

7. Halocarbons, the ozone layer and the precautionary principle

Joe Farman

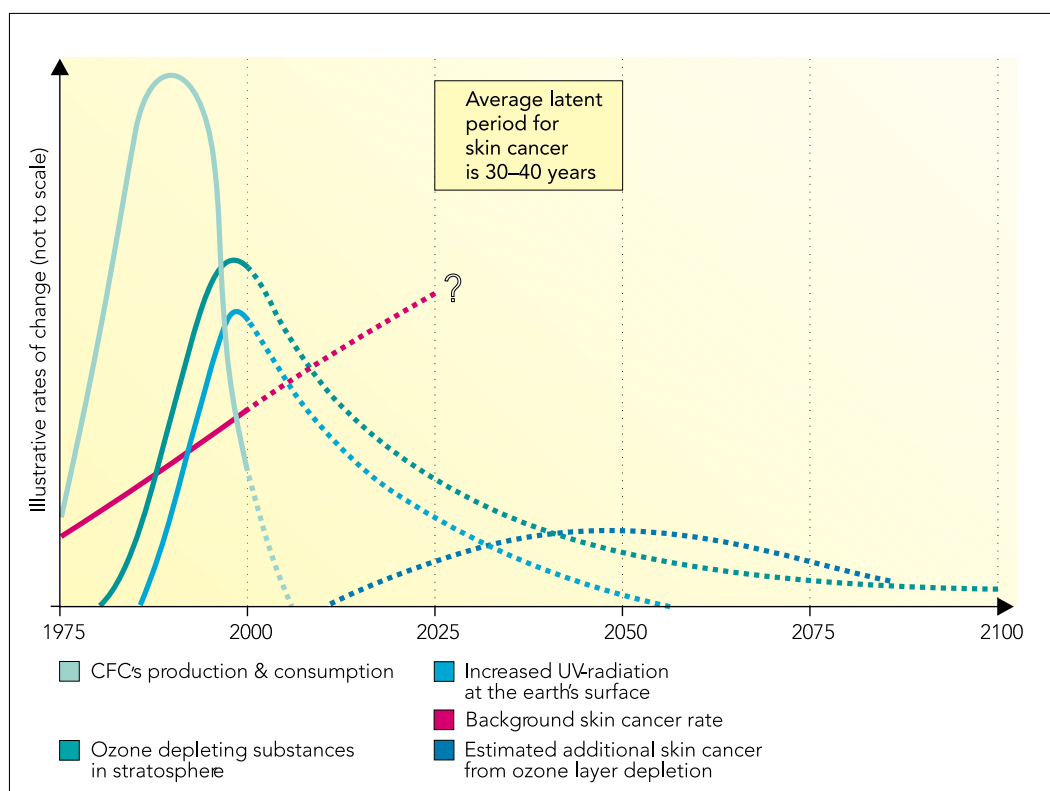
7.1. Overview

In the second half of the last century some 23 million metric tonnes of chlorofluorocarbons (CFCs), about 11 million tonnes of methyl chloroform, 2.5 million tonnes of carbon tetrachloride and 4 million tonnes of a hydrofluorocarbon (HCFC-22) were released into the atmosphere. All of these halocarbons have atmospheric lifetimes ⁽⁴⁾ long enough for them to be transported to the stratosphere. The amount of chlorine in the stratosphere today is between six and seven times what it was in 1950. There is an ozone hole over Antarctica from September

to December each year, less systematic but nevertheless large ozone losses in the Arctic, and moderate ozone losses in the middle latitudes of both hemispheres. The evidence which allows us to conclude, beyond reasonable doubt, that halocarbons are responsible for the damage to the ozone layer, is set out in a series of five reports prepared by the World Meteorological Organization (WMO) for the Parties to the United Nations Vienna Convention and Montreal Protocol (WMO, 1985, 1989, 1991, 1994 and 1999). As a result of this damage, there will be serious impacts including an increase in skin cancer (see Figure 7.1.).

Figure 7.1.

Source: EEA



This graph illustrates the approximate time lags between CFC production, the resulting depletion of the stratospheric ozone layer and subsequent extra penetration of UV radiation and the impact this will eventually have on increasing the background rate of skin cancer, given the 30-40 year average latent period for such cancers. Reality is far more complex than this schematic illustration. For example, there are other ozone-depleting chemicals (HCFCs, HFCs and methyl bromide); the ozone hole varies with latitude, time of the year and meteorological conditions; the increased UV radiation varies between different wavelengths and with latitude and cloud cover; and the skin cancer excess comes on top of a rising background rate of skin cancer, with differential effects on the different types of skin cancer, such as malignant melanoma and non-malignant skin cancers. Human behaviour is also a determining effect in skin cancer. Health effects also include cataracts and immune response suppression. However, the figure illustrates the main relationships and time lags between CFC production and skin cancer, and the 'success' in stopping CFC production and averting much more skin cancer from ozone depletion than what is now expected. (Slaper, et al., 1996).

(4) Lifetimes are given as e-folding times. The rate of removal of a constituent is proportional to its concentration, so that, in the absence of emissions, the residual concentration after N lifetimes is e^{-N} times the initial concentration.

The end of what might be called the CFC episode of industrial history is almost in sight. The consumption (consumption = production + imports — exports) and most production of CFCs, halons and methyl chloroform have already ceased in developed countries. Exceptions include feedstock use, a few so-called essential uses ⁽⁵⁾ and an allowance to supply the needs of developing countries whose own phase-out schedule began with a freeze in 1999 and culminates in cessation of supply in 2010. The reductions in releases are the basis on which the Montreal Protocol (signed in September 1987 and coming into force on 1 January 1989) and its later amendments and adjustments have been hailed as a major success.

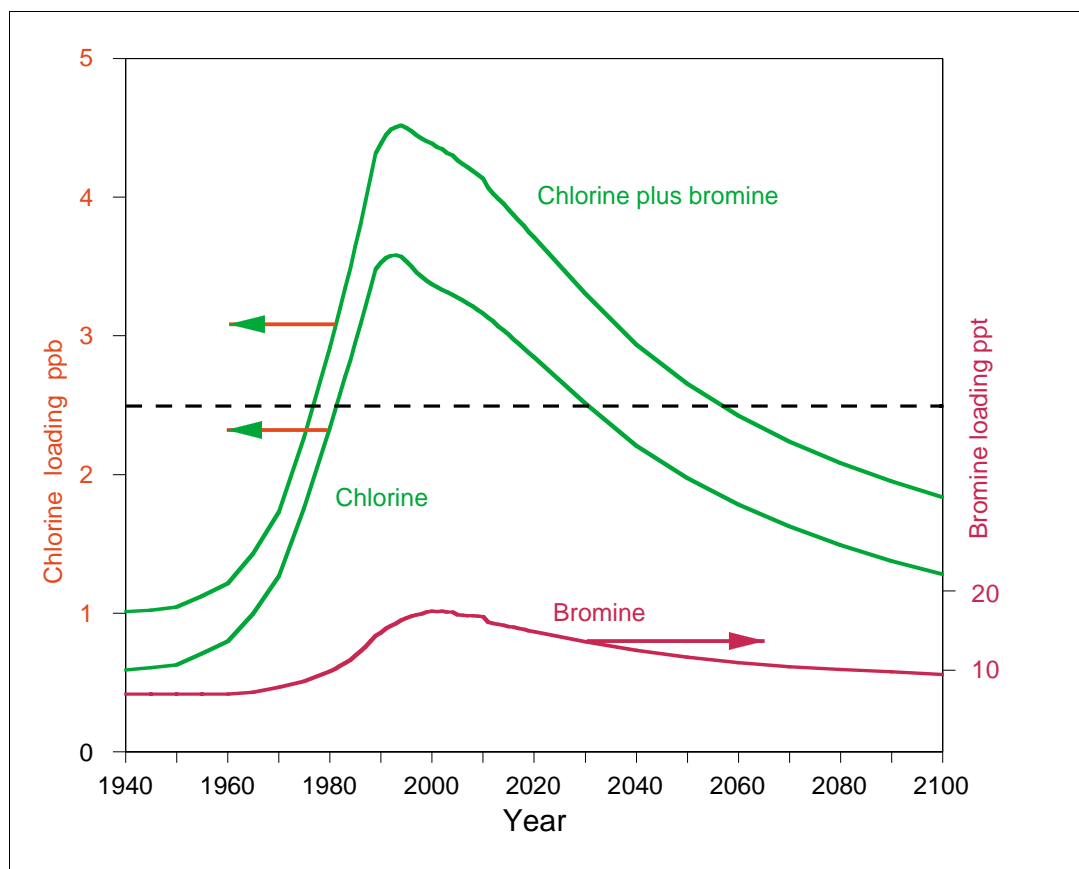
However the cessation of releases is not the end of the story for the atmosphere and for the ozone layer. Methyl chloroform has the shortest atmospheric lifetime, about 5 years, of the major ozone depleting substances

(ODS), and only about 2 % of the current atmospheric concentration will remain after four lifetimes, or 20 years. CFC-12, on the other hand, has a lifetime of about 100 years and the concentration in the atmosphere in 2100 will be at least 37 % of what it is today. The last statement is qualified because even in developed countries where production has ceased releases continue from the bank of past production held in equipment and plastic foams; this was estimated to be 791 kilotonnes in 1995. The production peaked in 1988 and ceased in developed countries at the end of 1993. Whilst there is some production in China, India and Korea, due to cease in 2002, the current releases come predominantly from the bank in developed countries, estimated at 70 kilotonnes in 1995 and being run down at about 4 % per year. This halon has an atmospheric lifetime of about 65 years, and its atmospheric concentration will continue to increase until about 2020, unless the protocol is amended to require the destruction of banked halons.

Historical and projected total chlorine and bromine loadings of the troposphere

Figure 7.2.

Source: DETR, 1999



Reactive bromine is scaled in pptv on the right, and in ppbv of equivalent chlorine on the left. The combined loading is expressed as equivalent chlorine. The line at 2.5 ppbv of equivalent chlorine indicates the loading in the late 1970s.

(5) These include medical use of CFCs in metered dose inhalers (now largely replaced by HFCs or PFCs — perfluorocarbons) and the use of halons in fire protection systems in military equipment.

As a guide to past and projected damage to the ozone layer the simplest indicator is the combined loading of chlorine and bromine in the troposphere, expressed as equivalent chlorine. Molecule for molecule, bromine is some 58 times more effective than chlorine in destroying ozone: equivalent chlorine = chlorine + 58 x bromine. Estimates of the historical and projected loadings are shown in Figure 7.2. Opinion is divided over just how far back in time damage to the ozone layer can be traced, but it has become conventional to regard a level of 2.5 ppbv (parts per billion by volume) of equivalent chlorine, first reached in the late 1970s, as significant. Under the latest amendments (1997) to the protocol a return to this level is expected between 2050 and 2060. For comparison it can be noted that under the original protocol, the London amendments of 1990 and the Copenhagen amendments of 1992, there was no guarantee that the equivalent chlorine loading would ever return to 2.5 ppbv. The adjustments in Vienna in 1995 did finally achieve a projected return, and the amendments in Montreal in 1997 brought the return a few years nearer. The failure to act more decisively in the early negotiations can be seen perhaps as the Parties to the protocol setting consensus before effectiveness; in retrospect it seems that the negotiators consistently took the view that it would be easier to get agreement at the next meeting ⁽⁶⁾.

Should the CFC episode have been avoided? Could it have been avoided? Three sketches of industrial and environmental history may help to put these questions in perspective.

7.2. Early history

The first episode is set at the end of the 19th century. The chlorinated derivatives of the simpler hydrocarbons had been studied, finding incidentally many compounds for which there are no significant sources outside the laboratory. Most ODS are compounds of that sort. Carbon tetrachloride was being produced industrially; it was used as a solvent, for dry cleaning and in fire extinguishers. Methyl chloroform was known but, surprisingly in

view of developments after 1950, found no application. A Belgian chemist, Swarts, had laid the foundation of the study of fluorinated hydrocarbons, making CFC-11 and CFC-12 by the catalysed reaction of hydrofluoric acid with carbon tetrachloride. At the turn of the century ozone was an important industrial chemical. In an episode, now largely ignored in textbooks, it was widely used in applications ranging from the chemical laboratory to municipal services. It was the most powerful oxidant known, left no objectionable residue, and was easy, if somewhat expensive, to make. It was used to sterilise public water supplies and to purify the air in the Central London underground railway system. As a bleaching agent and a deodorant of oils, waxes and fats, it was widely used in the manufacture of linen, cotton, paint, varnish, linoleum and perfumes. It was used as a preservative for food, and refrigerated warehouses and ships were often equipped with portable ozonisers. Little was known about ozone as a natural constituent of the atmosphere.

Measurements at Rouen in 1857 had shown that the mixing ratio near the ground was about 10⁻⁸ (10 ppbv) (Houzeau, 1857), and quite dense networks of stations undertaking such measurements had been set up, most notably in Belgium and France. It had been inferred from the cut-off at short wavelengths of the solar spectrum that much larger mixing ratios must occur in the upper atmosphere. At the turn of the century there was a comfortable feeling among meteorologists that the thermal structure of the atmosphere was simple: temperature decreased with height at a rate that was well understood, and the decrease should continue to the limit of the atmosphere. This complacency was shaken in 1901 when Teisserenc de Bort (see, for example, Goody, 1954) reported that the decrease stopped, often quite abruptly, at a height of about 11 km, and that from there to about 14 km, the greatest height attained by his instruments, the temperature remained almost constant. At first he called his discovery the isothermal layer, but later suggested the words troposphere, to denote the well-mixed lower region, and stratosphere for the region above, in

(6) Paragraph 9(c) of Article 2 of the Montreal Protocol states 'In taking such decisions, the Parties shall make every effort to reach agreement by consensus. If all efforts at consensus have been exhausted and no agreement reached, such decisions shall, as a last resort, be adopted by a two-thirds majority vote of the Parties present and voting representing at least 50% of the total consumption of the controlled substances of the Parties.' No issue has yet been put to a vote. Paragraph 11 of the same article states 'Notwithstanding the provisions contained in this Article, Parties may take more stringent measures than those required by this Article.' It has been invoked only once, by the European Union in March 1991, suggesting that, on the whole, the negotiators have been quite content to proceed at a pace compatible with consensus.

recognition of its high static stability. Routine soundings of the stratosphere had to await cheap portable radio, lightweight instruments and improved balloons. A start was made in 1933, but the successive effects of economic recession and world war made progress slow until the 1950s.

7.3. The 1930s — the CFC industry is born

The second sketch is for the decade centred on 1930. By then chlorine had largely replaced ozone as an industrial bleaching and sterilising agent. It was cheap, as large amounts were produced as a by-product of the electrolysis of rock salt, a process introduced to satisfy the growing demand for caustic soda for preparing sheet metal for painting. A Norwegian, Eric Rotheim, applied for a patent for the aerosol container (spray can) principle in 1926. (There is no record of use on a large scale until the Second World War, when insecticide sprays were needed in the Pacific sector. Mass production started in the United States in 1947 and in Germany in 1953.) In 1929 Thomas Midgely, at General Motors in the United States, conducted a survey of chemicals suitable for use as refrigerants, and recommended CFC-12 and CFC-11 as efficient, non-toxic and non-flammable. Du Pont started industrial production of CFC-12 in 1930 and of CFC-11 in 1934.

By this time, the ozone layer had been discovered and, considering the resources available, quite comprehensively investigated. The annual variation in ozone amount had been measured at stations ranging from the Arctic Circle to New Zealand, largely through the efforts of Dobson and his collaborators at Oxford, following up the pioneer measurement of Fabry and Buisson in France. The broad features of the vertical distribution of ozone had been established, by ground-based measurements of light scattered from the zenith sky at twilight (Götz, Meetham and Dobson), and by the Regeners at Stuttgart, who sent a small solar spectroscopy up on a balloon to 31 km, at which point it had passed through about 70 % of the ozone layer. These two very different techniques gave results that agreed remarkably well. To complete this sketch it should be mentioned that in 1930 Chapman published the first theoretical treatment of the formation of atmospheric ozone (for more on all this see, for example, Goody, 1954). Within its limitations, equilibrium

photochemistry in a static atmosphere, it gave a fair account of the upper part of the ozone layer (above 30 km), but failed completely to explain the observed variations of ozone with latitude and season. More than 50 years were to pass before realistic air motions could be incorporated into models of the ozone layer, and even today there remains a fascinating interplay between uncertainty in the chemistry and uncertainty in the dynamics of the atmosphere.

7.4. The 1970s — the seeds of doubt

Concern about the effect of human activities on the ozone layer became an international issue in 1970. Initially fears were expressed about the emissions of nitrogen oxides, carbon monoxide and water from the projected commercial fleets of supersonic stratospheric transport (SST) aircraft. These were heeded — the United States abandoned development of SSTs, and the combined total of Anglo-French Concorde and Russian Tupolev-144s never exceeded 40 aircraft. Attention then shifted to the CFC industry, which had expanded enormously throughout the 1960s. A survey, using a recently developed device capable of measuring small traces of CFCs, had shown that these gases, released largely in the northern hemisphere, had spread worldwide (Lovelock *et al.*, 1973). Moreover their concentrations were such as to indicate that processes removing CFCs from the troposphere must be extremely slow — virtually all of the amounts released were still in the atmosphere. In 1974 seminal papers by American scientists pointed out that CFCs were so stable that they would eventually reach the stratosphere, that chlorine would be released there by photolysis, and that an ozone-destroying chain reaction would ensue (Molina and Rowland, 1974; Cicerone *et al.*, 1974). A vigorous debate followed, which was to continue for over a decade.

The first significant move was the agreement in 1977 for a research-oriented ‘world plan of action on the ozone layer’, and the establishment by the United Nations Environment Programme (UNEP) of a Coordinating Committee on the Ozone Layer, to oversee the plan. It is noteworthy that representatives of non-governmental organisations (NGOs) were given the right to attend meetings of the committee. In the United States an effective public campaign, stimulated by the earlier debate on the impact of supersonic aircraft, resulted in

regulations in 1977 prohibiting the use of CFCs as aerosol propellants. Canada, Norway and Sweden took similar action. European environmental groups were at the time concentrating on the issue of acid rain, and there was little public pressure on governments over CFCs. However in 1980 European Council Decision 80/372 was passed, aiming to freeze the production capacity for CFC-11 and CFC-12, and to reduce their use in aerosols by at least 30 % from 1976 levels by the end of 1981. The effect of these measures on releases is not easily seen. Releases had fallen sharply a few years before the measures came into force, largely as a result of a downturn in world trade following a crisis in the oil market. The reduction in use in the aerosol sector was quickly offset by increased use in the foam-blowing sector. The European freeze was little more than a token gesture, since most plant was running well below its full capacity.

For all that, these measures appear to be the first, and last, unequivocal application of the precautionary principle in the ozone story. It was the only action taken before the evidence against CFCs had become compelling. The 1977 US Clean Air Act explicitly states that ‘no conclusive proof... but a reasonable expectation’ of harmful effects is sufficient to justify action (US EPA, 1987). This was in stark contrast to the ‘wait and see’ attitude adopted by industry. Du Pont, the world’s first and largest producer of CFCs, had set this out in a full page in the *New York Times* (30 June 1975). It declared that: ‘Should reputable evidence show that some fluorocarbons cause a health hazard through depletion of the ozone layer, we are prepared to stop production of the offending compounds.’ It was to deny the existence of reputable evidence until 1986. Nevertheless, it should be acknowledged that the industry, through the Chemical Manufacturers Association (an international funding agency), throughout this time gave substantial financial support to institutes and individuals engaged in research into the ozone problem.

In the early 1980s, the problem of the ozone layer seemed to have settled down. Computational models predicted only small long-term reductions of ozone, and this was in reasonable accord with observations, which showed no significant trend. Negotiations for an international convention on the ozone layer, started by UNEP in 1981,

proceeded slowly. While the United States favoured a range of controls on the use of CFCs in various applications, Europe argued for a cap on production capacity. The differences could not be bridged, and the Vienna Convention for the Protection of the Ozone Layer, agreed in March 1985, contained only pledges to cooperate in research and monitoring, to exchange information on CFC production, and to pass control protocols only if and when justified. By this time the United States was not prepared to act unilaterally, claiming that as a result of its earlier action, its production of CFC-11 and CFC-12 had fallen from 46 % of the world total in 1974 to 28 % in 1985. There was some consolation for those advocating controls; the Parties to the Convention gave UNEP immediate authority to convene working group negotiations for a protocol, to be signed if possible in 1987.

7.5. The Montreal Protocol and the ozone hole

The Montreal Protocol was, indeed, signed on 16 September 1987, after a hectic last week of controversy. Richard Benedick, the chief US negotiator, later claimed that this too was an application of the precautionary principle. A simpler interpretation would be that the working group had been overtaken by events. Ozone depletion over Antarctica had been reported in *Nature* (Farman *et al.*, 1985) in May 1985, much more severe than any prediction, and confirmed by NASA in October 1985. In reporting the NASA results, the *Washington Post* gave the world the expressive term ‘ozone hole’. Du Pont, reminded of its statement in 1975, wrote to its CFC customers in September 1986, declaring that it now accepted the need for some controls (Cagin and Dray, 1993, p. 308). Also in 1986, the US National Ozone Expedition (NOZE) to McMurdo Station in Antarctica had produced much evidence to support the view that the depletion was chemically driven. In September 1987 attention was again focused on Antarctica, with press releases expected from NOZE II, and from the US Airborne Antarctic Ozone Experiment (AAOE) whose planes had flown from Punta Arenas in Chile into and under the ozone hole. The timing of the announcement of the protocol makes sense only as a pre-emptive move astutely designed to preserve some credibility for the negotiators, and to give industry time for orderly reorganisation.

Success, compromise, muddle, failure — all these terms have been used to describe the 1987 protocol. There can be no doubt that it was a psychological breakthrough. However the terms were tempered by what was thought practicable, the ultimate objective was not clearly defined, and releases increased rapidly in the period before the next full meeting of the Parties. The protocol was ratified and came into force on 1 January 1989, in line with the timetable. The review procedure was set in motion at once. By then a consensus on the main scientific issues had been reached, NGOs had fought vigorous campaigns for public awareness, and industry was responding much faster to the problem than had initially seemed possible. The London amendments in 1990, although substantially stronger than the original protocol, nevertheless were disappointing by comparison with statements made by most of the Parties in preparatory meetings. However, in addition to the changes in the controls, two important decisions were taken. It was agreed that there should be full reviews every two years instead of every four, and it was agreed (in a new Article 10) to establish a Multilateral Fund for the Implementation of the Montreal Protocol (MFMP) to help developing countries reduce their dependence on ODS.

The main concern in these negotiations was to replace CFCs quickly with new chemicals, hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) being the options preferred by industry ⁽⁷⁾. Some 75 % of the global production of CFCs was in the hands of 13 groups of companies, who were quite content to close down old CFC plant if the protocol would allow reasonable time for the industry to profit from investment in HCFC and HFC production. The negotiators readily accepted this; these transitional substances were made subject to guidelines rather than controls and their future was left open-ended, as consensus could not be reached on a phase-out date ⁽⁸⁾. In my view, this approach was deeply flawed. Technical surveys had already shown that large quantities of CFCs and halons were released unnecessarily by poor working practices; the quantities of replacements needed were

much less than current consumption. More emphasis should have been placed on prudent long-term goals, with active encouragement of the development of halocarbon-free and energy-efficient technologies, to protect the ozone layer, to slow down the forcing of climate change and to reduce the cost of raising living standards in developing countries. The MFMP has been spent largely on the replacement of CFCs by HCFCs, and more money is now needed to phase-out HCFCs. It would surely have been better to stimulate more radical changes in technology from the outset.

The most recent full meeting of the Parties was in Beijing, China, in early December 1999, when 129 governments were represented. Two noteworthy events had taken place during the preparations for the meeting. In March 1999 the MFMP approved USD 150 million to fund the complete closure over the next 10 years of CFC production in China, now the world's largest producer and consumer of CFCs and halons. A week before the meeting the MFMP approved USD 82 million to lead to the complete phase-out of CFC production in India, the world's second largest producer of CFCs. At the meeting the Parties agreed to raise an additional USD 440 million for the MFMP; the fund has disbursed more than USD 1 billion since 1991. New controls were adopted for HCFCs, including a ban on trade in these chemicals with countries that have not yet ratified the 1992 amendment (for phase-out of HCFCs). A complete phase-out by 2002 of the production of the recently marketed chemical, bromochloromethane, was agreed. A Beijing Declaration was adopted, calling for continued efforts to halt illegal trade in ODS. There was one brief glimpse of the precautionary principle: the Scientific and Economic Assessment Panels were asked to propose means to prevent the development and marketing of new ozone-depleting chemicals ⁽⁹⁾. Important issues that were not resolved include the possible destruction of halon banks, an earlier phase-out for methyl bromide and reducing the current scale of CFC and halon consumption in Russia and other countries with economies in transition.

(7) HCFCs are ozone depleting substances, but much less harmful than CFCs. HFCs have zero ozone depletion potential, but they are powerful greenhouse gases.

(8) There were sharp differences of opinion on the date by which phase-out could be achieved. Targets ranged from 2010 to 2040.

(9) For more information on the Beijing meeting visit the web site: <http://www.iisd.ca/ozone/mop11/>

7.6. Late lessons

The report in 1985 of rapid and severe seasonal destruction of ozone over Antarctica was an outcome of systematic long-term measurements, begun solely for scientific exploration. It took everyone by surprise, including the authors. The accepted view was that the effects of CFCs should be seen first at high altitudes (30–50 km) in the tropics, and that any changes in the lower stratosphere in polar regions would be very slow. As it happened, two other groups were close to challenging the accepted view — Japanese scientists had presented anomalous ozone profiles from Antarctica, but without identifying a systematic trend, and NASA scientists were re-examining very low ozone amounts flagged as ‘suspect’ by their software in initial retrievals of satellite data. This was before the Internet, and the absence of effective collaboration, whilst regrettable, was not uncommon in institutions with stretched resources. It should also be noted that the ozone community was just completing the first of the WMO reports — an onerous task for authors and reviewers. The funding of long-term monitoring remains a serious problem. It is simply not practicable to provide open-ended funding at the level needed to cope with uncovering a major environmental issue.

Recession and war restricted the growth of the CFC industry. From 1930 to 1948 the cumulative releases of CFC-12 and CFC-11 were only 25 and 5 kilotonnes respectively. The next two decades brought spectacular growth — in 1970 the annual releases were 300 and 207 kilotonnes. People had been persuaded to buy CFCs and throw them away (aerosols). Industry’s dream of ‘wonder chemicals’ was apparently coming true. This was the time when it might reasonably have been asked whether such development was sustainable.

There can be little doubt that a conventional risk assessment, in say 1965, would have concluded that there were no known grounds for concern. It would have noted that CFCs were safe to handle, being chemically very inert, non-flammable, and having very low levels of toxicity. They were good heat insulators, and some were excellent solvents, mixing readily with a wide range of other organic substances. The

assessment might have pointed out that it was not known what happens to CFCs when they are released to the atmosphere, but would no doubt have added that they had been released for more than 30 years with no apparent harm being done. There would probably have been a long list of recommendations for further research. In retrospect, it is easy to see that these should have included investigating the ultraviolet and infrared spectra of CFCs, measuring their atmospheric concentrations, and identifying their decomposition products. As it happens, there were hints of the risk to the ozone layer available (Weigert, 1907; Norrish and Neville, 1934⁽¹⁰⁾) if it had been recognised that atomic chlorine and fluorine might be released from CFCs in the upper atmosphere. But they would surely have been dismissed on the grounds that there would be at least 10 000 times more ozone than CFCs at the relevant altitudes.

It is just possible that such an assessment might have accelerated the research needed to make out a plausible case against CFCs. But, as history shows, a plausible case brought only limited action. Serious negotiations did not begin until severe depletion had occurred, and strong evidence found to link it with CFCs. The protracted, and frequently amended, schedule for phase-out of ODS suggests that, even at this stage, precautionary management of the environment was not uppermost in the minds of policy-makers.

The recent decision (2001) of the US administration not to ratify the Kyoto Protocol on Climate Change will have disappointed many who were hoping that the experience gained with the Montreal Protocol would facilitate getting agreements for further protection of the global environment. One of the lessons should have been that neither governments nor multinational companies have a mandate for global experiments, even when such experiments consist solely of ‘business as usual’. The CFC issue provides a stark warning. Practices that appear to be reasonable when introduced (in this case when there were huge gaps in the understanding of atmospheric processes) may later (as understanding improves) be seen to be leading to a major global problem that can neither be avoided, nor rapidly

(10) These two papers report laboratory experiments on the decomposition of ozone photosensitised by chlorine. They are cited in a systematic review of stratospheric chemistry, dated 1977, but there is nothing to suggest that they had any influence on workers in the 1960s and early 1970s.

alleviated. There is a deep-seated paradox here. Short-term safety appears to demand that synthetic chemicals in everyday use should be non-reactive. It has taken a long while for it to be realised that this means that they will be extremely persistent.

It should not be assumed that environmental science has reached the stage where all

hazards can be foreseen. All too often technology outstrips the science needed to assess the risks involved. If there is to be a solution, policy-makers must learn to recognise, much more rapidly than they have in the past, when ignorance has been replaced by understanding, however rudimentary.

Halocarbons: early warnings and actions

Table 7.1.

1907	Laboratory experiments by Weigert on the decomposition of ozone photosensitised by chlorine
1934	<i>Ditto</i> by Norrish and Neville
1973	Global survey of CFCs by Lovelock <i>et al.</i> showing their distribution in the atmosphere worldwide
1974	Molina and Rowland publish their theoretical arguments that CFCs would be destroying the ozone layer
1977	United States bans CFCs in aerosols based on 'reasonable expectation' of damage, followed by Canada, Norway and Sweden.
1977	Research-oriented 'world plan of action on the ozone layer' agreed, overseen by UNEP
1980	European decision restricting use of CFCs in aerosols, but rising use in refrigerators, etc. marginalises this restriction
1985	UNEP Vienna Convention for the protection of the ozone layer agrees research, monitoring, information exchange and restrictions if and when justified
1985	Farman, Gardiner and Shanklin publish results showing hole in ozone layer over Antarctica
1987	Montreal Protocol on protection of the ozone layer is signed, with phasing out of ozone depleting substances for both developed and developing countries within different timescales
1990s	Increasing finance to developing countries to help them reduce their dependence on ozone depleting substances
1997	Amendments to the Montreal Protocol in order to restore levels of chlorine by 2050–60
1999	Beijing Declaration calling for efforts to stop illegal trade in ozone depleting substances

Source: EEA

7.7. References

Cagin, S. and Dray, P., 1993. *Between earth and sky*, Pantheon Books, New York.

Cicerone, R. J., Stolarski, R. S. and Walters, S., 1974. *Science* Vol. 185, p. 1165.

DETR, 1999. 'Stratospheric ozone 1999', DETR Reference No 99EP0458, United Kingdom Stratospheric Ozone Review Group, Department of the Environment, Transport and the Regions.

Farman, J. C., Gardiner, B. G. and Shanklin, J. D., 1985. *Nature* Vol. 315, p. 207.

Goody, R. M., 1954. *The physics of the stratosphere*, Cambridge University Press, Cambridge.

Houzeau, A., 1857. *Comptes Rendus Acad. Sci. Paris* Vol. 45, p. 873.

Lovelock, J. E., Maggs, R. J. and Wade, R. J., 1973. *Nature* Vol. 241, p. 194.

Molina, M. J. and Rowland, F. S., 1974. *Nature* Vol. 249, p. 810.

Norrish, R. G. W. and Neville, G. H. J., 1934. *J. Chem. Soc.*, p. 1684.

US EPA, 1987. Protection of stratospheric ozone, Fed. Register 52, p. 47491.

Weigert, F., 1907. *Ann. Physik.* Vol. 24, p. 243.

WMO, 1985, 1989, 1991, 1994 and 1999. *Global Ozone Research and Monitoring Project*, Reports Nos 16, 20, 25, 37 and 44, World Meteorological Organization, Geneva.