ZooMed Reptisun UVB/LED
Report by Frances M Baines

Product Description

Fig. 1

Two ZooMed Reptisun UVB/LED lamps were supplied by ZooMed Laboratories, Inc., 3650 Sacramento Drive, San Luis Obispo, CA93401, USA. (Figure 1). The lamps are 13-LED UV-emitting LED bars, each with 4 x UVB LED, 1 x UVA LED, 8 x 6500K LED, specified as 9 watts, 283 lumen, CRI 96, CCT 6500K.
The lamps were given reference numbers BZCU1 and BZCU2.

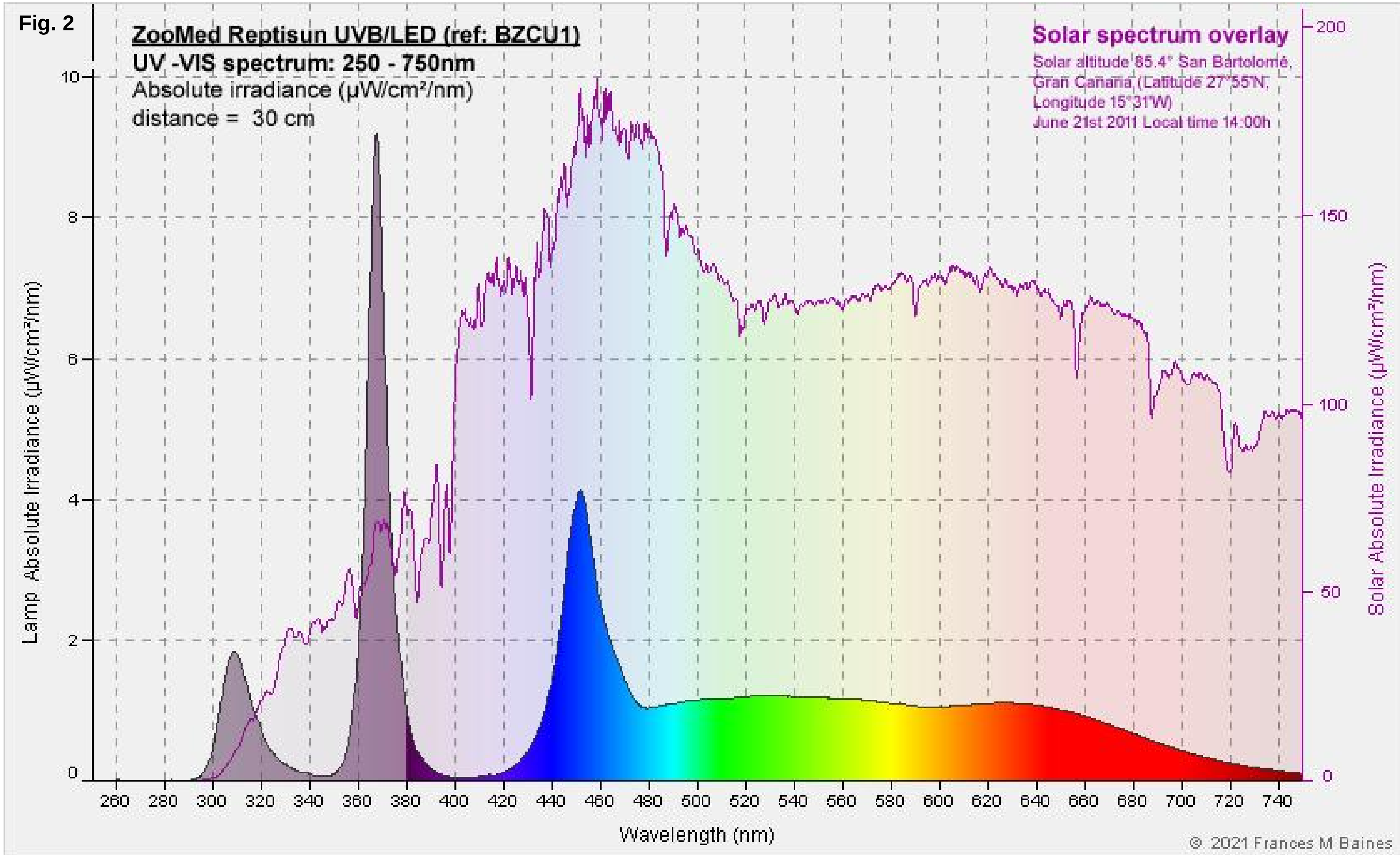
For testing, the lamps were to be mounted in a 12” ZooMed Naturalistic Terrarium Hood, designed to hold one ZooMed compact fluorescent lamp. The UVB/LED units are designed with E27 screw threads; when inserted into the hood and fully screwed into the fixture, the LED lamp face may not end up facing the front. For this reason it has a swivel function which enables the lamp to be rotated up to approximately 320° on its axis to face the front again, without unscrewing it from the fixture.
Unfortunately, although this allowed lamp BZCU1 to be rotated correctly, when lamp BZCU2 was screwed in properly the rotational position of its E27 screw resulted in the LED array squarely facing the rear of the fixture. The swivel does not allow sufficient rotation in either direction to bring the lamp face fully forwards (a 180-degree turn). The only way to achieve this was to partially unscrew it from the fixture as well, which disconnected it from the electricity supply. The lamp could not, therefore, be tested.
This would seem to be a manufacturing problem which could be a serious issue for lamps designed to be used in ZooMed Naturalistic Terrarium Hoods or other fixtures in which the ceramic portion of the lamp-holder cannot be itself rotated.

The lamp BZCU1 was operated on UK line voltage (nominally 220 -240v) regulated with a Variac transformer (*Carroll and Meynell CMV2E-1*) to 230 volts. The recordings were made after a one hour warm-up time in each session, with the sensor positioned at right angles to the axis of the lamp, at the midpoint of the lamp array. Meter readings were taken at one-inch and 5cm increments from the lamp surface. Spectrometer recordings were made at a standard distance of 30cm from the lamp surface.
No long-term testing has been performed.

Recordings include:
- Spectrograms (Ocean Optics Inc. USB2000+ spectrometer with UV-B fibre-optic probe with cosine adaptor)
- UV Index (UVB in the biologically active range of wavelengths) (Solarmeter 6.5R UV Index meter)
- Total UVB - 280 - 320nm (Solarmeter 6.2 broadband UVB meter)
- UVC (Solarmeter 8.0 broadband UVC meter)
- Visible light output (SkyTronic LX101 model 600.620 digital lux meter)
- Electrical consumption (Prodigit power monitor model 2000M-UK)

Spectrum - UV plus Visible Light

The full ultraviolet and visible light (UV-VIS) spectrum recorded at 10cm, is shown in Figure 2 (below). A mid-day solar spectrum with the sun close to the zenith (Solar altitude 85.4°, location San Bartolomé, Gran Canaria, June 21st 2011 Local time 14:00h) is overlaid on the chart below (but note the different irradiance scales). This enables comparison of the spectral power distribution (SPD) of the lamp with that of natural sunlight, which has a completely continuous spectrum from a threshold around 295nm.

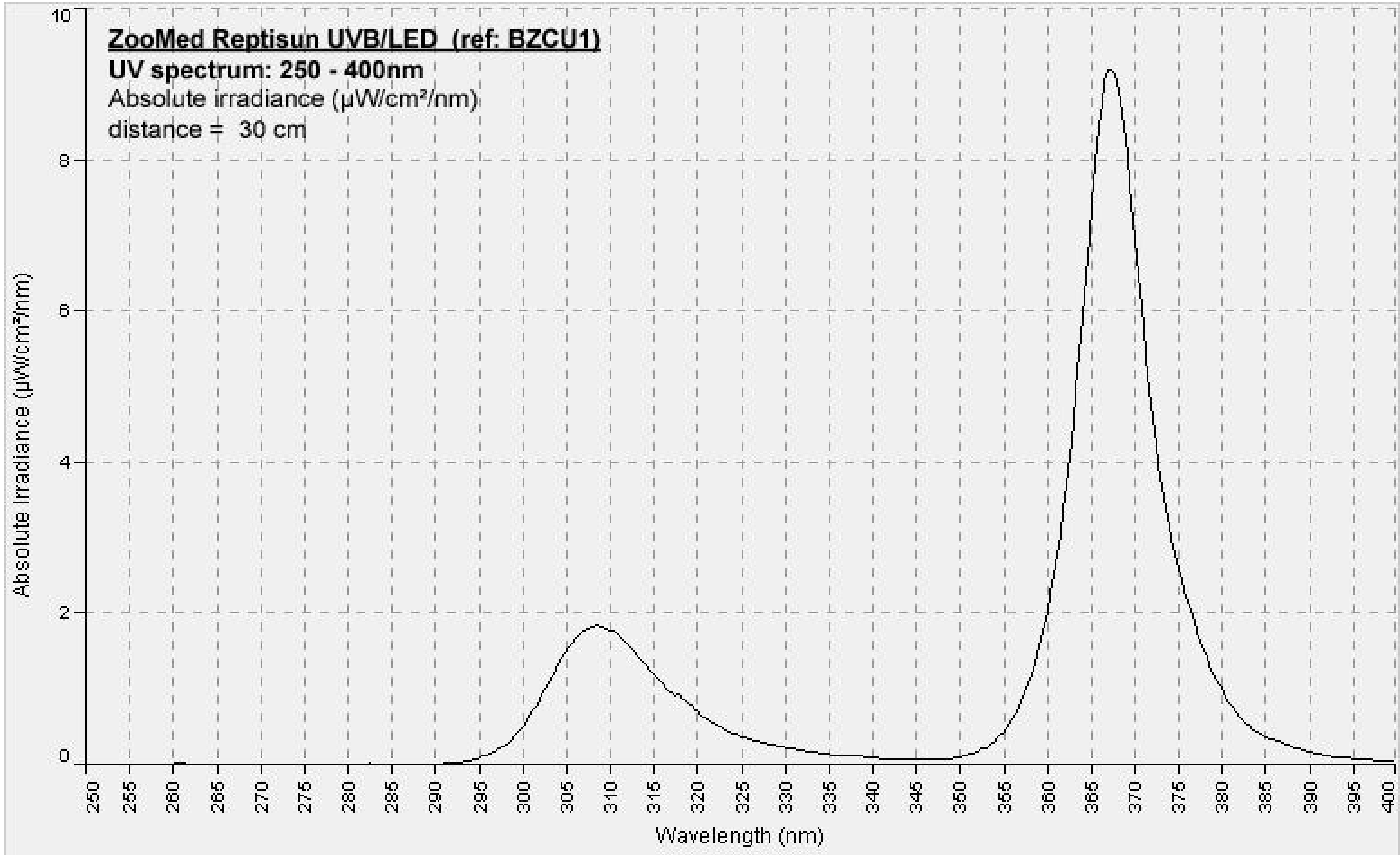


The three individual LED spectra are clearly defined. The four UVB LEDs have a peak wavelength of 308nm; the one very powerful UVA LED is at 367nm. The eight blue LEDs driving the phosphor for the white light are at 450nm. The total visible light output is very low in proportion to the UV output, when compared to the solar spectrum. There are obvious gaps in the mid-range UVA and purple wavelengths, and a deficit in the red waveband.

Spectrum - UV in more detail

Figure 3 (below) shows the UVB (280-320nm) and UVA (320 – 3400nm) ranges for this lamp in more detail.

Fig. 3



The UVB LEDs do not emit any UVC and the threshold wavelength is 290nm, with only insignificant output below about 295nm. This threshold is similar to sunlight, but the lamp has a much greater proportion of its total UVB below 315nm, as clearly shown in Figure1.
The LED emits only a very small amount of short-wavelength UVA (320 – 350nm), very different from sunlight in which the UV irradiance in these wavelengths greatly exceeds that of the total UVB. This may be an area of concern, warranting future research (see later).
The proportions of UVB: UVA: Visible light are 5.7 : 23.2 : 71.1, (irradiance in µW/cm²) in contrast to those of sunlight: 0.5 : 12.5 : 87.0 (data from reference spectrum for 60-degree altitude sun).

The strong UVA LED peaks at 367nm and has a reasonably wide bandwidth which will be strongly visible in the blend of light seen by reptiles, although it is such a comparatively powerful radiation that it is conceivable that it might give the “white” light a UVA-coloured cast to reptile eyes. The effect of absent wavelengths between about 390 and 430nm on colour perception of reptiles is unknown. However. these wavelengths are difficult to supply adequately with any conventional lighting; metal halides are the most successful source for reptile-visible light including long-wavelength UVA.

Spectral Analysis - photobiologically active UV (wavelengths from 270 - 350nm)

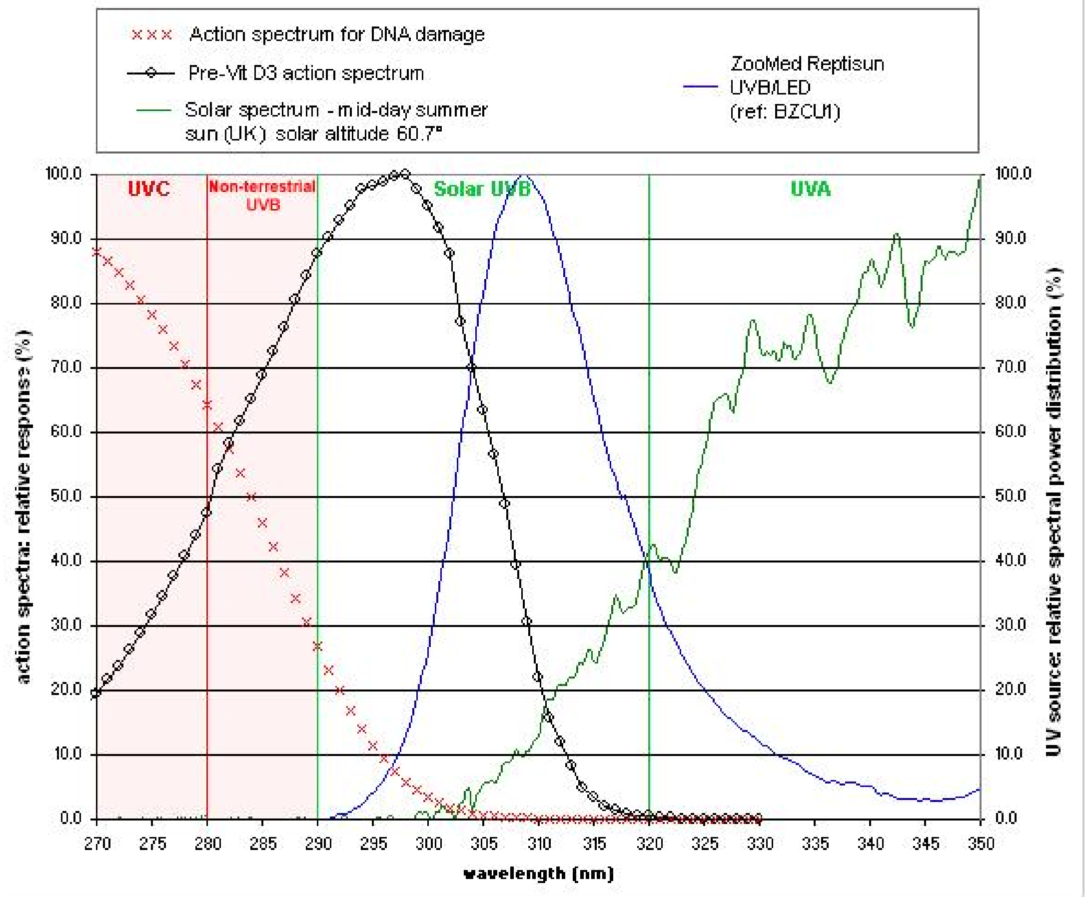
Figure 4 shows the relative spectral power distribution of the sun and the lamp, with the peak irradiance between 270nm and 350nm scaled to 100%, to enable comparison.
Overlaid are the Pre-Vitamin D3 Action Spectrum (CIE 174:2006) and an action spectrum for DNA damage (adapted from Setlow 1974). The action spectra for other damaging effects of UV radiation, such as photo-kerato-conjunctivitis, are similar to this one.
The extent to which each UV spectrum falls under each action spectrum determines the risks and benefits.

The natural system, as one might expect, is virtually perfectly balanced to minimize risk (very little of the solar spectrum falls under the curve for DNA damage) whilst maximizing benefit (a reasonable amount is within the vitamin D3 action spectrum, and the higher irradiance in wavelengths >300nm compensates for their lower synthetic potential).

From this chart, it can be seen that:

- The lamp does not emit hazardous UVC, or UVB in the non-terrestrial UVB wavelengths.
- A proportion of its output is below 300nm. The risk of DNA damage is therefore greater than for natural sunlight.
- Compared to sunlight, a far greater proportion of the total emission in this range is between 300 – 320nm, hence much greater photobiological activity is to be expected. There is a significant risk of “sunburn” and photo-kerato-conjunctivitis following over-exposure.
- There is significant UVB in the wavelengths which enable vitamin D3 synthesis in skin.
- The proportion of UVA from 320 - 335nm, important for natural prevention of excessive D3 synthesis, is very low. This may result in a significant reduction in the ability of the light to produce a natural balance of photoproducts in the skin, favouring synthesis of pre-Vitamin D3 over lumisterol, tachysterol and 7-DHC, and also restricting the breakdown of excess vitamin D3 into inert substances including suprasterols. This is likely to result in a higher vitamin D3 yield than would be predicted by the UV Index, which could in theory lead to oversupply of vitamin D3 and possibly an eventual hypervitaminosis. To determine whether this is a risk will require long-term monitoring of serum vitamin D3 and 25(OH)D3 levels in reptiles using these lamps under what are currently considered “natural” UVI ranges. For a fuller discussion, please see the Discussion.

Fig. 4. Spectral power distribution of the sun and UVB lamp in relation to the action spectra for the conversion of 7DHC to pre-vitamin D3, and for DNA damage



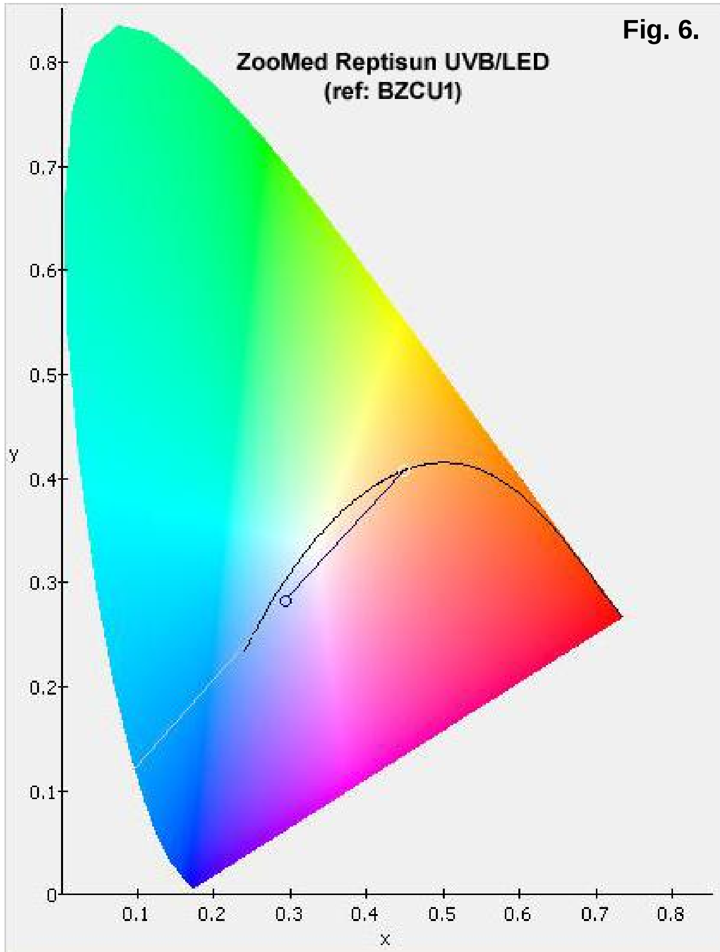
Colorimetry

Colour analysis performed on the spectral data gave the results shown below (Figure 5). The colour analysis chart provides an estimate of the Colour Rendering Index (CRI) and Corrected Colour Temperature (CCT) for the lamp. The colour of the light is not quite close enough to the Planckian locus to be within the range required for accurate calculation of the Colour Rendering Index (CRI) and Corrected Colour Temperature (CCT) by the spectrometer software. This is indicated by the entry: DC<5.4^{E-3} = FALSE. Even so, the software provides an estimate based upon the data provided. According to this calculation, the lamp has a good colour rendering index (CRI 90.2), and almost all colours are rendered very well, except for strong red (as indicated by CRI R9), since red light is not well represented in the spectrum of "white" LEDs which use a phosphor, as do these.

The colour temperature is estimated to be 8,864K, which is slightly more "blue" than daylight as seen by the human eye. There is no formula yet for calculating how these lamps render colour to a reptile or bird's eye, however.

Fig. 5: Colorimetry	Reptisun UVB/LED (BZCU1)
CRI Ra	**90.2**
CRI R1	86.0
CRI R2	92.4
CRI R3	92.0
CRI R4	90.9
CRI R5	88.9
CRI R6	88.4
CRI R7	97.7
CRI R8	85.1
CRI R9	50.5
CRI R10	89.4
CRI R11	87.9
CRI R12	69.1
CRI R13	87.4
CRI R14	94.5
CRI R15	80.0
CRI DC	1.48E-02
DC<5.4E-3	FALSE
CCT	**8864K**

Fig. 6.



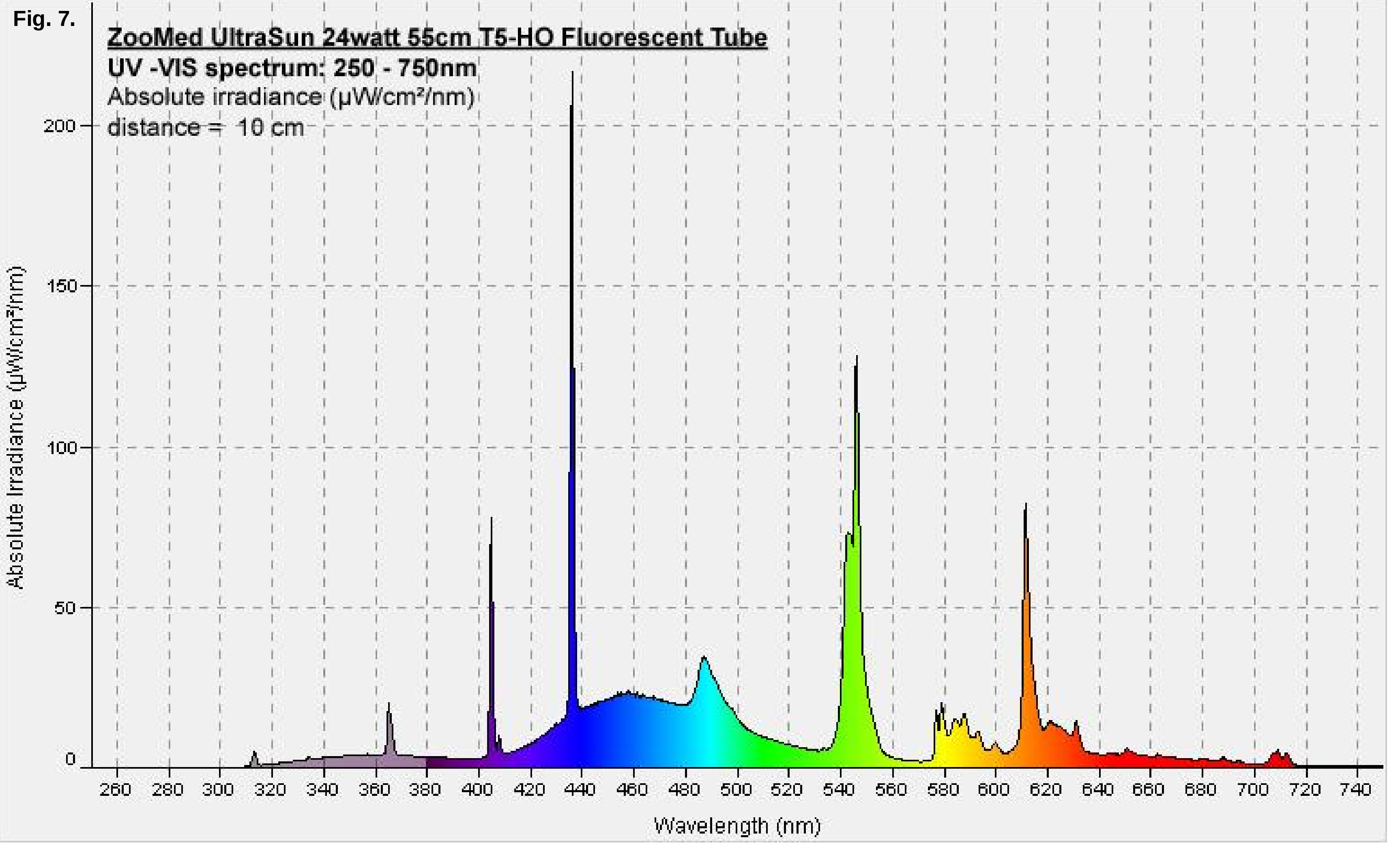
The spectrometer software also creates a Chromaticity Chart for each spectrum (Fig.6, right). The chromaticity coordinates are given by the dark blue circle; the arc represents the Planckian locus (the chromaticity coordinates of a perfect 'black body' radiator at all temperatures). The co-ordinates are close to the arc, resulting in the high CRI, and the "blue" higher colour temperature is also visualised. However, these colours are only relevant to the human eye. The colour space of reptilian vision is very different, since it includes UVA. It must not be assumed that this light looks white to a reptile.

Combining the UVB/LED with a “daylight” fluorescent tube

ZooMed have recognised that the UVB/LED lamp has only a low output in the visible range, and does not emit any short-wavelength infrared. They suggest in some of their publicity material that the UVB/LED should be combined with a “daylight” lamp and an incandescent basking lamp such as a halogen reflector bulb. A spectrum obtained when the UVB/LED was used together with an incandescent lamp is featured on their website.

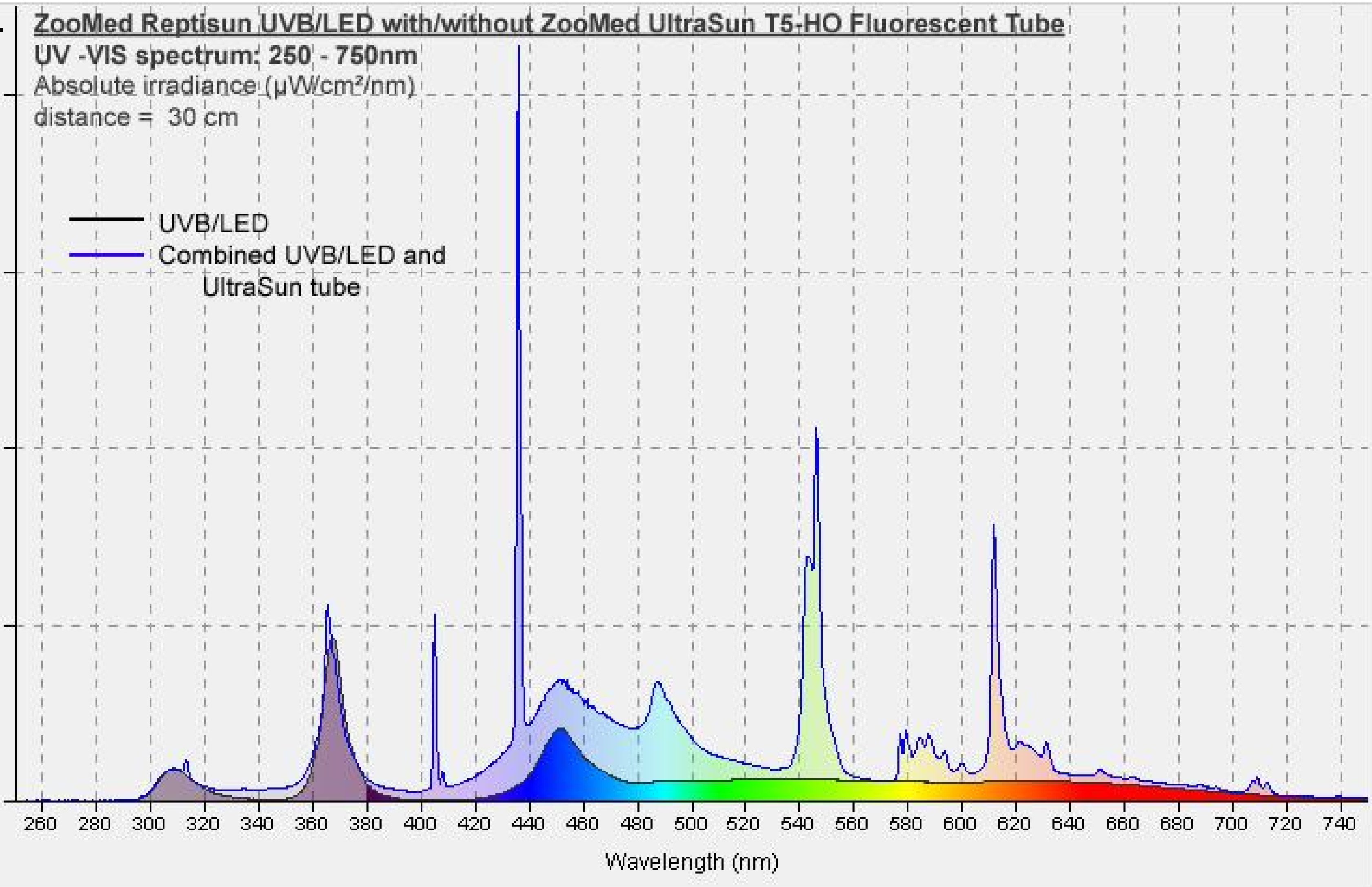
To facilitate investigation into the effect of adding these components, ZooMed supplied a T5-HO “daylight” fluorescent tube (ZooMed UltraSun Super Daylight 24watt 55cm T5-HO tube) with a ZooMed Reptisun T5-HO Hood fixture. This lamp has a typical triphosphor blend for visible light plus a small proportion of a UV-emitting phosphor providing primarily UVA (figure 7.)

Fig. 7.



The T5-HO tube was placed alongside the UVB/LED and the spectrometer set up at a distance of 30cm from both lamp faces. The combined beams from the two lamps produced the spectrum below (figure 8) overlaid by the UVB/LED spectrum for comparison..

Fig. 8.



This combination does improve the spectrum provided by the UVB/LED alone, adding some useful UVA in the under-represented wavebands and a spike in the purple wavelengths at 405nm. The triphosphor emissions in the blue, green and orange-red wavelengths are designed for human eyes to interpret as “white” and greatly improves the total illuminance, but the entire spectrum is still very discontinuous, unlike the sun, and it is not possible to tell whether this spectrum would seem white to any reptile.

ZooMed also recommend use of an incandescent lamp alongside these lamps to create a better simulation of sunlight. An incandescent lamp has the typical spectrum of a black body radiator, providing a small amount of UVA and a fair amount of visible light, with irradiance rising with increasing wavelength up into short-wavelength infrared. This adds very significant amounts of red light to the overall spectrum, improving this part of the spectrum, as well as providing basking warmth. However, the type of incandescent lamp used, its beam shape and its wattage will determine the temperature it generates on the surface below at any given distance. This distance will be determined by the desired surface temperature, and may be very different from the distance required for the desired UV Index under the UVB/LED. Since the irradiance will vary with distance, its effect upon the spectrum of light reaching the reptile from a combination of lamps will also vary. However for practical reasons, addition of an incandescent lamp was not tested in this trial.

Broadband Meter Readings

The “quality” of its light, as indicated by its spectrum, is only one factor in predicting the usefulness of a lamp. The “quantity” of UVB must also be assessed. Therefore the intensity of the UV at different distances must be measured. This is done using broadband UV meters.

UV Index Recordings

The spectral response of this meter is similar to the action spectrum for vitamin D3 synthesis, and so readings from this meter are normally used to estimate the potential of the lamp to enable vitamin D3 synthesis. Whether this is applicable to these LEDs is a subject for discussion (see later).
Recordings of the output of the lamp made with the Solarmeter 6.5R UV Index meter, are shown in Figure 9 (below). A standard mesh screen top such as those used with ZooMed and ExoTerra terrariums block 35% of the UVB and visible light. An estimate of the resulting UVI is also included below.

Fig. 9. UV Index (Solarmeter 6.5 readings)

	Distance from lamp surface (cm)															
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
Reptisun UVB/LED (BZCU1)	42.5	24.5	13.6	8.1	5.4	3.9	2.8	2.2	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.5
Estimated UVI beneath 35% mesh screen top	27.6	15.9	8.8	5.3	3.5	2.5	1.8	1.4	1.1	0.9	0.8	0.7	0.5	0.5	0.4	0.3

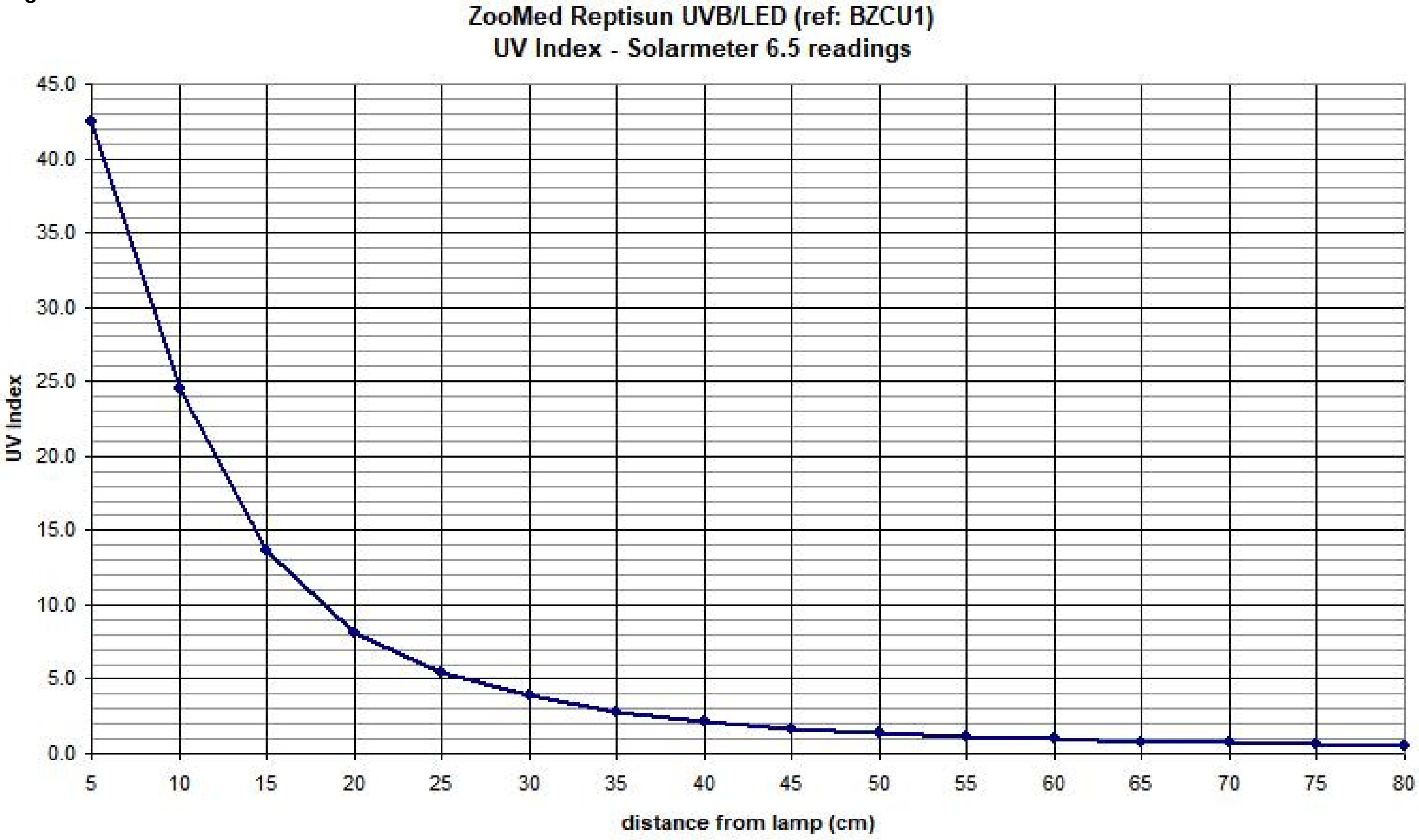
These readings suggest that *as long as the use of UV Index is a safe guide*, these lamps can be used to provide UVB to species with low requirements (e.g. Ferguson Zone 1, blue shading) at distances of 65cm or more (50cm if above a mesh screen); occasional baskers (Ferguson Zone 2, green shading) in a basking zone 35 - 60cm distance with a gradient to zero into shade, and full sun baskers (Ferguson Zones 3 and 4, yellow shading) in a basking zone 25 – 30cm below the lamp, with a gradient to zero into shade. Even the most sun-tolerant reptiles should not have access closer than 25cm as the UVI becomes too strong for safety at close range.
Figure 10 (below) charts the UV Index readings from the same lamp using imperial measurements (inches).

Fig. 10. UV Index (Solarmeter 6.5 readings)

	Distance from lamp surface (inches)															
	2	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**	**28**	**30**	**32**
Reptisun UVB/LED (BZCU1)	42.0	24.2	13.1	7.9	5.2	3.7	2.7	2.1	1.7	1.4	1.1	0.9	0.8	0.7	0.6	0.5
Estimated UVI beneath 35% mesh screen top	27.3	15.7	8.5	5.1	3.4	2.4	1.8	1.4	1.1	0.9	0.7	0.6	0.5	0.5	0.4	0.3

Figure 11 (below) shows the UV Index with increasing distance in graphical form.

Fig. 11



Comparison with figures published by ZooMed

The ZooMed instruction leaflet supplied with the lamp has a table labelled as an Application Chart giving recommended distances for Ferguson Zone categories. These are also printed on the box. These are cited in the table below (Fig. 12.) along with the widely-recommended UVI ranges for the Ferguson Zones, and the readings measured in this study at the distances stated.

Fig. 12. ZooMed “Application Chart” in comparison with Ferguson Zone ranges and UVI measurements from this trial

Ferguson Zone	Established Ferguson Zone ranges for max UVI in basking zone	**ZooMed Recommended Distances: Without Screen Cover**	Measured UV at those distances	**ZooMed Recommended Distances: With Screen Cover**	Estimated UVI at those distances (with 35% UV block)	Examples of species (listed on box)
Do Not Use	>UVI 8.0	2 - 20cm (1 – 8 ins)		1 - 19cm (0 – 8 ins)		
4	UVI 7.0 – 4.5	23 - 38cm (9 - 15 ins)	UVI 7.9 - 2.7	20 - 35cm (8 - 14 ins)	UVI 4.3 – 1.6	Pogona vitticeps (Bearded dragon) Uromastyx aegyptia (Egyptian uromastyx) Leiocephalus personatus (Haitian curlytail lizard)
3	UVI 7.0 – 3.0	38 - 61cm (15 – 24 ins)	UVI 2.7 – 1.1	35 - 55cm (14 - 22 ins)	UVI 1.6 – 0.6	Iguana iguana (Green iguana) Testudo marginata (Marginated tortoise) Chrysemys picta (Painted turtle)
2	UVI 3.0 – 1.0	61 - 79cm (24 – 31 ins)	UVI 1.1 – 0.8	55 - 66cm (22 - 26 ins)	UVI 0.6 – 0.4	Anolis (Anoles) Terrapene carolina carolina (Box turtle) Furcifer pardalis (Panther chameleon) Phelsuma (Day geckos)
1	UVI 1.0 – 0.5	79 - 102cm (31 – 40 ins)	UVI 0.8 – 0.4	66 - 91cm (26 – 36 ins)	UVI 0.4 – 0.2	Correlophus ciliates (Crested gecko) Pantherophis guttatus (Corn snake) Eublepharis macularius (Leopard gecko) Dendrobatidae (Dart frogs)

Some of these Ferguson Zone allocations are incorrect according to the current listing (Baines *et al.* 2016). *Leiocephalus personatus* is not listed, but *L. carinatus* is Zone 3. *Testudo marginata* is listed as Zone 4; *Furcifer pardalis* is listed as Zone 3 but recently re-categorised as Zone 4. Phelsuma (day geckos) are listed as Zone 3.

Unfortunately, as can be seen from the above figures, the UVI at the suggested distances do not correlate well with the Ferguson Zones, nor do the UVI suggested for “with” and “without” screen covers match up (This could be because ZooMed are assuming that the screen blocks less UV than it does.)

Apart from the figures at the top of the range for Zone 4, the UVI at the suggested distances is lower than the Ferguson Zone ranges would suggest as optimal for within the basking zone. However, in view of the theoretical risk of hypervitaminosis D developing through use of these lamps, it is perhaps a beneficial feature, since those following the printed instructions rather than actual UVI measurements taken with a UV Index meter will be giving their animals a lower “dose”. There does not seem to be any stated rationale for these recommendations, however.

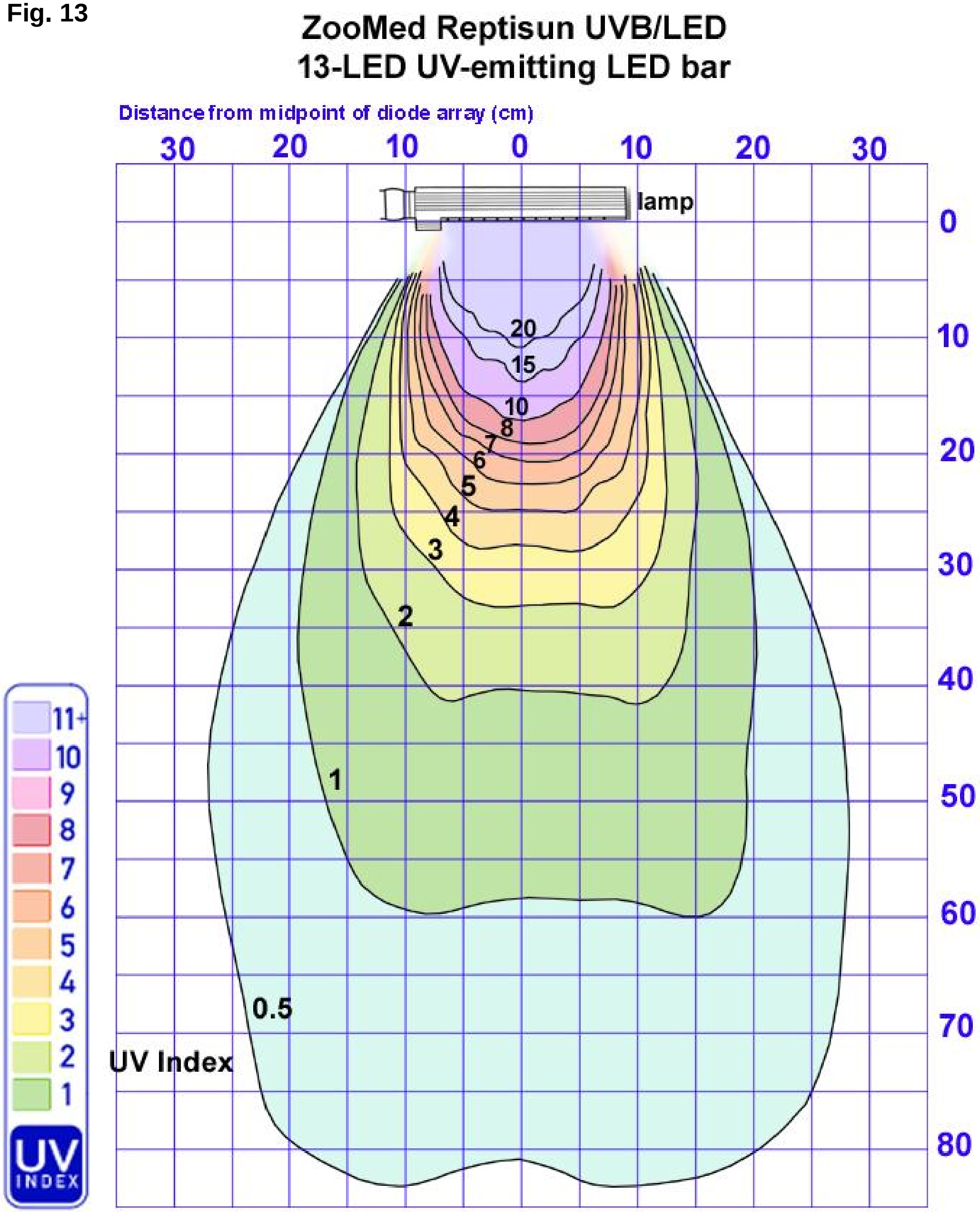
Iso-Irradiance Chart

Iso-irradiance charts give a clear picture of the UVB gradient in terms of the width of the beam across the basking zone. Figure 13 (right) was plotted for the Reptisun LED/UVB lamp after 2 hours of use.

The individual UVB LEDs have narrow beams which overlap and create a single beam but with a symmetrical pattern created by their interaction.

NB: This chart should not be used as a guide to lamp placement while uncertainties remain regarding the use of the UV Index to predict vitamin D3 synthesis from these lamps.

Fig. 13



UV Index iso-irradiance diagram (spread pattern) of lamp ref. BZCU1 tested 04.10.2021

Total UVB - 280 - 320nm

For some years now, measurement of the total UVB range (in µW/cm²) using another broadband meter, the Solarmeter 6.2, has become popular. For this reason, these measurements are routinely included in all reports.
The total UVB output of the lamp is shown in the table below (Figure 14).

Fig. 14. Total UVB µW/cm² **(Solarmeter 6.2 readings)**																
	Distance from lamp surface (cm)															
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**
Reptisun UVB/LED (BZCU1)	506	266	146	87	57	41	30	23	18	15	12	10	9	7	6	6

Relative Photobiological Activity

A simple, "rough-and-ready" estimation of the photobiological activity of the light emitted by a lamp can be made by comparing its total UVB output with that of natural sunlight when the UV Index of both is the same. It is only a crude estimation because broadband meters have a fixed sensor response affected by differing spectral power distributions. Moreover, different batches of Solarmeters (of either the 6.2 or 6.5) have slightly different spectral responses, so the actual ratios will vary between different Solarmeter pairs. However, this estimation has proven invaluable in the field, for detecting lamps with a dangerously high proportion of their output in the very low UVB wavelengths. This "Solarmeter 6.2 UVB : 6.5 UVI ratio" is unitless.
Paired readings with the current author's two meters, taken in sunlight across a wide range of solar altitudes and weather conditions in the UK, USA and Australia give a UVB : UVI ratio of between 35 : 1 and 60 : 1, depending upon solar altitude and degree of cloud cover. The higher the sun is in the sky, the greater is the proportion of short-wavelength UVB, and hence the lower the ratio.
When the solar UV Index is 3.5, the ratio is approximately 50 : 1; when it is 13.0, the ratio is 35 : 1. These figures are within the normal range for tropical sunlight at 8:30am and noon, respectively.
The following result was obtained by regression analysis of paired readings across all measured distances with these same two meters:

Reptisun UVB/LED (BZCU1) UVB : UVI = 11.5 : 1

This result is what would be expected, given the spectral analysis of the lamp. The ratio is far lower than seen from mid-day tropical sunlight, confirming that the light from the lamp has a much greater proportion of its UVB in the shorter UVB wavelengths than an overhead mid-day tropical sun. In simple terms, these lamps emit extremely "strong" UVB and great care must be taken to avoid over-exposure.
Lamps with UVB:UVI ratios less than 12:1 have in the past caused photokeratitis and "sunburn" to skin, although these have also emitted shorter wavelengths than sunlight, i.e., below 290nm. These LED spectra are new to this field and as yet, no long-term studies on their biological effects have been carried out.

Visible light output

Recordings taken with the SkyTronic LX101 model 600.620 digital lux meter from this lamp and the combination of this lamp and the ZooMed UltraSun fluorescent tube in the ZooMed T5-HO Hood are shown in Figure 15 (below)

Fig. 15. Illuminance (lux)												
	Distance from lamp surface (cm)											
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Reptisun UVB/LED (BZCU1)	11,220	5,050	2,810	1,730	1,185	880	666	530	433	364	306	256
ZooMed UltraSun 24W T5-HO tube	15,390	10,820	7,560	5,450	4,130	3,220	2,630	2,180	1,803	1,524	1,324	1,140
Reptisun UVB/LED plus UltraSun tube	26,610	15,870	10,370	7,180	5,315	4,100	3,296	2,710	2,236	1,888	1,630	1,396

For comparison, direct solar readings only five minutes after sunrise reach 3,000 – 5,000 lux. In clear weather, mid-day direct solar readings of 120,000 to 150,000 lux are often seen. It is obvious that alone, the visible light from the UVB/LED (e.g. 880 lux at 30cm) is not sufficient for illuminating any vivarium. Fluorescent tubes are not sources of bright illumination either. Illumination around 3,000 lux at 30cm distance, provided by the UltraSun tube alone, would seem suitable for background illumination of open areas in any enclosure, and might provide all that is required by non-basking, shade-dwelling species. However, a combination with the UVB/LED would not suitable as the sole source of visible light for any basking species, which should also be provided with a brighter lamp with a continuous spectrum, creating a “beam of sunlight”, in the basking zone. This might be supplied by a halogen “basking lamp” – which will be necessary in any case, since neither of these are emitting short-wavelength infrared (IR-A). Additional bright visible light from either a metal halide or a stronger “white” LED floodlight aimed at the basking zone would benefit many species.

UVC

The Solarmeter 8.0 broadband UVC radiometer measuring the UVC range (240 – 280nm), with filtering for extraneous UVA and UVB, gave zero readings at all distances. This is not surprising since UV LEDs have very restricted wavebands, and no UVC LEDs were used.

Electrical consumption

The electrical consumption of the lamp was measured at the time of testing, using a Prodigit power monitor (model 2000M-UK) with line voltage set at 230V

The lamp was operating at 7 Watts (11 VA, pf 0.64) drawing 0.05 amps at 230 volts. The power factor of only 0.64 means that the voltage and current waveforms are not in phase, so that although the lamp is running on only 7 watts, the apparent power is 11 watts and a higher current is drawn.

Discussion

LEDs and Vitamin D synthesis: possible risks

The most important feature of any lamp used in animal husbandry must be that if used according to instructions, it is safe to put over an animal – safe for eyes, safe for skin, and for general long-term health. The use of LED lighting itself is new to reptile husbandry, and yet it is widely replacing human lighting everywhere, from street lamps to desk lamps. The increased blue component is known to affect circadian rhythms in humans and other animals owing to its action on the brain via non-visual perception; however, since its use in reptile husbandry is largely restricted to daytime lighting,

this is not normally considered to be a significant problem for the animals.
The situation regarding the use of UV LEDs is very different. The UV LEDs currently available all have very short bandwidth – typically no more than about 20nm – and have a strong peak wavelength which gives a LED its name (eg. 308nm LED, 450nm LED.) Reliable UV LEDs with good longevity are only available in a small number of nominal wavelengths, and most are also only available with a low output, necessitating multiple diodes of the same wavelength. This makes it very difficult to recreate the sun's natural spectrum in the UV range, which would require juxtaposing a range of LEDs of steadily increasing wavelength, since such large numbers would be unviable; and at present, it is actually impossible to recreate anything similar to sunlight in the UVA range owing to an absence of suitable LEDs altogether in the shorter UVA wavelengths.

The solution tried here by ZooMed is to use one 308nm LED for the UVB, and one at 367nm for the UVA.
The 308nm LED has a spectrum in the region between 395nm and 308nm which is not dissimilar to that of strong sunlight in that the irradiance increases with increasing wavelength, but above 308nm, there is no resemblance at all; instead of increasing irradiance with increasing wavelength, the UVB falls away by 320nm and there is no further UV until around 350nm, on the threshold of reptile vision.

Although UV, in species-appropriate levels, has many benefits to reptiles *per se*, including skin disinfection and immune modulation, the most well-known benefit is vitamin D3 synthesis. To understand why this lack of longer-wavelength UVB and shorter-wavelength UVA is a problem, it's important to understand a complex phenomenon: the way vitamin D3 synthesis occurs and why, in natural sunlight, it is a self-regulating process and excess, which could cause hypervitaminosis, is never produced.

It has long been known that that the shorter wavelengths in the UVB range are the most effective in synthesising vitamin D3 from the cholesterol, 7-DHC, in the skin. Wavelengths between 295nm and 315nm are required. The UVB converts the 7-DHC into pre-D3. Warmth (e.g. infrared from the sunlight) then converts pre-D3 to vitamin D3. Vitamin D3-binding protein (DBP) attaches to the vitamin D3 molecule and the pair are carried into the bloodstream.
But that's a great simplification of the process, because all the wavelengths between 295nm (in the UVB) and 335nm (in the UVA), act upon 7-DHC. It's not just pre-D3 that's created. This was elucidated in a key paper by MacLaughlin *et al.* (1982). Vitamin D3 synthesis is a multi-stage process involving a "molecular dance". Four photoproducts form an equilibrium, the amounts of each depending on the nature of the UV spectrum reaching the skin. Only wavelengths below 320nm – and especially those below 310nm – transform molecules of 7-DHC into preD3. However, all wavelengths right up to 335nm can transform 7-DHC into two other photoproducts, lumisterol and tachysterol – and can also recycle all four of these molecules, one into another and back again. This happens continuously in daylight and sunlight. At the end of the day, the skin will hold a mixture of all these compounds: 7-DHC, lumisterol, tachysterol and pre-D3. The warmth will steadily convert much of the preD3 to D3 which will be removed. The rest remain, to become part of the "dance" again – although it is now known that these molecules also have some biological activity themselves, and some are converted by enzymes into other vitamin D metabolites.
So there is a "brake", a "buffer" in the system, and it is a powerful one, because there is far more UV above 320nm than below it, and so lumisterol and tachysterol will always be formed in sunlight to keep things under control. If the spectrum is sun-like, the amount of preD3 in the skin rarely exceeds the amount that can be safely taken into the body. This is why those longer wavelengths (320 -335nm) are so valuable.

There is even a "back-up" process to remove any excess vitamin D3 if too much of this starts to accumulate for the DBP to take it away. This was first identified by Webb *et al.* (1989) who found that wavelengths up to 330nm would degrade vitamin D3 remaining in skin, breaking it down into inert metabolites - 5,6-transvitamin D3, suprasterol I, and suprasterol II. Another "brake" in the system, preventing over-production of vitamin D3.

So for the natural self-limiting process to occur, preventing excess and potentially damaging levels of vitamin D3 formation, a full spectrum from short-wavelength UVB around 295nm, right up to UVA around 335nm is needed. **These lamps do not provide this.**

In human medicine, UVB lamps have been designed to enable rapid, strong vitamin D3 synthesis, with the shortest exposure time possible, for treatment of deficiency in a clinical setting. If a lamp contains only the shorter wavelengths, synthesis is sustained and the "brake", the "buffer" is severely weakened because of the absence of all those longer wavelengths. These lamps can produce astonishing yields of vitamin D3 with very low output. Studies with human patients demonstrating enormous increases in vitamin D3 following short exposures to UVB LEDs with similar spectra,

emitting predominantly short-wavelength UVB, confirm the apparent loss of much of the normal "buffering". Similar results have been seen in other studies conducted with mammal skin. See: Barnkob *et al*. 2016; Morita *et al.* 2016; Kalajian *et al*. 2017; Veronikis *et al*. 2020 and Lin *et al.* 2021.
Of course, for treatment regimes, this is desirable. But reptile UVB lamps are used to create the effect of natural full spectrum sunlight in the vivarium, with modest levels of UV offered in a basking zone along with sources of visible light and infrared, provided for full daylight hours (typically 10 – 12 hours per day). Lamps with spectra in the UVB and short-wavelength UVA range which are similar to sunlight should not cause overproduction of vitamin D3, as the "buffering" will be maintained. The UV Index, a measure of the photoreactivity of sunlight on human skin, has been developed as a useful guide to suitable, "natural" UV ranges for creating safe basking zones. For example, UVI 4.0 in the basking zone is often suggested as appropriate for bearded dragons, following research on wild, free-living animals in Australia (Howard, 2019) demonstrating UVI 4.0 as a preferred exposure level.
The UV Index was designed to measure the effects of a natural solar spectrum, not one only containing wavelengths driving vitamin D synthesis with "no buffer". An early trial with UVB LEDs conducted using a ZooMed prototype (Cusack *et al.* 2017) demonstrated that a UVI average 0.24 (extremely low) created high serum 25(OH)D3 levels in bearded dragons, whereas a traditional compact UVB lamp with a UVI average 0.92 (nearly 4 times higher) did not raise serum 25(OH)D3 levels at all, over the test period of 11 months.
This study in particular is alarming, since a UVI 0.24 would not be expected to enable any increase in serum 25(OH)D3 levels in bearded dragons at all! The risk of hazardous uncontrolled vitamin D3 synthesis from these lamps under apparently modest UVI cannot be ignored; and whether the UV Index can be used as a measure of vitamin D3 synthetic ability is in serious doubt with these very un-natural UVB spectra.

No long-term studies of blood levels of vitamin D3 have yet been conducted with these lamps, either with animals maintained under UVI levels as recommended by ZooMed, or UVI levels as indicated by the Ferguson Zones (See: Baines et al. 2016). For sun-basking species these UVI recommendations are far higher than used in the trials conducted by Cusack et al. The question that remains unanswered is: will these lamps cause excessive synthesis and even hypervitaminosis D? In theory, they certainly should!

It is essential that properly controlled trials are set up, with significant numbers of animals and preferably including several different species. These must include blood tests for 25(OH)D3 measurements before, during and after long-term daily lamp use, using the LC-MS/MS chromatographic method, not an immunoassay as those appear to be very inaccurate with reptile bloods owing to cross reactivity with different vitamin D metabolites, DBP and other factors (Hurst *et al.* 2020). Other measurements should include serum calcium, ionised calcium, vitamin D3, parathyroid hormone and 1,25(OH)D3 to assess calcium metabolism, since hypercalcaemia is the primary diagnostic feature of hypervitaminosis D as well as the cause of its toxicity. Unfortunately, the symptoms of hypercalcaemia are mild, insidious and non-specific, variously described as lethargy, anorexia, increased thirst, muscle weakness and lameness. In addition, high serum calcium levels are normal in female reptiles during folliculogenesis, which may confuse the issue. Mobilisation of calcium from bone results from increased oestrogen activity and calcium levels return to normal after egg laying.

UVB Overexposure
When any artificial source of UVB with unknown potential is used, animals should be monitored regularly for any sign of UVB damage to skin and eyes, since this is a symptom of acute over-exposure to high UVB. The cornea (or spectacle of snakes and geckos) is usually affected first. Photo-kerato-conjunctivitis presents as an opacity or lesion on one or both corneas, causing intense pain. Affected animals will become immobile and depressed. Those with eyelids will keep the eyes permanently closed to reduce the pain. The eyelids often become swollen and their skin may appear burned. Fortunately, removing the UVB source enables rapid healing in most cases. More severe overexposure causes UV radiation burns to the skin of the rest of the body as well. Milder burns resemble dysecdysis; more severe damage will form blisters and layers of dead skin which may slough. (See: Gardiner *et al.* 2009.)

Lamp Longevity
This trial was carried out on new lamps with no measurement of decay in UVB output and can give no indication of the useful lifespan of these lamps. Long-term trials are required. Single-wavelength LEDs which do not succumb to overheating and are not subjected to abnormal electrical load may have very little further decay over the course of their lifetime, which depends upon the manufacturer's specifications. In this case, ZooMed claim a lifespan of "up to 4 years or 20,000 hours" for the UV LEDs.

"White" LEDs utilise a blue LED to activate a phosphor for the rest of the spectrum; this can degrade slowly, resulting in a reduction in light output. However, it is possible that their lifespan exceeds that of the UVB LEDs. Unfortunately, because the UVB is invisible to us, it will not be possible to tell, without a UV meter, if or when the UVB diodes fail. It is possible that their failure will not cut off the power supply to the rest of the lamp, in which case the lamp may appear no different to the human eye, but be emitting no UVB.

Lamp Fittings

One of the two lamps in the trial could not be tested in the equipment available because it could not be rotated far enough round, in the E27 fitting used, to bring it to the front of the fixture. If this was not a case of user error (and it did not appear to be) there may be incompatibility between a percentage of all E27 screw threads on these lamps and sockets in hood-type fixtures which cannot themselves be rotated without loosening their electrical connections.

Looking to the Future

In my opinion this lamp needs improvement before it can replace high quality UVB fluorescent tubes in reptile husbandry. At present, my research suggests that no commercially available LEDs exist with a stable, suitable irradiance to fill in in the "missing" wavelengths in that short-wavelength UVA region between 320nm and about 340nm. However, there is no doubt that in time they will be developed, and a way found to create a much more "sunlike" spectrum. With the inevitable phasing-out of lamps using mercury, and increasing concern with improving electrical efficiency, fluorescent tubes will eventually become obsolete and it seems likely that LEDs will take their place.

Should these short-wavelength UVA LEDS be developed, and incorporated in lamps such as this, the future could be bright in more ways than one.

Author's note.

Individual lamps will vary in their UVB output, depending upon their original specifications and upon their age, the quality of the electrical supply, external temperature and doubtless, other factors. Only one lamp has been tested. To be certain that this is typical of its kind would require a much larger sample to be tested.

Because there will inevitably be differences between individual lamps, the charts for the lamp tested in this report should not be relied upon as an accurate guide to the exact output of all lamps of this type.

Comments in this report reflect my personal opinions only.

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