Automatic Switching of Lights
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6.1.2

AUTOMATIC SWITCHING OF LIGHTS

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SUMMARY

For economic reasons, it is preferable to ensure that lights are only left on at night. This applies in particular to buoys.
The general instructions of the French Lighthouse Service state that lights must be lit from semi-twilight in the evening to semi-twilight at dawn. A 1931 circular authorized switch-on and deferred switch-off in overcast or foggy weather to provide an additional safety factor for navigators.
Observation of automatic lights has shown that there are considerable variations in the switch-on and switch-off times. From the beginning of the investigation, it has been clear that insufficient data is available regarding values and variations in luminance at twilight.
This article shows results obtained in this field, and technical recommendations to permit automatic devices to be correctly specified and installed.

AUTOMATIC SWITCHING OF LIGHTS

1- INTRODUCTION

1.1. Regulations

According to the general instructions of the French Lighthouse Service, maritime aids to navigation lights must be switched on and off at the local time corresponding to twilight in the evening and morning respectively.

The limits of the two twilights defined by the true heights of the centre of the sun with respect to the horizon, are as follows:

-36' 6 for sunrise and sunset, this height corresponding with the value used for correcting refraction.

-6° this height being used for the end of civil twilight in the evening, and the beginning of civil twilight in the morning.

At semi-twilight, the true height of the centre of the sun below the horizon is therefore h= -3° 18' 3.

According to the general instructions, lights must therefore be lit or extinguished when the true height of the centre of the sun below the horizon reaches this level at the point under consideration during evening and morning twilight.

In clear weather, these instructions may be assumed to fulfil navigation requirements, since (when required) they can be used as a replacement for daytime sea marks, their luminous range being approximately equal to the visual range of the sea mark in daylight.

This does not apply to overcast or foggy weather.

A circular dated 18 March 1931 authorized early switch-on or delayed switch-off of certain lights in overcast or foggy weather.

1.2. Full automatic control

Originally, unmanned lights and light buoys in particular (although few in number) were at one time left constantly alight.

The number of lights has increased considerably, and it has become necessary and feasible to extinguish them during the daytime. This permits a reduction in power consumption, and substantial economies in respect of light buoys, where recharging operations are very costly.

The appearance of cheap and reliable photoelectric cells on the market means that they can now be considered for automatic control of lights in the evening and morning respectively. However, the above mentioned regulations cannot be applied directly, since these cells do not react in accordance with time or the height of the sun, but in accordance with the luminance in the area of the sky to which they are directed.

The luminance varies not only in accordance with the time and the meteorological conditions obtaining at the particular place and time, but also in accordance with the area of the sky under consideration. This applies particularly at twilight, when the sun is near the horizon. The movement of floating bodies such as buoys prevents the cells having a fixed orientation, and this causes considerable variations in the switching times.

Observation of buoys in LE HAVRE channel has shown that on certain days switching times for buoys having identical equipment may vary as much as half an hour. This is unsatisfactory for navigators, and delayed switch-on or early switch-off could cause accidents for which the Service would be liable. These problems have not arisen with non floating lights, although these have often required additional initial adjustement.

For these reasons, a decision was made to investigate the different switching times obtained with the automatic devices. It was found that knowledge regarding luminance values and variations at twilight were almost zero, and it was impossible to find any precise information in litterature. For this reason, the investigation comprised two distinct parts:

1) An investigation of luminance in the sky at twilight. This investigation was carried out by Ingénieur Général Blaise.

2) An investigation into the variable operation of automatic devices.

2-INVESTIGATION OF LUMINANCE AT TWILIGHT

As specified above, the luminance of the sky at a given time varies in accordance with the area of the sky under consideration. A decision was made to measure the zenithal luminance independently of the azimuthal luminance, since it has a greater effect on navigator's vision.

2.1. Operating mode.

Routine measurements were carried out at BAGNEUX (Southern Suburb of Paris) in 1978 by the French Lighthouse Service.

A silicon planar photodiode was used for these measurements , being optimised for operation at zero voltage. The cell was corrected by means of a green coloured filter, and was placed under a transparent "altuglas" cover to protect it from the weather and to limit its range to a space angle of 90° centred on the zenith. To begin with, the cell was calibrated against a standard lamp on a rotating table, using the Moon and Spencer law for variations in luminance with incidence, i.e.

$$L(\theta = \frac{Lz \quad 1 + 2\cos\theta}{3}$$

Where θ is the zenithal distance, and Lz is the zenithal luminance.

The current generated by the sensor was converted to voltage using a current-voltage converter, and the output voltage was measured by means of a digital voltmeter. The measurements were automatically recorded on a punched tape.

Measurements were restricted to zenithal luminances between 0 and 50 candelas per square metre. They were carried out over $1^1/2$ hour periods in the evening and morning twilight. 40 recordings were made at regular 135 second intervals.

These measuring periods were staggered at 45 minute intervals in accordance with the hours of sunset and sunrise.

The date and stages of the different measuring sequences were also recorded. Figure 1 provides a photograph of the automatic recorder used.

When the recordings were analysed, the necessary astronomical calculations were made to determine the true height of the sun with respect to the horizon, in accordance with the date and time of the measurements. The height h was expressed as a function of the latitude ϕ and the declination δ at the hour angle H of the location, using the following formula:

$$\text{sine } h = \text{sine } \phi \text{ sine } \delta + \cos \phi \cos \delta \cos H$$

2.2. Results obtained

The results were presented in two forms, as follows:

- Firstly, by representing the different values obtained for zenithal luminance as ordinates, in accordance with the true height h of the sun (for results covering a period of 20 days from 4 to 23 April 1978).
- Then, by calculating the distribution functions of the sun heights for the zenithal luminance values, with intervals of 5 $cd.m^{-2}$ between 5 $cd.m^{-2}$ and 45 $cd.m^{-2}$(for results covering a period of 100 days from 14 January to 23 April 1978).

The first display (see figure 2) provides a cloud of points which:

- Show the important effect that variations in cloud cover have on measured values of Lz.
- Permit use of the following empirical formula for variations in luminance in clear weather (lefthand limit of cloud):

$$Lz = (a\ h + b)e^{ch} \quad \text{(Figure 3)}$$

For Lz values between 0 and 50 candelas, and centre of sun true heights between -2° and -6°, the following apply:

$a \simeq -415$, $b \simeq -77$ and $c \simeq 1{,}355$

Lz is expressed in $cd.m^{-2}$ and h in degrees.
For h= -3° 18' 3= -3.305 degrees, the above formula gives the following:

$Lz = 14.7\ cd.m^{-2} = 14.7$ lux

For zenithal luminance in clear weather, h may be shown as= -3° 18' 3 $\sim$ Lz $\simeq 15\ cd.m^{-2} \simeq 15$ lux.

The second display (figure 4) shows the heights of the sun in degrees as abscissas, and the frequency at which these heights are not reached for a given zenithal luminance is given in ordinates (h= -3.305 degrees).

The curves obtained were used to provide the following table for zenithal luminances of 5, 10, 15, 20 and 25 lux, permitting the reference value h= -3.305 to be "bracketed".

True heights in degrees of the centre of the sun for which the frequency of lower heights is equal to F for zenithal luminance values Lz between 5 and 25 lux.

		Frequency F (as %)				
		10	25	50	75	90
Lz in cd/m^2	5	- 4.40	- 4.25	- 4.00	- 3.40	- 3.00
	10	- 3.75	- 3.65	- 3.33	- 2.80	- 2.15
	15	- 3.45	- 3.30	- 2.97	- 2.38	- 1.80
	20	- 3.17	- 3.00	- 2.70	- 2.08	- 1.42
	25	- 2.95	- 2.80	- 2.47	- 1.78	- 1.00

2.3. Consequences.

Because of variations in switching times due to the cell/programmer combination, it was necessary for light switching to be set on average for a luminance value equivalent to 22 lux.

The graph of figure 4 shows that by using this value of Lz for light switching times, the risk of a light not being lit a semi-twilight is limited to 1%.

It must be noted that when the sun is close to the horizon, the rate of variation in height will vary depending on the season of the year. It is maximum at the equinoxes and minimum at the solstices. At the BAGNEUX latitude, the limit values for 1978 were 0.00275 and 0.00219 degrees per second. If a Lz value of 22 lux is used for light switching with F between 10 and 90% (that is to say, for 80% of the atmospheric conditions recorded), the switching times will be distributed respectively as follows:

over $\frac{3.08-1.25}{0.00275}$ = 11 min 5 sec at the equinoxes

and over 3.08-1.25= 13 min 56 sec at the solstices.

It is to be noted also that the distributions of switching hours increases steadily with the value used for Lz, and that this distribution is higher at the solstices than at the equinoxes.

Lz VALUES USED(in lux)	DISTRIBUTION OF SWITCHING HOURS		DIFFERENCE BETWEEN SOLSTICE AND EQUINOX DISTRIBUTIONS
	AT THE EQUINOXES	AT THE SOLSTICES	
5	8 min 29 sec	10 min 39 sec	2 min 10 sec
10	9 min 42 sec	12 min 11 sec	2 min 29 sec
15	10 min	12 min 33 sec	2 min 33 sec
20	10 min 36 sec	13 min 19 sec	2 min 43 sec
25	11 min 49 sec	14 min 50 sec	3 min 1 sec

Variations in Lz with time when the sun is near the horizon in clear weather

From the formula :

$$Lz = (a\,h + b)\,e^{ch}$$

The following can be deduced :

$$d(Lz) = (a + c\,(ah+b))\quad{}^{ch}\quad dh$$

$$= \left(\frac{a}{a\,h + b} + c\right) Lz \times dh$$

$$= -\left(\frac{a}{a\,h + b} + c\right) \; Lz\;(V)_M\;dt$$

For an average rate of change in the height of the sun in degrees per minute :

$$\frac{0.00275 + 0.00219}{2} \times 60 \qquad 0.148$$

$$d(Lz) = -\,0.148 \times \left(\frac{a}{a\,h + B} + c\right)\;Lz\quad \text{lux/minute}$$

The factor $-\left(\frac{a}{a\,h+b} + c\right)$ varies slowly around unity for $-2^{\circ} \leqslant h \leqslant -6^{\circ}$

The rates of change in Lz in lux/minute vary as a function of Lz

L(degrees)	- 2	- 3	- 3.7	- 4.3
$Lz(cd.m^{-2})$	50	20	10	5
$-\left(\frac{a}{a\,h+b} + c\right)$	0.80	1	- 1.07	- 1.11
Δ (Lz) lux /minute	6	3	1	0.8

3- INVESTIGATION INTO VARIATIONS IN CONTROL OF LIGHT USING PHOTO-ELECTRIC CELLS

Following the observations made of control variations mentioned in the introduction, the French Lighthouse Department carried out routine tests in 1976 to investigate the causes of variations in the control of lights using photo-electric cells. They used 123 devices, of which 97 were of recent manufacture, and 26 selected at random from stock or returned after use.

The variations found may arise:

1) From variations in the cells themselves
2) From variations in the orientation of the cells
3) From variations in switching on the main control device (programme economiser).

Successive investigations were carried out to ascertain the effect of all three.

One point must be made. It is impossible, or at least unsafe, to place cells so that they react in accordance with the zenithal luminance. In this position, they are at the mercy of sea birds who regularly cause problems with maritime navigational equipment with their deposits. Cells must therefore be located on a lateral surface and will thus react in accordance with the luminance at the horizon.

3.1. Variations in the cells themselves.

Low cost photoconductive cells are used. They are reasonably strong, and give no problems when used with a flasher.

Figure 5 shows the characteristics of the cells on which tests were carried out. The graph shows tolerances in sensitivity due to manufacture and aging. The following can be noted:

- For a luminance of 10 lux, a nominal cell resistance of 2,400 ohms may vary between 1,500 and 3,500 ohms.
- For a luminance of 20 lux, a nominal cell resistance of 1,400 ohms may vary between 800 and 1,800 ohms.
- Conversely, for a resistance of 1,500 ohms, a luminance of 18 lux may vary between 9 and 25 lux.

This variation is of the order of 30 to 50%. It is obviously a problem, but any post manufacturing selection required to obtain a better tolerance would multiply the unit cost by a factor of 10. Even then, one could not in any way be certain that the improved characteristics would be maintained with time. On the other hand, since variations in the zenithal luminance Lz are of the order of 3 lux per minute for $Lz \geq 20$ lux, the nominal variation in luminance of the cell over a range of 9 to 25 lux could bring about maximum variations of approximately from -3 to +2.5 minutes, all things being equal, with switching set for Lz= 18 lux.

3.2 Variations due to orientation of the cells.

The tests showed that the difference in luminance can reach and exceed 12 lux between cells facing east and west, and that this difference in luminance may lead to variations in the switching time of around 6 minutes. It is therefore necessary to allow ± 3 minutes around the average value due to variations caused by the orientation of the cells.

3.3. Variations due to switching of the main control devices (programmers).

During previous tests carried out in 1973 and 1975, it was found that although the programmer switching resistors used to switch the lights varied to a considerable extent from one manufacturing batch to another, the variation in resistance within a batch was much more satisfactory.

The 1978 tests confirmed that variations in switching using programmers from one recent manufacturing batch did not exceed from -3 to zero minute. However, taking all programmers currently in service, the variation could reach from -8 to + 5 minutes, with switching set for Lz= 18 lux.

3.4. Maximum overall variation.

All of the above mentioned results permitted subsequent evaluation of the maximum overall variation in switching, using a reference luminance of 18 lux corresponding to a cell switching resistance of 1,500 ohms (the corresponding differences being given in minutes).

1 Variation due to the cell	2 Variation due to orientation of the cell	3 Variation due to switching	4 Total variation	5 Total quadratic variation
-3 +2.5	-3 +3	-8 +5	-14 +10.5	-9 +6

An overall variation of the order of 20 minutes was found in the switching time of light buoys in a given channel, where all the buoys were fitted with programmers taken from the Lighthouse Service current stock. When programmers were taken from the same recent manufacturing batch, the maximum variations were as follows:

1 Variation due to the cell	2 Variation due to orientation of the cell	3 Variation due to switching	4 Total variation	5 Total quadratic variation
-3 +2.5	-3 +3	-3 0	-9 +5.5	-5 +4

3.5 Possibility of reducing variations in switching.

1) Variations in the cells themselves.
It has been shown that for economic reasons, no reduction in variations due to the cells themselves can be expected with current manufacturing processes.

2) Variation due to orientation of the cells
Tests were carried out on two cells placed symetrically on either side of a rotating lantern.
When the lantern was rotated, it was found that the switching time varied between -15 sec and +15 sec, as against a range of -3 min and + 3 min using a single cell.

By placing the cells in parallel or in series, switching was delayed or advanced respectively within the range- 3 min and + 3 min specified above. A decision was therefore made that floating lights would have two diametrically opposite cells operating in series.

3) Variation in programmer switching

It has been shown that recently manufacured programmers provide a very low variation in switching. On the other hand, considerable variations occur with older equipment.

Figure 6 shows the basic circuit of the switching device used. Variations may be caused by the following:

- Variations in characteristics of switching transistors from different manufacturing batches.
- Variations in transistor characteristics with time, and the inadequacy of the setting resistance R in the circuit of figure 6.

The technical method used to overcome problems with component manufacturing tolerances is to let the supplier choose the value of resistance R.1 for a manufacturing batch, the tolerance of the switching cell nominal 1,500 ohms resistance being at the most 20 or 25%, which is wide.

Assuming that Rc may vary up to $\pm$ 40% with aging of components, the following reduced values in minutes will be obtained for buoys with two diametrically opposite cells:

1 Variation due to cells	2 Variation due orientation of the cells	3 Variation switching	4 Total variation	5 Quadratic variation
- 3 + 2.5	-0.25 +0.25	-4 +1	-7.25 +3.75	-5 +2.7

Under these conditions, switching of buoy lights in a particular channel will vary to a maximum of 11 minutes, the quadratic difference being less than 8 minutes.

4- CONCLUSIONS

The investigations carried out with a view to overcoming variations in the operation of automatic switching devices, showed an apparently astonishing gap in our knowledge of twilight phenomena.

It has been possible to determine the following fairly precisely:

1) The clear weather zenithal luminance corresponding to the regulation switch-on and switch-off times, i.e. 15 lux.

2) Variations for overcast weather.

3) A law of distribution

4) The rate of decrease in luminance at semi-twilight in the evening (at least 2 lux per minute in clear weather)

This basic data facilitated the establishment of specifications and admissible tolerances for fully automatic switching devices.

A technical investigation into variations occurring with existing automatic devices using photoresistant cells has led to the following:

1) The establishment of a theoretical switching luminances.

2) The technological improvement of installations and manufacturing processes.

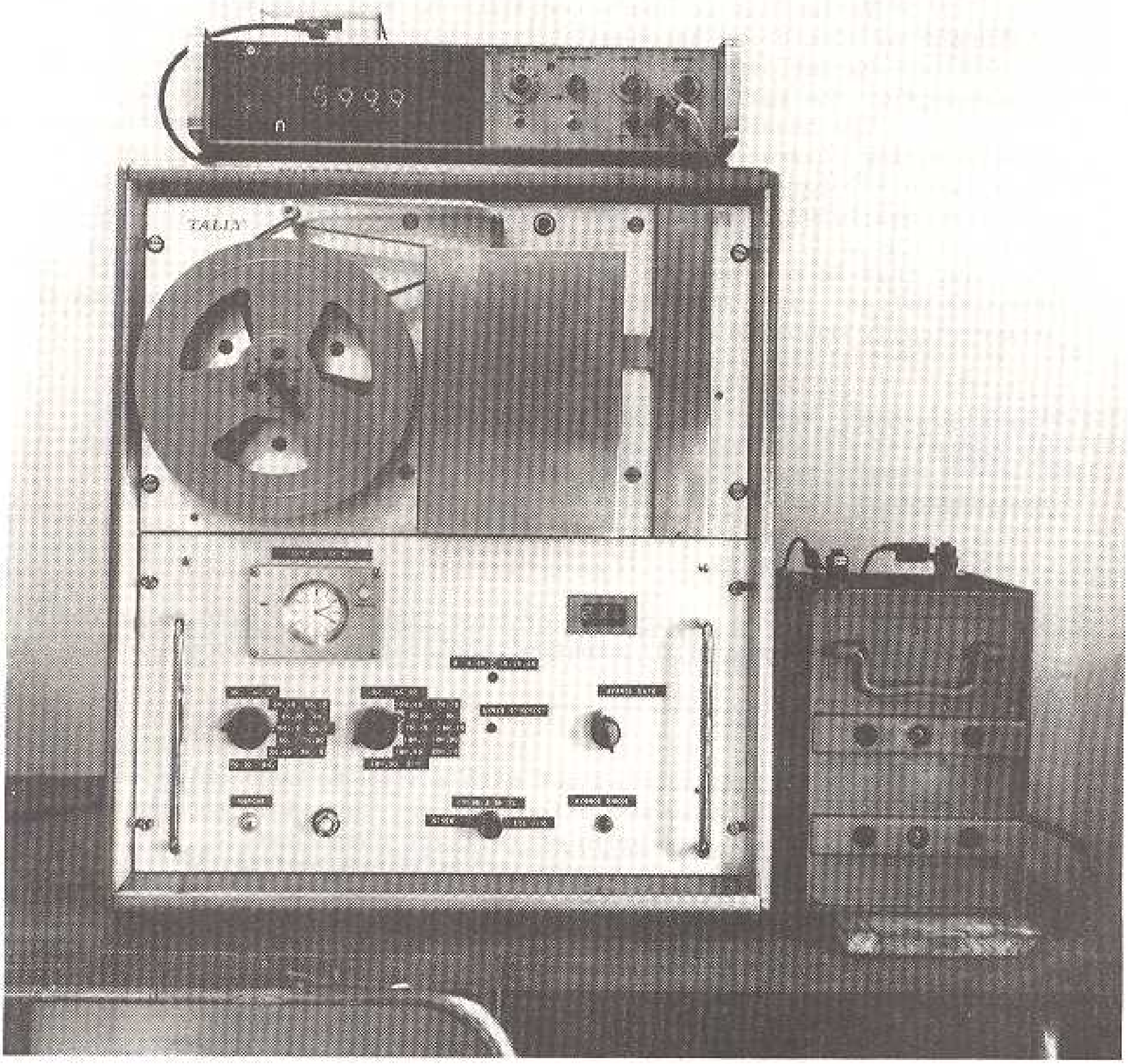
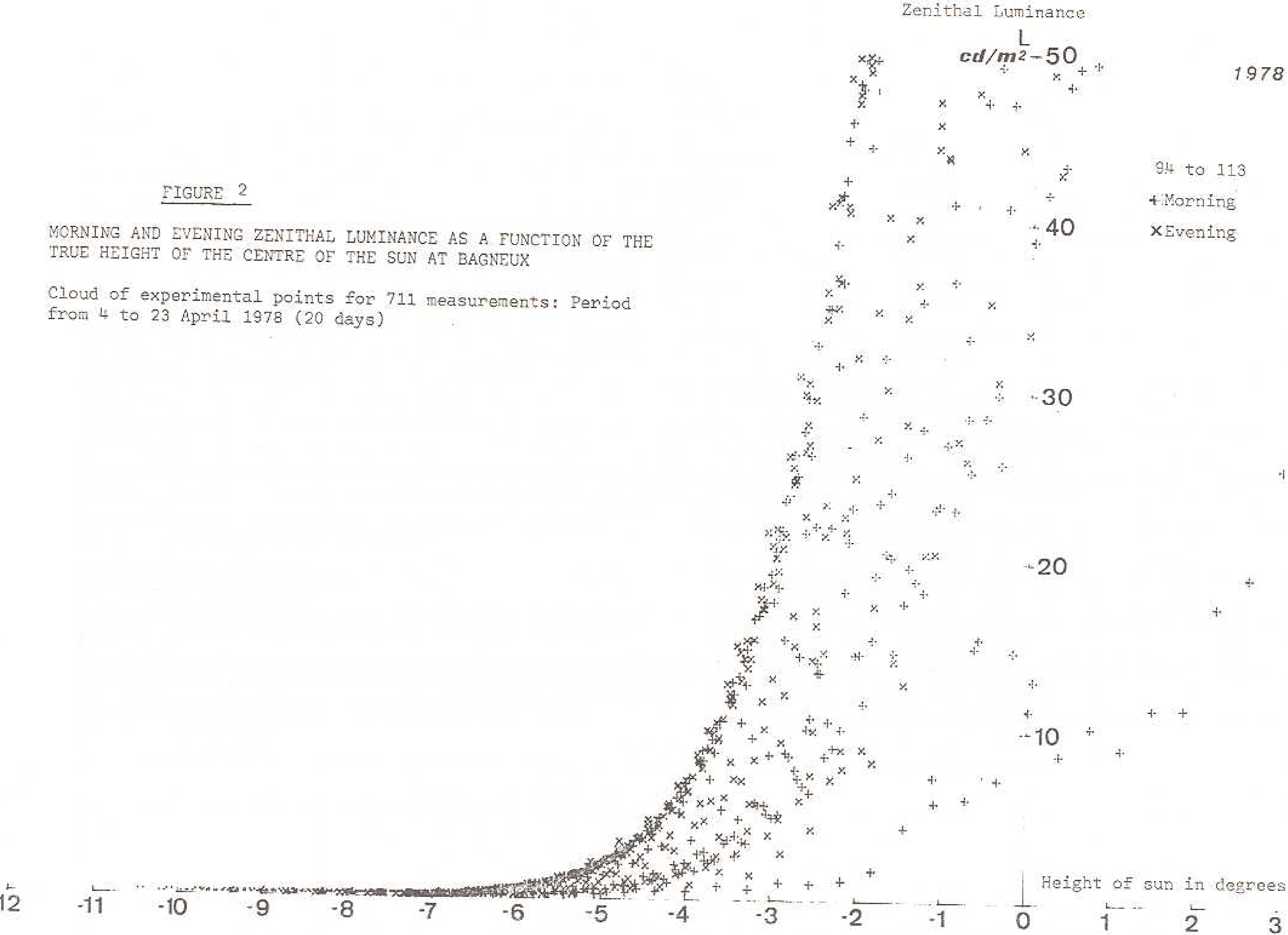


Figure 1: Automatic recorder of the zenithal luminance.

FIGURE 2

MORNING AND EVENING ZENITHAL LUMINANCE AS A FUNCTION OF THE TRUE HEIGHT OF THE CENTRE OF THE SUN AT BAGNEUX

Cloud of experimental points for 711 measurements: Period from 4 to 23 April 1978 (20 days)



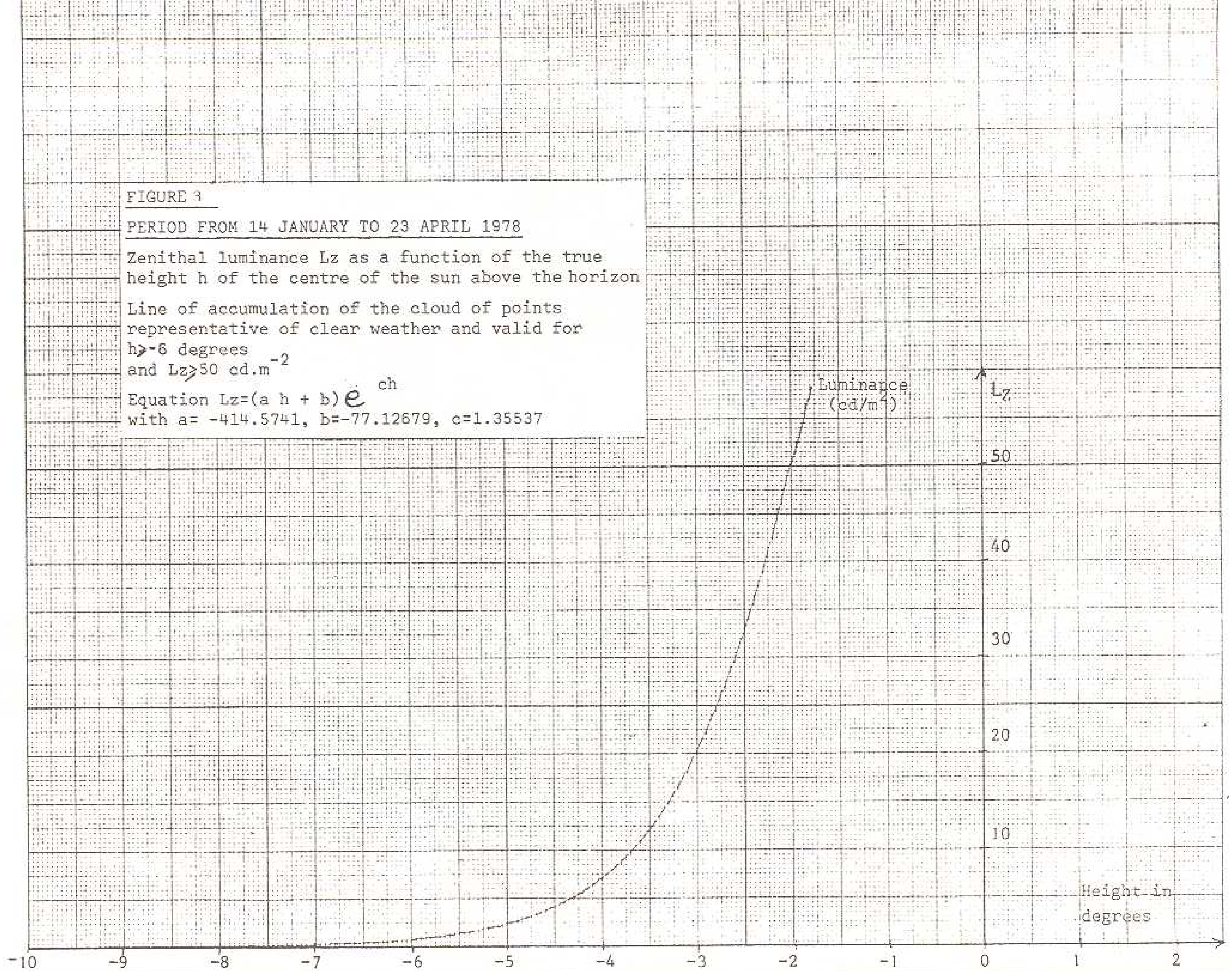


FIGURE 3

PERIOD FROM 14 JANUARY TO 23 APRIL 1978

Zenithal luminance Lz as a function of the true height h of the centre of the sun above the horizon

Line of accumulation of the cloud of points representative of clear weather and valid for
$h \geq -6$ degrees
and $Lz \geq 50$ $cd.m^{-2}$

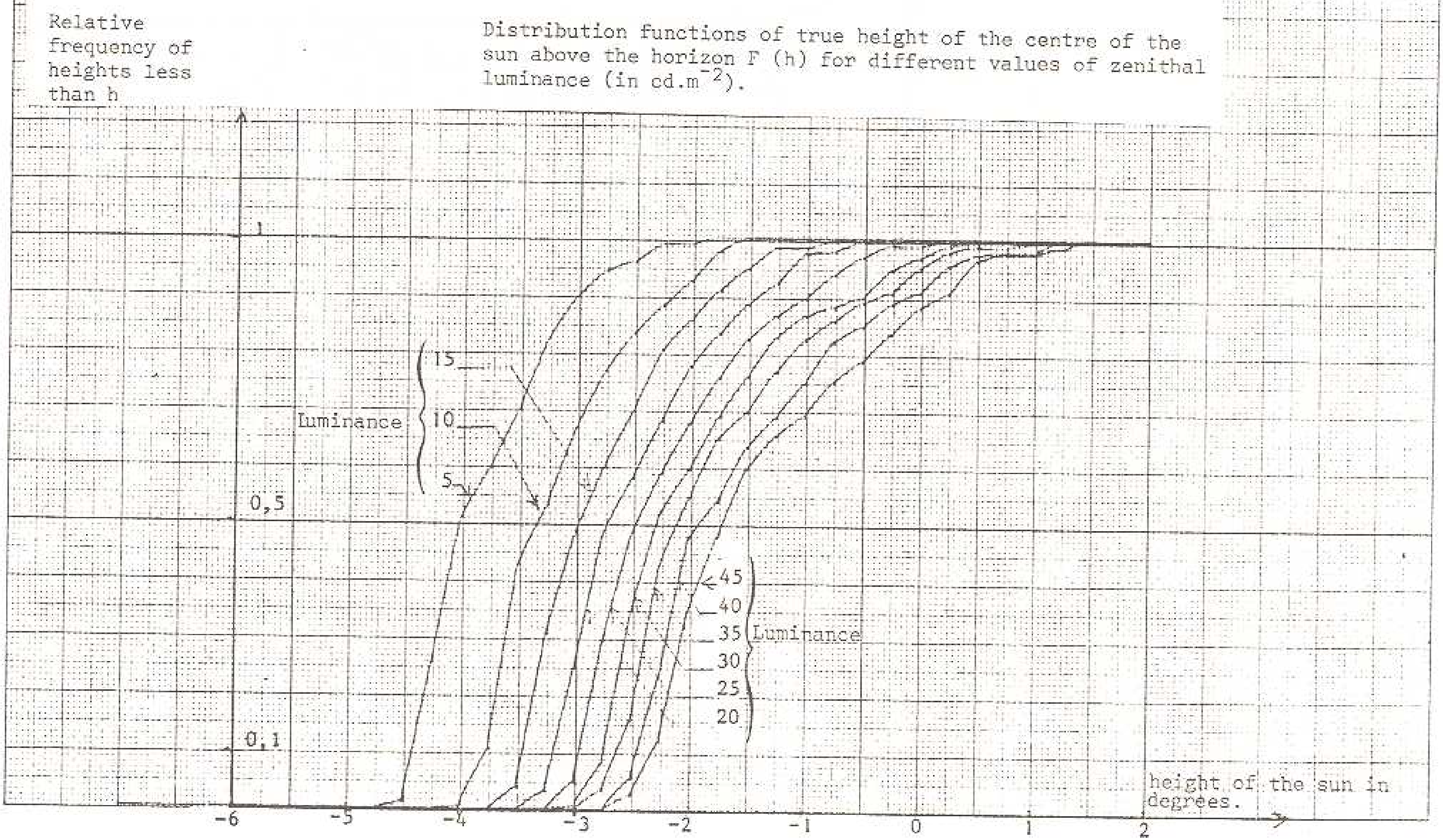
Equation $Lz=(a\,h + b)\,e^{ch}$
with a= -414.5741, b=-77.12679, c=1.35537

FIGURE N° 4

PERIOD FROM 14 JANUARY TO 23 APRIL 1978

Zenithal luminance and height of sun at Bagneux (2° 18'55"E-48° 48'25"N)
morning and evening

Distribution functions of true height of the centre of the sun above the horizon F (h) for different values of zenithal luminance (in $cd.m^{-2}$).

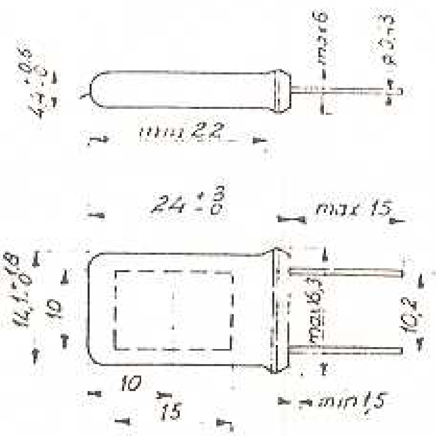


CHARACTERISTICS OF RPY 10 PHOTORESISTANT CELLS

ARRANGEMENT OF ELECTRODES

AND OVERALL SIZE

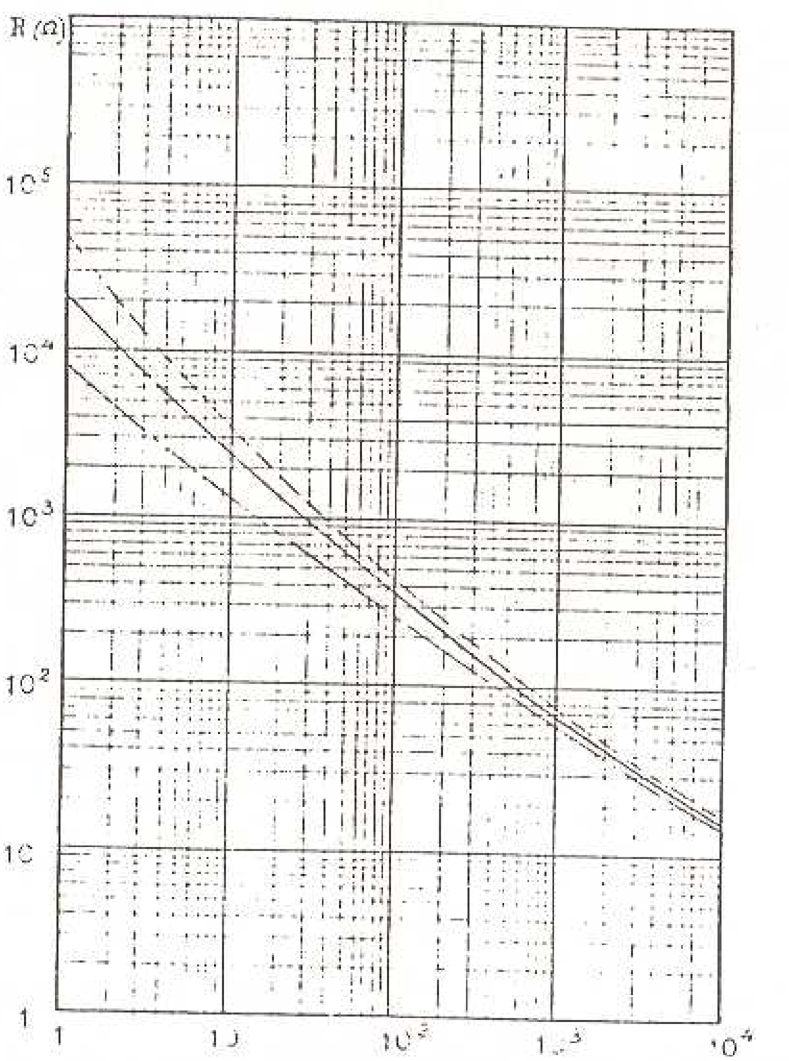
Fig. 1



VARIATIONS IN RESISTANCE OF THE CELL AS A FUNCTION

OF LUMINANCE

Fig. 2



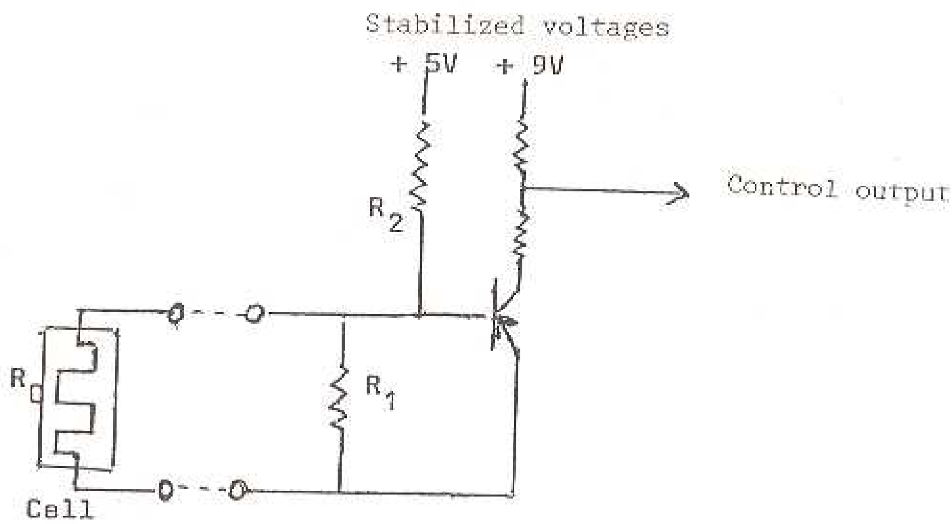
Average variation. ————

Maximum variation. — — — —

Minimum variation. —. —. —

- Figure 6 -

CIRCUIT OF PROGRAMMER SWITCHING DEVICE



Rc : 1500 Ohms approx.

R1 : 2700 Ohms

R2 : 4700 Ohms