

ULTRAVIOLET RADIATION:

Current Instrumentation and Methodology

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EXECUTIVE SUMMARY

This report is concerned with the sources and measurement of ultraviolet radiation.

Ultraviolet radiation (UVR) is the part of the electromagnetic radiation spectrum with wavelengths between ~1 nm and ~400 nm. The principle source of UVR on the earth is the Sun. There are also many artificial sources of UVR in everyday use. The general public has become familiar with the various uses of radiowaves, microwaves, infrared, UV, X-rays and gamma rays; though in the recent past, they have been inclined to think that UV had rather mundane and trivial uses, for example to enhance disco lighting and provide artificial tanning.

In reality there are a great many positive applications in science and industry; and it is now becoming clearer that exposure to UV has many negative implications for health, safety and the environment. Further, as the properties of this range of the electromagnetic spectrum are studied, the wavelength dependence of UV action on various biological and ecological systems is being revealed. It is clear that a great deal of work needs to be done to understand how much Solar UV (SUV) reaches the top of the atmosphere; how it interacts with the various layers of the atmosphere; how much bypasses the atmosphere and consequent effects on the land and in aquatic environments. Equally, more work is required to fully assess the impact of exposure to both SUV and Artificial Sources of UV (ASUV) in the workplace and in other human environments.

There is currently only very limited interaction between different UV measurement communities leading to different measurement methodologies. However, recent advances such as the European ultraviolet thematic network offer the promise of a consensus approach to UV metrology across the range of measurement applications.

Current measurements, for example, of UV spectral irradiance, are hampered by a calibration chain that ends with uncertainties that are of the order of 10% or more. This is largely due to the poor quality of transfer standards; it is not trivial to produce a source of UV whilst excluding the visible and infrared portions of the spectrum, much less trivial to produce one that is stable and uniform. To date the 'best' UV transfer standards have therefore been based on tungsten halogen lamps which emit a continuum from the UV to the infrared. The UV radiation emitted is only a tiny fraction of the total output of the lamp which often leads to a multiplicity of measurement difficulties.

In order to move forward, it is essential new uniform and stable sources of UV will have to be developed. Whilst there are ad-hoc talk shops amongst certain parts of the UV measurement community, the various methodologies used by the many different disciplines have not been systematically reviewed as they are not always fully described as part of the experimental procedure. On the whole, papers appear to be result-driven and the sources, components, accuracy, calibration and other important aspects of experimentation are not generally included. Thus comparisons between measurements and methodologies made, for example, underwater or for medical purposes are virtually impossible at this time. This is in part because the research areas are so disparate. It is the view of the authors that the discussions need to include all disciplines that use UV whether in science or industry and that a culture of openness in experimental methodology be encouraged. There should be more linkage between industry, pure science and metrology. Thematic networks and other discussion forums are one method to achieve this objective and they should be fostered and encouraged at every opportunity.

There are no simple solutions to improving UV metrology. Improvements in base scales at national standards laboratories and the introduction of 'best practice' methodology across the UV community can only address a certain range of problems. Major effort is still required to improve the stability and reliability of source and detector transfer standards for dissemination of UV scales. A lot of work is already underway in this area. However, it will be many years before UV transfer standards approach the quality of those available for the visible spectrum.

Ultraviolet Radiation : Current Instrumentation and Methodology

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ABSTRACT

The accurate measurement of ultraviolet (UV) radiation is of great significance in many areas of modern life. Environmental measurements of the UV component of sunlight is one area in which accurate UV measurements are of primary importance, since UV is known to be an agent that can cause damage to biological systems. However, as with all complex systems this is not the whole story. Many creatures use UV to ‘see’ and many plants have evolved with markings that are only ‘visible’ within this wavelength range, whilst in the human population, photoproduction via UV is the main source of vitamin D. Measurement of UV dosage for medical and cosmetic applications and the determination of exposure levels for industrial applications such as semiconductor photolithography are other examples that require accurate, stable and reliable measurement of UV radiation. This report aims to review the range of UV measurement instrumentation from hand held UV meters to large, monochromator based UV spectroradiometers. Environmental UV radiometers and calibration systems will be the dominant thrust of this report.

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1. ABOUT THIS REVIEW

1.1 Introduction

UV radiation is that portion of the electromagnetic spectrum that falls between the visible and vacuum ultraviolet regions (400 nm down to 200 nm). In everyday life the predominant source of exposure is the sun. The amount and type of UV reaching the surface of the earth depends on the output from the sun, which is known to fluctuate and various mechanisms within the earth's atmosphere. There are many academic and governmental groupings attempting to monitor Solar UV and in order to do this successfully, it is vital to have good calibration methodology and traceability back to the SI system of units.

Accurate determination of UV radiation exposure for medical, cosmetic and safety at work are other areas in which measurement of UV is important to avoid injury or illness. In these areas the expected UV dosage is generally comparable to typical solar UV levels, at least within an order of magnitude, and the instrumentation is often very similar to that employed to monitor solar UV.

The level of UV radiation in industrial processes such as curing of polymers, photolithography or sterilisation of water is usually several orders of magnitude higher than solar UV exposure levels. Industrial measurement systems therefore have to be much more robust and stable under UV irradiance levels of up to several watts per square centimetre. This review provides a background to the issues surrounding UV measurement science and investigates current techniques with a particular emphasis on solar UV measurements.

There are innumerable sources on ultraviolet (UV) and UV-related issues, from articles published in journals to items posted on the world wide web (www) [Grant (1998), Parson (1998)]. The main focus of this review is ultraviolet (UV) measurement techniques, but this is a huge subject with many overlapping areas, from the implications for the earth's biological and ecological systems, to the many uses of UV in everyday life. Information that might be necessary to aid understanding of some of the concepts (or that is simply of interest), but not immediately relevant is given in more detail in the Appendices.

1.2 UV Nomenclature

UV radiation (UVR) is arbitrarily subdivided into the part that reaches the surface of the earth UVA (400-320 nm) and UVB (320-280 nm) and that part which does not UVC (280-100 nm). The absolute boundaries of these ranges varies from discipline to discipline. Sometimes only that part of the UV-C that is transmitted through air will be included in that range, that is 280-200 nm [Diffey (1982 p2)]. The short wavelength end of the UV range seems to be a moveable feast, and there are a variety of different ranges and names for those ranges. According to Cowan the whole UV range extends from 380 - 1 nm, and ranges from shortward of 200 nm are called Near {200-100 nm}, Far {100-10 nm} and Extreme {10-1 nm} Vacuum UV (VUV) [Cowan (1981) p25].

Another name which appears in the (industrial/non-medical) literature is Deep UV (DUV), though apart from reference to the 254 nm line, a range for this name is not given. On the other hand, the Extreme Ultraviolet (EUV) seems to be different things to different people. According to researchers at the University of Berkeley in California this is the range 76 nm -5 nm [Antia et al (1998)], whilst researchers using the SOHO/SUMER satellite system provide 'The Solar EUV' spectrum over the range 160 nm - 79 nm [Brekke et al (1996)].

In the health and related literature, there are references to a variety of action spectra, in particular the *erythema action spectra* which has been the subject of much debate (see Appendix 1) the current working model has been provided by McKinlay and Diffey (1987) and is usually shown on a plot in the range ~240 - 400 nm [Diffey (1991)].

Section 1 References

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Grant, W. B (1998) *UV Bibliography*, to 1995 from GRANT@vaxine.larc.nasa.gov and 1995 to date online at sites such as <http://w3.osa.org/HOME/GENERAL/BIBLIO/uvb95.htm>

Parson, R (1998) *Ozone Depletion FAQ Part IV: UV Radiation and its Effects*, online at sites such as <http://www.cs.ruu.nl/wais/html/na-dir/ozone-depletion/intro.html>.

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Cowan, R.D (1981) *The Theory of Atomic Structure and Spectra*, University of California Press, ISBN 0520038215

Antia, B et al (1998) *EUV Astrophysics and the World Wide Webb*, online at <http://www.ncsa.uiuc.edu/SDG/IT94/Proceedings/Astronomy/antia/antia.html>

Brekke, P et al (1996) *The Solar Spectrum (790 - 1600D) from SUMER*, online at http://www.uio.no/~paalb/sumer_atlas.html

Diffey, B.L (1991) *Solar Ultraviolet Radiation Effects on Biological Systems*, Physics in Medicine and Biology, 36 (3) p299-328

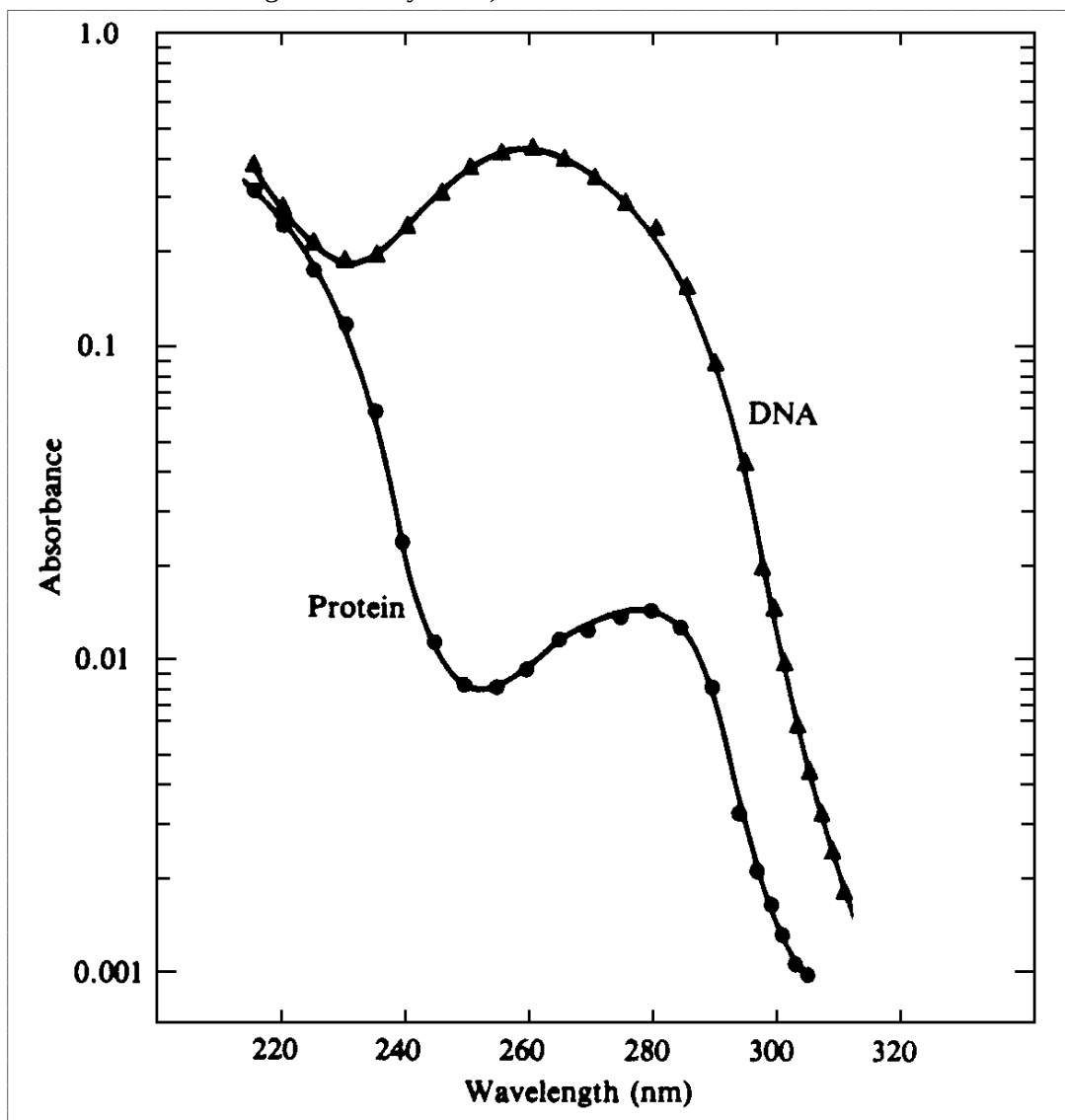
2. THE IMPORTANCE OF MEASURING SOLAR UV

2.1 Health, Ecological and Other Effects

Solar UV radiation has been a factor in the environment since the earth was formed. Life on earth has evolved many protection mechanisms to deal with UV radiation. However, increased exposure to UV radiation whether from changes in solar or atmospheric conditions or due to excessive sun bathing poses many risks. Typical effects of UV exposure on human health include increased levels of non-melanoma skin cancers, cataract formation and suppression of the immune system. Increased levels of solar UV can also lead to damage to terrestrial plant life and marine and freshwater aquatic systems.

UV-B is the most dangerous to life because the energies of these UV photons are comparable to the molecular bond energies in the Biosphere, hence the accurate measurement of the UV component of sunlight is important because of the harmful effects to life on earth, that is to biological and ecosystems. For example, absorption by DNA reaches a maximum at around 260 nm and causes damage to the nucleotide bases where the absorption occurs. [Diffey(1991), Harm (1980)]

Figure 2.1: From Harm (1980) p25 “Absorption spectra of DNA (calf thymus DNA) and a protein (bovine serum albumin), both at concentrations of 19.3 :g/ml” (courtesy Cambridge University Press).



This review will discuss the problem in terms of wavelengths. UV (and visible) photons have enough energy to excite electrons in atomic or molecular orbitals from their ground state to chemically reactive higher states. This absorption in biologically important molecules is extremely wavelength dependent, for example, amino acids such as tyrosine, phenylalanine and tryptophan (amino acids) and Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA). In addition, UV photons can 'sensitize' molecules which in turn excite a target molecule and via this photochemical interaction the unwanted UVB/UVC energy can be transferred to the nucleotide bases. [Cridland and Saunders (1994)]

Harm's plot of the absorption spectra of (non-human) DNA and protein, figure 2.1, is still widely reproduced in the literature. Harm explains that absorption of the photons in the range 240-300 nm in most proteins is significantly lower than in similar nucleic acid solutions. This seems to be because only a few amino acid residues of proteins are found to absorb measurably in this range. In figure 2.1 there appears an absorption maximum at ~280 nm for the proteins, increasing again below ~250 nm and it is thought these are due to tryptophan and tyrosine (which are not common), whilst the high absorption below ~230 nm seems to be due to absorption by the peptide bond. [Harm (1980) p25]

For further information and references, See Appendix 1

It should be noted from the 'positive' perspective, however, that many creatures use UV to 'see' [Silberglied (1979)] and a significant number of plants and insects, some birds and fish have evolved with markings that can only be seen within this wavelength range [Douglas et al (1989), Lutz (1933), Silberglied (1979)]. There is a great deal of work still to be done in these areas, in particular on the photopic environment of aquatic systems. Another well known 'positive' is the UV photoproduction of vitamin D.

For further information and references, See Appendix 2

An in-depth review of the effects of Solar UV (SUV) is beyond the scope of this review and can be found elsewhere, in particular Diffey (1991). For a good current overview of the molecular and cellular effects of UVA and UVB see Cridland and Saunders (1994).

References Section 2.1

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Diffey, B.L (1991) *Solar Ultraviolet Radiation Effects on Biological Systems*, Physics in Medicine and Biology, 36 (3) p299-328

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Cridland, N.A & Saunders, R.D (1994) *Cellular and Molecular Effects of UVA and UVB*, NRPB Didcot, HMSO

Silberglied, R.E (1979) *Communications in the Ultraviolet*, Ann.Rev.Ecol.Syst., 10, p373-398

Douglas, R.H; Bowmaker, J. K & Kunz, Y.W (1989) *Ultraviolet Vision in Fish*, In 'Seeing Contour & Colour', Eds: J. J. Kulikowski & C. M. Dickinson; Oxford Pergamon Press, p601-616

Lutz, F.E (1933) "Invisible" colors of flowers and butterflies; attempting to get a better idea of how things in this world look to its principal inhabitants, the insects, Natur.Hist., 33 p565-576

2.2 Solar UV Interaction with the Atmosphere

2.2.1 Solar UV and Ozone

It is impossible to review the effects of UV without discussing ozone. This story has two main parts:

- a) The first part deals with the discovery of the attenuation of Solar UV leading to the suggestion that atmospheric ozone was responsible for the observed absorption (this will not be dealt with in this review, but see the brief historical review at the end of Appendix 3).
- b) The second part is concerned with the theoretical mechanism for the ozone life-cycle [Chapman (1929)], which highlights the balancing act between positive and negative aspects of UV, since UV both **produces** ($130\text{ nm} < \lambda < 185\text{ nm}$ required [Chapman p104] to dissociate the O_2 molecules allowing the resulting oxygen atoms to combine with O_2 molecules to form ozone) and **destroys Ozone** ($230\text{ nm} < \lambda < 290\text{ nm}$ required [Chapman p107] to dissociate O_3)

The second part, on which this review will focus, is concerned with the depletion/destruction of ozone via anthropogenic mechanisms; and more recently with the role solar variability and other ‘natural’ phenomena might play in ozone variability over time.

The relationship between ozone and the fluctuating nature of solar UV will be discussed in Appendix 4, however that is not the only variable which complicates our ability to model its various effects on the biosystem. Certain types of pollution exacerbate the situation, as they can increase the amount of UVB that arrives the surface of the Earth by depleting the stratospheric ozone.

In addition to the damage caused by the UVB, its presence in the troposphere has resulted in ozone forming in the ‘wrong’ place [Devlin *et al* (1997)]:

“..Ozone is the principal component of photochemical air pollution and is formed when natural or man-made volatile organic compounds react with oxides of nitrogen in the presence of sunlight...Inflammatory injury as well as neurally mediated changes in lung function induced by high levels of ozone are thought to result mainly from the formation of free radicals...” [Devlin *et al* (1997)]

2.2.2 Other Interactions

Whilst most people would agree that the ‘ozone question’ is one of the key areas of UV research because the depletion of ozone could be catastrophic for life on earth; there are other, emerging, applications of UV measurement especially in the Atmospheric Sciences; some examples follow.

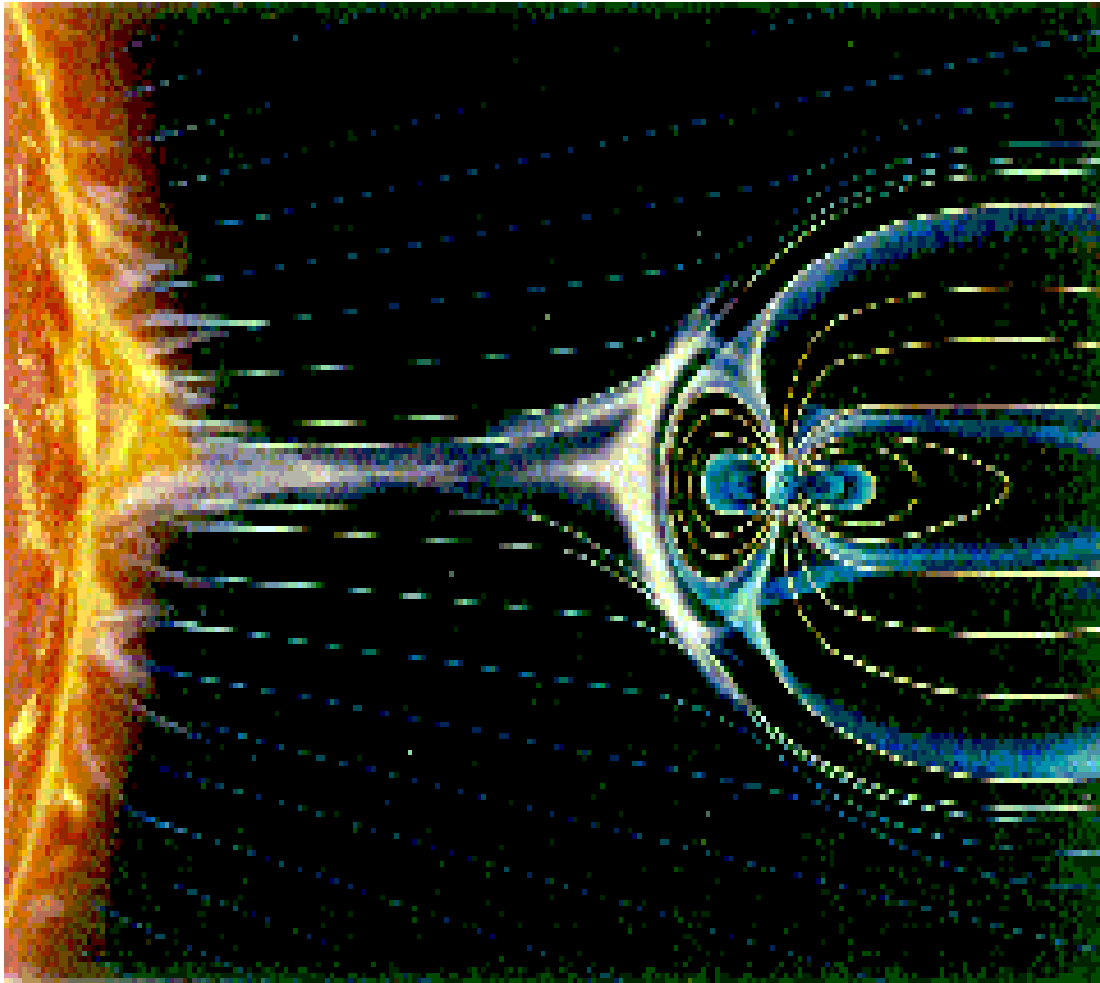
2.2.2.1 Global Auroral Imaging

“Aurora are part of what is now understood to be a complex structure of electric and magnetic fields, together with associated currents of charged particles, surrounding the earth...The principal structural feature in UV global images of polar regions from space is the auroral oval[(p138)]” [Huffman (1992)]

The aurora is the most visible manifestation of the sun-earth interaction, figure 2.2 is a schematic of the effect of the solar wind and solar magnetic field on the earth’s magnetic field.

In addition to the magnetic field effects, there are interactions between the atmospheric constituents and highly energetic electrons and protons which form part of the solar wind.

Figure 2.2: From Hathaway (1998) Schematic of the interaction of the sun and earth magnetic fields (US Government website)



Both polar regions exhibit these colourful features which appear in various moving ovoid shapes from space, altering in shape and intensity as the sun moves through the polar skies. The main feature, called the (northern) auroral oval is viewed from earth in the 300-400 nm wavelength range, other measurements have been taken by instruments flown on various satellites. This information is adding to the growing understanding of the behaviour of the earth's magnetic field and atmosphere and their respective interactions with the sun.

Ultraviolet measurements of auroral emission from space are called Global Auroral Imaging. Auroral imaging, airglow, fluorescence and other measurements are combined into a growing body of knowledge about global space weather systems, which when added to ground-based work, provide information on electron densities in the ionosphere, and improved knowledge of the behaviours of the thermosphere and ionosphere with respect to communications science [Huffman (1992)].

For an excellent overview see Robert Huffman's *Atmospheric Ultraviolet Remote Sensing*.

2.2.2.2 The Whitehouse Effect

More recently it has been recognized that the interaction of shorter wavelength radiation with anthropogenic aerosols has led to an increased planetary albedo in this part of the EM spectrum. This has been called the 'whitehouse' effect (compare with 'greenhouse' effect at longer wavelengths) and has two processes identified with it: [Schwartz (1996A)]

- "1 'direct effect' - enhanced scattering of shortwave radiation due to increased concentrations of aerosol particles in the clear (noncloud) air
- 2 'indirect effect' - enhanced cloud reflectivity resulting from increased multiple scattering in clouds containing higher concentrations of droplets owing to increased concentrations of aerosol particles that serve as nuclei for cloud droplet formation (cloud condensation nuclei . CCN)" [Schwartz (1996A) p362]

For further information and references, See Appendix 3

References Section 2.2

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Chapman, S (1929) *A Theory of Upper-Atmospheric Ozone*, Mem.Roy.Meterol. Soc., Vol III (26) pp103-126

Devlin, R.B et al (1997) *Health Effects of Ozone* Sci&Med, May/June p8-17

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Hathaway, D. H (1998) *Figure showing sun-earth magnetic field interaction*, On NASA Marshall Space Flight Centre website http://www.ssl.msfc.nasa.gov/ssL/pad/solar/the_key.htm

Schwartz, S (1996A) *The Whitehouse Effect - Shortwave Radiative Forcing of Climate by Anthropogenic Aerosols: An Overview*, J.Aerosol Sci. 27 (3) p 359-382

2.3 Solar UV Variability

One of the major problems facing the UV measurement community is the intrinsic variability of solar UV, a more detailed discussion of this important area of solar UV research can be found in Appendix 4. Lean's plot of spectral irradiance during solar cycle 21 (1976-1986) is reproduced in Figure 2.2. Though the sun's output at visible wavelengths behaves (strictly) like a Greybody, and is usually shown as in this figure, with the relevant blackbody curve, in fact, there are huge variations in the UV which makes it much harder to model.

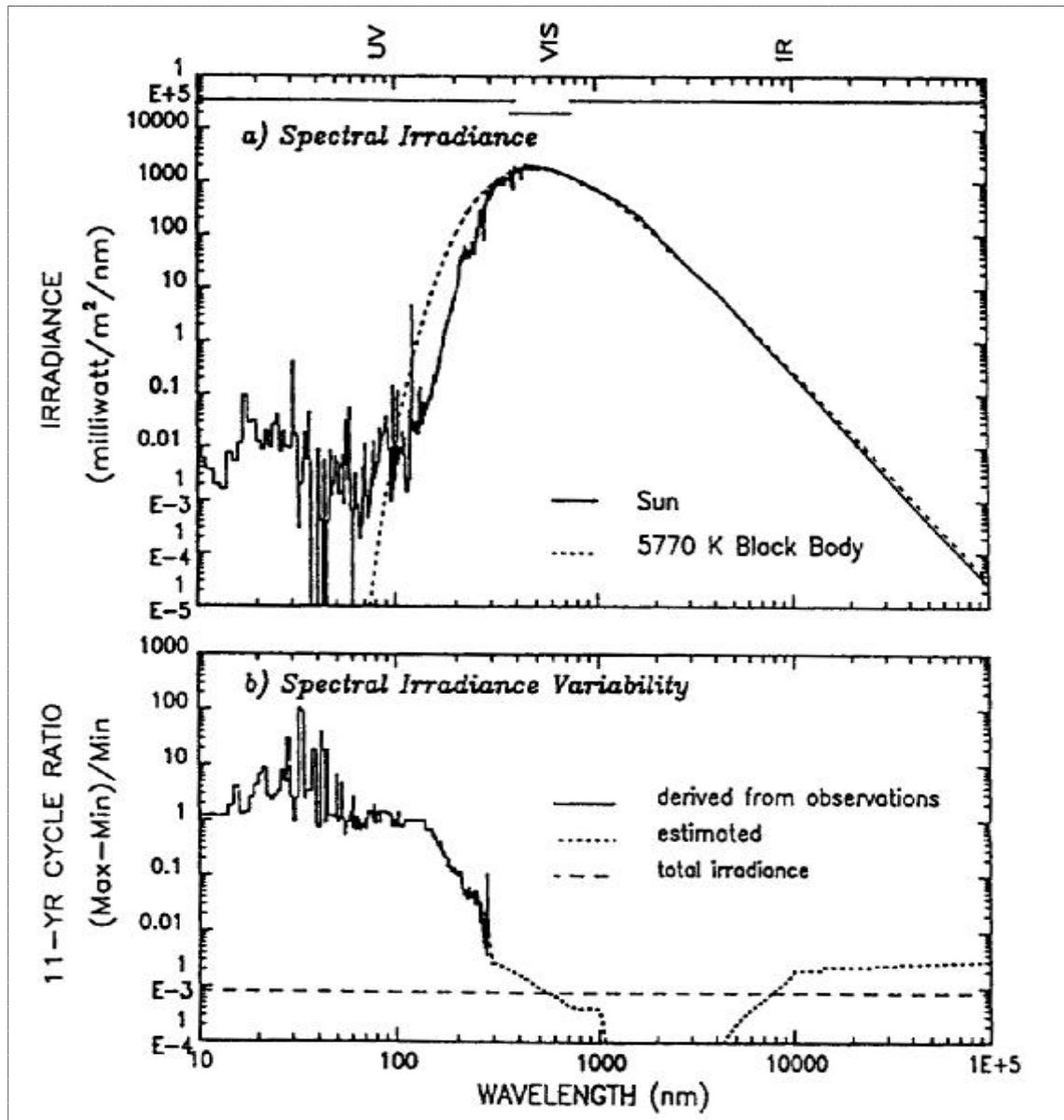


Figure 2.2: From Lean p506 '(a)..spectral irradiance typical of solar minimum conditions, compared with.. spectrum of BB at 5770K... (b) ..approximate amplitude of ..spectral irradiance variation from maximum to minimum of..11-year cycle...also shown....variations at $\lambda < 300$ nm (solid line)...derived from satellite observations during solar cycle 21....variations at longer λ (dotted line)...determined from knowledge of..solar cycle variation in the fraction of the Sun's disc covered with active regions and of their contrasts (Lean p514-5)...dashed line indicates variation during solar cycle 21 of total (spectrally integrated) irradiance.....' (courtesy Dr Judith Lean).

Whilst the lower plot is extremely helpful in that it shows the variability of spectral irradiance over a solar (half) cycle of 11 years, it is important to note that a) there is currently no evidence that there is such a thing as a 'typical' solar cycle (see figure Ap4.3 in Appendix 4 and discussion therein) and b) it is becoming clearer that health and ecological effects are wavelength dependent (for example DNA absorption is maximal at ~260 nm).

With regard to this latter point, what is required is spectrally resolved information on the amount of say ~260 nm solar radiation produced in different time frames (daily, monthly, annually, solar cycle etc) then seasonal and long-term **averages** might emerge. Information currently available is in ranges and averaged over one particular 11 year cycle, see table 2.1 adapted from Lean p509.

Table 2.1: From Lean (1991) [p509] Coupling between the Sun's Radiative Output and the Terrestrial Environment (courtesy Dr Judith Lean).

Spectral Band	11-Year Cycle Variation	Terrestrial Absorption Region	Absorbers
10-120 nm	2x to 10x	thermosphere, 150-300 km	O ₂ , N ₂ , O, N
Ly α , 121.6 nm	2x	mesosphere, 60-100 km	O ₂ , H ₂ O, NO, CH ₄ , CO ₂
125 - 175 nm	50%	thermosphere, 100-160 km	O ₂ /SRC (Schumann Runge Continuum - of O ₂ absorption spectrum)
175 - 205 nm	15%	stratosphere, 20 - 80 km	O ₂ /SRB, H ₂ O, HCl (Schumann Runge Bands - of O ₂ absorption spectrum)
205-250 nm	4%	stratosphere	O ₂ , O ₃ , HCl, CFC's
250 - 300 nm	0.5%	stratosphere, troposphere	O ₃ , H ₂ O ₂ , NO ₂ , ClONO ₂
300 - 400 nm	0.1%	troposphere, 0 -15 km	O ₃ , H ₂ O ₂ , NO ₂ , ClONO ₂

With the limited data currently available, it is difficult to make accurate long term predictions about the behaviour of the sun at UV wavelengths. Judith Lean's paper is an excellent overview as at 1991.

For further information and references, See Appendix 4

References Section 2.3

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Lean, J (1991) *Variation in the Sun's Radiative Output*, Rev.Geophys., 29 (4) p505-535

3. ARTIFICIAL SOURCES OF UV

3.1 ‘Artificial’ Sources of UV (ASUV)

Following Johann Ritter’s discovery of Solar UV in 1801, people began to develop artificial sources of this electromagnetic radiation (EMR) so that they could study its properties [Perkin (1910), Phillips (1983)]. Artificial sources of UV are still being developed and measured to increase this body of knowledge [ibid, Coaton (1997)], for example a press release in August of 1998 from the University of Central Florida reported the development of a new Extreme UltraViolet (EUV) source by William Silfvast, which will be used for EUV photolithography [Klein (1998)], see section 3.2.1 on industrial uses of ASUV.

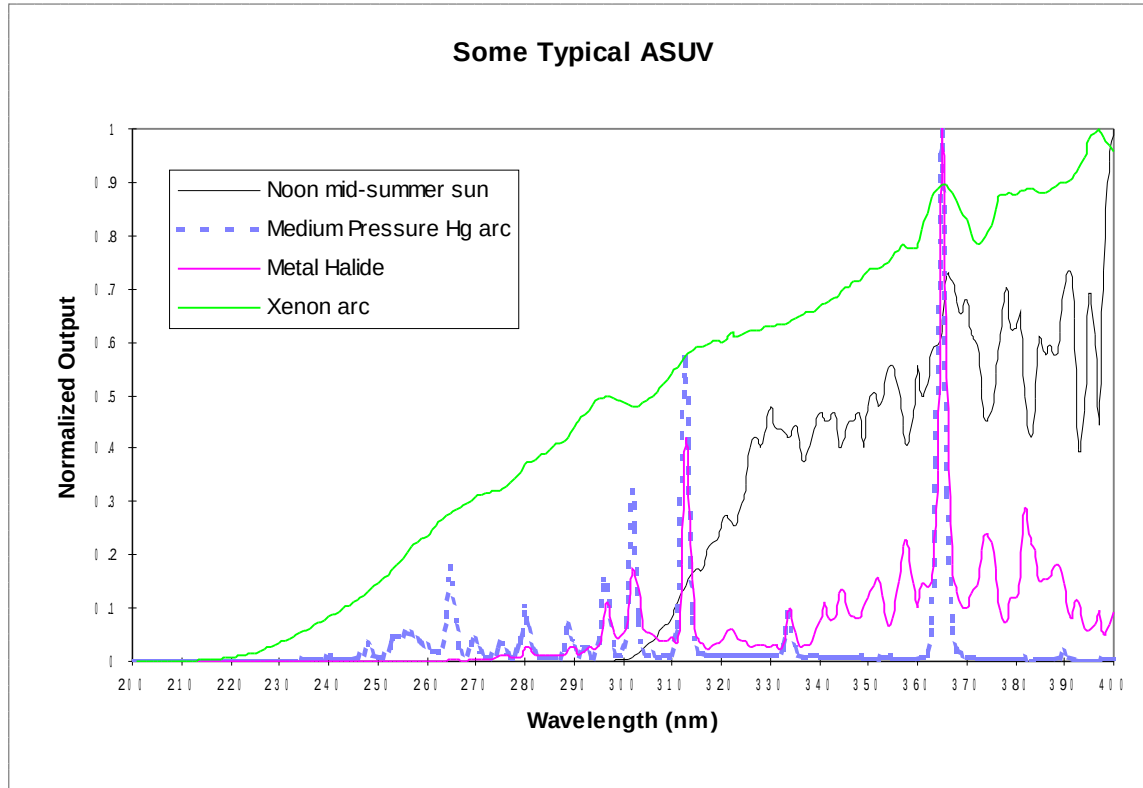


Figure 3.1: A selection of graphs of some state-of-the-art ASUV at 1997, showing normalized output against wavelength in nanometres. Also shown for comparison, is the noon midsummer sun. With thanks to Professor Brian Diffey (1997) for the data for this plot.

Artificial UV sources are used for ‘domestic’, industrial, medical and scientific purposes. ‘Domestic’ uses are generally modifications of the other three categories, hence they will not be discussed separately here. Some examples of domestic uses related to the other three categories are:

industrial modifications: *for example, lighting in general such as fluorescent lighting and ‘exotic’ lighting such as nightclub lights*

medical modifications: *for example sun tanning equipment*

scientific modifications: *for example domestic water sterilization units, fly {insect} traps*

Figure 3.1 is a plot of normalized output against wavelength in nanometres for some current state-of-the-art ASUV, the noon mid-summer sun is also shown. As there is already a lot of information in this figure, examples of Deuterium, Quartz Tungsten-Halogen and high pressure Mercury (Hg) lamps are shown separately in figure 3.2.

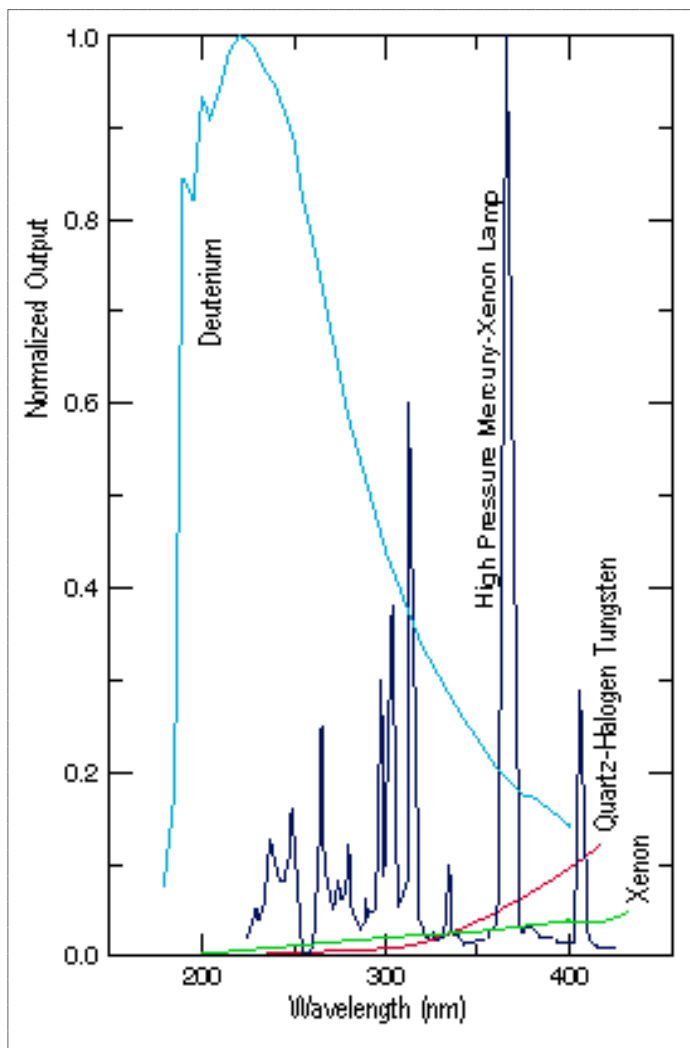


Figure 3.2: Deuterium, Quartz Tungsten-Halogen and High Pressure Hg graphs. Adapted from Ryer (1996) (courtesy International Light Inc).

Figure 3.3 is of photomedical lamps and the wavelength range is more detailed to emphasise the particular lines used in photomedicine.

As can be seen in these plots, most artificial UV sources have a significant amount of structure.

See Appendix 5 for a listing of types of ASUV and associated problems.

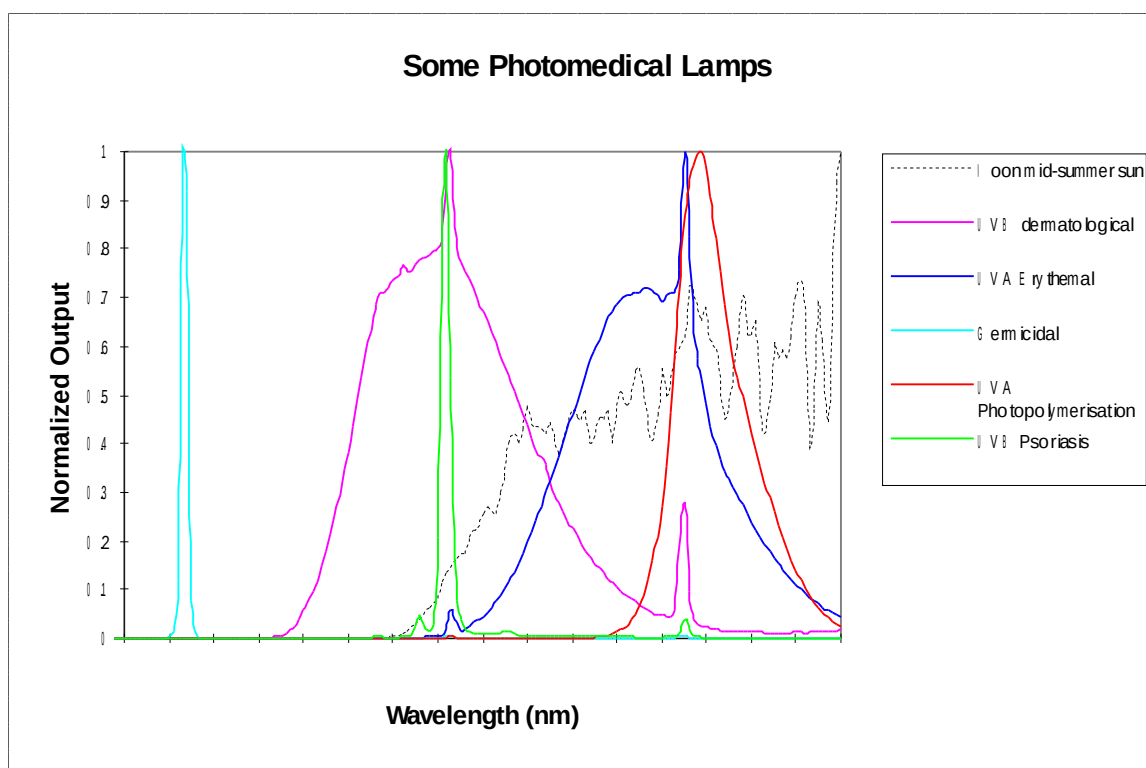


Figure 3.3: A selection of graphs of some photomedical lamps as at 1997. With thanks to Brian Diffey (1997) for the data for this plot.

3.2 ASUV Uses and Associated Hazards

ASUV are not simply found in remote laboratories, see table 3.1 for a guide to the applications of ASUV. Many people are regularly exposed to UV as a by-product of their work and some people are deliberately exposed during certain dermatological practices [Moseley (1988) p184]. Consequently ASUV must be studied to assess the hazards associated with their use [Bickford (1974), CIE (1987)]. Table 3.1 lists examples of some key ASUV and their (typical) applications; though it should be noted that the ASUV are generally only one component within (usually) highly complex systems.

Table 3.1: Applications of ASUV [Hamamatsu (1996), Philips (1998)]

Lamp	Envelope Material and Wavelengths 'range' (nm)	Applications
Deuterium	Fused Silica ~160-400 MgF ₂ ~115-400 Synthetic Silica ~160-400 UV Glass(0.4mm) ~185-400 UV Glass(0.8mm) ~185-400	Chromatography, Fluorospectrometers, SO _x , NO _x , NH ₃ analyzers, UV standard light source
Deuterium Pulse-driven	not given	Background correction in atomic absorption analysis
Deuterium (Water cooled, Vacuum)	MgF ₂ ~115-400	Excitation light source, Fluorospectrophotometers, Photo CVD (Chemical Vapour Deposition), Spectrophotometers
Hollow Cathode Elements made from Aluminium to Zirconium	Spectral lines depend on element. From 193.7 nm to 852.11 nm	'Most widely used method of measuring minute amounts of metals present in a material' (ie atomic absorption {AA} analysis) [Hamamatsu (1997) p15]
Galvatron (see-through hollow cathode lamp)	often bespoke	laser stabilization
High Pressure Mercury Xenon	Fused Silica ~185-2000 Ozone-free Silica ~220-2000	Blood analyser, Fluorescent microscope, Interferometer Microfilm enlarger, Refractometer, Semiconductor annealing, UV curing for epoxies
Medium Pressure Mercury	Various Mercury lines, in particular the 254.07 nm line	Drinking and waste water disinfection
Low Pressure Mercury	Silica (ozone generating) Vycor (ozone free) Various Mercury lines, in particular the 254.07 nm line	Chromatography, Climatological testing, Germicidal, Fluorospectrophotometers, Insect traps, Ozone generators Sterilizing lamps (disinfection); Testing, inspection and analysis of food, Textile industry, Water pollution analyzers, Wavelength calibration for spectroscopy
Metal Halides	Depends on additive used	Blacklight blue applications (with filter), Episcopy, Fibre Optics, Fluorescent displays, In and outdoor filming, Professional photography, Solar simulation; UV curing of glue, resin and pigmented lacquer
Tungsten Quartz-Halogen 1000 Watt	~280 nm->	Calibration Standards
Tungsten Quartz-Halogen	~280 nm->	Domestic, Commercial and Industrial Lighting
Xenon 'Continuous'	Fused Silica ~185-2000 Ozone-free Silica ~220-2000	Blood Cell Counters, Chromatography, Colour analyzers, Colorimeters, Densitometers, Fibre optics, Fluorospectrophotometers, Microscope light source, Photochemistry, Projection systems, Solar simulation, Spectrophotometers
Xenon Flash Mode	Borosilicate ~240 - 2000 Synthetic Silica ~160 - 2000 UV Glass ~185-2000	Chromatography, Colour analyser, Fluorospectrophotometer, Stroboscopes, Photoacoustic spectroscopy, High-speed cameras, Photomask source SO ₂ analyzer

See Appendix 5.4 for definitions of some of the more unfamiliar terms.

In addition to the requirement for safe-practices of direct usage of ASUV in the workplace, it is important to identify any UV produced indirectly as an unwanted but possibly unavoidable by-product of a lamp or industrial procedure - such as arc welding [Bennet & Harlen (1980)]. Effects of ASUV on the skin and eyes (in particular) have been researched and reported [ibid, Berral (1982)]. Again, with regard to positive and negative effects, the irony is that whilst the damaging effects of UV on the skin are well known, UV phototherapy is still the treatment of choice for a number of skin conditions. [Diffey (1982) Chapter 6]

3.2.1 Industrial Uses and Hazards

Two major direct uses of ASUV in industry are in photolithography and sterilization - especially of water, these will be described as examples.

3.2.1.1 Photolithography

The word photolithography is derived from the Greek for light (*phos*), stone (*lithos*) and the verb 'to write' (*graphein*), and is a modern variant of lithography, which was invented by Aloys Senefelder in the 1790's. Photolithography is the process by which integrated circuits are produced on the surfaces of semiconductors. Masks (essentially electromagnetic radiation filters) are produced by etching the desired pattern of circuitry through them (cut out) or fashioning the filter so that only the areas containing the circuitry pattern is not opaque to the EMR being used. The 'curing' radiation is directed through the mask onto the surface of a semiconductor wafer which has been coated with substances which undergo a photochemical reaction (in this case, they harden) when exposed to the particular radiation being applied. The residual 'un-cured' substance is then removed by placing the wafer into an acid bath.

Improvements in the technique have been achieved by moving from visible to UV, to electron beams and more recently to X-rays; that is, to shorter and shorter wavelengths in order to produce ever smaller patterns. This increases the amount of information that can be stored on the surface of the semiconductor 'chips'. In an article in May 1998, Katherine Derbyshire (1998A) of Semiconductor Online stated that whilst there have been new achievements in the so-called Deep UV (DUV) at 248 nm {features printed ~100 nm (1998B)} and 193 nm {features printed ~80 nm (1998B)}; the trend is away from 'optical' photolithography and towards even shorter wavelengths with competing technologies being EUV at 13 nm, proximity X-ray at 10 nm, scattering with angular limitation projection electron-beam (no wavelength quoted) and ion beam projection (no wavelength quoted).

Figure 3.4: From Derbyshire (1998C) Researchers at Sematech. {Courtesy Semiconductor Online News}

Of these, EUV has already moved into the lead by a) developing a multi-mask method that goes a long way towards overcoming the problem of the inherent absorption properties of known optical materials at such short wavelengths; and b) the announcement of a new, small and cost-effective EUV source [Klein (1998)]. The hazards associated with this work are dealt with by clothing the workers from head to toe in UV resistant outfits and masks and the photo-etching process itself is conducted behind UV resistant barriers, see figure 3.4.



3.2.1.2 (Water) Sterilization

Whilst micro-organisms found in water are not all harmful, a great many are (including some algae, bacteria, moulds, nematode eggs, viruses and yeasts) and these need to be removed in some way to render the water safe [Gadgil (1998), Dalecomb (1998), UVTA (1998), Visa UV-Technologie (1998)]. The deaths of over 400 children per hour in the developing countries are directly attributable to waterborne diseases, for example; cholera, dysentery, gastroenteritis, hepatitis and typhoid [Gadgil (1998)].

The preferred method is to use the germicidal properties of UV-C. The water is irradiated using low pressure mercury vapour lamps since ~90 % of the EMR produced by these sources is in the 254.07 nm spectral line. As a consequence, the DNA and RNA bases of the micro-organisms absorb the UV-C and are photochemically altered so that the micro-organisms can no longer reproduce.

Figure 3.5 from UVTA (1998) is a plot of relative germicidal effectiveness against wavelength. In this field of UV work, the UV-C is often defined as the range 100 nm - 280 nm and called 'the germicidal band'.

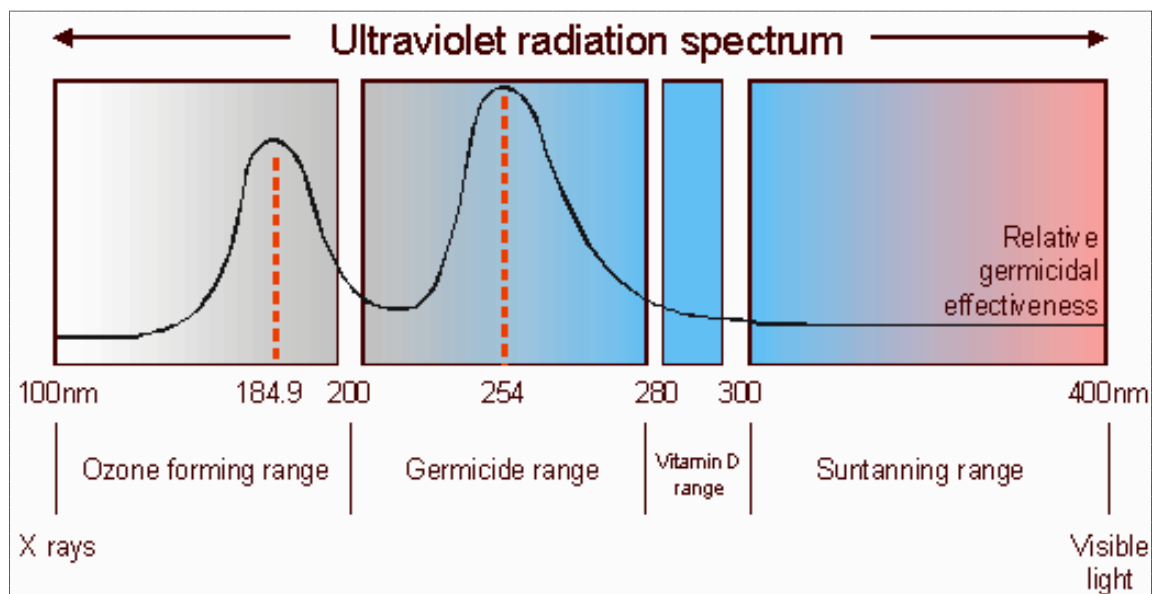


Figure 3.5: From UVTA (1998) showing Relative Germicidal Effectiveness against wavelength. Ozone forming, vitamin D and erythral (sunburning) ranges are also indicated. Figure produced by Tony Gardner, Managing Director UVTA, and reproduced with permission.

The germicidal lamps used are fabricated using the same basic technology as for the standard fluorescent lamp, with two key alterations. The phosphor coating on the glass tubes that protects office workers from UV (it emits in the visible and absorbs in the UV) is not used; and the tubing itself is constructed of quartz crystal since ordinary glass absorbs UV. Additional quartz tubing is used as a thermal shield to ensure the lamps are kept at temperatures required for maximum UV-C production.

The water is brought into contact with the UV-C in a chamber containing the lamp/s - which will depend on the size of the body of water being treated. Figure 3.6 is a photograph of the Center for Building Science (CBS), Lawrence Berkeley National Laboratory (LBNL), Indoor Environment Program's UV Waterworks water-disinfection unit and Figure 3.7 is a schematic of the basic closed system type, where the lamp is enclosed in a cylindrical tube. The water is circulated for the appropriate 'dwell time' necessary to reach a high kill rate of the micro-organisms that have been found to be present in that body of water. Maximum effectiveness can only really be achieved by 24 hour running [Dalecomb (1998)]. Open channel systems are also used.

Figure 3.6: From Gadgil (1998): The UV Waterworks water-disinfection unit, with a plastic cover and cutaway reflector revealing its interior. Municipal tap water is uncommon in many developing-country households. To address the significant public health and energy problem, an effort is underway at the CBS, LBNL Indoor Environment Program to introduce a water-purification system using ultraviolet light to rural villages in India, Mexico, and South Africa. The goal of this project is to design and field-test a water-purification device for developing countries that is durable, easy to use, and inexpensive and can be constructed and maintained locally. It has resulted in the development of a prototype device called UV Waterworks. (US government website)

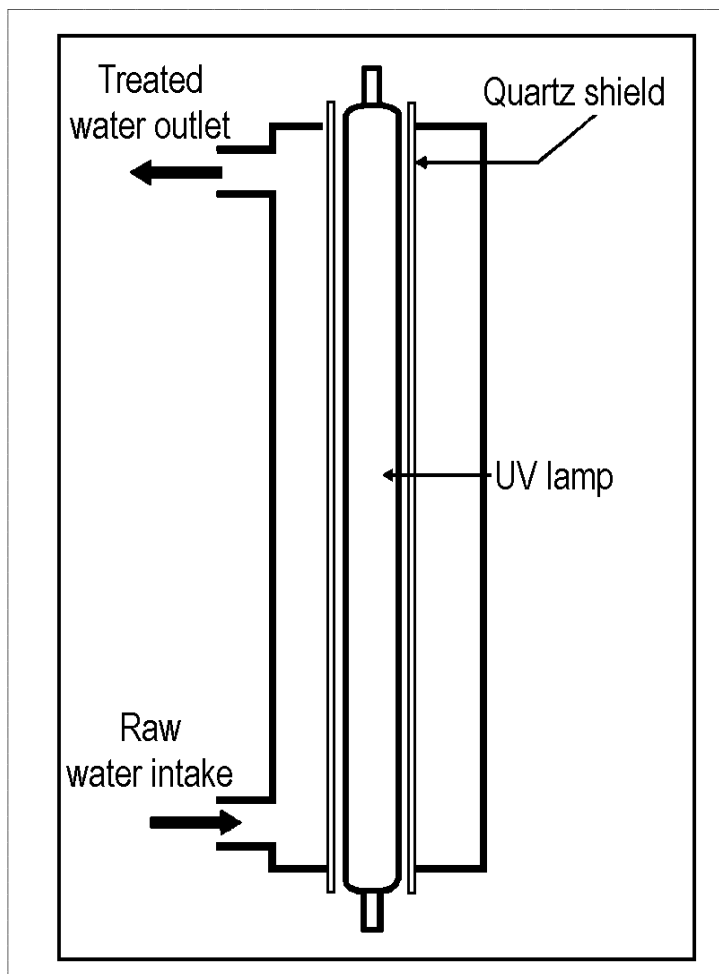
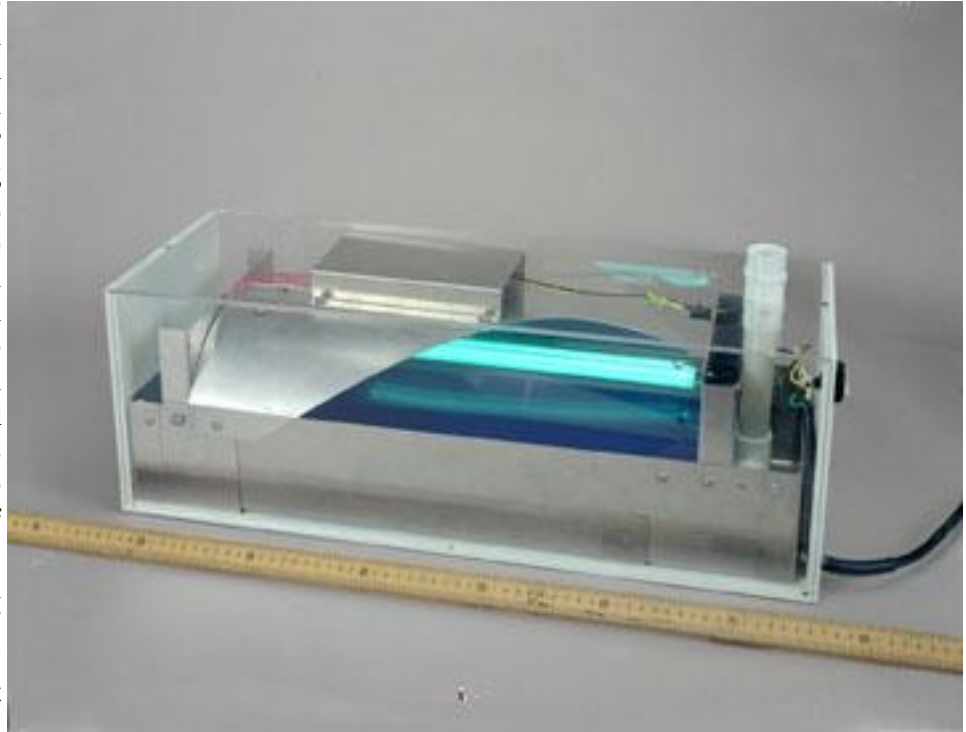


Figure 3.7

From Degrémont (1991) [p912]
Closed-type UV-reactor (Courtesy Degrémont)

The UV 'dosage' is measured in microwatt seconds per square centimetre (Ws.cm^{-2}) and the following are some of the factors that need to be taken into account in order that the sterilization process be effective [Dalecomb (1998)]

Micro-organism size: *Larger organisms require higher dosages*

Lamp Power: *Lamp wattage is related to flow-rate of water through the sterilization unit*

Contact/dwell time: *Also related to flow-rate of water through the sterilization unit*

Temperature: *UV-C output is related to the operating temperature of the lamps*
($40^{\circ}\text{C} < \text{UV-C}_{\text{max}} < 43.3^{\circ}\text{C}$)

Other key considerations are the lamp diameter and the diameter of the water tube in which the lamp is located. The effect of the UV treatment falls off with distance $\sim \text{Effect vs (distance)}^{-2}$, so that the water furthest away may be less irradiated. [Goodman (1999)].

Table 3.2 indicates typical UV-C dosages corresponding water flow-rates required according to Dalecomb (1998). UVTA's dosage figures are given as ranges, for example, for bacteria they give the range 2,500 - 26,400 Ws.cm^{-2} , however they do not quote the corresponding water flow-rates required.

Table 3.2: UV-C dosage and corresponding flow-rate required to eliminate typical micro-organisms. Information from [Dalecomb (1998)]

Micro-Organism	UV-C Dosage (Ws.cm^{-2})	Water flow-rate in gallons per hour
Viruses & Bacteria	15,000	1000
Pond Algae	30,000	500
Fungi & Protozoa	45,000	333.33

Operator or public hazard due to the sterilizer is minimized by enclosing the unit in UV-absorbing materials.

To underscore the point made at the beginning of this section regarding the use of the ASUV within a system it should be noted that whilst the manufacturers of these systems are fulsome in their praise, this process is not without limitations.

"UV..is suitable for the disinfection of supplies which are free from suspended matter, turbidity and colour....The UV penetration depends upon the quality of the water and is highest in waters with very low colour, little dissolved iron and manganese and of a high and consistent clarity. It is best suited to groundwaters which require disinfection only....use is bound to be limited since it cannot act as a substitute for ozone to assist in the reduction of organics in a partially treated water..and it cannot provide a residual disinfectant" [Twort et al (1994)]

However, what Twort et al., do not say is that ozone is a highly dangerous pollutant, which can enter the body via the airways and once there will react extremely quickly with biomolecules to form free radicals [Devlin (1997)]. The cost-effectiveness of safety procedures for the ozone method may prove prohibitive for poorer countries.

3.2.1.3 Industrial Processes as Indirect Sources of UV Hazard

Two key examples of indirect and unwanted sources of ASUV. The first is of an industrial process, arc-welding and the second deals with ambient lighting conditions in offices and factories.

UV hazard from welding - from Bennet and Harlen (1980): "The principal damaging effects of UVR

are keratitis and conjunctivitis ('arc-eye') to the eye and erythema ('sunburn') to the skin. Close proximity to an open arc is a necessary feature of many welding operations, for which complete shielding of the arc is often impossible (p541).....Other personnel could be at risk up to distances of 30 m, unless individual work stations are screened or eye protection worn (p549)".

UV hazard from fluorescent lights: -from Beral et al (1982): "In a study of 279 women aged 18 to 54 years with malignant melanoma and 549 matched controls in New South Wales, Australia, reported exposure to fluorescent light at work was associated with a doubling of melanoma risk...the risk increased with increasing duration of exposure to fluorescent light... and was higher in women who had mainly worked in offices...than in women whose main place of work was elsewhere".

3.2.2 ASUV and Medicine

ASUV are used directly for their photomedical qualities and as sources in a variety of scopes and other instrumentation.

3.2.2.1 Direct Medical Applications

According to Diffey (1982) "It is difficult to summarise the current status of ultraviolet radiation in medicine; its use in physiotherapy has certainly diminished in recent years, but the combination of ultraviolet radiation with photoactive drugs is now the treatment of choice for many skin diseases" [p108].

For a comprehensive account of UV in medicine, see Diffey (1982).

3.2.2.2 ASUV in Medical Equipment

Whilst lamps with a UV component - especially Xenon seem to be widely used, it is not easy to obtain information on whether any of the UV component is used or filtered out in some way. Fibre optics with 300W and 150W Xenon lamps are advertised as being used in the following applications: Arthroscopy, Cardiovascular medicine, Dentistry, ENT, Gynaecology, Ophthalmology, Plastic surgery; amongst others.

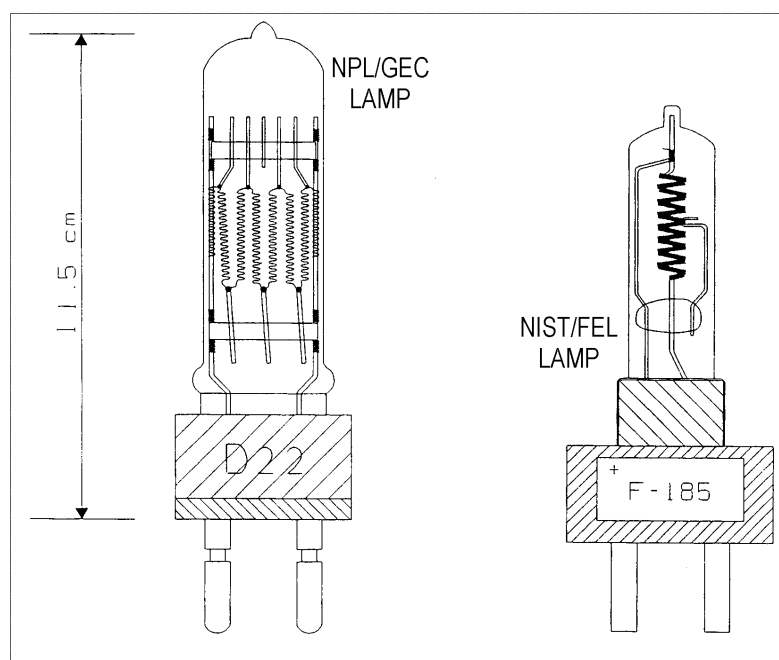


Figure 3.8: From Walker et al (1991) [p649] showing lamps used in the 1991 intercomparison of spectral irradiance measurements by National Laboratories.

3.2.3 Scientific Uses of ASUV

There is some overlap in each of the three categories chosen (industrial, medical and scientific). Since this review is concerned with the measurement of UV itself, the reader is directed to table 3.1 for a listing of the most common scientific/industrial uses.

The principle scientific use dealt with here, will be calibration standards, in particular for use by the SUV measurement community.

3.2.3.1 Lamps as Standards

QUARTZ TUNGSTEN-HALOGEN LAMPS

Although tungsten- halogen lamps produce a negligible amount of UV [Coaton (1997)], they are currently the lamp of choice for calibrating SUV measurements. This is generally because using a lamp that has a similar intensity and spectral response (blackbody) to the sun reduces the assumptions that would otherwise have to be made regarding instrument linearity and stray light. Whilst a filtered Xenon lamp would match the solar output more closely, they are not sufficiently stable for this work. Deuterium lamps are sometimes used with or without the tungsten halogen lamps. [Webb {Ed} (1997)].

Figure 3.8 is a schematic of two types of these lamps, which have been used as irradiance standards, a NIST/FEL standard and an NPL/GEC standard; (NB: the NPL/GEC standard is no longer manufactured). The latest design of FEL standard lamp has the central filament support removed to improve irradiance uniformity.

However, quartz halogen lamps are known to have the following shortcomings.

- 1 They are fragile and often do not survive transportation, however well they may have been prepared for transport.
- 2 They suffer from coil collapse, sometimes unpredictably, but usually after ~150 switchings
- 3 They are prone to sudden, unpredictable and irreversible changes when powered up or down.

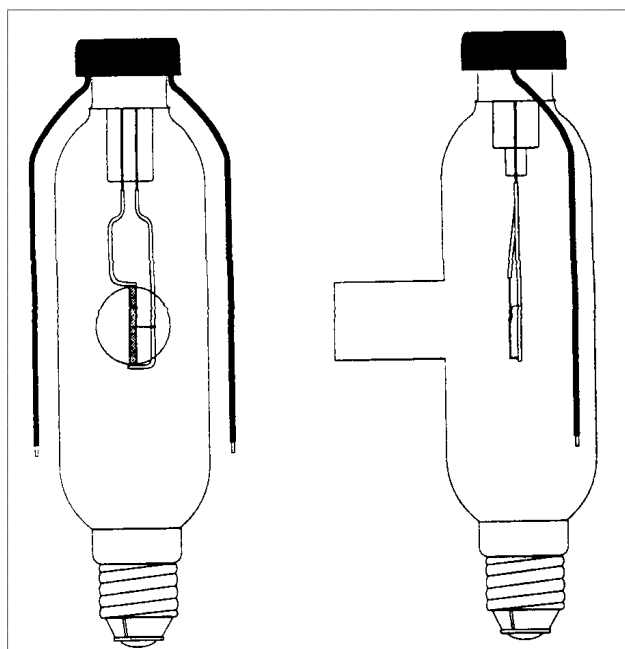


Figure 3.9: From Lambe (1997) Ribbon filament radiance standard lamp

The ribbon filament radiance standards shown in figure 3.9 are normally operated cap down with the filament in a vertical position. The protrusion shown locates the plane window which is used to allow good optical imaging. Calibration is performed about an horizontal axis the location of which is indicated by a pointer adjacent to the ribbon or notch in the ribbon itself.

The spectral radiance of these lamps is calibrated against the NPL high temperature black body.

The SUV measurement community purchase secondary irradiance standard lamps from standards laboratories such as NPL and NIST and these are used to calibrate their instrumentation see the example in figure 3.10.

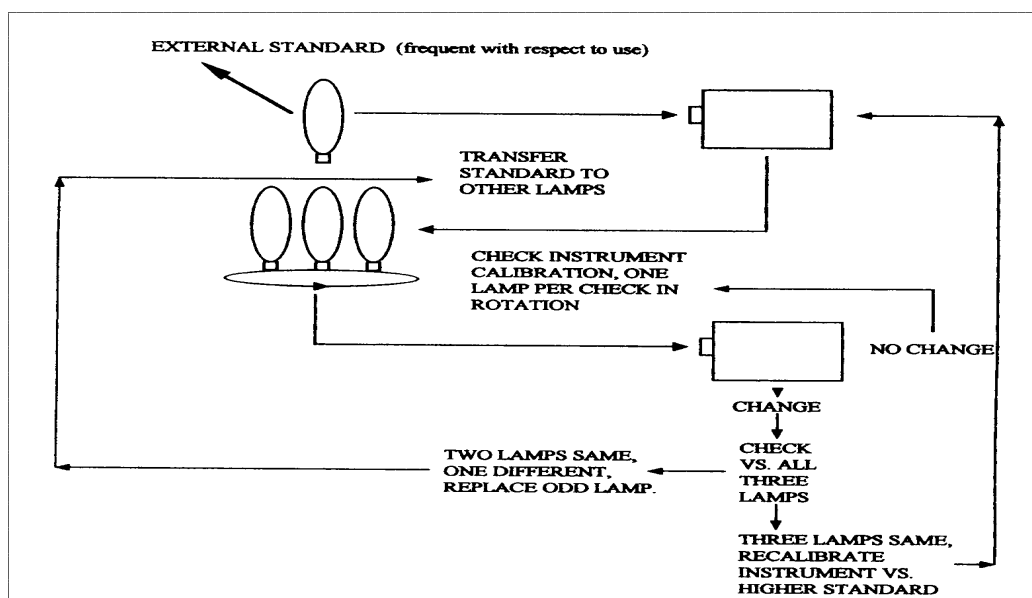


Figure 3.10: From Webb (1997) [p34] “On-site calibration procedures. If several working standards are available the complete procedure can be employed as illustrated. The single reference lamp shown may itself be one of a suite of three (or more), and several hierarchical suites of lamps may exist at one site allowing multiple levels of lamp check on-site. When only one lamp is available on-site it must be frequently checked against an external higher lamp standard.” (Courtesy Gordon & Breach Science Publishers)

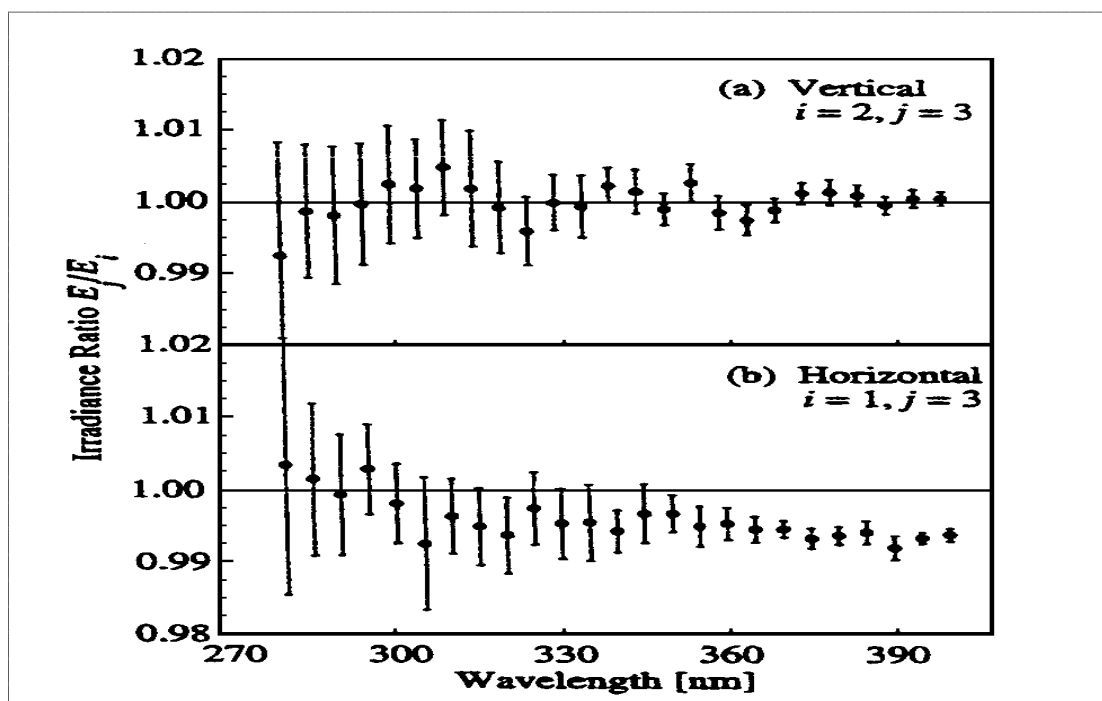


Figure 3.11: From Early and Thompson [1996 p150] “Irradiance ratio E_j/E_i between days as a function of wavelength for lamp OS-27 in the a) vertical and b) horizontal position. The days used in the ratios are given by the indices i and j . The vertical bars indicate the expanded combined uncertainty (coverage factor $k = 2$) of the ratios without including the uncertainty component arising from the alignment of the lamps.”

Another problem is that many users of calibrated FEL lamps use them in a horizontal plane as opposed to the vertical plane in which they were aged or calibrated. In a more recent paper from NIST [Early & Thompson (1996)] the authors discuss the problems associated with orientation of 1000 W standard lamps.

Standard lamps are 'burnt in' or seasoned with their filaments in the vertical position. However, most SUV instrumentation - for obvious reasons - normally face upwards. This has meant that researchers either had to use the lamps in the horizontal position - not to be recommended since the spectral output of the lamp will not be the same in both positions - or the researchers might consider re-orienting their measuring instrument for the calibration procedure. Even if this is physically possible, it is inadvisable. Since primary standard lamps seasoned in the horizontal position are not currently available from standards laboratories, an intermediate solution is to use a flexible light guide [Webb (1997)].

Early & Thompson attempted to address this problem in 1996, by calibrating two lamps in the horizontal position, using an integrating sphere to measure to rotate through 90° to view a lamp in both horizontal and vertical positions and using a lasers to align the positioning of both lamps. Their results are shown in figure 3.11 and they concluded that the irradiance of the lamp in the horizontal position was less than that of the vertically positioned lamp by ~6-12% .

For further information and references, See Appendix 5

References Section 3

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4. ORGANIZATIONS MONITORING UV

4.1 Measurement communities

Refer to Appendix 6.1 for a listing and for acronyms used in this section. There are a great many people involved directly or indirectly in measuring solar UV from above and below the earth's atmosphere. These include;

- | | |
|---------------------------------|---|
| <i>Academics</i> | <ul style="list-style-type: none"> a) Working in Educational Institutions who are simply interested in learning more about the subject and increasing the body of knowledge b) Working in quasi-educational/commercial institutions such as National Standards Laboratories who are required to consider both the academic and commercial aspects of their research |
| <i>Government</i> | NASA, ESA, SRRB (NOAA), BAS, WMO for example through 'Agencies' politicians who set up such agencies to 'do science' for national and world advancement and in this case, to monitor this aspect of 'the environment' since public awareness has raised the profile of such matters on political agendas. |
| <i>Commercial Organizations</i> | Academics are generally unable to make the items required for their research, because of the prohibitive costs of both the raw materials and machinery required. As a consequence, there is a growing linkage between commercial companies and academic institutions, a symbiosis whereby the academics might suggest or sell an idea to the companies, who in turn make the cutting-edge products the academics require. The rationale being that the companies can then develop other more generalized and profitable products from these developments. For example yesterday's UV filters to tomorrow's sunglasses. For good examples of this, see 'Solar Light' in the section on Commercial Organizations later. |

Since the sun is the main source of natural UV radiation and since the earth's atmosphere either attenuates or blocks that radiation, measurements are taken above and below the atmosphere, so they can be compared.

Modelling the atmosphere is not trivial, however, there are many mathematical and computer based models being developed (these will not be described here as they are beyond the scope of this report). These models are then used to 'subtract' the atmospheric effects from data taken at the earth's surface and the results compared to the above-atmosphere data. In this way, it is hoped to establish how much UV is getting through the atmosphere.

The key players in UV tend to get involved in most or all of the types of measurement - whether by direct involvement (doing the measuring and writing it up) or by committee (talk shops and ad-hoc organizational structures). See Appendix 6.2 for a discussion on key players. NB: The phrase 'Key Players' refers to people whose name appears in multiple contexts, and whose work is most cited). Major groupings are given a more in-depth treatment in the Appendices.

4.2 Thematic Networks

These may be ongoing conferences or one-off workshops. They can be ad-hoc or formalized through academic or government institutions. They usually generate papers and or discussions on how to proceed. For example, The European Thematic Network for Ultraviolet Measurements held its first workshop in Finland in March 1998. There were oral presentations, posters and excursions to relevant academic sites. Four working groups were set-up to deal with problems identified within UV measurement science.

Group 1:	Leader: A. Gugg-Helminger Gigahertz-Optik Germany	<i>Guidance for UV power meter classification for particular applications</i>
Group 2:	Leader: Jürgen Metzdorf PTB Germany	<i>Improvement of measurement and calibration methods for spectrally resolved UV measurements</i>
Group 3:	Leader: Nigel Fox, NPL, UK	<i>Improvement of measurement and calibration methods for spectrally weighted UV measurements</i>
Group 4:	Leader: Harry Moseley University of Dundee	<i>UV measurements related to health and safety</i>

From minutes of the first workshop in Espoo, Finland, produced and circulated by Petri Kärhä, dated 5th June 1998.

For further information and references, See Appendix 6

References Section 4

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

5. FORMALIZING UV MEASUREMENT

5.1 Radiometry

5.1.1 Realizing Scales in UV Measurement

The watt is the radiometric base unit and realizable by a number of different methods; such as, primary sources (blackbodies and synchrotrons):

“..the term primary meaning the equation of state can be written down explicitly so that the quantity of emitted radiant flux can be calculated using a physical law, requiring only the measurement of parameters independent of radiant output. Primary sources, do not, therefore, require calibration against any other radiometric standard”
[Fox (1996) p536]

Calculable detectors are a practical (and simple) and lower cost method of realizing the primary optical scales and the two principle techniques use thermal detectors:

“..scales use the electrical substitution principle and vary only in the type of temperature sensing element used to detect the temperature rise, eg pyroelectric, thermopile or bolometer. These realizations can be further subdivided as operating at either ambient or cryogenic temperatures” [ibid]

or photon detectors:

“..scales use solid-state-physics modelling, commonly called the self calibration technique, to predict the response of photodiodes. In this technique, a number of measurements may be performed to calculate the quantum efficiency of the device, ie the number of charge carriers reaching the sensing electrical circuit per photon ..However, the technique was limited to...400 - 900 nm and lost favour ..further development ..unlikely to challenge the ultimate achievable accuracies of the cryogenic ESRs.” [ibid]

However, the same author with others, describes a detector based spectral irradiance scale centred at 358 nm using a combination of filter radiometers and lasers as follows. If the spectral responsivity of the filter radiometer (fr) and the relative spectral radiance of the source are known, then the absolute radiance at any wavelength within the bandpass of the filter radiometer can be calculated using equation 5.1 [Hartree (1996) p519]:

$$L(\lambda_1) = \frac{I}{s(\lambda_2)\tau_g \int_0^{\infty} L_r(\lambda)s_r(\lambda)d\lambda} \quad \text{Units: W.m}^{-2}.\text{sr}^{-1} \quad \text{Equation 5.1}$$

Where:

L(8₁) is absolute radiance at **8₁**,
s(8₂) is fr responsivity at **8₂**,
I is the signal from the fr,

L_r is relative radiance normalized to unity at **8₁**
s_r is fr relative response normalized to unity at **8₂**
J is transmission of the lens

g is a geometric factor denoting the proportion of radiation from the source which passes through both lens and detector apertures, and is a function of the aperture radii and the distance between apertures

A point on the UV spectral-radiance scale was defined by the authors in 1995-6 with an uncertainty of 0.7%. More recently, Fox et al (1998) have established a new primary UV spectral responsivity scale (200 - 400 nm) with an uncertainty of less than 0.5% which is maintained on Gallium Arsenide Phosphide (GaAsP) detectors traceable to the NPL cryogenic radiometer.

5.2 UV irradiance scales

While UV spectral responsivity scales have been linked to a cryogenic radiometer and have been established with uncertainties of less than 1%, spectral irradiance scales currently have scale uncertainties of several per cent. In practise spectral irradiance is much more commonly used in the UV measurement community than spectral responsivity. Hence, measurement uncertainties at the end of the calibration chain are typically in the region of 10%+ (although published estimates are usually a factor of two or more lower!). A major factor in the uncertainty figures is the poor quality of UV spectral irradiance transfer standards. In 1991 Walker et al gave the results of the intercomparison of spectral irradiance measurements by National Laboratories as agreed at the September 1986 meeting of the CCPR (Comité Consultatif de Photometrie et Radiometrie) of the Comité International des Poids et Mesures and subsequently carried out over the period 1987-1990. National Laboratories from twelve countries participated and are listed in Appendix 5.5

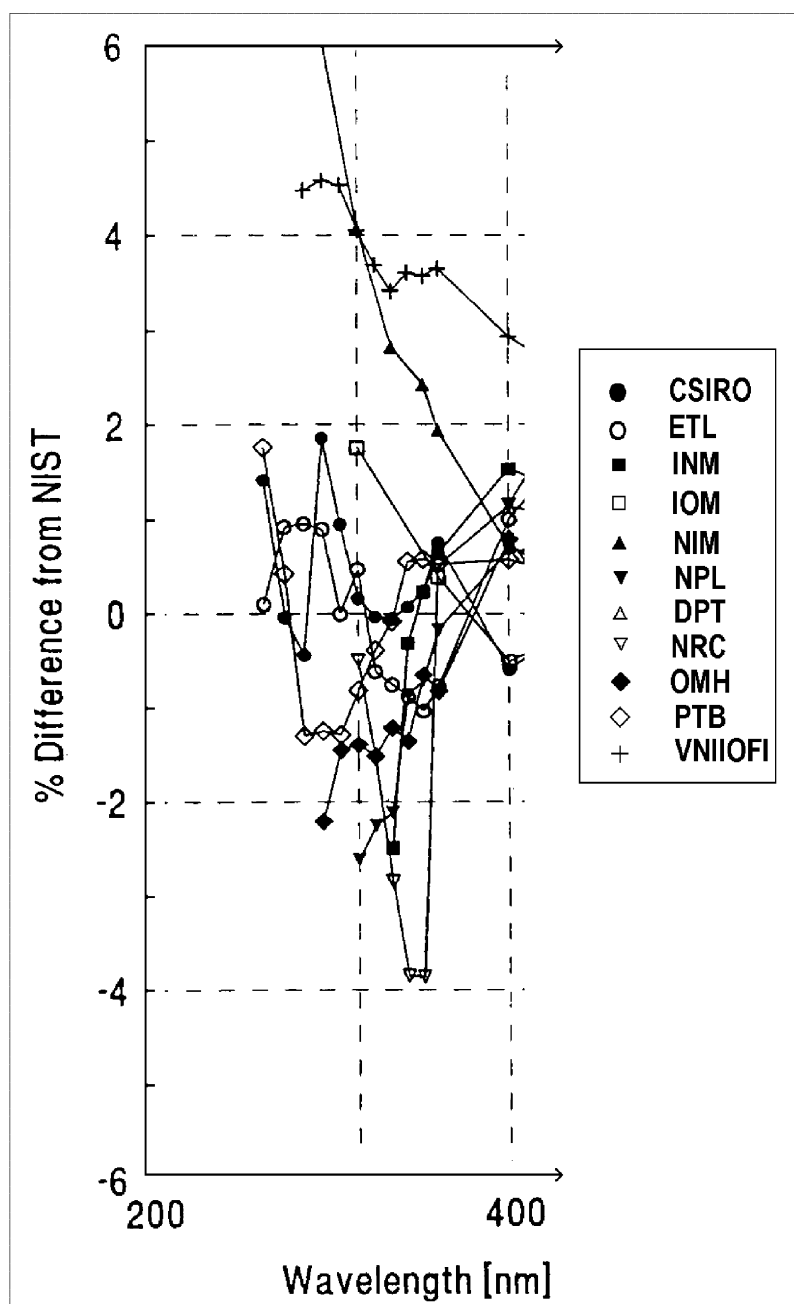


Figure 5.1: Adapted from Walker et al (1991) [p654] “Grand-mean percent differences from NIST of all participants’ spectral irradiance measurements”

Figure 3.6 in section 3 shows the two different types of lamp used. The NPL/GEC (General Electric Company) 770 W tungsten bromine lamp which had been originally chosen for the intercomparison, was found to have a uniformity field better than $\pm 5\%$ over an angular range of 5° subtended at the lamp in the horizontal plane at right angles to the plane containing the filament. Unfortunately of the three lamps delivered to NIST for the intercomparison, 'some' failed early on and GEC was unable to supply replacements. Consequently NIST provided some 1000 W FEL lamps also produced by GEC (USA) {uniformity field not given} [Walker (1991)].

Figure 5.1 shows the grand-mean percent differences from the NIST measurements of all the other participants' measurements. Only the 200 nm - 400 nm range of this graph is reproduced as that is the area of interest of this review. As can be seen, at wavelengths in the range shown, differences which lie in a 10% band, and differences greater than $\pm 6\%$ are not shown but listed elsewhere in Walker et al's paper.

It should also be noted that uncertainty estimates carried out by the participating laboratories varied greatly, and were quite low in many instances, however Walker et al used the standard deviation of the world average to estimate the consistency of national scales and the intercomparison uncertainties to be $\sim 2\text{-}4\%$ in the UV though the spread is greater as can be seen in figure 5.1 [Walker (1991) p655]

Any results and errors quoted by researchers in the SUV measurement community, should be noted with respect to these results.

Work is currently underway in many National Standards Institutes to reduce UV irradiance scale uncertainties and to develop improved transfer standards.

For further information and references, See Appendix 7

References Section 5

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Fox, N.P (1996) *Radiometry with Cryogenic Radiometers and Semiconductor Photodiodes*, Metrologia, 32 p535-543

Hartree, W.S; Fox, N.P & Lambe, R.P (1996) *Towards a Detector-Based Spectral-Radiance Scale in the Near-UV*, Metrologia, 32 p519-522

Fox, N.P et al (1998) *Establishing a New UV and NIR Spectral Scale*, Metrologia, 35 IN PRESS proceedings of NEWRAD97

Walker, J. H (1991) *Results of a CCPR Intercomparison of Spectral Irradiance Measurements by National Laboratories*, J.Res.NIST, 96 p647-668

6. SOLAR UV MEASUREMENT

In order to obtain some standardization across Europe, a three year study was carried out to compare instrumentation being used and the results they provided (see later). In the introduction of the final report edited by Gardiner and Kirsch the following important points are made (*the bold lettering has been added for emphasis*):

“Although the importance of ultraviolet radiation in the biosphere has been known to scientists for a long time, it is only in recent years that its deleterious effects have become the subject of widespread public interest and debate. Even in the scientific community, however, it is not always fully appreciated just how diverse the effects of ultraviolet radiation can be, **nor how much they depend on the wavelength of the radiation**. Whether the effect is beneficial or detrimental, or more complex; whether it is in a plant or an animal, marine or terrestrial; whether it is acute or a chronic effect, superficial or systemic; in fact whatever its character, it will invariably be found to depend on wavelength.....In fact each effect has its own characteristic spectral response.....**It follows that assessment of ultraviolet flux effects requires spectrally-resolved data on the incident radiation flux.**”[Gardiner & Kirsch (1995):p3]

6.1 SUV Measurement and The Earth's Atmosphere

To record the radiation from any star - including the sun - from within the earth's atmosphere, it becomes necessary to understand the physics, chemistry and gross behaviour of the atmosphere, hence it must be accurately modelled so that its various effects can be separated from the collected data. It is necessary to differentiate between the 'natural' behaviour of the atmosphere (how it has evolved to some kind of equilibrium over the millennia) and what are now seen as external or 'new' effects whether anthropogenic or solar.

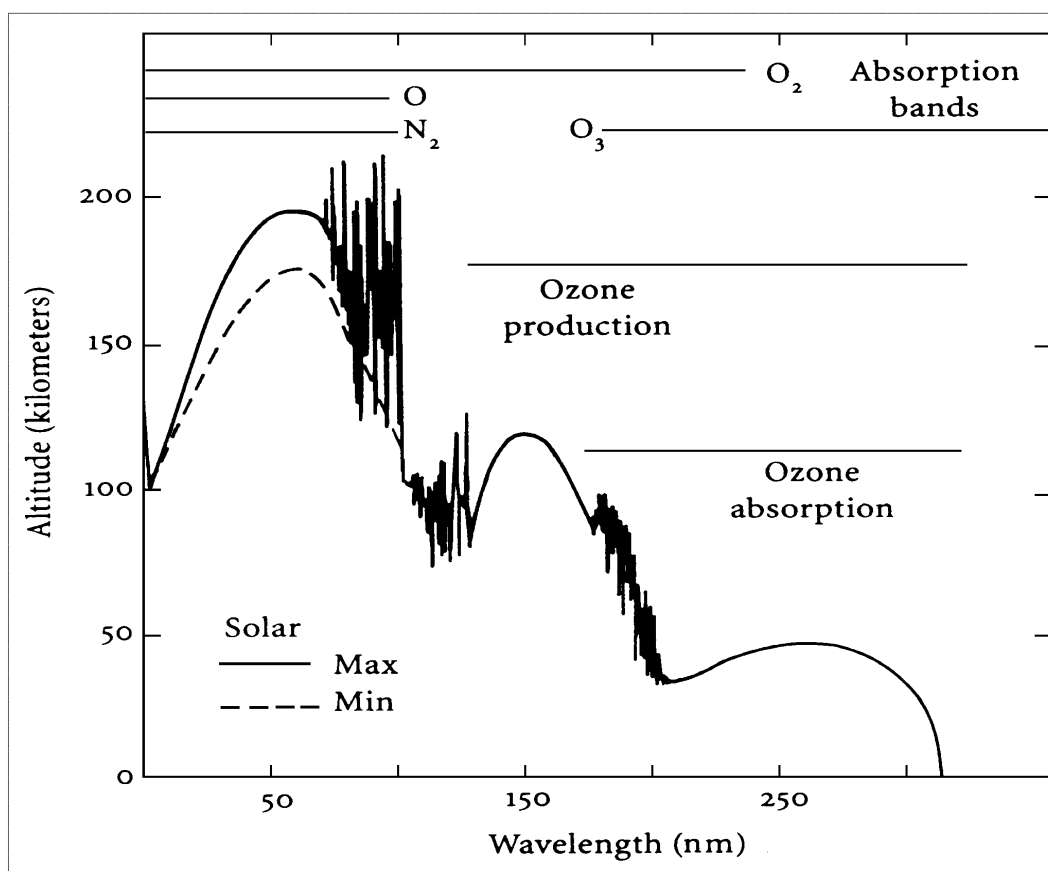


Figure 6.1: Atmospheric Absorption figure from Lang (1995) [p211] text from Huffman (1992) [p16] 'Altitude unit optical depth (1/e absorption) for ultraviolet radiation from or to space in the nadir or zenith direction'. (Reproduced with permission)

EMR interaction with the atmosphere was discussed earlier, however in order to emphasise the effects of the UV component, figure 6.1 has been included. This is a plot of short wavelength absorption by the atmosphere and the species responsible for that absorption. This appears in several texts, in this case from Lang (1995), which he has adapted from a plot by R.R. Meier (1991) Space Science Reviews 58 p1-185 and the text from Huffman (1992); Huffman's figure was adapted from the Handbook of Geophysics and the Space Environment (no further information provided).

6.2 Types of SUV Measurement

According to Bais (1997) there are currently four types of SUV measurement being undertaken at various sites world-wide, each type of measurement producing data for different areas of research, refer to table 6.1.

Table 6.1: Current types of SUV measurement according to Bais (1997) [p5199]

Type of UV measurement	Purpose or use
1. Global UV Irradiance	<i>Most common, used to study the effects of ozone, clouds, and aerosols on SUV, useful for long term trends. Some use for biological work</i>
2. Actinic Flux:	<i>Photochemical and Biological studies</i>
3. Diffuse SUV	<i>Atmospheric Aerosols</i>
4. Direct Measurement of Spectral Irradiance	<i>Used to determine aerosol optical depth and column abundance of atmospheric species that absorb SUV</i>

6.2.1 SUV Measurement Input Parameters

Weihs and Webb (1997) have described the exponential development of computers in conjunction with improvements in radiative transfer calculations in the last two decades as having led to dramatic improvements in mathematical models;

"UV models based on exact analytical methods are widely considered to be absolutely accurate with errors in results widely attributed to inaccurate input parameters...{which} may be determined in four different ways: 1} by calculation using well-known equations,...2} tabulated values or climatological data...3} directly measured data (routine or special measurements)...4} using known relationships between other meteorological parameters and required input data." [Weihs & Webb (1997) p1541-2]

Whilst generalized input parameters can be obtained from the literature, these are only suitable if average results are required. For greater accuracy, input parameters are required for a *given site* at a *given time*.

These days, some of the required input data are routinely available from, for example, meteorological offices or satellites. Where parameters are not routinely monitored, additional measurements must be taken to characterize that part of the atmosphere through which the UV to be measured, will pass. When this is not possible due to expense or unavailability of the highly specialized instrumentation required to make these measurements, researchers make deductions from other meteorological parameters. [Weihs & Webb (1997) p1542]

In Air Pollution Report 53 for STEP Project 76 (for which Webb was Project Coordinator and Weihs a participant) the editors, note that, "(UV) Radiation Flux is determined by a number of factors..." [Gardiner and Kirsch (1995)]. These 'factors' and Weihs and Webb 'Input Parameters' are combined and described in Appendix 7.2, table Ap7.2. In table 6.2 below, they are re-listed along with their associated errors/problems and the possible solutions that various researchers envisage.

For further information and references, See Appendix 8

Table 6.2: Errors and Solutions of SUV Measurement Input Parameters from *{Gardiner & Kirsch(1995)} and #{Weihs & Webb (1997) p1541}, unless otherwise stated.

Input Parameter	How Values are Obtained or Derived	Errors and/or Problems	Possible Improvements/Solutions
# Aerosol Optical Depth (AOD) Symbol: * (#) J_a [Schwartz (1996)]	Refer to Table Ap7.2 in Appendix 7.2 for fuller descriptions Usual method: solar(NIR) irradiance is measured with sun photometers and the presumed reduction in the transmission is obtained by used of (computer based) models. These models have varying levels of sophistication/accuracy depending on the assumptions that have been used. For example, has actual physical geometry of the atmosphere been used ie spherical or an approximation using plane parallel layering? For simplicity, the aerosols are assumed to have spherical symmetry. Number of species of absorbing gases (CO ₂ for example) the more species introduced, the more computer memory required, generally those considered to be most abundant are used. Using radiative transfer models, for example, the 'knowns' are eliminated.	<u>GENERAL</u> Aerosols are transient species (~days) and even within these relatively short timescales they can be significantly altered both chemically and physically. Consequently, it is not trivial to predict their behaviour over time. <u>AOD</u> "Provided all other contributions to error are small, uncertainty in aerosol optical thickness (AOD) is dominated by uncertainty in V_0 " $\Delta\tau_{aerosol} = \frac{1}{m} * \frac{\Delta V_0}{V_0}$ Where: m = no. airmasses in path .sec(SZA) V_0 = instrument response to direct-normal radiation extrapolated to TOA (top of atmosphere)" [Schwartz (1996)]"	<u>GENERAL</u> Visible and NIR methods can be used to obtain global detection information. See for example, Shiobara et al (1996) #Though a vertical profile of all the characteristics of aerosols is necessary it is impossible to obtain.
# Aerosol Phase Function			
# (aerosol) single-scattering Albedo (SSA) Symbol: $\tilde{a}_0$	# Continuous AOD measurements can be performed by observers and satellite observations provide some coverage of AOD... The concentration, vertical profile, absorption and scattering properties are all important in the characterization of aerosols. These are calculated from the size distributions and from the real and imaginary components of the aerosols. Spherical symmetry is assumed. [Mie (1908) Ann.Phys., 25 p377; Wiscombe (1980) Appl.Opt., 27 pp1505-15].....The various coefficients that make up the aerosol parameters - including the phase function, are generally taken from tables where they are stated for each wavelength, for example, from <i>International Association of Meteorology and Atmospheric Physics</i> (IAMAP) 1984. However, most aerosol parameters are estimated, though models are available from IAMAP and others.	#AOD accuracy depends on instrument and wavelength and calibration. Calibration of sunphotometers is usually via the Langley method, a calibration referenced to extraterrestrial irradiance. "It is very difficult to find a location with good conditions for the Langley calibration. Thus calibration of sun photometers is still subject to investigation, see Forgan (1994) General Method for Calibrating Sun Photometers, Appl.Opt (33) p1291-1303" [Shiobara et al (1996)]	
* Air Pollution (in the form of suspended particles) 'aerosols'			

Table 6.2 continued:

Input Parameter	How Values are Obtained or Derived	Errors and/or Problems	Possible Improvements/Solutions
*# Atmospheric Ozone (Total column)	#1) Global ozone is measured via ground-based networks of Brewer and Dobson spectrophotometers which are usually calibrated by the use of lamps or standard instruments. According to Gleason et al (<i>Record low global ozone in 1992, Science 260 p523, 1993</i>) the calibration of the world standard dobson instrument 83 (I83) has been maintained to an accuracy of $\pm 0.5\%$	#1) A discrepancy in ozone determination between the Brewer and Dobson spectrophotometers of 2% ($\pm 1\%$) is reported by various researchers, which is thought to be due to the use of different ozone absorption coefficients each instrument type: Dobson researchers use Vigroux 1953 (<i>Ann.Phys.</i> , 8 p709), whilst Brewer researchers use Bass & Paur 1985 (<i>Proc.Quad.Oz.Symp Ed. Zerefos & Ghazi, Reidel</i>) which measures the SO ₂ column separately.	# 1) If the influence of SO ₂ at the site where measurements are being taken is included as a correction onto Brewer measurements, the difference in results between the two instrument is greatly reduced
	#2) Instrumentation on board various satellites collect global ozone data using different techniques, for example: a. TIROS/TOVS uses ozone absorption band at 9.6 μm [<i>Lefevre et al (1991) J.Geophys.Res.</i> , 96 p12893-911] b. TOMS uses backscattered radiance measurements at six selected wavelength bands [<i>Fleig et al (1982) TOMS Users Guide</i>]	#2) Lefevre et al (1991) compared the TOVS and TOMS data over Antarctica and found discrepancies of up to 10% at large SZAs of $\sim 80^\circ$ and discrepancies of $\sim 4\%$ at SZAs of $\sim 50^\circ$ #3) Comparisons between these satellite data and some of the ground-based Dobson measurements give varying results in agreement between the various instruments: a. TOVS-Dobson Melbourne $4.2 \pm 2.3\%$ (<i>Lefevre et al 1991</i>) b. TOMS-Dobson Melbourne $1.7 \pm 3.3\%$ (<i>as above</i>) c. TOVS-Dobson Hobart $2.5 \pm 2.1\%$ (<i>as above</i>) d. TOMS-Dobson Hobart $1.3 \pm 2.1\%$ (<i>as above</i>) Gleason et al., report a 4.5% absolute offset between TOMS and the Dobson I83 and a 3% offset relative to the 22-station average which they suggest may be due to an error in the original ground calibration of the satellite instrument.	#2) None suggested
#Atmospheric Ozone (vertical profile)	#1) Efficiency of ozone absorption of UV depends on air temperature hence on altitude since the temperature profile changes through the atmosphere (See Appendix 7) the height integral of the vertical profile of ozone gives total ozone. Various researchers have provided typical ozone profiles for various latitudes and seasons, over the years from ground based and satellite instruments. Whilst measurements may be carried out with radiosondes ¹ , there are still some unknown reactions. Most measurements are based on the "Umkehr method" developed by Götz in 1931 [<i>Ger.Beitr.Geophys.</i> , 31 p119-154]. This requires the ratios of the intensities at two wavelengths from a clear zenith sky, one of which is more absorbed by ozone and for SZA between 60° and 88° [<i>Walton (1955) Proc.R.Soc.</i> , 11]	#1a) Brewer Umkehr agree with radiosonde data to better than 10% [<i>McElroy et al (1989) in Ozone in the atmosphere, ed by R.Bojhov & D. Fabian, Deepak, Hampton Va</i>] #1b) The SBUV satellite measurements were compared with measurements from chemical and optical sensors launched on balloons and rockets and from ground based Umkehr measurements, and were found to be better than 8% for pressures ~ 1 -64 mbar and better than 15% for pressures ~ 64 -253 mbar radiosondes ¹ : A balloon-borne instrument for the simultaneous measurement and transmission of meteorological data up to a height of approximately 30,000 meters (100,000 feet). The height of each pressure level of the observation is computed from data received via radio signals. [http://www.hq.nasa.gov/iwgsdi/glossary.html]	#1 a&b) None suggested

Table 6.2 continued

Input Parameters	How Values are Obtained or Derived	Errors and/or Problems	Possible Improvements/Solutions
* Barometric (or Atmospheric) Pressure (vertical profile)	Send up radiosonde balloon prior to experiment [Sommers (1998)]	Varies with season and transient weather systems [Sommers (1998)]	no suggestions found during literature search
#Ground Air Pressure	#Measured locally	#none listed	#none listed
* Clouds	Estimated from meteorological or satellite data [Webb (1997) p13]	'..most difficult parameter to model' [Webb (1997) p13]	Visible and NIR methods can be used to obtain global detection information. See for example, Shiobara et al (1996)
* Elevation of the Sun above the horizon #Solar Zenith Angle (SZA) [& Dahlback (1996) p6514]	#1) From well known astronomical formulae' [Weihs & Webb p1542]	none listed	N/A
* #Extra-terrestrial solar spectrum	# 'from SUSIM {refer to Appendix 5.3.1D} via van Hoosier et al, (1988) Astron Lett.Comm., 27 p163-8'	Depends on availability of satellite instrumentation. Problems can occur as recently with SOHO. In general calibration of on-board instrumentation an ongoing problem	Detector stabilized lamp or other source
# Ground (or * Surface) Albedo	#"Mean albedo 0.03 determined from TOMS satellite data (Weihs & Webb reference the first European intercomparison, which took place in 1991)	The reflected radiation is often intercepted by clouds and undergoes further reflections. Clouds and other transient phenomena need to be monitored.	Coordination of satellite and ground-based measurements
#Temperature (vertical profile)	Send up radiosonde balloon prior to experiment [Sommers (1998)]	Varies with season and transient weather systems [Sommers (1998)]	Visible and NIR methods can be used to obtain global detection information. See for example, Shiobara et al (1996)

References Section 6

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Gardiner, B.G & Kirsch,P.J (Editors) (1995) *Setting Standards for European Ultraviolet Spectrometers*, Air Pollution Research Report 53,EC Commission, STEP Project 76 Final Report, ISBN: 9282654052

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Weihls, P & Webb,A.R (1997) *Accuracy of Spectral UV Model Calculations: 1. Consideration of Uncertainties in Input Parameters*, J.Geophys.Res., 102 (D1) p1541-50, January 20th

Schwartz, S.E (1996) *Specification of Aerosols*, Slide Presentation ARM Science Team Meeting Texas March 5th, Brookhaven National Laboratory website, [http://www.ecd.bnl.gov /...](http://www.ecd.bnl.gov/)

Webb,A.R (1997) *UVB Instrumentation and Applications*, Gordon & Breach Amsterdam, ISBN 9056991213

Dahlback, A (1996) *Measurements of biologically effective UV doses, total ozone abundances, and cloud effects with multichannel, moderate bandwidth filter instruments*, Appl.Opt., 35 (33) p6514-6521

Shiobara, M et al (1996) *Optical Depth of Aerosol, Cloud and Water Vapor Using Sun Photometers during FIRE Cirrus IFO II*, J.Appl.Meteorl., 35 January p36-46

7. UV INSTRUMENTATION

According to McCluney (1994):

<i>Spectrometer</i>	An instrument system incorporating some dispersing unit (such as a monochromator) that measures the positions of spectral features and displays the resulting spectrum completely or scans it over time, recording flux levels of each wavelength [<i>ibid p292</i>]
<i>Spectroradiometer</i>	A spectrometer designed and calibrated for measurements of spectral radiant flux, “since it is intended to serve as a radiometer for each wavelength of interest in the spectrum” [<i>ibid p292</i>]
<i>Spectrophotometer</i>	Indicates a laboratory scanning spectrometer designed to measure one or more spectral optical properties of gases liquid or solids [<i>ibid p292</i>]

However, the words spectrophotometer and spectroradiometer seem to be used interchangeably in some of the literature. Note that the Commission International de l’Eclairage (CIE) has standardized these terms, and the official versions are:

<i>Spectroradiometer</i>	An instrument for measurement of radiometric quantities in narrow wavelength intervals over a given spectral region
<i>Spectrophotometer</i>	An instrument for measurement of the ratio of two values of a radiometric quantity at the same wavelength [<i>ibid p293</i>]

Most SUV collecting instrumentation are based on the same principles, whether they are in space on board satellites or ground based. Aperture to collect radiation, collecting optics (mirrors and or diffusers) some method for filtering out unwanted IR and VIS radiation, a detector or detector system, electronics to connect all the various components and some method of recording the information collected (usually a computer these days).

In addition it is vital to have good calibration methodology for the each component part of the instrumentation or for the instrument as a whole and traceability for the irradiance or radiance being measured.

7.1 Key Components

Some additional key components (other than ASUV which have already been discussed in section 3) are now described to provide an insight into the amount of work involved not only in making but in specifying these components. The uncertainties related to these components must also be taken into account somewhere in the overall uncertainty budget. As an example, a stable power supply is extremely important when using ASUV, since ; ‘a change in current of ~0.1% can lead to a change in lamp irradiance of ~1.0%’ [*Webb (1997)*].

7.1.1 Filters

Only filters that are required to transmit UV will be discussed.

It is hard to produce filters that transmit in the UV, without leakage from the much more dominant visible and infrared portions of the EM spectrum and damage to the filter materials from the high energy UV photons. UV Filters are generally produced by serial layering onto a dielectric or metallic substrate.

“ Based on the principle of destructive and constructive interference..For most optical applications the coating materials are inorganic, usually consisting of metals, metal oxides (silicon dioxide, titanium dioxide, zirconium dioxide etc) and metal nitrides (silicon

nitride, aluminium nitride, boron nitride etc). Other coating materials include carbides (silicon carbide, germanium carbide etc), fluorides, mixtures of metal oxides, or mixtures of oxides and fluorides...The number of layers...may range... to more than 50 layers for more complex coatings, such as those that separate heat from light. [Morelli (1991)]

Figure 7.1 shows the response of a typical coating/blocker/detector combination, and figure 7.2 is shows the transmittance profile of a typical filter with key terms indicated.

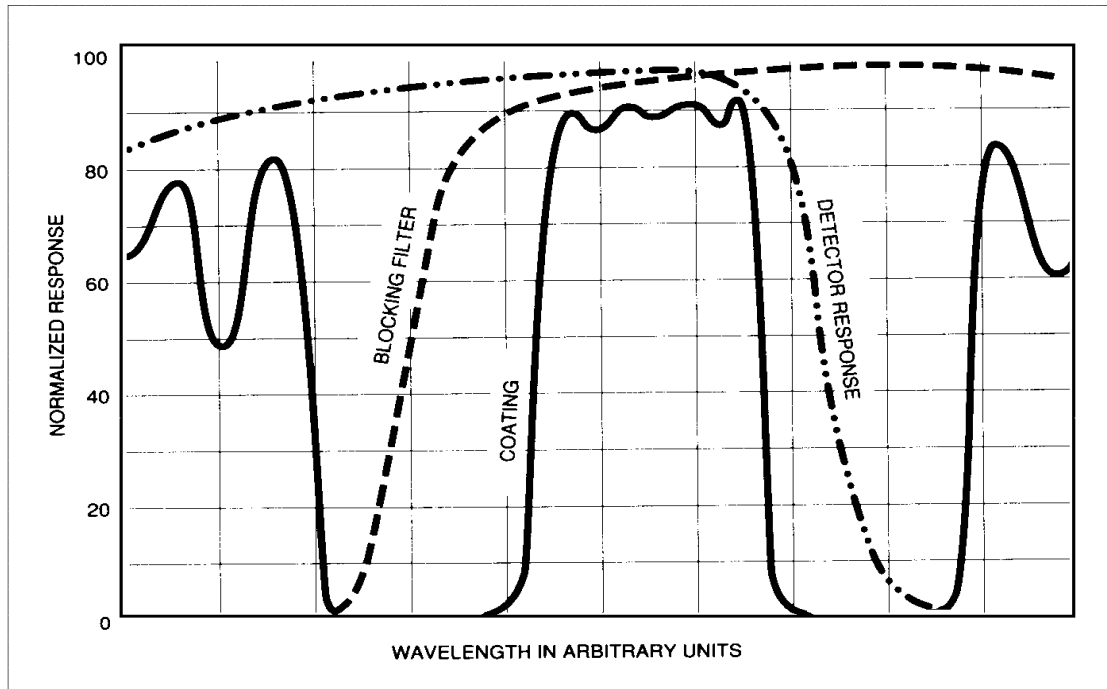


Figure 7.1: From Morelli (1991) Typical Coating/Blocker/Detector Combination, courtesy OCLI

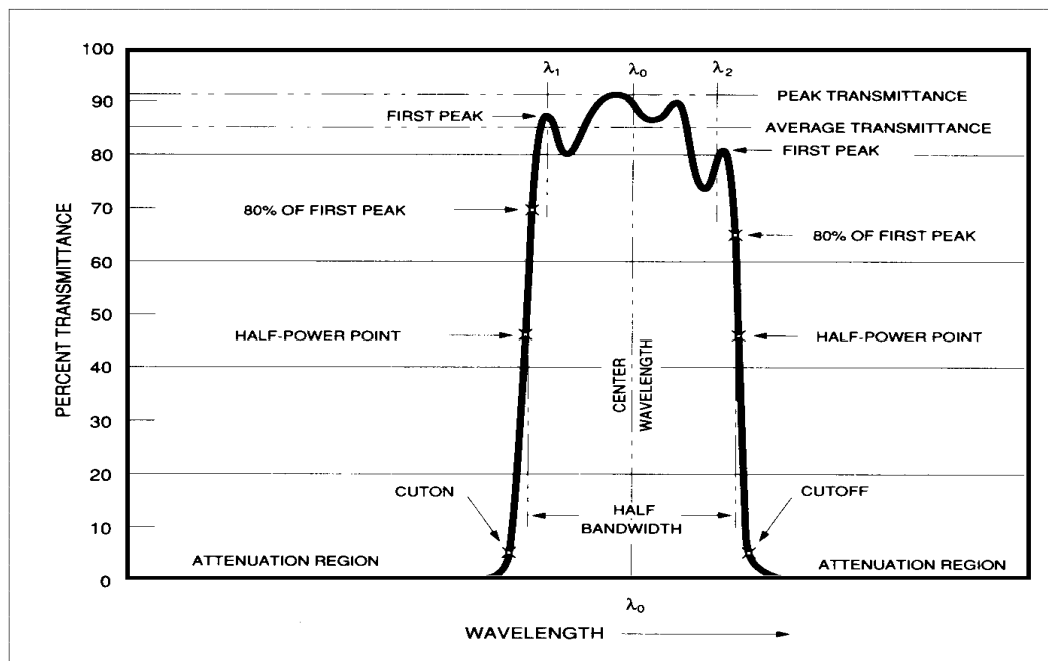


Figure 7.2: From Morelli (1991) Transmittance against wavelength for a typical filter, courtesy OCLI

In general UV filters are tested by exposing them to high levels of UV and comparing their transmittance before and after exposure. Tests are also carried out to look for out-of-band leakage and finally the uniformity of the filters is determined. For example, work performed at NPL on a

296.7nm filter is described [Durant (1997)]. Broad spectral scans were carried out to determine the rough shape of the passband and spectral distribution of leakage, (200 - 1000 nm in 10 nm steps). A finer scan (1 nm resolution in the 200 - 360 nm range) was then carried out to determine the transmission peak more accurately. Scans were repeated at varying time intervals to check reproducibility

7.1.1.1 Transmission & Reproducibility Following Exposure to UV

The 296.7nm filter was irradiated at approximately 10 W.cm⁻² (integrated over a ~250 nm - ~330 nm wavelength range) for four hours, with broadband UV from a Mercury Xenon lamp. The transmission of the filter was measured before exposure, immediately after exposure and sixteen hours after exposure. There was negligible difference between the two post-exposure scans, but the transmission decreased by a few percent following exposure as shown in figure 7.3. Further measurements were taken and are noted in table 7.1.

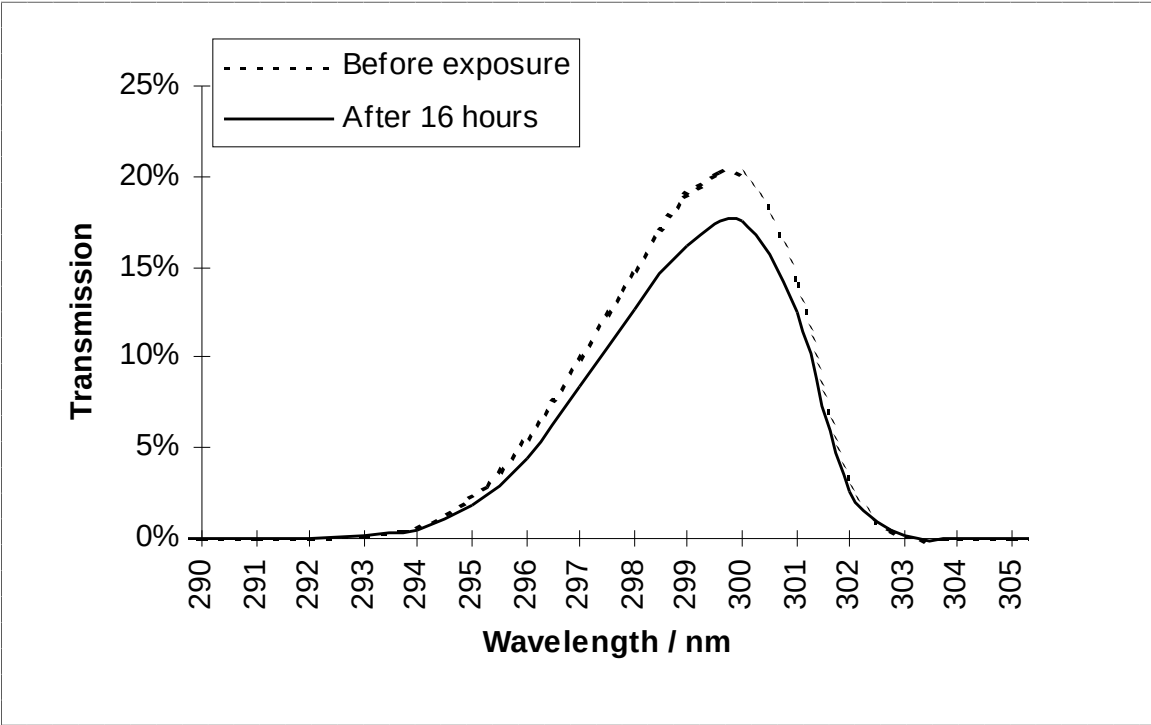


Figure 7.3: Change in transmission of 296.7 filter following exposure to 10 W.cm⁻² from HgXe source for four hours. A WG320 filter was used to remove light in the pass band.

Table 7.1: Change in Peak Transmission of 296.7nm filter following exposure.

Initial transmission	20.1%
Immediately after exposure	17.5%
16 hours after exposure 1	17.5%
44 hours after exposure 1	17.5%
Immediately before exposure 2	17.5%
Immediately after exposure 2	17.7%
16 hours after exposure 2	17.5%
36 hours after exposure 3	17.9%

7.1.1.2 Uniformity

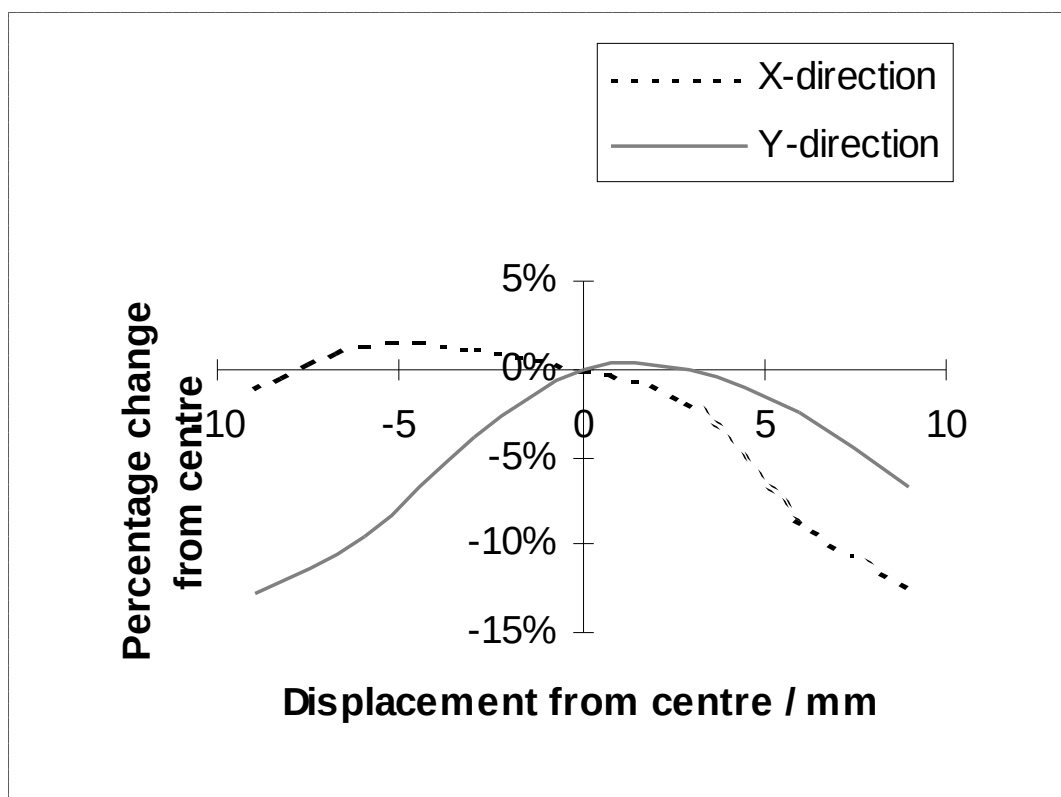
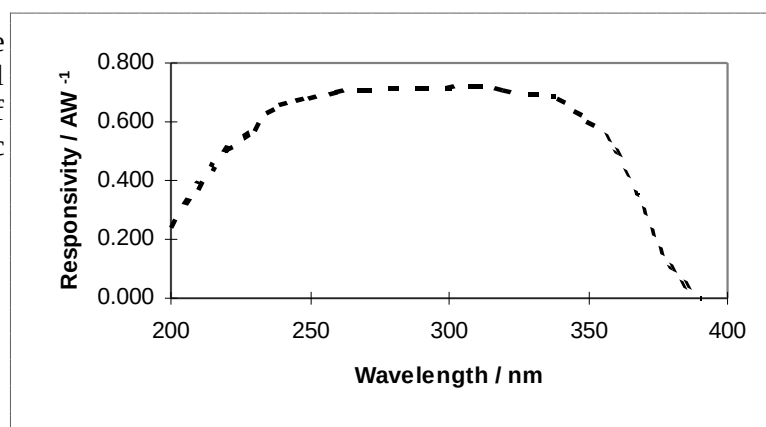


Figure 7.4: Spatial Uniformity of the Transmission of the 296.7 filter at 297 nm

A pseudo-collimated beam of ~ 297 nm (5 nm bandwidth) was set up and the uniformity of the 296.7 nm filter was measured in an x-y plane across the surface presented to the beam. Measurements were taken in a cross-formation at 3 mm intervals. Uniformity across the surface was found to be $\sim 12\%$ (though this result is thought to be low due to low signal levels and noise. Figure 7.4 is a plot of the percentage change recorded from the centre of the filter.

7.1.2 Detectors

Figure 7.5: Absolute Spectral Responsivity of Gallium Arsenic Nitride (GaN)



Detectors that are used to realize scales have to be well characterized, UV detectors will be discussed with respect to that usage, and in particular GaAsP detectors. In order to realize and disseminate ultraviolet scales with a defined uncertainty solid state detectors with predictable spectral responsivity are required. Whilst silicon has been used for a great many years, its responsivity in the UV varies rapidly, in addition, it is not 'solar-blind'. [Durant and Fox (1996), Durant (1997)]. Figures 7.5, 7.6 and 7.7 show the response for a selection of detectors either in use or being developed for use in the UV. Table 7.2 lists some of the measurement parameters required to characterize detectors.

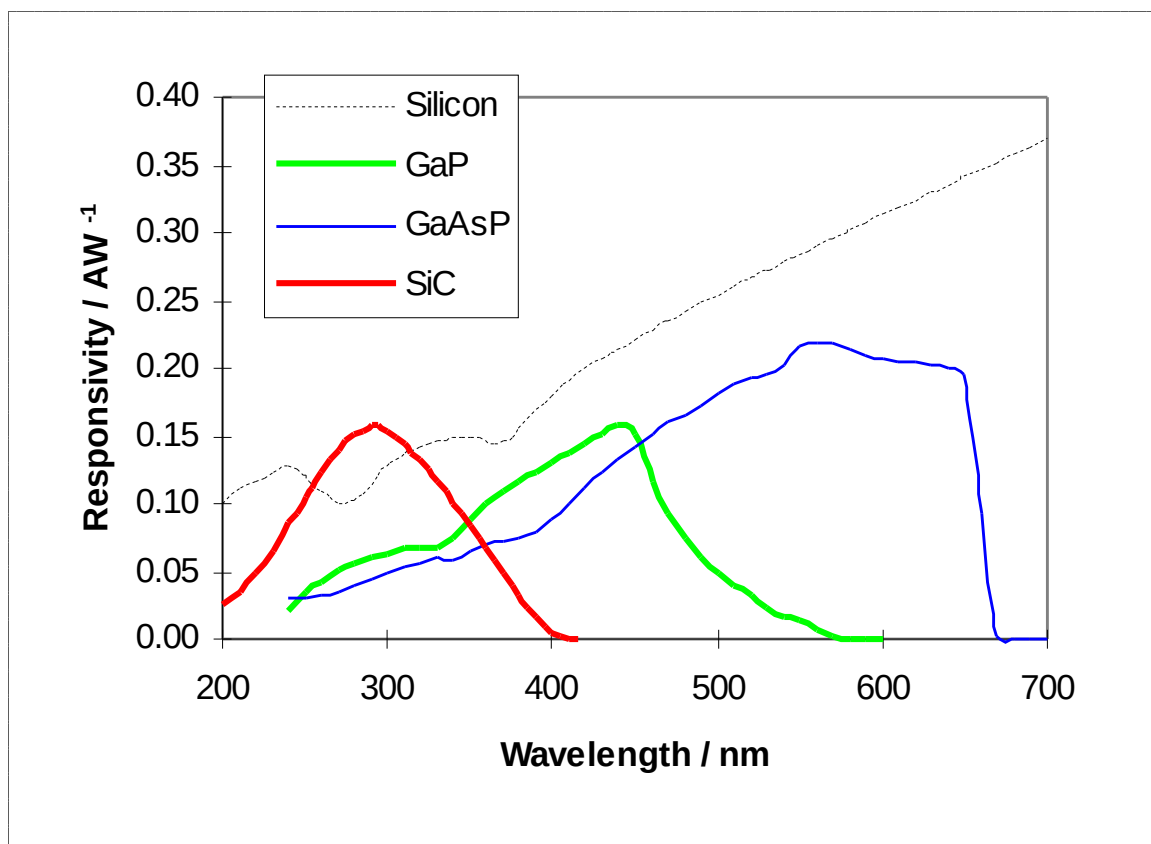


Figure 7.6: Absolute Spectral Responsivity of Silicon, Gallium Phosphide (GaP), Gallium Arsenic Phosphide (GaAsP) and Silicon Carbide Detectors

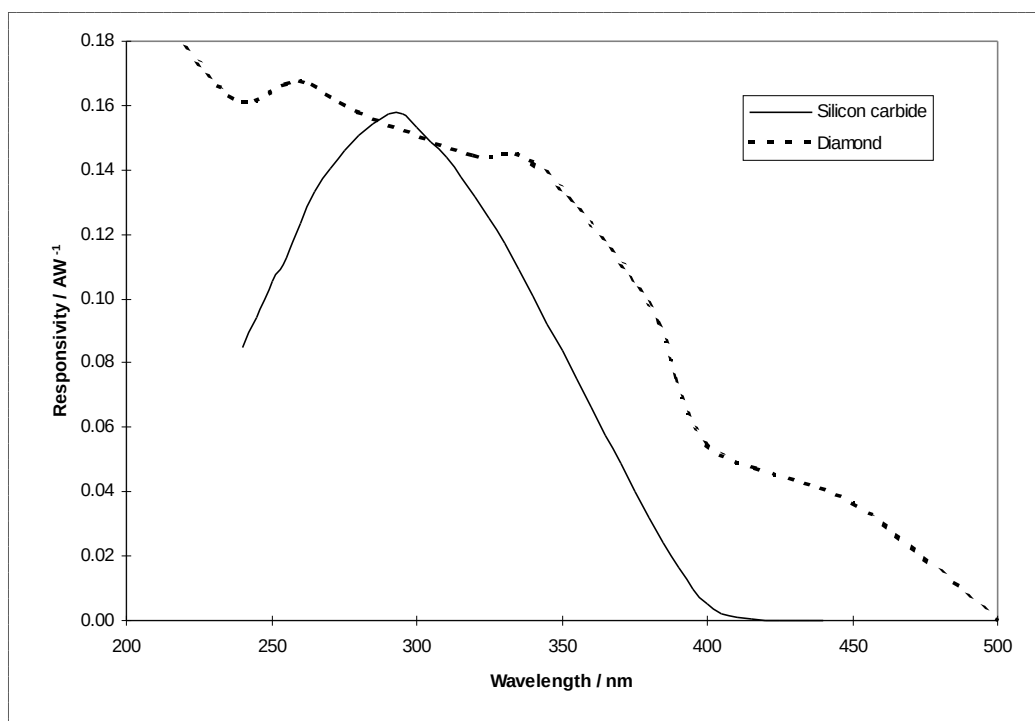


Figure 7.7: Absolute Spectral Responsivity of Silicon Carbide (SiC) and Diamond Detectors (new technology)

Table 7.2: Characterization of detector performance [McCluney (1994) p215, Durant & Fox (1996), Sze (1981)]

Term & Symbol	Unit	Description
Responsivity, R		The ratio of photocurrent to the optical power
a) Detector under-filled by incoming radiation	a) amps per watt ($A.W^{-1}$) {or volts per watt ($V.W^{-1}$)}	a) Defined as the response of a detector to an optical signal, when the <i>whole</i> optical beam falls onto the detector.
b) Detector over-filled by incoming radiation	b) $A.m^{-2}.W^{-1}$	b) Defined as the response of a detector to an optical signal, when placed in a radiation field which over-fills the detector.
Spectral Responsivity, $R(\lambda)$	as above	The variation of responsivity with wavelength, definition is as above and units are unchanged.
Relative Spectral Responsivity, $r(\lambda)$	Dimensionless	The variation of spectral responsivity of a detector with wavelength, but normalized at a specified wavelength.
Quantum Efficiency, η	% the number of carriers generated per photon [Sze (1981) p687 & 745]	The difference internal and external QE is subtle (or confusing depending on your point of view..) and often ignored. A useful comparison from Neil Durant (1998).
a) external		a) Percentage of photons incident on the detector surface which become converted to current. Eg 20% external QE means 20% of the photons hitting the detector are converted to electrical power. A significant proportion of photons are reflected, so 100% external QE can only be approached
b) internal		b) Percentage of absorbed photons (ie *NOT* reflected) which become converted to current. Eg 20% internal QE means that once a proportion of photons are reflected from the surface, out of the remaining ones absorbed only 20% are converted to electrical power.
		“External QE(%) = Internal QE(%) * (100% - Reflectivity(%)); 100%-Reflectivity(%), represents the percentage *not* reflected, ie absorbed. A typical example for Hamamatsu silicon detectors: Internal QE ~99%, meaning once a photon gets through the surface, it is almost certain to become converted to electrical power. Reflectivity ~40%, so ~60% of the incident photons are absorbed. Therefore, external QE ~99% * 60% ~59.4%” <i>The only difference is the reflectivity of the surface</i> “External QE tends to be used by manufacturers to describe how good their detectors are, because it is basically the percentage of photons which get turned into electrical power. Internal QE tends to be used by people developing detectors, because they are often not concerned with reflected losses, but more concerned with losses within the device. Reflection losses can always be reduced using antireflective coatings. Internal QE is also the most relevant thing to use when dealing with trap detectors, where reflected photons can almost be ignored”

7.1.2.1 GaAsP (Gallium Arsenic Phosphide) Detectors

Though GaAsP detectors have been available for some time, they have been too small ($\sim 2\text{-}3\text{mm}$ square) to be useful. In recent years Hamamatsu have produced detectors with an active area of $10.1 \times 10.1\text{mm}$ (effective area 98mm^2). Hamamatsu claim a Spectral Response Range of $190\text{nm} - 680\text{nm}$ with a peak sensitivity of 610nm (see figure 7.8) [Hamamatsu (1996)].

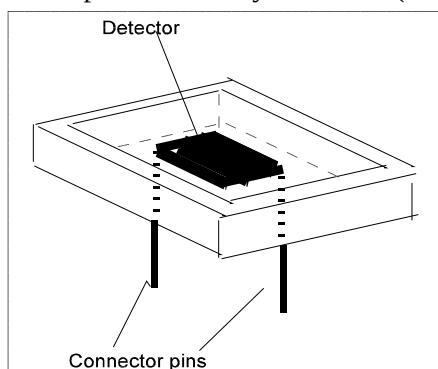


Figure 7.8: Schematic of Hamamatsu GaAsP detector package.

The photocurrent produced by a given level of incident light varies with wavelength. This relationship is referred to as the Spectral Response Characteristic (Spectral Responsivity) and is expressed primarily in terms of spectral response (or photo sensitivity). In addition, GaAsP are ‘Schottky’ type detectors, that is, a thin coating of gold is sputtered onto the surface of an N-type semiconductor to form a Schottky effect PN junction. These devices have high ultraviolet sensitivity since the distance from the outer surface to the junction is short. The detectors are housed in a ceramic package and can be obtained with or without a protective window.

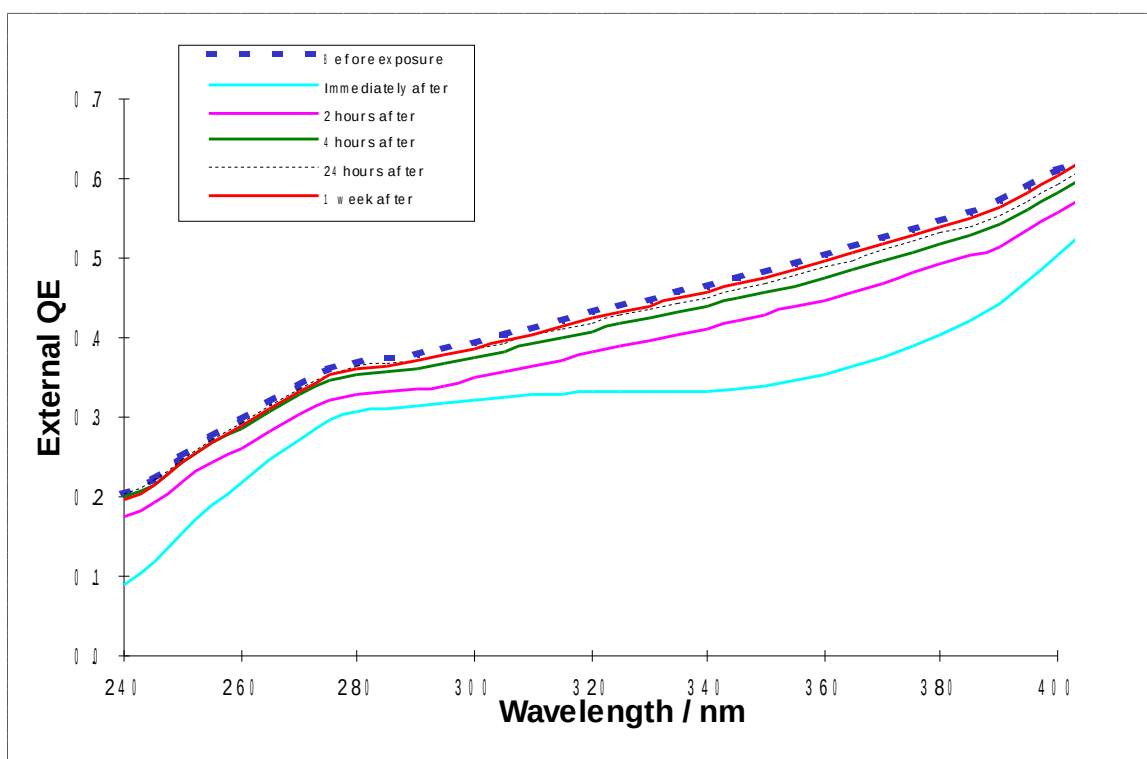


Figure 7.9: From Hunt et al (1998) “Change in the pre-irradiated external QE of a GaAsP Detector following a 2 hour exposure to broadband UV ($2\text{ mW}\cdot\text{cm}^{-2}$)”

Figure 7.9 shows the effects of UV exposure from a Xenon source on the external quantum efficiency (QE) of a windowless GaAsP G2119-01 detector. Following the exposure, there was an immediate drop in QE. However, after two hours, the values had begun to approach their original levels which were almost re-established after ~ 5 hours. After the exposure tests, the difference was negligible, but note that at wavelengths longer than $\sim 280\text{ nm}$, the recovery appears to take a little longer. [Hunt et al (1998)]

7.1.3 Monochromators

Material for this section is taken from Hunt and Ward (1998).

As discussed in earlier sections, since it is UV at specific wavelengths that causes damage to biological and ecological systems, it is important to be able to know ‘how much’ of these particular wavelengths is contained in the UV arriving at the surface of the earth. In order to obtain quasi-monochromatic UV it becomes necessary to disperse it.

The instrument of choice for most SUV research is still the monochromator, though it has been around for many years now. Monochromators come in a variety of configurations, but all have an entrance slit for the incoming radiation and an exit slit where an image of the entrance slit is formed. This image will be in a range of the wavelengths present in the light source being measured and will depend (apart from the detector system being used) mainly on the slitwidths and the dispersing element within the monochromator. Some discussion on a Czerny-Turner double monochromator will be described as an example.

The Greek word ‘monochromos’ means ‘one colour’ and a ‘monochromator’ is used to select a particular wavelength from the spectrum of radiation emitted by a source. This is achieved using various combinations of optics which usually include: *(there follows some description with sources of potential error italicized)*:

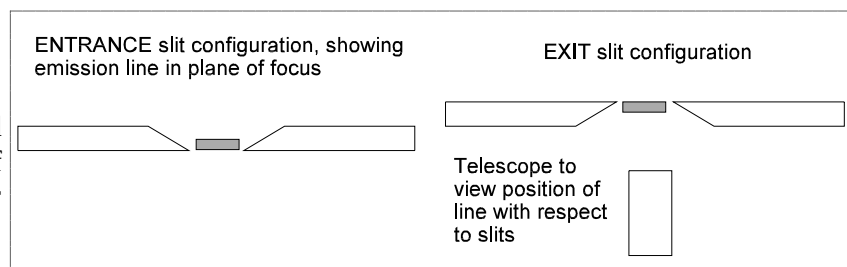
7.1.3.1 Slits

Two pieces of steel fashioned with very *straight edges*, and mounted *parallel* to one another. In combination they are called ‘slits’ and their *movement with respect to one another* is precisely controlled so that the distance between them, the ‘slitwidth’ can be accurately determined at any time.

(Note that what is important, is that these two pieces of steel, open evenly about their combined central position). There are two types of slits, entrance slits, where the radiation enters the monochromator and exit slits where the radiation leaves the monochromator. See figure 7.10 which shows a ‘bird’s eye’ view of the position of the ‘knife edge’ with respect to the beam of radiation, for both types of slit.

Figure 7.10:

From Hunt & Ward (1998) showing plane of focus for monochromator slits.



7.1.3.2 Focusing /Collimating Optics

Usually some combination of plane and concave mirrors, which must be properly *aligned* and *focussed*, and have *undamaged and clean surfaces* so that they reflect the highest proportion of radiation possible.

7.1.3.3 A Dispersing Element

The dispersing element can be transmissive or reflective gratings, or prisms. Only reflective diffraction gratings will be discussed here.

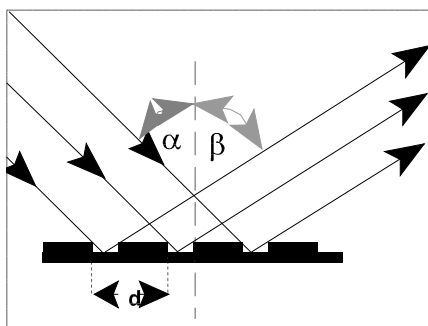


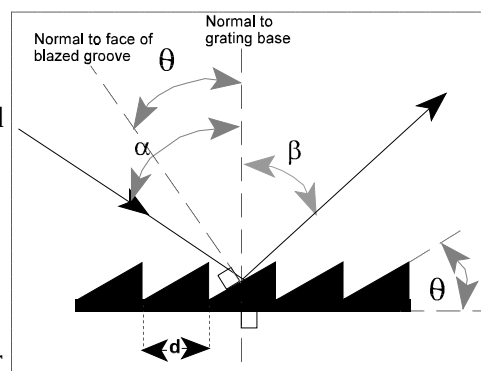
Figure 7.11

Schematic of a section through a grating with grooves etched into the surface.

A reflective grating is made from a flat or curved surface of reflective material with (usually) varying numbers of equally spaced lines or grooves etched into the surface (depending on the wavelength range of interest and resolution required).

Radiation collimated by one of the mirrors onto the surface of the grating, interferes constructively with its own reflections so that the 'grating equation' $m\lambda = d(\sin \alpha + \sin \beta)$ is fulfilled (ie the gratings are designed to achieve this). Where m is the order of diffraction and takes any whole value, including zero; λ is the wavelength, d is the distance between the lines, α is the angle of incidence and β is the angle of diffraction. It is possible to increase the grating efficiency (proportion of reflected to incident radiation) at a particular wavelength by increasing the surface area presented to the incoming radiation. This is called 'blazeing' and the blaze angle θ , defined as $\theta = (\alpha - \beta)/2$ results in a blaze (or optimal) wavelength for that particular grating.

Figure 7.12: Schematic of a section through a blazed grating



This does not mean the grating will not transmit other wavelengths, but it will transmit the blaze wavelength most efficiently and the efficiency will drop off either side of that wavelength. Gratings are usually described by the number of lines (or grooves) per millimetre and blaze wavelength, for example a 600/200 grating means 600 l/mm at a blaze wavelength of 200 nm (nanometres), this would be used for ultraviolet work. The characteristics associated with the manufacture of the grating (ie these can be related to its resulting performance) are generally documented by the manufacturer as follows:

Grooves/mm = 600
 Radius if concave = 4
 Blaze wavelength = 200 nm
 Blaze angle = $3^\circ 26'$
 Efficiency* = 66% at 240 nm; 67% at 231.8 nm; 70% at 222.4 nm
 Resolution = +85% of theoretical
 Intensity of Maximum ghost* = 0.1% of parent in 1st order of 546.1 nm

7.1.3.4 Radiation Path

Figure 7.13 is a schematic of a Czerny-Turner double monochromator showing the radiation path. This particular monochromator is a Hilger Watts D330/331 and does not have internal slits.

Radiation passing through the entrance slit (E1) is reflected through $\sim 90^\circ$ by plane mirror PE1, set

at $\sim 45^\circ$ to the axis of the entrance slits, on to spherical mirror M1. M1 collimates the radiation and directs it towards the first diffraction grating G1.

G1 disperses the incident radiation, part of which falls on a second spherical mirror M2. M2 focuses the radiation onto the intermediate baffle, where it diverges again onto the third spherical mirror, M3 (the radiation passes close to a second plane mirror PE2 which is used when the monochromator is in single mode. However, whilst it is in double mode, PE2 is folded flat against the single mode entrance slit E2). M3 collimates the radiation and directs it towards the second diffraction grating, G2.

G2 disperses the incident radiation, part of which falls on the last spherical mirror, M4. M4 focuses and directs the radiation to the exit slit by way of the last plane mirror PEx which is set at $\sim 45^\circ$ to the axis of the exit slits.

The wavelength of the emerging radiation is changed by rotation of the diffraction gratings in their mount, either manually with a micrometer drum, or by motor drive for spectral scanning purposes. The arrangement of two spherical mirrors with respect to a grating (as depicted in each half of the monochromator) is a design first introduced by Czerny and Turner in the 1930's and is called variously a Czerny-Turner (CT) mount, CT monochromator, CT instrument or CT arrangement.

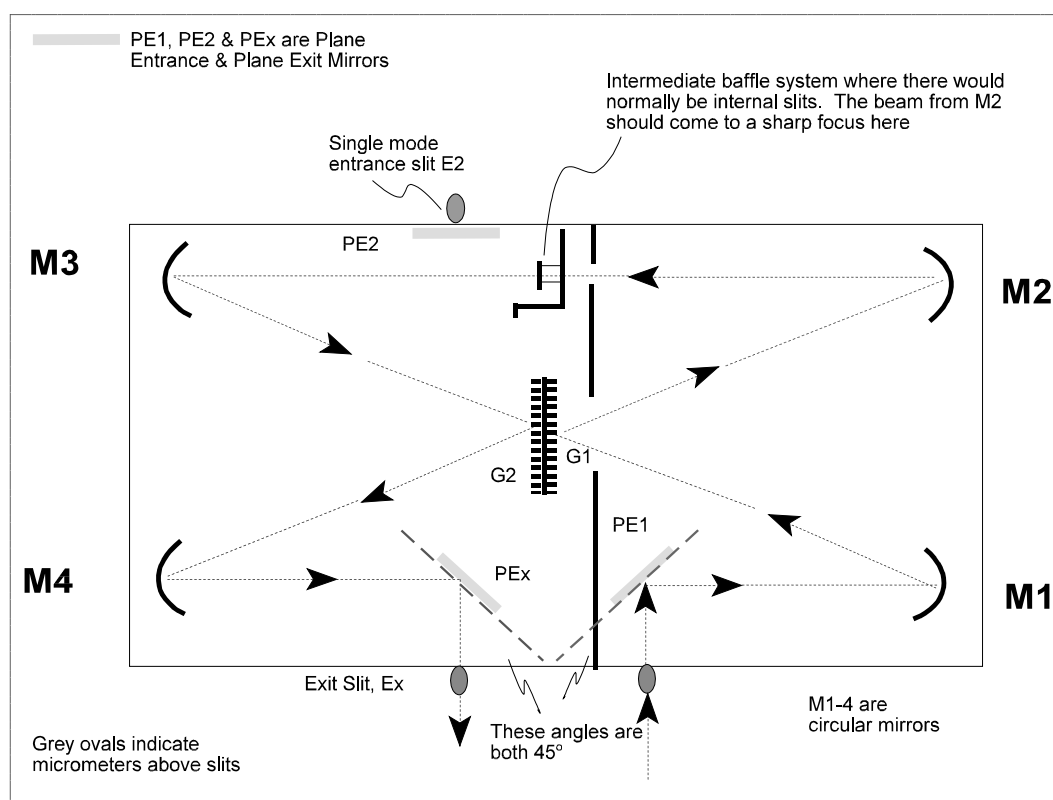


Figure 7.13: From Hunt and Ward (1998): Schematic of radiation path through Hilger Watts D330/331 double monochromator

7.1.3.5 Slit Function/Instrumental Profile

For a thorough discussion on slit function (or instrument profile), see Lerner and Thevenon (1988). Some of the issues will now be discussed to give a flavour of the details which should generally be considered in order to make meaningful measurements. For example, Imaging radiation onto a detector via the exit and entrance slit of a monochromator leads to magnification or demagnification of the image (or images) of the radiation source (anamorphism). According to Lerner and Thevenon (1988), for diffraction based monochromators, the image of the entrance slit is NOT imaged 1:1 in

the optical plane of the exit slit, except in very special circumstances.

In general, the instrumental line profile of a monochromator using a monochromatic source (for example particular mercury line) will be broadened since it is a function of:

- 1 The widths of the entrance and exit slits
- 2 Diffraction phenomena
- 3 Aberrations
- 4 System (optical) alignment
- 5 Quality and response of detectors etc

Figure 7.14 shows the slit function of an NPL Czerny-Turner double monochromator before and after instrument overhaul which included replacing the four spherical mirrors. A Pen-Ray low-pressure mercury lamp was used as a source for the 546.07 nm line. The distortions in the shape are due in part to one or more of the mirrors being out of focus, and modifications required in the mechanism controlling the sin θ mechanism of the grating movement. These are presented to emphasize the difficulty in ensuring the slit profile is as narrow and symmetrical as possible. The resolution of the D330/D331 with any 300 l/mm grating (regardless of the blaze wavelength) depends on the width to which the entrance and exit slits are set. For equal entrance and exit slit widths of 0.1 mm, the theoretical resolution is 0.55 nm. Following the monochromator overhaul, there is symmetry on either side of the peak value and the new FWHM is 0.66 nm, compared with 0.86 nm prior to the overhaul. [Hunt and Ward (1998)].

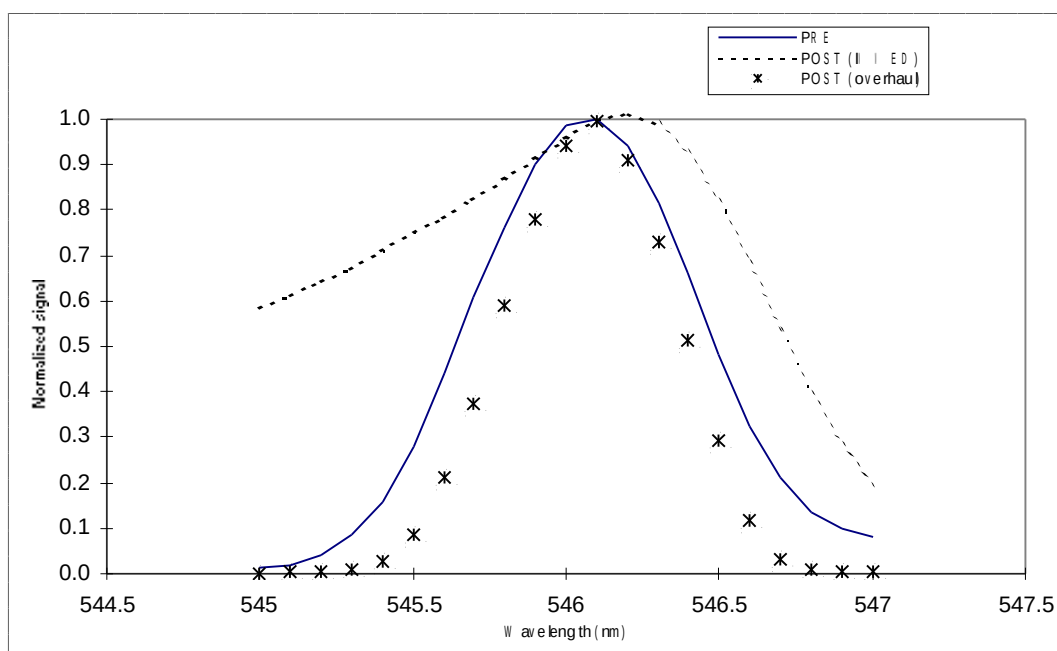


Figure 7.14: From Hunt and Ward (1998) slitprofiles of a Czerny-Turner double monochromator at 546.07 nm using a 300 l/mm grating and slitwidths of 0.1 mm

For further information and references, See Appendix 9

References Section 7.1

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7.2 Instrument Types and Problems - Overview

Example/s	Generic	Brief Description of Methodology	Problems/Discussion
Brewer (Sci-Tec Instruments)	[Spectrometer] Spectroradiometer	“..was originally designed to perform total ozone measurements in the UV region by using either direct sunlight or diffuse skylight from zenith. With the addition of a diffuser the Brewer also became capable of taking spectral measurements of the global solar irradiance. These scans cover the spectral region 290-325 nm for the conventional single-monochromator (Mark II & IV) and 285-365 nm for a double-monochromator (Mark III) instrument.” <i>[Bais (1997) p5200]</i> <u>From Sci-Tec Website, http://www.sci-tec.com/product/ozone/brewersp.htm:</u> 1) Accuracy: 1% (on direct sun total ozone) 2) Resolution: 0.6 nm @ 303.2, 306.3, 310.1, 313.5, 316.8, 320.1 nm 0.85 nm @ 426.4, 431.4, 437.3, 442.8, 448.1, 453.2 nm Additional in MKIV 3) Operating Temperature: -50/C to +50/C (with cover and heater options) 4) Wavelength Precision: 0.005 nm, Stability: 0.01 nm over operating temperature Range: 290-325 nm - MKII, Range: 286.5-363 nm - MKIII Range: standard 286.5-363 nm and 430-540 nm - MKIV 5) Control Microprocessor RCA COSMAC 6) Interface RS232C, (optional) limited distance data sets for PC/Brewer communications over 15 m 7) Photomultiplier Low noise EMI 9789QA or equivalent 8) Optics Modified Ebert* spectrometer, focal length 16 cm, width 11 and aperature ratio F/6 - MKII, MKIV Modified dual Ebert* spectrometers, focal length 16 cm, width 11 cm, and aperature ratio F/6, 3600 line Holographic gratings - MKIII 9) "Standard" Source Internal tungsten halogen lamp, 20 W, 12 V 10) Wavelength Calibration Internal mercury germicidal lamp 11) UV Calibration Source (optional) Tungsten halogen; 50W,12V: typically mounted 5 cm from diffuser 12) Shutter Cycling 0.112 sec. slit-1, 1.6 sec. total cycle time for 6 slits 13) Azimuth Tracking Height, 91 cm, mechanical enclosure, 30 cm x 30 cm x 35 cm. power requirements, 100 VAC/240 VAC, 50/60 Hz resolution, 14) Zenith Tracking Resolution 0.13//step 15) UV Scanning A quartz dome and Teflon facilitate good cosine response and hemispherical field of view. This allows for spectral, and integrated weighted and non-weighted irradiance monitoring over the wavelength ranges.	Direct SUV measurements have only recently been included in observational programs due to the following problems: 1) Need for pointing system to direct the SUV into the spectrometer, which could be used with existing instruments - resolved by the use of fibres 2) Difficulty in establishing reliable methodology for absolute calibration of SUV - still unperfected <i>[Bais (1997) p5199]</i> * Ebert - also known as Ebert-Fastie or Fastie-Ebert. This configuration normally consists of a large spherical mirror and single plane diffraction grating. Radiation from the sources is directed towards one portion of the spherical mirror which collimates it and directs onto the grating. The dispersed radiation is directed back onto another section of the spherical mirror which it then focuses onto an exit slit. <i>[Lerner and Thevenon (1988)]</i> “It is an inexpensive and commonly used design, but exhibits limited ability to maintain image quality off-axis due to system aberrations such as spherical aberration, coma, astigmatism, and a curved focal field” <i>[ibid section 2.2]</i> NB: Sci-Tec refer to a ‘modified’ Ebert.

Example/s	Generic	Brief Description of Methodology	Problems/Discussion
Dobson For a historical review, see Dobson (1968)	[Spectrometer] Spectroradiometer	A double monochromator based instrument used to measure SUV at each wavelength interval over a wavelength range usually from ~290-400 nm; the data may be weighted with a particular biological action spectrum to assess the health and/or environmental impacts. “..measures ratios of ultraviolet light at two pairs of wavelengths. Within each pair, one wavelength absorbs ozone strongly, the other weakly, so that the ozone absorption can be determined. The wavelengths were chosen to make the field measurements relatively simple and robust and to minimize sensitivity to Rayleigh scattering and to extinction by stratospheric aerosols....can also be used to measure the ozone profile by means of the Umkehr technique. Measurements are made as the Sun is setting (or rising) and the vertical distribution of ozone is inferred from the changing path of the sunlight through the atmosphere (in particular, as the mean altitude of the Rayleigh scattering changes).” [Harris et al (1997) p1572] “The calibration of the Dobson instruments has been maintained through a program of intercomparisons traceable to the international standard instrument (I-83) and through instrumental tests. The standard of maintenance of calibration has varied greatly from station to station, but the general quality has increased steadily over time {WMO (1994) <i>Survey of WMO_sponsored Dobson spectrophotometer intercomparisons</i>, Global Ozone and Monit. Network WMO report 20, Geneva}....the stability of the international standard is estimated to be $\pm 1\%$ per decade {McPeters & Komhyr (1991) <i>J.Geophys.Res.</i>, 96 p2987-2993}” [ibid]	“It is relatively easy to detect ozone in the atmosphere. However, it has proved difficult to make sufficiently precise and numerous measurements to determine changes of a few percent in a decade. Difficulties include knowing how the absolute calibrations of the instruments change with time; assessing how much variability in any set of measurements is caused by the instrument and how much by natural variability in the atmosphere; and the interpreting comparisons of measurements made by different instruments, especially when different techniques are used. [ibid p1571]
Robertson-Berger meter (RB meter)	Broadband Radiometer	NB: Berger himself calls this a Sunburning Ultraviolet Meter (SUV Meter) “A meter for measuring the skin sunburn effectiveness of a light source..that..utilizes the principle of a fluorescing phosphor with associated prefilter, post filter and detector. The meter spectral response is essentially the excitation spectrum of magnesium tungstate phosphor which is similar to the erythema action spectrum.” [Berger (1976) :p587] “Light enters through a quartz dome and passes through a broad solar visible filter. The phosphor reradiates light in the green band that passes through a second filter to eliminate any stray transmitted UVR before reaching a photodiode. A current is produced by the photodiode in proportion to the incident light. A capacitive integrator sums the detector current and triggers a count once a specific voltage threshold is reached. Every half hour the meter prints the accumulated count on paper tape, then resets the counter to zero.” [Grainger (1993) p344]	“Virtually the only long-term systematic monitoring programs are those using the RB meter.....which was designed to measure the erythema potential of solar insolation by approximating the spectral response of human skin to UVB irradiance. However, the approximation is not perfect, which together with other uncertainties of instrument characterization and calibration has led to doubts about how well the instrument and its data are able to detect trends in incident UVB insolation levels.” [Grainger (1993):p343]
	Dosimeter	“Dosimetry is the measurement of the dose of radiation received by a given surface over a specified period of time.... Several dosimeters for UV radiation have been proposed and used in a variety of studies...The most widely employed....is polysulphone film {Davis et al (1976) <i>A possible dosimeter for ultraviolet radiation</i>, Nature 261 p169-70} a clear polymer film that can be made into small badges for epidemiological or other uses....The film changes its absorbance at 330 nm on exposure to UV radiation and has a response spectrum similar to the erythema action spectrum. Pre and post dose absorbance measurements are required and the absorbance can then be related to the erythemally effective dose of radiation received by the film badge, and the surface to which it was attached” [Webb (1997) p28]	“Dosimeters suffer from the same restrictions as broadband meters in that they report only the total (weighted) result of an irradiation, most often expressed in biologically effective units. The relation between two ‘effect units’ established under one source will not hold if the source changes.” [ibid p29] refer to Webb (1997) p29 for more discussion and references on this topic.

Example/s	Generic	Brief Description of Methodology	Problems/Discussion
GUV-511 made by Biospherical	Multichannel Instrument	“A compromise between single broadband instruments and spectroradiometers is multichannel instruments with channels in both the UV-B and UV-A regions.. I show that data from such instruments combined with radiative transfer calculations provide reliable data on biologically effective UV dose rates, total ozone abundance, and effective cloud optical depth or cloud transmission. Only two channels are required to determine these quantities. Furthermore, by using the derived total ozone abundance and the effective cloud optical depth as input to a radiative transfer model, one can compute a high-wavelength-resolution spectrum covering both UV-B and UV-A regions.....the optical part of a multichannel filter instrument consists typically of a Teflon or a quartz diffuser, interference filters, and photosensitive detectors....One can calibrate each channel in the filter instrument in absolute units (ie $W \cdot m^{-2} \cdot nm^{-1}$) by placing the instrument in front of calibration lamp....(however) Booth et al {(1994) <i>Errors in the reporting of solar spectral irradiance using moderate bandwidth radiometers and experimental investigation</i>, Ocean Optics XII Proc SPIE 2258 p654-663} ...showed that using the Sun ..instead..will reduce errors considerably. The ... instrument has been compared with a Dobson and a Brewer.. For more than one year. The agreement between ozone values is good for at least all SZA's<83° and for clear as well as cloudy skies. ” [Dahlback (1996)] “ The GUV-511C Ground-based Ultraviolet Radiometer has been specifically designed to measure cosine-corrected downwelling irradiance at 305, 320, 340, 380 nm and PAR (400-700 nm). Incorporating a custom interference filter with a "solar blind" detector to reduce red-leakage, the 305-nm sensor is designed to respond to the region of the UV-B spectrum strongly affected by atmospheric ozone concentration. Similarly, the 320- and 340-nm sensors incorporate custom interference filters that, in combination with UV-passing/light blocking filters and sensitive silicon photodiodes, minimize errors associated with spectral leakage. To minimize instrument variability in the measurement, the GUV-511 features active internal heating to maintain the temperature of the optical elements at 40/C or 50/C. The GUV-511 may be purchased as a stand-alone monitoring systems or as an AC-powered surface reference for the PUV-500 vertical profiling system.” [Biospherical (1998)] The type of ‘solar-blind’ detector is not stated, nor is the methodology for cosine correction.	“For a channel with center wavelength of 305 nm and a bandwidth of 10 nm FWHM.....the error in measured irradiance with such a channel relative to a high wavelength-resolution spectroradiometer depends on how much the atmospheric conditions during the measurement differ from the atmospheric conditions at the time of calibration.” [Dahlback (1996)]

Example/s	Generic	Brief Description of Methodology	Problems/Discussion
Microtops II Ozonometer made by Solar Light Inc	Sunphotometer	“A first comparison of total ozone measurements done with the Microtops II sunphotometer and the Uccle Brewer spectrophotometer {see section on intercomparisons for more information}. The Microtops measurements are manual measurements, done by the operator when weather conditions allow, eg when bright sun-shine is available. The instrument is always directed at the sun; the readings correspond to the ‘best’ mean computed from 40 fast measurements done during approximately 10 seconds. For computing the total ozone thickness, several other parameters are simultaneously measured: barometric pressure, precipitable water column, aerosol optical thickness. Location, altitude and time are programmed into the device.” <i>[Massen (1997)]</i> “ MICROTOPS II is a 5 channel hand-held sunphotometer for measuring total ozone column easily, accurately and dependably. Direct solar ultraviolet radiation at 3 wavelengths within the UV-B range is measured and stored. Optionally, MICROTOPS II can measure total water vapor (940 nm) and aerosol optical (AOD) at 1020 nanometers. MICROTOPS II features an accuracy comparable to much larger and more expensive instruments. Optional GPS receiver automates operation. This instrument is also available in standard WMO or custom configuration for sunphotometry <u>Specifications</u> Optical channels (std. configuration) 305.5 ±0.3 nm, 2.4 nm FWHM 312.5 ±0.3 nm, 2.4 nm FWHM 320.0 ±0.3 nm, 2.4 nm 940 ±1.5 nm, 10 nm FWHM (optional) 1020 ±1.5 nm, 10 nm FWHM (optional) Stray light 1E-6 for 305.5 nm filter, 1E-5 for 312.5 nm ,1E-5 for 320.0 nm filter Resolution 0.0001uW/cm² on 300nm channel Dynamic range >300,000 Angle of view 2.5/ Precision 1-2% Nonlinearity max 0.002% Operating Environment 0 to 50/C, no precipitation Computer interface RS-232C Power source 4xAA Alkaline batteries” <i>[Solar Light (1998)]</i> Filter/s and detector type not specified.	Massen (1997) suggests that the Microtops is a ‘very useful’ device for measuring total ozone thickness, due to its ‘outstanding ease of use’. But notes that it cannot rival the performance of instruments such as the Brewer. See section on intercomparisons for the results of Massen’s experiment.

7.3 Overview of Functional Dependencies

Refer to Grainger (1993) [p344]

Functional Dependency (FD)	Brief Description/Discussion
Azimuthal Response (AR)	“ It is any change in the response of the instrument, to a fixed input, as the input source rotates around the input optics in the azimuthal direction at a fixed zenith angle (like the sun moving east to west, but in the test the zenith angle does not change). This has to be tested at a range of zenith angles, so another way to consider it is to look for any change in the cosine response between 0° and 90° zenith, measured in different azimuthal planes (points around the diffuser). Hopefully there is insignificant azimuthal response, as it is very difficult to correct for. “ [Webb (1998)]
Cosine Response (CR) you will also see the term <i>cosine error</i>, the reciprocal of the cosine error, is sometimes called the <i>cosine correction</i>. These describe the same phenomenon	1) “The radiance of a pencil beam on a horizontal surface varies as $\cos \theta$, where θ is the angle between the beam and the surface normal”. [Grainger (1993) p345] {compare with Lambert’s Law - see McCluney (1994) p13-14} However, “..few instruments can adequately match this ideal cosine response’ 2) “A radiation beam $\{A\}E_{\text{DIR}}(\theta)$ received by a radiance instrument at the incidence angle θ (0°- 90°) should produce a signal proportional to $\{B\}E_{\text{DIR}}(\theta=0^\circ)\cos \theta$. If direct radiation is measured with an instrument designed for global radiation measurements, the measured radiation..deviates from this cosine law, particularly at high incidence angles. The ratios $X(\theta)$ between the measured radiation $\{A\}$ and the value $\{B\}$ that the instrument should measure are not =1 for all incidence angles of θ, but ..deviate in dependence of the incidence angle. They are called the cosine error of the instrument and the reciprocal values, $C(\theta)$...can be considered a cosine correction for direct radiation” [Feusterm et al (1997)] 3) “Global solar irradiance measurements performed by most of the existing spectroradiometers....suffer from cosine error..which can vary from a few percent ..to 20% depending on the measurement conditions and the characteristics of the system. These systematic but variable magnitude errors..impose great difficulties on attempts to establish comparable data sets among instruments, but may also affect the homogeneity of the measurements performed by the same instrument under variable conditions” [Bais et al (1998) p6339] According to Bais et al (1998), for actual irradiance, F and measured irradiance F_N, the for a particular global irradiance measurement a correction factor f_g can be defined as: $f_g = \frac{F'_g}{F_g} = \frac{(F'_d + F'_b)}{F_g} \quad \text{Where: } F_N \text{ and } F_g \text{ are the measured and actual global irradiances, } F_{Nd} \text{ is the diffuse component of the measured irradiance, } F_{Nb} \text{ is the direct component of the measured irradiance}$ The correction factor for the diffuse component of the <i>measured</i> irradiance is given by $f_d = \frac{F'_d}{F_d}$ and $f_b = \frac{F'_b}{F_b}$ is the correction factor for the <i>direct</i> component of the measured irradiance, “..which is the so-called angular response of the spectroradiometer and is defined as the ratio of the incident to the measured light intensity, is a function of the angle of incidence and wavelength, and can be determined in the laboratory “ [ibid p6340]. Rearranging in terms of the correction factors, yields $f_g = (1 - f_{bg})f_d + f_{bg}f_b$ which may be obtained subject to the following requirements, that f_d and f_b are known and that the ratio of the direct and global solar irradiances f_{bg} be calculated.

Functional Dependency (FD)	Brief Description/Discussion
Field of View (FoV)	The maximum area that can be seen through a lens or an optical system, “the angle 2 which the extreme rays entering the system make with the axis is called the half-field angle and limits the width of the object that can be seen” <i>[Jenkins & White (1976)]</i>
Linearity (Lin)	“It is desirable for all measuring systems to have a linear response over the entire range of radiation intensities which they may be expected to measure.” <i>[Webb (1995) p10]</i>
Sensitivity (Sen)	“..the smallest incremental change in irradiation that can be detected” <i>[Webb (1995) p10]</i>
Spectral Response (SR)	(See Appendix 8) Responsivity (of a detector) is the ratio of photocurrent produced to the optical power received by the system. Spectral Responsivity is the wavelength dependent version .
Temperature Response (TR)	Instrument response to ambient temperature changes

7.4 Functional Dependencies Characterized?

Only two examples will be listed to give some idea of the detail required. Note that there is a vast body of literature to be scanned. It may be that some of this work has been done and is tucked away in a paragraph of a paper which would not immediately suggest its presence.

Example/s	Functional Dependencies Characterized?
1) Brewer (Sci-Tec Instruments: see Appendix 2) Dobson	AR: None located in the literature CR: Bais et al (1998) have developed a method for correcting the CR of the Brewer MKIII. Applying the theory described in table 7.3, the angular response of the instrument was determined using a 1000W quartz halogen lamp. The authors give uncertainties in these laboratory measurements to $\pm 1.5\%$. For the direct-to-global ratio, f_{db} synchronous direct and global measurements were made at each wavelength of interest and it was noted that f_{db} decreases with decreasing wavelength with a non linear response below ~ 310 nm. By way of example, the authors give their results at 330 nm for daytime measurements (diurnal). A variation of $\sim 4\%$ was reduced to 2.5% when their cosine correction method was applied to the Brewer data. Lin: "For a spectroradiometer, making an instantaneous measurement, non-linearity of response can be accepted as long as the non-linearity is well characterised and can be dealt with as part of the calibration procedure." *[Webb (1995) p10] Sen: "...is dependent on the type of detector and the electrical noise generated by signal processing." [Webb(1995) p10] SR: None located in the literature TR: None located in the literature
Robertson-Berger meter (RB meter)	AR: None located in the literature CR: None located in the literature Lin: * "In dosimetry, this is not possible as the dosimeter integrates the effect over a period of time and a single calibration scale must be applicable to all incident intensities during that time. This does not mean that the calibration graph of exposure vs response needs to be a straight line, but that a dose assessment does not depend on the manner of irradiance: a short, high intensity exposure will give the same result as a long, low intensity exposure" [Webb (1995) p10] SR: None located in the literature Sen: "For a dosimeter, this will be determined by the threshold dose required for the dosimeter reaction and the sensitivity of the analysis processes used to evaluate the exposed dosimeter." [Webb (1995) p10] TR: Whilst it is acknowledged that this may be an important source of error, little is known (at 1993) about it.[Grainger p344]

References Sections 7.2 - 7.4

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

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8. UV INSTRUMENT INTERCOMPARISONS

Researchers in the field were finding that the uncertainties in their results differed significantly. In order to achieve some standardization, various intercomparisons of instrumentation and methodology was undertaken in various parts of the world. These are discussed below and since inter-country co-operation is significant, the intercomparisons are listed according to where the intercomparison was carried out rather than the countries from where the instrumentation originates. 'European' is placed in parenthesis because from the second intercomparison, New Zealand and other non-European countries were involved, that is, take European to mean experiment carried out in Europe and so on. Whilst there will almost certainly be some work that has not come to our attention, the following major intercomparisons will be discussed briefly:

1990	German	- held in Germany
1991	European	- held in Greece
1992	'European'	- held in Greece
1992	Antipodean/German	- held in New Zealand
1993	European	- held in Germany
1993	Nordic	- held in Izana, Tenerife (Spain)
1994	Antipodean/German/US	- held in Germany
1994	North American	- Boulder, Colorado
1995	North American	- Boulder, Colorado
1995	European	- held in Italy

See Webb (1997) [p54-58] for more information

8.1 'European' Intercomparisons

8.1.1 GREECE 1991 & 1992

Whilst other smaller intercomparisons had taken place (for example Seckmeyer et al, in July 1990, Germany but not published until 1994); the first major European intercomparison took place outside the village of Panorama in Greece, 12km from Thessalonika during July 1991 [*Gardiner & Krisch (1991) p3, Gardiner et al (1993)*]; the second occurred at the same venue in August 1992 [*Gardiner (1993)*]. .

The objective of the intercomparison was to establish the criteria for a Europe-wide network of radiometers which would be measuring UVB irradiance

In August 1992, the original participants were joined by Canada, Germany, Netherlands and New Zealand.

Location:	Latitude 40° 36' N; Longitude 23° 04' E, Altitude of Instrument Pad 385m above Sea Level
Principal Requirement:	Measurement of Global (hemispherical) Spectral Irradiance, that is, the amount of energy arriving per second on unit area of a horizontal surface, per unit wavelength interval from all parts of the sky above the horizontal, including the disc of the Sun itself: Units W.m ⁻² .nm ⁻¹

These 'European' intercomparisons are discussed in slightly more detail to give an indication of the participants, types of instrument and methodologies used. Others will be discussed in general terms. For Participants Refer to table 8.1

Table 8.1 Participants [*Gardiner & Krisch (1991) p4*] in First European Intercomparison and

their Instruments [ibid Appendix C & D]. New Participants at Second Intercomparison #[Gardiner & Kirsch (1993) p4] and update of instruments #[Gardiner & Kirsch (1993) Appendix D]

Country	Institution	Instrument Used
Austria - Innsbruck AI	Institut für Medizinische Physik	Bentham DM150 Double Monochromator. <i>Complete commercial spectroradiometer modified in collaboration with manufacturer</i>
Austria - Wien AW	Universität für Bodenkultur, Vienna	Based on Jobin-Yvon DH10 Double Monochromator <i>Bespoke instrument, built in house</i>
Belgium B	Institut d'Aéronomie Spatiale de Belgique	Based on Jobin-Yvon DH10 Double Monochromator <i>Bespoke instrument, built in house</i>
#Canada CA	Sci-Tec Instruments Inc	Brewer MKIII (includes modified Ebert-Fastie 'monochromator') <i>Complete commercial spectroradiometer, manufacturer participating</i>
#Germany D	Institut für Biochemische Pflanzenpathologie	Bentham DM300 Double Monochromator <i>Commercial spectroradiometer, possibly modified, but not stated</i>
Great Britain GB	University of Reading	Optronic 742 spectroradiometer {Double (?) Monochromator} <i>Commercially available spectroradiometer operated as supplied.</i>
Greece GR	University of Thessaloniki	Brewer MKII (includes modified Ebert-Fastie 'monochromator') 1) Ozone spectrometer No: 005 2) SCI-TEC instruments Ozone Spectrometer No: 017 (the Canadian travelling standard) set up on 6/7/91. Both with Teflon diffusers of ~35 mm diameter under quartz domes. <i>Commercially available spectroradiometer operated as supplied.</i>
Norway N	University of Tromsø	Based on Jobin-Yvon HR320 Single Monochromator <i>Bespoke instrument, built in house</i>
#Netherlands N	Royal Netherlands Meteorological Institute	EG&G M1232: Based on a crossed Czerny-Turner, Single Monochromator using diode array hence no need to scan <i>Bespoke instrument, built in house</i>
#New Zealand NZ	Industrial Research Ltd	Kratos GM200-2: Double Monochromator <i>Commercially available spectroradiometer operated as supplied?</i>

It was generally concluded that there was a marked improvement from the first to the second intercomparison and discussion regarding the setting up of a network began. With that in mind it was determined that there would be two requirements;

- 1 Technical specification, "which will allow process studies involving the relationships between irradiance and the atmospheric parameters which affect it....A more ambitious aim is to achieve long-term stability in absolute calibration to enable monitoring of secular change in irradiance beyond what would be calculable from total ozone determinations by a Dobson or Brewer....in summary the minimum requirement for a network spectroradiometer (is that it) should combine the best features of the AI and GB instruments, both in specification and performance" [Gardiner & Kirsch (1993) p 17]
- 2 Operational Competence, "Good laboratory practice will be reflected in stable lamp calibrations. These will typically be scans of a certified 100W lamp at a distance of 500 mm and will be computed on the basis of an instrument calibration which has been derived solely from the operator's own system of

lamps.....A competent operator will produce results quite rapidly, because the procedures are routine, the calibrations are stable, and the data are quality controlled more or less automatically.....a competent operator will adopt and adhere to a consistent policy on time zone, physical units, file format, and file naming....Laboratory measurements of instrumental characteristics such as slit function, angular response, stray light, dark current, noise and data to irradiance will be documented, including the spectral calibration and any non-linearity, and cosine effect..There will also be a description of the observing site, including drawings and measurements of the azimuth and elevation of obstructions above the horizon, in order to establish that the instrument has an adequate view of the sky hemisphere.” *[ibid p18]*

8.1.2 GERMANY 1993

This was considered the third and final intercomparison in a set with the two held in Greece. Only new participants will be listed, but note that some of the acronyms have changed. AI and AW become ATI and ATW respectively. B was changed to BE, N to NO, D has gone and there are three new participants from Germany. NL becomes NLK as there is another participant from the Netherlands. Canada and New Zealand did not take part. See table 8.2

Table 8.2 Participants [*Gardiner & Krisch (1995) p5*] and their Instruments [*ibid Appendix C & D*].

Country	Institution	Instrument Used
Germany DEG (?) DEM	Institut für Atmosphärische Umweltforschung	Bentham DM 300 Double Monochromator
Germany DEH	Deutscher Wetterdienst	Optronic 752
Germany DEK	Botanisches Institut der Universität Karlsruhe	Brewer with Single Monochromator
France FR	University of Lille	Jobin-Yvon DH10
Netherlands NLR	National Institute of Public Health	1) NLRD: Dilor XY Double Monochromator 2) NLRE: Diode Array Spectrograph

At the end of this STEP project, the participants concluded that the act of participating in these intercomparisons had led to significant improvements in specification and operation of spectroradiometers. It was noted in this third and last intercomparison that, “some of the instruments displayed systematic errors of 15%, even with the Sun high in the sky. The issues of instrument specification and operator competence were re-emphasized. [*Gardiner & Kirsch (1995)*]

8.1.4 ITALY 1995

Although STEP report 59 was described as ‘final’, a fourth intercomparison took place in Italy and another ‘final’ report was produced. [*Webb (1997b) P69*].

Participants from one or more of the previous intercomparisons were ATI, ATW, BE, DEG, FR, GB, GR, NLK, NLR, NO. New participants were:

FI, Finland: Finnish Meteorological Society (Instrument: not explicitly stated)
IT, Italy: Joint Research Centre, Ispra (Instrument: Optronic 754)

It was concluded that this was the most successful of the four intercomparisons due to the high-quality results and operation of campaign protocols. Six of the participating instruments were found

to be producing consistent results. Problems outstanding were issues to do with cosine response and “the absence of a proven technique for achieving a uniform calibration at all the home sites.....these regular intercomparisons provide the only satisfactory evidence of competent and reliable performance in the measurement of absolute spectral irradiance at the surface of the earth.” [Webb (1997b) p87]

8.2 North American Intercomparisons

Only the 1995 intercomparison will be discussed.

The site was Table Mountain, ~12.9 km north of Boulder, Colorado.

“For synchronized measurements of solar irradiance, the spectroradiometers were located on individual concrete pads on the south side of the plateau at a latitude of 40.125°N, longitude 105.237°W, and elevation 1689 m.” [Early *et al* (1998)]

Co-ordinators were NIST and NOAA. See table 8.3 for a list of participants

Table 8.3 Participants in the 1995 North American Intercomparison and their Instruments [ibid].

Country	Institution	Instrument Used
Canada AES	Atmospheric Environment Services	Sci-Tec Brewer MK II (No: 039)
USA EPA	Environmental Protection Agency: University of Georgia, Dept of Physics and Astronomy	Sci-Tec Brewer MKIV (No: 114)
USA NSF	National Science Foundation	Biospherical Instruments SUV-100 (No: B-007)
USA SERC	Smithsonian Environmental Research Centre	SERC SR-18 (No: UD)
USA USDA	United States Department of Agriculture: Atmospheric Sciences Research Centre (ASRC)	ASRC/RSI UV Spectroradiometer (No: 901)

It was generally concluded that the 1995 intercomparison improved on the 1994 results, in particular there was an improvement in outdoor characterizations. Lamps calibrated in the horizontal position were used which improved the calibration of the instruments. Differences between the NIST and participants irradiance scales were -5 to 10% apparently within the same range as the 1994 results.

The wavelength uncertainties (~0.15 nm) were a significant component of the relative standard deviation and it was thought that a common technique for calibrating wavelength might improve the situation. [ibid]

References Section 8

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

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9. THE NATIONAL MEASUREMENT SYSTEM (NMS)

This report was produced as part of the current programme for Optical Radiation Metrology (ORM) 1998 - 2001. In order to discuss the relevance and implications of this work in relation to the NMS, it is first necessary to outline the work and brief of the NMS.

9.1 Role of The National Measurement System Directorate (NMSD)

The National Measurement System Directorate (NMSD) is part of the United Kingdom (UK) Department of Trade and Industry (DTI); and consists of the National Measurement System Policy Unit (NMSPU) and the National Measurement Laboratory Unit (NMLU) [Hooley (1998A)].

The NMSDs role is:

- 1 To promote industrial competitiveness by providing a comprehensive National Measurement System (NMS) for industry and to act as the centre within Government for policy on measurement standards for industrial, commercial, environmental, healthcare and regulatory use. This work is accomplished by the NMSPU.
- 2 To supervise the contract under which the National Physical Laboratory (NPL) is operated by a private contractor, and to provide a contact point for questions regarding the DTI's former research laboratories. The NMLU provides this function.
[Hooley (1998A)].

9.2 NMSPU Research Programmes

Following consultations with industry, the NMSPU produces a forward plan covering work programmes it hopes to fund over a three-year period (these have been reduced from five years). Rolling reports appear to be produced approximately annually, and an example produced by the DTI's Measurement Advisory Committee (MAC) dated October 1997 can be downloaded from the DTI's NMS website [MAC (1997)]. The programmes are chosen to, 'extend, refine and maintain the range of measurement standards needed....' [Hooley (1998B)].

A Public Release Version (PRV) of the current ORM programme (1998 - 2001) can also be downloaded from the DTI's NMS website [NMSPU (1998A)].

References Section 9

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

Hooley, A (1998A) *The National Measurement System Directorate*, Department of Trade and Industry, National Measurement Directorate Website, <http://dtinfo1.dti.gov.uk/nmd/index.htm>, updated 11th August

MAC (1997) *Five Year Forward Look: Version 1.3 October 1997*, Department of Trade and Industry, National Measurement Directorate Website, <http://dtinfo1.dti.gov.uk/nmd/....> Downloadable file 5yflprv.doc dated 28/1/98

Hooley, A (1998B) *National Measurement System Policy Unit (NMSPU)*, Department of Trade and Industry, National Measurement Directorate Website, <http://dtinfo1.dti.gov.uk/nmd/nmspu.htm>

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10. CONCLUSION

The need to accurately monitor Solar UV is no longer in dispute. Whilst there is much work still to be done in particular areas to understand the way other life forms use UV to 'see', and plants seem to have evolved to cater for this, on the whole we are currently agreed that too much UVB is harmful to biosystems. As it is becoming clear that these effects are wavelength dependent, the importance of spectrally resolved data grows. Photopic environments must be evaluated to discover what the ambient levels of UV are both on land and in water where there is still much work to be done.

Most measuring systems still rely on incandescent lamps as transfer standards which produce relatively small amounts of UV and are not sufficiently stable over long periods of time. Since it is now believed that the harmful effects of UV are wavelength dependent, the requirement now, is for repeatable and accurate spectrally resolved measurements. These will require stable, portable standards. In addition, there appears to be a requirement for a consensus on how uncertainties are determined.

11. ACKNOWLEDGEMENTS

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My grateful thanks also to Dr Peter Gillespie for the translations of all the older French papers for which no translation could be found, and to Dr Michael Stock for the translation of Ritter's paper.

Last but not least, my thanks also go to Dr Teresa Goodman for reading the report and commenting on accuracy and completeness.

12. APPENDICES

12 APPENDICES

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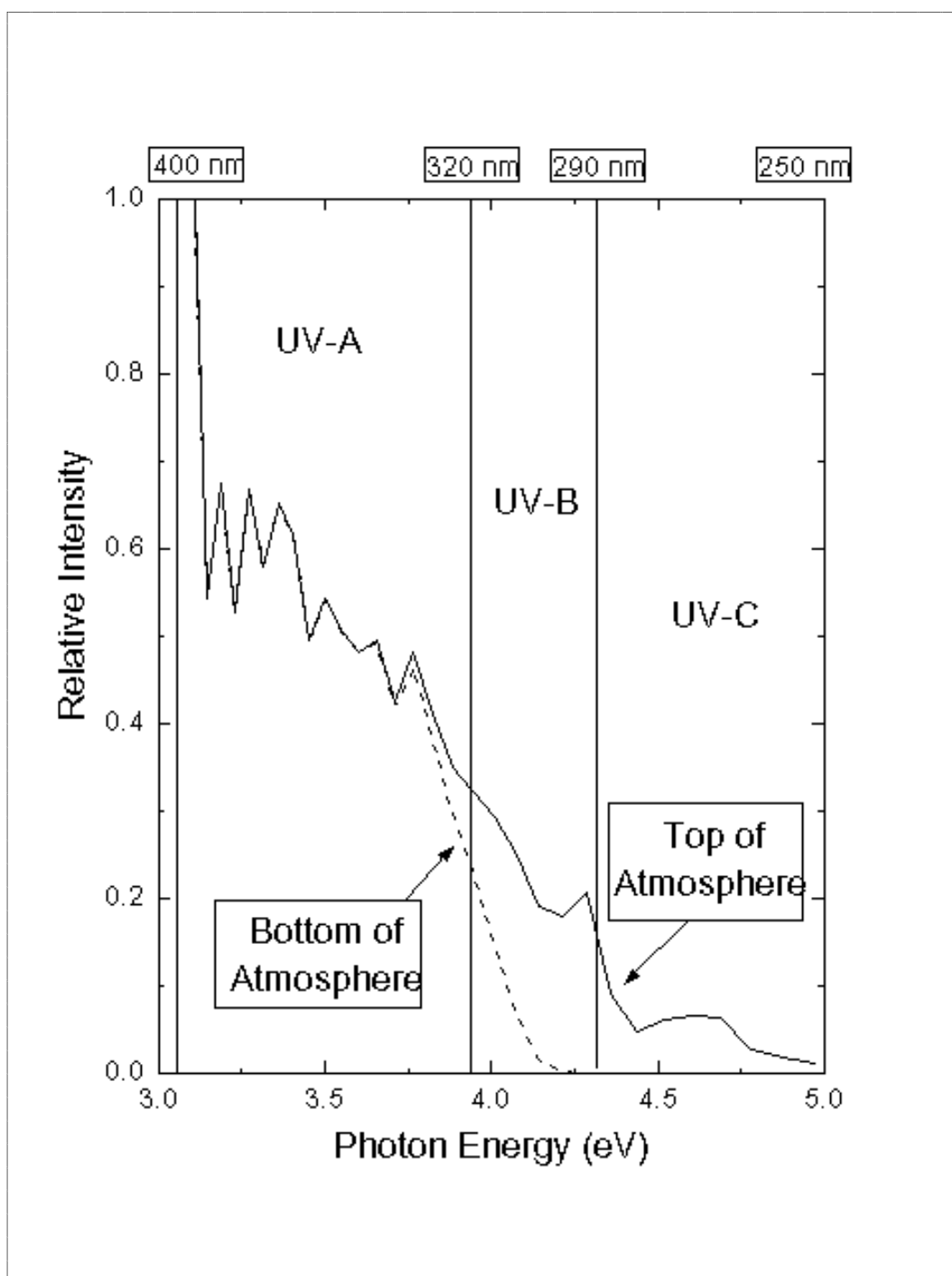
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APPENDIX 1 HEALTH AND ECOLOGICAL EFFECTS

It is worth noting that the UV ranges are not cast in stone and seem to depend on the discipline undertaking the particular piece of research. Figure Ap1.1 from Kansas State University website is a plot of these three ranges above and below the earth's atmosphere for a particular 'column' of ozone, ie under the particular conditions in which this data was taken or modelled.

Figure Ap1.1: With permission, from Manney (1998) Spectrum of UV at the top of the atmosphere and at the surface of earth for 300 Dobson Units of Ozone. *{The graph was generated using the UVRISK.EXE programme which can be downloaded from Kansas State University Website. The reference to the data used in the program is given in the help file as follows: Atmospheric Ozone 1985 Assessment of our understanding of the processes controlling its present distribution and change Volume 1. NASA,FAA,NOAA,UNEP,WMO,CED,BFFUT}*



Areas of concern include:

<u>Human-Health:</u>	Increased non-melanoma skin cancers Cataract formation Cataract-related blindness Suppression of the immune system
<u>Terrestrial Plant-life:</u>	Damage to crops and trees
<u>Aquatic Systems:</u>	Damage to marine and freshwater systems.

But as with most other areas of UV science, there is still a lot of work to be done, and much debate about what various areas of research seem to be telling us. For example, the issue of the wavelength dependence of the action of UV appears to remain largely unresolved. Diffey (1982) [p9] recalls the work of Bie and Bang (no paper cited) wherein they establish that , ‘...wavelengths less than 300 nm and especially around 250 nm, were most efficient at killing bacteria.’

The point is, by the ranges defined above, this should fall into the so-called UVC range which only penetrates at high altitudes. There is also an on-going debate regarding the so-called ‘Action Spectrum’ for UV Erythema (sunburning), first determined by Hausser and Vale in 1921 [*Diffey (1982) p9, Diffey (1991) Sec 5.1, Hauser & Vale (1921)*]. Whilst their results indicated that;

‘...there was a rapid increase in skin sensitivity as the radiation wavelength approached 300 nm, with a maximal sensitivity at 297 nm. The sensitivity dropped sharply again at wavelengths below 280 nm but thereafter increasing slowly to reach a second, but lesser, peak at 254 nm’ [*Diffey (1982) p10*]

However, according to Diffey, in 1966 , Freeman et al’s results [*J.Invest.Dermatol., 47 p506*] ‘invert’ these findings, so that the major ‘peak’ now appeared at ~250 nm whilst ~297 nm became the minor ‘peak’ [*Diffey (1982) p90-1*]. Since then;

‘A large number of published erythema action spectra were subject to statistical analysis and combined to produce the reference action spectrum (McKinlay and Diffey 1987)...This action spectrum has been accepted by both the Commission International de l’Eclairage {CIE} and the International Electrotechnical Committee {IEC}, and has been shown to accurately predict the erythematous effectiveness of several polychromatic light sources differing greatly in spectral composition (Urbach 1987)’ [*Diffey 1991*]

Figure Ap1.2 is the action spectrum described in the quote above which Diffey reproduced as figure 7 in his 1991 paper.

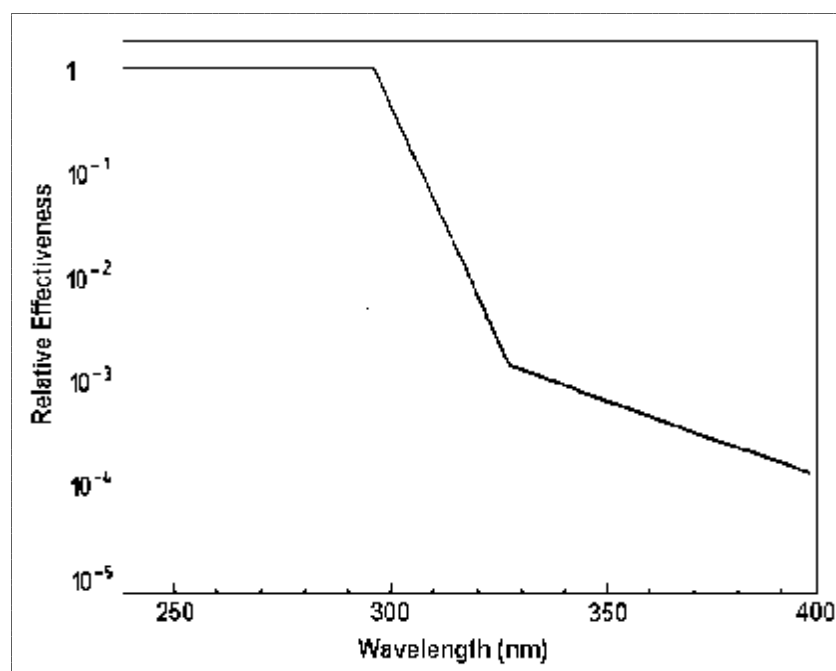


Figure Ap1.2: With permission, from Diffey (1991) “The CIE reference erythema action spectrum”

Figure Ap1.3 from Diffey (1982) is a good illustration of the differences in the various earlier action spectra described above. I have not thought it necessary to obtain the references quoted by Diffey in his figure caption, those may be obtained from his book if required.

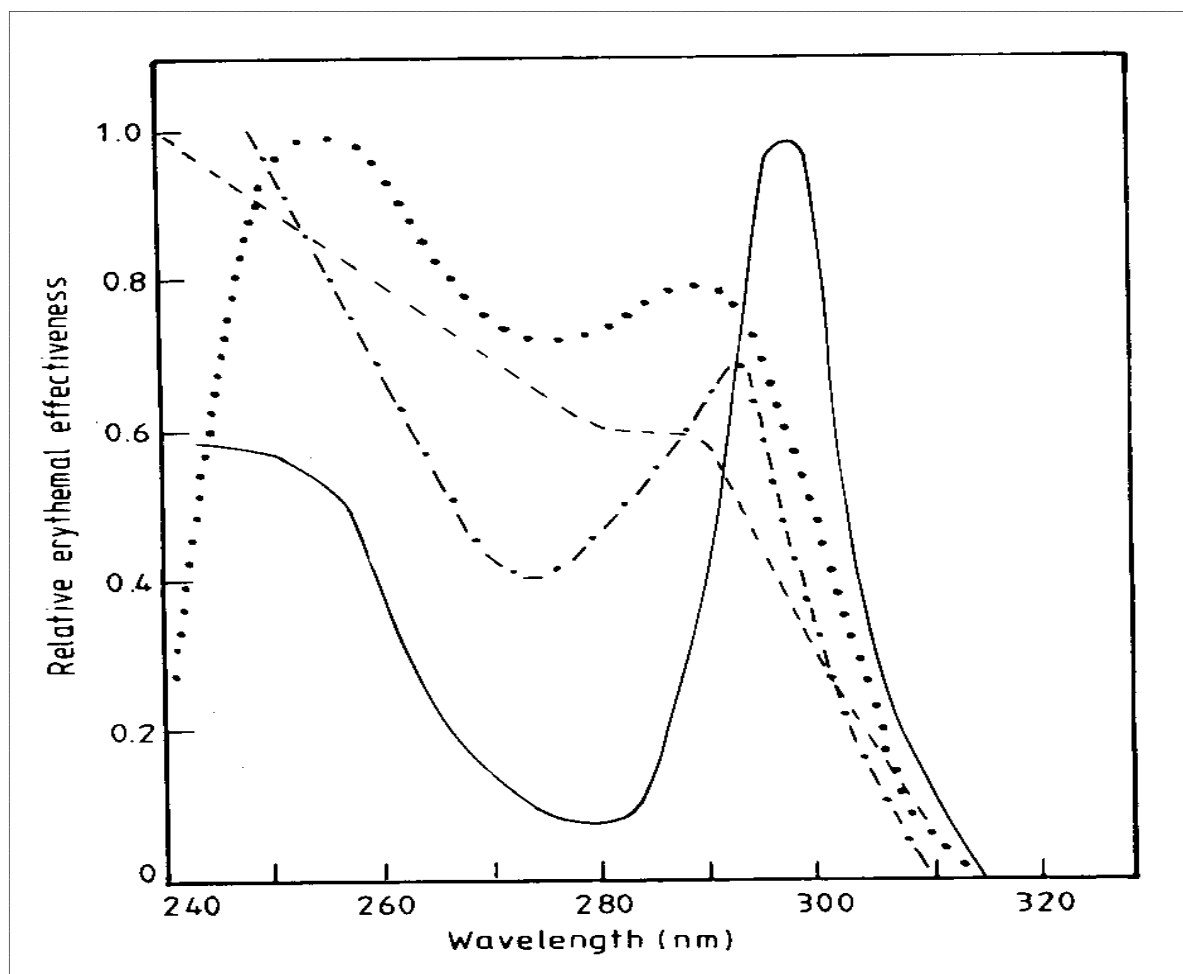


Figure Ap1.3: From Diffey (1982) [p91 figure 5.4] “Comparison of the standard erythemal curve (ICI 1935) with the erythema action spectra determined by Everett et al (1965), Freeman et al (1966), and Cripps and Ramsay (1970): full curve, standard erythemal curve; broken curve, Everett et al; dotted curve, Freeman et al; and chain curve, Cripps and Ramsay” {*Courtesy Professor Brian Diffey*}.

In a private communication, Professor Brian Diffey was asked whether he thought the issue had been resolved and he replied that he, “...currently does not think there are key wavelengths in the skin's response to UVR - rather that action spectra are smoothly varying functions of wavelength with no characteristic lines or discontinuities” [Diffey (1998)].

However, others continue to quote the pre 1966 results in current texts which might mean that the authors are either unaware of the current thinking or do not agree with it (though obviously subjecting the differing spectra to statistical analysis does not of itself, provide any physical conclusions). One example of those quotes:

‘The exact cause of erythema is not known, but it has been shown to be dependent on the wavelength of the radiation. Erythemal efficacy rises to a maximum at a wavelength of 297 nm, declines to a minimum around 270-280 nm, and increases again at shorter wavelengths.’ [Coaten & Marsden (1997) p13]

In aquatic ecosystems, the situation appears even more complex. According to Häder (1991):

"Recent results indicate that orientation mechanisms responsive to both light and gravity are affected by solar ultraviolet radiation in a number of ecologically significant phytoplankton groups [Häder & Liu (1991) *Curr. Microbiol.*, 21 p161-168]. Action spectra inhibitory effects are different from the DNA absorption spectrum and the action spectra calculated for higher plants, indicating that UV radiation affects these organisms by a totally different mechanism (see figure)" [Häder (1991)]

Refer to figure Ap1.4; what is particularly interesting here, is the apparent re-appearance of wavelength dependence on a biosystem. Aquatic ecosystems are particularly important since they, "contribute more biomass than all terrestrial ecosystems combined" [Häder (1991) p33]

In addition it seems there is some evidence that some organisms 'protect' themselves against the harmful effects of UVB.

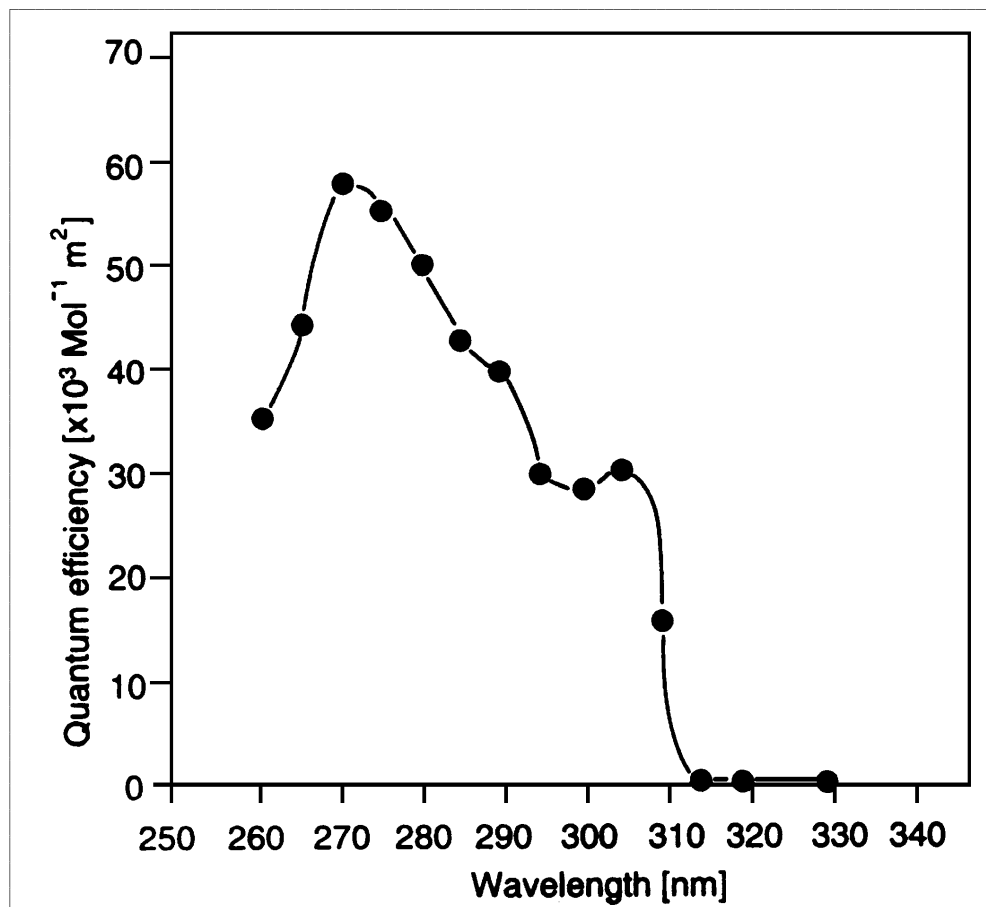


Figure Ap1.4: From Häder (1991) [p36], 'Action Spectrum of the inhibition of motility in the flagellate *Euglena gracilis* by ultraviolet radiation'. (Courtesy United Nations Environment Programme [UNEP])

"Higher plants are known to produce UVB absorbing substances when exposed to ultraviolet radiation, thus protecting them from solar short wavelength radiation [UNEP, 1989]. Recently UV-absorbing substance have been isolated from phytoplankton, as well as from a number of primary and secondary feeders (Caretto et al, 1990; Karentz et al 1991b). However, all of these mycosporine-like amino acids have a maxima in the UVA range and only secondary peaks in the UVB. In addition, it is not clear whether the production of these potentially screening substances can be induced by exposing organisms to ultraviolet radiation [Raven, 1991]. On exception is cyanobacteria where a UVB inducible pigment has been found within the slime sheath surrounding the organisms, which absorbs up to 88% of the UVB radiation [Garcia-Pichel and Castenholz, 1991]" [Häder (1991) p36]

I have not thought it necessary to obtain the references quoted by Häder, those may be obtained from his publication, if required.

Appendix 1.2 CIE Update

Although the Commission Internationale de L'Eclairage (CIE) or International Commission on Illumination (in English) proposed an erythema action spectrum in 1987; [refer to McKinlay, A.F. and B.L. Diffey (1987) *A reference action spectrum for ultraviolet induced erythema in human skin*. CIE J 66, 17-22] “..no erythema quantity and radiometric equivalence was agreed...” until 1997 [CIE (1997)]. The press release for the standard states:

“The CIE undertook a major review of its official recommendations on photobiological effects, their dose relationships and measurement. Based on these investigations the present standard describes present day knowledge of the erythema effect. **The problem of dosimetry in skin photobiology lies in the fact that the ability of ultraviolet (UV) radiation to elicit erythema in human skin depends strongly on wavelength**, encompassing a range of four orders of magnitude between 250 nm and 400 nm. Thus a statement that a subject received an exposure dose of 1 J. cm^{-2} (10^4 J. m^{-2}) of UV radiation conveys nothing about the consequences of that exposure in terms of erythema. If the radiation source was a UVA fluorescent lamp, no erythema response would be seen apart from in people exhibiting severe, abnormal pathological photosensitivity. The same dose delivered from an unfiltered mercury arc lamp or fluorescent sun-lamp would result in marked violaceous erythema in most white skinned individuals. Consequently, photobiologists have long recognised the need to express the exposure as an erythemally-weighted quantity. Recently the term minimal erythema dose (MED) has been used widely as a 'measure' of erythema radiation. This is unreasonable because the MED is not a standard measure of anything but, on the contrary, encompasses the variable nature of individual sensitivity to ultraviolet radiation. Variables which affect the MED include optical and radiometric characteristics of the source; determinants of the exposure such as dose increment and field size; nature of the skin such as pigmentation, previous light exposure, and anatomical site; and observational factors such as definition of the end point, time of reading after exposure, and ambient illumination. To avoid further confusing misuse of the term MED, we propose that this term be reserved solely for observational studies in humans and other animals, and that a new term, the standard erythema dose (SED) {1 SED is equivalent to an erythema effective radiant exposure of 100 Jm^{-2} . [CIE 1997]} be used as a standardized measure of erythemogenic UV radiation. This Standard specifies the erythema reference action spectrum $s_{\text{er}}(\lambda)$, and the Standard Erythema Dose. This Standard has been approved by the National Committees of the CIE and supersedes the recommendations made in Publication CIE 106/4 - 1993 (reprint from CIE-Journal 6/1 17-22 1987) *A reference action spectrum for ultraviolet induced erythema in human skin* [CIE (1998)].

The section on wavelength dependence has been emboldened for emphasis.

Appendix 1.1 Brief Historical Review

- 1859 Charcot suggests that erythema, ‘... is produced by the chemical rays of an electric arc - though his hypothesis is not proven for almost 20 years’
- 1877 Downes and Blunt report the bactericidal effects of sunlight for the first time, although they are, ‘.. not able to determine whether it was light or heat that was effective.’
- 1885 Downes and Blunt demonstrate light rather than heat is responsible for the bactericidal effect of sunlight
- 1892 Ward demonstrates, ‘..the most efficient bactericidal action occurred in the ultraviolet’
- 1893 Finsen publishes *On the Influence of the Light on the Skin* and stresses that UVR is responsible for sunburn
- 1903 Finsen wins Nobel Prize for Medicine for treatment of lupus (tuberculosis of the skin). [Diffey (1982) p3&p9]

References Appendix 1

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APPENDIX 2 SUV INTERACTION WITH FLORA & FAUNA

It is important to remember that whilst on the whole UV is dangerous to ecological and biological systems, we are still learning about its positive role. For example, it is known that a great many insects, birds, fish and other animals 'see' in the UV [Bennet & Cuthill (1993), Douglas *et al* (1989), Fleishman *et al* (1993), Goldsmith (1994), Jacobs *et al* (1991)]. For an excellent overview, see Silberglied (1979). It is also well recorded that plants hoping to attract certain insects have markings that can only be seen in the UV [Lutz (1933)]. The insight into UV vision began with Lubbock's experiments on ants in 1876 which he eventually published in 1882.

Appendix 2.1 UV 'Vision' & Markings

Douglas *et al.*, suggest that since pigments that absorb UV are found to be present in a number of species, this indicates these species must almost certainly be sensitive to particular UV wavelengths. However, one of the problem in this field is that confirmation and quantization of that sensitivity (at 1989) is primarily by behavioural[#] methods. In addition, as McFarland and Munz pointed out in 1975, much more detailed work on the photic environments of such species is required before a meaningful assessment of the role of UV vision or photoreception in general can be ascertained. For an overview of plants and vegetation at 1978, see Klien's paper.

[#]I asked Professor Ron Rutowski how 'sensitivity' (ie wavelength dependent) was assessed and he responded as follows:

"There are a variety of techniques that can be used to measure/assess sensitivity. As a behaviorist I devise tests to ask if conditions are such that a signal elicits a overt or behavioral response from an animal. The human threshold for hearing was established by delivering hearing tests to the thousands of people who passed through a booth at the World's Fair around the turn of the century. One can also record from sensory neurons at various levels in the nervous system from the sense organ to deep processing centers in the brain and see, in the case of the visual system, what photon flux is required to stimulate a physiological reaction."

Appendix 2.1.1 Overview: INSECTS

The earliest work in this field was on the ant [Lubbock (1882)] a superb review (as at 1979) can be found in Silberglied, complete with a detailed table on his p379 of the then current work. For example:

Butterflies: most research at 1979 had been carried out on UV reflectance on butterflies, with the earliest work by Crane in 1954 [p380] Wavelengths were not quoted in this work

Appendix 2.1.2 Overview: FISH

In their excellent overview, Douglas *et al.*, list the biological significance of UV vision in fish as at 1989 [Douglas *et al* (1989) p604]. They then query the reasons for identifying the *need* for UV photosensitivity**, and suggest, it might be more appropriate to ask why *all* fish do not possess UV sensitivity. This author's view is that as we discover more about the deleterious effects of UV (especially UV-B) it becomes increasingly important to understand how and why creatures have evolved to use these 'dangerous' wavelengths.

UV photosensitivity - not unsurprisingly - depends on the ambient UV of the environment in which the fish find themselves. Hence fish found living near the surface of a body of water or in sufficient depth such that there is little suspended material (to absorb or scatter the UV) can be exposed to significant amounts of UV [ibid p604]. Figure Ap2.1., shows Douglas's and McGuigan's classification of fish lenses as follows; "colourless" lenses with 50% transmission occurring below 355 nm, "colourless" lenses with 50% transmission at 360-305 nm, and distinctly "yellow" lenses with 50% transmission occurring above 425 nm [ibid p604]. What is of particular interest for this review, is though there is a steep cut-off at ~300 nm, that it is inside the boundary of so-called UV-B.

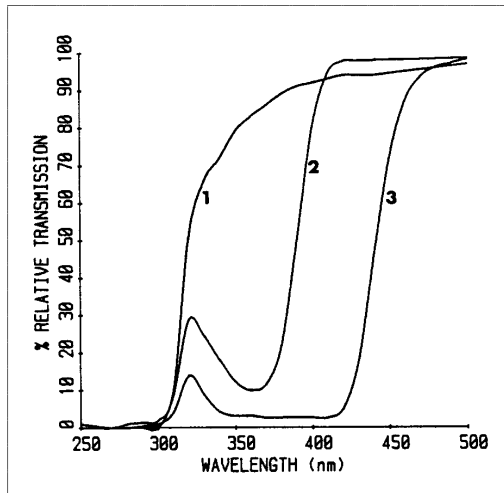


Figure Ap2.1: With permission from Douglas et al., [p605]. Relative transmission spectra of lenses from 3 fish representative of the 3 general classes of teleost lens. 1. *Rutilus rutilus*, 2. *Pelmatochromis kribensis*, 3. *Trichogaster trichopterus*. All curves have been normalised so that transmission at 700 nm is 100%.

In relation to the photic environment of water, at 1975 McFarland and Munz said; ‘...reliable quantitative measurements of natural light’ were difficult to obtain, and there was, ‘..an enormous gulf between realization of the significance of underwater light in understanding vision and the making of reliable measurements’, because, ‘...effective instruments that could provide a useful picture of the directional properties of underwater space light,’ were unavailable at that time. In a private communication, a researcher in the field, was asked if there was any work on shorter (UV) wavelength penetration at greater depths and he replied, “While UV radiation in the 300-400 nm range does penetrate the water column, scattering and absorption (mainly chlorophyll) limits its ultimate penetration. UV-sensitive receptors in a broad range of aquatic animals have absorption maxima which cluster in the 340-370 nm range.” [Hawryshyn (1998)]

Appendix 2.1.3 Overview: BIRDS

For an excellent overview, see Bennet & Cuthill (1993).

It seems that Huth & Berkhardt (1972) and Wright (1972) [‘discovered’ UV vision in birds independently], and Berkhard (1982 & 1989, references in Bennet & Cuthill) went on to catalogue birds with UV reflecting plumage. [Bennet & Cuthill (1993) p1471]

Whilst work so far seems to concentrate on 300 nm # 8# 400 nm [ibid p1471], it may be that techniques currently available, do not “allow reliable calculation of sensitivity.” [ibid p1472]. With regard to the function of UV vision, Bennet & Cuthill suggest the main hypotheses are: “1) orientation, 2) for foraging and 3) for sexual selection” (and here I am bound to ask the same question** as in the section on ‘fish vision’ above regarding ‘need’) which leads nicely to the current position that, “all evidence suggests that birds, like bees, use UV perception as part of their colour vision system.” [ibid p1474]

Appendix 2.2 Update

Figure Ap2.2: With permission, from Douglas (1999): Relative transmission spectra for: a) Cornea of macaque monkey - *Macaca fascicularis* [Douglas & Marshall (1998)]; b) Lens of a newt - *Cynops pyrrhogaster* [ibid]; c) Goldfish vitreous humour - *Carassius auratus* [ibid]; d) Lens of deep-sea fish *Opisthoproctus soleatus* [Douglas et al. (1998)]. Plots produced by data generated by Ron Douglas and A. Thorpe, using a Shimadzu UV 2101PC spectrophotometer which according to the manufacturer, is accurate to 250 nm.

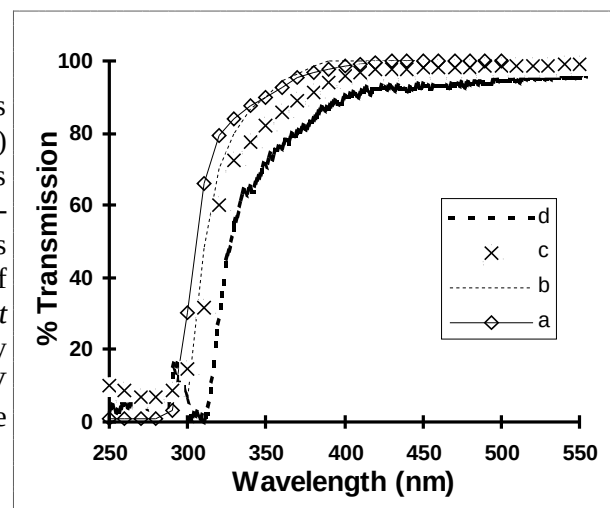


Figure Ap2.2 shows that the general shape appears to be the same for these different creatures (fish, mammal and amphibian) and again, the tail of these curves is within the UVB.

It would be extremely helpful to know more about the various methodologies and uncertainties that researchers in these fields use. We have found that UV measurements below ~300 nm are notoriously difficult and are often detector limited.

Appendix 2.3 Brief Historical Review

- 1876 Sir John Lubbock, Lord Avebury begins experimentation on ants' sensitivity to UV
- 1882 Lubbock, Lord Avebury publishes his discovery of ants sensitivity to UV
- 1924 Schiemenz reports first convincing demonstration of UV sensitivity in fish Douglas (1989)]
- 1954 Although Crane was, ' the first person to investigate the colours of many species of butterflies using a quantitative colorimetric technique', her sample was such that it contained samples, 'peculiarly low' in UV reflection which led her to suggest (quite wrongly) that UV reflection is rare in butterflies [Silberglied (1979) p380]
- 1972 Independent discovery of UV vision in Birds: Huth & Berkhardt in hummingbirds and Wright in Pigeons
- 1982 Berkhardt begins to catalogue birds with UV reflecting plumage [Douglas et al (1989)]

References Section 2

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APPENDIX 3 THE SUV/OZONE RELATIONSHIP

It is probable that the UV/O₃ cycle took a great deal of time to reach the equilibrium necessary for the ozone layer to form and hence create the possibility that life could be sustained on earth. As with all such complex systems it takes almost as long for their physics to be understood sufficiently well, and even longer to get to grips with implications of that balance being disrupted.

Appendix 3.1 Ozone Depletion

Appendix 3.1.1 Ozone Depletion and SUV

Whilst there is general agreement that there is a linkage between ozone and the variability of SUV, it is also generally agreed that a more detailed understanding of associated areas is required before any definitive answers can be obtained; 'A clear explanation of the observed solar cycle variation in the upper stratosphere will require improved understanding of the coupled chemical, radiative, and dynamical processes of that region' [Chandra et al (1996) p2938]. As might be expected from discussions on solar variability (section 2.3 Appendix 4) Since timescales vary from minutes to centuries it would not be surprising to find some correlation in the ozone depletion/SUV scenario.

One short timescale effect described by Sheldon et al, deals with a daily event occurring around dawn. As the sun rises (05:43am-06:03am) there is a catastrophic decline in ozone of up to ~50% in the dawn stratosphere, when SUV of $240\text{ nm} < \mathbf{8} < 350\text{ nm}$ catalyzes the ambient ozone. However this situation is rapidly reversed as SUV at $\mathbf{8} \# 240\text{ nm}$ begins to penetrate the atmosphere at 06:03am and photolyzes the ambient O₂ till at 06:13am the ambient levels of ozone are virtually restored to their pre-dawn values [Sheldon et al (1997) p4].

For an analysis of SUV variability and ozone as a function of latitude, longitude and season (ie annual) see Hood (1997)

For an overview of the variable SUV/Ozone relationship in general, see Hood (1997), Zerefos (1997) and references therein.

Appendix 3.1.2 Anthropogenic Causes of Ozone Depletion

Paul Crutzen discovered in 1970 that nitrogen dioxides (NO_x) are an efficient catalyst for the destruction of stratospheric ozone and the following year Johnson predicted the depletion of stratospheric ozone due to the catalytic effect of NO_x emitted by supersonic transport [see also Storlarski et al (1992) p349]. In 1974 Molina and Rowlands warned that the increasing levels of halogenated aliphatic hydrocarbons in the environment due to their (then) use as aerosol propellants and refrigerants, could lead to the further destruction of ozone:

"Two chlorofluoromethanes, CF₂Cl₂ and CFCl₃ have been detected throughout the troposphere....The most important sinks {for these molecules} seems to be stratospheric photolytic dissociation to CFCl₂ + Cl and CF₂Cl + Cl, respectively at altitudes of 20-40 km. Each of the reactions creates two odd-electron species - one Cl atom and one free radical. The dissociated chlorofluoromethanes can be traced to their ultimate sinks. An extensive catalytic chain reaction leading to the net destruction of O₃ and O occurs in the stratosphere: Cl + O₃ → ClO + O₂ and ClO + O → Cl + O"

[Molina & Rowlands (1994) p810]

Figure Ap3.1 shows the ozone creation cycle [Chapman (1929)] and anthropogenic destruction [Crutzen (1970), Johnston (1971), Molina & Rowlands 1974] in the stratosphere described earlier this century. It also shows processes occurring in the troposphere, where "...natural and man-made volatile organic compounds and nitrogen oxides react in the presence of sunlight to form ozone." [Devlin et al (1997)]

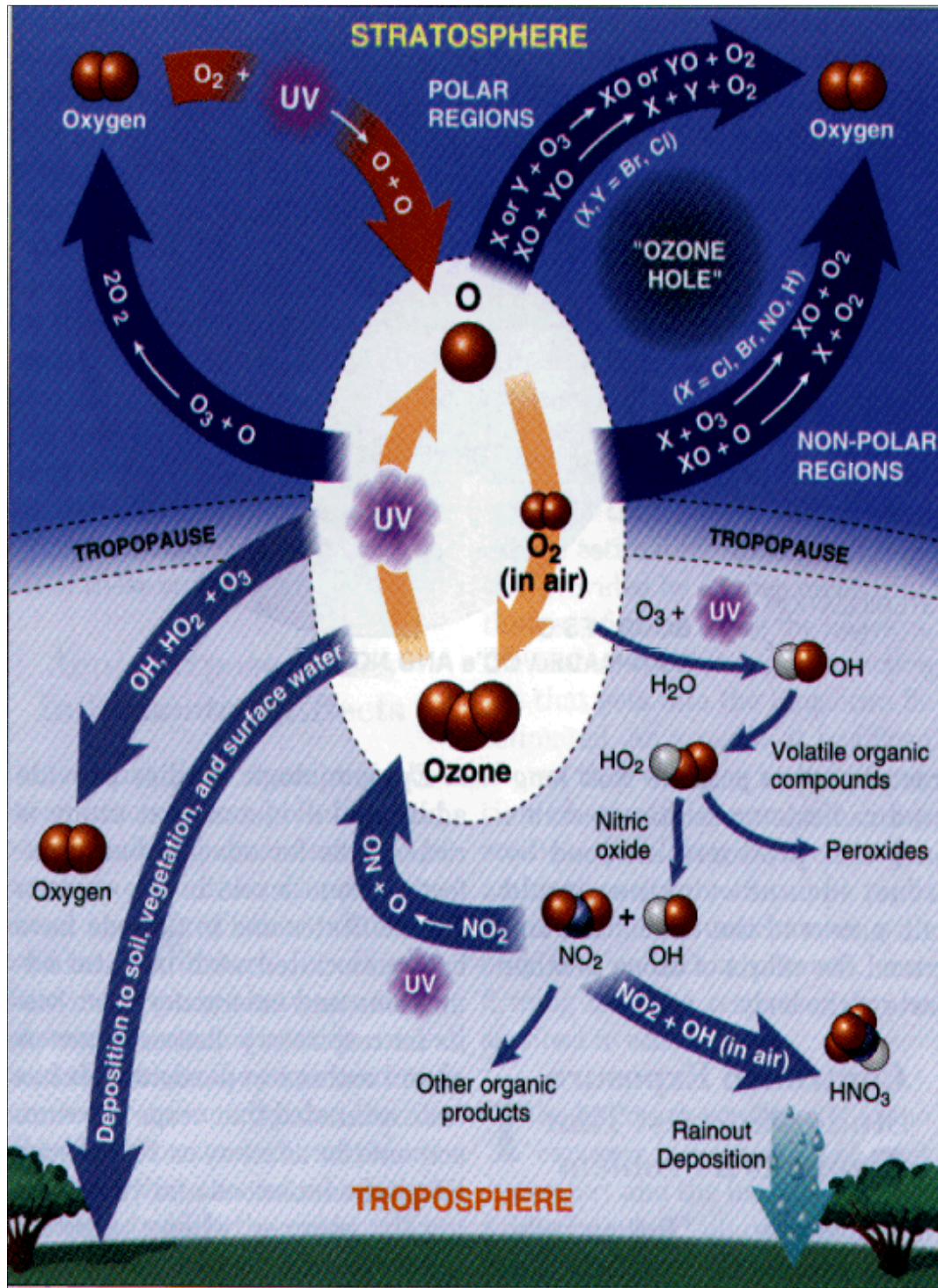


Figure Ap3.1: Formation and destruction of atmospheric ozone Devlin et al (1997) [p9].
 Illustration by James A. Perkins {Assistant Professor of Medical Illustration at Rochester Institute of Technology, New York}; configuration by Dr Joseph B. Pinto {US EPA}.
 Courtesy J.A.Perkins and Science & Medicine Magazine.

The first evidence for Johnston and Molina & Rowlands' predictions, came in 1985 Farman, when Gardiner and Shanklin discovered the so-called Antarctic Ozone Hole.

Total O₃ has been (and continues to be) measured at various British Antarctic Survey Stations, including Halley Bay at 76°S 27°W, from where the data they present have been collected, since 1957, but the first noticeable evidence for depletion came in 1984. In attempting to explain this, Farman et al., say, 'The present-day atmosphere differs most prominently from that of previous decades in the higher concentrations of halocarbons..'.
 They also show the first compelling evidence for seasonal variation in O₃ with separate plots of monthly averages in February and October from ~1957-1984. They attribute their findings to increased chlorine in the atmosphere during the cold spring Antarctic stratosphere [Farman et al (1985)].

Following emission measurements of Concorde in the lower stratosphere, Kärcher and Fahey suggested in 1997 that, '...the surprisingly efficient conversion of fuel sulfur to H₂SO₄ in the exhaust plume. By means of a comprehensive model, the formation and evolution of aerosol particles and precursors are calculated in the diluting aircraft wake' [p389].

The results provide strong evidence that high levels of SO₃ present in the nascent plume are required to explain the observations of large numbers of nanometre-sized aerosols (p389)....Controlling aerosol formation in aircraft plumes may be required to minimize chemically-induced ozone losses and other climate change parameters. (p392)' [Kärcher and Fahey (1997)].

Table Ap1.1 Is a crude overview of sources of ozone depleting substances and sources of man-made volatile organic compounds (VOCs) and nitrogen oxides (NO_x)

Table Ap3.1: Information adapted from Devlin et al [p10]

Sources of Ozone Depleting Substances		Sources of Man-Made volatile organic compounds (VOCs) and NO _x	
Aerosols	5%	Chemical Plants, Factories and other Industrial Sources	20%
Foam Products	14%		
Other Products	12%	Motor Vehicles and Fuels	50%
Refrigeration and Air Conditioning	30%		
Solvents and Cleaning Products	36%	Solvents, Consumer Products and Other small Sources	30%
Sterilization	3%		

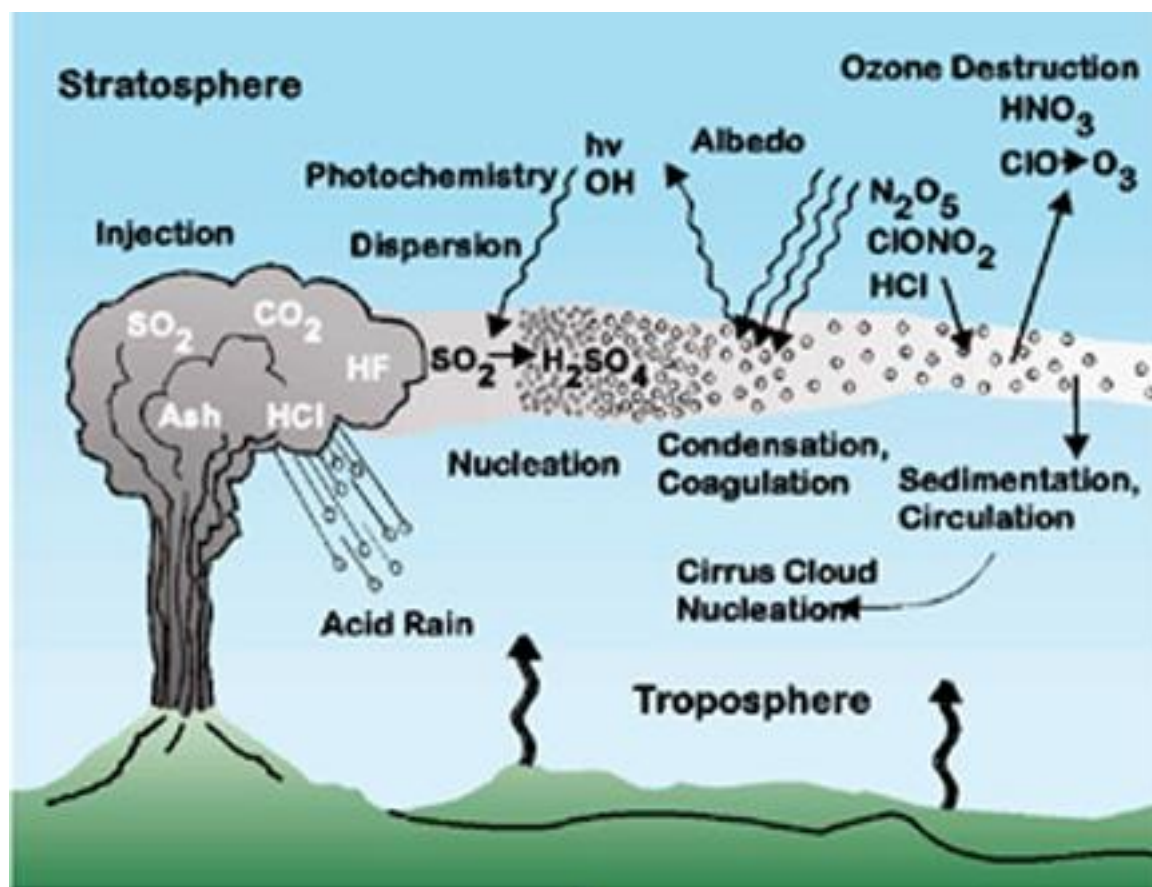
Hoffman strikes a positive note in a letter in Nature in 1996, entitled 'Recovery of the Antarctic Ozone Hole', in which he claims that, 'Continuous global monitoring now indicates that the total ozone destroying potential of the atmosphere... peaked in the troposphere in 1994 and barring non-compliance with the Montreal Protocol, will peak in the stratosphere between 1997 and 1999' [p222]. No 'up-date' has been found in the literature to confirm this projection.

Appendix 3.1.3 Other Possible Causes of Ozone Depletion

Major volcanic eruptions (such as the 1991 Mount Pinatubo eruption) introduce ash particles and SO₂ into the stratosphere, resulting in sulphuric acid and aerosols which can alter the absorption and scattering of SUV, thus affecting the photolysis rates of photoactive chemicals and as a consequence perturb ozone concentrations [Huang and Massie (1997)]. Figure Ap3.2 from McGee et al (1997) is a schematic of the various effects of volcanic eruptions.

Figure Ap3.2:

From McGee et al (1997) “Large, explosive volcanic eruptions inject water vapor (H_2O), carbon dioxide (CO_2), sulfur dioxide (SO_2), hydrogen chloride (HCl), hydrogen fluoride (HF) and ash (pulverized rock and pumice) into stratosphere to heights of 10-20 miles above the Earth's surface. The most significant impacts from these injections come from conversion of sulfur dioxide to sulfuric acid (H_2SO_4), which rapidly in the stratosphere to form fine sulfate aerosols. The aerosols increase the reflection of radiation from the Sun back into space and thus cool the Earth's lower atmosphere or troposphere; however, they also absorb heat radiated up from the Earth, thereby warming stratosphere. The sulfate aerosols also promote complex chemical reactions on their surfaces that alter chlorine and nitrogen chemical species in the stratosphere. This effect, together with increased stratospheric chlorine levels from chlorofluorocarbon pollution, generates chlorine monoxide (ClO), which destroys ozone (O_3). As the aerosols grow and coagulate, they settle down into the upper troposphere where they serve as nuclei for cirrus clouds and further modify the Earth's radiation balance. Most of the hydrogen chloride (HCl) and hydrogen fluoride (HF) are dissolved in water droplets in the eruption cloud and quickly fall to the ground as acid rain. The injected ash also falls rapidly from the stratosphere; most of it is removed within several days to a few weeks. Finally, explosive volcanic eruptions release the greenhouse gas carbon dioxide and thus provide a deep source of carbon for biogeochemical cycles. (figure modified from Richard Turco in American Geophysical Union Special Report: Volcanism and Climate Change, May 1992)”. (US Government website)



Appendix 3.2 Environmental/Health Effects of Ozone

Electrostatic devices, for example, photocopiers and laser printers, produce small quantities of ozone. Though these levels can be reduced by building ventilation, people spend most of their time indoors [Devlin et al (1997) p9] hence the negative effects on human health discussed applies to these sources of ozone as well.

Appendix 3.2.1 *Ozone in the Atmosphere*

Refer to Appendix 7.1 for details on the structure of the atmosphere. Most atmospheric ozone, ~90%, is in the Stratosphere, with the remaining 10% in the troposphere. There is still much work to do to ascertain the level of ozone and method of transport in/to the remaining layers. From the limited search conducted for this review, Brogniez et al (1997) discuss and compare ground based, balloon borne and satellite measurements of aerosols to a maximum height of ~24 km. Sheldon et al (1997) took measurements at ~40 km from a Balloon borne gondola (see Appendix 4 on Solar variability).

Appendix 3.2.2. *Ozone as Pollution*

Refer to figure Ap3.1 Until comparatively recently, ozone found in the troposphere was transported there from the stratosphere, ‘.. where it is a precursor to the hydroxyl radical, a key intermediate species in the tropospheric degradation of the large amounts of volatile organic compounds (VOCs) emitted into the atmosphere by plants’. However, these so-called “biogenic” VOCs also react with naturally occurring NO_x, ‘to form additional ozone.’ But made-made VOCs and NO_x also react with atmospheric oxygen in strong sunlight, ‘contributing to photochemical air pollution (smog)’ [Devlin et al (1997) p8]

From a ‘human-health’ point of view, the problem is that ozone (whether from an indoor or outdoor source) ‘is a potent oxidant, capable of reacting with a variety of biomolecules, particularly those containing thiol or amine groups or unsaturated carbon-carbon bonds. It reacts rapidly with bio-organic compounds in the fluids, cells and tissues that it comes into contact with, especially those lining the respiratory tract.’ [ibid p9] In addition to the deleterious effects on human health, plants growth and agricultural activity can also be affected [Crutzen and Lawrence (1997) p625]

Suhre et al (1997) reported extremely high concentrations of ozone over the tropical Atlantic using automated instrumentation on ordinary passenger aircraft. This is contrasted with extremely low concentrations found over the ‘cleanest region’ of the earth that is, the tropical Pacific. This anomaly has yet to be explained. [Crutzen and Lawrence (1997) p625]

Appendix 3.2.3 *Ozone and SUV - A Twist in the Tale*

Less ozone in atmosphere leads to more SUV and in particular UV-B reaching the earth. However, an interesting twist to this story comes from Bruhl and Crutzen, in 1989 they found that the ‘new’ tropospheric ozone was ironically, a ‘better filter’ for UVB than stratospheric ozone (the ozone layer). This they found was to be related to the lower zenith angles where there is more scattering in the troposphere [ibid, Sabziparvar and Shire (1997) p64] in 1997 Sabziparvar and Shine modelled, ‘the disproportionate effect of tropospheric ozone for various atmospheric conditions’ and discussed, ‘the influence of ozone height for filtering surface UVB over various surface albedos.’ Finally they produced a new index (the Offset index) which, ‘ indicates the change in tropospheric ozone which is required to offset the increased UVB,’ caused by typical stratospheric ozone depletion [ibid p64]

In addition, we now know that ozone is being transported to and produced in the troposphere. When ozone absorbs SUV at wavelengths of $\lambda < 325$ nm, the resulting ‘ionized oxygen’ reacts with water vapour to produce Hydroxyl (OH) radicals, ‘which are involved in the removal of almost all atmospheric gases emitted by human and natural activities...hydroxyl’s high reactivity makes it the detergent of the atmosphere’ [Crutzen and Lawrence (1997)]

Appendix 3.2.4 *Measuring Atmospheric Ozone*

Ozone measurement is inferred by measuring SUV. Although the methodology varies these days (see section on UV instrumentation) essentially the earliest measurements were made by collecting data on wavelengths of SUV that are absorbed by Ozone and those that are not, the difference in intensities being ascribed to the absorption by ozone. Whilst the early work was done by Fabry &

Buisson, including design of the special spectrographs (Fabry and Buisson (1913 & 1921)), Dobson is

generally credited with having perfected the instrumentation and the unit of measurement for ozone still bears his name [*Dobson (1968)*].

The Dobson Unit (DU) is the unit of measure for a total column of ozone. Parson describes it as follows: For temperature, $T = 0^{\circ}\text{C}$; Atmospheric Pressure, $P = 1$ the ozone layer over the USA would be ~ 3 mm thick. Hence 0.01 mm thickness at that temperature and pressure are defined to be 1DU ($\sim 2.687 \times 10^{16}$ ozone molecules. cm^2) [*Parson (1997)*]

Appendix 3.3 Brief Historical Review

- 1840 Schöenbein notices a particular odour during the electrolyzation of water and suggests a new substance may be responsible
- 1845 Marignac reports on his investigations into Schöenbein's discovery of a new substance [Hunt (tba)] and concludes that, "It is clear that oxygen alone, or some particular compound of oxygen and hydrogen must be responsible for these (phenomena)".
- 1846 Miller reports that the solar spectrum of UV is shorter than those of metallic spectra he has taken in the lab
- 1879 Cornu suggests that the limitation in the solar spectrum is due to absorption by the atmosphere "For several years I have worked with the goal of obtaining the extreme limit of the solar spectrum on the ultraviolet side, that is to say, on the side of short wavelength. The extent of knowledge of the limit of the spectrum, or rather of the law from which the decline in intensity of the continued ideal spectrum of the photosphere follows, could bring, on the difficult question of the temperature of the sun, data at least as important as corresponding thermal measurements of radiation at long wavelengths. Unfortunately, as one is going to see, the atmosphere exercises on shortwave radiation, an absorption effect, so energetic, that the majority of the ultraviolet solar spectrum is, for want of another word, abruptly intercepted in a total manner.."
- 1880 Hartley measures the absorption of ozone in the uv (the Hartley Band)
- 1881 Hartley suggests that the, 'limited extent of the ultraviolet region of the solar spectrum' is due to absorption by atmospheric ozone
- 1913 Fabry & Buisson use their measurements the absorption coefficients of ozone and compared them with the absorption of sunlight in the atmosphere. From these measurements they conclude that there was $\sim 0.5\text{cm}$ thickness of ozone in one vertical thickness of the atmosphere and suggest that ozone is formed in the upper atmosphere by the action of SUV.
- 1921 in 1919-20 Fabry & Buisson designed a double spectrograph and took measurements of ozone at Marseilles
- 1922- Dobson's Oxford team begin taking regular measurements to observe trends [*Dobson (1968)*]
- 1929 Chapman produces a theory which describes how ozone, O_3 , is created by the dissociation of oxygen, O_2 in the earth's stratosphere. He is also responsible for the phrase 'ozone layer'.
- 1970 Paul Crutzen discovers that NO_x can be an efficient catalyst for the destruction of stratospheric ozone.
- 1971 Johnston predicts depletion of stratospheric ozone due to the catalytic effect of NO_x emitted by proposed fleet of supersonic transports
- 1974 Molina and Rowlands suggest a mechanism whereby Chlorofluourocarbons (CFC's) could damage the ozone layer . In this model, UV photons are absorbed by CFC molecules causing them to lose one or more of their Chlorine atoms. The 'free' Chlorine atoms interact with the ozone to produce Chlorine Monoxide (ClO) and an oxygen molecule severely depleting the ozone layer and resulting in increased levels of UV reaching the surface of the earth
- 1985 Crutzen, Molina and Rowlands are awarded the Nobel Prize for Chemistry for their work in this field. [*Parson (1997)*]
- 1985 That same year, the Antarctic 'ozone hole' was discovered by Farman et al

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APPENDIX 4 SOLAR VARIABILITY

Appendix 4.1 Overview of the Basics

Total solar irradiance has been termed the Solar Constant and is given by:

$$\frac{L}{4\pi r^2} = \text{Constant} \quad \text{Equation: Ap4.1}$$

Where: L is solar Luminosity and r is the mean sun-earth distance

However, calling it a ‘constant’ is something of a misnomer, since it has been known for many years that the sun’s output fluctuates - especially in the UV [Lean (1991)].

People may have suspected that the sun’s output was not constant when they experienced extremes of temperatures within their lifetimes, for example, the Medieval Climactic Optimum; a “warm period during the eleventh to thirteenth centuries” to the “mini ice-age” known as the Maunder Minimum (1645 - 1715) [Eddy (1977) p69]; but it was not until Galileo published his Siderius Nuncius (Sidereal Messenger) in 1610 describing the dark (sun)spots on the face of the sun [Smith and Jacobs (1973) p245] that there was any real indication that this was more than a static, unblemished sphere.

Note that this was only true in ‘the west’, since the Chinese had been recording sunspots since well before the first millennium AD [Donahue & Farrell (1995)]

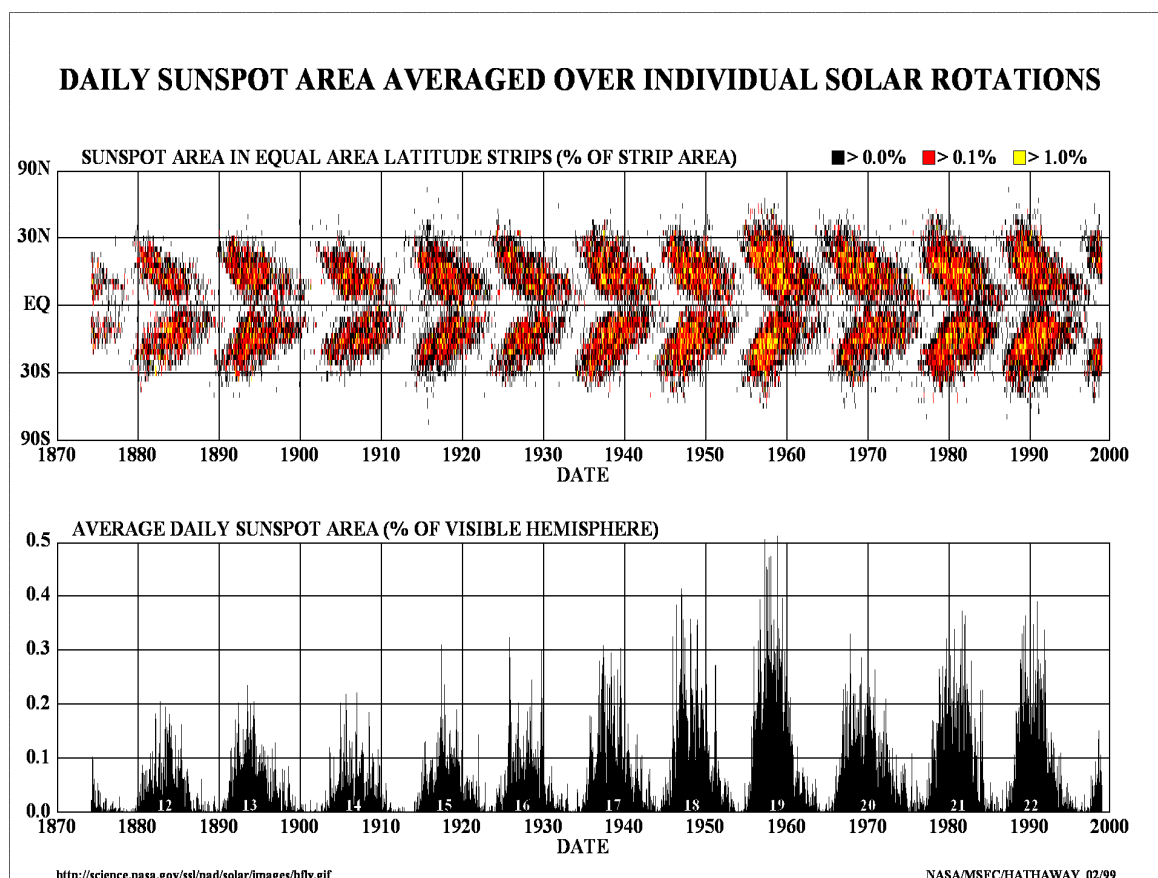


Figure Ap4.1: From Hathaway (1996) Butterfly Diagram, showing total sunspot area as a function of time and latitude.

Thereafter, a great many people meticulously kept records of the sunspots as they appeared and the positions where they appeared (see brief historical review at the end of Appendix 4). This painstaking work was rewarded by the discovery of the well-known ‘butterfly’ diagram, which is a plot of number and location (solar latitude) of sunspots against time; see figure Ap4.1.

The Butterfly Diagram also shows that the number of sunspots rises to a maximum relatively quickly and falls to a minimum much more slowly [Illingworth (1979)].

Heinrich Schwabe’s painstaking observational work over 17 years resulted in the discovery of (‘half’ of) the solar cycle, which is now known to take ~ 11 years.

According to “Spörer’s Law”, hardly any sunspots appear above $\sim \pm 40^\circ$, they tend to appear at the beginning of a cycle around $\sim \pm 35^\circ$. As the cycle progresses, the bulk form at $\sim \pm 15^\circ$ and finally at solar minimum, the appear at $\sim \pm 5-7^\circ$ [Moore and Hunt (1983) p36]. This can give the impression that the sunspots are migrating towards the solar equator, but in fact they ‘fade’ or disappear where they originally materialized in time periods lasting from days to months [Smith and Jacobs (1973) p249].

Solar theory suggests that magnetism is the mechanism responsible for these and other solar phenomena, a discussion on that subject is beyond the scope of this work.

We now know (from a geometrical point of view) that the sun is a differentially rotating, oblate spheroid, with rotation speed greatest at the equator.

Appendix 4.2 Current Science

Thanks to satellite measurements over the last ~ 18 years, there is now no doubt about the variability of the solar ‘constant’ (more usually known these days as total solar irradiance) [Lean (1991) p505].

However, continuous space-based observations of total solar irradiance exist for less than one full (22 year) solar cycle - an insignificant timespan in the lifetime of the sun [ibid p507], so there are very many more years work necessary to establish what may be happening. Nevertheless, from the data that has been gleaned from the past, and from current works, it is known that solar variations occur on many differing timescales [ibid p505, Hudson (1988) p485], and these scales will probably extend in both directions ie shorter and longer (as our instrumentation becomes more sensitive), the longer we are around to take measurements.

Table 4.1 Produced with permission, from information on timescales in Lean (1991) p505

Time	Solar Phenomenon
Minutes	Solar flares and oscillations of the sun’s interior
Days	Variations which correspond to solar rotation of 27 days
~ 11 & 22 years	There is the well-established 11-year cycle (though the full cycle is 22 years if the switch of sunspot polarity is taken into account [Smith and Jacobs (1973) p249] Figure Ap4.2 is Judith Lean’s up-to-date version of the Waldmeier plot
10's of years	80-100 year Gleissberg cycle
Longer periods	Miscellaneous periods of either greater activity or ‘unusual’ quiescence (for example the Maunder Minimum 1650-1690 when there were ‘no’ or negligibly few sunspots).

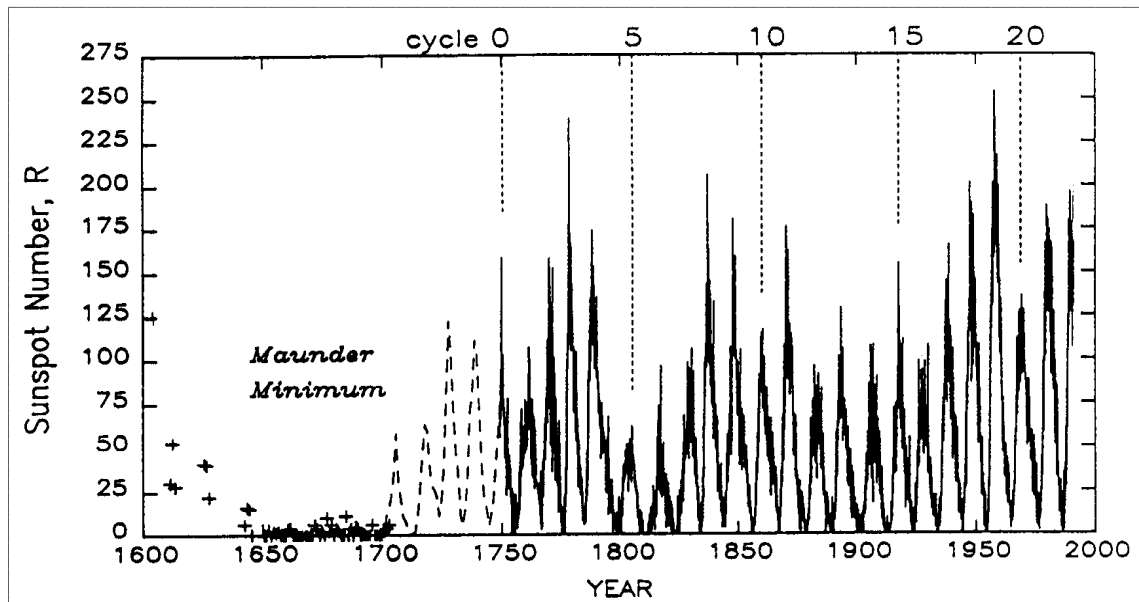


Figure Ap4.2: With permission, from Lean (1991) [p506] “Monthly means since 1750 of the sunspot number (solid line) with yearly means from 1610 to 1750 (from the {US} National Geophysical Data Center (*dashed line*) and Eddy [1976, *Science*, 192, p1189-1202] (plus signs).” {NB: The sunspot number is defined in 15.6: Table 2 p511 and is not included here} “Prominent in the record is a cycle of 11.04 years. According to Eddy, the 11-year sunspot cycle may not have been operative before about 1700 (but see also Ribes et al., [1989, *Ann.Geophys.*, 7 p321-330]. Instead, solar activity appeared to have been characterized by extended periods of either enhanced activity or inactivity. Thus during the past 290 years, when the Sun has been observed most intensely, its behaviour, shown in this figure, may have been unusually regular and benign.”

Hudson puts it in tabular fashion as follows in table Ap4.2

Table Ap4.2: From Hudson (1988) [p485] “Identified variability mechanisms for solar total irradiance”. (*With permission, from the Annual Review of Astronomy & Astrophysics, Volume 26, © 1988, by Annual Reviews* <http://www.annualreviews.org>)

Mechanism	Time Scale	Amplitude	References (in Hudson)
Oscillations	5 minutes	Few ppm	Woodward, M; Hudson, H.S (1983) <i>Nature</i> , 305 p589-593
Granulations	10's of minutes	10's of ppm	Hudson & Woodward (1983) <i>Bull.Am.Astron.</i> , 15,p715
Sunspots	Few days	<0.2% peak-to-peak	Wilson et al.(1981) <i>Science</i> , 211 p700-702
Faculae	10's of days	<0.1% peak-to-peak	as above
Rotation	27 days	Variable	Frölich, C (1984) <i>Adv. Space.Res.</i> , 4 (8) p112-120
Active Network	~11 years	~0.1% peak-to-peak	Foukal , P.A & Lean, J (1988) <i>Astrophys.J.</i> , 328 p347-357

Figure Ap4.3 from Eddy (1977) [p68] provides a good visual summary of the variability of solar output over the last one thousand years, and Eddy adds this important postscript:

"We have long been accustomed to thinking of solar behaviour as cyclic and regular and, through training and assumption to treating the modern cause of the solar cycle as representative of past behaviour. Recent and more critical analyses of historical and modern evidence give cause to doubt these basic beliefs."

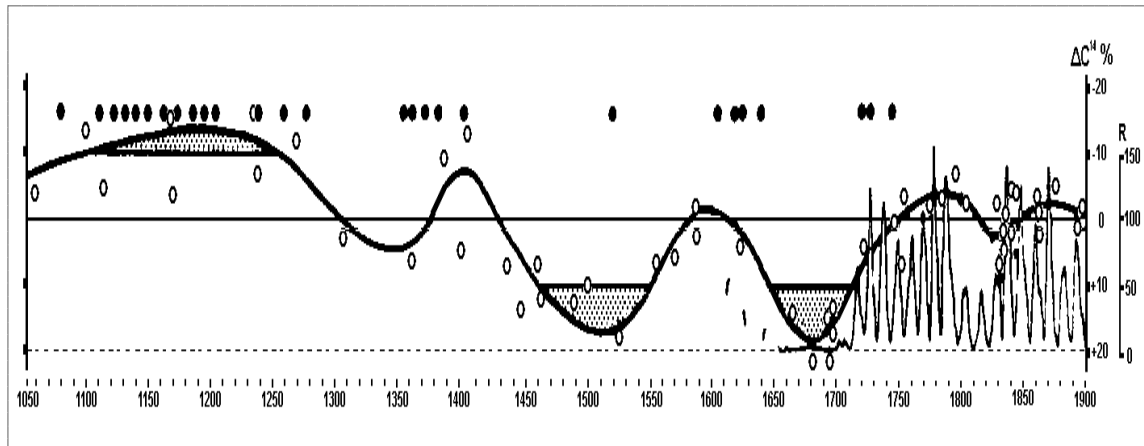


Figure Ap4.3: With permission, from Eddy (1977) [p68] " ^{14}C variation since 1050 A.D (open circles and heavy curve) compared with other indirect indices of solar activity. Curve at lower right is telescopically-observed sunspot number. Dark circles are naked-eye sunspot observations, from Kanda [1933, Proc.Imp.Acad.Japan, 9, p293]. Times when ^{14}C deviation exceeds ± 10 parts per mil are shaded."

The reference by Eddy to Carbon 14 (^{14}C) work is beyond the scope of this report, however he notes [*ibid* p65] that the use of ^{14}C as an indicator of the sun's behaviour over time is well known. Eddy's suggested reading on this subject (amongst others) is, P.E. Damon, p571 onwards in *Radiocarbon Variations and Absolute Chronology* (1970) edited by I.V. Olsson, Almquist & Wiksell, Stockholm.

For an up-to-date review of Solar Variability in general, see Solanki & Fligge (1998) in which they inform us that measurements of solar irradiance with a view to detecting variations have only been sufficiently accurate since 1978 [*ibid* p341] (the year after Eddy's paper).

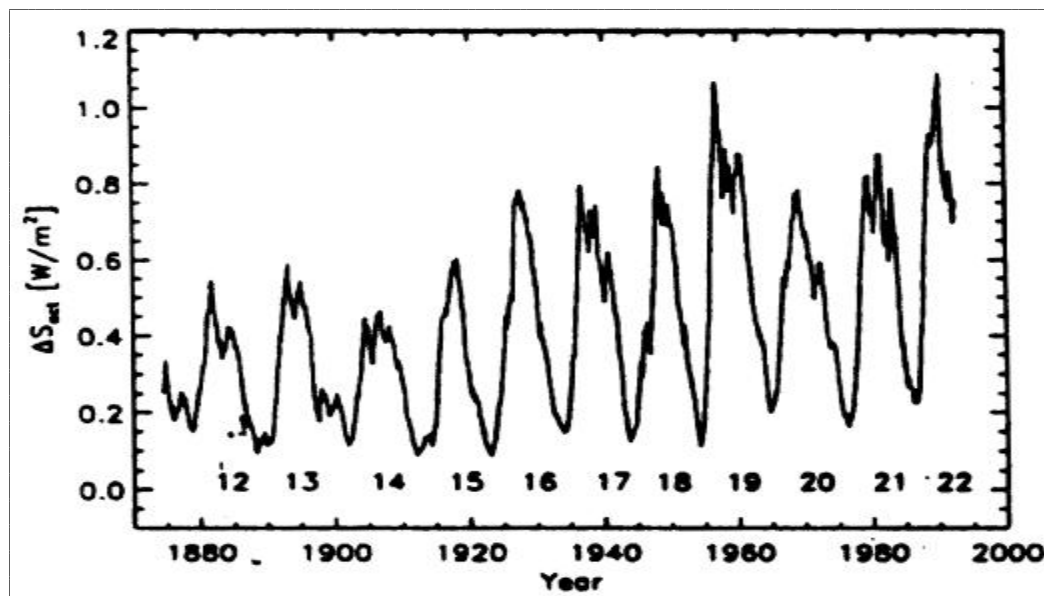


Figure Ap4.4: With permission, from Solanki and Fligge [p343] "Time-dependence of reconstructed solar irradiance due to solar active regions, ΔS_{act} , vs. Time. The irradiance has been smoothed by a 1-year running mean. Data gaps have been accounted for in two different ways, by interpolating across them and by binning the data points. Both techniques give almost indistinguishable results. Solar cycle numbers are indicated."

Solanki and Fligge also claim that, “much of the data needed...have been improved” in particular due to the, “excellent correlation between solar cycle length and terrestrial temperature” found by Friis-Cristensen and Lassen and published in two papers called: *Length of the Solar Cycle: An Indicator of Solar Activity Closely Associated with Climate* {Science (1991) 254 p698-700} and *Solar Activity and Global Temperature*, {p339-347 in ‘The Sun as a Variable Star: Solar and Stellar Luminosity variations’ (1994) edited by Pap et al., CUP} [Solanki and Fligge (1998) p341].

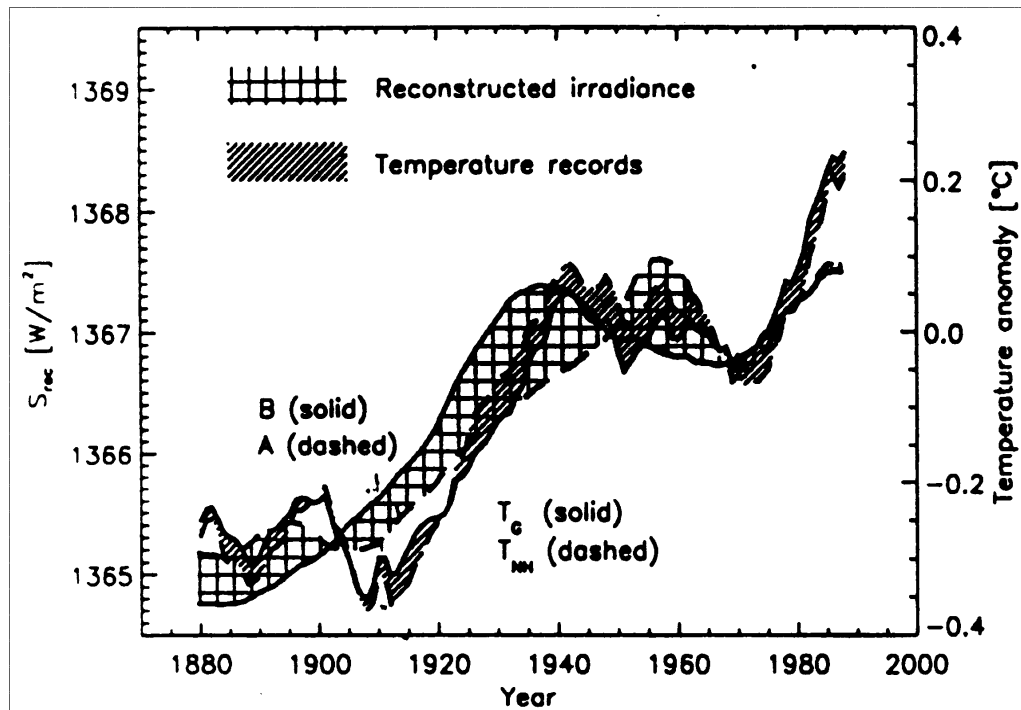


Figure Ap4.5: With permission, from Solanki and Fligge [p344] “Left-hand scale: irradiance reconstructions, S_{rec} between 1880 and 1889. The dashed curve is based on model A while the solid curve results from model B. The hatched area indicates the range within which S_{rec} may lie. Right-hand scale: temperature records. Plotted are the global land and sea temperature (solid curve, T_G) and the northern hemisphere land and sea temperature (dashed curve T_{NH}) relative to epoch 1950 as provided by the World Data Center (WDC), Boulder, CO. Global temperatures are as in the report of the International Panel on Climate Change (IPCC, 1992). All curves have been subjected to an 11-year running mean.”

Solanki & Fligge suggest that their work shows that, since 1975, ‘air temperatures have increased by 0.2K, whereas solar irradiance has risen by a disproportionately smaller amount. Therefore, unless the influence of solar variability on Earth is very strongly non-linear {and Eddy has argued that it is} at least this most recent temperature increase reflects the influence of man-made greenhouse gases or non-solar sources of natural variability.’ [ibid p341]

The models A and B referred to in the caption for figure Ap4.5 refer to, “two different relationships between solar activity and long-term irradiance trends” which were found, “via stellar activity measurements”.

The key thing to keep in mind is that though humans are driven to look for patterns and meaning, there is currently no justification for stating that we are living through a period of ‘typical’ behaviour. Note that in this context ‘currently’, means the last few hundred years, since even that is an extremely small fraction of the lifetime of the sun and the sun/earth system.

Appendix 4.3 Brief Historical Review

- 1322 First edition of Chinese Encyclopaedia is published describing observations of sunspots between 301 and 1275 [*Hathaway, D. A (1996)*]
- 1610 Gallileo's work which includes the first published record of sunspots, but note that as with all discoveries, there are others who may lay claim to being "first", 'The discovery of sunspots is variously attributed to Johann Fabricius, Gallileo and Christoph Scheiner' [*Moore and Hunt (1983) p415*].
- The gap in progress on this work is due to the fact that sunspots did not appear from ~1645 - 1715 (Maunder Minium, discovered retrospectively) so it was not until spots began to reappear and were then observed over a long period that any further progress was made.
- 1843 Heinrich Schwabe publishes 17 years of observational data and establishes there is a cycle though he thought it was a ~10 years long [*ibid p36*]
- 1858 R.Carrington discovers that sunspots form at higher solar latitudes at the beginning of a cycle and Gustav Spörer investigates it more fully so that "Spörer's Law" states that the spots tend to appear at solar latitudes of $\sim \pm 35-40^\circ$ at maximum they appear at $\sim \pm 15^\circ$ and at minimum at $\sim \pm 5-7^\circ$ [*ibid p36*]
- 1858 R. Wolf publishes his formula for determining daily sunspot number, the Zurich or Wolf number $R = k(10g + f)$; where g is the number of spot groups, f is the number of spots seen on the surface of the sun (including those in the groups) and k is a calibration factor that differs for each observer. [*ibid p36, Donahue & Farrel (1996)*]
- 1893 Walter Maunder (and Gustav Spörer) draw attention to the missing sunspots and the period is subsequently called the "Maunder Minimum". This work was re-evaluated by John Eddy in 1976. [*Noyes (1982)*]
- 1904 Maunder produces what is believed to be the first example of the Butterfly diagram in (The Monthly Notices of the Royal Astronomical Society, 64 p 747) called "Maunder's" Butterfly diagram. [*Donahue & Farrel (1996)*]
- 1908 George E. Hale discovers the magnetic character of sunspots [*Smith and Jacobs (1973) p249*]
- 1960 Babcock-Leighton model for the magnetic mechanism responsible for the full 22 year solar cycle [*Babcock (1960)*].

References Appendix 4

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APPENDIX 5 'ARTIFICIAL' SOURCES OF UV

The most common artificial sources of UV (ASUV) are either an a electric discharge through a gas or the heating of a solid until it becomes incandescent. Incandescent sources radiate because they are heated and their output resembles blackbody radiation, whilst arc/discharge sources on the whole, produce spectral lines via electrical discharge through a gas. A list of artificial sources of UV is given in table Ap5.1 which has been compiled from Phillips (1983) and Lambe (1994) except where otherwise stated.

Table Ap5.1: 'Artificial' Sources of UV

Generic	Source Type				
Discharge	Open Discharge (ie in open Air) ‘Arcs’		Carbon Arc		
	Enclosed Discharge ie (in Envelope filled with ‘Air’, single gas or mixture of gases). Only single gas types are listed, though mixtures are available for the production of particular spectral lines, for example, Mercury-Neon and so on..		Argon arc, Krypton, Neon, Xenon		
			Cadmium, Zinc		
			Electrodeless lamps		
			Deuterium, Hydrogen arc		
			Mercury	Low Pressure	
				Medium Pressure	Mercury only
		Metal Halides (Iodides mainly, some chlorides and bromides - fluorides are too reactive	Antimony Gallium Iron Lead Magnesium Thallium		
Electroluminescent	Phosphor based	Activated by pulsating electrical field	"Light is produced by a phosphor - usually embedded in one plate of a capacitor - when excited by a pulsating electric field. ..see recent reports of UV electroluminescence by 1) Saski, T et a; (1992) Research Reports of the School of Sci&Tech, Meiji University, 8 p15-22 and 2)Kozłowski, F et al (1993) J.Luminescence, 57 (1-6) p185-9" [Lambe (1994)]		
		Activated by Radioactivity	"Low energy electrons emitted by a radioactive source (tritium) strike a phosphor coating which emits photons at a wavelength characteristic of the phosphor..If the electrons were energetic enough, and the phosphor chosen correctly this technology could produce a UV source. No recently published research." [Lambe (1994)]		
	Light Emitting Diode (LED)	"Although junction electroluminescence was first reported over 80 years ago [Round (1907) - not cited] concerted efforts to develop LEDs date from 1962 when it was noted that a GaAs junction biased in the forward direction was an efficient emitter..." [Coaton, J.R & Marsden, A.M (1997):p287]			
		"There has been reported success with UV emission 1) Goldenberg, B et al (1993) Appl.Phys.Lett., 62 (4) p381-3 January and 2) Akasaki, I et al (1992) Extended Abstracts Int'l Conf. Solid State Devices and Materials, p327-9, ISBN 4930813506 "[Lambe (1994):p9]			
	Electron Storage Rings	Synchrotron Radiation		Conventional - hundreds of square feet 'Room' Sized - see example at University of Maryland website http://www.ipr.umd.edu/ebte/ring/ ...	
Incandescent	‘Black Body’ Radiators		Blackbodies		
			Filament {/Gas or vacuum} Lamps	Tungsten (vacuum or inert gas)	
				Tungsten Halogen	Tungsten Bromine Tungsten Iodine
Lasers [Lambe (1994)]	TYPE	EMISSION	WAVELENGTH MODE		
	He-Cd	325 nm and 354 nm	Both CW		
	Ar+	lines in the range 275-407 nm	CW		
	Kr+	337-407 nm	CW		
	Excimer	193-351 nm	Pulsed, low rep.rtes (<100 Hz)		
	Nitrogen	337 nm	Pulsed, low rep.rtes (<100 Hz)		
	Nd3+	266 nm	CW and pulsed		
	“ difference hosts	355 nm	CW and pulsed		

Table Ap5.2: Problems associated with ASUV

Generic	Source Type		Problems
Discharge (most of these are line sources, though some produce a reasonable continuum)	<i>Open Discharge</i>	Carbon Arc	Added for historical interest. Were used for high power, high intensity requirements for example, searchlights, printing and solar simulators. On the whole these have been superseded by Hg, Xe and other discharge lamps.
	<i>Enclosed Discharge</i>	Argon(Ar) arc, Krypton (Kr), Neon (Ne), Xenon (Xe)	“An electrical discharge through a gas causes short lived electronic state changes within the gas atoms or molecules, which emit radiation on relaxation or by collisions. The spectral distribution of the radiation is determined by the species, pressure and electrical power delivered to the electrodes and envelope materials. As the pressure is increased, emission lines broaden and at very high pressures, the radiation approximates a BB so that lower pressure sources are more efficient producers of UV radiation” [Lambe (1994):p3] D₂: Continuum ~170- 350 nm, low intensity compared with other sources, continuum drops rapidly from ~200 nm with lines beginning to appear ~400 nm Hg: <u>Low Pressure</u>: Sharp line source, intensity is low* and bulk of output is from the 253.7 nm line so they are virtually monochromatic unless fluorescent coatings are used to convert to visible (fluorescent lighting tubes) {*NB whilst this is true in the UV, in the visible the 546.1 nm line is very intense [Goodman (1998)]} <u>Medium pressure</u>: Pressure broadened line source, lifetimes of lamps depends on the loss of material from the electrodes via sputtering or evaporation - especially during lamp warm-up period
		Cadmium (Cd) , Zinc (Zn)	
		Electrodeless lamps	
		Deuterium , Hydrogen (H) arc	
		Mercury (Hg)	
Electroluminescent	<i>Phosphor based</i>	Activated by pulsating electrical field	Most usage has been non-UV and there have only been a few papers published. There is added difficulty of Health and Safety issues in relation to the radioactively activated sources
		Activated by Radioactivity	
	<i>LED</i>		Low power - used in displays, work on blue LED's is ongoing
Electron Storage Rings	<i>Synchrotron Radiation</i>	Conventional - hundreds of square feet	Continuum radiation: Prohibitively expensive (~£M), not portable and time consuming, main use is as primary standard.
		'Room' Sized	
Incandescent (Sources of continuum radiation)	<i>'Black Body' Radiators</i>	Blackbodies	Very little UV output unless operating at temperatures above 3000 K
		Filament	The W filament is essentially a resistor and the electricity it conducts is only by free electrons. W has the highest melting point of any metallic element (3655K) and W filaments can be operated at ~3000-3300K (a BB at ~3000K peaks at ~966 nm) and the relatively small amounts of UV produced are reduced by absorption by the glass envelope which has to be large as W evaporates onto its surface in the absence of a halogen. Introducing small amounts of iodine or bromine results in the W halide diffusing back towards the filament and being redeposited. Silica envelopes allow more UV through, but are harder to obtain. Fluorine has been tried and is a possibility for the future, once the problem of reaction with the Silica envelopes is solved. On the whole filament lamps are very inefficient sources of ultraviolet radiation. [Philips (1993):p165-9, Lambe (1994):p1-2]
Lasers			Comparatively expensive, not easily portable and time consuming.

Appendix 5.1 Incandescent ASUV

Incandescent ASUV are sources that behave like blackbodies (BB), or e strictly like GreyBodies (GB) or nonBlackBodies (nBB)- see later [Coaton (1997), McCluney (1994)].

Appendix 5.1.1 Some Background Physics - Blackbodies

Ideal BB are a theoretical construct which can only be approximated. Since people also tend to refer to instruments they build to approximate BB's as 'blackbodies' it can become confusing. In order to avoid this problem, perfect (or theoretical or ideal) blackbody will be denoted by BB_I.

BB_I are perfect emitters and absorbers. Experimental blackbodies have been used as primary standards for many years, as their physics is related to fundamental constants and not to the materials from which they are constructed.

"...a standard source of radiation having well-defined area of uniform brightness is required. Often it is also necessary to know the radiant intensity of the source as a function of the wavelength and the temperature.....The blackbody takes in this an unique place since it is up to now the only source whose radiation can be described completely with the aid of formulae deduced from theory" [de Vos (1954)]

The total radiant intensity (total 'energy') of a perfect blackbody as a function of temperature, T, and integrated over all wavelengths is given by the Stefan-Boltzmann equation:

$$I_{BB_I}(T) = \sigma(T^4 - T_o^4)$$

Units: W.m⁻² Equation Ap5.1

(NB: if the blackbody is in thermal equilibrium with it's surrounding medium, there will be no net radiation since the right hand side of this equation will be zero)

Where: T is temperature of the BB_I (Kelvin), T_o is the ambient temperature (Kelvin)

However, If T > 4T_o
Equation Ap5.2

It is usual to neglect T_o and the more familiar version of the equation is obtained. (Note: in the ideal case , the ambient temperature is zero Kelvin)_Planck matched theory with observation with his law which gives the distribution of radiant intensity ('energies') as a function of wavelength and temperature:

$$I_{BB_I}(\lambda, T) = \frac{2hc^2}{\lambda^5} * \frac{1}{e^{\frac{hc}{\lambda kT}} - 1} \quad \text{Units: W.m}^{-2} \quad \text{Equation Ap5.3}$$

Where:

F is Stefan's constant ~5.67 x 10⁻⁸ W.m⁻².K⁻⁴ Note: $\sigma = \frac{2\pi^5 k^4}{15h^3 c^2}$ Equation Ap5.4

T is temperature of the BB_I (Kelvin),
λ is wavelength (metres)

h is Planck's constant ~ 6.26 x 10⁻³⁴ J.s (Joule.seconds)

k is Boltzmann's constant $\sim 1.38 \times 10^{-23} \text{ J.K}^{-1}$ (Joules/ Kelvin)

c is the velocity of light $\sim 3 \times 10^8 \text{ m.s}^{-1}$ (metres per second)

Figure Ap5.1 shows plots of Equation Ap5.3 for different values of T , and note that T is fixed for each curve. The units of both equations are the same which can lead to confusion. Equation Ap5.1 gives the area under equation Ap5.3. There is one more equation in this suite, Wien's displacement law:

$$\lambda_{\max} T = \text{constant} \quad \text{Equation Ap5.5}$$

This defines the locus of the peaks of BB_1 curves. As can be seen in Figure Ap5.1, the higher the temperature of the BB_1 , the higher the peak and (therefore the intensity). Note also the peak wavelength moves to shorter wavelengths as the temperature increases.

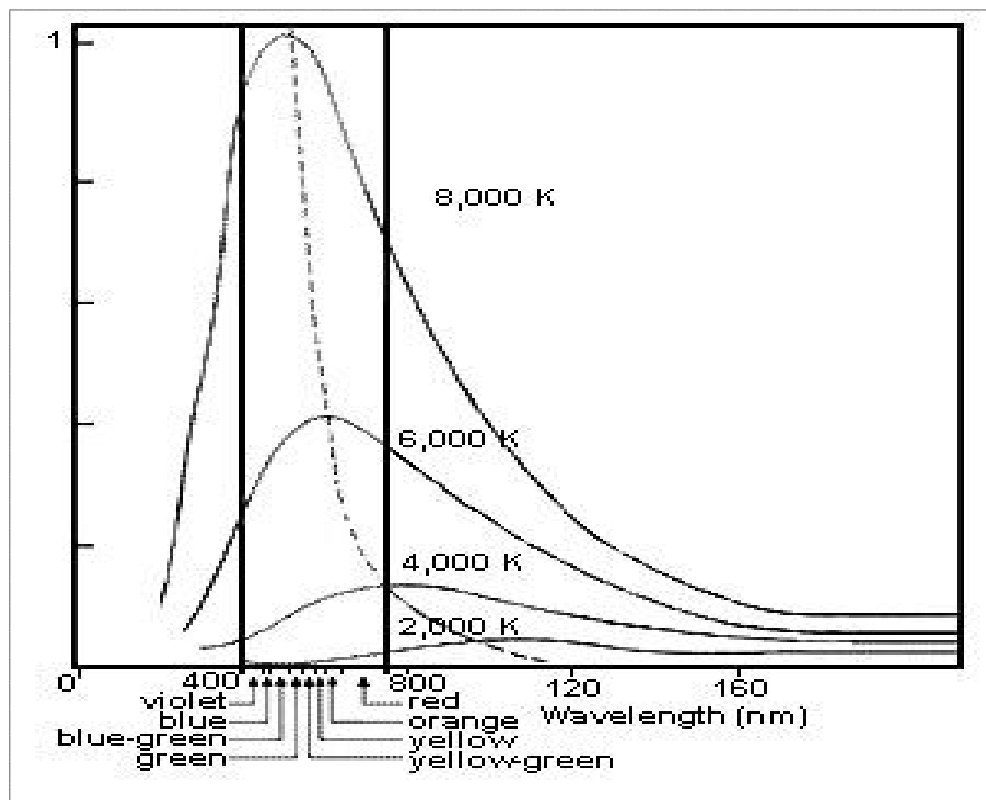


Figure Ap5.1: With permission, from Moore and Hunt (1983) [p22] Black Body radiation curves. The dotted line is the locus of peaks of the curves as described by Wien's displacement law.

Another concept used in ASUV science is colour temperature T_c , this originated in astronomy, and is related to Wien's law.

Since the bulk of the radiation of a BB_1 originates from wavelengths near $\lambda_{\max}$, stars 'have' a colour appropriate to that maximum wavelength, so that hot stars with shorter $\lambda_{\max}$ are called 'blue', whilst stars with longer $\lambda_{\max}$ are called 'red'[1.13:p229]. For ideal black bodies, BB_1 , the colour temperature is the same as the true temperature, however, incandescent ASUV only approximate this theoretical model. The 'best' of these are artificial blackbodies (BB) which are cavities with internally blackened surfaces and very small exit apertures. They are heated until they reach a fixed temperature (which is held by controlling the power input).

Non-perfect BB are called grey bodies since they deviate from the theoretical model in that they are

not perfect absorbers or emitters, however their spectral shapes closely match those of BB_i (the sun is a good example). In this case emittance or emissivity ϵ , (which is a directional quantity) is defined as the ratio of the emission of the thermal radiant flux from the GB to the thermal radiant flux from a BB_i at the same temperature [McCluney (1994) p132]. For hemispherical emittance,

$$\epsilon(\theta, \phi) = \frac{\pi \Phi_{GB}(\theta, \phi)}{\Phi_{BB_i}}$$

Equation Ap5.6

(Note that **B** is used because that the radiant flux from a perfect blackbody is independent of direction)

For BB_i , $\epsilon_{BB_i} = 1$; for GB, $\epsilon_{GB}(\theta, \phi) < 1$.

To complicate matters further, there is another variant called a nonblackbody (nBB) and note, though these concepts are accepted as a matter of theory, in practice the expression ‘blackbody’ tends to be used as ‘shorthand’ for all three cases. nBBs (real surfaces) are not perfect emitters, their spectral shape do not match that of BB_i s, and their emitted radiances vary with wavelength as well as direction. The emittance of a nBB, given in terms of hemispherical spectral radiance is given by:

$$\epsilon_{nBB}(\lambda, \theta, \phi) = \frac{\pi I_{nBB}(\lambda, \theta, \phi)}{I_{BB_i}}$$

Equation Ap5.7

Appendix 5.1.2 Tungsten/Halogen Lamps

The Tungsten/Halogen lamp (filament type/ambient Halogen gas) is the most widely used incandescent source). However, even the most expensive of these lamps produces UV as a relatively small fraction of its total output since Tungsten melts at 3695K [11.22] and the lamps can be operated at ~3300 [11.16]. Remember that the bulk of the sun’s output can be modelled by a BB at ~5700K and that peaks in the visible. However, these lamps are useful as components in ‘solar simulators’, sources that attempt to mimic the sun’s output (range of wavelengths - though not including X-rays or gamma-rays).

Appendix 5.1.3 Brief Historical Review of Incandescent Lamps

- 178? Aimé Argand, a Swiss chemist and inventor makes the first tubular wicks for oil lamps
 - 1783 Tungsten (heavy stone in Swedish) discovered by Fausto & Juan José de Elhuyar, in Spain. Symbol, W ‘wolfram’ after the mineral ‘wolframite’. [Winter (1997)]
 - 1848 J.W. Swan begins using thin strips of carbonized paper in evacuated bulbs [Asimov (1966) p312]
 - 1860 Swan makes an electric light with a carbon filament [ibid]
- Karl Auer (Baron von Welsbach) was the first person to use a compound that incandesced without melting. He patented his ‘Welsbach mantle’, in 1885. He constructed the mantle by impregnating a cylindrical fabric with a mixture of thorium nitrate and cerium nitrate. By doing this he was also the first person to find a practical use for rare earth elements [ibid p414]. The next steps were by Edison.
- 1879 Edison announces his new light bulb

- 1898 Auer improved on Edison's work by introducing an osmium filament in 1898 which was much longer lasting than Edison's carbon filament, though much too rare to be useful. [Asimov (1966)]
- 1910 Coolidge, ductile tungsten.(US) General Electric
- 1910 Langmuir replaces vacuum in lamp envelope with gas (US) General Electric Patent

Appendix 5.2 ARC /DISCHARGE ASUV

An electrical discharge is passed between electrodes either in air (open arc) or through a gas contained in a glass, quartz or other type of envelope. It is useful to think of the discharge as an input of electrical energy which is absorbed by the constituent atoms or molecules of the gas. These then become 'excited' to higher energy states and subsequently relax back by emitting a UV photon. The wavelength and energy of the emitted photons will depend on the gas being used, also the spectrum produced will not be smooth but some low background over which a series of spectral lines are superimposed due to the particular energy levels which have produced the outgoing photon. Increasing the gas pressure tends to broaden these lines.

Appendix 5.3 Definitions of Terms used in Table 3.1

Table Ap5.3: Definitions of terms used in Table 3.1, Section 3.
From Collins English Dictionary 1994 (by permission of HarperCollins Publishers) unless otherwise stated.

Adsorb	To undergo or cause to undergo a process in which a substance, usually a gas, accumulates on the surface of a solid forming a thin film, often only one molecule thick: <i>to adsorb hydrogen on nickel; oxygen adsorbs on tungsten.</i> <u>Compare absorb</u> To cause to undergo a process in which one substance, usually a liquid or gas, permeates into or is dissolved by a liquid or solid: <i>porous solids absorb water; hydrochloric acid absorbs carbon dioxide.</i>
Aerosol	1) <i>Aerosol</i>: small droplet or particle suspended in the atmosphere, typically containing sulfur. Aerosols are emitted naturally (e.g., in volcanic eruptions) and as the result of human activities (e.g., by burning fossil fuels). There is no connection between particulate aerosols and pressurized products also called aerosols (see below). <i>[USA EPA Ozone related definitions, EPA website]</i> 2) <i>Aerosol</i>: a product that relies on a pressurized gas to propel substances out of a container. Consumer aerosol products in the US have not used ozone-depleting substances (ODS) since the late 1970s because of voluntary switching followed by federal regulation. The Clean Air Act and EPA regulations further restricted the use of ODS for non-consumer products. All consumer products, and most other aerosol products, now use propellants that do not deplete the ozone layer, such as hydrocarbons and compressed gases. <i>[USA EPA Ozone related definitions, EPA website]</i>
Anneal	1 to temper or toughen (something) by heat treatment. 2 to subject to or undergo some physical treatment, esp. heating, that removes internal stress, crystal defects, and dislocations. 3 (often followed by <i>out</i>) <i>Physics</i>. to disappear or cause to disappear by a rearrangement of atoms: <i>defects anneal out at different temperatures.</i> <i>[Old English onælan, from ON + ælan to burn, from al fire]</i>
Chromatography	The technique of separating and analysing the components of a mixture of liquids or gases by selective adsorption in, for example, a column of powder (column chromatography) or on a strip of paper (paper chromatography). See also gas chromatography <u>gas chromatography.</u> A technique for analysing a mixture of volatile substances in which the mixture is carried by an inert gas through a column packed with a selective adsorbent and a detector records on a moving strip the conductivity of the gas leaving the tube. Peaks on the resulting graph indicate the presence of a particular component. Also called: gas-liquid chromatography.
Colorimeter	1. Also called: tintometer. an apparatus for determining the concentration of a solution of a coloured substance by comparing the intensity of its colour with that of a standard solution or with standard colour slides. 2. any apparatus for measuring the quality of a colour by comparison with standard colours or combinations of colours.
Densitometer	An instrument for measuring the optical density of a material by directing a beam of light onto the specimen and measuring its transmission or reflection.
Electrophoresis	The motion of charged particles in a colloid under the influence of an applied electric field. Also called: cataphoresis.
Epoxy	<i>Chem.</i> 1. of, consisting of, or containing an oxygen atom joined to two different groups that are themselves joined to other groups: <i>epoxy group.</i> 2 of, relating to, or consisting of an epoxy resin. 3 short for epoxy resin. <u>epoxy or epoxide resin</u> any of various tough resistant thermosetting synthetic resins containing epoxy groups: used in surface coatings, laminates, and adhesives.

Fluorospectrophotometer Fluorospectrometer aka: Spectrofluorophotometer	<u>fluorescence</u> 1. <i>Physics</i>. a. the emission of light or other radiation from atoms or molecules that are bombarded by particles, such as electrons, or by radiation from a separate source. The bombarding radiation produces excited atoms, molecules, or ions and these emit photons as they fall back to the ground state. b. such an emission of photons that ceases as soon as the bombarding radiation is discontinued. c. such an emission of photons for which the average lifetime of the excited atoms and molecules is less than about 10^{-8} seconds. 2. the radiation emitted as a result of fluorescence. [Collins English Dictionary] Measuring Intracellular Ions with the RF-5301PC Spectrofluorophotometer. Compared to absorbance methods, fluorescence sensitivity is tens to thousands times better - this means that you can analyze nanogram to picogram samples with great results. Fluorescence can be used also to identify a specific molecule in a complex background. When the compound of interest does not exhibit natural fluorescence, functional group-specific probes may be used to label the compound and assist your research. The synchronous scanning mode allows mixtures of fluorochromes to be analyzed. RF-5301PC employs a blazed holographic grating, photomultiplier and digital signal processing. [Shimadzu website: http://www.sel.shimadzu.com]
Interferometer	1. <i>Physics</i> . any acoustic, optical, or microwave instrument that uses interference patterns or fringes to make accurate measurements of wavelength, wave velocity, distance, etc.
P h o t o a c o u s t i c Spectroscopy	When molecules in the air absorb energy from a laser beam, they heat up. If the laser beam is pulsed repetitively, the molecules alternately heat and cool. The cycle of heating and cooling produces an acoustic wave, which can be detected by a microphone and amplified electronically. The intensity of the sound wave is directly proportional to the concentration of molecules absorbing energy. [www.geocities.com/SiliconValley/.../photoacoustic.html]
Refractometer	any instrument for determining the refractive index of a substance.
Spectrophotometer	an instrument for producing or recording a spectrum and measuring the photometric intensity of each wavelength present, esp. such an instrument used for infrared, visible, and ultraviolet radiation. <u>See also spectrometer.</u> any instrument for producing a spectrum, especially one in which wavelength, energy, intensity, etc., can be measured. See also mass spectrometer.

Appendix 5.4 CCPR Intercomparison - Participating Organizations

National Laboratories from twelve counties participated in the CCPR intercomparison, as shown in table Ap5.4

Table Ap5.4: Participants in the CCPR Intercomparison of Spectral Irradiance Measurements

Participating Organisation (& Country)	Full name of Laboratory	Principal Investigator
CSIRO (Australia)	Commonwealth Scientific and Industrial Research Organization, Division of Applied Physics, Lindfield	J. L. Gardner
DPT (South Africa)	Division of Production Technology, CSIR, Pretoria	F. Hengstberger
ETL (Japan)	Electrochemical Laboratory, Ibraki	M. Nishi
INM (France)	Institut National de Metrologie du Conservatoire National des Arts e Metieres, Paris	J. Bastie
IOM (Spain)	Instituto de Optica Daza de Valdes, Madrid	A. Corrons
NIM (China)	National Institute of Metrology, Beijing	Chen Xiaju
NIST (USA)	National Institute of Standards and Technology, Gaithersburg MD	J. H. Walker
NPL (UK)	National Physical Laboratory, Teddington, Middlesex	J. R. Moore
NRC (Canada)	National Research Council, Ottawa	L. P. Boivin
OMH (Hungary)	National Office of Measures, Budapest	G. Deszi
PTB (Germany)	Pysikalisch-Technische Bundesanstalt, Braunschweig	J. Metzdorf
VNIIOFI (USSR)	All-Union Research Institute of Optical and Physical Measurements, Moscow	V. I. Sapritsky

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Shimadzu (1998)
http://206.55.43.7/shimadzu/de/products/3_spectroscopy/spectrofluorophotometers/uf_5301pc/index.html

Wasserman at <http://www.geocities.com/SiliconValley/Pines/8516/photoacoustic.html>

APPENDIX 6 ORGANIZATIONS MONITORING UV

Appendix 6.1 World-Wide Listing

Listing of Acronyms and Names of Organizations involved in Monitoring and Measuring UV. This list is not exhaustive and is based on one European Grouping called SUVDAMA (1995)* [SUVDAMA] and from the US SRRB(NOAA) UV website [Weatherhead (1996)].

So far there is only one listing for 'Africa' and that is in South Africa. Since Antarctica is jointly 'owned' by a number of countries, it is listed here under 'World-Wide Organizations'.

AFRICA	
South Africa	
SPRI	Space Physics Research Institute (Ozone Group, Dept. Physics, University of Natal, Durban)
ASIA	
China	
IAC	Inst of Atmospheric Chemistry at the Chin. Academy of Meteorological Science (CAMS), Beijing
Japan	
CGES	Centre for Global Environmental Research in the National Inst for Env. Studies (NIES) Tokyo
JWA	Japan Weather Association, Ibaraki
OLMO	Ozone Layer Monitoring Office at the Japan Meteorological Agency (JMA) Tokyo
India	
SSO	Space Science Office, Bangalore
PRL	Physical Research Laboratory, Ahmedabad
Malaysia	
AARU	Astronomy and Atmospheric Research Unit, Penang
MMS	Malaysian Meteorological Service, Selangor
Taiwan	
CWB	Central Weather Bureau
AUSTRALIA	
ARL	Australian Radiation Laboratory, Yallambie, Victoria

EUROPE	
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre
?	European Union Thematic Network on UV Measurement (Chair HUT, Finland)
*SUVDAMA	Scientific UV Data Management
Austria	
BOKU	University of Vienna, Institute fur Bodenkultur*
IMP	Institut fur Meteorologie und Physik, University of Agriculture, Forestry & Renewable Natural Resources, Vienna
UG	University of Graz*
UI	University of Innsbruck*
UVV	University of Veterinary Medicine, Vienna, Institute of Medical Physics*
Belgium	
IASB	Institute d'Aeronomie de Spatiale de Belgique*, Brussels
RMI	Royal Meteorological Institute, Brussels
Czech Republic	
BOK	Background Observatory Kosetice
CHI	Czech Hydrometeorological Institute, Hradec Kravlove
IPA	Institute of Physics of the Atmosphere, Academy of Sciences of the Czech Republic
Germany	
AWI	Alfred Wagner Institute for Polar Research*
BfS	Bundesamt fur Strahlenschutz
DLRKP	German Aerospace Research Establishment, Institute of Aerospace Medicine*
DLROP, DLR	Oberpfaffenhofen, Institute for Physics of the Atmosphere*
DWD	German Meteorological Service*
IFU	Fraunhofer Institute for Atmospheric Environmental Research*
PTB	Phys-Tech Bundesanstalt (<i>National Standards Laboratory</i>)*
UBA	Umweltbundesamt*
UKA	University of Karlsruhe, Inst for Botany*
Great Britain	
BAS	British Antarctic Survey*
MO	Meteorological Office, Bracknell, Berkshire
NPL	National Physical Laboratory (<i>National Standards Laboratory</i>)*
NRPB	National Radiation Protection Board, Didcot, Oxfordshire
UMIST	University of Manchester, Institute for Science & Technology (Reading)*
Greece	
LAP	Aristotle University of Thessaloniki, Laboratory of Atmospheric Physics*
UALM	University of Athens Laboratory of Meteorology
Hungary	
HMS	Hungarian Meteorological Service, Budapest
Ireland	
IMS	Irish Meteorological Service
Italy	
IFA	Istituto di Fisica dell'Atmosfera, (CNR?) Rome
IG	Istituto de Gallicano*
LCP	Laboratorio Chimico Provinciale, Bolzano
JRC	Joint Research Council, Ispra *
URO	University of Rome, Physics Department*
Netherlands	
KNMI	Koninklijk Nederlands Meteorologisch Instituut*
RIVM	Rijksinst voor Volksgezondheid en Milieuhygiene*
Poland	
IMWM	Institute of Meteorology and Water Management
Spain	
INM	Institute Nacional de Meteorologia, Dept Izana GAW Station*
Switzerland	
SWI	Swiss Meteorological Institute
MIDDLE EAST	
Bahrain	
-	Chief of Meteorology
NEW ZEALAND	
NIWA	National Institute of Water and Atmospheric Research, Lauder
RUSSIA	
MO	Meteorological Observatory at the Geographical Department of Moscow State University

SCANDINAVIA/NORDIC	
NOG	Nordic Ozone Group (Includes GREENLAND)
Denmark	
DMI	Danish Meteorological Institute, Copenhagen
Finland	
FMI	Finish Meteorological Institute*
HUT	Helsinki University of Technology
STUK	Finish Centre for Radiation & Nuclear Safety*
Iceland	
IMO	Icelandic Meteorological Office
UI	University of Iceland
Norway	
NORUT	Information Tech Ltd *
UT	University of Trondheim, Department of Physics*
Sweden	
SMHI	Swedish Meteorological & Hydrological Institute*
SSI	Swedish Radiation Protection Institute*
THE AMERICAS -NORTH	
Canada	
AES	Atmospheric Environment Service, Ontario
TU	Trent University, Ontario
Mexico	
-	Run by TU, Canada
United States of America	
BGC	Board on Global Change
CGER	Commission on Geosciences, Environment and Resources
EPA	Environmental Protection Agency
JPL	Jet Propulsion Laboratory
LLNL	Lawrence Livermore National Laboratory
NASA	National Aeronautics and Space Administration
NBS	National Biological Survey
NCAR	National Center for Atmospheric Research
NIST	National Institute for Science and Technology (<i>National Standards Laboratory</i>)
NOAA	National Oceanic and Atmospheric Administration
NREL	Natural Resource Ecology Laboratory
NRL	Naval Research Laboratory
NSF	(USA) National Science Foundation (<i>site operation by BIOSPHERICAL INSTRUMENTS, INC.</i>)
Smithsonian	Smithsonian Institute, Maryland
SRRB	Surface Radiation Research Branch of the National Oceanic and Atmospheric Administration (NOAA)
USDA	US Department of Agriculture
-	UV-B Critical Issues Workshop (Sponsored by US Dept. of Energy)
USGS	US Geological Survey
THE AMERICAS -SOUTH	
Argentina	
CADIC	?
Chile	
MDC	Meteorological Direction of Chile at Dept. Of Climatology and Applied Meteorology, Santiago
WORLD-WIDE ORGANISATIONS	
UNEP	United Nations Environmental Programme
WMO	World Meteorological Organization
WHO	World Health Organization
<u>ANTARCTICA</u>	
BAS	British Antarctic Survey
IAC	(China) Institute of Atmospheric Chemistry
IFA	(Italy) Istituto di Fisica dell'Atmosfera, (CNR?) Rome
NSF	(USA) National Science Foundation (<i>site operation by BIOSPHERICAL INSTRUMENTS, INC.</i>)

Appendix 6.2 Key Players in UV-Related Sciences

Since the UV/Ozone community has mushroomed into a hugely diverse community, for example, physicists, meteorologists, environmentalists, chemists, biologists, biophysicists, metrologists, astronomers, astrophysicists to name but a few. It is easier, therefore, to note who the key players are, as it is often impossible to keep up with each specialty. That is, seminal papers are harder to locate and identify, but if a key player's name is on a paper, it is worth looking at. To see who some of these individuals are, it is worth looking at the membership of some of the organisations listed in Appendix 6.1.

Appendix 6.2.1 World-Wide

A COMMISSION INTERNATIONALE DE L'ECLAIRAGE (CIE); INTERNATIONAL COMMISSION ON ILLUMINATION

CIE Administration: GENERAL ASSEMBLY [*From
<http://www.cie.co.at/cie/doc/admin.htm> at August 1998*]

Chairman: Jack J. Hsia [Chief, Office of Academic Affairs NIST]

ARGENTINA	Maria Louisa F. Mattiello	ISRAEL	Eliyahu Ne'eman
AUSTRALIA	Bryan Powell	ITALY	Paolo Soardo
AUSTRIA	Peter Dehoff	JAPAN	Sadao Takahashi
BELGIUM	G. Vandermeersch	MOLDOVA (REPUBLIC OF)	Victor Vladislav Betsa
BRAZIL	Milton Martins Ferreira	NETHERLANDS	Jan Blom
BULGARIA	Christo Vassilev	NEW ZEALAND	John F. Clare
CANADA	Jacques Roberge	NORWAY	Odd Arnesen
CHINA	Li Min Fu	PAKISTAN	?
CROATIA	Slavko Sever	POLAND	Jan Grzonkowski
CZECH REPUBLIC	Vladimir Dvoracek	ROMANIA	Cornel Bianchi
DENMARK	Bjarne Nielsen	RUSSIAN FEDERATION	Guennady Chahparunians
ESTONIA	Enn Uusküla	SLOVAK REPUBLIC	Jan Novomesky
FINLAND	Pentti Hautala	SLOVENIA (REPUBLIC OF)	Evgen Ogrinc
FRANCE	Jacques Lecocq	SOUTH AFRICA	Eddie Chapman
GERMANY	Heinz Terstiege	SPAIN	Fernando Ibanez
GREAT BRITAIN	Alastair McKinlay	SWEDEN	Allan Ottosson
HONG KONG	Lily Chang	SWITZERLAND	Philippe C. Joye
HUNGARY	Janos Schanda	THAILAND	Pramoht Unhavaithaya
ICELAND	Gisli Jónsson	TURKEY	Mehmet Kucukdogu
INDIA	Pranab K. Bandyopadhyay	U.S.A.	Alan Lewis

CIE: DIVISION 6: PHOTOBIOLOGY AND PHOTOCHEMISTRY [<http://www.cie.co.at/cie/doc/div6.htm>]

Director of Division:	Dr. D. H. Sliney
Associate Director:	Mr. Jean-Pierre Césarini
Secretary of Division:	Dr. Ambler Thompson (NIST)
Editor of Division:	Dr. Myron L Wolbarsh

B The World Meteorological Organization's (WMO) Scientific Steering Committee on UV

Monitoring

{Adapted from SRRB site; <http://www.srrb.noaa.gov/UV/ssc.html>, compiled by E.K. Weatherhead (1996)}

1. Paul Simon chairs the Scientific Steering Committee.
2. Betsy Weatherhead (NOAA, Uni. Chicago) helps coordinate international efforts.
3. Petteri Taalas heads up data analysis of UV data.
4. Gunther Seckmeyer (IFU, Chair SUVDAMA) is in charge of instrument characterization.
5. Ann Webb (UMIST, SUVDAMA) works on issues of quality assurance.
6. Sasha Madronich coordinates UV modelling.
7. David Wardle is in charge of the WMO Ozone and UV Data Center.
8. Anne Krickler represents the users of UV data.
9. Christos Zerefos (LAP, SUVDAMA) is the delegate of the WMO EC panel.
10. John Miller is the WMO representative.
11. J. M. Libre is the UMAP(?) representative.
12. Georgios Amantidis is the EC representative.
13. Dr. Osamu Uchino is a representative of JMA acting as an observer to the SSC(?)

C From the Metrological community Refer to Quin (1995)

Acronym	Name	Established	Location
BIPM	Bureau International de Poids et Mesures	1875	Paris, France
PTB	Physikalisch-Technische Reichsanstalt	1887	Berlin, Germany
NPL	National Physical Laboratory	1900	Teddington, UK
NBS (now NIST)	National Bureau of Standards (National Institute for Science and Technology)	1901	Washington, USA
NRLM	National Research Laboratory of Metrology	1903	Tokyo, Japan

Appendix 6.2.2 The Americas (USA)

A UV-B Critical Issues Workshop

{Partial List of Participants, to show links [US DoE (1993)] reproduced with permission}

- | | | |
|---|-------------------|------------------------------------|
| 1 | Daniel Berger | (SOLAR LIGHT) |
| 2 | Rocky Booth | (BIOSPHERICAL) |
| 3 | John DeLuisi | (NOAA) |
| 4 | Bronek Dichter | (Yankee Environmental Systems) |
| 5 | John Frederick | (University of Chicago) |
| 6 | Ambler Thompson | (NIST) |
| 7 | Betsy Weatherhead | (NOAA, University of Chicago, WMO) |
| 8 | Joseph Zawodny | (NASA Langley Research Centre) |

B US NRC (1994) Report ‘Solar Influences on Global Change (Courtesy National Academy Press)

Contributing Scientists

- | | | |
|----|-----------------|----------------------------|
| 1 | Daniel Baker | (University of Colorado) |
| 2 | Judith Lean | (NRL) |
| 3 | Martin Geller | (SUNY at Stony Brook) |
| 4 | Thomas Potemra | (Johns Hopkins University) |
| 5 | George Reid | (NOAA) |
| 6 | David Rind | (NASA) |
| 7 | Raymond Roble | (NCAR) |
| 8 | Oran White | (NCAR) |
| 9 | Donald Williams | (Johns Hopkins University) |
| 10 | Richard Willson | (JPL) |
| 11 | George Withbroe | (NASA) |
| 12 | Donald Wuebbles | (LLNL) |

Connected Groupings

- | | |
|---|--|
| 1 | Board on Global Change |
| 2 | Commission on Geosciences, Environment and Resources |

Appendix 6.2.3 *European*

- A. European Union Thematic Network on UV Measurement
Set up to ascertain areas where UV measurements are required and how to meet those requirements See section 4.2.

Appendix 6.3 *Satellites (NASA, ESA in collaboration with others)*

Below are some examples of Satellites that are or have recently been involved in UV and UV related measurements. These instruments tend to be 'bespoke' even if a number of the constituent parts are provided by commercial companies. They are usually built by large, collaborative teams often from several countries comprising some or all of the following; academic institutions, government agencies and commercial companies.

Appendix 6.3.1 *Brief Description*

A. ERS (European Remote Sensing Satellite)

GOME (Global Ozone Monitoring Experiment)

"..is a passive imaging spectrometer of high spectral resolution (for space borne instruments). It measures light reflected and scattered by the Earth's surface and the atmosphere in the ultraviolet....For calibration purposes the sensor also has the capability to observe the sun and the moon, as well as to carry out internal calibration measurements." [ERS GOME 91997]

B. SOHO (Solar and Heliospheric Observatory)

SOHO carries a number of different instruments on-board, those related to UV measurements are:

1. *EIT (Extreme Ultraviolet Imaging Telescope)*

"..will provide wide field images of the corona and transition region on the solar disc and up to 1.5 $R_{\odot}$ above the solar limb. Its normal incidence multilayer-coated optics will select spectral emission lines from ..171D... to 304 D.... The EIT will probe the coronal plasma on a global scale, as well as the underlying cooler and turbulent atmosphere, providing a basis for comparative analyses with observations from both the ground and other SOHO instruments." [Delaboudinière, et al 1995]

2. *SUMER (Solar Ultraviolet Measurements of Emitted Radiation)*

"..is a telescope/spectrometer operating in the wavelength range from 50 to 161 nm....covering emission lines of the upper chromosphere, the transition region, and the lower corona in its vacuum ultraviolet (VUV) spectral range." [Hollandt, et al 1996]

3. *UVCS (Ultraviolet Chronograph Spectrometer)*

"..was designed for UV spectroscopy and visible light polarimetry of the extended solar corona." [Pernechele et al 1996]

4. *VIRGO (Variability of solar IRradiance and Gravity Oscillations)*

"...will provide the following observational and derived data:

C continuous high-precision, high stability and high accuracy measurements of the solar total and spectral irradiance and spectral radiance variation;.....

..these data will be utilized to achieve the main scientific objectives of VIRGO summarized in the following list:.....

C study the influence of solar active regions and other large-scale structures on total and spectral irradiance.....

C provide accurate total and spectral irradiance data for input in terrestrial climate modelling.....

....The causes of irradiance changes are crucially important for the understanding of solar and stellar evolution. Irrespective of the cause., knowledge of the possible medium- and long-term variations of the solar irradiance are equally important for the understanding of terrestrial climatic change. solar energy in the entire spectrum and particularly at UV wavelengths has been monitored from space for more than one and a half decades...." [ESTEC (1995)]

C) UARS (Upper Atmosphere Research Satellite)

UARS carries a number of different instruments on-board, those related to UV measurements are:

1. *SOLSTICE (SOLar STellar Irradiance Comparison Experiment)*

"...measures the magnitude of the solar spectral irradiance of the total solar disk in the wavelength range 115 to 430 nm... to determine solar variability on three basic timescales:

C Short term variations spanning time periods of minutes to hours (exemplified by solar flares)

C Intermediate-term variations lasting days to weeks (characterized by the solar rotation and the development of active regions)

C Long-term variations (associated with the 11-year sunspot cycle or the 22-year magnetic field cycle

....the unique feature of the SOLSTICE is its ability to compare accurately (to within 1%) the solar irradiance with the ultraviolet flux of bright blue stars. These stars then become the standard against which the solar irradiance is measured."

[UARS SOLSTICE (1997)]

2. *SUSIM-UARS (Solar Ultraviolet Spectral Irradiance Monitor)*

See below

D) SUSIM (Solar Ultraviolet Spectral Irradiance Monitor)

SUSIM ATLAS is flown periodically on the shuttle and is, "... calibrated before its flight and carries four deuterium lamps to help to maintain its calibration."

SUSIM UARS {Upper Atmosphere Research Satellite} is one of the experiments on board UARS.

There are two 'SUSIM's because, "Calibration is an important task for UV instrument scientists because measured UV light degrades the responsivity of their instruments by an uncertain amount". Essentially, the results from the SUSIM ATLAS missions are used to maintain the calibration of the SUSIM UARS mission. "NASA sponsors the two SUSIM's in the SUSIM program of the Solar Physics Branch (SPB) of the Space Science Division (SSD) at the Naval Research Laboratory (NRL)... The observations...have a three fold general objective 1) To improve the accuracy of knowledge of the absolute solar fluxes, 2) To provide highly accurate traceability of solar fluxes to a variety of UV standards to be able to establish long-term (solar-cycle) variations and 3) To measure the variability of solar fluxes during several different time periods ranging from flare produced changes (hours) to the variability caused by solar rotation (27 days)." [SUSIM (1997)]

Appendix 6.3.2 *Some Results from UV Satellites*

Table Ap6.1 below gives Satellite and Space Shuttle measurements of the Sun's UV Spectral Irradiance and is from Lean (1991).

Table Ap6.1: With permission, from Lean (1991) [p522] "Satellite and Space Shuttle Measurements of the Sun's UV Spectral Irradiance"

<i>Instrument and Launch Vehicle</i>	<i>Measurement Duration</i>	<i>Spectral Band</i>	<i>Description</i>	<i>References (in Lean)</i>
OS05	1969-1975	Lyman "	Hydrogen and deuterium resonance cells at exit of predisperser	Vidal-Madjar [1975] Vidal-Madjar and Phissamay [1980]
AE-E	1977-1980	14.2-125 nm	Multiple spectrometers with PMTs and CEMS.	Hinteregger et al. [1981]

SBUV Nimbus 7 NOAA 9 NOAA 11	1978-1986 1984- 1986-	160-400 nm	1.1 nm resolution double Ebert-Fastie spectrometer with PMT and diffuser on-board Hg calibration mid PMT gain monitor	Heath & Schlesinger [1986] Donnelly [1988] Schlesinger et al. [1990]
SME	1981-1989	115-305 nm	0.75 nm resolution, two separate monochromators each with PMTs and operational and stored diffusers.	Rottman [1988]
SUSIM Space Lab 2 UARS ATLAS	Aug. 1985 Sept. 1991- 1992-	115-140 nm	0.15 nm, 1.1 nm, and 5 nm resolution two identical double Wadsworth spectrometers with multiple, redundant optical elements, four on-board deuterium calibration lamps.	Van Hoosier et al. [1988]
SOLSPEC UV Space Lab 1 ATLAS	Dec. 1983 1992-	200 -300 nm	1.3 nm resolution, double monochromator with diffuser and PMT; on-board calibration with deuterium and FEL-type lamps.	Labs et al [1987]
ASSI	March-Dec. 1988	20-700 nm	0.7-3 nm resolution, two separate Rowland circle spectrometers with PMTs and CMEs; in-flight detector calibration.	Schmidke et al. [1985, 1990a]
SSBUV STS 34 STS 41 STS 43 ATLAS	Oct. 1989 Oct. 1990 July 1991 1992-	160-400 nm	1.1 nm resolution, double Ebert-Fastie spectrometer with PMT and diffuser; in-flight calibration using deuterium, 45-W quartz-halogen, and fig lamps.	Cebula and Hilsenrath [1990]
SOLSTICE UARS EOS	Sept. 1991- 1999-	115-430 nm	0.15 nm resolution, three separate monochromators with PMTs on-board calibration by observations with different apertures of bright UV stars.	Rottman [1988]

Appendix 6.4 Commercial Organizations (with others)

These are some of the commercial companies involved in making UV instrumentation. They often get involved in collaborative projects with academics. There are other companies who make components, such as filters and detectors but there does not appear to be such a close relationship between such companies and the measurement community.

1 BIOSPHERICAL INSTRUMENTS INC

It appears that a lot of the major players on both sides of the Atlantic have used Biospherical's Sunburning UltraViolet (SUV) Scanning Spectroradiometers (these instruments are monochromator based):

"SUV instruments have seen nearly a decade of continuous service in the National Science Foundation's Polar UV Monitoring Network : Anderson et al 1993,

Benavides et al 1994, Booth et al 1988-94, Cullen et al 1992, Diaz et al 1990-94, Frederick et al 1993, Holm-Hansen et al 1993, Lubin & Frederick 1989-92, Madronich 1993, Seckmeyer et al 1995, Smith et al 1989-92, Stamnes 1993, Stamnes et al 1990-92

In addition, the reliability and accuracy of the SUV have been proven through numerous Intercomparisons with other UV measuring devices from around the world: Seckmeyer et al 1995, Thompson et al 1996." [Biospherical (1998)]

The US NSF UV Monitoring Network webpage is on the Biospherical website.

2 SCI-TECH INSTRUMENTS

Sci-Tech Instruments have disclosed that in 1997, approximately one hundred and thirty of their BREWER SPECTROPHOTOMETERS were in operation in thirty-three countries and Antarctica.[Sci-Tech (1998)]

3 SOLAR LIGHT INC

An SUV meter was designed by Roberstson (1969) to fulfill a proposal made in 1958 to measure the daily variation of SUV in Australia over several years. In 1972, a second generation meter was designed by Berger [Berger (1976)] for the US Department of Transport's study into the effects the effluents of super-sonic transports could have on the earth's climate. This instrument, now called the Roberstson-Berger Meter is made by Solar Light and widely used by the measurement community.

On the webpage advertising their UV-Biometer model 501A, Solar Light have a photograph of one of these instruments in used by IFU's (Germany) Solar UV Radiation Group, headed by Dr G. Seckmeyer.

References Appendix 6

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

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UARS website (1998) http://uarsfot08.gsfc.nasa.gov/UARS_INSTS
A. SOLSTICE is provided by the University of Colorado
B. SUSIM(UARS)

SUSIM (ATLAS) website (1998) <http://louis14.nrl.navy.mil/susim.html#why>

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APPENDIX 7 FORMALIZING UV MEASUREMENT

Appendix 7.1 SI Units and Standards

Appendix 7.1.1 Base Units & Fundamental Constants of Physics

For UV work, the candela, SI base unit of luminous intensity is the most important, and has been derived in times past, from primary standard sources based on flame or incandescent filament standards. “This has progressed from a standard candle (circa 1880) to a black body at the temperature of the freezing point of platinum (1948)” [Martin *et al* (1985)p147] when the 9th CGPM adopted the new international name ‘candela’ with the symbol ‘cd’ [Bell (1993) p8], this was the position at 1979.

However, the uncertainty associated with the temperature of the freezing point of platinum was translated into uncertainty in calculating a value for the maximum spectral luminous efficacy of radiation, K_m [Martin *et al* (1985) p147].

Radiometric (X_e) and Photometric (X_v) quantities are related by K_r , the Radiation Luminous Efficacy, which is ‘..a measure of the effectiveness of a beam of radiation in stimulating the perception of light in the human eye’ and can be defined for any of the four basic quantities [McCluney (1994) p41], and for luminance and radiance is written as follows [Goodman & Key (1985) p29]:

$$K_m = \frac{L_v}{\int L_{e,\lambda} V(\lambda) d\lambda} \quad \text{Units: (lm.W}^{-1}\text{) Equation Ap7.1}$$

Where: L_v is the luminance of the source
 $L_{e,\lambda}$ is the spectral radiance of the source
 $V(\lambda)$ is the photopic spectral luminous efficiency function defining the standard observer for photometry and tabulated by the International Lighting Commission (CIE) {which is based on the French version Commission Internationale de l’Eclairage}
 K_m is a constant giving the number of lumens equivalent to 1 watt of power at the wavelength corresponding to the peak of the $V(\lambda)$ function

In 1985, Quinn and Martin reported measurements made using a cryogenic radiometer at NPL from 1972-1983 through which they were able to calculate a value of $5.66967 \pm 0.00076 \times 10^{-8} \text{ W.m}^{-2}.\text{K}^{-4}$ for the Stefan-Boltzmann constant, F which is related via equation Ap7.2 to three fundamental constants.

$$\sigma = \frac{2\pi^5 k^4}{15h^3 c^2} \quad \text{Units: W.m}^{-2}.\text{K}^{-4} \text{ Equation Ap7.2}$$

Where: h is Planck’s constant (J.s),
 k is Boltzmann’s constant (J/K)
 c is the velocity of light (m/s)

“This is the first radiometric determination of F having an uncertainty comparable with that calculated directly from fundamental physical constants. This measured value differs from the calculated one by 13 parts in 10^5 , which is less than the combined standard deviations of the measured and calculated values.”
 [Quinn & Martin (1985) p86]

These and other developments in radiometric and spectroradiometric techniques led to the re-definition of the candela in 1979:

“From 1948 until 1979, the photometric base unit, the candela was defined in terms of the luminance of a black-body radiator at the freezing point of platinum... This definition

was found difficult to realize in practice, due to problems such as large variations in luminance from one freezing of the platinum ingot to the next, non-uniform emission from the black-body cavity and imperfect black-body behaviour....To establish a value for K_m based on the black-body definition for the candela ..requires precise knowledge of the temperature of the black-body, so that the Planck function can be evaluated.....In October 1979 the 16th CGPM adopted a new, radiometric definition of the candela: 'The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity of $(1/683)$ watt per steradian'. The frequency..was selected as corresponding closely to the wavelength at which the $V(\lambda)$ function is a maximum (ie 555 nm) thus K_m has the value $683.002 \text{ lm.W}^{-1}$ according to this new definition." [Goodman & Key (1985) p29-30]

References Appendix 7

Based on: Hunt, T.M (1998) *Current Techniques for Measuring Ultraviolet Radiation: Problems & Possible Solutions*, 2nd Year Dissertation for Brunel/Surrey Engineering Doctorate

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APPENDIX 8 UV MEASUREMENT

Appendix 8.1: Structure and Composition of the Earth's Atmosphere

In order to record the radiation from any star - including the sun - from within the earth's atmosphere, it becomes necessary to understand the earth's atmosphere, hence it must be accurately modelled so that its various effects can be separated from the collected data. Figure Ap8.1 from the Oklahoma Climatological Survey website, is a good visual representation of the basic layers of the atmosphere.

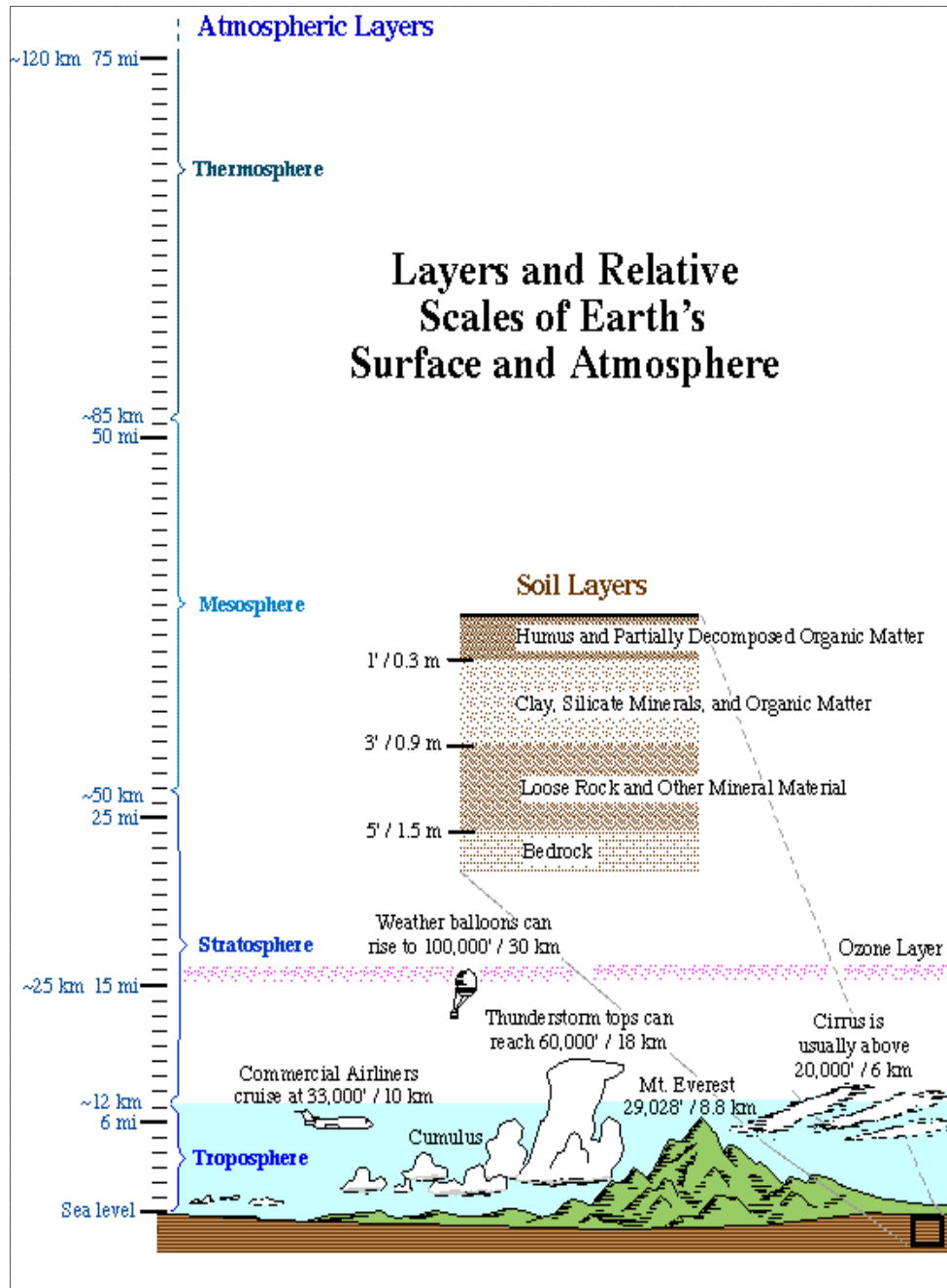


Figure Ap8.1: Vertical Structures of the Atmosphere, Oklahoma Climatological Survey (1997). *Original figure produced by Sue Weygandt with minor modifications by T.Hunt. Reproduced with permission.*

It is probably impossible to produce one schematic which shows the full complexity of the atmosphere, especially its essentially spherical geometry. Most representations will show - indeed most mathematical models tend in the first instance to treat - the atmosphere as parallel layers with a rectangular geometry.

The other thing to note is that these layers are not ‘fixed’, so you will see schematics with the same key layers shown at different heights. This is because the boundaries will vary according to season and location on the earth (topology).

Temperature plays a major role in defining the layers of the atmosphere [Barry (1972)]. Although one might intuitively expect the ambient temperature to drop with altitude, in fact due to EM interactions with different species there are two inversions of temperature [ibid p721]. See figure Ap8.2, a fuller description of the atmosphere is contained in Table Ap8.1 and composition of the atmosphere is listed in table Ap8.2.

Table Ap8.1: Heights and Descriptions of the Various Layers of the Earth’s atmosphere [Sources: Barry (1972) p72; Devlin (1997) p8; Collins English Dictionary (1995); NASA/IWGSDI (1998)].

Heights and Descriptions of the Various Layers of the Earth’s Atmosphere	
Troposphere (or Lower Atmosphere)	~ 10 - 18 km from the surface of the earth, depending on latitude and season and in which air temperature decreases normally with height at about 6.4/C per km. Most meteorological phenomena occur in this layer.
Tropopause:	Boundary between Troposphere and Stratosphere, (about 8 km in polar regions and about 15 km in tropical regions), usually characterized by an abrupt change of *lapse rate. The regions above the troposphere have increased atmospheric stability than those below. The tropopause marks the vertical limit of most clouds and storms. The tropopause is ~isothermal
Stratosphere:	~15-50 km above tropopause: Temperature increases through the stratosphere, due mainly to Ozone absorbing UV and re-emitting longer wavelength EM.
Stratopause:	at ~50 km, this is the boundary between Stratosphere and Mesosphere, the transitional zone of maximum temperature between the stratosphere and the mesosphere, it is also isothermal. The thermal structure is determined by its radiation balance and is generally very stable with low humidity.
Mesosphere	~50-100 km: the atmospheric layer lying between the stratosphere and the thermosphere, characterized by a rapid decrease in temperature with height.
<i>The Stratosphere & Mesosphere together are sometimes referred to as the ‘middle atmosphere’</i>	
Mesopause	Another isotherm, and the zone of minimum temperature between the mesosphere and the thermosphere.
Thermosphere	~100-400 km: an atmospheric layer lying between the mesosphere and the exosphere, the temperature begin to rise with height due primarily to absorption of SUV by molecular oxygen and subsequent re-emission of longer wavelength EM. There is no ‘thermopause’, however there is a dramatic increase in gradient at ~150 km, till at ~400 km the temperature is over 1000/C.
<i>‘ionosphere’ sometimes used to refer to upper mesosphere & thermosphere where electrons & ions are abundant.</i>	
Exosphere	Beyond 400 km: the outermost layer of the earth's atmosphere. It extends from about 400 kilometres above the earth's surface.
<i>Thermosphere & Exosphere sometimes called ‘upper atmosphere’ - some refer to everything above the troposphere in this way</i>	

*lapse rate: The rapidity with which temperature decreases with altitude. The normal lapse rate is defined to be 3.6 degrees F per 1000 feet change in altitude. The dry adiabatic lapse rate is about 5.5 degrees F per 1000 feet, and the wet adiabatic lapse rate varies between 2 and 5 degrees F per 1000 feet.

Table Ap8.2: Composition of the atmosphere.

Species	Symbol	~Volume (%)
Nitrogen	N ₂	76
Oxygen	O ₂	21
Argon	A	1
Water (average)	H ₂ O	up to 1
Carbon Dioxide	CO ₂	0.03
Neon	Ne	2 x 10 ⁻³
Helium	He	5 x 10 ⁻⁴
Methane	CH ₄	1.5 x 10 ⁻⁴
Krypton	Kr	1 x 10 ⁻⁴
Xenon	Xe	9 x 10 ⁻⁵
Hydrogen	H ₂	5 x 10 ⁻⁵
Nitrous Oxide	N ₂ O	3 x 10 ⁻⁵
Carbon Monoxide	CO	1 x 10 ⁻⁵
Ozone	O ₃	up to 10 ⁻⁵

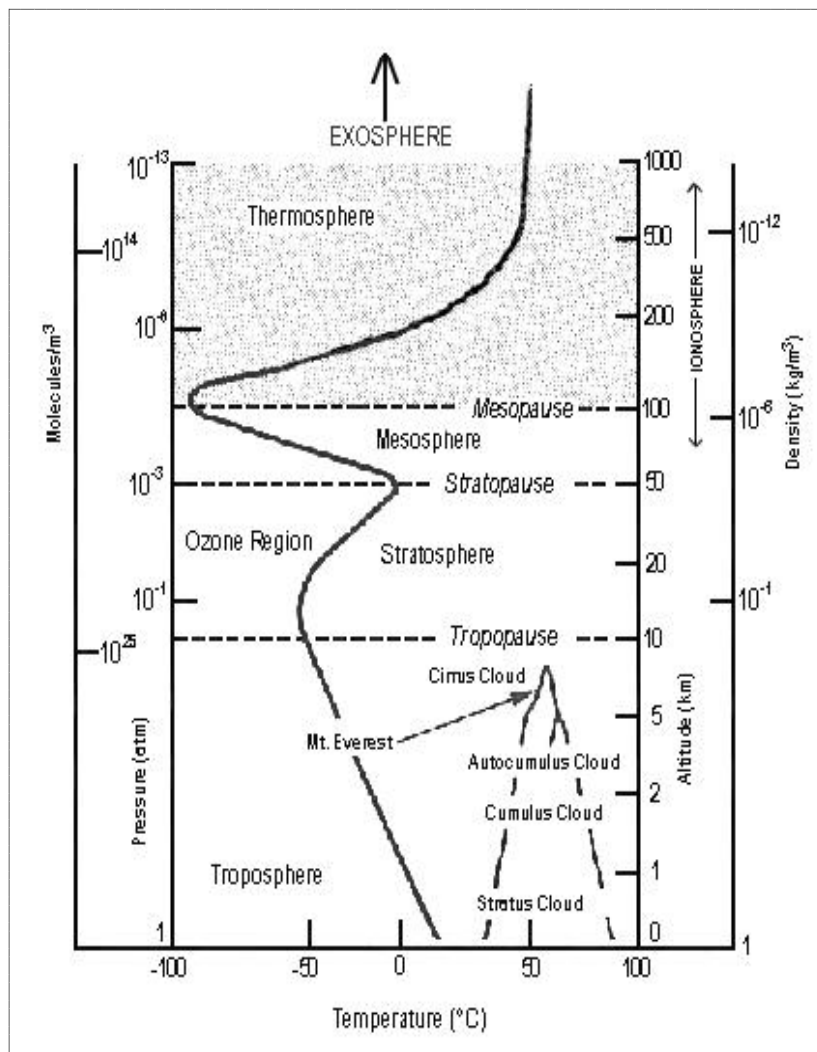


Figure Ap8.2: Modified from Paterson (1995) Temperature, density and pressure change with altitude through the layers of the Earth's atmosphere. See also Zeilik and Smith (1987).

There are other mechanisms which must be taken into account when modelling the atmosphere, for example, density, the gross and local motion of atmosphere due to the earth's rotation, local, ambient pollution, water vapour, clouds, electrostatics and ozone and other factors, the detail of which is beyond the scope of this report. For a more detailed analysis, see Barry (1972).

Appendix 8.2 Atmospheric Measurement Input Parameters

Table Ap8.2 is a tabulated compilation of atmospheric measurement parameters that need to be defined, measured and subtracted from SUV measurements.

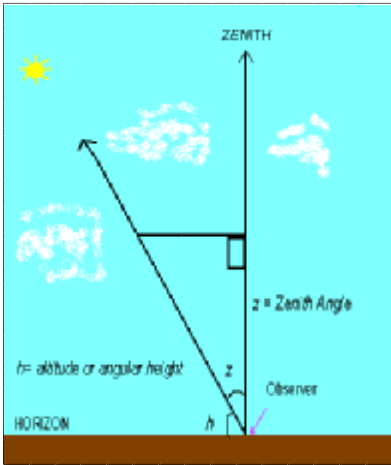
Table Ap8.2: Description of Atmospheric Measurement Input Parameters from *{Gardiner & Kirsch (1995)} and #{Weihs & Webb (1997) p1541)}.

Input Parameter	Description	Notes
# Aerosol Optical Depth (AOD) Symbol: * (#) J_a [Schwartz]	“AOD equals integral over vertical distribution: $J_a = \int F_{ep}(z, RH) dz = \int F_{sp}(z, RH) / \ddot{a}_0 dz$ requires knowledge of vertical structure of F_{ep} and other factors AOD by Direct Beam Sun Photometry Bouguer-Lambert-Beer Law: $\tau_{aerosol} = \frac{1}{m} [\ln V_0 - \ln V_{d-n}] - \tau_{Rayleigh} - \tau_{ozone}$ Where: m = no. airmasses in path .sec(SZA) V_{d-n} = instrument response to direct-normal radiation V_0 = instrument response to direct-normal radiation extrapolated to TOA” [Schwartz (1996)]	“Atmospheric aerosol particles are defined as particles suspended in air with diameters ~0.001-10 μm. They are formed by the reaction of gases in the atmosphere or by the dispersal of material at the surface. Although they make up only 1 part per billion of the mass of the atmosphere, they can significantly influence the amount of shortwave radiation arriving at the surface of the Earth.” [Buchdahl (1997)] “Aerosol properties...include aerosol optical depth, and components of the light extinction coefficient at one or more wavelengths (total scattering F_{sp}, backwards hemispheric scattering F_{bsp}, and absorption F_{ap})” [Sheridan (1997)] <i>NB: These components seem to have slightly differing names which can be confusing to those not in the field. Schwartz lists them as follows:</i> LOCAL OPTICAL PROPERTIES: <i>Extensive Properties - all are wavelength dependent</i> Scattering coefficient F_{sp}, unit: m^{-1} (F_{sp} has a strong dependence on relative humidity) Backscatter coefficient F_{bsp}, unit: m^{-1} Absorption coefficient F_{ap}, unit: m^{-1} Extinction coefficient $F_{ep} = F_{sp} + F_{ap}$ <i>Intensive Properties</i> Backscatter Fraction F_{bsp}/F_{sp} Ångström exponent, b, and $F\%$ 8^b
# Aerosol Phase Function	“The phase function specifies the angular dependence of scattering” [Ortland (1998)] “..is the differential scattering cross section as a function of scattering angle” [Sommers (1998)] “..describes the probability of energy scattering into a specific direction” [Durkee (1998)]	
# (aerosol) single-scattering Albedo (SSA) Symbol: $\ddot{a}_0$	$\ddot{a}_0 = \frac{\sigma_{sp}}{\sigma_{ext}} = \frac{\sigma_{sp}}{(\sigma_{sp} + \sigma_{ap})}$ “..is defined by this equation, and describes the relative contributions of scattering and absorption to the total light extinction. Purely scattering aerosols (e.g., sulphuric acid) have values of 1, while very strong absorbers (e.g., elemental carbon) have values around 0.3.” [Sheridan (1997)]	

Table Ap8.2 continued

Input Parameter	Description	Notes
* Air Pollution (in the form of suspended particles)		"Atmospheric aerosol particles are conventionally defined as those particles suspended in air having diameters in the region of 0.001-10 μ m. They are formed by the reaction of gases in the atmosphere, or by the dispersal of material at the surface. Although making up only 1 part in a billion of the mass of the atmosphere, they have the potential to significantly influence the amount of short-wave solar radiation arriving at the Earth's surface." [Buchdahl (1997)]
*# Atmospheric Ozone (Total Column)		See Section 2.2 and Appendix 3
*# Atmospheric Ozone (vertical profile)		
* Barometric (or Atmospheric) Pressure (Vertical profile)		A barometer is an instrument that measures atmospheric pressure. (From Greek Baros=weight, Metron=measure) The atmosphere is held to the Earth by gravity. <i>At sea level</i> the weight of the atmosphere(atmospheric pressure) is ~15 pounds per square inch (lb/in ² or p.s.i.) is referred to as "one atmosphere" and is equivalent to the pressure of a column of water ~ 34 feet high or a column of mercury (Hg) ~760mm (or ~30 inches). Barometric (or atmospheric) pressure is commonly quoted in "mm or inches of mercury" and decreases with increasing height. [Pitt (1977), Sheridan (1997)]
#Ground Air Pressure		
* Extra-terrestrial solar spectrum		See sections 2.3 and Appendices 4 and 6.3
#Temperature (vertical profile)		Refer to figure Ap8.2
* Clouds	Whilst there is still outstanding research to be done, it is generally agreed that clouds form when water vapour condenses on soluble, hygroscopic nuclei which are microscopic particles (aerosols) such as dust, smoke, sulphur dioxide, salts and so on.[Bais (1997) p86]. There are ten basic groups of clouds, classified according to general shape, structure, vertical extent and altitude [Bais (1997) p89]	As with most systems, things are often more complex and inter-related than at first sight. It has been known for many years that, 'marine plankton can create clouds' [Hamilton & Lenton (1998) p29] and in a recent paper, Hamilton and Lenton suggest an interesting theory in the developing story of clouds: 'We hypothesise that marine algae and various common microbes of the atmosphere (spora) use chemical induction of water condensation to enable or increase their wind dispersal between their aquatic, terrestrial or epiphytic growth sites. Biogenic chemical cloud condensation nuclei (CCN) and ice nuclei (IN), sometimes co-occurring in single species (e.g Pseudomonas syringae, release heat energy of phase change, thus contributing to local air movements that can be used both for lofting and for lateral dispersal of their producers.' [ibid p1]

Table Ap8.2 continued

Input Parameter	Description	Notes										
*Elevation of the Sun above the horizon Solar Zenith Angle (SZA) [Dahlback (1996) p6514]	 Figure Ap8.3: “Assume the Earth’s atmosphere is plane-parallel. Define h as the angular height of a star (or the sun) above the horizon and z as the angle between the direction to the zenith and the direction to the star ($z=90^\circ-h$), z is the zenith angle.” [Zeilik & Smith (1987) p209] See figure Ap8.3.	<i>Celestial Sphere</i>: An imaginary sphere of indeterminate but immense radius that provides a convenient surface on which to draw and study the directions of celestial bodies and other points in the sky as seen from an observation point on earth at the sphere’s centre. Celestial bodies, etc., may thus be thought of as points projected onto the surface of the celestial sphere. The earth’s radius is negligible with that of the celestial sphere so that every observer may be considered as located at the sphere’s centre. The earth’s west-to-east rotation causes an apparent rotation of the celestial sphere about the same (extended) axis once every 24 hours but in an east-to-west direction.” [Illingworth (1979)]  Figure Ap8.4: “The Horizon System: The observer on earth sees his ZENITH directly overhead, while the NADIR is directly underfoot. The celestial horizon contains the four cardinal points North, South, East, West; the observers celestial meridian is the great circle containing NO, ZENITH and SO. The azimuth and altitude of a point X are indicated by the arrows, as is the zenith distance..”[p10 Smith & Jacobs(1973)]										
# Ground (or * Surface) Albedo	“The reflecting power of a non luminous object, such as a planet or planetary feature...the ratio of the total amount of light reflected in all directions to the amount of incident light (from the sun); an albedo of 1.0 indicates a perfectly reflecting surface..a value of 0.0 indicates a totally black surface that absorbs all incident light” [Illingworth (1979)]	“The reflectivity or albedo of the Earth’s surface varies with the type of material that covers it. For example, fresh snow can reflect up to 95% of the insolation that reaches its surface. Some other examples: Dry Sand (35-45%); Deciduous Forest (5-10%); Coniferous Forest (10-20%); Grass (15-25%). <u>Taking incoming Solar Radiation as 100%:</u> <table><tr><td>Absorbed by ‘surface’(ie all surfaces)</td><td>~51%</td></tr><tr><td>Absorbed by atmosphere and clouds</td><td>~19%</td></tr><tr><td>Reflected by Clouds</td><td>~20%</td></tr><tr><td>Reflected by Atmosphere</td><td>~6%</td></tr><tr><td>Reflected from ‘surface’(ie all surfaces)</td><td>~4%</td></tr></table> The Earth’s average albedo reflectance from both the atmosphere and the surface is ~30%.” [Pidwirny (1998)]	Absorbed by ‘surface’(ie all surfaces)	~51%	Absorbed by atmosphere and clouds	~19%	Reflected by Clouds	~20%	Reflected by Atmosphere	~6%	Reflected from ‘surface’(ie all surfaces)	~4%
Absorbed by ‘surface’(ie all surfaces)	~51%											
Absorbed by atmosphere and clouds	~19%											
Reflected by Clouds	~20%											
Reflected by Atmosphere	~6%											
Reflected from ‘surface’(ie all surfaces)	~4%											

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APPENDIX 9 UV INSTRUMENTATION

Appendix 9.1: More Key Components

Appendix 9.1.1 Apertures

The word 'aperture' in optics has come to refer to a (usually circular) pathway through which EMR (or perhaps particulate flux) is directed and need not simply be a well defined hole. For example a mirror aperture is simply the diameter of its reflecting surface. A high quality aperture of known dimensions is of vital importance for accurate, absolute measurements of radiance or irradiance from a source.

Appendix 9.1.2 Mirrors

Although mirrors are widely used, the precision with which they need to be made in order to perform in the UV may not be so widely known. Mirror surfaces exposed to extremes ambient of temperature or thermal shock (from lasers or high powered UV sources) will degrade. Where mirrors are likely endure high levels of UV materials with low thermal expansion should be used. For example Low Expansion Borosilicate Glass (more usually known as PYREX) although this material is known to suffer from internal inhomogeneities. Synthetic fused silica has a low coefficient of thermal expansion and is therefore suitable amongst others.

These substrates are coated (usually by evaporation) with metal and/or dielectric coatings. The preferred coating combination for UV is Aluminium a Magnesium Fluoride (MgF_2) which prevents the Aluminium from oxidizing and preserving the reflectance of the Aluminium at UV wavelengths. Reflectance for these mirrors is ~86 % at ~ 200 nm rising to ~89 % at ~ 400 nm. [*Melles Griot ((1990), Oriel (1990))*].

It is important to keep the mirrors in a dust free and low humidity environment. A layer of water or dust will alter the refractive index and greatly reduce the reflectance and hence output of an instrument with several mirrors. Most UV measuring systems use double monochromators which have six internal mirrors.

References Appendix 9

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