INCORPORATING THE ENVIRONMENTAL CONTEXT IN THE STUDY OF CANCER

ISSUES AND IMPLICATIONS

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Summary

The analysis in Section 2 of this chapter presents several lines of evidence that implicate the environment in cancer causation; specifically, findings from wildlife studies, cancer trend reports, immigrant studies, childhood cancer studies and twin studies are reviewed. Having established the general evidentiary basis for the cancer-environment linkage, in Section 3 we turn to a discussion of the current methodological difficulties in incorporating the environmental context in the study of cancer. The particular focus here is on exposure assessment - a key methodological limitation in studying the cancer-environment linkage. It is reasonable to expect that cancer cases arising from point source environmental exposure will tend to cluster geographically. For this reason the role of exposure assessment and other methodological issues in the context of cancer cluster investigations are considered. The case of the Woburn Massachusetts leukaemia cluster is reviewed to illustrate some of the pertinent issues involved. In Section 4, we move to a general discussion of the implications of cancer risk assessment methodologies for cancer policy and intervention. In light of the observational evidence concerning the cancer-environment link (Section 2), as well as the uncertainties involved in assessing the risks associated with environmental carcinogens (Section 3), it is suggested that the precautionary principle be adopted as a guiding principle for cancer policy and intervention. The precautionary principle calls for protective action, even when the evidence of harm remains inconclusive and the adoption of this principle seems warranted under the present technical and policy circumstances. The final section ends the chapter with some recommendations and concluding remarks.

P. Nicolopoulou-Stamati et al. (eds), Cancer as an Environmental Disease, 11-38.

1. Introduction

The 'environment' can be broadly defined as including the surroundings constituted by the natural, built, and social dimensions. Today, natural environments (including air, water, and soil) are often plagued with environmental pollutants that are potentially carcinogenic. The toxic effects of these pollutants are difficult to document because they generally result from low-level chronic exposure to a multiplicity of carcinogens through a variety of environmental routes. The analysis of data concerning the ***body burden*** - the total sum of carcinogens in the body - becomes quite complicated because it must cover all routes of entry (i.e. inhalation, ingestion and dermal absorption) as well as all sources of carcinogens (i.e. food, air, water).

Unlike natural environments, built environments include the human-made infrastructure, as well as the products of industrialisation - in particular, the numerous synthetic and radioactive substances produced and introduced into the environment after the Second World War. Concern over the health impacts of such substances has prompted the formation of environmental movement organisations that have brought to the forefront issues pertaining to the social environment, that is, the institutional arrangements within society (specifically, the relationship between industry, government and the citizenry). The social dimension is an important consideration because it draws attention to the social, political and economic ramifications associated with cancer risk management, especially issues such as risk distribution and the question of voluntary exposures due to lifestyle choices versus imposed exposures due to industrial activity and policy decisions. The importance of all three dimensions of the environment in the study of cancer is well-illustrated by the following historical study.

The linkage between cancer and the environment was noted as early as 1755 when Sir Percivall Pott recognised the association between scrotum cancer (then referred to as 'soot wart') and exposure to soot amongst chimney sweeps (the active agent in the soot was later identified as benzo[a]pyrene, now classified as Group 2A by IARC). Although commonly regarded as the first documented discovery linking an occupational environment to cancer, it is important to recognise that lifestyle played a determining role as indicated by the fact that 'scrotum cancer was not a world-wide phenomenon, but that which mainly adhered to British chimney sweeps' (Butlin, 1892a: 1341). Further investigation into this matter led Butlin to the following conclusions more than a century after Pott's initial discovery:

> '[C]himney sweeps in Great Britain typically wore loose clothing which was often torn leaving parts of their bodies accessible to dirt when sweeping chimneys, they lived in soot-filled homes in which two or more generations of the business of sweep was conducted and they seldom washed the whole body more than once or at most twice a week, unlike chimney sweeps in other regions of the world.'
>
> (Butlin, 1892b: 5)

This historical case clearly indicates that the cancer-environment relationship is quite complex and very much influenced by the interaction of a multiplicity of factors such as occupation, lifestyle and socioeconomic status. More recently, this research tradition involving the avoidable causes of cancer is found in the classical analysis by Doll and Peto (1981) and the present chapter builds on some of their general research focus.

The percentage of cancer that is attributed to the environment varies between 2 per cent (Trichopoulos *et al.*, 1996) and 80 per cent (Schneiderman, 1978: 559). Such extreme differences reflect the polarities and debates that exist within the field of cancer risk assessment, with those supporting estimates at the lower end accusing those supporting higher-end estimates of being 'alarmists', while charges of being 'nay-sayers' and 'pro-industry' flow in the opposite direction. To some extent, efforts to fix an exact percentage may be futile, simply because the number of variables, assumptions, data-types and definitions that need to be considered in making such an estimate is formidable. As such, a 'weight of evidence' approach may be more appropriate. In this light, we consider several lines of evidence that build on some of the classical approaches of Carson (1962), Doll and Peto (1981) and Schneiderman (1978), in addition to our own emphasis.

2. Evidence for the Environmental Basis of Cancer

The first line of evidence discussed below examines studies on cancers in the wildlife setting. Due to the varying susceptibilities of different animal species, an increasing number of cancer cases in particular wildlife species may be the first hint of the pervasiveness and impacts of carcinogens in the general environment. Secondly, the examination of cancer trends may reveal important information about the environmental basis of cancer. If cancer was attributed solely to genetic factors, then dramatic fluctuations in cancer rates could not occur over short periods of time nor 'would they be sharply increasing in some cancers and not in others' (Schniederman, 1978: 559). A third important line of evidence involves findings from immigrant studies. If genetics/ethnicity factors played a determinant role in cancer risk, then immigrants would retain the cancer incidence of their homelands. On the other hand, if the cancer rate of immigrants tended to approximate those of the host country, then this would suggest that environmental factors play an important role in cancer incidence (Steingraber, 1998: 58). Fourth, childhood cancer rates are noteworthy because they minimise the confounding effects associated with a long latency period. It is argued that although low-level environmental exposures may not affect adults, they may have adverse effects on children. Increased cancer rates amongst children may therefore signal the presence of environmental carcinogens. Indeed, studies have shown that removal of environmental carcinogens may have an immediate effect, as illustrated by the immediate decrease in different types of childhood cancer after the cessation of atmospheric nuclear weapons testing (Mangano *et al.*, 2002: 29). Finally,

the findings from twin studies perhaps represent the most compelling evidence of the role of the environment in cancer causation. As will be discussed, since the genetic makeup of identical twins is virtually the same, the occurrence of differential cancer rates between twins cannot logically be ascribed to genetic factors, thus pointing to the importance of environmental factors in the onset of cancer.

2.1. Wildlife Studies

Silent Spring by Rachel Carson (1962) was perhaps the first and most influential document that dealt with the issue of how environmental carcinogens, particularly pesticides, may affect a disturbingly large number of different species ranging from robins to caddis fly larvae, to quail, salmon, cats and ultimately humans. Increased frequencies of unusual disease outcomes in wildlife may represent the first warning signs of the health impacts of environmental contaminants on humans (Colborn *et al.*, 1997) because 'wild animals living in contaminated habitats are exposed to low levels of ever-changing combinations of chemicals throughout their lifetimes,' just as humans are (Steingraber, 1998: 142). The enhanced sensitivity of animals to particular environmental contaminants has been known for some time as, 'over a century ago, coal miners carried caged canaries into underground mines to alert them to the presence of carbon monoxide gas' (Manuel, 1996: 934). Similarly, diseased wildlife may also signal the widespread presence of carcinogenic agents and/or pollution in the general environment which may in turn endanger human health; the three examples that follow illustrate this.

An increased rate of cancer deaths amongst beluga whales in the St. Lawrence estuary (which drains the North American Great Lakes system) was found to be related to pollutants; more specifically polycyclic aromatic hydrocarbons (PAHs), originating from the nearby aluminium smelters. (Fox, 2001; Watanabe, 2000; Steingraber, 1998; Colburn *et al.*, 1997). 'The human population living in the proximity of this beluga habitat is affected by rates higher than those found in people in the rest of Quebec and Canada, and some of these cancers have been epidemiologically related to PAHs' (Martineau *et al.*, 2002: 285). Such increases of cancer within a particular community are also known as a cancer cluster, as further discussed in Section 3.3.

A second example includes the relationship that was found between liver cancer in wild fish and PAHs that entered the Black River in Lorain County, Ohio from storm, sewer and road run-off (US Fish and Wildlife, 2000; Baumann and Harshbarger, 1995). Similar findings have been documented in other seaways (Pinkey *et al.*, 2000; Harshbarger and Clark, 1990; McMahon *et al.*, 1990).

A third example pertains to the high levels of Persistent Organic Pollutants (POPs), particularly hexachlorocyclohexane (HCH - one substance within the class of POPs; IARC, 2000 Group 2A carcinogen), found in Arctic wildlife. The accumulation of POPs in the Arctic region readily occurs because of the particular chemical and

physical properties of these substances, such as the capability to undergo long cycles of volatilisation followed by condensation (McGinn, 2000). Since HCH is fat-soluble, it tends to bioaccumulate in the fat of Arctic mammals that are at the top of the food chain, such as polar bears, seals and human beings. In fact, Canadian Inuit mothers have been found to have some of the highest HCH body burdens in the world (NRTEE, 2001). Furthermore, HCH tends to concentrate in the mothers' milk because of the high fat content, thereby posing a threat to infants (NRTEE, 2001).

2.2. Growing Cancer Trends

In the current world population of 6,157,400,560 (The World Fact Book, 2001) it is estimated that 20 million people have cancer (WHO, 2002: iii). The annual world-wide cancer incidence is estimated to be over 10 million new cases, while 6 million people world-wide succumb to this disease each year. Two decades ago, the respective figures were 6 million and 4 million (Tomatis *et al.*, 1990). Such findings are particularly alarming in light of how 'in the middle of the nineteenth century, cancer deaths accounted for only 1.3 per cent of all deaths' (Logan, 1982: 8), while 'today cancer is the second-leading cause of mortality in the developed world and fourth in the developing world - accounting for 12 per cent of all deaths world-wide' (WHO, 2002: 17). Furthermore, in approximately 20 years' time, it is projected that the annual cancer mortality will increase from 6 to 10 million (WHO, 2002: 17).

Cancer incidence for specific sites varies considerably between different world regions and by gender. For instance, North American females are found to have the highest age standardised rate of breast cancer incidence at 90.41, compared to Middle Africa at 13.46 (Ferlay *et al.*, 2001). In the case of esophageal cancer, males in East Asia experience much higher rates (21.79) than their female counterparts (8.92) and males in Western Africa (1.08). There is no real consistency between sites, country or gender; it is only known that certain countries are more prone to specific types of cancer(s) (see Table 1), thus indicating that lifestyle and environmental factors must play some role alongside genetic factors in cancer causation. In this connection, Taubes (1995: 165) notes 'the fact that no single cancer affects every population at the same rate suggests that factors external to the human body cause 70 per cent to 90 per cent of all cancers'.

It should also be noted that relatively rapid changes in trends in cancer incidence rates cannot be accounted for by genetic changes alone, thus providing supporting evidence for the role of environmental and lifestyle factors in influencing cancer. The most notable illustration of this involves changes in lung cancer incidence trends that tend to reflect changes in cultural norms related to smoking. Specifically, this refers to the dramatic increase in male lung cancer incidence after the approximately 20-year latency period that elapsed following both World Wars, as well as the increase in female lung cancer incidence following the Second World War (during which time changes in gender roles led to increased smoking in females as an increasing number of

females entered the workplace). The subsequent decline in lung cancer incidence thereafter also reflects the decrease in smoking among both genders (ACS, 1994).

Table 1. Incidence of most common cancers, 2000 (WHO, 2001; 2002; Ferlay *et al.*, 2001).

		Males			Females	
	Rank	Cancer	ASR*	Rank	Cancer	ASR*
World	1	Lung	34.92	1	Breast	35.66
	2	Stomach	21.46	2	Cervix	16.12
	3	Prostate	21.23	3	Colon/rectum	14.44
	4	Colon/rectum	19.11	4	Lung	11.05
	5	Liver	14.97	5	Stomach	10.38
More developed countries	1	Lung	55.62	1	Breast	63.22
	2	Prostate	46.65	2	Colon/rectum	25.37
	3	Colon/rectum	37.30	3	Lung	15.62
	4	Stomach	24.63	4	Cervix uteri	11.35
	5	Bladder	18.94	5	Corpus uteri	11.33
Less developed countries	1	Lung	24.79	1	Breast	23.07
	2	Stomach	19.87	2	Cervix uteri	18.73
	3	Liver	17.43	3	Stomach	9.97
	4	Oesophagus	12.80	4	Lung	8.44
	5	Colon/rectum	9.91	5	Colon/rectum	7.88

*ASR: Age-Standardised Incidence Rates

2.3. Immigrant Studies

Although Maskarinec (1996: 704) has found that 'cancer risk is strongly associated with ethnicity - Japanese, Chinese, and Filipinos have a much lower risk than Caucasians and Hawaiians', it has also been found that cancer incidence rates among some immigrant groups tends to converge with the existing (non-immigrant) rates of the host country. 'Such changes in cancer risks experienced by migrants for particular sites, such as the breast, esophagus, large bowel, pancreas and prostate, have provided some indication of the relative importance of environmental factors in aetiology, and to the stage of carcinogenesis at which they may act' (Parkin, 1993: 1).

Several studies have indicated that higher breast cancer incidence and mortality rates have occurred among migrants originally from countries with low breast cancer rates (Probst-Hensch *et al.*, 2000; Kliewer and Smith, 1995; Ziegler *et al.*, 1993). For example, an analysis of breast cancer incidence among ethnic Japanese women in Los Angeles County revealed that 'breast cancer incidence is the highest reported anywhere in the world for Japanese [women] and is nearly as high as the rate for non-Hispanic whites, who, alongside non-Hispanic blacks, have had higher breast cancer rates than other ethnicities in the United States' (Deapen *et al.*, 2002: 747). Conversely, an increasing trend in breast cancer incidence in Japan has been attributed to the fact that Japanese women's 'lifestyle has become progressively more Westernised over the past several decades' (Deapen *et al.*, 2002: 749) as evidenced by the fact that, relative to previous generations, contemporary Japanese women tend to marry later, have fewer children, are taller, engage in less physical activity and

experience increasing rates of obesity (Tung *et al.*, 1999; Nagata *et al.*, 1997). Such findings suggest that factors associated with a Westernised lifestyle may increase the susceptibility of Japanese women to breast cancer.

A study of cancer incidence amongst Asian migrants to New South Wales, Australia from 1972 - 1990 found that 'for cancers of the breast, colorectum and prostate, rates were relatively low in the countries of birth, but migrants generally exhibited rates nearer those of the Australia-born' (Grulich *et al.*, 1995: 400). It was concluded that 'for these cancers, environmental factors related to the migrant's adopted country, and migrant selection appeared to have a major effect on the risk of cancer' (Grulich *et al.*, 1995: 400). Further, in an analysis by Mohandas and Desai (1999) it was noted that an increase in the 'incidence of large bowel cancers in immigrants and urban Indians compared to rural populations supports a role for environmental risk factors including diet' (Mohandas and Desai, 1999: 118). It should be noted however, that 'while certain aspects of the physical environment (e.g. air and its pollutants, water and trace elements, irradiation - solar and other forms) may change abruptly on migration, other aspects of lifestyle - patterns of diet, childbearing, alcohol and tobacco consumption - will likely be retained to a greater or lesser extent in the new place of residence' (Parkin, 1993: 1-2). Nevertheless, in general, it is evident that where people decide to settle physically will influence the risk(s) of disease.

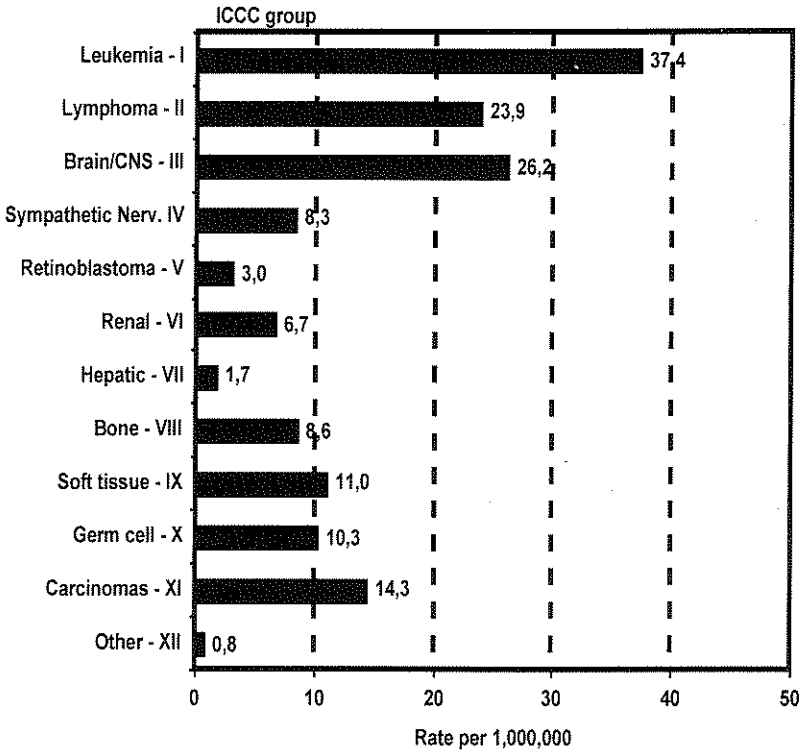
2.4. Childhood Cancer

Childhood cancer is rare in comparison with adult cancer as 'childhood incidence is only about 1 per cent of that found in adults (for developed countries)' (Parkin *et al.*, 1998: 1). However, Schmidt (1998) notes that the rate of childhood cancer in the US is increasing by approximately 1 per cent each year. Notably, cancer is the main cause of death by disease in children between 1 and 14 years of age in the US (ACS, 2002: 10). It is the most common cause of childhood disease mortality in developed countries (NUH, 2002: 2), although, 'mortality from childhood cancer in general and childhood leukaemia in particular has sharply declined in economically-developed countries over the last 30 years' (Vecchia *et al.*, 1998: 2223). Nevertheless, this decline is much less pronounced in South America, Eastern Europe, and other economically less-developed areas (Levi *et al.*, 1995). Such trends may be attributed to the modernised treatment services now available in the more developed countries compared to the less-developed regions of the world (Levi *et al.*, 2001; Craft, 2000; Vecchia *et al.*, 1998; Hesseling and Wessels 1997; Lukens, 1994; Draper *et al.*, 1994).

It should be noted however, that differences in opinion exist concerning the reliability of US childhood cancer data gathered from 1973 - 1993 because of problems related to age-group classification and inconsistent data-collection methods employed by registries (Bukowski, 2001; 2000; Mangano, 2001; 2000; 1999; Gurney *et al.*, 1996), which in turn makes interpretation difficult and contradictory. Taking into account such limitations, Coleman *et al.* (1993) report that, since the early 1960s, the

incidence of childhood cancers, particularly childhood leukaemia, has remained relatively stable, or at the very most, has risen moderately in those geographic areas where there are adequate cancer registration systems. Similarly, Stiller and Parkin (1996) observe that the *total* childhood cancer incidence rates exhibit little variation between different regions of the world, whereas McBride (1998) concludes that 'there are differences in how common childhood cancers are in different parts of the world, suggesting that there may be environmental factors that contribute to disease'.

In regard to specific cancer types amongst children, it has been noted that leukaemia and brain cancer have increased in the United States (Linet *et al.*, 1999; Gurney *et al.*, 1996; Ries *et al.*, 2002). Childhood leukaemia, brain/CNS and lymphoma continue to rank amongst the top 3 most common incidence types for children under 20 years of age (see Figure 1). This is also true for those afflicted between the ages of 0 - 19 in the European context (see Table 2).



*SEER 9 Areas. Rates are age-adjusted to the 2000 US standard million population by 5-year-age groups.

Figure 1. Childhood cancer SEER* incidence rates 1973-1999, by ICCC group under 20 years of age, both sexes, all races (Ries *et al.*, 2002).

At the societal level, childhood cancers have raised public concerns partly because of 'the special emotional attention that is focused on children' (Savitz, 2001: 562) and

also because of increased public sensitivity to the possibility of neighbourhood cancer clusters (for examples refer to: Michelozzi *et al.*, 2002; San Sebástian *et al.*, 2001; Balter, 1996; 1995; Bithell *et al.*, 1994; as well as Section 3.3. of this chapter). On the other hand, at the medical level, it should be noted that the *types* of cancer that occur in childhood are very different from those experienced in adulthood. For this reason, Parkin *et al.* (1998: 1) note that 'it is essential that childhood cancer be classified by histology rather than by the tumour site' (i.e. the reverse of what is conventionally done with adult cancer classifications).

Table 2. National estimates of incidence rates standardised to world standard population age 0-19 (ACCIS, 2003).

Country	Total	Leukaemia I	Lymphomas II	CNS tumours III	Neuroblastoma IV	Retinoblastoma V	Renal tumours VI	Hepatic tumours VII	Bone tumours VIII	Soft tissue sarcomas IX	Germ cell tumours X	Carcinomas XI	Other and NOS XII
Europe	**144.6**	**37.3**	**21.0**	**29.5**	**7.1**	**3.3**	**7.1**	**1.4**	**7.6**	**9.4**	**8.0**	**9.9**	**2.9**
Bulgaria	104.0	32.9	17.0	13.1	4.3	2.8	4.4	0.9	7.9	6.9	4.5	7.3	1.9
Denmark	157.6	41.7	18.5	37.3	8.2	3.5	7.3	1.6	6.8	9.5	10.5	10.6	2.1
Estonia	130.1	35.3	22.8	23.6	5.3	2.8	9.7	2.2	6.4	6.9	5.9	6.9	2.4
Finland	159.4	45.0	19.0	35.8	8.3	3.6	8.6	1.3	7.1	10.7	7.2	11.7	1.2
France	143.6	36.3	23.4	23.4	11.4	3.5	9.4	1.1	8.1	9.1	7.1	10.2	0.6
Germany	138.6	32.5	22.0	30.0	7.2	2.8	6.2	0.6	8.3	9.4	11.7	6.9	1.1
Iceland	140.9	35.5	16.6	30.7	5.9	2.6	5.6	1.5	9.0	10.4	8.7	14.4	0.0
Ireland	141.0	37.0	18.5	37.0	5.6	2.4	5.2	1.1	8.7	8.6	6.9	8.2	1.7
Italy	165.6	46.7	28.5	30.2	9.6	2.3	6.8	1.5	8.5	10.2	7.5	11.6	2.2
Lithuania	135.6	34.0	28.2	17.4	7.8	4.0	7.8	0.8	6.6	7.1	5.3	10.4	6.1
Malta	143.4	41.1	19.5	24.4	12.9	6.5	9.2	0.0	6.9	11.2	4.5	6.3	0.9
the Netherlands	151.6	36.6	23.2	26.9	6.4	4.9	7.9	1.2	8.3	11.5	9.2	15.2	0.3
Norway	149.1	39.7	15.7	32.3	7.3	3.9	6.3	2.5	7.7	9.1	10.6	11.6	2.5
Poland	113.0	29.9	18.7	22.5	4.9	1.3	6.7	1.4	7.3	5.2	6.1	4.8	4.2
Portugal	139.1	28.0	28.0	23.6	9.6	3.1	7.7	1.3	8.8	11.8	5.8	8.9	2.3
Romania	97.5	28.3	16.1	15.0	1.8	1.4	3.8	1.1	6.5	4.1	4.3	3.0	12.1
Slovakia	136.1	33.4	22.3	27.7	7.7	3.2	6.3	1.7	6.5	8.5	9.0	8.0	1.8
Slovenia	120.6	33.1	21.8	20.3	5.9	2.3	6.1	1.4	5.7	8.4	7.1	6.9	1.6
Spain	145.9	38.9	25.1	25.6	9.7	2.7	6.1	2.0	9.2	9.7	6.1	9.8	1.0
Sweden	158.2	37.1	18.2	40.2	4.0	3.7	8.2	1.9	7.7	9.9	7.2	10.0	10.2
Switzerland	161.3	42.6	24.6	28.7	9.6	3.6	7.3	1.5	9.4	10.8	9.1	14.1	0.0
Turkey	119.5	36.2	21.2	17.0	6.1	2.6	5.6	0.9	9.0	8.1	5.4	6.4	1.0
United Kingdom	133.5	38.7	17.5	24.9	7.5	3.8	5.7	1.0	6.9	8.7	7.0	10.5	1.3
Yugoslavia	135.6	35.6	24.4	25.9	4.0	1.5	5.1	0.5	7.4	10.7	7.0	10.2	3.2

In addition, particular attention must be focused on the *environmental aetiology of childhood cancer* because, generally speaking, 'children are highly vulnerable to environmental toxicants' (Suk, 2002: A284).

Citing work by the National Academy of Sciences (NAS, 1993), Suk (2002: A284) points out that this enhanced childhood susceptibility is related to four factors. First, because of metabolic differences, 'children have greater exposures to environmental toxicants than adults'. This is a consequence of the fact that children tend to breathe in more air and eat more per unit body weight compared to adults. Second, 'children's pathways, especially in the first months after birth, are immature compared to those of adults', thus making the child's internal pathways particularly vulnerable to toxic effects of foreign environmental agents. Third, 'children's growth and development occur very rapidly, and their delicate developmental processes are easily disrupted'. Lastly, 'children have more future years of life than most adults, therefore they have more time to develop chronic diseases that may be triggered by early exposures'. For these reasons, children are particularly susceptible to the levels generally found in environmental exposure scenarios.

Several researchers (Mangano *et al.*, 2002; Guizard *et al.*, 2001; Pobel and Viel, 1997; Zaridze, 1994) have presented convincing evidence concerning the association between childhood cancer and proximity of residence to nuclear facilities. In a study by Mangano *et al.* (2002: 23), it was found that 'cancer incidence in children under the age of 5 fell significantly after shutdowns of nuclear plants in proximate areas'. This suggests that 'smaller exposures may result in measurable improvements in health, especially in infants and young children' (Mangano *et al.*, 2002: 29). (This has certain implications for risk assessment and risk management as elaborated in Sections 3.2. and 4). Aside from ionising radiation, several other environmental factors have also been examined as links to childhood cancer, for example the association between melanoma and sunburn during early childhood (Committee on Environmental Health, 1999: 330; Nasir, 2001: 653). Furthermore, there exists supportive but inconclusive evidence for links between childhood cancer(s) and a wide range of other environmental factors, including: pesticide exposure from ambient air conditions (Reynolds *et al.*, 2002; Zahm and Ward, 1998; Daniels *et al.*, 1997; Baker *et al.*, 1996; Hawthorne *et al.*, 1996; Majewski and Capel, 1995); parental occupational exposure (Feychting *et al.*, 2001; Draper *et al.*, 1997; Peters *et al.*, 1981); parental use of tobacco (Sorahan *et al.*, 2001; Boffetta *et al.*, 2000); household solvent exposures (Epstein, 1998; Freedman *et al.*, 2001); genetic factors (Felix and Lange 1999; Li *et al.*, 1997); radiation used to combat childhood cancers at risk of a second malignancy (de Vathaire *et al.*, 1999; Kony *et al.*, 1997); and viral infection (London, 2002; Stewart, 2001; Doll, 1999a).

2.5. Twin Studies

In addressing the 'nature versus nurture' debate, Hoover (2000: 315) remarks that 'the gold standard for distinguishing genetic from environmental traits has been the study of twins'. Since identical twins have the same genetic makeup (i.e. genotype), differences in cancer incidence between twins cannot be attributed to genetics alone, but must necessarily involve differential environmental exposures (conversely, similarities in cancer incidence between twins will support the genetic basis of cancer). Thus, Hoover (2000, citing NCI, 1999) notes that 'information about types of environmental exposure that affect the risk of cancer should point to genes that modify this risk, and the identification of genes associated with risk could help to indict previously unrecognised risk factors'. Conclusions from several important and recent twin studies are briefly summarised below.

A large study of 44,788 twin pairs in the Nordic regions conducted by Lichtenstein *et al.* (2000) concluded that 'the environment has the principal role in causing sporadic cancer'. Similarly, findings by Harris (1997: 270) suggests that generally only '5 to 10 per cent of specific cancers can be attributed to inheriting very high risk genes'. Furthermore, an examination of childhood leukaemia in twins by Buckley *et al.* (1996) found that 'there is generally not a strong constitutional genetic component for childhood cancers other than retinoblastoma', while the results of a study by Verkasalo *et al.* (1999: 747) suggests that 'at least two-thirds of the inter-individual variation in general susceptibility to cancer can be attributed to non-genetic causes'. In addition, Buckley *et al.* (1996) found that both twins experienced the same type of cancer only 5 per cent of the time. The cumulative evidence from twin studies therefore tends to support the conclusion that environmental agents must play some key role in the incidence of cancer.

3. Studying the Cancer and Environment Relationship

3.1. Approaches to Studying the Cancer - Environment Relationship

Despite the various types of observational evidence outlined above, the establishment of a causal relationship between the environment and cancer has been fraught with inherent methodological difficulties, as reflected in the wide range of estimates regarding the percentage of cancer that can be attributed to the environment. Randomised clinical trials are generally thought to be the best method to use to study causality in medical research but the experimental requirement of exposing humans to suspected carcinogens is obviously unethical. Consequently, evidence from experimentally-based clinical trials is largely nonexistent in the study of human cancer.

The main advantage of experimental trials pertains to the ability of the researcher to control for various types of systematic errors (bias), confounding and chance, thereby eliminating alternative explanations of causality (Hennekens and Buring, 1987). To some extent, the advantages of controlled conditions may be pursued in toxicological risk assessment studies done on animals. Such animal studies, however, have been criticised for two main methodological reasons. First, the suspected carcinogen doses administered to laboratory animals are in much higher concentrations than those found in the real world; the environment created in a laboratory does not realistically parallel the environment humans live and work in. Consequently, high- to low-dose extrapolations must be made through mathematical models and may introduce uncertainties in the analysis. Second, the need to make animal-to-human comparisons also introduces significant difficulties in interpretation. The International Agency for Research on Cancer (IARC, 2000: 4) notes however, that, in the absence of evidence from human data, it is 'prudent' to consider that chemical agents which are carcinogenic in animals may be carcinogenic in humans because 'all known human carcinogens that have been studied adequately in experimental animals have produced positive results in one or more animal species' (Wilbourn *et al.*, 1986; Tomatis *et al.*, 1989). Such conclusions also highlight the need for future research to more seriously consider the results of wildlife studies (see Section 2.1.).

The role of bias, confounding effects and chance must be carefully considered in the design of all epidemiological studies, but they become even more critical in investigating the relationship between cancer and the environment. First, the long latency period of many cancer outcomes poses particular difficulties in assessing exposure. In *retrospective* case-control studies, past exposure is usually assessed on the basis of subject interviews and/or workplace exposure records, thereby allowing for the possibility of recall bias by subjects or systematic errors from incomplete historical records. On the other hand, the long latency period may make interpretation of *prospective* cohort study data difficult because prior knowledge of exposure by the researcher may lead to observation bias (while the long follow-up period may lead to the loss of study subjects and high financial expenditure). Second, the investigation of the environment-cancer relationship typically involves situations in which there are a large number of exposures that occur in low concentrations and in complex mixtures over a long period of time. Consequently, there are problems with controlling for confounding effects in all epidemiological studies of cancer (Pekkanen and Pearce, 2001: 1). Third, as we shall later discuss with respect to cancer clusters, the ability to rule out the role of chance is particularly difficult in the establishment of a causal connection between environmental exposure and cancer.

The above discussion alludes to the point that exposure assessment is the 'weakest methodological link' in determining carcinogenic risks from both the risk assessment and the epidemiological approach (Cole *et al.*, 1999). This problem is further compounded by the fact that the role of the biophysical (and social) environment

tends to be minimised by both approaches. This problem stems from the fact that the controlled conditions of the experiment consciously eliminates the influence of the environment, while the qualitatively defined categories of cancer incidence/non-incidence and exposure/non-exposure (however defined) used in epidemiological approaches tends to minimise the intricacies of the environmental pathways of exposure. Consequently, improvements in the techniques related to exposure assessment represents a necessary first step in incorporating the environmental context in the study of cancer - an important step in light of the evidence reviewed in Section 2.

3.2. The Importance of Environmental Exposure Assessment

Traditionally, exposure measurements are almost always ecological because exposure is measured by taking air, water, food and soil samples from particular locations (Hertz-Picciotto, 1995: 487). It is therefore assumed that the concentration present in environmental emissions represents the amount of substance that is absorbed by the body (i.e. the internal dose). This can be misleading unless multiple sources and pathways for exposure are carefully considered (recall ***body burden***, as defined in the introduction). For example, Lioy (1997, citing the work of Wallace, 1989) notes that previous policies aimed at reducing benzene exposure targeted motor vehicle emissions because it was found that tailpipe emissions accounted for 83 per cent of the benzene found *in the environment*. It was therefore thought that tailpipe emissions would be the major contributing factor to the benzene burden in humans. This was later found to be an incorrect assumption when other exposure sources and pathways were considered. In fact, through the use of personal monitors, it was later found that the predominant source of benzene exposure *in humans* was from cigarette smoking (over 50 per cent). Consequently, regulatory strategies aimed at reducing benzene exposure based on emissions data were misguided because they incorrectly targeted motor vehicle emissions rather than cigarettes. As we shall discuss later, such complexity in exposure analysis is an important consideration in studying the cancer-environment relationship in general and in assessing cancer clusters in particular.

Recently, personal monitors and biomarkers have facilitated greater accuracy in exposure assessment. First introduced in the early 1990s, personal monitors (also called micro-environmental monitors) are worn by individuals during their daily activities to identify the primary route of contaminant exposure as well as to develop an exposure database (Lioy, 1997: 955). On the other hand, molecular biomarkers of exposure/dose are measured from samples of bodily fluids (NRC, 1989a; b). For example, volatile organics and pesticides in blood and urine were measured through biomarkers in studies that dealt with environmental exposures at hazardous waste sites (Bennett and Waters, 2000; Pellizzari *et al.*, 1995). Additionally, biomarker techniques now exist to measure metabolites and DNA adducts (Ashley *et al.*, 1992; Perera *et al.*, 1987). Notably, a major advantage of the use of biomarkers is that they integrate exposures from different pathways (or media), thereby yielding an

integrated dose measurement that gives a better indication of the total body burden of a particular carcinogen (Bennett and Waters, 2000; Henderson *et al.*, 1992).

Improvements in exposure assessment measurements have prompted movements towards the integration of risk assessment with epidemiological data. Thus, Hertz-Picciotto (1995) provides a framework for classifying individual epidemiological studies in terms of their adequacy for use in dose-response extrapolations, while specific examples of efforts in this direction have been made concerning the carcinogenic risks of 1,3-butadiene (Stayner, *et al.*, 2000) and acrylonitrile (Schulz *et al.*, 2001). However, as noted by Hertz-Picciotto (1995: 485) difficulties arise in integrating the two types of studies because of different methodological orientations. In risk assessment, exposure is defined in quantitative terms where the outcome is defined as added risk (i.e. absolute risk, excess risk or risk difference), whereas, in epidemiological studies, exposure is usually operationalised as qualitative categories and the outcome is expressed in terms of relative risk (or odds ratio). Furthermore, risk assessors ask, 'How many excess cases of disease Y will occur in a population of size Z due to exposure to agent X at dose level D?' On the other hand, epidemiologists tend to address the question of, 'What is the risk of disease Y in the presence of agent X relative to the risk of disease Y in the absence of X?'. (Hertz-Picciotto, 1995: 485). Notably, the former questions tend to be of greater relevance to regulatory policy-makers who are interested in quantifying the amount of exposure associated with specific levels of risk in order to establish occupational and environmental standards for potential carcinogens (Kaldor, 1992: 91; NIEHS, 2000). On the other hand, the latter questions tend to be of greater interest to public health officials, particularly those involved in the investigation of cancer clusters.

3.3. Cancer Clusters

According to Matthews (1988), any disease that is associated with environmental factors will tend to cluster geographically. As such, a cancer cluster is defined as a geographic area, time period, or group of people with a greater-than-expected number of cancer cases. Cancer clusters have been identified in occupational settings such as the mesothelioma cluster traced to asbestos in the shipbuilding industry during the Second World War (Blot *et al.*, 1978), as well as clusters of hepatic angiosarcoma associated with occupational exposure to the vinyl chloride monomer (Creech and Johnson, 1974). In addition, cancer clusters have been detected in the aftermath of toxic environmental disasters such as the radioactive contamination in Chernobyl (Balter, 1995), and the chemical spills in Bhopal, India (Anderson *et al.*,1985) and Seveso, Italy (Bertazzi *et al.*, 1989; 1993).

Complications in the identification, analysis and interpretation of cancer clusters may arise because of the possibility that the risk factors are evenly distributed across a given population. As a result, associations would not be readily discernible from a completely random process (Matthews, 1988). That is, since the environmental

exposures are universal, comparing individuals (as is done in conventional epidemiological study designs) will not achieve sufficient contrast in exposure. Thus, Pekkanen and Pearce (2001: 3) suggest that the focus should be on the comparison of populations and not individuals. Secondly, if exposure-incidence associations are discernable, they will usually yield low relative risks, as relative risks for environmental exposures are typically found to be below 1.5 (Pekkanen and Pearce, 2001: 2). Such low relative risks tend to dissuade public officials from investigating potentially serious environmental health problems in the community.

The value of studying cancer clusters has been questioned by those who contend that little has been gained in terms of acquiring etiological understanding (Alexander, 1999; Robinson, 2002). Such critiques commonly cite the issue of 'pre-selection bias' or the 'bulls-eye problem'. That is, it is argued that the practice of defining the geographic borders of a cluster on the basis of prior knowledge of where cases are located (referred to as 'reactive clustering'), artificially leads to the identification of non-genuine clusters, so that what is actually random appears to be a cluster pattern - a product of the study design (NCI, 2001). Furthermore, since identified clusters usually involve a relatively small number of cases, statistical analyses tend to indicate that the number of cases could occur simply by chance (Heath, 1996). The over-emphasis on the use of such limited statistical criteria in cluster analysis may, however, be misguided, because, as Sir Austin Bradford Hill (1965) remarked in his classic exposition on 'causality' in epidemiological research, statistical significance in-and-of- itself does not contribute to 'proof' of cause and effect. Second, conventional tests of significance do not explicitly take into account spatial parameters that are so integral to defining clusters in the first place. That is, statistical tests (e.g. chi-square and t-test) consider only the relationship between the qualitatively defined categories of disease and exposure. In response to this inadequacy, specialised techniques for assessing the significance of spatial patterns have recently been developed, including spatial Monte Carlo randomisation methods and Geographic Information Systems (GIS) techniques (Jacquez, 2002; Hoover and Devesa, 2001; Haining 1996; Hjalmars *et al.*, 1996; Oliver, 1996). The science of cancer clustering is constantly evolving (Whelan, 1999) and the application of newer spatially-sensitive techniques may prove more useful and valid in the application of statistical criteria in future cluster analysis.

Regardless of statistical significance, clusters at the very least should signal the possibility that there may be a common source or mechanism for carcinogenesis amongst members of the cluster. This is especially true if the cluster involves a larger number of a rare, site-specific cancer that is found within an age/sex/race grouping that is not usually affected by that type of cancer (NCI, 2001; Heath, 1996: 135). For example, the identification of a cluster of just seven cases of a rare form of vaginal cancer (adenocarcinoma) amongst 15 - 20 year-old women in the Boston area led to the discovery that maternal intake of a drug used to prevent miscarriages (diethylstilboestrol) resulted in cancer amongst the daughters; previously this type of

cancer was found only in women over 50 years of age (Herbst and Scully, 1970). In light of such evidence, and in the spirit of precaution and ethical responsibility, the investigation of childhood cancer clusters (in particular) must be pursued in a more diligent manner. We now turn to an illustrative case study of one cluster situation.

3.4. The Woburn Leukaemia Cluster

Woburn, Massachusetts (population 35,000) is located about 13 miles northwest of Boston. In 1972, parents of childhood leukaemia victims identified 12 leukaemia cases located within several blocks of each other (Brown and Mikkelsen, 1997). Around the same time, the illegal dumping of the industrial solvents trichloroethylene (TCE) and perchloroethylene (PCE) - both probable carcinogens (IARC, 2000 Group 2A) - was discovered near two drinking-water wells that served the community. The residents suspected that their drinking water was contaminated by these chemicals since it was consistently discoloured, with a bad odour and taste. As such, they believed that there was a link between the contaminated water and leukaemia. After considerable urging on the part of the residents, the Massachusetts Department of Public Health (MDPH) conducted a matched case-control study; however, the study yielded negative results.

In response, 301 volunteer residents collaborated with several epidemiologists from the Harvard School of Public Health and conducted their own telephone survey from April to September 1982 and surveyed 57 per cent of the Woburn residents (Brown and Mikkelsen, 1997). Their study found that children with leukaemia had received an average of 21 per cent of their yearly water supply from the contaminated wells compared to 9.5 per cent for children without leukaemia (Lagakos *et al.*, 1986). The community-based study was criticised for various reasons, but the most frequent charge was that of observer bias, since the survey was conducted by members of the Woburn community (despite the fact that the study passed various tests for reliability).

By 1996, nine additional cases had been diagnosed, and the MDPH (1997) initiated a more carefully-designed matched case-control study that found: (i) the risk of developing leukaemia was greater for a child whose mother drank water from the contaminated wells while pregnant (O.R. = 8.33; C.I. = 0.73, 94.67), and, (ii) the existence of a dose-response relationship (the greater the amount of contaminated water provided to the house during pregnancy, the greater the risk of the child developing leukaemia [$p < 0.05$]). There did not, however, seem to be a relationship between the consumption of water from the contaminated wells by children and the development of leukaemia.

The Woburn case also highlights the importance of reliable exposure assessment in the investigation of cancer clusters. As alluded to above, the MDPH (1997) study employed a more accurate model of exposure assessment, based on a refined water

distribution model (developed by a hydraulic engineer) that incorporated household water-flow data linked to the place and length of residence. The investigative emphasis nevertheless seemed to be on *water consumption*. However, this may only represent one route of exposure. In preparing for the civil action suit against the local industries responsible for the contamination, experts recruited by the lawyer representing the victims noted that the highly volatile TCE could vaporise and accumulate in the confined space of a bathroom at concentrations two to three times higher than that found in the tap water (Harr, 1995: 207). Consequently, a 10-minute shower would result in a TCE air concentration equivalent to 60 gallons of water - which may explain the burning eye sensation felt by some Woburn residents during their baths. Thus, TCE exposure through inhalation could be significant. Furthermore, TCE may be absorbed during bathing when warm water dilates pores in the skin, especially in body areas affected by rashes (or sunburn and cuts) - and rashes had been common in the Woburn victims (Harr, 1995: 208). As such, although families had *consumed* only about one quart of water each day, their exposure to TCE may have been much higher, thereby accounting for the discrepancy between the severity of their symptoms and the (alleged) low levels of exposure.

4. Implications of Risk Assessment for Cancer Policy and Intervention

The results of technically-based risk assessment and epidemiological studies are used by government agencies to develop regulatory levels, as well as to evaluate the public health, economic, and socio-political consequences of these derived levels (NRC, 1983). This second phase, referred to as risk management, tends to be controversial because of the issues that arise in translating inconclusive and uncertain technical results into public policy. As discussed in the examples below, such controversy may ensue because of the different logic, assumptions and language used in the two phases, as well as the nature of voluntary versus non-voluntary exposure.

4.1. Uncertainties in Environmental Exposure Assessment

As mentioned in Section 3.2., exposure assessment is often limited for several reasons, including an incomplete assessment of multiple exposure routes and types, and the lack of attention given to the synergistic, interactive and timing effects of exposure. Consequently, different assumptions concerning exposure will lead to derived regulatory levels that vary quite dramatically. For example, Hoberg and Harrison (1994: 26) found that differences in assumptions about 'worst case exposure' versus 'typical exposure' resulted in a regulatory level for the pesticide alachlor that was a thousand times greater in Canada than in the US Such differences have led to contentious public debate within and between these two countries.

4.2. Statistical Significance versus Practical Significance

As illustrated in Section 3.3., the level of significance required for intervention in cancer cluster situations is a frequent source of contention, as many community efforts to document cancer hazards are often thwarted by citing statistical criteria (Brown and Mikkelsen, 1997: 133). However, Paigen (1982) argues that statistical criteria is simply not appropriate in making decisions concerning environmental risk issues. Supporting this position, Ozonoff and Boden (1987) contend that, on the basis of ethical considerations, *public health significance* should be given priority even if statistical probabilities are not realised. They therefore recommend that risk management decisions be based on the criteria used in clinical medicine rather than that used in laboratory science - that is, by erring on the safe side of false positives (i.e. claiming a relationship when there may not be one) instead of false negatives. By adopting this logic, the degree of risk to human health does not need to be proven as statistically significant to justify public health or regulatory intervention. Furthermore, the investigative and policy emphasis would then be on assessing the likelihood that an individual is *exposed* to the suspected carcinogen rather than on the probability of the disease outcome itself (Couto, 1986). This is a particularly pertinent and politically volatile issue given that many exposures to environmental carcinogens are involuntary. We now turn to the implications of this exposure-based rationale for cancer risk policy.

4.3. The Precautionary Principle and the Cancer-Environment Relationship

In light of the mounting observational evidence concerning the cancer-environment relationship (see Section 2), policy and interventionist strategies should place special emphasis on reducing public exposure to suspected carcinogens. For several reasons, such strategies must be guided by a precautionary and preventative orientation informed by an ethic of 'better safe than sorry'. The precautionary principle is rooted in the *primacy* of environmental and public health and is generally comprised of four major components: decision-making in the face of uncertainty; shifting the burdens of proof; a full analysis of alternatives to potentially harmful activities; and democratic decision-making structures (Raffensperger and Tickner,1999: 350). All of these components fall within the realm of risk management and follow from the need to politically address the limitations of risk assessment and epidemiological studies - particularly those uncertainties related to exposure, the models used to relate exposure to cancer, and the uncertainty due to individual variation in human susceptibility (Raffensperger and Tickner,1999: 350).

The precautionary principle is implicitly invoked by Tomatis *et al.* (2001) who note that difficulties in assessing cancer risks due to low-level exposures to multiple carcinogens do not warrant the denial of these risks. This recognition is especially important considering that there are thousands of existing chemicals whose carcinogenic risk potential has not yet been assessed (NRC, 1983). Several

approaches have been put forward as to how to address the magnitude of this problem. First, Cranor (1999) recommends the adoption of quicker, inexpensive scientific approximations to identify carcinogens, such as mutagenicity and structure-activity tests, as well as screening for cancer precursors (for further details concerning cancer precursors, refer to Franco and Rohan, 2002). Secondly, efforts could be made to at least stem the tide of new carcinogens entering the environment. For instance, by reversing the burden of proof, it would then become the responsibility of the manufacturer to demonstrate that the chemical agent is harmless, *before* it is put into circulation (as is presently done with the licensing of new medicines) (Jordan and O'Riordan, 1999; Wahlstrom, 1999). In addition, O'Brien (1999; 2000) suggests that all possible alternatives to the potential carcinogen (or potentially harmful proposed undertaking) be considered before approval for use is given. In this way, that alternative which eliminates (or at least minimises) exposure could be identified and preferentially adopted in the interests of public health.

The alternatives assessment approach may be considered an example of a larger class of preventative approaches to cancer risk. Although cancer prevention initiatives are considered to be the most effective way of reducing cancer incidence, they are not considered high priorities in many health research and policy programmes (Tomatis *et al.*, 1997; Jasny and Bloom, 1998). Perhaps such reluctance is due to the view that the adoption of a preventative orientation will require large-scale structural changes and costs. However, there already exist various feasible preventative engineering strategies that eliminate the very possibility of carcinogenic by-products and waste entering the environment (thus eliminating the problem of exposure altogether); these include approaches such as: Industrial Ecology (Allenby, 1999), and Design for Environment (Graedel and Allenby, 1996). Such strategies need to be more seriously considered in recognition of the fact that effective cancer prevention necessarily requires a multi-pronged, integrated approach that is sensitive to the complex relationship between cancer and lifestyle, genetics, society and environmental causes.

The democratisation of risk assessment and management is particularly important because ordinary individuals are often the first to discern environmental health problems - as illustrated by the Woburn leukaemia clusterepisode. This is not surprising, as 'people who inhabit and intimately know a single place day after day, understand things about environmental risks they face that no outside or objective perspective can provide' (Slove and Scammell, 1999: 252). For this reason, public input into cancer risk assessment should not be regarded by officials as 'interference', rather, at the very least, as a useful way to gain better insight into the complexities of exposure assessment. Furthermore, increased lay involvement will certainly help curtail the conflicts that frequently arise when lay and expert ways of knowing about environmental health risks meet (for examples of collaborative expert-lay methods, see the work of Phil Brown (2000) on 'popular epidemiology').

Finally, it should be noted that reduced exposure to environmental carcinogens cannot be accomplished through regulatory interventions alone. Regulatory intervention is perhaps better suited to imposed risks stemming from *involuntary* exposure. However, for there to be a significant decline in cancer incidence, attention also needs to be directed towards *voluntary* exposure, such as those associated with lifestyle and behaviour. In this connection, Sir Richard Doll (1999b: 18) notes that:

> 'Ways of living might well be possible that would reduce the age-specific incidence of [cancer] by some 80 to 90 per cent ... even if attention were restricted to practicable changes it was soon concluded that more than half the premature deaths from cancer - by which I mean deaths occurring under about 70 years of age - could be avoided.'

As such, the reduction of cancer risk requires attention to both voluntary and involuntary exposures to environmental carcinogens.

5. Conclusions

Undoubtedly cancer may arise from non-environmental factors because of the production of carcinogens within the body and the occurrence of unrepaired genetic faults. At the same time however, the weight of evidence reviewed in this chapter indicates that cancer may also arise from exposures to carcinogens in the environment. The question of what percentage of cancer can be attributed to environmental versus non-environmental causes, so passionately pursued by some researchers, may not perhaps be so worthwhile. The rationale behind this quest seems to be that if the percentage were known, then better decisions could be made about the allotment of scarce resources (financial and otherwise). To some extent this may be true, but what should be noted is that even if the actual percentage fell in the lower end, this would still represent, in absolute terms, an immense number of cancer victims world-wide. The key point is that environmentally induced cancers are largely *preventable* through the *reduction of public exposure* to suspected carcinogens. Thus, a great number of lives could be saved through exposure reduction. This realisation has several significant implications.

First, because exposure plays an important connecting role in the relationship between the environment and cancer, more attention needs to be paid to improving exposure assessment techniques. Second, the emphasis on environmental exposures should inspire efforts to reduce carcinogens at the (usually industrial) source, that is, the adoption of a more 'upstream' and preventative approach (as well as the method of alternatives assessment). Third, due to the inherent uncertainties involved in cancer risk methodologies, a precautionary approach to cancer risk management policy should be adopted. Fourth, although exposure reduction may be partly accomplished through individual lifestyle change, this only addresses voluntary exposure; it should

be explicitly acknowledged in risk management processes that non-voluntary exposure - such as exposure to industrial carcinogens in the environment - is a violation of the fundamental right to a safe environment. As such, cancer risk policy-makers should strive to close the gap between those making decisions about cancer risk and those affected by these risks (as exemplified in popular epidemiology). Efforts in this direction can only be accomplished if public health significance is given priority over statistical significance. In addition, rather than the current practice of exclusively focusing on specific types of cancer risks in the community, the adoption of policies that focus on reducing exposure is necessary.

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