50. IDENTIFICATION AND PROTECTION OF EXISTING AND POTENTIAL OBSERVATORY SITES (PROTECTION DES SITES D'OBSERVATOIRES EXISTANTS ET POTENTIELS)

(Committee of the Executive Committee)

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I. INTRODUCTION

Whereas the identification of existing or potential observatory sites was an important part of the report for the first three years of existence of Commission 50, during the period 1976-78 the emphasis has been mostly on establishing recommendations for the protection of observing conditions.

The report defining "acceptable levels of interference" was issued at mid-'78, with five recommendations translating the defined levels into practical terms.

At the same time a survey has been conducted to learn how directors of all observatories have dealt with public authorities in order to control the threat of increase in street lighting, industrial pollution, air traffic, and radio interferences. A second report is in preparation in order to supply IAU guidelines on how to deal with these problems.

Contacts have been made with the CIE (Commission Internationale de l'Eclairage) to obtain its advice and support on actions to control public lighting around outstanding observatory sites.

The subsequent sections deal more specifically with each of these topics.

II. NEW OBSERVATORY SITES

In the report presented at the 1976 Grenoble General Assembly a fully comprehensive review of the very best potential or already developed sites was presented. In this report we shall merely indicate new sites (not already included in the 1976 report) which are used or considered for developing an astronomical facility.

Brazil - A site for astrophysical observation is presently developed on Brazópolis peak (lat: 22° 31' 10" S, long: 45° 33' 50" W, alt. 1860 m.); this will be the main optical Brazilian observatory. The completion is expected for December 1982. The main instrument will be a 1.6 m. reflector. National site testing is still being conducted for an astrometric observatory and a radio astronomy observatory.

Canada - A new observatory has been inaugurated in Quebec at Mt. Megantique. The site is not outstanding, but has been selected to be at a manageable distance from the University of Montreal and Laval University.

Czechoslovakia - A national site survey is going on in order to secure a good site for a long term (beyond year 2000).

India - A 2.3 m. telescope is planned at Kavalur (12° 34' N, 78° 50' E, alt. 725 m), an infrared telescope at Gurusikhar (24° 36' N, 72° 43' E, alt. 1500 m.) and a solar telescope on an island in Lake Fatehsagar at Udaipur (24° 35' N, 73° 42' E. alt. 600 m.).

Japan - The construction of a new radio observatory has been started at Nobeyama in Nagano prefecture. It includes a five dish synthetic array for millimetric wave lengths.

Mexico - An interesting site has been found south of Mexico City at Teotepec (lat. 17° N, elev. 3500 m.). The site, thanks to the elevation, seems to be clear 50% of the time in summer, whereas south of 23° such conditions are usually not encountered.

USSR - Three mountains have been studied near Mt. Maidanak (elev. $\simeq$ 2700 m.) Uzbekistan, Middle Asia. The seeing has been found to be close to 0.7" and the average vapour content of the atmosphere in the range of 2 to 4.5 mm.

III. REPORT AND RECOMMENDATIONS ABOUT ACCEPTABLE LEVELS OF INTERFERENCE

The report, prepared by the Vice-President of the Commission is given in Annex 1. The choice of a 10% contribution of artificial lighting to the natural background is, of course, somewhat arbitrary and is intended to mean that the background should not be significantly increased. The recommendation refers both to white light and to spectral lines, with some relaxation for the sodium D lines. It is very difficult to recommend sacrificing some spectral band (supposedly not astronomically interesting) for public lighting, and leaving undisturbed the rest of the spectrum, now that interesting lines may be observed Doppler shifted by a factor between 0.99 up to 4.0. The less stringent statement about the D lines comes from the fact that the natural background has very large time variations which will in any case be the limiting factor in sky subtraction.

The recommendations concerning pollution and air traffic are straightforward. Mining has been identified as a particularly dangerous threat as it can very well develop in a region of very low density population where outstanding observatories already exist (Chile, for example).

A possible misinterpretation of the recommendations, which should be carefully avoided, is that observatories where conditions are worse than the defined levels of interferences cannot perform any work and have no longer to be supported. Only observations of faint sources are hampered by artificial lighting and a few types of observation, mainly astrometric, may be carried out even in the heart of large cities, like Paris, without serious trouble. Large astrophysical reflectors are those to which the recommendations apply more readily.

IV. ATTEMPTS FOR CONTROLLING INTERFERENCES NEAR OBSERVATORY SITES

A report summarizing the recommended types of action will be ready before the General Assembly in Montreal. We shall give here an account of the actions which have actually taken place during the past years.

It first should be noted that control of interference near observatories did not start with the ordinances at Flagstaff or in Tucson, but already in 1905 in the leasehold agreement between the Carnegie Institution and the Pasadena and Mt. Wilson Toll Road Company. This leasehold specifies that the lessor "shall not construct or permit the construction of any power plant, railroad or machinery by which smoke, dirt or vibrations may be carried to, or prevent the successful operation of said research upon said leasehold premises.". Also, "During the leasehold period the lessor will not permit to be used upon said section 29 any single lamp or unit of illumination which shall exceed in intensity the equivalent of 100 candle power, without the consent of the lessee.". It is frightening to see what the actual situation was fifty years later, although clearly the problem of interferences was not overlooked in the beginning.

Legislation has been successfully passed in many places now. It should be noted that even if there is no legislation, the observatories are sometimes able to obtain significant results by informal contacts with local authorities (example: Ritter Observatory and the University of Iowa). In addition to Flagstaff, Tucson, and Hawaii County, already mentioned in the preceding report, places for which legislation exist are Itapetinga in Brazil, Ondrejov in Czechoslovakia, Mizusawa in Japan (law against noise and land vibration is limited to 60 decibels in the daytime and 50 decibels at night-time), Wise Observatory in Israel, Yerkes Observatory in Williams Bay, USA, Kapteyn Observatory in Roden, and possibly other places which have not been called to the attention of the Commission.

Typical protection zones are of the order of 5 to 20 km.

It should be noted also that even if the observatories are not the primary goal for enacting anti-pollution legislation, they can benefit from such

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legislation. In Belgium Dr. J. Dommanget reports that a royal ordinance was issued on 8 January 1978, imposing annual check-ups of smoke emission from heating installations over the whole Belgian territory.

Many observatories have struggled to keep decent observing conditions in spite of adverse developments in their vicinity. In many cases observatories have been caught by surprise and have not had the opportunity of reacting before important damage had been caused to their observing conditions. Such an example is Hopkins Observatory at Williams College which while it was negotiating with one town planning commission, discovered that another commission went ahead with unshaded street lighting and could not reverse the action. Table Mountain JPL station was also unpleasantly surprised by the development of a large ski resort at only one mile from the observatory. The sky brightness increased by a factor of three at 25° above the horizon, southward. Flood lighting is used all night for "slope grooming".

Van Vleck Observatory has not been able to get control of 100,000 candle power mercury lamps installed by its own University for security reasons at less than 300 m. from the observatory and aiming towards the domes.

Radcliffe Observatory is facing several new threats including city smog, city expansion and the expansion of a nearby military airport. Mill Hill Observatory reports that the observing conditions are becoming untenable partly because of a school playing field illuminated with 72 Kw. of high pressure sodium lamps, less than half a mile from the observatory.

To end this list of mishaps let us go to the case of Brorfelde Observatory in Denmark where gravel pits near the observatory are being considered as suitable dump sites for the neighbouring cities. Commission 50 did act to try to stop this horror.

Large observatories had to be very alert in keeping pressure to turn down new threats in their vicinity.

Lick Observatory is still arguing with local authorities to prevent a large use of high pressure sodium lamps in San José area. The arguments have become very technical, and it was decided to have test sets of 1000 lamps each of low pressure and high pressure sodium in order to have a decisive evaluation of the economic advantage of one system over the other one. In Chile La Silla, Cerro Tololo and Las Campanas had to intervene in order to avoid having their site selected for microwave and radio relay stations.

At La Palma (Canary Islands) a new project of lighting for Santa Cruz is being discussed between the public authorities and the Institute of Astrophysics of the Canary Islands.

Concerning air traffic, it should be widely known that, in the past, three aircraft crashed right into three world-known observatories. On 18 December 1957 a B-47 Air Force jet crashed at Palomar Observatory barely missing the 48-inch Schmidt Telescope dome. On 21 May 1939 an Air Force A-17 aircraft crashed into the main building of Lick Observatory at Mt. Hamilton. On 19 September 1963 a small civilian aeroplane crashed at Mt. Wilson, California, within 200 feet of the 100-inch telescope. More recently, Dr. Babcock, who relayed to us the above information, had to object to military flight plans just above the Palomar site at an altitude of 500 to 1500 feet above ground.

V. RELATIONSHIP WITH THE "COMMISSION INTERNATIONALE DE L'ECLAIRAGE"

No serious action can be taken to protect observatory sites if there is no proper input in the world of lighting engineering and lighting equipment manufacturers.

It is for this reason that Commission 50 has established connection with the "Commission Internationale de l'Eclairage" (International Commission of Illumination) whose help may be a critical item in practical actions.

We have been very fortunate in finding that Dr. A.J. Fisher, who is chairman of the Road Lighting Committee at the CIE, is very interested in the problem and

had carried out himself one of the most detailed computations of sky illumination by a city near an observatory, namely the illumination of the sky at Mt. Stromlo by the various districts of Canberra (A.J. Fisher and H.J. Turner; Illuminating Engineering Society Lighting Review, February 1977). Thanks to his help a statement has been produced by the CIE concerning the protection of sites for astronomical observations (Annex 2).

This action will be continued, the objective being to make the problem widely known among those who are responsible for designing and implementing public lighting.

ANNEX 1

Report and Recommendations of Commission 50 (F.G. Smith)

I. INTRODUCTION

Modern astronomy is increasingly concerned with observations of very faint objects, which can only be achieved by the use of large telescopes on the best possible observatory sites. The 1976 Report of Commission 50 shows that the number of suitable observatory sites in use, or possibly available for use, is very limited; furthermore, the Report shows that the rapid growth of artificial light which is now experienced at many existing optical observatories already interferes very seriously with sensitive observations. Accordingly the IAU adopted the following Resolution at the 1976 General Assembly:

> The IAU notes with alarm the increasing levels of interference with astronomical observations resulting from artificial illumination of the night sky, radio emission, atmospheric pollution and the operation of aircraft above observatory sites.
> The IAU therefore urgently requests that the responsible civil authorities take action to preserve existing and planned observatories from such interference. To this end, the IAU undertakes to provide through Commission 50 information on acceptable levels of interference and possible means of control.

This report reaffirms the serious nature of the threat to modern astronomy from the various forms of interference at existing and potential observatory sites, and recommends acceptable levels of interference which should not be exceeded if the best possible sensitivity is to be achieved. The main source of interference is artificial light, but serious interference may also be experienced from aircraft, from radio transmitters and from atmospheric pollution. This report therefore also states the conditions under which these two other sources of interference are known to be harmful, and recommends that observatory sites should be protected accordingly.

The report then considers the way in which the recommendations may be put into practice, and gives examples of the restrictions that may be required on artificial lighting. Recommendations for sites already experiencing interference will be discussed in a separate report.

The protection of radio observatories from radio frequency interference is a separate problem, which is the concern of IUCAF (Inter-Union Commission on the Allocation of Frequencies for Radio Astronomy and Space Research).

II. THE ACCEPTABLE LEVELS OF ARTIFICIAL LIGHTING

2.1 Artificial lighting illuminates the sky both in continuum (white) light and in spectral lines, which are generated in various types of metal vapour lamps. This light is scattered back from the sky, forming a background against which an astronomical source must be detected. A natural background already exists, both in continuum light from starlight, zodiacal light and atmospheric "airglow", and in spectral lines from the airglow.

2.2 Continuum (white) light. The limit to sensitivity due to the white light background deteriorates in proportion to the total of the natural and artificial contributions. A contribution of 10 per cent of the natural level, which therefore worsens the basic sensitivity of a telescope by the same proportion, is generally agreed to be the maximum tolerable limit under ideal circumstances, except for the study of the airglow itself, which may require more stringent conditions. This level of sky brightness due to artificial light is specified for 45° elevation above the horizon, and for wavelengths throughout the optical spectrum from 300 to 1000 nanometers (nm). These considerations lead to Recommendation 1.

2.3 Spectral line radiation. Similar considerations to those applying to white light apply also to artificial light concentrated in spectral lines, as occurs in sodium, mercury vapour, or metal halide lamps. Some of the spectral lines in radiation from certain types of these lamps occur naturally in the airglow, and the criteria for harmful interference must then be related to the strength of the airglow. Other spectral lines will generally be more harmful.

In the optical region, light from low-pressure sodium lamps is mainly confined to a close pair of spectral lines, the sodium D-lines, which coincide with strong airglow lines. Since the airglow lines are both strong and variable, it is unlikely that the sensitivity of astronomical observations will be seriously affected if the total skylight from the sodium D-lines of artificial light does not exceed the minimum natural airglow. This criterion is taken to apply in a band-width of 1 nanometer containing the two D-lines. These considerations lead to Recommendation 2.

III. THE ACCEPTABLE LEVELS OF RADIO FREQUENCY INTERFERENCE

Experience in existing optical observatories shows that radio signals from nearby transmitters, and electrical discharges from overhead power lines, can cause serious interference to modern electronic apparatus, such as photo-electronic detectors and on-line computers. It is important to keep the level of radiated power from these sources below a level known from experience to be harmful; furthermore, some allowance must be made for future increases in sensitivity of electronic apparatus, which may make it more vulnerable to the effects of interference. The level should be assessed without taking account of the screening characteristics of the observatory buildings. These considerations lead to Recommendation 3.

IV. ABSORPTION DUE TO ATMOSPHERIC POLLUTION

Smoke and dust from industrial processes may absorb starlight and disturb photometric measurements. For observatories at high altitudes such pollution may be usually confined below an inversion layer, but the possibility must be considered that a large production of heat in an industrial process may disrupt the inversion layer locally. The most damaging aspect of absorption is its variability on a time scale of about 1 hour, during which time comparative observations are commonly made between a series of stars. These considerations lead to Recommendation 4.

V. INTERFERENCE FROM AIRCRAFT

Condensation trails from aircraft and the cloud build-up which often results from them, have very serious effects on atmospheric transparency. Aircraft lights may interfere directly with astronomical observations. It is essential that regular air routes, and where possible individual aircraft, should avoid the sky visible from observatory sites, except at elevation close to the horizon. Even at low elevations aircraft should avoid the immediate vicinity of observatory sites, since exhaust products and heat may affect conditions for astronomical observations. These considerations lead to Recommendation 5.

VI. RECOMMENDATIONS

6.1 Recommendation 1. The increase in sky brightness at 45° elevation due to artificial light scattered from clear sky should not exceed 10 per cent of the lowest natural level in any part of the spectrum between wavelengths 300 and 1000 nm except for the spectral line emission from low pressure sodium lamps as set out in Recommendation 2. (Near wavelength 550 nm the natural level of continuum radiation of the dark sky at the zenith, as observed at a good observatory site, is approximately 10 Rayleigh per nm, equal to 2.0×10^{-11} stilb or 2.0×10^{-7} Nit. This level corresponds to one 21.6 mag. star per square arc second. These figures may be derived from the mean sky brightness quoted by C.W. Allen, Astrophysical Quantities, 3rd ed., p. 134, Athlone Press 1973. The brightness at 45° elevation is approximately 5% greater than at the zenith.) The application of this recommendation is discussed in section 7.1.

6.2 Recommendation 2. The increase in sky brightness at 45° elevation due to artificial light from low pressure sodium lamps, taken as the total intensity within the wavelength band 588.8 to 589.8 nm, should not exceed the total minimum level of natural radiation over the same band. (The minimum level at a good observatory site may be taken for the purpose of this recommendation as 30 Rayleigh; Allen, op.cit. p.135.) The application of this recommendation is discussed in section 7.2.

6.3 Recommendation 3. The flux of radio frequency power from transmitters located close to an optical observatory should be restricted so that the free space flux, calculated from the radiated power of the transmitter and the directional characteristics of its antenna, but not including the local effects of terrain or buildings, will be less than 2×10^{-6} w m^{-2} at any part of the observatory, its buildings and other apparatus. The application of this recommendation is discussed in section 7.5.

6.4 Recommendation 4. Atmospheric absorption of starlight due to industrial or other forms of pollution should not exceed 1 per cent of light at any wavelength in the range 350 to 1000 nanometers, as measured at elevation angles greater than 30° above the horizon. In addition, this absorption should not vary by more than 0.1% during any period of one hour.

6.5 Recommendation 5. Aircraft should not be allowed in the sky more than 10° above the horizon, as viewed from the observatory site, nor within 5 km horizontal distance from the site.

VII. PRACTICAL APPLICATION OF THE RECOMMENDATIONS

7.1 Continuum lighting. The brightness of scattered artificial light in the visible part of the spectrum (approximately 450 to 650 nm) has been related to the light output of large cities in practical studies, notably by Walker (Lick Observatory, Bulletin No. 760). Walker's studies included a range of distances and a range of sizes of city in California. As an example, the city of Salinas has the following characteristics:

Population	68,000
Light output of street lighting system	4.2×10^{7} lumens

The effect of this city on the night sky brightness, which also includes an unknown extra contribution from other sources of outdoor illumination, was found to be an increase of 0.8 times the dark sky at an elevation of 45° and at a distance of 16 km. This measurement referred to the integrated brightness over visible wavelengths. Further, the brightness at other distances, and the brightness due to towns with different populations, was found to follow the law:

$$\text{Sky brightness proportional to (Population)} \times (\text{distance})^{-2.5}$$

From this example, and bearing in mind the extra unknown contribution from other sources of outdoor illumination, the following guideline may be deduced:

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A town 16 km (10 miles) from an observatory will not cause interference from white light in the visible range if the street lighting is restricted to below 5×10^6 lumens.

It must be emphasised that further measurements may lead to revision of this guideline.

7.2 Acceptable forms of street lamps. Apart from incandescent lamps, the only form of street lighting which can, under properly controlled conditions, provide both useful illumination in streets and no serious effects on observing conditions is the low-pressure sodium lamp. (The use of other types of lamp may be considered in circumstances which depart somewhat from the ideal as in section 7.3 below.) The effect of the sodium D-lines must, according to Recommendation 2, be compared with the lowest brightness of the natural airglow in the band 588.8 to 589.8 nm.

The sky brightness due to the sodium D-lines, as quoted by Allen (see section 6.2) was measured at Kitt Peak Observatory by Broadfoot and Kendal (J. of Geophysics Research, 73, 426, 1968). The combined effect of the sodium D-lines was found to be equivalent to $30\,\mathrm{R\,nm^{-1}}$ averaged over the bandwidth of 1 nm. (Higher values may be found for observatories at higher latitudes, and at different times of year.) This is approximately three times the brightness of the dark sky, averaged over the same bandwidth of 1 nm.

Since the effective visible bandwidth of white light is approximately 100 nm, and since Recommendation 2 allows the brightness of the sky to be doubled in the 1 nm band, the allowable light output (in lumens) from low pressure sodium lamps is approximately one-third that of incandescent lamps.

7.3 The use of other types of metal vapour lamps. Mercury vapour lamps, high pressure sodium lamps, and metal halide lamps are in use in many communities. Such lamps may already be seriously affecting the sky brightness at existing observatories. Where the present levels of sky brightness due to these types of lamp do not already exceed the level recommended for white light, as in Recommendation 1, every effort should be made to restrict their further use. This question will be the subject of further discussion by Commission 50, along the following lines. It is often found in existing observatories that mercury spectral lines from artificial lighting are already so strong that they preclude any possibility of sensitive observations at the wavelengths of those lines. It may then be expedient to allow further sky illumination in the mercury spectral lines, provided that the light is confined to narrow lines, as in clear mercury vapour lamps. The few narrow lines of clear mercury vapour lamps are in these circumstances less harmful than the broad bands emitted by colour corrected mercury vapour and high pressure sodium lamps and the much larger number of emission lines and bands emitted by metal halide lamps (see, for example, Osterbrock, Walker and Koski, Publ. Astron. Soc. Pacific, 88, 349, 1976).

In all situations the use of colour corrected mercury, high pressure sodium and metal halide lamps should be avoided, on account of the very complex and confusing spectrum of light which they produce.

7.4 Filtering and Shielding of Lights. Most light sources have emissions both inside and outside the visual range. The emissions outside the visual range are of no value for street lighting and are harmful to the work of the astronomer, who works in all regions of the spectrum. Light at shorter wavelengths is scattered more strongly by the atmosphere, and therefore affects observations more severely. Filters are available which will filter out the emissions at wavelengths shorter than 440 nm, all of which are out of the visual range, with little effect on the visual range itself. This filtering is needed with mercury vapour, metal halide and fluorescent light sources, but is not required for incandescent, low pressure sodium lamps, or high pressure sodium lamps.

The efficiency of all types of lamp used in street lighting is improved by the use of shields and reflectors which direct the light downward, where it is needed,

and not upward, where it can only illuminate the sky. Street lighting in the cities referred to by Walker (see section 7.1) uses a variety of lamp types and housings, including both shielded and unshielded types. Where the total light output of a community is approaching the interfering limit set out in the Recommendations, further installations might be allowable, provided that they were shielded and gave no direct upward light. The sky brightness would then be due to scattered and reflected light from the ground, which is unavoidable, and the allowable increase in lighting would depend on the proportion of light which ultimately reached the sky.

7.5 Radiofrequency interference. The quoted level of 2×10^{-6} w m^{-2} corresponds to the maximum radiated power from a transmitter power of 1 Kw using a dipole antenna at a distance of 8 km. At other distances a simple inverse square law applies, e.g. at 20 km the transmitter power, using a dipole antenna, should be restricted to 6 Kw. (In practical cases the actual radiation characteristics of the antenna and the propagation characteristics of the local terrain must be taken into account.)

ANNEX 2

Statement of the C.I.E. concerning protection of sites for astronomical observations

At its June 1978 meeting it was brought to the attention of the Action Committee that the International Astronomical Union is very concerned about the interference of outdoor lighting upon astronomical observations. Accordingly, the following statement was prepared by the Action Committee and approved by the Board of Administration for publication in the CIE Bulletin. It also is suggested that National Committees may wish to publish it in appropriate journals in their countries.

1. Modern astronomy is increasingly concerned with observations of very faint objects, which can only be achieved by the use of large telescopes on the best possible observatory sites. A report of the International Astronomical Union (IAU) shows that the number of suitable observatory sites in use, or possibly available for use, is very limited; furthermore, the Report shows that the rapid growth of artificial light which is now experienced at many existing optical observatories already interferes very seriously with sensitive observations. Accordingly, the IAU adopted the following Resolution at its 1976 General Assembly (quoted in part):

> "The IAU notes with alarm the increasing levels of interference with astronomical observations resulting from artificial illumination of the night sky, radio emission, atmospheric pollution and the operation of aircraft above observatory sites.
> The IAU therefore urgently requests that the responsible civil authorities take action to preserve existing and planned observatories from such interference. ..."

2. Because a major source of interference is artificial light and because much astronomy is on an international basis a liaison has been established between the IAU and the CIE. Direct contacts have been made between representatives of IAU and Committee TC-4.6 (Road Lighting) of the CIE.

3. As a result of these contacts the CIE acknowledges that only a limited number of sites exist which meet all the conditions necessary for modern astronomy including the absence of disturbing radiation of the sky by artificial light.

Therefore, the CIE agrees that all possible action be taken to preserve these sites from such interference. This Statement refers only to the protection of existing and potential astronomical observatories at these special sites. It does not refer to observatories where observational conditions have significantly deteriorated through the growth of adjacent urban areas.

4. The CIE draws the attention of lighting technologists in general and of CIE National Committees in particular to this problem. Lighting technologists responsible for or engaged in designing public lighting in the vicinity of astronomical observatories should make themselves familiar with the details of this special problem and with measures to alleviate it. It should be noted that lighting at considerable distance from an observatory can cause interference.

National Committees should make themselves available to give specialist advice since observatories are often run on a national or even on an international basis.

5. The general recommendation of IAU is that the increase in sky brightness at 45° elevation due to artificial light scattered from clear sky should not exceed 10 per cent of the lowest natural level in any part of the spectrum between 300 and 1000 nm.

The special techniques for public lighting in the vicinity of observatories may include the shielding and filtering of the light emitted and the careful choice of light sources with respect to their spectral energy distribution. Further information is given in a Report of IAU and in: A.J. Fisher and H.J. Turner, Outdoor Lighting and Observatories, IES Lighting Review, Feb. 1977[1]

6. The CIE has undertaken to give urgent consideration to this problem and to give detailed guidance on how the IAU recommendation can be realized.

Reference

[1] Illuminating Engineering Society. Lighting Review - GPO Box 4628 Sydney 2001 Australia.

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