IFA
Institut für Arbeitsschutz der
Deutschen Gesetzlichen Unfallversicherung

Emission of UV radiation during arc welding

1 Introduction

Skin cancer caused by ultraviolet (UV) radiation has risen to prominence in the occupational disease sector. When establishing the work-related preconditions for recognition of occupational diseases, it is important to investigate of the sick person's exposure to UV radiation. Employees engaged in welding work in particular may be exposed to a high level of UV radiation. Although it is possible to measure UV radiation in such cases, this is often very time-consuming and costly. Efforts have therefore been made to find other ways of estimating UV radiation exposure during welding with sufficient precision for investigations into occupational diseases. A general study into UV radiation emission from different welding processes and with different welding parameters has therefore been conducted.

In cooperation with the Metalworking BGs North & South (now Wood- and Metalworking BG) and the German Association for Welding and Allied Processes (DVS), the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) has conducted radiation measurements during welding work. UV radiation emission was measured during the application of different arc welding processes in a welding booth of the Welding Training Centre of the DVS.

2 Description of the measurement locations and welding processes

The measurements were carried out in a 2.4 x 2.7 m welding booth. Two of the walls of this welding booth consisted of grey-painted concrete and the other two of woven aluminium (see Figure 1 in Section 3.2). The entrance to the welding booth was closed with a protective welding curtain. A 0.75 m high welding bench was available in the booth. The following welding processes were applied:

- Tungsten inert gas welding (also known as “gas tungsten arc welding”) (abbreviated to TIG welding)
- Metal inert gas welding (also known as “gas metal arc welding”) (abbreviated to MIG welding)
- Metal active gas welding (abbreviated to MAG welding)
- Shielded metal arc welding (also known as “manual metal arc welding”, abbreviated to MMA welding)

The following welding equipment was used:

- Fronius TransPuls Synergic 2700: for MIG, MAG and MMA welding
- Fronius Magic Wave 3000: for TIG welding

For the radiation measurements, the following welding work was performed with the welding equipment mentioned:

- TIG welding of CrNi and Al
- MIG welding of Al (pulsed and unpulsed)
- MAG welding of structural steel (St-37) and CrNi
- MMA welding of structural steel (St-37)

All the welding work was performed on a metal plate resting on the welding bench. The welding point on the plate was such that the distance from the measuring instruments remained largely constant. All the details of welding current, welding wire, inert gas etc. are listed in Table 1 (measurement results).

3 Measurements

3.1 Measuring instruments used

Radiation spectrum

Spectral radiometer CAS 140 CT from Instrument Systems
This spectrometer equipped with a diode array in combination with EOP 120 optical probes has a wavelength measurement range of 200 to 800 nm.

Effective irradiance in the UV A/B/C range (weighted)

Radiometer X1 No. 2447M-0 with measuring heads XD 9506-4 Nos. 4636/4607 (UV-A) and 4612 (UV-B/C) from Gigahertz-Optik
With the two detectors integrated in the measuring head XD 9506-4, this measuring instrument measures the effective irradiance with a spectral weighting S(λ) in accordance with Table 1.2 of Directive 2006/25/EC [1] in the wavelength range from 200 to 400 nm (UV-A/B/C). For the effective irradiance, the measurement range is 50 nW/m² to 1 W/m² in the UV-A range and 0.8 mW/m² to 16 kW/m² in the UV-B/C range.

Irradiance in the UV-A range (unweighted)

Radiometer P9710-2 No. 4667M with detector UV-3701-1 No. 1007 from Gigahertz-Optik
With the detector UV-3701-1, this instrument measures the irradiance in the wavelength range of about 315 to 400 nm (UV-A). The response sensitivity is virtually constant in this wavelength range. The measurement range for the UV-A irradiance is 0.02 mW/m² to 390 kW/m².

The following relative measurement uncertainties were ascertained during the last calibration:

- Detector UV-3701-1 (UV-A) ± 5% (December 2009)
- Detector XD 9506-4 (UV-A/B/C) ± 10% (December 2009)
- Spectral radiometer CAS 140 CT ± 10% (July 2010)

3.2 Performance of measurements

To perform the radiation measurements in the welding booth, the welding processes named in Section 2 were practised in succession at different welding currents. The welding wire or electrode diameters used here were adapted in each case to the set welding current. During the welding processes, the radiation spectrum and irradiances E_{eff} and $E_{UV\text{-}A}$ were measured in each case along the lines of DIN EN 14255-1 [2]. All the detectors of the radiation measuring instruments used for this were positioned at the same time to the left of the welding bench at a height of 1.0 m above the floor and were directed at the welding point at a distance of 0.6 m from the arc. During the various welding processes, all the measurements to determine the irradiance and radiation spectrum were initiated at the same time. The radiation intensities were determined in each case as mean values over a period of 10 s. The radiation spectra, on the other hand, were measured as the mean values of 100 single measurements. The duration of these single measurements was automatically controlled by the spectrometer software and varied – depending on the radiation intensity – from about 10 to 60 ms. Where possible, all the measurements were repeated once. However, measuring and repeat measuring were not always possible with MAG/MIG welding, as the arc at welding currents of 60 A (MAG, MIG) and 250 A (MIG) could not always be sustained long enough for measurements to be performed.

In addition to the described measurements of direct radiation from the welding arc, the diffuse radiation issuing from the walls of the welding booth was also measured. To this end, the detectors of the measuring instruments were directed towards the surrounding wall surfaces without changing their position during the application of MMA welding (see Figure 1).

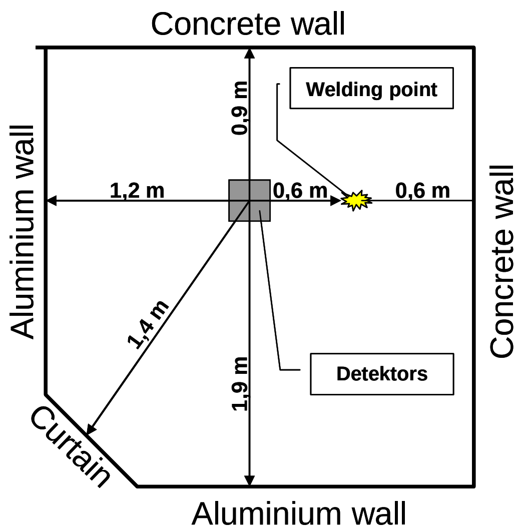

Figure 1: Design of the welding booth with the location of the welding point and the detectors. The arrows show the direction in which the detectors were pointing during measurements.

3.3 Measurement results

3.3.1 Radiation spectrum

The radiation spectra measured for the various welding processes in the wavelength range of 200 to 800 nm for welding currents I = 180 A are presented in Figures 2 to 9. The radiation intensities presented in them are assigned to the following radiation ranges:

- UV-C radiation: 200 nm to 280 nm
- UV-B radiation: 280 nm to 315 nm
- UV-A radiation: 315 nm to 400 nm
- Visible radiation: 400 nm to 780 nm
- Infrared (IR) radiation: 780 nm to 800 nm

The radiation spectra measured at higher and lower welding currents and at different distances from the arc differ in the absolute magnitude of their spectral radiation intensities. However, the relative changes in the spectral radiation intensities as a function of wavelength remain largely the same. These spectra have therefore been disregarded.

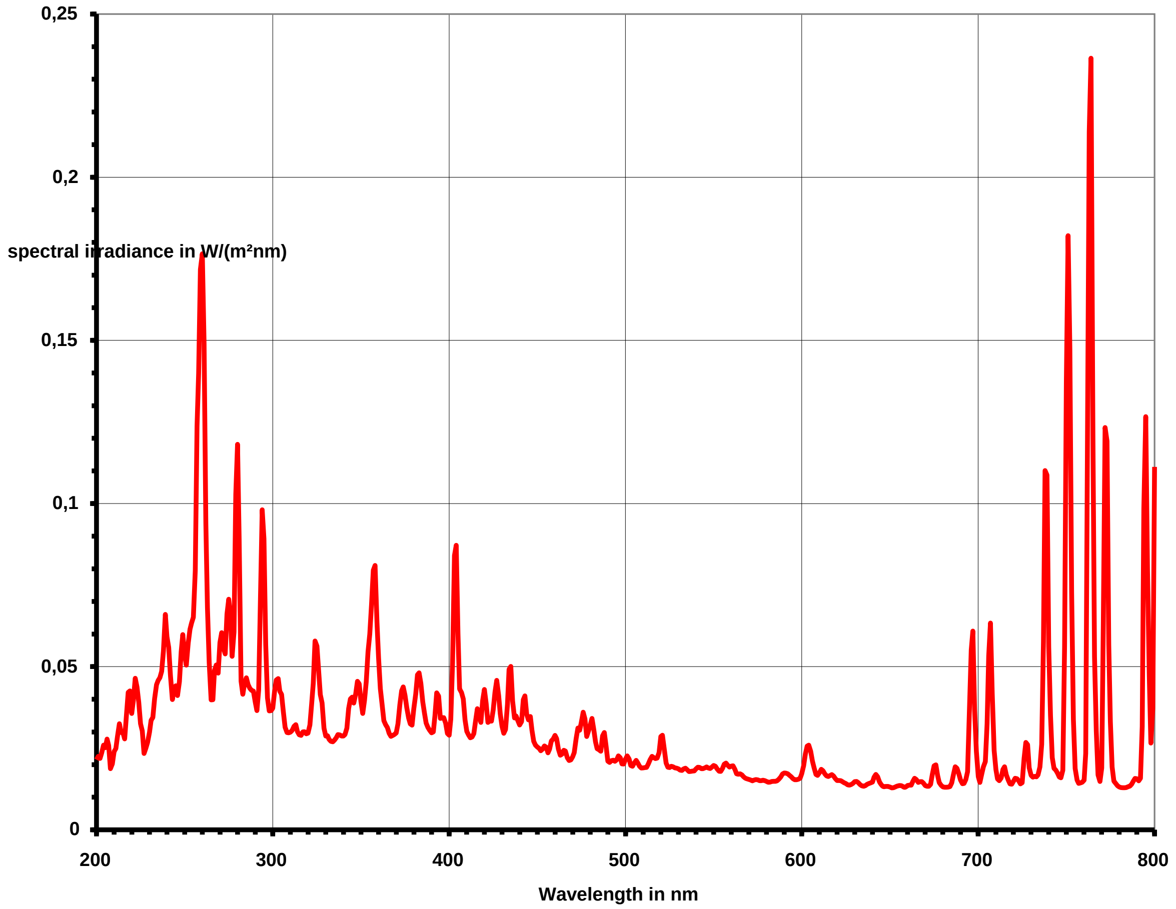

Figure 2: Radiation spectrum during the TIG welding of CrNi (welding current 180 A)

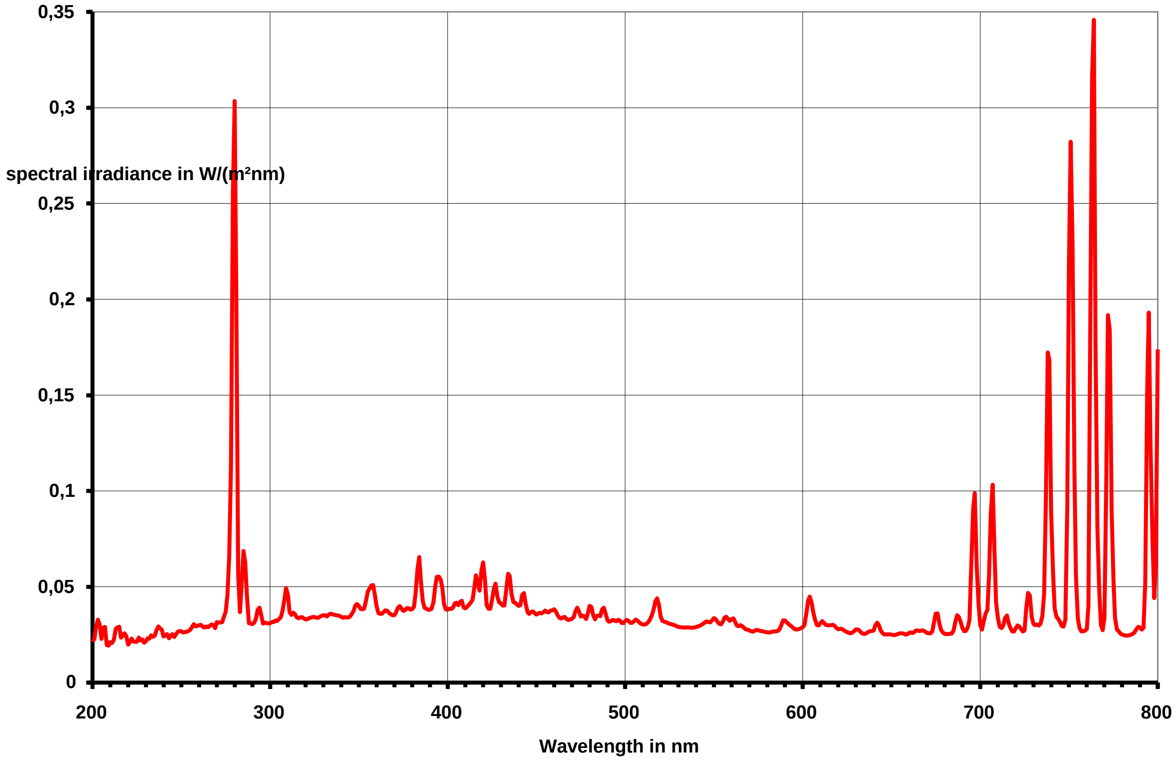

Figure 3: Radiation spectra during the TIG welding of Al (welding current 180 A)

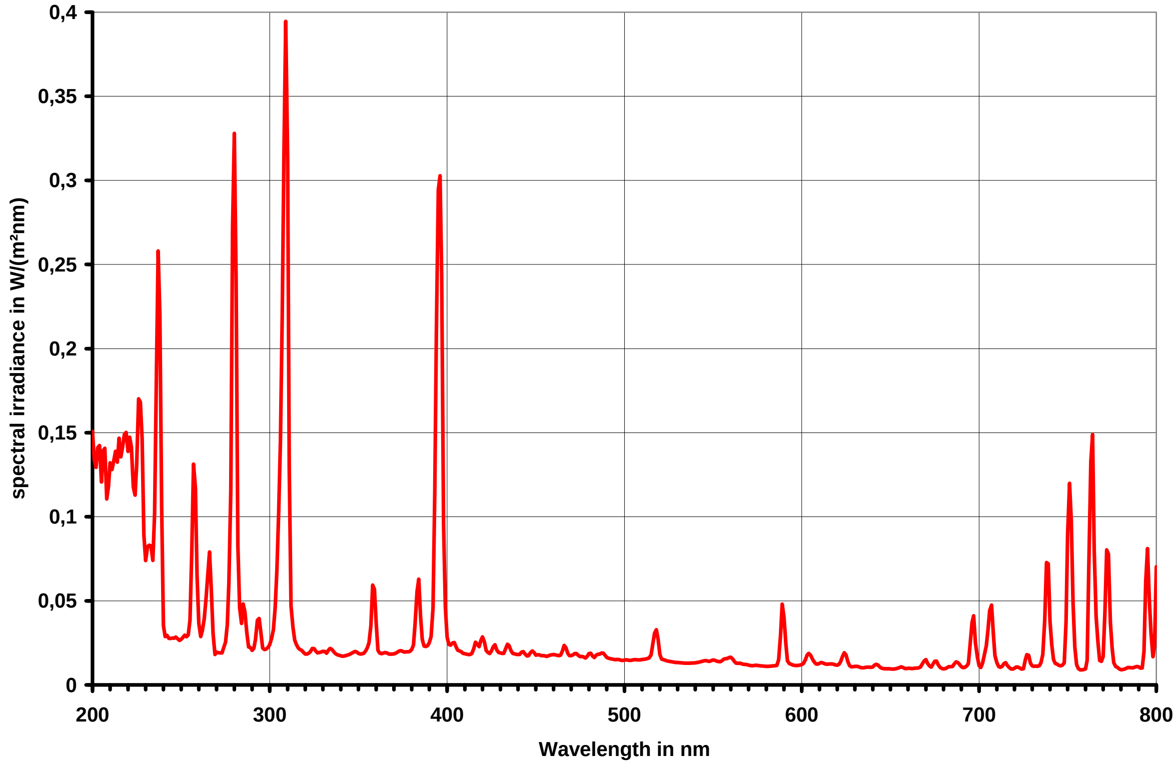

Figure 4: Radiation spectra during the MIG welding of Al (pulsed welding current 180 A)

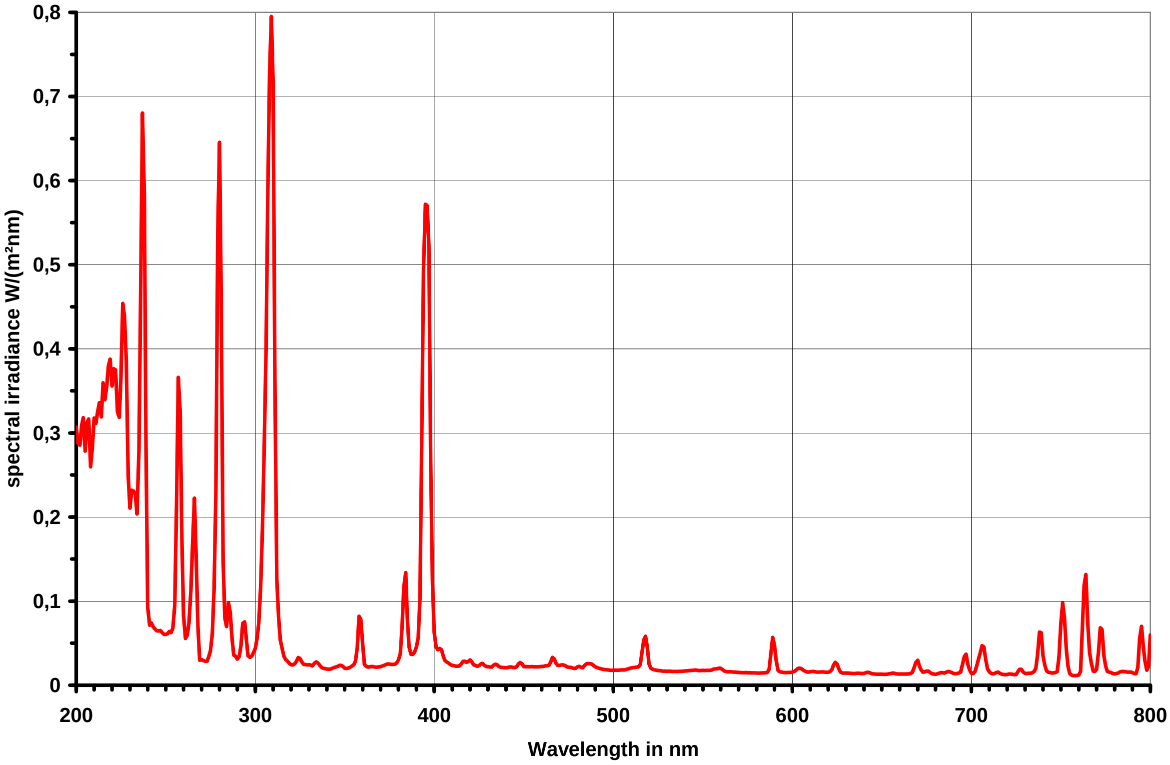

Figure 5: Radiation spectra during the MIG welding of Al (unpulsed welding current 180 A)

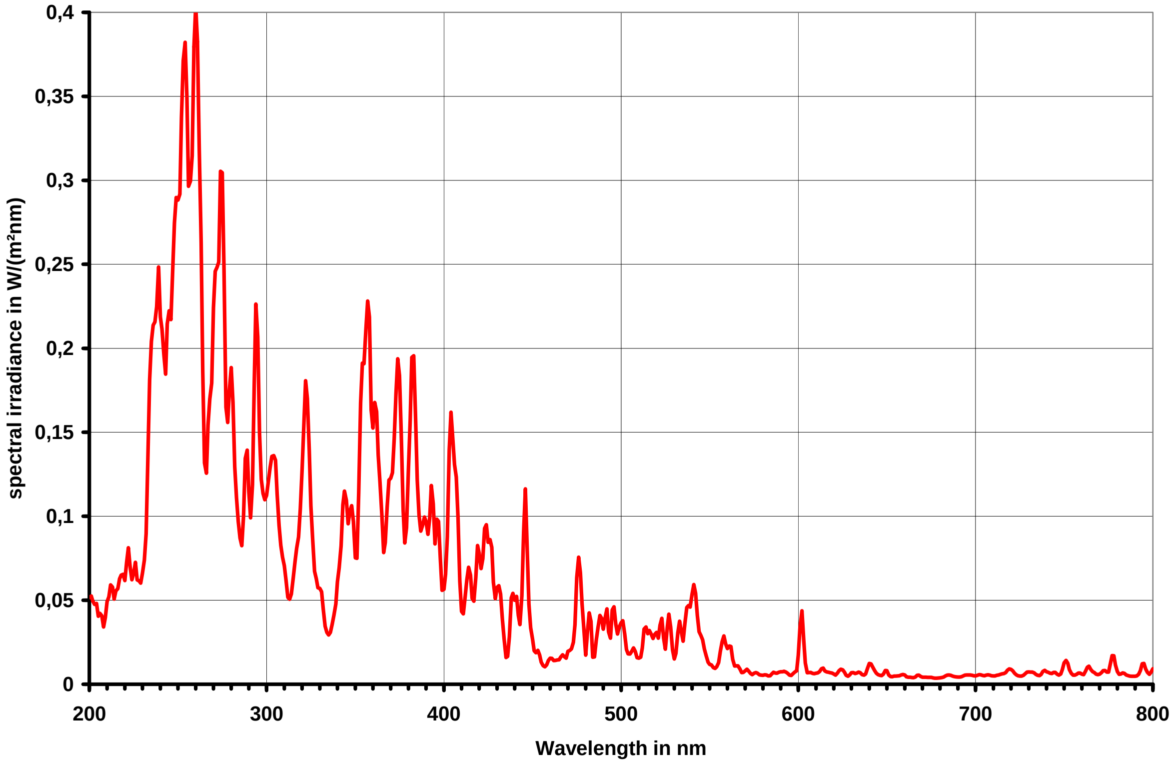

Figure 6: Radiation spectra during the MAG welding of St-37 (welding current 180 A)

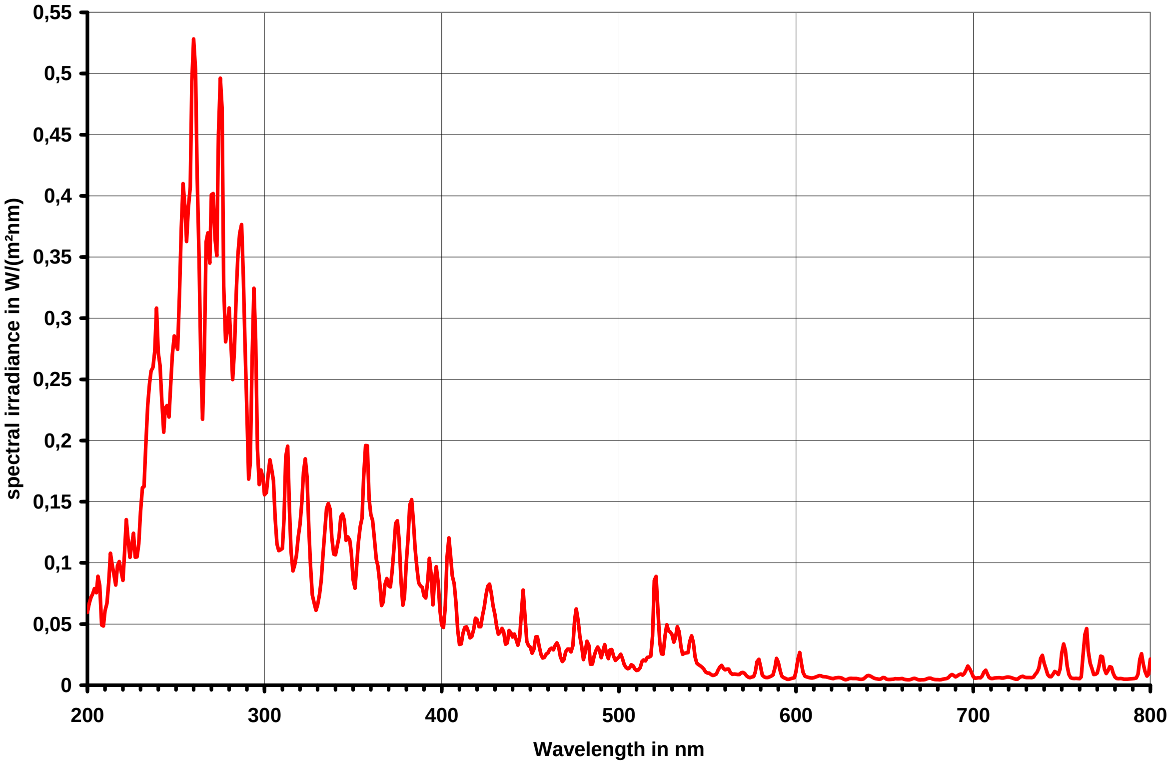

Figure 7: Radiation spectra during the MAG welding of CrNi (welding current 180 A)

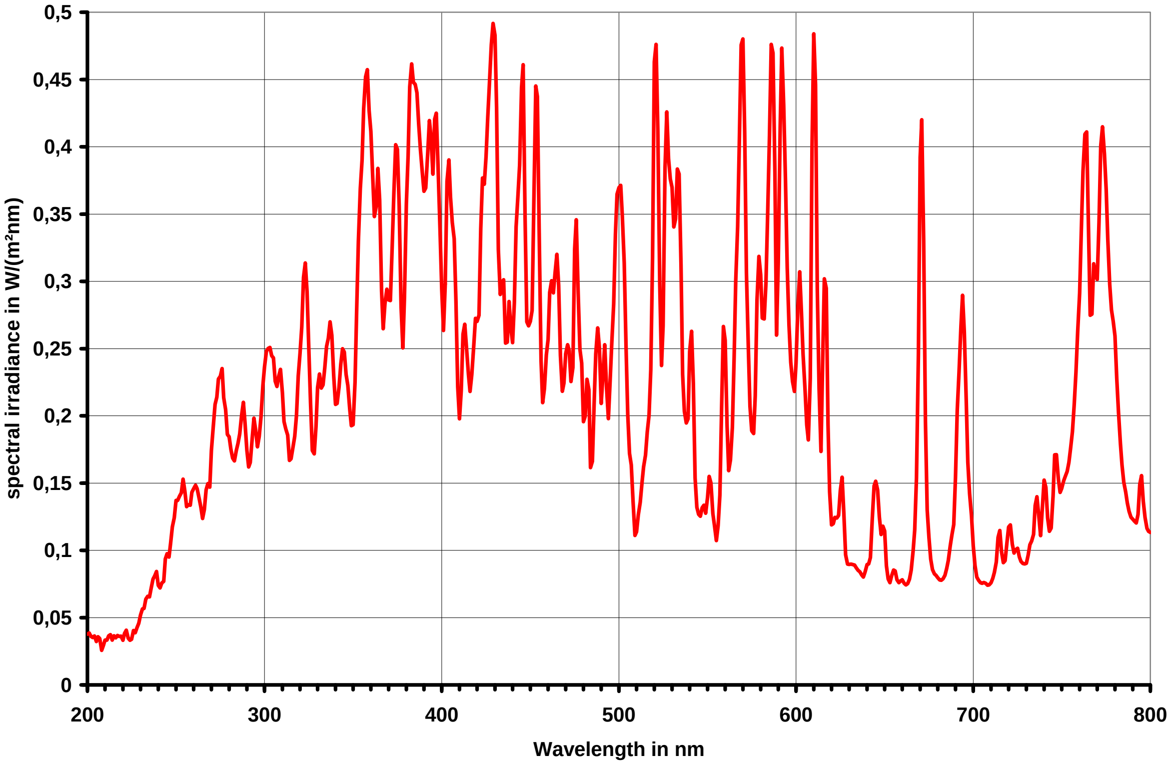

Figure 8: Radiation spectra during the MMA welding of St-37 (welding current 180 A)

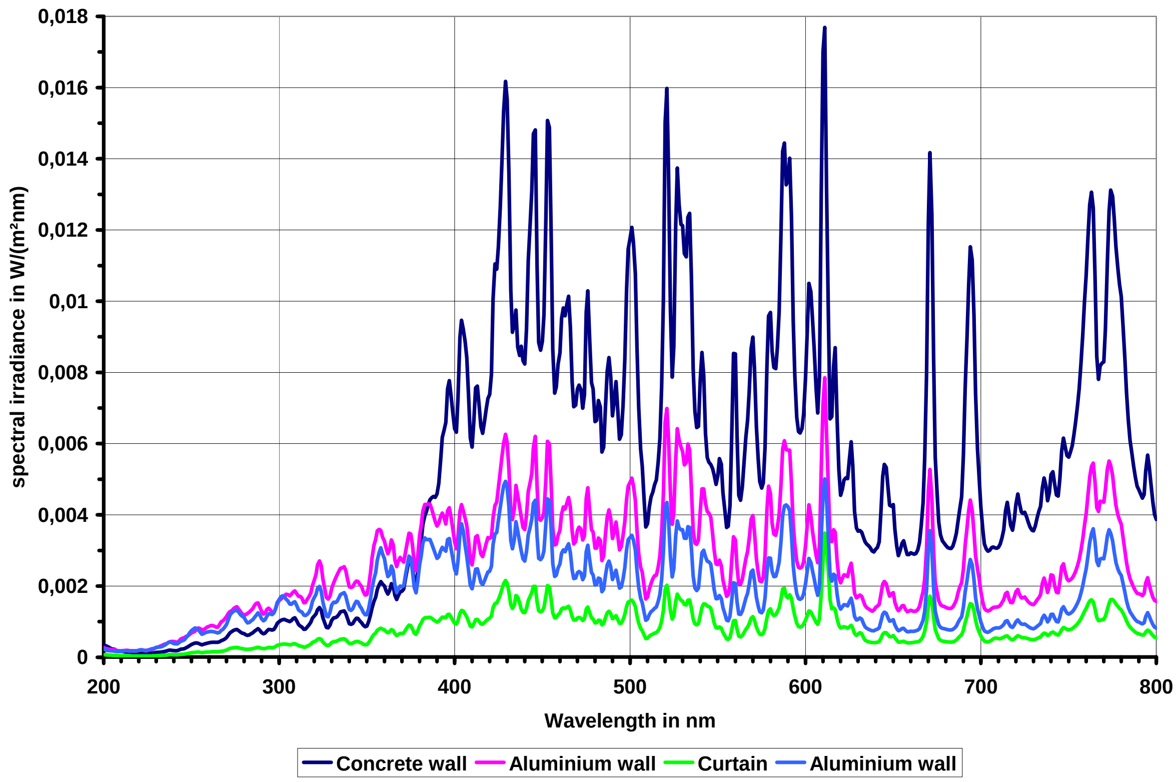

Figure 9: Radiation spectra of diffuse radiation during the MMA welding of St-37 (welding current 250 A)

3.3.2 Irradiance

Direct radiation from the arc

The values for the effective irradiance E_{eff} measured in relation to the welding current are presented in Figure 10. Each of the entered measurement points was measured with the radiometer as a 20 s mean value at a distance of 60 cm from the arc.

Note: Investigations into the work-related preconditions for recognition of an occupational disease demand determination of the NMSC-weighted UV radiation exposure (see [3]). This can be calculated from the values of effective irradiance E_{eff} (see Section 4.4). Information on the UV-A irradiance is not required in this connection. This is why the measured UV-A irradiance values are not reported here.

Diffuse radiation

Measured with the radiometer, the welding arc radiation reflected by the walls of the welding booth yielded effective radiation intensities E_{eff} of 0.3% to 1.3% of the effective irradiance emitted directly by the light arc.

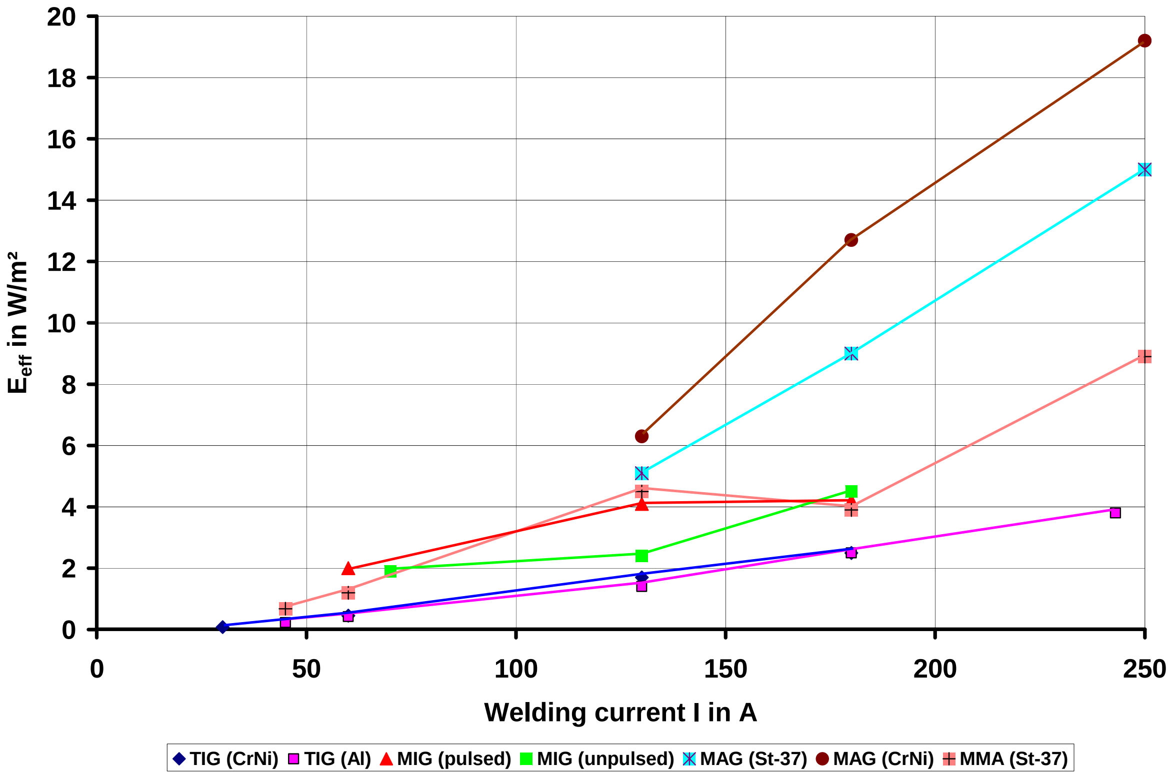

Figure 10: Effective irradiance at a 60 cm distance from the arc for different welding processes (radiometer readings)

4 Evaluation

4.1 Comparison of the UV radiation spectra of the various welding processes

Figures 2 to 8 show the UV radiation spectra of the welding processes with a uniform welding current of 180 A. The graphs show the following:

- During TIG welding (Figures 2 and 3), there is a broad distribution over the entire UV radiation range. This broad distribution is superimposed by a number of lines. During the TIG welding of aluminium (Figure 3), the emission is dominated by a line with a wavelength of roughly 280 nm. On the other hand, during the TIG welding of CrNi steel (Figure 2), the highest emission occurs at a wavelength of roughly 260 nm and, in a lower intensity, at other wavelengths as well.

- The radiation spectra measured during MIG welding (Figures 4 and 5) show a clear line structure. These lines are found mainly in the UV-B and UV-C range. The radiation emission during pulsed welding is slightly lower than during unpulsed welding.

- During MAG and MMA welding (Figures 6 to 8), there is a broad distribution across the entire UV range. The spectral distribution of the emission during the MAG welding of St-37 and CrNi steel (Figures 6 and 7) is similar, although the bulk of the emission can be found in the wavelength range from about 230 to 300 nm (UV-B and UV-C). By contrast, during the MMA welding of St-37 steel (Figure 8), the emission increases steadily with increasing wavelength and achieves its highest values in the UV-A range.

4.2 UV radiation emission of the light arcs from the various welding processes (direct radiation)

The graph in Figure 10 shows, on the one hand, that the radiation emission from all the investigated processes increases with increasing current and, on the other hand, that there are marked differences in the radiation emission from the various processes at the same current level. If one assumes a linear relationship between UV radiation emission and welding current for each of the welding processes, the measured values after linear regression yield the functions given in Table 1. Using these functions, it is possible to approximately calculate the effective irradiance of the investigated welding processes for any welding currents within the given validity range.

Table 1: Relationships between welding current and UV radiation emission calculated from radiometer readings

Welding process	Material	Number of measured values	Function	Correlation coefficient	Validity range I [A]
TIG	CrNi	4	E_{eff} [W/m²] = -0.4661[W/m²]+0.0165[W/m²A]*I [A]	0.999	30 to 180
TIG	Al	5	E_{eff} [W/m²] = -0.6951[W/m²]+0.0180[W/m²A]*I [A]	0.995	45 to 243
MIG (pulsed)	Al	3	E_{eff} [W/m²] = 1.0798[W/m²]+0.0191[W/m²A]*I [A]	0.926	60 to 180
MIG (unpulsed)	Al	3	E_{eff} [W/m²] = 0.0033[W/m²]+0.0231[W/m²A]*I [A]	0.923	70 to 180
MAG	St-37	3	E_{eff} [W/m²] = -5.7385[W/m²]+0.0827[W/m²A]*I [A]	0.999	130 to 250
MAG	CrNi	3	E_{eff} [W/m²] = -7.1578[W/m²]+0.1066[W/m²A]*I [A]	0.996	130 to 250
MMA	St-37	5	E_{eff} [W/m²] = -1.0455[W/m²]+0.0367[W/m²A]*I [A]	0.953	45 to 250

4.3 Radiation emission reflected from the wall surfaces (diffuse radiation)

The spectra of the diffuse radiation (Figure 9) show that the spectral distributions of the reflected radiation and direct radiation (see spectrum in Figure 8) are similar in the visible range. It is worth noting that more is reflected by the concrete wall in the range of long-wave UV radiation and visible radiation (390 nm to 800 nm) than by the booth's other wall surfaces. The percentage of UV reflection calculated from these spectra is depicted in Figure 11.

In the wavelength range relevant for determination of the effective irradiance of about roughly 270 nm, Figure 11 shows that about 0.06% to 0.4% of the direct radiation from the welding arc is reflected from the walls of the welding booth. The share of reflected effective irradiance measured with the radiometer ranges, on the other hand, from 0.3% to 1.3% (see Section 3.3.2). The differences in the values measured by the radiometer and spectrometer may be attributable, on the one hand, to the fact that the spectrometer measures wavelengths selectively while the radiometer measures integrally over the entire UV wavelength range. Furthermore, the measurement times for the two measuring systems were different (see Section 3.2). As a result, the usual variations in the intensity of the welding arc contribute to the measured value to a different degree for the two measurement methods. It should also be borne in mind that the intensity of the reflected radiation depends not only on the properties of the reflecting surface, but also on the distance from this surface (see Figure 1 in Section 3.2).

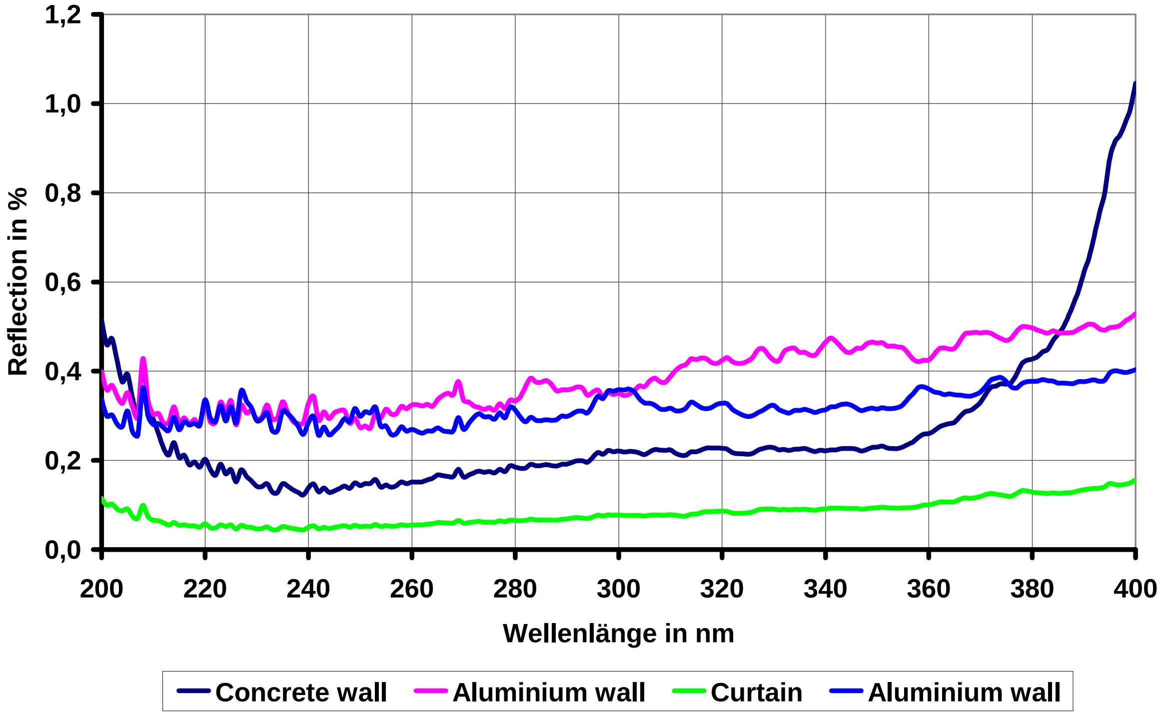

Figure 11: Spectral shares of reflected radiation during MMA welding with a welding current of 250 A

4.4 Conversion of E_{eff} to E_{NMSC}

The radiation spectra measured for the various welding processes can be used for converting effective radiation intensities E_{eff} into NMSC-weighted radiation intensities E_{NMSC} (see [4]). For this, the mean conversion factor $f_{eff\text{-}NMSC}$ was determined in each case from all the measured radiation spectra:

- TIG welding: $f_{eff\text{-}NMSC} = 0.286 \pm 0.027$ (n = 9)
- MIG welding (pulsed): $f_{eff\text{-}NMSC} = 0.290 \pm 0.057$ (n = 3)
- MIG welding (unpulsed): $f_{eff\text{-}NMSC} = 0.270 \pm 0.054$ (n = 3)
- MAG welding: $f_{eff\text{-}NMSC} = 0.251 \pm 0.014$ (n = 10)
- MMA welding: $f_{eff\text{-}NMSC} = 0.509 \pm 0.022$ (n = 5)

The conversion factors mentioned can be used for obtaining the NMSC-weighted irradiance E_{NMSC} during welding for $E_{NMSC} = E_{eff} * f_{eff\text{-}NMSC}$. Farther-reaching conversions can be undertaken with the Excel file listed in [5] as long as the radiation spectrum is available as a spectral irradiance in 1 nm increments. To this end, the radiation spectra presented in Figures 2 to 8 are stored in [6] in the suitable format.

Acknowledgements

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Institute of Occupational Safety and Health of the German Social Accident Insurance (IFA), Sankt Augustin

5 Literature

[1] Directive 2006/25/EC of the European Parliament and of the Council of 5 April 2006 on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)

[2] DIN EN 14255-1: Measurement and assessment of personal exposures to incoherent optical radiation – Part 1: Ultraviolet radiation emitted by artificial sources in the workplace; German version EN 14255-1:2005. Beuth, Berlin 2005

[3] DGUV-Rundschreiben: Hautkrebs nach UV-Strahlungsexposition; Eine Hilfestellung für die BK-Sachbearbeitung: www.dguv.de/ifa, Webcode d103710

[4] IFA-Information: Umrechnung von UV-Strahlungsgrößen: www.dguv.de/ifa, Webcode d95943

[5] IFA-Programm: Umrechnung von Strahlungsgrößen: www.dguv.de/ifa, Webcode d95334

[6] IFA measured data: Radiation spectra of different welding processes: www.dguv.de/ifa, Webcode e137045

[7] Verordnung zum Schutz der Beschäftigten vor Gefährdungen durch künstliche optische Strahlung (OSH Ordinance on Artificial Optical Radiation – OStrV). BGBl. I (2010) No. 38

[8] ISO 28077:2006(E)/CIE S 019/E:2006: Joint ISO/CIE Standard: Photocarcinogenesis Action Spectrum (Non-Melanoma Skin Cancers)

[9] Sliney, D.; Wolbarsht, M.: Safety with Lasers and Other Optical Sources. Plenum Press, New York and London, 1980