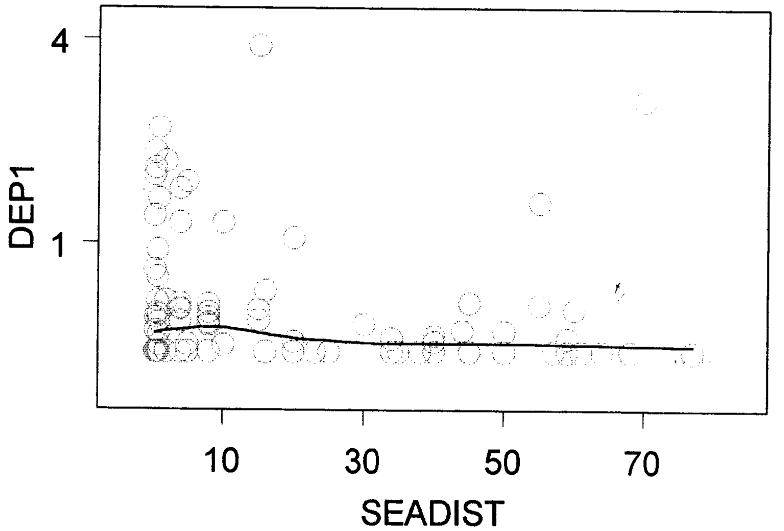

Fig 6.6.7.1 DEP1 deprivation index by distance from the sea in the study area AORs.

6.6.8 CARSTAIRS

This index, and its correlation with cancer rates has also been discussed in Chapter 4. The index has a slightly different relation with distance from the sea to DEP1, for reasons which are not clear. One possibility is that many of the coastal towns are either sea-side resorts or university towns and both have a large proportion of rented accomodation either for students or for holiday makers and CARSTAIRS gives a different weighting to overcrowding and car ownership than does DEP1. It is for this reason, given the peculiar urban rural mixture of Wales that the Welsh office favour DEP1 to the rather blunter CARSTAIRS index. However, most important, CARSTAIRS shows a small increase in the coastal 0-5km AOR'. This is shown in Fig 6.6.8.1 below. Is this the explanation for the coastal effect we find?

The answer is no. The range of this increase in CARSTAIRS units is from about 0 at the 5km line to +1 at the 0km line. If this increase in socioeconomic deprivation were affecting cancer rates, the correction to the Relative Risks found would be modest and in some cases would increase them. The correction factors based on the results from Carstairs and Morris in Scotland (1991) and Leon in England and Wales (Leon, 1988) are calculated and given in Table 6.6.8.1

It is clear that CARSTAIRS variation cannot explain the magnitude of the coastal effect. In addition, given the increases in child and adult leukemia and adult breast cancer found near the coast the CARSTAIRS increase would predict higher risks that we have found. This inability of CARSTAIRS or DEP1 to explain any part of cancer in Wales is clearly demonstrated by examination of the overall rates in the counties. Except for a low level of cancer in Powys, in the east, the other counties, in the highly deprived south of Wales to the less deprived north of Wales show little correlation with deprivation. Results are calculated for the Counties and are given in Table 6.6.8.1A and B.

It is clear that deprivation is of secondary importance to cancer risk in Wales where proximity to the sea is a much larger indicator of risk.

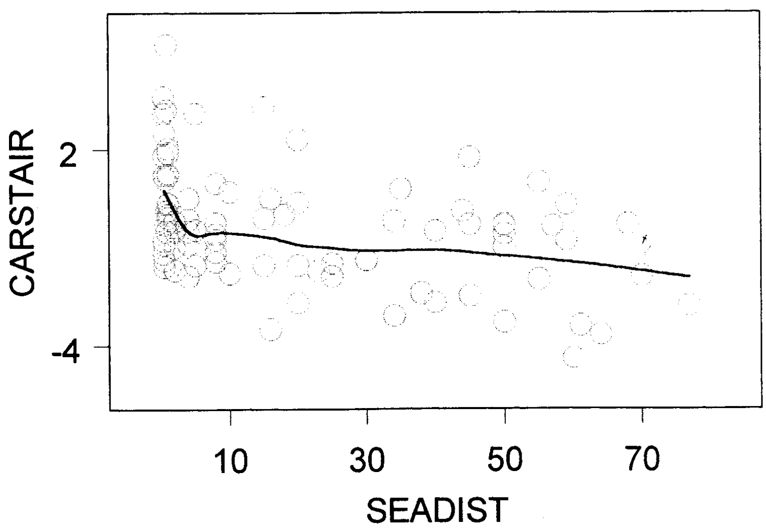

Fig 6.6.8.1 Variation in CARSTAIRS index of deprivation by distance from the sea.

Table 6.6.8.1A Calculated expected variation in Relative Risk in coastal AORs based on CARSTAIRS index and correlations between CARSTAIRS and standardised cancer incidence found in Scotland and in England and Wales.

Cancer Type	**Correction Factor to Relative Risk in Coastal AORs**
all malignancy	1% decrease
Leukaemia	1% increase
breast cancer	0.5% increase
lung cancer	4% decrease
colon cancer	no difference
cervical cancer	4% decrease
prostate cancer	no difference
Childhood cancer	2% increase

Table 6.6.8.1B Variation in all malignancy SRR in Welsh Counties 1984-88 with mean CARSTAIRS index. (*Source: Welsh Office, 1994 and Small Area Health Statistics Unit)*

County	**Type**	**Number of wards**	**SRR all malignancies 1984-88**	**Carstairs means (Standard Deviations)**
Gwynedd	North rural	139	103	+0.32 (2.7)
Mid Glamorgan	South industrial	120	100	+2.37 (3.03)
Clwyd	North mixed	150	103	-0.21 (2.64)
East Dyfed	Mid rural	162	100	-0.45 (2.13)
Pembroke	South west rural		98	-0.14 (2.5)
Gwent	South industrial	111	103	+0.8 (2.9)
South Glamorgan	South industrial	47	93	+0.38 (3.58)
West Glamorgan	South Industrial	84	105	+1.12 (3.05)
Powys	mid rural	84	84	-2.07 (1.95)
all Wales	-	1066	100	0.02 (2.85)

6.7 Conclusions from the Welsh studies

At the end of this section of results I will briefly draw together what we believed the data showed us at the end of the study of the Wales Cancer Registry data. First, there was clear evidence that something was causing a sharp increase in most cancer rates in coastal populations of Wales. The effect was there for most of the cancers we studied and the effect got worse over the period of the study. It could not have occurred by chance since the statistical power and significance were high. This was because the analysis was of a very large population over a sixteen or seventeen year period. This also enabled us to show that the effect was there in children, particularly the 0-4s. A pointer to the cause of the effect was the sharp increase very close to the coast: clearly it was something happening very close to the coast that was the cause or related to the cause. What could this be? We examined all the possible causes we could imagine, coding disadvantagement, rainfall, radioactivity in soil and radon. The only factors that could explain the sea proximity effect were plutonium in air, or seaspray, or the level of contamination of intertidal sediment, SEAPU. In other words, the regression was telling us that the trend in cancer risk with distance from the sea was the same as the trend in plutonium with distance from the sea, as measured by the Harwell scientists Eakins and Lally in the 1980s. A separate regression told us that, among the sea coast AORs, those with the highest risks were those with the highest levels of Plutonium contamination. Finally, examination of the development of the increases in risk over time showed that the overall increases between 1974 and 1989 were in the coastal strip, particularly after 1982. This was some five years after the Sellafield material washed up on the coast and began to expose local people who would have inhaled the airborne seaspray and resuspended radioactive particles, or eaten the contaminated local food. The data for adult leukaemia is most interesting. We can see the development of the risk in the coastal strip relative to the inland areas in Fig 6.7.1.

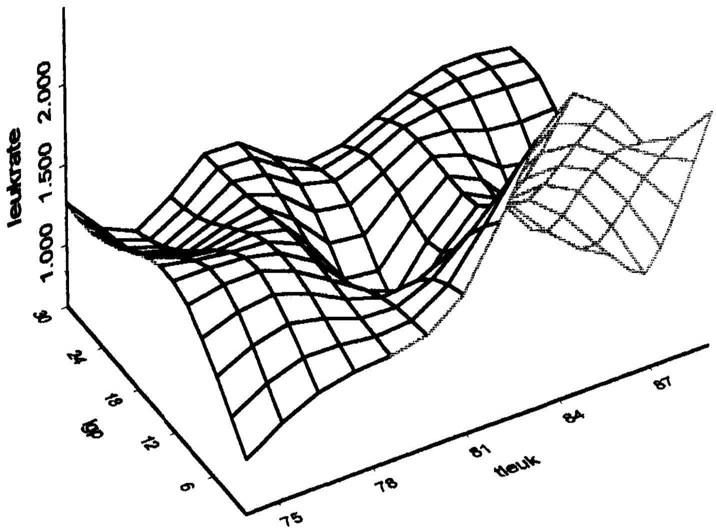

Fig 6.7.1 Changes in relative risk for adult leukemia by time and distance from coast. Note increase near the coast in period 1981 to 1984 and compare with Sellafield pollution trends shown in Section 2.

The response of the authorities was to deny the data in the case of the child leukemias and brain tumours and then, because the WCR data had apparently been wiped from the computer when WCR was closed down to undertake a different analysis based on wards in bands by distance from the sea. In the case of the adult cancers, their response was to ignore the assertion that the adult cancer sea coast effect existed and concentrate on the children. I will return to these responses to the bad news in Part III, and will now turn to evidence from Ireland. Before I do so, I will just relate an incident which occurred to me in North Wales in 1999.

In 1999 I went to North Wales to look for independent evidence of childhood leukaemia. In fact I eventually found someone who knew about the many cases of children with leukaemia but before I did so I was in Llanrwst one day looking for the cemetery to see if their were any children's graves and to talk to the priest. I fell in with some workmen who were digging up the road. One of them I had met before when he did some work near my house in Mallwyd. He told me the following tale:

I took my children last year to Disneyland in Florida. They were always pestering me to go and so at last I gave in. When we checked in at the door and bought the tickets, we were asked where we came from. 'I don’t suppose you have heard of it', I said,' but we come from Wales'

'Of course we have heard of it', they replied. They added.' That's the place where there is that awful Sellafield atomic plant where the children catch leukaemia'. Astonished, I asked how they knew this. The answer was grim. ' It's because every year we have these children from the area come here to see Disneyland. The local people have got together to donate money to sent these dying children for a last treat.'

And so there they stand, conjured immediately in our minds, sad happy little creatures with their bald little heads and white faces, shining with hope and despair, cosied along by their desperate mothers and fathers, visiting Mickey Mouse and Donald Duck, perhaps for the last time courtesy of Sellafield and British Nuclear Fuels.

If these results represented evidence of an effect on the coasts of the Irish Sea, then we would also expect to find similar effects on the Irish coast, where there are estuaries and inlets, contaminated mud banks and coastal populations. Although Ireland had no cancer registry until 1994, some data became available for the three years 1994-6, and in addition, in 1999 I devised a cancer questionnaire study which was undertaken in Carlingford in early 2000. The results of these Irish studies confirmed the existence of the sea coast effect, and I will briefly describe the history and the consequences of our researches in Ireland.

7
Ireland

Ich am of Irlonde
Of the holy lande of Irlonde
God Syr I pray Thee
For of Saint Charitie
Come and daunce with me
In Irlonde

7.1 Background

People living in the north east of Ireland have believed that the operation of Sellafield has caused increases in cancer in their locality for a very long time. I was first there when I gave a contribution in the late 1990s to a conference organized by the Association of Irish County Councils in Galway and heard many people who attended this meeting give vent to their concerns about the health effects of the Sellafield pollution. The problem was that there was no national cancer registry operating over the period of peak output from the plant from 1974-90, and so no one really knew. Of course, the Radiological Protection Institute of Ireland (RPII) maintained, whenever the question arose, that the doses were too small. But no one paid them any heed.

At a second public meeting on the subject of Sellafield called by the Mayor of Drogheda, Fergus O Dowd in 1996, I first met Grattan Healy, who had become energy researcher for the Greens on the European Parliament and who has been a great friend and helper in this matter of nuclear risk. Grattan suggested that I ask the Minister, at the conference in front of all those attending, to supportthe Welsh Cancer data research and ultimately this led to the contract that enabled us to carry out the work. But an initial follow up to this first meeting with Avril Doyle was not encouraging. Following publication of my report `Nuclear Waste Reprocessing at Sellafield and Cancer near the Irish Sea: Arguments for an Independent Collaborative Study' (Busby, 1996b) correspondence between Green Audit and the Irish Minister for Energy, Emmet Stagg made clear that the Department of Health was advising the government that there was no excess risk near the coast. This was despite the fact that no study had been done.

However, Mr Stagg sent us a copy of a report by an expert committee commissioned by the Department of Health in 1986 which showed results of a study of incidence and mortality from acute lymphoid leukemia in the 0-14 age-group over the period 1971-83. This was presented also as evidence that there was no problem. However, the following extract from the conclusion section of the report suggests otherwise:

More detailed examination of mortality showed a small excess in coastal strips approximately three miles wide on the east and south coasts for the period 1971-86 but not for the period 1977-82. Deaths were evenly distributed along these coastal strips and no particular area of coast had *higher rates than another. On the east coast in 1971-76 an average of 2.7 deaths per year occurred whereas 1.5 would have been expected if the rate there had been the same as the rest of the country. On the south coast 0.8 deaths per year occurred whereas 0.5 would nave been expected. A strip of approximately 18 miles deep inland of the coastal strip in both areas had fewer deaths than the national average prior to 1977, and when this was combined with the 3 mile strip, death rates from ALL in children there were identical to the national average.* (p. 8)

Here we see immediately that the effect is similar to that in Wales. Note that the committee are looking at the 0-1