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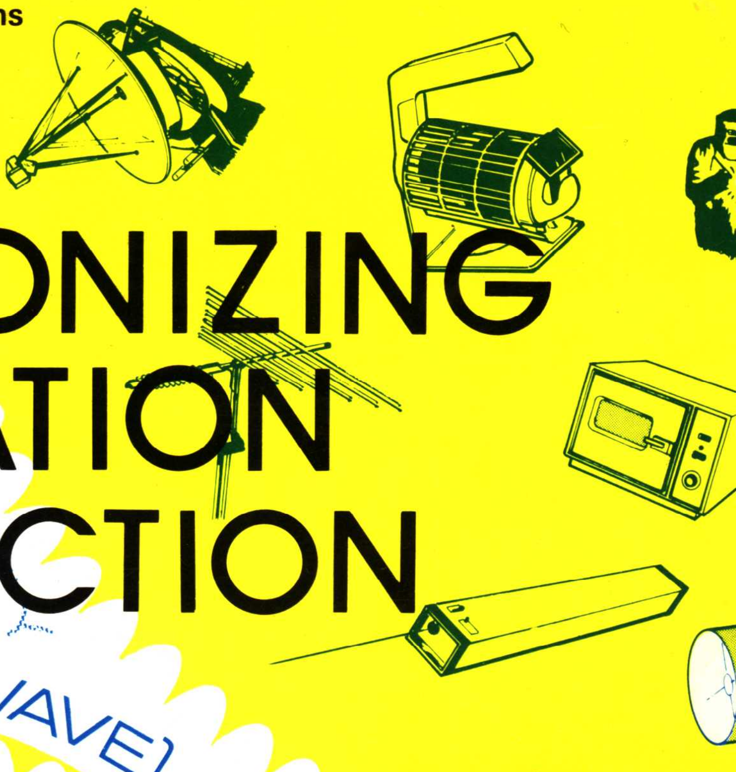

NONIONIZING RADIATION PROTECTION

RADIO (WAVE) FREQUENCY
MICROWAVE
INFRARED
VISIBLE LIGHT
ULTRAVIOLET

WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR EUROPE
COPENHAGEN

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NONIONIZING RADIATION PROTECTION

Edited by

Michael J. Suess

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PREFACE

As human populations multiply and industrialization increases and diversifies new hazards arise, some of which have become more and more critical. To limit and, as far as possible, reverse this trend, the WHO Regional Office for Europe mounted an intensive intercountry programme during the period 1969–1979, which has culminated in the successful completion of many projects in different sectors.

One of the newer environmental hazards is nonionizing radiation (NIR), which may lead to adverse effects on human health. Exposure to NIR extends from occupational health right into the field of public health. When considering exposure limits and setting up control programmes, the heterogeneity of the population to be protected has to be kept in mind. Possible genetic and carcinogenic effects, as well as effects on development, have all to be carefully considered and are of prime importance in protecting the public. Therefore, one of the major efforts within the radiation sector of the programme during these years was directed towards the development of this book, which I now introduce with pleasure to a broad professional audience. This publication represents the results of the collaborative effort of over 200 experts from 20 countries, to whom we are indebted not only for their professional competence but for their deep dedication. With equal satisfaction, I wish to commend the work of the WHO staff directly responsible for this activity. The financial assistance of the United Nations Environment Programme in the project on NIR protection, and in the publication of this book, is greatly appreciated.

Protection against exposure to NIR is a subject of increasing concern to European countries, but is also of growing importance to those in other parts of the world. I hope that this work will be of practical value to the many scientists, engineers, physicians and community leaders concerned with and responsible for protection against NIR and human health.

Leo A. Kaprio
WHO Regional Director for Europe

NOTE ON TERMINOLOGY

The policy of the World Health Organization in respect of terminology is to follow the official recommendations of authoritative international bodies such as the International Union of Pure and Applied Physics (IUPAP), the International Commission on Illumination (CIE) and the International Organization for Standardization (ISO). Every effort has been made in this publication to comply with such recommendations.

Nearly all international scientific bodies have now recommended the use of the SI units (*Système international d'Unités*) developed by the Conférence générale des Poids et Mesures (CGPM)[a] and the use of these units was endorsed by the Thirtieth World Health Assembly in May 1977. Only SI units are used in this publication.

In the establishment of scientifically acceptable protection standards, both for workers and for the public, the first requirement is that internationally acceptable units for use in measurements must be available. The introduction of SI units means that this requirement has now largely been satisfied.

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[a] An authoritative account of the SI system entitled *The SI for the health professions* has been prepared by the World Health Organization. Copies may be obtained through the sales agents listed on the back cover of this book, or direct from the Distribution and Sales Service, World Health Organization, 1211 Geneva 27, Switzerland.

Contents

Introduction

M.J. Suess[a]

In recent years there has been an increase in the development and use of equipment that produces nonionizing radiant energy, and the question has been raised as to whether adequate measures are being taken to guard the user and the general public from its possible adverse effects. In contrast to ionizing radiation, radiation of longer wavelengths is intrinsically less energetic and usually interacts with human tissue primarily by generating heat. For want of a better collective term, "nonionizing radiation" (NIR) is used to encompass this group of electromagnetic radiations and also ultrasound. Nonionizing radiation pervades the entire environment but, except for the narrow spectrum of visible radiation, it is unperceived by any of the human senses unless its intensity becomes so great that it is felt as heat. Differences in wavelength, even within a single type of radiation, are particularly important when evaluating hazards from exposure to NIR. The ability of the radiation to penetrate into the human body and the sites of absorption will depend on this characteristic and will differ from one type of radiation to another.

In developed countries there has been a remarkable growth in the number of processes and devices that utilize or emit NIR. They find an ever increasing use in industry, engineering, telecommunications, medicine, research, education and the home. This gives rise to a number of questions. How serious are the problems linked with NIR, what are their dimensions, and what acute and chronic effects on the human body are involved? Is there sufficient knowledge of occupational risks and public health hazards? How can exposure be reduced? Are national protection standards adequate and, if not, how can better regulations be drafted and enforced to reduce exposure? Because of the rapidly developing technology and the associated health implications, there is a need to develop international cooperation in the use of NIR and measures to prevent overexposure. Moreover, governments will be expected to intensify the establishment of rules and regulations and means of enforcing them.

The NIR part of the electromagnetic spectrum is divided into five regions (Table 1). No exact ranges for these regions can be defined, and those given in Table 1 are only approximations. In some cases, and for various reasons, different international bodies have developed and agreed on slightly different ranges, depending on the purpose of the definition. This is similarly true for some of the working

[a] Regional Officer for Recognition and Control of Environmental Hazards, WHO Regional Office for Europe, Copenhagen, Denmark.

Table 1. Ranges of frequency, wavelength and energy for some types of electromagnetic radiation

Type of radiation	Frequency range[a, b]	Wavelength range[a]	Energy range per photon[a, b]
Ionizing	> 3000 THz	< 100 nm	> 12.40 eV
Ultraviolet (UV) (nonionizing part)	3000 – 750 THz	100 – 400 nm	12.40 – 3.10 eV
extreme (vacuum)	3×10^5 to 30 000 – 1580	1 to 10 – 190	1240 to 124 – 6.53
far	1580 – 1000	190 – 300	6.53 – 4.13
near	1000 – 750	300 – 400	4.13 – 3.10
UV-C[c]	3000 – 1070	100 – 280	12.40 – 4.43
UV-B[c]	1070 – 952	280 – 315	4.43 – 3.94
UV-A[c] ("black light")	952 – 750	315 – 400	3.94 – 3.10
Visible light[d]	750 – 385 THz	400 – 780 nm	3.10 – 1.59 eV
Infrared (IR)	385 – 0.3 THz	0.78 – 1000 μm	1590 – 1.24 meV
IR-A[c]	385 – 214	0.78 – 1.4	1590 – 886
IR-B[c]	214 – 100	1.4 – 3	886 – 413
IR-C[c]	100 – 0.3	3 – 1000	413 – 1.24
near	385 – 100	0.78 – 3	1590 – 413
middle	100 – 10	3 – 30	413 – 41.33
far	10 – 0.3	30 – 1000	41 – 1.24
Lasers	1500 – 15	0.2 – 20	6200 – 62
Class 1 — non-risk laser devices			
Class 2 — low-risk, low-power laser devices			
Class 3a — low-risk, medium-power laser devices			
Class 3b — moderate-risk, medium-power laser devices			
Class 4 — high-risk, high-power laser devices			
Microwave (MW)	300 – 0.3 GHz	1 – 1000 mm	1240 – 1.24 μeV
EHF (extremely high frequencies)	300 – 30	1 – 10	1240 – 124
SHF (super-high frequencies)	30 – 3	10 – 100	124 – 12.40
UHF (ultra-high frequencies)	3 – 0.3	100 – 1000	12 – 1.24
Radar	56 – 0.23	5.4 – 1300	230 – 0.95
Radiofrequency (RF)	300 – 0.1 MHz	1 – 3000 m	1240 – 0.41 neV
VHF (very high frequencies)	300 – 30	1 – 10	1240 – 124
HF (high frequencies)	30 – 3	10 – 100	124 – 12.4
MF (medium frequencies)	3 – 0.3	100 – 1000	12 – 1.24

[a] The ranges given are only approximations, since no precise limits can be defined.
[b] The figures given here have generally been rounded up or down to the third significant digit.
[c] Radiation bands of biological significance designated by the International Commission on Illumination (CIE) (Chapter 3, Ref. *11*).
[d] The visibility limits of the human eye vary among individuals between about 380–400 nm and 750–780 nm.

groups involved in the preparation of this book.

Ultraviolet (UV) radiation has been used extensively for sterilizing equipment and air, and in different types of medical apparatus. In recent years industrial uses of UV sources has greatly increased, and a certain risk still exists for workers from open UV sources. Damage is confined to the eye and the skin, but there is a certain long-term risk of skin cancer. The largest exposed group comprises those who spend a great deal of time in the sun, and attention should be drawn to protective measures. As far as human cancer is concerned, little quantitative knowledge of dose-effect relationships and latency periods is available. Ultraviolet lamps for private use are widely distributed among the public and should be supplied with appropriate warnings.

Exposure to infrared (IR) radiation can occur in almost any industry from direct IR sources as well as from other heat sources, and the risks under certain working conditions are well known. Still unanswered is the question of whether IR radiation has produced lenticular cataract. In any case, the presence of well developed temperature sensors in the skin around the eye provides a good biological warning system.

Risks from the use of lasers should receive more attention because of the rapid development of these instruments and their increased use for both military and non-military applications. The emitted light can damage the eye and the skin, and under certain conditions perhaps also internal tissues. The difficulty in evaluating the risks from lasers is due partly to the difficulty of extrapolating the results of animal experiments to man.

Microwave (MW) and radiofrequency (RF) radiation are recognized as the types of NIR that present the greatest perceived risk. The expansion in the use of MW in the communications field and of MW ovens, if appropriate safety devices are not present in such ovens, presents a possible public health hazard.

Some questions have been raised with respect to possible adverse effects of electric and magnetic fields, particularly those at low frequencies, in connexion with high-voltage lines. However, no effects due to occupational exposure have been reported, nor are there any indications of injuries to human organs. At present, there is still a dearth of information, and there is a need for better experimentation and more objective and relevant observations.

The versatility of ultrasound has led to its widespread employment in industry, medicine and science for measurement, scanning and control applications, and for thermally modifying material. Ultrasound is relatively safe because of its inability to pass an air-water interface. Whether potential adverse effects exist from immersion of hands in ultrasonic cleaning baths is not known. It has been claimed that chromosome aberrations can be produced by ultrasound radiation, but the evidence tends to be negative. So far, no major adverse effects have been recognized following diagnostic exposure of children *in utero*, and there is general agreement that the risk is much less than from X-ray examinations.

The World Health Organization has always recognized that the protection of the environment is an integral part of protecting the health of the people who live in it. Conscious of the seriousness of the issue, the WHO Regional Committee for Europe decided in 1969 to adopt a comprehensive long-term programme on environmental health and pollution control, including NIR protection. The main aim of the programme was to develop management guides and decision aids for use by government administrations, executive agencies, scientific institutions and individual specialists concerned with the quality of the environment and the protection of public health.

Development of the NIR protection sector of the programme began with a working group which was held in The Hague in November 1971 to consider the health effects of ionizing and nonionizing radiation. This meeting could perhaps be considered the beginning of international activities on NIR protection. The working group reviewed the existing situation with regard to the use of NIR and concluded that although the existing codes and guidelines were sufficient to prevent injury, it was doubtful whether they would be adequate in the future in view of the expected growth in the use of all types of NIR. The group went on to make a number of specific recommendations with respect to surveys in the field of health protection, dissemination of information, and the preparation of codes of practice. The major project that followed this meeting consisted of a series of activities which have led to the publication of this book.

This book is the culmination of a decade of concerted effort by over 200 scientists from 20 countries in Europe, North America and Asia (Annex 1). Five scientific groups (Annex 2), each addressing the subject matter of one or two chapters, met at various times to review draft chapters and to recommend ways and means of finalizing them. Drafts went through several reviews before and after the group meetings, followed by revisions and final editing. The purpose of this book is to provide practical information on health aspects of exposure to NIR energies. Descriptions are given of the physical characteristics, biophysical principles and biological effects of exposure to these energies. Public and occupational health implications and protective measures against the hazards of exposure are also described. Existing standards for general public and occupational exposures are described to inform the reader about the maximum permissible exposure levels, or threshold limit values, at present accepted in various countries. The book is intended to provide information and recommendations that will assist in setting up NIR control programmes and establishing a unified system for the recording and evaluation of results. It is also designed to serve as a technical guide for scientists, engineers and medical personnel active in the field of NIR protection and control. Evidence is presented on possible adverse health effects of NIR, so that where appropriate standards and legislation may be enacted to protect health. Although the book was originally planned by the Regional Office for use in European countries, it should be of value to countries in other parts of the world and to the other international organizations concerned. Moreover, it should provide NIR specialists everywhere with helpful information based on up-to-date international practice.

Work began in 1973, when Professor Michaelson was invited to prepare a document on the potential hazards and safety considerations of human exposure to NIR energies. The first draft was ready in May 1973 and was sent to specialists for review. Moreover, advantage was taken of the International Symposium on Biologic Effects and Health Hazards of Microwave Radiation, held in Warsaw in 1973, to convene a small *ad hoc* group with the participation of Professors Czerski, Faber, Gordon, Michaelson and Schwan. It was decided to divide the document into two parts: that on MW and RF would be subjected to further revision and review, and a second on lasers would eventually be submitted to a working group on that subject. The final manuscript on MW and RF, following significant and elaborate changes, was ready for final editing in February 1976 and was issued by this Office in 1977. Some of the major contributions to the completeness and accuracy of this version were made by Professors Gordon and Schwan, and Dr Silverman.

However, this document had neither the advantage of being discussed by a working group, nor was it up to date by the time other chapters were completed. An *ad hoc* meeting in Freiburg in May 1978, attended by Czerski, Harlen, Kossel, Michaelson, Repacholi, Shore and Suess, decided to submit the MW/RF document for further review and revision. Consequently, Professor Michaelson convened a group of experts from Europe and North America for a review meeting, which was held in 1978 at the Bureau of Radiological Health in Washington, DC. This meeting led to a new, rather lengthy and detailed text, but one that was very comprehensive and acceptable to all the points of view represented. The new chapter was revised and corrected, and submitted for final editing in December 1979. Mr Harlen in particular was very helpful in checking the nonbiological sections of the manuscript for adequacy and accuracy.

The Working Group on Health Effects from Lasers, held in Dublin in October 1974, considered the revised working document provided by Professor Michaelson, and the authorship was then enlarged and the material redrafted. After further review and revision, the chapter was submitted for final editing in February 1976 and was issued by this Office in a provisional form in 1977. Mr Sliney and Dr Wolbarsht were particularly instrumental in giving this chapter its present form, while Professor Michaelson was the coordinator of the team and technical editor of the material.

The chapters on UV and IR radiation were both commissioned in 1976. The former was reviewed by correspondence and examined thereafter by a working group in Sofia, in February 1978. After further revision, the chapter was submitted for final editing in January 1979. The draft chapter on IR radiation went through a number of reviews and revisions before submission to the same working group. It was revised, reviewed and corrected thereafter, and submitted for final editing in October 1978.

The chapter on ultrasound was commissioned in 1975 and was passed through a similar process. It was discussed by a working group in London in October 1976, and after further review and corrections, was submitted for final editing in May 1977. A provisional edition of this chapter was issued by this Office that same year.

The two last chapters to be mentioned, which were discussed by the working group in Freiburg in May 1978, are concerned with electric and magnetic fields at low frequencies, and with regulations and enforcement procedures. They were commissioned in 1976, went through a similar review, revision, and correction process, and were submitted for final editing in December and October 1978, respectively.

Some chapters contain conclusions and/or recommendations of various types and purpose. These were agreed on, as were the contents of the chapters themselves, by the participants in the various working groups, and presented by the respective authors in their chapters. It will be obvious, considering the time spent in compiling this work, that some literature references are not as recent as one would wish. However, the reader will appreciate that the objective of this book is not to provide (even if it were possible) an up to date literature review. What is important is that the fundamental information contained in this publication is sound and will remain valid for some years. The updating of the material and the references will be dealt with in future revisions.

A great effort has been made to present a uniform text as regards style and terminology. Moreover, the general rule of WHO in its publications is to follow authoritative, internationally approved scientific terms and units, some of which are rather new. A short glossary provides definitions of some essential terms. However, terms in common use in related fields, such as physics, optics, radiosciences, ionizing radiation and medicine, and their definitions in other glossaries, have been excluded.

This Office has also embarked on a survey of national legislation and regulations, and of institutions and specialists concerned with one or more sectors of the NIR field. The survey is based on replies to two questionnaires received from various governments, and on information from many experts involved in this project. The survey has revealed that only in a relatively small number of countries are there institutions dealing with NIR. In addition to the two countries that have long been involved in this area, namely the United States and the USSR, only about two dozen other countries in the world are known to have institutions that are concerned with the study of NIR, and of these about three quarters are European countries. Since the listing at present is incomplete, and the first attempt will inevitably contain errors and omissions, the results will be issued separately so that it can easily be revised and updated.

The World Health Organization is grateful to the Governments of Bulgaria, the Federal Republic of Germany, Ireland and the United Kingdom for support through their kind agreement to host working group meetings in their countries, and to the Government of The Netherlands for financial support. Also recognized with appreciation is the United Nations Environment Programme which, through its significant financial assistance from 1978 onwards, made the completion of this project and the publication of this book possible. The consistent support given to this project by Mr J.C. Villforth, Director of the Bureau of Radiological Health (BRH) of the US Public Health Service, and members of his staff, is greatly appreciated. In its capacity as the WHO collaborating centre for standardization of non-ionizing radiation, the BRH kindly hosted a review meeting on health effects of exposure to microwave radiation. My thanks go also to Dr W.H. Parr, Chief of the Physical Agents Effects Branch, National Institute for Occupational Safety and Health (NIOSH), and his staff for their work on and contribution to the chapter on IR radiation.

Some of the figures and tables in this book have been reproduced from published works. In all cases this has been acknowledged by means of a suitable reference. The authors and WHO wish to thank the publishers for granting permission for such use to be made of copyright material.

I should like to record my personal indebtedness to all the colleagues, reviewers, and participants in the meetings who have contributed in many ways and at various stages. All of these are listed in Annex 1, and I offer my sincere apologies to anybody whose name may have been unintentionally omitted. The very close collaboration with the authors of the chapters and other particularly active contributors among the working group participants, some of whom have become personal friends in the course of the work, and their endless efforts to upgrade and update the material, are warmly acknowledged.

The friendly assistance and goodwill of various members of the Regional Office staff on different occasions is greatly appreciated. They include secretaries, draftsmen, publications and reproduction staff, registry and mailing personnel, and the administration. Though too numerous to mention individually, all have contributed toward the successful implementation of this project. I am also grateful to Mr J. Kumpf and Mr J.I. Waddington, former Chief and present Director, respectively, of the environmental health team in the Regional Office, for their support during the implementation and completion of this work. The understanding of Dr Leo A. Kaprio, WHO Regional Director for Europe, and the late Dr F. Bauhofer, former Director of Health Services, of the potential value of this work in promoting NIR protection in many countries was a great encouragement.

Finally, acknowledgements and thanks should go to Dr Shore for his farsightedness and recognition of the significance and benefits of this work to international understanding and cooperation, and for his repeated encouragement and support; to Professor Michaelson for sparing no time and effort in providing special advice and essential assistance; to Dr R.B. Dean for his editorial assistance; and to Christiane Sørensen who, as my secretary from 1974 to 1978, worked tirelessly on behalf of this project and helped with the organization of all four working groups.

A revised and updated edition of this book may be prepared in the future and readers are invited to submit comments, corrections and observations, as well as suggestions for additional material, to the World Health Organization, Regional Office for Europe, 8 Scherfigsvej, 2100 Copenhagen Ø, Denmark.

Ultraviolet radiation

M. Faber[a]

CONTENTS

INTRODUCTION

Of the various types of nonionizing radiation, ultraviolet (UV) is of special interest because of its relatively high photon energy as compared to the other types included in this group. This could lead to greater variation in biological response. On the other hand, the low penetration will restrict most of the direct biological responses to the superficial tissues.

Although man-made UV radiation can arise from a large number of sources, it is the sun which is the main source and both the general public and people working out of doors will be exposed to it. This natural background radiation and the variations in its magnitude must be taken into account when exposure limits are discussed.

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It is well known that UV can initiate photochemical reactions and that some of these take place in the skin. The best known is the production of vitamin D_3, which is necessary for the prevention of rickets in man. The full extent to which UV affects human well-being is difficult to quantify. Artificially produced UV has, however, been used in mines and cellars as a supplement to combat functional impairment among the workers *(26, 27)*. Many of the observed effects, such as a decrease in the incidence of infectious diseases and in absenteeism, may be due to the bactericidal nature of the radiation *(91)*. On the other hand, large doses of UV have an acute destructive effect on the skin and eye. Doses so low that they give rise only to normally acceptable acute symptoms can, if repeated, induce changes resulting in late effects such as elastosis of the skin, keratosis and the various skin cancers. These effects will be of greatest significance in people with lightly pigmented skin.

Our goal in protecting the population against the harmful effects of UV is to establish the most appropriate exposure limits based on a biological risk–benefit analysis of all these factors in as quantitative a fashion as possible *(77)*.

PHYSICAL DESCRIPTION

Ultraviolet radiation is that part of the electromagnetic spectrum lying between the softest ionizing radiation on the one side and visible radiation on the other. For biological purposes, it is convenient to regard the range of wavelengths from 100 to 380–400 nm as constituting UV. The lower limit of 100 nm is equivalent to photon energies of 12.4 eV, which corresponds approximately to the limit for the production of ionization in biologically important materials. At the other end, the limit is the shortest visible wavelength; this varies slightly from individual to individual, but lies between 380 and 400 nm.

Because of differences in physical properties and in biological effects, the UV region has been subdivided. Wavelengths shorter than approximately 190 nm constitute the region of vacuum UV. This radiation is absorbed by air to such an extent that no biological effects would be expected, unless very powerful sources are used. The remainder can then be divided into the far-UV region between 190 and 300 nm and the near-UV region between 300 and 400 nm.

A somewhat different way of dividing up the UV region takes some of the biological effects into account. In this arrangement the range 400–315 nm, the so-called "black light" region, is called UV-A. In this wavelength region, fluorescence can be induced in many substances. UV-B covers the range 315–280 nm (the skin erythemal region). Most of the biologically active and potentially harmful UV from the sun reaching the surface of the earth comes within this spectral region. UV-C includes the radiation of wavelength less than 280 nm (the germicidal region). These divisions are, however, arbitrary and usage varies from one worker to another.

PRODUCTION

Matter at a temperature of 2 500 K or higher may emit a significant number of photons with energies inside the UV range. Such incandescent sources emit a smooth spectrum, a continuum, possibly with superimposed lines.

Most man-made sources of UV radiation can be grouped together in the categories shown below:

Gas discharges

Mercury lamps (low-, medium- and high-pressure).
Mercury lamps with metal halides
Noble gas lamps
Flash tubes
Hydrogen and deuterium lamps
Welding arcs

Incandescent sources

Tungsten halogen lamps

Fluorescent lamps

Fluorescent tubes
Fluorescent sun UV emitters
Black-light UV emitters

Mixed sources

Carbon arc

The spectrum of the UV emitted varies from one source to another. In the case of low-pressure mercury lamps, a line spectrum will be emitted. These lines are broadened into bands in high-pressure lamps (often called medium-pressure lamps by photobiologists) and there may also be emission of a continuum over a wide range of wavelengths. This continuum is most strongly marked in the highest pressure lamps. Addition of metal halides will increase both the continuum and the number of superimposed lines in the spectrum. In high-pressure xenon or hydrogen lamps there is also a combination of disinct bands with a continuum (*93*) (see Fig. 1 and 2).

The arc produced during welding will depend not so much on the atmosphere in which the welding takes place but rather on the composition of the electrodes. An example of an emission spectrum produced by a welding process is shown in Fig. 3.

The spectrum of fluorescent lamps depends on the properties of the fluorescent phosphors employed in the envelope. The small UV part of the spectrum of daylight fluorescent lamps stems, however, from the mercury discharge inside the lamp. The amount of UV depends to some extent on the glass used in the fluorescent tube.

In the case of lasers, the line spectrum will depend on the active medium and on the operating conditions.

To permit the transmission of UV when the discharge does not take place in free air, gas discharge arcs and other UV sources must be contained within an envelope of quartz or UV-transmitting glass. On the other hand, sources that are designed primarily to emit visible radiation but which also produce significant but unwanted amounts of UV should be provided with an external screen of glass that does not permit the passage of UV-B and UV-C radiation.