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REVIEW PAPERS ON THE EFFECTS OF UV-B ON NON-HUMAN BIOTA

Submitted by

Chemical Manufacturers Association

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7 Aug 81

Dear Dr Engelmann

CCOL

In response to the call in your letter to CCOL members of 23rd June, for input on the effects of UV-B on non-human biota, I enclose the following three review papers

1	UV-B Measurements	Dr W H Klein
2	Effects on Plants	Professor R H Biggs, University of Florida
3	Marine Effects	Professor D M Damkaer, University of Washington

These were commissioned by the DuPont Company of the USA who members of the CMA Fluorocarbon Panel, and reviews have been made freely available to that panel.

Yours sincerely

G.D.

G Diprose

COMMENTS ON THE NATIONAL ACADEMY OF SCIENCES REPORT: "PROTECTION AGAINST DEPLETION OF STRATOSPHERIC OZONE BY CHLOROFLUOROCARBONS."

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COMMENTS BY DR. W. H. KLEIN ON THE NATIONAL ACADEMY OF SCIENCES REPORT, "PROTECTION AGAINST DEPLETION OF STRATOSPHERIC OZONE BY CHLOROFLUOROCARBONS."

1. INTRODUCTION

I have examined the National Academy of Sciences (NAS) Report entitled, "Protection against Depletion of Stratospheric Ozone by Chlorofluorocarbons" (NAS, 1979) with particular emphasis concerning measurements of UV-B (285-320 nm) and techniques of UV-B supplementation. The comments concerning this aspect of the report are my opinion and can only be attributed to me and no other person or organization.

The report, in its entirety, is a rather comprehensive and very good review of the ozone and UV-B situation. However, the effort to summarize the complex problems does oversimplify and possibly results in statements that may be misleading.

The following comments (Sections 2-4) are intended to be constructive and informative, so that future experiments can be improved.

2. DIFFICULTIES IN THE MEASUREMENT OF UV-B

A. UV-B Measurement as an Experimental Complication

NAS acknowledged the difficulties in the measurement of UV radiation:

> "Measurement of the UV radiation itself introduces additional complications, which were especially troublesome in earlier experiments. While spectroradiometric measurements (that is, absolute measurements of the radiation per unit area and unit spectral bandpass at a sufficient number of representative wavelengths) have been made recently by most investigators, this was not done in most of the earlier studies. Instead, simpler dosimeters were utilized, such as the Robertson-Berger meter, which characterizes a broad waveband with respect to a weighting function that may not be biologically correct. The uncertainty introduced by meters of this kind is discussed in Appendix E." (NAS, 1979, p. 66).

However, definitive information about the magnitude of the difficulties was not provided.

B. Laboratory Measurements

The best spectral irradiance measurements that can be made today between 250 and 350 nm are accurate to about 3 to 5 percent in a rigidly controlled laboratory measurement. Depending on what kind of standard source is used, calibration accuracy of UV-B instruments can vary from less than 5 percent to about 10 percent (National Bureau of Standards, 1977). Argon mini arcs have an uncertainty in their irradiance of an estimated 6 percent for wavelengths greater than 140 nm. The National Bureau of Standards (NBS) synchrontron UV radiation facility can calibrate spectrometer and photometer units to better than 5 percent.

C. Field Measurements

The measurement of UV-B radiation under unfavorable field conditions can vary by as much as 25 percent (National Bureau of Standards, 1977). Temperature, depending on the detector, has an important effect on the accuracy of a measurement and normally under field conditions this is not controlled. Therefore, some kind of compensation is required for temperature-sensitive detectors. The cosine correction and the transmission factors of a diffuser can introduce sizeable errors if not determined and evaluated. Stray light problems associated with unwanted visible light not being sufficiently blocked out in daylight field measurements can introduce significant errors.

D. Weather Corrections

If atmospheric conditions were always clear and pollution-free, there would not be the need for accurate measurements of UV-B, since the amount of energy would be primarily dependent upon ozone concentration. However, there are not too many clear days; therefore, clouds, aerosols, dust and other pollutants such as sulfur dioxide should be considered. Table 1 shows a comparison of the measured* Radiation Biology Laboratory (RBL) daily averages of UV-B centered at 305 nm at 40°N latitude and calculated values. In addition, the cloud correction figures used by Mo and Green (1974) were applied to the calculated values. It is obvious that deviations of calculated values from measured values under the best of conditions range up to 25 percent. There is little doubt that meterological conditions have a strong influence on the quantity of UV-B reaching the surface of the earth, indicating that monitoring of UV-B should be performed in order to evaluate properly UV-B energy doses received by biological organisms (Klein and Goldberg, 1978).

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* Instrument accurate to ± 5 percent based on a NBS referenced standard lamp.

Table 1

The calculated integrated daily global UV radiation for 5 nm centered at 305 nm at sea level for a clear sky in units of joules m^{-2}. Average amounts of ozone for latitude and season have been used in the calculations (Mo and Green, 1974). The measured values are daily averages for the month.

	Latitude 40°N				
Month	Calc.	Meas.	Calc / Meas.	Cloud Correction	[Calc] / Meas. Corrected
Jan.	62.78	42.64	1.47	.664	.98
Feb.	154.5	137.6	1.12	.664	.74
Mar.	350.6	239.2	1.47	.630	.93
Apr.	665.8	532.9	1.25	.759	.95
May	957.4	543.0	1.76	.614	1.08
Jun.	1163.	687.2	1.69	.647	1.09
July	1230.	NO DATA	-	-	-
Aug.	1087.	NO DATA	-	-	-
Sept.	731.2	NO DATA	-	-	-
Oct.	351.6	271.8	1.29	.619	.80
Nov.	121.4	104.7	1.16	.670	.78
Dec.	55.88	44.78	1.25	.608	.76

Table 2

Comparison of relative DNA dose, daily total UV from 280 nm to 322.5 nm (J m^{-2}), and daily total insolation from 280 nm to 2800 nm (J m^{-2}) for representative days in Rockville, MD.

	29 Mar 76	29 Jun 76	20 Sept 76	13 Jan 76
Daily DNA dose	24.12	45.34	30.10	4.60
Daily total UV	3.95×10^4	5.64×10^4	4.60×10^4	1.44×10^4
Daily total insolation	1.16×10^7	1.98×10^7	1.49×10^7	6.95×10^6

E. Significance of UV-B Measurement Difficulties

It is essential that instruments and standards be developed to enable researchers to measure changes in UV-B with an accuracy that will provide the data needed to follow changes to which biological organisms will be exposed at the surface of the earth. These measurements must be sensitive and accurate enough to indicate relatively small changes in ozone, or to indicate small changes in ultraviolet irradiation to which biological material will be exposed. Calculations are only valid for essentially clear days. They should not be used to determine UV-B exposure since the error can be large.

3. LATITUDINAL VARIATION OF UV-B AND ACTION SPECTRUM SELECTION

A. Projected UV-B Changes Versus UV-B Changes With Latitude

The NAS Report commented:

> "Recognizing all the above uncertainties, Figure 2.1 indicates the increases in the annual DNA-damaging UV at 40°N latitude expected from possible ozone-layer reductions over the next century (assuming continued release of chlorofluorocarbons at the 1977 rates). A 7.5 percent ozone-layer reduction would, for example, lead to about a 19 percent increase in DNA-damaging UV, and a 16 percent reduction to about a 44 percent increase. (These values will be somewhat less at latitudes toward the equator and greater at higher latitudes). The increase in DUV for a given decrease in ozone concentration is larger than the figure estimated in earlier reports, but this is hardly a significant change in the light of remaining uncertainties about the proper weighting function. The change arises from more recent knowledge of the solar intensity distribution at the shorter wavelengths, coupled with a presumably better action spectrum (Appendix C)." (NAS, 1979, p. 62)

B. Comparison of Measurements at Various Latitudes

It is estimated, considering all the uncertainties during continued 1977 releases of chlorofluorocarbons, that an increase in UV-B reaching the earth's surface would be of the order of 19 to 44 percent. This is small compared to existing differences at latitude 39°N (Rockville, MD), 30.4°N (Tallahasee, FL) and 9°N (Panama), all from actual UV-B totals and from DNA dose equivalents that follow (see Table 4).

Table 3

Comparison of relative DNA dose and daily total UV from 280 nm to 322.5 nm (J m-2) for representative days in Tallahassee, FL.

	20 Mar 76	21 Jun 76	28 Sept 76	06 Jan 76
Daily DNA dose	45.68	55.54	36.75	16.00
Daily total UV	4.60×10^4	4.57×10^4	3.01×10^4	2.42×10^4
No totals available	-	-	-	-

Table 4

Comparison of relative DNA dose, daily total UV from 280 nm to 322.5 nm (J m-2), and daily total insolation from 280 nm to 2800 nm (J m-2) for representative days in Panama, and a comparison with corresponding quantities for Rockville, MD.

	23 Mar 76	30 Jun 76	27 Sept 76	18 Dec 75
Daily DNA dose	130.96	112.25	124.85	90.24
Daily total UV	1.02×10^5	9.50×10^4	1.01×10^5	8.32×10^4
Daily total insolation	2.12×10^7	1.66×10^7	1.54×10^7	1.50×10^7
Ratios, Panama: Rockville				
Daily DNA dose	5.4	2.5	4.1	19.6
Daily total UV	2.6	1.7	2.2	5.8
Daily total insolation	1.8	0.8	1.0	2.2

C. Calculating DNA Dose from Five Nanometer Energy Integrals

A necessary part of doing UV mutagenesis studies is to determine the dose of radiation received by the organisms of interest. There are two ways to measure this dose with radiometric instruments; either measure with an instrument that has the same spectral sensitivity of DNA, or measure with an instrument of different sensitivity and use the DNA-sensitivity relationships to convert these measurements to some relative dose measure. In this case, we have chosen the latter method, using an eight channel UV radiometer that measures the integrated energy in a nominal bandwidth of five nm, centered at 285, 290, 295, 300, 305, 310, 315, and 320 nm (Goldberg and Klein, 1974). For the DNA sensitivity curve (action spectrum) we have used the one from Setlow (1974), as used by NAS. The choice of action spectrum represents a major uncertainty itself, as discussed in 3.D and 3.E below.

Given a relative sensitivity function, the dose (D) is defined:

$$D = \int E(\lambda)\ I(\lambda)\ d\lambda$$

where $E(\lambda)$ is the relative sensitivity curve
$I(\lambda)$ is the spectral density of the light input
and λ is the wavelength

Since we do not measure $I(\lambda)$ directly, but rather measure the energy integrals over the eight channels (each 5 nm wide), we approximate:

$$D = \sum_{i=1}^{8} \left(E(\lambda_i) \int_{\lambda_i - 2.5}^{\lambda_i + 2.5} I(\lambda)\ d\lambda \right); \quad \lambda_i = 285, 290, \ldots, 320$$

A further assumption is that dose and radiant flux are linearly related with respect to time; doubling the exposure time while cutting the flux in half should give the same dose. Dose units used here are arbitrary; one dose unit is the equivalent of 1000 Jm^{-2} of 310 nm light. In terms of flux, one dose unit is equivalent to 10 W m^{-2} of 310 nm light for 100 seconds (or 5 W m^{-2} of 310 nm light for 200 seconds).

The tables presented here show total dose, total UV (280 nm - 322.5 nm), and total insolation (280 nm -2800 nm) for three sites at four times of the year for representative days. Hourly totals are given for dose and UV. Days are deemed representative on the basis of having a daily total insolation that is near average for the location and season. Tables 5-7 show hourly totals, and are summed to provide the daily totals in Tables 2-4. Table 4 also compares the ratios between Panama and Rockville, MD. Using the Setlow DNA action spectrum the average DNA daily dose is 340 percent larger in Panama, while the average daily insolation is only 28 percent larger in Panama.

Table 5

Hourly totals for relative DNA dose and total UV from 280 nm to 322.5 nm (J m^{-2}) for representative days in Rockville, MD (1976).

	29 Mar 76		29 Jun 76		20 Sept 76		13 Jan 76	
Hour	Dose	Total UV	Dose	Total UV	Dose	Total UV	Dose	Total UV
4-5			0.0	4				
5-6	0.00	1	0.02	191	0.00	1		
6-7	0.02	192	0.21	1068	0.02	198		
7-8	0.25	1257	0.91	2571	0.28	1201	0.02	26
8-9	0.86	2559	2.66	3880	3.04	5408	0.31	1428
10-11	3.23	4988	4.60	5478	5.20	7397	0.74	2548
11-12	4.40	5956	8.59	8632	6.71	8489	1.06	3001
12-13	5.06	6602	10.41	9917	6.27	8033	1.22	3335
13-14	4.58	6432	8.83	9029	4.31	6232	0.77	2232
14-15	2.53	4217	4.41	5416	2.45	4381	0.34	1185
15-16	0.92	2078	1.27	2328	0.61	1497	0.04	243
16-17	0.30	1083	1.09	2494	0.05	223	0.01	56
17-18	0.04	297	0.37	1416	0.00	27	0.00	2
18-19	0.00	15	0.07	442				
19-20			0.00	31				

Table 6

Hourly totals for relative DNA dose and total UV from 280 nm to 322.5 nm (J m^{-2}) for representative days in Tallahassee, FL.

	20 Mar 76		21 Jun 76		28 Sept 76		06 Jan 76	
Hour	Dose	Total UV	Dose	Total UV	Dose	Total UV	Dose	Total UV
5-6			0.00	6				
6-7	0.00	9	0.06	261	0.00	16		
7-8	0.10	403	0.54	1214	0.10	488	0.00	8
8-9	0.77	1782	2.13	2924	0.76	1364	0.04	198
9-10	2.63	3683	5.09	4849	3.64	3587	0.27	745
10-11	4.33	4474	7.47	5678	2.81	2200	1.27	2299
11-12	5.68	4979	9.45	6290	7.41	5008	2.95	4183
12-13	10.02	7956	8.55	5557	7.45	4899	3.93	5047
13-14	8.61	7014	9.44	6261	6.42	4272	3.63	4766
14-15	7.56	7024	6.04	4368	3.72	2887	2.45	3718
15-16	3.93	4560	3.23	3050	2.90	3014	1.13	2260
16-17	1.65	2857	2.47	3003	1.16	1934	0.31	903
17-18	0.39	1138	0.89	1668	0.08	423	0.03	116
18-19	0.02	113	0.16	508	0.00	9		
19-20			0.01	40				

Note: The instrument used at Tallahassee differs from the others in that instead of measuring a 5 nm wide integral centered at 300 nm, it measured a ten nm wide integral at 297 nm. This measurement is used with the 295 nm integral to estimate the 300 nm integral.

Table 7

Hourly totals for relative DNA dose and total UV from 280 nm to 322.5 nm (J m^{-2}) for representative days in Panama.

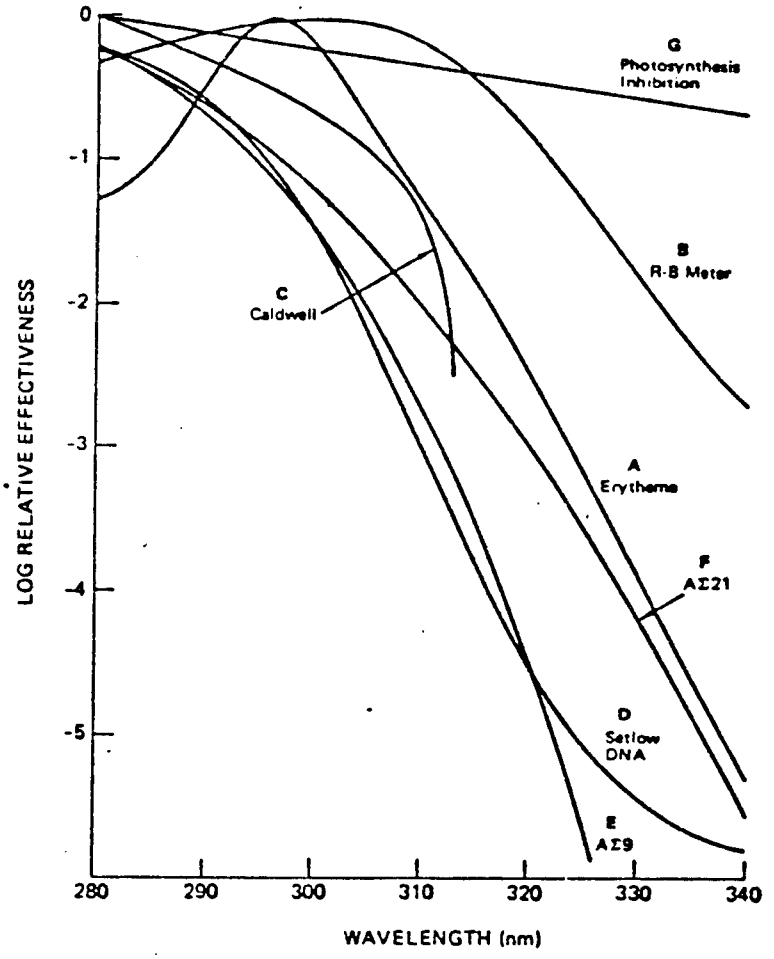
	23 Mar 76		30 Jun 76		27 Sept 76		18 Dec 75	
Hour	Dose	Total UV	Dose	Total UV	Dose	Total UV	Dose	Total UV
6-7	0.01	72	0.03	205	0.02	98	0.00	50
7-8	0.47	1361	0.71	1952	0.60	1645	0.34	1319
8-9	3.15	4971	3.14	4732	1.26	2155	2.53	4889
9-10	6.57	6834	8.14	8401	3.57	3899	8.41	10121
10-11	14.45	10892	18.77	15056	11.95	9918	14.84	13516
11-12	25.54	16533	28.47	19586	33.99	24206	23.51	18229
12-13	25.14	15552	22.43	15039	32.36	22381	18.53	13948
13-14	24.92	16144	14.81	10758	25.61	19123	14.16	11513
14-15	18.29	13898	6.48	5928	9.97	9335	5.74	5643
15-16	8.98	9143	5.80	6783	4.11	5531	1.55	2217
16-17	3.02	4788	3.05	5176	1.33	2661	0.57	1519
17-18	0.42	1345	0.41	1269	0.09	390	0.05	239
18-19	0.01	49	0.02	100	0.00	2	0.01	7

D. Action Spectrum Choice

The relative response of a system to various wavelengths of the visible and near-visible light spectrum is termed an action spectrum. A particular action spectrum is a very specialized thing and may apply only under the conditions used to obtain it. Therefore, it is probably more appropriate to indicate that this is an action spectrum and not the action spectrum.

E. Action Spectra Other than DNA

Figure 1 shows the weighting functions in current use for biological effects. For our comparison of measured UV-B values and calculated DNA dose for each latitude, we have used, and NAS used, the most effective action spectrum for biological material. Therefore, the maximum effect is shown and all the other weighting functions will generally be considerably less.



Weighting functions in current use for biological UV effects.

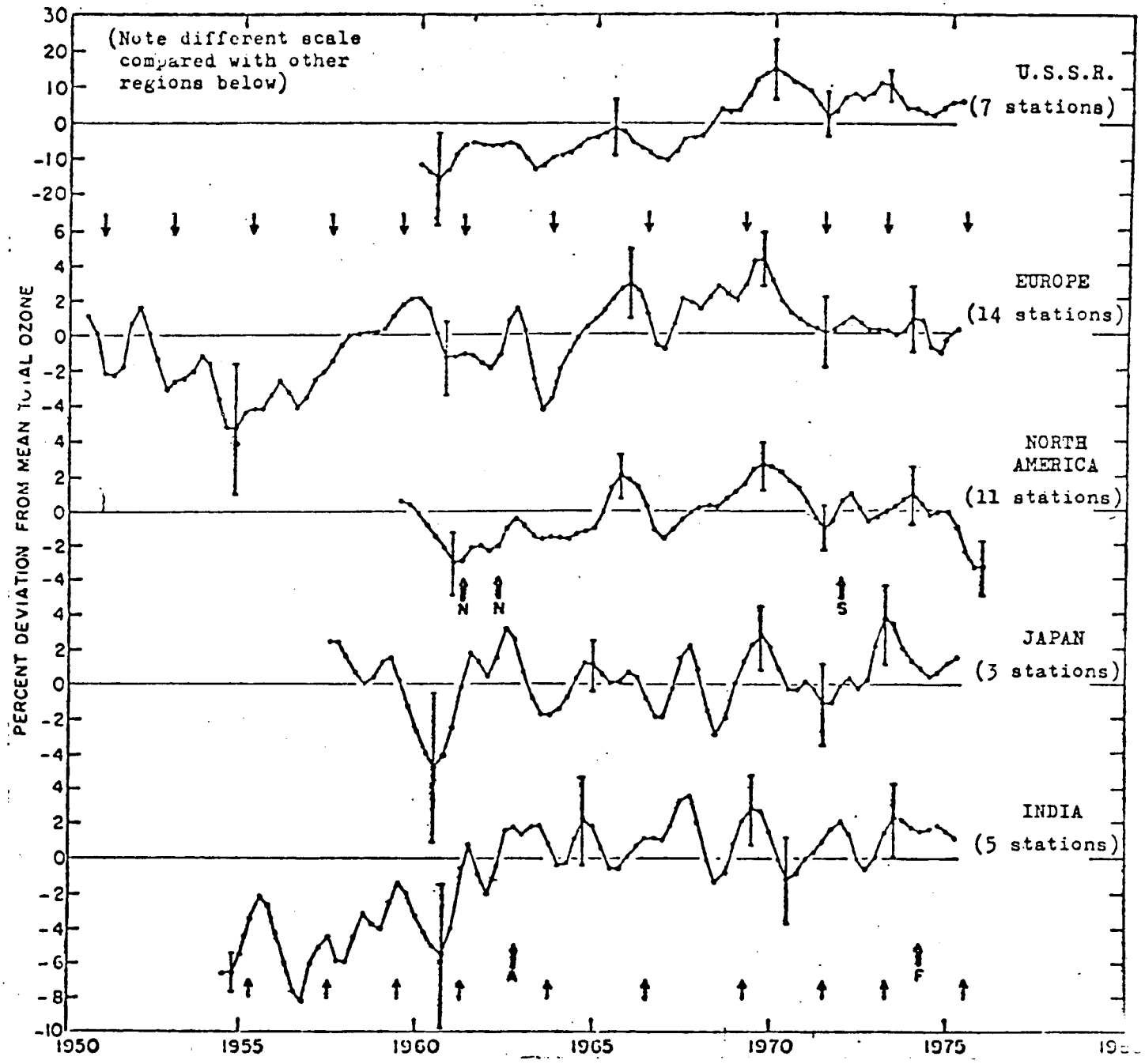
FIGURE 1
(from NAS, 1979, p. 307)

F. Significance

There is already a natural variation with latitude that greatly exceeds the anticipated change in UV-B due to ozone changes. My opinion is that comparisons can be made between latitudes using modern controlled environment facilities in ultraviolet transmitting glasshouses. In fact, it is recommended in the Report under Major Research Issues (NAS, 1979, p. 71) that such a monitoring facility be established at various locations. The action spectra for most biological effects of ultraviolet radiation are not well known and caution should be used when using generalized action spectra for estimating effects. Use of the DNA or Setlow action spectrum represents a "worst case" choice.

> "Another type of natural ozone variation offers an opportunity to set limits on the magnitude of ozone-depletion effects. These are cyclic variations, amounting to approximately 5 percent total amplitude at temperate latidudes, over a period of about a decade (Angell and Korshover, 1973). Weighted for DNA-damaging effectivenss, such ozone variations would produce roughly a 13 percent change in DUV. The common experience of temperate areas of the world (which have repeatedly been through such cycles) shows that changes of this magnitude do not produce any spectacular effects on plants or animals over the relatively few years of their duration. (Small effects would, of course, tend to be blurred by the ordinary variations in weather and other factors.) While there seems to have been no concerted effort at detecting effects due to these changes, it would seem safe to say that most organisms can reasonably accommodate decade-long oscillations in ozone concentration, of the order of one third of the 16 percent change expected from continued CFC release at current rates." (NAS, 1979, p. 64)

I agree with the above statement about cyclical variations and according to Figure 2 (World Meterological Organization, 1977) this kind of variation in ozone has been occurring for twenty or more years. It would seem to me that most organisms could safely handle a two or three percent change in ozone with little or no detectable effect. It would probably not be a measureable biological response with current techniques and methods.



Time variation in total ozone in north temperate latitudes expressed as a percentage deviation from the mean for the total length of record (the annual oscillation has been removed). A 1-2-1 smoothing (divided by four) has been applied twice to the successive seasonal values.

Vertical bars represent two standard errors of estimate based on individual station values within the regions. Single-shafted arrows indicate occurrence of quasi-biennial west wind maximum at 50 mb in the tropics;

A = Eruption of Mt. Agung (Indonesia) F = Eruption of Mt. Fuego (Guatamala)
N = Large nuclear explosions S = Large solar proton event.

FIGURE 2
(from World Meterological Organization, 1977)

4. SUPPLEMENTATION OF UV-B WITH LAMPS

A. Experimental Limitations and Sources of Error

The NAS report acknowledges difficulties associated with experimental supplementation of UV-B with lamps:

> "The measured spectral composition of radiation from the lamp sources is not the same as that of sunlight over the biologically effective wavelengths (Figure E.1, Appendix E). Consequently, in comparing its effects on plants and animals with those of natural sunlight, a weighting function based on the proper action spectrum must be applied to the spectral distributions of both sources. If the biological action spectra for UV radiation damage to plants and animals were known precisely, one might make an accurate comparison by this means and be able to predict the consequences of ozone depletion from the lamp experiments. However (as explained above and in Appendix D), the action spectra for most biological effects of UV-B radiation are not well known, and one must usually surmise their form approximately. This can introduce an uncertainty of as much as twofold in predicting the increased biological damage accompanying a 16 percent reduction in the ozone layer." (NAS, 1979, p. 65)

and:

> "Finally, the environmental conditions under which many of the experiments have been performed may in some cases have altered the sensitivity of plants and animals to UV-B radiation. For example, the UV sensitivity of plants appears to be as much as fourfold greater in the artifical illumination of plant environment growth chambers or in greenhouses, than in the open-field environment, possible because of the different level of photosynthetic illumination. Unfortunately, this means that the experiments providing the most completely controlled conditions (which should therefore allow more refined testing) are not by themselves able to evaluate the consequences of increased solar UV on plants. Also, in most experiments, plants and animals have been subjected to environmental conditions free from other stresses besides the UV radiation. Thus, the interaction of such other stresses with the UV-B has not yet been evaluated." (NAS, 1979, p. 66)

Further justification for these concerns follows below.

B. Physical Characteristics

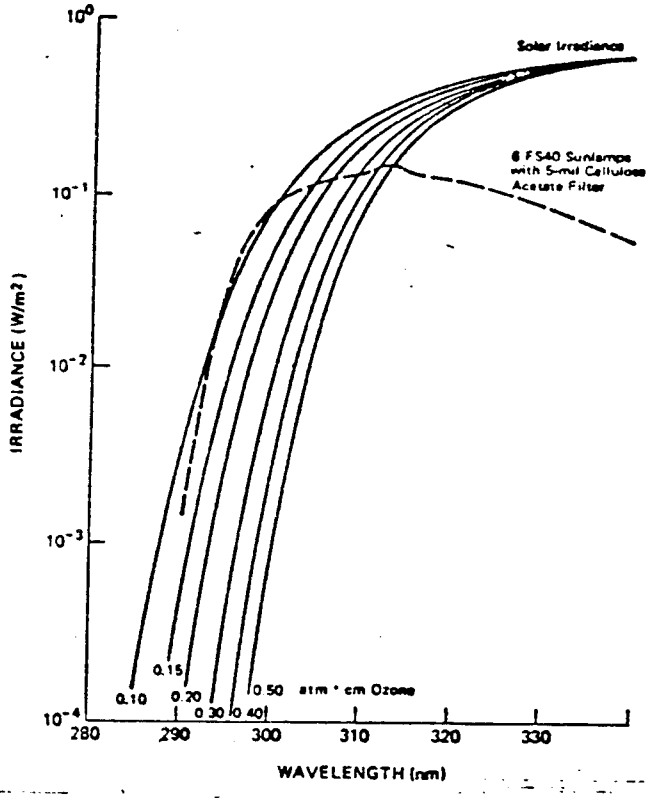
Experiments using fluorescent lamps to provide supplemental UV-B must be carefully examined before accepting the results, even on a qualitative basis. Lamps age and filters change and the shortwave cutoff (Figure 3) often is not appropriate, as well as the spectral quality and intensity of the rest of the spectrum. Figure 4 presents the aging effect on the emission of a UV-B lamp. Forty percent of the energy is lost at the end of 2000 hours and the decrease is relatively uniform after the first 10 hours of use. This loss associated with the slow darkening of the filters introduces significant errors in doses unless measured and adjusted practically every day.

C. Experimental Factors in the Use of Lamps

One of the serious defects in UV-B supplemental lamps is the inability to irradiate in the natural min-max-min mode as occurs in natural daylight. This produces an improper dose rate and could cause a completely different response to occur. Tables 5-7 show the ourly doses of UV-B and also equivalent DNA dose at three latitudes for a representative day, indicating change with time of day. It is evident that a fixed intensity for four to six hours would not simulate the natural exposure conditions. The lamp position is fixed and usually produces a non-uniform source of UV-B energy, with also a fixed shade over certain portions of the plant canopy. This, then, results in less uniform visible light for photoreactivation effects to occur. Most growth chambers cannot simulate the natural daylight, neither from the spectral distribution nor intensity standpoint and, therefore, results cannot be used to predict field responses unless an appropriate transfer function is first determined. It is plausible that this light quality and intensity difference is the reason for a 4-fold difference in UV-B sensitivity of plants grown in growth chambers versus natural conditions.

D. Significance of Difficulties in Supplementing UV-B with Lamps

Extreme caution should be used in attempting to extrapolate V-B effects from growth chamber results to natural conditions because of the inability to reproduce natural conditions. Even experiments under natural conditions with supplemental UV-B lamps should be evaluated with the full knowledge that lamps and filters change on a daily basis. Experiments should be conducted in which monitoring of these factors are performed on a daily basis.

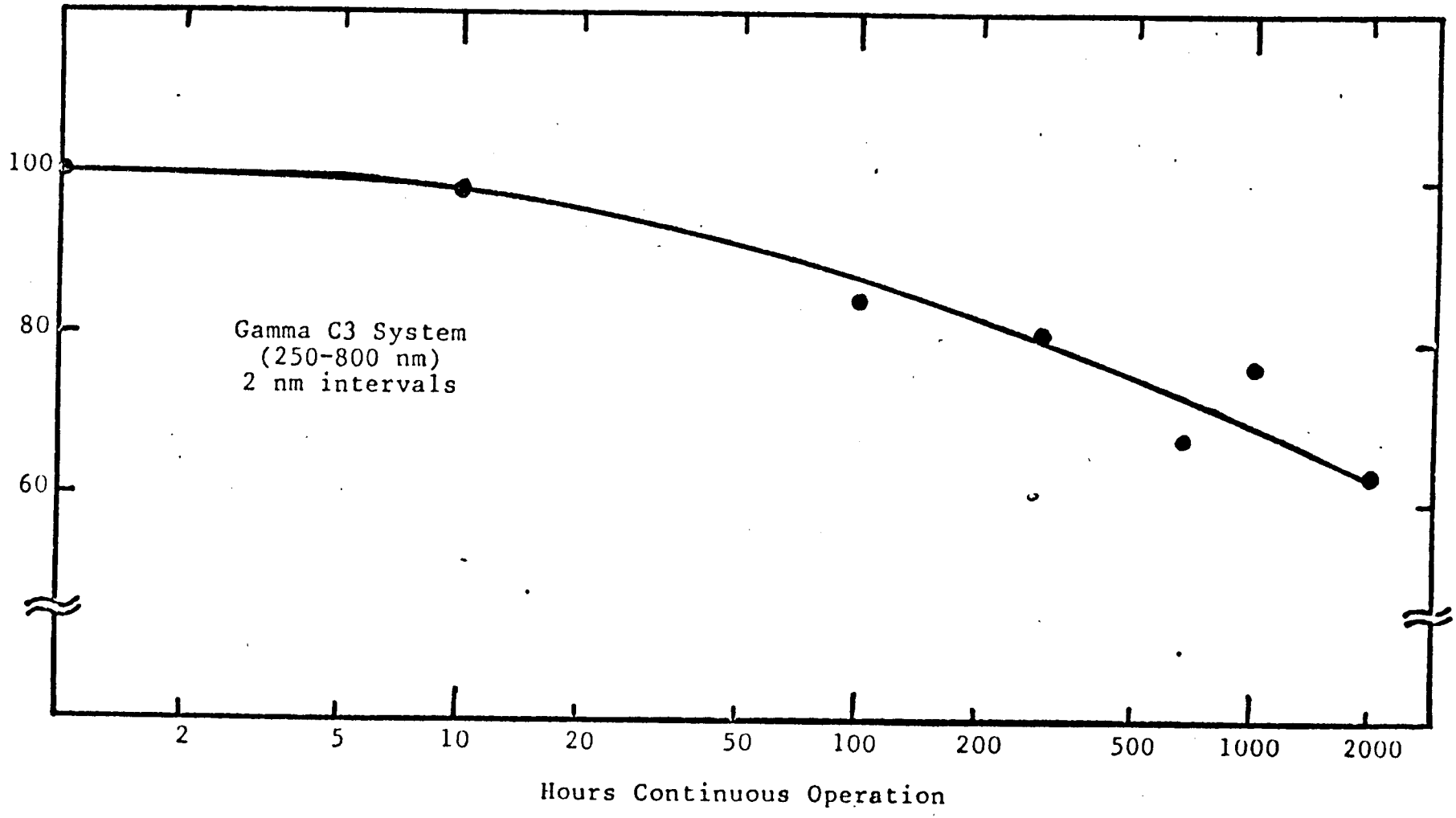


Spectral irradiance at a distance of 16.5 cm from six FS40 sunlamps, filtered with 5-mil cellulose acetate, superimposed on the solar spectral irradiance (sun 30° from zenith) with different ozone thicknesses.

FIGURE 3
(from NAS, 1979, p. 320)

FIGURE 4. DECAY CURVE FOR SYLVANIA UV-B LAMP #2021

GTE SYLVANIA UV PHOSPHOR F48T12/2021/VHO
Test duration 2000 h (2 May 80 - 24 July 80)



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