The human health consequences of ozone depletion – an overview

Bruce K. Armstrong
Director, Cancer Control Information Centre, New South Wales Cancer Council, Australia
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Measured total column ozone has fallen between about 1970 and 1994. The minimum is expected to be reached around 2000 and recovery to 1970 levels should occur after the middle of the next century. UV irradiance increases at the surface of the earth due to ozone depletion should peak at about 15 per cent in mid-latitudes. There are, however, few data that testify directly to the existence and size of this trend in UV irradiance and no satisfactory data on current and long-term trends in sun-related behaviour and actual exposure of humans to solar UV radiation. The incidence of harmful health effects of UV radiation can be expected to rise, eventually, at mid-latitudes. Measurement difficulties and confounding effects of changes in sun-related behaviour, however, will make these trends difficult to measure. The necessary environmental response to depletion of stratospheric ozone has probably been taken with the Montreal Protocol on ozone-depleting substances, provided that it works. Public health action is still necessary to reduce sun exposure and increase protection against the sun and to develop clear policies on the action that should be taken on early detection and treatment of skin cancers. From a health perspective, to monitor the adequacy of these responses it will be essential to institute or continue monitoring of stratospheric ozone levels, spectral UV irradiance at the surface of the earth, personal exposure of humans to UV irradiation, and trends in the major health consequences of UV radiation.

Introduction

After the possibility of global nuclear war, the reality of depletion of stratospheric ozone due to build up of stable, synthetic halocarbons in the atmosphere was the first global environmental threat to be taken really seriously by the world community. Thirteen years after it was first postulated that halocarbons would destroy stratospheric ozone (Molina and Rowland 1974) and two years after evidence emerged that this was happening (Farman et al. 1985), the major halocarbon-producing and using nations agreed, in 1987, to the first Montreal Protocol on Substances that Deplete the Ozone Layer. From the first of January 1996, the 1992 revision of the Protocol has required zero production and consumption of chlorofluorocarbons – the most prevalent ozone depleting chemicals – by developed countries. Corresponding advancements of phase-out dates were made for other ozone depleting substances and phase-out dates were 10 years later for developing countries (Chatterjee 1995). One hundred and seventeen countries have signed the Protocol, including the major developing economies, such as India and China. If there is full compliance with the Protocol, atmospheric chlorine loading should peak before 2000 (Madronich et al. 1995) and return to the levels of the early 1970s by about 2060.

Corresponding author address: Dr Bruce Armstrong, New South Wales Cancer Council, PO Box 572, Kings Cross, NSW 2011, Australia
Complacency about stratospheric ozone depletion has followed the success of the Montreal Protocol in reducing production and use and reports that the rate of growth in the concentration of chlorofluorocarbons in the atmosphere has begun to slow. For most government environmental agencies the problem has been fixed; we just have to wait for its manifestations to go away. It is commonly assumed that the adverse effects of increased UV (ultraviolet) radiation at the earth's surface have been contained to tolerable levels and, in any case, will not last much beyond the turn of the 22nd century. Is this apparent complacency justified? If not, why not? Does science have any more to offer in understanding and controlling this environmental indiscretion?

**Trends in stratospheric ozone**

The concentration of ozone-destroying chlorine and bromine (measured in terms of their combined effectiveness, in chlorine equivalents, in destroying ozone) appears to have reached a peak in the troposphere in about 1994, and fell in 1995 (Montzka et al. 1996). However, it will take some three to five years for this lower concentration to reach the stratosphere. Thus, it will only be after sometime between 1997 and 1999 that stratospheric ozone can begin to recover.

Measured mean and minimum October total column ozone levels in Halley, Antarctica, have fallen steadily from about 1970 to 1994 (Jones and Shanklin 1995). In 1995, minimum total column ozone values were below 130 Dobson Units (DU) compared with values of less than 100 DU in the two preceding years. This apparent perturbation in the downward trend was probably due to anomalously low values in 1993 and 1994, due to effects of aerosols persisting from the 1991 eruption of Mount Pinatubo, rather than to an end to the long-term trend.

An added complication in all of this is the possibility that the greenhouse effect, which is now in the centre of the global environmental stage, may increase ozone depletion. Paradoxically, as the lower atmosphere (the troposphere) warms up, the upper atmosphere (stratosphere) cools down. This cooling may promote ozone depletion by increasing the formation of polar stratospheric ice clouds which contribute to the conditions favouring the photochemical destruction of ozone in the Antarctic and Arctic springs.

Some questions needing answers are:

- Are there any indications that the Montreal Protocol will be more or less effective than expected?
- Are there any new grounds for believing that substantial, ongoing ozone depletion is occurring for reasons other than atmospheric accumulation of chemicals controlled by the Montreal Protocol?

**Trends in ambient solar UV radiation**

The major environmental consequence of stratospheric ozone depletion is an increase in ambient levels of UV radiation at the surface of the earth. This is not all UV radiation because ozone is selective in its absorptive capacity: all at wavelengths less than 290 nm, 90 per cent under 304 nm, 50 per cent at about 314 nm and one per cent at about 339 nm. Thus, ozone prevents all the high energy UV-C radiation (100 to 280 nm) from reaching the earth's surface, most of the UV-B (280 to 315 nm), less than half of the shorter wavelength UV-A (315 to 340 nm), very little of the longer wavelength UV-A (340 to 400 nm) and, of course, no visible light (400 to 780 nm) or heat. This selectivity has an important influence on our speculations about the health effects of ozone depletion.

Has ambient UV irradiance increased at the earth's surface as a result of ozone layer depletion? Estimates for clear skies from a radiative transfer model based, among other things, on stratospheric ozone measurements suggest that it has, particularly in mid-latitudes in both the northern and southern hemispheres. At its expected peak early in the next century, it is estimated that erythemal UV irradiance will have increased some 15 to 17 per cent in winter and spring and 8 to 9 per cent in summer and fall in northern mid-latitudes and 15 per cent in southern mid-latitudes (all seasons) (Madronich et al. 1995). Clear-sky estimates may not be all that realistic because of the importance of clouds in determining UV irradiance. On average in Darwin, Alice Springs, Brisbane, Perth and Melbourne, cloud cover reduces irradiance by between 10 and 40 per cent depending on the city and month (Roy et al. 1995).

A recent report takes the clear-sky estimates somewhat further (Herman et al. 1996). UV irradiances at the surface of the earth were estimated by use of ozone measurements from the Total Ozone Mapping Spectrometer on the Nimbus 7 satellite taking into account atmospheric UV scattering, meteorological conditions and ground reflectivity. The reflectivity data suggested that there were no long-term changes in annual cloudiness over large geographical areas. Between 1979 and 1992 the upward trends in estimated UV irradiances were greater than two standard deviations poleward of 40° latitude for each of erythema, DNA damage and plant damage action spectra.
What about measured UV irradiance at the earth’s surface? There are good observations of short-term changes that correlate with locally measured trends in ozone concentration (Roy et al. 1994; Jokela et al. 1995). However, there have been very few sets of long-run observations and even fewer adequate analyses. In addition the year-to-year variability in UV irradiance due to short-term variability in ozone concentrations (20 per cent annually) and cloud cover (10 to 20 per cent annually) is large compared with the maximum expected 10 to 15 per cent increase in irradiance from ozone depletion over populous areas. It has been estimated that in most areas of the world it will take 30 years or more from the onset of ozone depletion for the expected change in UV irradiance (adjusted to the action spectrum for skin cancer in mice) to exceed 1.96 times the standard deviation of noon UV irradiance attributable to interannual variability in cloud cover (Lubin and Jensen 1995). Thus there is a lot of ‘noise’ that might obscure the UV trend signal; or create short-term trends that do not reflect accurately the long-term trend due to halocarbon-caused depletion in ozone. The expected trends may also be confounded by contrary trends in air pollution: accumulation of ozone in the troposphere as the main component of photochemical smog and particulate air pollutants may have, in some areas at least, ameliorated the effects of stratospheric ozone depletion.

Several recently published analyses suggest that medium-term ozone-related increases have occurred in measured UV irradiance but also illustrate some of the complexities outlined above.

Kerr and McElroy (1993) reported measurements of UV-B from a single Brewer spectroradiometer in Toronto, Canada, over the period 1989 to 1993. Ozone levels fell annually by averages of 4.1 per cent in winter and 1.8 per cent in summer and erythemal UV-B increased annually by 5.3 per cent in winter and 1.9 per cent in summer. The size of the trend in UV-B increased with decreasing wavelength as would be expected if it were due to ozone depletion; at 300 nm it increased annually by 35 per cent in winter and 6.7 per cent in summer. It is important to note that this five-year period is not long enough to eliminate trends due to quasi-biennial oscillation in ozone and effects of the 11-year sunspot cycle. In addition, record low ozone levels were recorded in 1993, possibly due to effects of the 1991 eruption of Mt Pinatubo.

Basher et al. (1994) used a Robertson-Berger meter to record clear-sky UV-B irradiance in a continuous series at Invercargill, New Zealand, from 1981 to 1986. The ‘de-seasonalised measurements’ were shown to correlate very closely, inversely, with satellite measurements of ozone taken at the same time. In summer half years UV irradiance increased by 1.84 per cent a year while ozone fell by 1.70 per cent a year (p<0.05 for each trend), while in winter half years the trends were -0.31 per cent and +0.37 per cent for UV-B and ozone respectively. The authors noted that the summer half year series ended in a period of very low ozone in late 1985 while the winter series ended in a period of relatively high ozone in mid-1986.

In a third study (Munakata 1995), Bacillus subtilis spores were exposed to the sun on the roof of the National Cancer Centre Research Institute in downtown Tokyo for periods of half a day on arbitrarily chosen days (but generally not heavily clouded or rainy days) for a total of 127 observations over the period 1980 to 1993. An ‘inactivation dose’ was estimated as the absolute value of the natural logarithm of the fraction of the spores surviving after each exposure. The value of this dose would be expected to correlate positively with the amount of biologically active UV radiation received by the spores; it did correlate positively with physically measured global solar irradiance during the periods of exposure. In addition, however, the lines of log-linear regression of the inactivation dose with global solar irradiance shifted upwards with each successive period of observations from 1980-86 to 1989-91 to 1992-93. This shift indicates that for any particular level of global solar irradiance the fraction of B. subtilis spores killed increased in successively later time intervals: The inactivation dose was negatively correlated with total column ozone measured on a plain some 53 km northeast of Tokyo. But variation in total column ozone explained only part of the variation over time in the inactivation dose. Thus it is not at all clear that this trend towards increasing biologically effective UV radiation at the earth’s surface was related to depletion of stratospheric ozone. Other possible explanations include trends in tropospheric ozone and other air pollutants over Tokyo.

Some questions needing answers are:

- Is there a long-term trend towards increasing UV irradiance at the surface of the earth?
- Is the size and rate of increase, if any, in line with what would be expected from the observed long-term trend in stratospheric ozone?
- Is the spectral distribution of the increase consistent with an effect of ozone depletion?

**Trends in human exposure to solar UV radiation**

It was Brian Difffey who made the obvious point that small changes in human behaviour can have as great or greater effects on human exposure to UV radiation than the expected change in ambient UV irradiance due to ozone layer depletion. He estimated that, for the average resident of the British Isles, staying indoors for one hour around midday between May and August or wear-
ing a wide-brimmed hat every day during a two week summer vacation would reduce exposure to UV radiation by about the same amount as ozone depletion might increase it (Diffey 1992). Further, the availability of shade has a large effect on exposure. During a walk along a canal in summer in the south of France, UV exposure to a sensor clipped to the waist band was consistently <0.01 med/h (med = minimal erythema dose) when walking in the shade and 0.4 to 1.9 med/h when walking in the open (Diffey and Saunders 1995). Thus, even if ambient UV irradiance is increased by about 15 per cent when stratospheric ozone reaches its minimum this change need not necessarily translate into harmful effects on human health. Indeed, it could be argued that the effects of fear of ozone depletion engendered by news reporting and supported by health promotion campaigns may have already changed behaviour sufficiently to negate the effects of UV irradiance increases.

Speculation is all very well, we need evidence; and here, again, we have very little. There have been very few short or medium and no long run observations on the sun-related behaviour of a population measured by carefully standardised techniques. Nor, except in isolated studies (Herlihy et al. 1994; Gies et al. 1995), has there been measurement of the effects of sun-related behaviour or the local environment (e.g. presence of trees or other shade structures (Diffey and Saunders 1995)) on the exposure of sun-sensitive tissues to UV radiation, and there have been no measurements of trends in this exposure.

Data on trends in sun-related behaviour in New South Wales over four years have been obtained as part of the evaluation of the New South Wales Health Department's 'Me No Fry' campaign (Sanson-Fisher 1995). Surveys of adolescents were carried out in high schools on Mondays with, among other things, questions about sun exposure on the preceding weekend. The surveys were generally carried out in late summer and early autumn, except in 1994-95 when they occurred in late autumn. Some results are summarised in Table 1. They suggest increasing protection against the sun running in parallel with an increase in sun exposure. There was little evidence, at least from the reports of students, that schools were consistently introducing environmental measures aimed at protecting students from the sun.

Some questions needing answers are:

- What evidence is there for changes in exposure to UV radiation due to changes in behaviour or local environments?
- How do such changes, if any, compare with changes likely to be due to ozone depletion?
- Have increases in protection against the sun been traded off against increased sun exposure?

### Table 1. Some trends in weekend sun exposure and protection from the sun in adolescents in New South Wales in 1991-92 to 1994-95 (based on Sanson-Fisher 1995).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of adolescents</td>
<td>868</td>
<td>3,569</td>
<td>3,312</td>
<td>1,489</td>
</tr>
<tr>
<td>Periods of sun exposure¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2</td>
<td>41%</td>
<td>45%</td>
<td>37%</td>
<td>39%</td>
</tr>
<tr>
<td>3-5</td>
<td>44%</td>
<td>34%</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>6-8</td>
<td>16%</td>
<td>21%</td>
<td>23%</td>
<td>21%</td>
</tr>
<tr>
<td>High level protection when outdoors³</td>
<td>39%</td>
<td>47%</td>
<td>54%</td>
<td>57%⁴</td>
</tr>
<tr>
<td>Enough shade for students who wanted it</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required to wear a hat:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>when playing outdoor sports</td>
<td>20%</td>
<td>32%</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>when outdoors at lunchtime</td>
<td>14%</td>
<td>21%</td>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>

1. There were eight periods of one hour between 11:00 am and 3:00 pm (Eastern Summer Time) over the two weekend days.
2. P value for trend in proportions is 0.004.
3. A 16-point solar protection score was calculated based on protection by a hat, clothing or SPF 15+ sunscreen, number of body sites protected and the risk of skin cancer at the site. High protection was 12+ points.
4. P value for trend in proportions is <0.0001.

### Trends in human health effects of solar UV radiation

The major known or suspected health effects of UV radiation, both beneficial and harmful, are summarised in Table 2 (Armstrong 1994a). The vast majority of them are harmful effects and the only certain beneficial one, production of vitamin D, is most likely an issue only for those who are deprived of sun exposure or have heavily pigmented skins and live in an area of low ambient UV radiation. Thus, the net effect on health of an increase in ambient UV is more likely to be harmful than beneficial.

How much increase in risk of human disease is an increase in ambient UV radiation likely to cause? This question can only be answered for the major UV-related conditions and the answer is based on analysis of the way in which incidence varies geographically with changing ambient UV. It is answered in terms of the biological amplification factor – the percentage increase in incidence that would be expected to result from a one per cent increase in ambient radiation. This measure can also be expressed in terms of the amplification factor, or the percentage increase in incidence of the effect that would be expected to result from a one per cent fall in stratospheric ozone.
Table 2. Summary of the main effects of solar ultraviolet radiation on the health of human beings (updated from Armstrong 1994a)

<table>
<thead>
<tr>
<th>Nature of effect</th>
<th>Direction of effect</th>
<th>Strength of evidence for effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effects on immunity and infection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suppression of cell mediated immunity</td>
<td>Probably Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Increased susceptibility to infection</td>
<td>Harmful</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Impairment of prophylactic immunisation</td>
<td>Harmful</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Activation of latent virus infections</td>
<td>Harmful</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Effects on the eyes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute photokeratitis and photoconjunctivitis</td>
<td>Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Climatic droplet keratopathy</td>
<td>Harmful</td>
<td>Limited</td>
</tr>
<tr>
<td>Pterygium</td>
<td>Harmful</td>
<td>Limited</td>
</tr>
<tr>
<td>Cancer of the cornea and conjunctiva</td>
<td>Harmful</td>
<td>Limited</td>
</tr>
<tr>
<td>Lens opacity (cataract)</td>
<td>Harmful</td>
<td>Limited</td>
</tr>
<tr>
<td>Uveal melanoma</td>
<td>Harmful</td>
<td>Limited</td>
</tr>
<tr>
<td>Acute solar retinopathy</td>
<td>Harmful</td>
<td>Probably Sufficient</td>
</tr>
<tr>
<td>Macular degeneration</td>
<td>Harmful</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Effects on the skin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malignant melanoma</td>
<td>Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Nonmelanocytic skin cancer</td>
<td>Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Sunburn</td>
<td>Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Chronic sun damage</td>
<td>Harmful</td>
<td>Variable</td>
</tr>
<tr>
<td>Photodermatoses</td>
<td>Harmful</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Other direct effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vitamin D production</td>
<td>Beneficial</td>
<td>Sufficient</td>
</tr>
<tr>
<td>Non-Hodgkin’s lymphoma</td>
<td>Harmful</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Other cancers</td>
<td>Beneficial</td>
<td>Inadequate</td>
</tr>
<tr>
<td>General well being</td>
<td>Beneficial</td>
<td>Inadequate</td>
</tr>
<tr>
<td>Indirect effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effects on climate, food supply, disease vectors, atmospheric chemistry, etc.</td>
<td>Probably harmful</td>
<td>Inadequate</td>
</tr>
</tbody>
</table>

The best currently available estimates for these amplification factors are summarised in Table 3 (Armstrong 1994a; Longstreth et al. 1995). The biological amplification factors vary from as low as 0.4 for melanoma to 2.5 for squamous cell carcinoma. The additional multiplier for the amplification factor arises because a fall in stratospheric ozone produces a greater relative increase in shorter wavelength UV radiation which, generally, is more biologically damaging. No attempt has been made to estimate amplification factors for melanoma and cataract because the action spectra for these effects are uncertain.

It is important to note that estimates of biological amplification factors also assume action spectra because the spectral composition of UV radiation varies geographically. Shorter wavelengths are more attenuated with increasing latitude than longer wavelengths. For the estimates shown in Table 3, the spectrum assumed was that for the induction of skin cancer in albino hairless mice (adjusted for differences between mice and humans in the absorptive capacity of the epidermis) or the response spectrum of the Robertson-Berger meter (on which geographical measurements of UV irradiance in the United States have generally been based). If the assumptions about action spectra are wrong, the estimates of both the biological amplification factor and the amplification factor will be wrong.

The estimates of biological amplification factor derived from geographic variation in incidence of health effects and ambient UV irradiance have also generally assumed that geographic variation in sun sensitivity (e.g. skin type) and sun-related behaviour do not contribute appreciably to the value of the factor. While the former may be true for the United States, from which all the estimates in Table 3 come, the latter is probably not, and it seems likely that the present best estimates of biological amplification factors are over-estimates of the true values, at least for skin cancer (Armstrong 1993).
Table 3. Estimates of the biological amplification factor and the amplification factor for major health effects of UV radiation (Armstrong 1994a; Longstreth et al. 1995).

<table>
<thead>
<tr>
<th>Health Effect</th>
<th>Biological amplific. factor</th>
<th>Amplific. factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal cell carcinoma of skin</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Squamous cell carcinoma of skin</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Malignant melanoma of skin</td>
<td>0.4</td>
<td>-</td>
</tr>
<tr>
<td>Cortical cataract</td>
<td>0.7</td>
<td>-</td>
</tr>
</tbody>
</table>

However, until better estimates are obtained, for example by way of combined geographical and individual studies (Armstrong 1994b), they are the best we have.

By use of these biological amplification factors and trends in UV irradiance to 1992 derived from a radiative transfer model (Madronich and de Gruijl 1994), it has been estimated that incidence of basal cell carcinoma of the skin could eventually increase, as a result of stratospheric ozone depletion, by about one per cent near the equator and 12 per cent at latitudes 45° north and south. The corresponding increases for squamous cell carcinoma were estimated to be three per cent and 23 per cent. These estimates assumed, implicitly, lifetime exposure of at least one generation to increased UV irradiance levels resulting from ozone depletion to 1992 without compensating behaviour change. While the degree of depletion at its peak around 2000 will be greater than that reached by 1992, no generation is likely to be exposed to the correspondingly increased UV levels for a lifetime. These issues, together with doubt about the accuracy of the biological amplification factors, mean that the increases in population incidence of skin cancer that will result from ozone depletion cannot yet be estimated with any certainty.

A recent attempt has also been made to estimate the effect of UV irradiance change due to ozone layer depletion on risk of infection (Garson et al. 1996). Based on the very limited data available and some new experimental studies in rats and with in vitro preparations of human skin, it was estimated that under sunny skies in July at latitude 40° north it would take 104 minutes of sun exposure to produce 50 per cent suppression of the specific T-cell responses to Listeria monocytogenes in the most sensitive human beings. With a 20 per cent depletion of stratospheric ozone, it was estimated that this degree of suppression would occur after 94 minutes of exposure.

Has the incidence of any of these effects increased as a result of depletion of stratospheric ozone? The answer is almost certainly yes in the sense that some incidence rates are now higher than they would have been had stratospheric ozone remained constant. This answer assumes that adaptive responses would have been the same whether or not ozone had fallen.

There are two important qualifications to this answer: first the incidence of the more delayed health effects (e.g. skin cancers and cataract) may not yet have had time to respond to the change in UV irradiance and, second, if and when changes in incidence do occur, it will be very difficult to distinguish them from other trends that may be occurring at the same time.

With respect to time, skin cancers are rare before about 20 years of age. Thus skin cancers initiated as a result of an increase in UV irradiance are unlikely to appear before 20 years from the increase. However, UV radiation may also have effects in the late stages of carcinogenesis on the time at which the cancer becomes clinically manifest. This possibility is illustrated by, for example, the observed seasonal variation in diagnosis of melanoma (Schwartz et al. 1987) and the fact that sunscreen use can reduce over the course of a summer the number of new solar keratoses that appear and increase the number of existing ones that regress (Thompson et al. 1993). Thus an earlier effect of increased ambient UV is a possibility.

The other trends that will make it difficult to observe, with any certainty, trends in skin cancer due to ambient UV irradiance increase include changes in UV exposure due to changes in sun-related behaviour and local environmental change, and trends in the detection, diagnosis and recording of skin cancer. These difficulties will apply to a greater or lesser extent to all health effects of UV radiation.

Some questions needing answers are:

- What is the net impact on health likely from depletion of stratospheric ozone?
- Can that impact be measured directly and, if so, how?
- If not, how adequately can it be estimated from present estimates of amplification factors?
- If the answer is ‘not adequately’, how can the estimates of amplification factors be improved?

Response to the health threats

There are two broad kinds of response that can be made to the health threats presented by depletion of stratospheric ozone. The first is to deal with the problem at its environmental source – namely the chemical pollutants that destroy ozone. Action has been taken through the Montreal Protocol and, for the present, it may be as much action as can reasonably be taken; but it must be kept continuously under review. The second is public health action directed at minimising the health conse-
quences of any increase in UV radiation that may occur. This action falls into three broad categories:

- Local environmental and policy changes that will make it easier for people to protect themselves against sun exposure. These changes include, for example, provision of more shade in areas in which people commonly spend time outdoors, removing taxation from effective sun protection products, making effective sun protection products tax deductible for outdoor workers, and introduction of sun protection policies in schools and workplaces.
- Education for changes in behaviour that will favour protection from the sun.
- Promotion of early detection and treatment of sun-caused diseases when this may lead to a better outcome. The obvious examples are early detection and treatment of skin cancers.

Given the importance of sun-related disease in Australia, any action taken especially to ameliorate effects of ozone depletion comes on top of already well-established public health programs. There remain, however, some important questions:

- Have our sun-exposure control strategies worked?
- If so, which have been the most effective and which have been the most cost-effective?
- How much more control of sun exposure can we reasonably expect to achieve?
- How should we approach the issues of early detection of melanoma and nonmelanocytic skin cancers? Is education about early warning signs sufficient? Should there be organised screening programs?

Monitoring the outcomes

Clearly, to know whether or not environmental measures aimed at controlling ozone depletion are working, continuing measurement of trends in stratospheric ozone concentrations is important. It will not be sufficient simply to report on the size and depth of the Antarctic (or Arctic) ozone hole. Much more important are the resulting trends in stratospheric ozone over the populous parts of the earth and in summer as well as late winter and early spring. These will require regular analysis and reporting of data from the network of ground-based meters and from satellite-borne instruments. These measurements will provide a ready means of ongoing estimation of trends in clear sky UV irradiance and, less certainly, total UV irradiance around the world. These measurements will not be enough, however, to allow us to infer trends in the health consequences of UV radiation. The confounding trends mentioned above, cloud cover, particulate air pollution, etc., leave as yet undispelled uncertainty about real trends in UV irradiance. Thus UV irradiance itself must be measured. These measurements should meet certain criteria. They should be made where people live, be representative of most human environments and populations, be standardised and subject to quality control so that confident comparisons can be made between different places and different times, and be spectral.

Why spectral? The most sensitive indicator of whether or not ozone depletion has influenced measured UV irradiance will be a shift in the distribution of radiant energy in the UV-B range towards shorter wavelengths. In addition, to be able to infer trends in different health effects from UV irradiance trends, it will be important to know the wavelength specificity of those trends.

Trends in ambient UV irradiance will only paint a small part of the public health picture. Regardless of the size of any increase, or hoped-for later decrease, in ambient UV, the key short-term measure of the success or failure of the public health response to ozone depletion will be personal exposure to UV radiation. There are a number of possible approaches to its measurement: simple short-term recall or diary recording of time spent outdoors in the sun, use of protective clothing and sunscreens; occurrence of sunburn; standardised observation of groups of people in common outdoor activities; personal monitoring by way of film badges (Herlihy et al. 1994) or more sophisticated devices (Diffey and Saunders 1995) and, possibly, some kind of biological monitor. In the last case, the measurement of UV-specific p53 gene mutations in normal skin has appeared promising (Nakazawa et al. 1994).

Finally we come to monitoring the harmful consequences of exposure to UV radiation. The only one to be routinely monitored over long periods and in many populations is incidence of cutaneous malignant melanoma; and this, we suspect now, is much more sensitive to the effects of variation in efforts at detection than we had previously believed (Burton et al. 1993). While knowledge of the incidence of skin cancers is important to estimate the burden they place on human health, it is doubtful whether they will ever be able to be measured accurately enough to allow us to certainly monitor trends in harmful consequences of UV radiation. Periodic, standardised surveys of the prevalence of benign cutaneous or ocular effects of UV radiation may be a more accurate monitor of these trends. We know little, however, of the accuracy with which most of these can be measured.

Some questions that need to be answered are:

- What is the most efficient and effective way of organising global standardised monitoring of UV irradiance in a way that will inform about the consequences of ozone trends?
- Are the data that we have about the action spectra for different health effects of UV radiation and the way in which incidence of these effects varies with changing UV exposure sufficient to allow us to infer trends in health effects from trends in spectral UV irradiance?
• What are the most accurate and cost-effective ways of monitoring actual human exposure to solar UV radiation?
• Is there a way of accurately measuring trends in the incidence of any kind of skin cancer?
• Can periodic measurement of the prevalence of any benign sun-related condition be used as a proxy measure of trends in the burden of all UV-related disease?

Conclusion

We know that stratospheric ozone is being depleted, we think that ambient UV irradiance at the surface at the earth is increasing as a result. We do not know whether there are trends in human exposure to UV radiation or in its harmful health effects that can be attributed, thus far, to ozone depletion. Does it matter that we know so little about any other than the geophysical effects of this global environmental indiscretion? Yes it does, for at least two reasons. First, there are yet 70 years to run of the probable 100-year life of anthropogenic depletion of stratospheric ozone. If our comfortable extrapolations from limited facts prove to be wrong, many may have suffered needlessly before we wake up to it. Second, if we do not fully tell the history of this, the first major, realised man-made threat to the global environment, our children will, to their detriment, be deprived of its lessons.

References


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