

INDUSTRY REPORT

Measuring key parameters of intense pulsed light (IPL) devices

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Abstract

Background: Unlike medical lasers, intense pulsed light (IPL) devices are largely unregulated and unclassified as to degree of safety hazard. With the exception of most of the USA, the United Kingdom and parts of Europe, the Far East and Australia, the sale of IPLs is generally unrestricted, with the majority being sold into the beauty therapy and spa markets. Standards are only imposed on manufacturers for technical performance data and operating tolerances determined by CE-compliance under electrical safety standards or the EU Medical Device Directive. Currently, there is no requirement for measurement of key IPL performance characteristics. **Objective:** To identify the key IPL parameters, emphasize their importance in terms of safe and effective treatment and provide examples of preliminary measurement methods. These measurements can highlight changes in an IPL device's performance, improving patient safety and treatment efficacy. **Methods:** Five key parameters were identified as having an important role to play in the way light interacts with the skin, and therefore an important role in patient safety and effective treatment. Simple methods were devised to measure the parameters, which include fluence, pulse duration, pulse profile, spectral output and time-resolved spectral output. **Results:** The measurement methods permitted consistent and comparable measurements to be made by two of the authors at working clinic locations on 18 popular IPL devices and allowed assessment of output variations. Results showed discrepancies between the measured IPL device outputs and those values displayed on the system or claimed by the manufacturers. The importance of these discrepancies and their impact is discussed. **Conclusions:** This study, of 18 popular devices in regular daily use in England and Wales, provides example methods for measuring key IPL device parameters and highlights the need for regular measurement of at least those five key parameters measured in this study. These methods can help service technicians to check performance and eliminate device malfunction.

Key words: Energy density, fluence, optical hazard, spectral output, square pulse

Introduction

In Europe, medical lasers are governed by strict safety standards (1,2). The European Standard EN 60825 is designed to protect individuals from laser radiation in the wavelength range 180 nm to 1 mm by indicating safe working levels of laser radiation and introducing a system of classification of lasers according to their degree of hazard. The Standard requires both user and manufacturer to establish procedures and supply information so that proper precautions can be adopted. Medical lasers intended for irradiation of the human body require internal controls to measure radiation emission levels with an error in measurement of no more than $\pm 20\%$ given in SI units and instructions specifying a procedure and schedule for calibration of the measurement system (1). No such requirement exists for intense

pulsed light (IPL) devices whether or not they comply with the European Medical Device Directive. Technical Report IEC TR60825-9 confirms risk factors and measurement practices applied by specialists in the optical radiation field. It identifies retinal thermal hazard and blue light photochemical hazard as relevant in considering the safe use of incoherent light sources. However, at the time of submission of this study, standards, which will deal specifically with IPL sources are still only at draft stage (3).

This means that there is no incentive to perform measurement, and no standard procedures in place to help manufacturers. IPL devices are being used widely with limited accurate knowledge of their performance characteristics. Measurement of certain key parameters could help reduce the risk of under- or over-treatment or burn injury to patients. The

absence of any published standards for IPL safety eyewear, used by the patient and the operator, increases the risk of eye injury (4).

The issue of IPL safety was raised by experts at the ASLMS Joint International Laser Meeting in Edinburgh, Scotland (21–23 September 2003), when Hode of the Swedish Laser Medical Society considered the hazards of IPL sources (5).

Clarkson has also documented the hazards of non-coherent light sources within the framework of IEC TR-60825-9 (6).

In England and Wales, the Care Standards Act 2000, as amended by the Health and Social Care Act 2001, treats establishments using IPL devices in a similar way to users of Class 4 medical lasers. The statutory definition of an IPL states 'an intense light, being broadband non-coherent light which is filtered to produce a specified range of wavelengths; such filtered radiation being delivered to the body with the aim of causing thermal, mechanical or chemical damage to structures such as hair follicles and skin blemishes while sparing surrounding tissues' (7).

It is therefore clear that such high-power devices can cause tissue damage in a similar way to medical lasers and should be subject to equivalent standards to those provided for Class 4 medical lasers.

The purpose of this study is to identify the key IPL parameters that impact on safety and treatment efficacy, providing results from preliminary measurements carried out on 18 IPL devices. Clarkson (8,9) describes methods for measuring pulse duration and pulse profile; in a similar manner the methods described in this paper can be used as a simple guide for service technicians to follow. It is acknowledged that these methods will not provide absolute values in terms of traceability to national standards; however, they will serve as a useful diagnostic tool enabling performance to be checked regularly during device lifetime.

The primary purpose of IPL devices is to destroy target structures through controlled thermal absorption in specific skin chromophores such as melanin and haemoglobin, resulting in the long-term reduction of unwanted hair or the removal of benign vascular and pigmented lesions (10–17). IPLs may also be used to produce a photochemical effect alone or in conjunction with topically applied photosensitive drugs such as 5-ALA (18–20), which is used to stimulate the production of naturally occurring porphyrins to destroy bacteria. IPLs may also provide penetrating wavelengths of light to directly stimulate tissue regeneration through a wound healing response (photobiomodulation or low level laser therapy) at the mitochondrial level (21,22).

It is therefore increasingly important that the user can be assured of accurately measured and correctly distributed energy at the skin surface. The pulse duration of delivered light and the associated spectrum of light produced also play a key role in

correct targeting of key structures. There is little objective evidence provided by manufacturers even in user and service manuals to validate claims for pulse features or stability of spectrum characteristics.

The authors identified the following five key parameters to measure:

1. energy density (fluence) for various popularly used pulse patterns over the claimed lifetime of the lamp and filter assembly to establish whether there is any significant deviation or deterioration compared with established standards for medical lasers. Clearly, excessive energy density above stated values may result in burns to patients' skin and low-energy density may result in under-treatment and patient dissatisfaction.
2. pulse duration (or durations of sub-pulses in a pulse train) of the intense light emitted from the xenon flashlamps. The pulse duration can be critical in the efficacy of the type of treatment, particularly where the pulse duration is to be matched to the thermal relaxation time of the target. Overstated pulse duration may result in a more aggressive treatment than was intended by the operator with concomitant side effects.
3. electrical discharge pulse shape, recorded as an oscilloscope trace, entering the lamp versus manufacturers' claims, to determine whether the discharge to the xenon lamp is constant ('square pulse') or variable ('free discharge'). The input pulse energy pattern to the lamp is pivotal in determining the efficiency of the spectral output and determines output intensity.
4. the average spectral output of the IPL to identify undesirable wavelengths, as there is increased risk of retinal, corneal and epidermal damage from IPL systems that deliver wavelengths below 500 nm. Accuracy and effectiveness of cut-off filters and the distribution of light energy at different wavelengths could also influence certain treatment outcomes.
5. the time-resolved spectral output of the IPL across the entire pulse width to determine the extent of spectral shift and confirm that the optical output reflects the profile of the electrical discharge claimed by the manufacturer. The time-resolved spectrum defines the effective pulse duration during which the desired wavelengths are delivered in the optimum intensity.

Materials and methods

The 18 devices and 36 applicators tested included IPLs manufactured in the USA, UK, Israel, Sweden, Switzerland and Italy (markings on IPL 'F' suggested that it was originally manufactured in China).

All of the data were gathered over a 6-month period by two of the authors. All measurements were made on site in the IPL treatment rooms where the equipment was in daily use between scheduled patient appointments. Where available, the following general information was recorded:

- device identity (name, model, manufacturer, serial number, manufacturing date withheld) and coded for the study
- maximum stated pulse energy and/or maximum stated fluence
- CE classification (e.g. medical device or not) / labelling details^a
- number of shots claimed in the company literature, web site, user manual or system software.

The following parameters were measured on up to 18 devices and 36 applicators in common use in UK clinics:

- fluence (energy density) for a range of popular programs and energy settings including maximum fluence; this was compared with the claimed maximum fluence
- accurate pulse durations for different treatment types / settings
- electrical discharge across the xenon lamp (oscilloscope trace)
- spectral output
- dimensions of glass transmission block.

^aCE mark for medical devices – explanatory note

The CE mark is a visible declaration by the manufacturer (or his representative, importer, etc) that the equipment which is marked conforms to the required regulatory standards for safety and environmental protection legislation under all of the applicable European Union (EU) directives. The letters ‘CE’ are initials for the French phrase ‘Conformité Européenne’ (‘European Conformity’).

IPL devices are normally classified as Class IIa/b electro-medical devices with medium risk. Medical Class 3B and IV lasers must comply with the Essential Requirements of the European Medical Device Directive, which requires a device-specific CE mark certificate from a Notified Body.

Manufacturers who register IPL devices under this scheme issue a Declaration of Conformity to standards, maintain a Quality Assurance monitoring system under ISO9000 and are obliged to report any accidents to the authorities. A medical CE mark can be identified easily by the four-digit number next to the official CE mark on the device identification label, which denotes that the Notified Body that has independently evaluated the device.

Medical authorities in several non-European countries (including South Africa and Australia) recognize the medical CE mark as a requirement for electro-medical equipment.

Energy density measurement

IPL energy density (fluence) is the amount of light energy delivered per unit area and is measured in Joules per centimetre squared. For treatments utilizing ‘selective photothermolysis’, the light energy is absorbed by chromophores in the skin, such as melanin and oxyhaemoglobin, and converted into heat energy. As energy is absorbed the temperature of the chromophore increases and tissue goes through biological changes. The ideal fluence will raise the temperature of the chromophore to a level that causes damage to the target but does not lead to adverse side effects such as burns or blisters. Even the most restrictive IPL devices will at least allow the user some control over energy density, which makes reproducible measurement very important to ensure consistent output and prevent under- or over-treatment.

An isopropyl alcohol wipe and an optical cloth were used to thoroughly clean the IPL light guide and head aperture of the energy meter (Ophir LaserStar Power Energy Monitor, Ophir L40 (150) A-DB-SH-NS Absorber Head: Ophir Optronics Ltd, Jerusalem 91450, Israel). The slightest fragment of dirt or a thin layer of dried ultrasound gel residue can make a significant difference to the passage of light from the handset applicator to the energy meter absorber head. Clear optical coupling ultrasound gel (Henleys Medical, Hertfordshire AL7 1AN, UK) was applied to the top of the energy meter IPL absorber unit glass without any air bubbles in the gel (Figure 1A). A 2 mm thick white poly-tetra-fluoro-ethylene (PTFE) plastic mask/spacer with a 4.84 cm² (2.2 × 2.2 cm) aperture was used to prevent burning of the surface paint around the energy absorber head and to fix the depth of gel between the absorber glass lens surface and the applicator glass coupling block (0.1 mm). The applicator handset was placed in a horizontal position above the absorber head using a laboratory retort clamp and stand (Figure 1B). The applicator handset glass transmission block was in direct contact with the PTFE white spacer on the energy meter absorber unit and perfectly flat and horizontal on the absorber head glass aperture with no lateral tilting. The angle of the handset applicator position is critical as the slightest movement can result in an 8–10% difference in energy readings. As the whole of the output from the transmission block usually cannot be measured owing to the size limitation of the absorber head aperture, the IPL glass transmission block was centred over the aperture to ensure that maximum output energy was measured from the centre of the lamp plasma phase (Figure 1C). Firm downward pressure was applied to eliminate air bubbles, which will impede light passage by light scattering, in the gel between the glass block and the energy meter absorber head (Figure 1D). Sufficient time was left between each lamp discharge to again prevent excess heat creating small bubbles in the



Figure 1. (A) Mask the absorber head with a white PTFE sheet with aperture exposed for energy collection; (B) fix the applicator in place on the absorber head energy collection aperture using a laboratory retort clamp and stand; (C) take fluence measurements with the applicator transmission block flat and central on the absorber head energy collection aperture; (D) apply firm downward pressure to eliminate air bubbles and tighten clamp fixing.

ultrasound gel. An average of 10 shots was measured and divided by the area of the head aperture to give the energy density. Measurements were taken for the most popular and the highest IPL settings.

For assurance of continuing reliability of the lamp and filter it is useful if these measurements can be repeated throughout the lamp's lifetime. If output drifts significantly from the results recorded with a new lamp then procedures should be in place to replace the lamp or treatment head. Detailed records should also be kept so that consistency between new lamps can be checked. The described method used for energy density measurements was devised following discussions with several leading UK manufacturers (see acknowledgements) of IPL devices and is therefore similar to the quality assurance testing performed prior to despatching new or refurbished applicators to IPL users.

The skin contact surface area of the quartz glass or sapphire transmission block of each IPL was measured in mm using a Vernier gauge in order to calculate the energy density accurately.

Lamp discharge duration measurement

The measurement of lamp discharge duration (also known as pulse width or pulse duration) is important

because, according to Anderson and Parrish (10), the optimum pulse width should be close to the thermal relaxation time. Previous studies have confirmed this, proving that higher clearance rates occur when the pulse duration is close to or higher than the thermal relaxation time (23). However, if pulse duration is too long the heat diffuses to surrounding tissue, increasing the risk of adverse side effects. Risk is also increased if the pulse duration is short and the fluence high.

The duration of the discharged pulse or sub-pulses of intense white light was measured using a reversed biased photodiode, acting as a light-dependant switch (Figure 2). The pulse duration was captured as an oscilloscope image using a Fluke 196 Scopemeter and its counterpart FlukeView version 4 software (Optimum Energy Products Ltd., Calgary T2-Z4M3, Canada).

The pulse duration can differ considerably between IPL systems from different manufacturers: some use true single pulses but most utilize two or more sub-pulses to extend pulse duration to allow intra-pulse epidermal thermal relaxation and to help extend flashlamp lifespan. Ideally, the pulse durations should be adjustable as various chromophores have differing thermal relaxation times (TRT) and

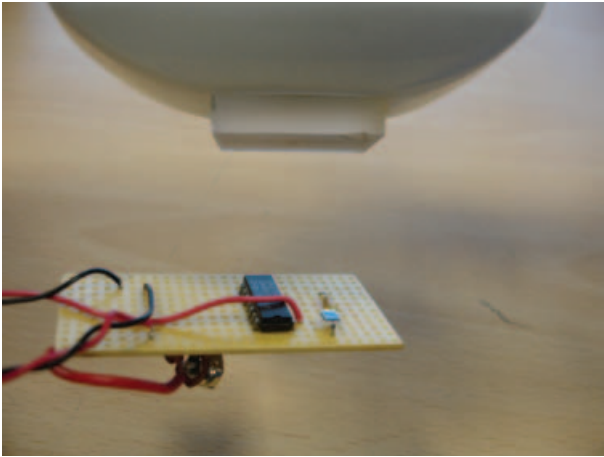


Figure 2. Test apparatus for pulse duration measurement using a reversed biased photodiode acting as a light-dependent switch.

therefore the IPL should match such times to target the correct chromophore.

Lamp discharge profile measurement

A constant current through the xenon flashlamp may be critically important in the treatment of skin conditions. The spectrum of a flashlamp whose energy is supplied from a free discharge capacitor will change as the current follows a standard distribution curve (24).

The current discharge profile through the xenon flashlamp, which should produce a balanced spectrum of light to achieve the desired photo-therapeutic effect, can be measured by two methods. The current can be measured by inserting a 0.01Ω resistor in series with the flashlamp inside the applicator handpiece. The current flowing through the electrodes is measured across the 0.01Ω resistor using a digital oscilloscope and plotted against time to give a graphical representation of the current ionizing the xenon gas. Alternatively, the current waveform can be measured by the induced current through a hand-turned cable of thin enamelled copper wire wound around the electrode wire and a ferrite core. This method can be used when the applicator can be opened easily by a technician but cannot be physically altered in any way without the manufacturer's permission.

Spectral output measurement

The chromophores in the skin, which are important for many IPL treatments, have individual absorption spectra. This means that depending on the target chromophore, certain wavelengths will be more effective at treating certain conditions than others. Therefore, each treatment will be best suited to a particular wavelength range. The range used should take into account the absorption spectra of all chromophores because heating a non-target chromophore can damage the skin. Knowing the

spectral output will also provide information on any unwanted wavelengths, such as ultraviolet and infrared radiation, which can present immediate and long-term health risks.

The photo-spectrometer apparatus was arranged to produce accurate results with minimal experimental error. The applicator of the IPL system was used to direct the optical discharge energy into an HR2000+ spectrometer (Ocean Optics, Dunedin, FL 34698, USA) at a distance from the spectrometer probe of approximately 150 cm to avoid saturation of the apparatus. The spectrometer probe was held with a retort clamp fixed to a laboratory stand to ensure no movement of the probe. The spectral output was saved digitally and presented in a Microsoft Excel graph for later analysis.

Time-resolved spectral output measurement

It has been noted earlier that a free discharge capacitor will exhibit changes in current, which will in turn affect the emitted spectrum. We can test this assumption with time-resolved spectral output measurements.

The time-resolved spectrum was produced using an Ocean Optics HR2000+ spectrometer and its counterpart Spectra Suite software. This software has the capability of sampling the spectrum of light with a minimum integration time of 1 ms. This test is intended to demonstrate the stability and degree of efficiency of spectral output for free discharge versus square pulse systems in delivering their stored energy to the chromophore targets within the patient's skin.

Results and Discussion

General information

Example test measurements on 18 IPL devices (including 36 applicators with different cut-off filters) were made as described and data were collected using the above methods. The data and measurements were recorded and are summarized in Tables I and II.

The authors gathered the general information from the manufacturer's user manual, web site and/or current literature. In most cases, manufacturers accurately quoted the size of the treatment area. Only device 'N2' claimed the treatment area to be 15% larger and device 'J' claimed the treatment area to be 5% larger than was measured by the authors with a vernier mm scale.

Eight devices carried the medical CE mark and 10 had only the standard CE mark.

Example energy density measurement

Fluence results were plotted on graphs for the example 18 devices against the systems' displayed fluence (or manufacturers' claimed fluence in the

Table I. Information recorded from manufacturer's specification in the user manual and measurements of spot size and range/maximum fluence.

IPL study ref.	Cut-on filter	Claimed maximum fluence (J/cm ²)	Measured maximum fluence (J/cm ²)	Actual spot size (cm ² : mm × mm)	Claimed shot lifetime	CE class	Free or partial (square) discharge
A	600	21	20.8	4.8 (48 × 10)	30 000	Med CE	Free
A1	600	22	24.5	4.8 (48 × 10)	30 000	Med CE	Free
A2	555	8	9.2	4.8 (48 × 10)	30 000	Med CE	Free
B	450	22	11.1	7.5 (50 × 15)	100 000	Non-Med	Free
B1	450	22	13.0	7.5 (50 × 15)	100 000	Non-Med	Free
C	535	25	14.5	7.5 (50 × 15)	200 000	Non-Med	Free
C1	610	25	No data	7.5 (50 × 15)	200 000	Non-Med	Free
D	650	20	16.3	6.4 (40 × 16)	30 000	Non-Med	Free
D1	540	20	No data	6.4 (40 × 16)	30 000	Non-Med	Free
E	530	20	20.4	8.9 (33 × 27)	10 000	Med CE	Partial
F	560	50	22.2	2.69 (34 × 7.9)	10 000	Non-Med	Free
F1	690	37	12.4	2.69 (34 × 7.9)	10 000	Non-Med	Free
G	420	30	19.6	7.7 (52 × 14.9)	50 000	Non-Med	Partial
G1	530	17.6	13.5	7.7 (52 × 14.9)	50 000	Non-Med	Partial
G2	600	18	16.7	7.7 (52 × 14.9)	50 000	Non-Med	Partial
H	560	45	44.4	2.72 (34 × 8)	12 000	Med CE	Free
H1	695	45	51.0	2.72 (34 × 8)	12 000	Med CE	Free
I	645	35	41.8	2.72 (34 × 8)	12 000	Med CE	Free
I1	695	35	No data	2.72 (34 × 8)	12 000	Med CE	Free
I2	755	28	No data	2.72 (34 × 8)	12 000	Med CE	Free
J	600	23.1	21.1	5.0 (50 × 10)	50 000	Non-Med	Free
K	600	50	50.0	2.0 (10 × 20)	10 000	Non-Med	Free
L	650	34	39.7	5.0 (50 × 10)	20 000	Med CE	Free
L1	585	34	38.4	5.0 (50 × 10)	20 000	Med CE	Free
M	610	45	34.6	5.0 (50 × 10)	10 000	Med CE	Free
M1	530	51	No data	5.0 (50 × 10)	10 000	Med CE	Free
N	400	10	11.6	12.1 (55 × 22)	2500	Non-Med	Free
N1	430	7	10.7	12.1 (55 × 22)	2500	Non-Med	Free
N2	400	10	5.8	3.6 (33.6 × 10.9)	2500	Non-Med	Free
O	560	32	37.3	6.75 (15 × 45)	300 000	Med CE	Free
O1	695	32	36	6.75 (15 × 45)	300 000	Med CE	Free
O2	515	32	36	6.75 (15 × 45)	300 000	Med CE	Free
P	590	38	13.7	5.25 (35 × 15)	12 000	Non-Med	Free
P1	640	38	No data	12.5 (50 × 25)	12 000	Non-Med	Free
Q	540	20	20.2	6.4 (40 × 16)	30 000	Non-Med	Free
Q1	650	20	14.9	6.4 (40 × 16)	30 000	Non-Med	Free

user manual if not displayed on the IPL screen) (Figures 3 and 4). By measuring devices in routine daily use, measurements were effectively taken at different stages in the manufacturers' claimed warranty lifetime of the applicator or lamp/filter assembly, which allowed observation of the degree of deterioration in fluence against claimed values.

Using this test method, 30 IPL applicators were measured at maximum fluence, of which 11 were more than 20% below and eight were more than 10% above the fluence levels given on the device display or claimed in user manuals, even where brand new lamps were tested. Altogether, nine IPL devices out of 18 had applicators that were outside of the standard for medical Class 4 lasers ($> \pm 20\%$). The authors considered the accuracy of maximum fluence values to be of greatest importance owing to the risk of under- or over-treatment. However, if a manufacturer performs a different fluence test method than the method used in this study, then it is likely that comparing our measured results to the

stated values will show discrepancies. It is not possible for us to definitely prove traceability to national standards so no conclusion can be drawn on the correct absolute fluence. The energy density measurements are more valuable as consistency checks prevent lamp output dropping below tolerance levels.

Example lamp discharge duration

Measured pulse and sub-pulse durations using a reversed biased photodiode were recorded as an oscilloscope trace to permit measurement of pulse and sub-pulse durations and intra-pulse delay times (Table II). This test also served to validate the number of sub-pulses in a pulse train. Using this method, there was generally a poor correlation between manufacturers' claims or system-displayed values and the pulse durations measured. The data measured for six of the eight medical CE-marked IPLs were consistent with displayed values (where given).

Table II. User manual indicated pulse data and measured pulse durations showing an approximately 3% deviation from specification.

Study ref.	Cut-off filter	% deviation of cut-off filter	% UV (below 400 nm)	Stated pulse duration (ms)	Measured pulse duration (ms)
A	600	1.8%	0.4%	30 (3 sub-pulses)	18 (3 sub-pulses)
A1	555	8.5%	0.5%	14 (1)	14.5 (1)
	600	?	0%	2 × 2.5 ms=15	2 × 3 ms=15.5
B	450	8.4%	1.5%	5	15–17
	450	8.4%	1.5%	5	15–17
C	535	31%	1.6%	5	15–17
	610	52%	1.6%	5	15–17
D	650	13.4%	2.2%	50	51
	540	5.4%	0.2%	10–15	No data
E	530	2.1%	0%	10–50	10–51 ms
F	560	8.5%	0.2%	20–150	Missing pulses
	690	45.1%	0%	20–151	Missing pulses
G	420	0.3%	0%	10	6
	530	0.1%	0%	20	6.6
	600	0%	No data	20	8.7
H	560	1.6%	0%	5.5/5.5/5.5	5.4/6.4/7.0
	695	16.8%	0%	–	–
I	645	4.6%	0%	short:5.5/5.5 (2)	5.5/5.5 (2)
	695	15.7%	0%	med:3.6/3.6/3.6 (3)	4.0/4.0/4.0 (3)
	755	21.8%	0%	long:3.6/3.6/3.6 (3)	4.5/4.5/4.5 (3)
J	600	21.6%	0.1%	40	40
K	600	19.6%	0%	34.8	37
	–	–	–	123	121
L	650	5.1%	0%	15 black	2.2
	585	17.1%	0%	15 blonde	5
M	610	No data	0.7%	3	3
	530	2.1%	No data	5	5
N	400	No data	0.1%	35	132
	430	0.3%	3.6%	35	132
	400	No data	0.1%	10	24
O	560	2.5%	0.2%	40	42
	695	7.4%	0.2%	–	–
	515	3.4%	1.4%	–	–
P	590	No data	No data	Not given	No data
	640	No data	No data	Not given	No data
Q	540	No data	No data	30/40/50	30/40/50
	650	No data	No data	30/40/50	30/40/50

Only 14 of 31 pulse duration measurements were within $\pm 20\%$ of the manufacturers stated or system-displayed values.

IPLs ‘B’ and ‘C’ stated single-pulse durations of 5 ms, which were measured at 15–17 ms across all programs and settings.

In one example IPL program for IPL ‘F’, one sub-pulse was found to be entirely missing which correlated with the low fluence measured for that program compared with others on the same device. Such discrepancies are clearly unacceptable as they may lead to selecting incorrect fluence values and under- or over-treatment of the patient leading to either ineffective treatment or unwanted side effects (Figure 5).

Example lamp discharge profile

In manufacturers’ advertisements and marketing materials, it has become fashionable to promote a non-typical xenon lamp pulse shape (meaning the pulse of electrical energy discharged across the lamp)

as ‘unique’ and ‘desirable’ and it is often described using colourful artist’s illustrations rather than shown as an actual oscilloscope trace. It was apparent that almost all claims recorded in this study made in manufacturers’ literature for a ‘square pulse’ were not reflected in our example oscilloscope measurements as the pulses were usually the typical xenon (krypton) discharge slope (increasing/decreasing) of a free discharge system. Note: most of the useful light output is generated during the decay phase of the free discharge waveform (Figure 6).

Only IPLs ‘E’ (Figure 7) and ‘G’ exhibited a true single square pulse shape confirming that they used partial discharge capacitor technology, although close pulse-stacking in devices ‘A’ and ‘O’ effectively achieved the same pulse shape and device ‘D’ showed a nearly square pulse shape. Only a comparison of time-resolved spectral output will demonstrate whether there is any spectral deterioration across the entire pulse duration when comparing these devices.

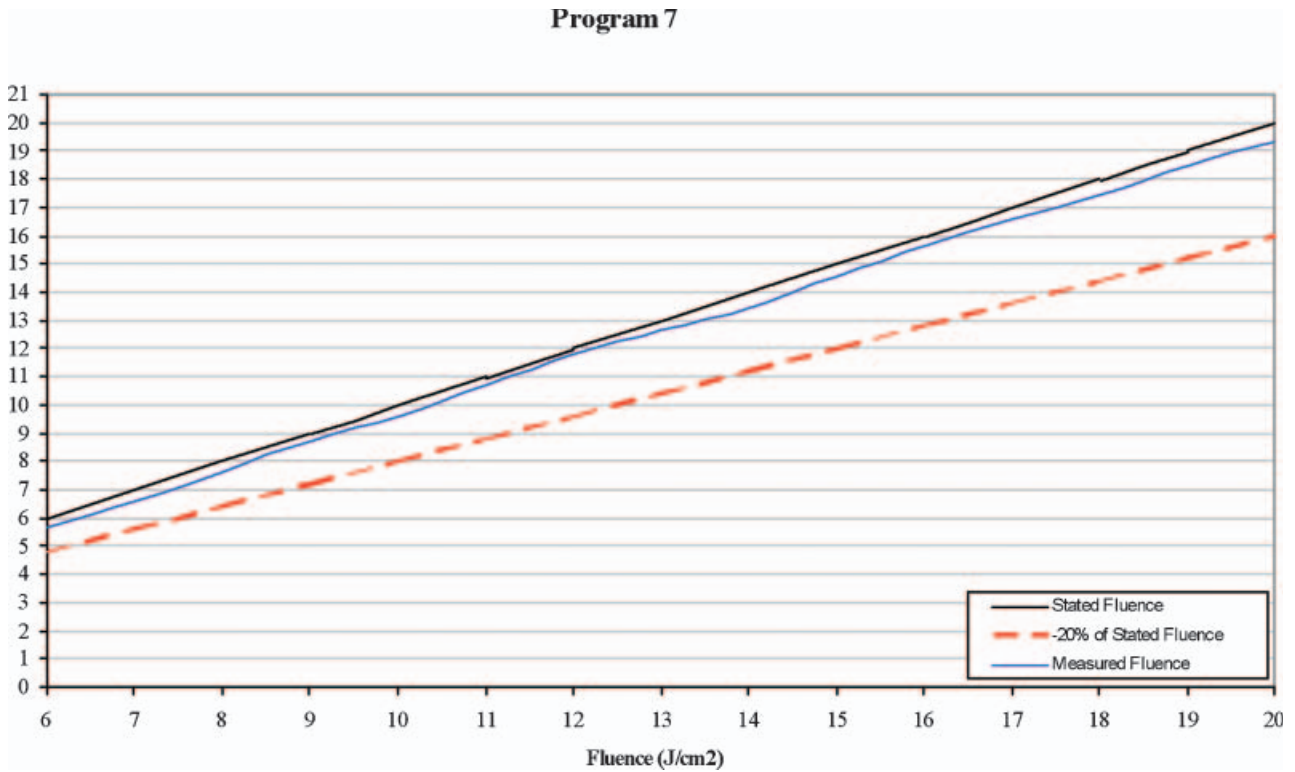


Figure 3. Example standardized energy density measurement showing IPL system 'E' whose energy output is well within the accepted tolerance of $\pm 20\%$ for Class 4 medical lasers (EN 60825).

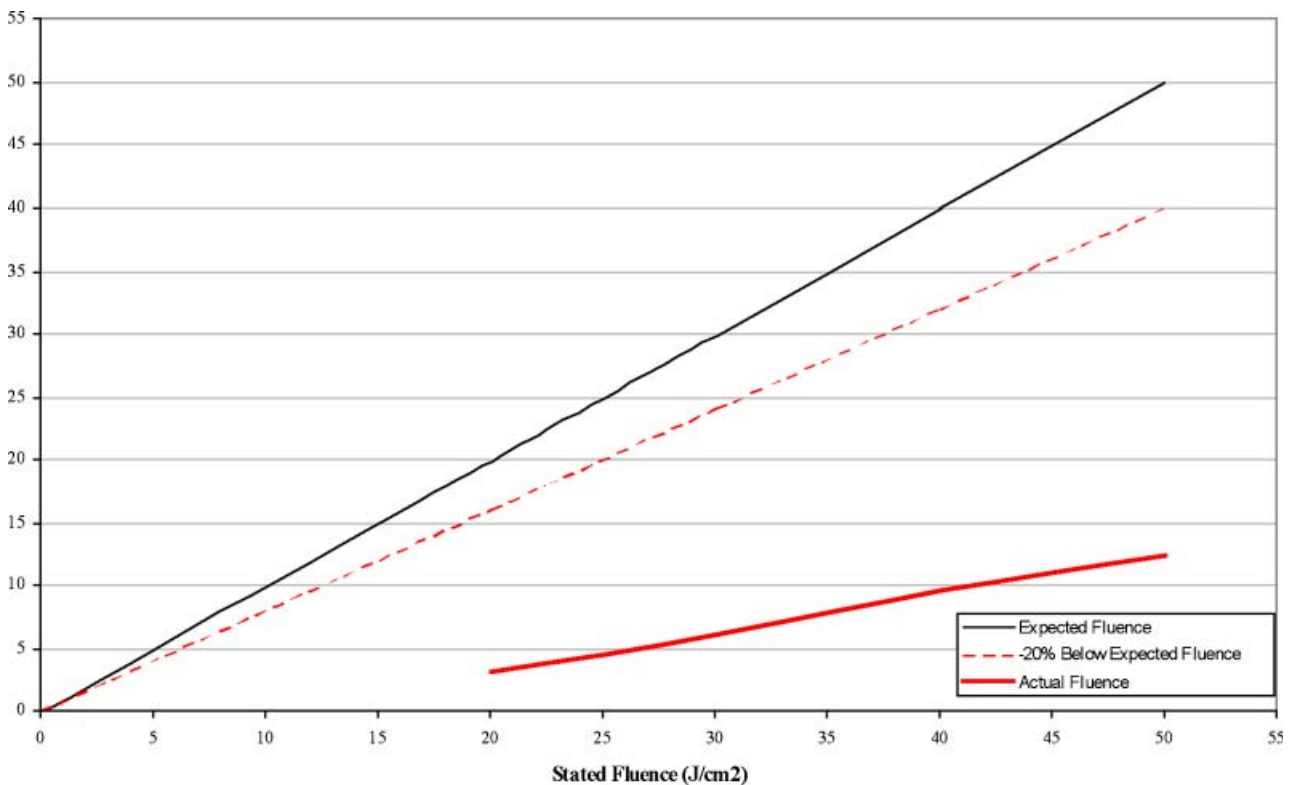


Figure 4. Example standardized energy density measurement showing IPL system 'F' whose output energy is only ca. 25% of the stated energy on the device screen display and which is well outside the accepted tolerance of $\pm 20\%$ for Class 4 medical lasers (EN 60825).

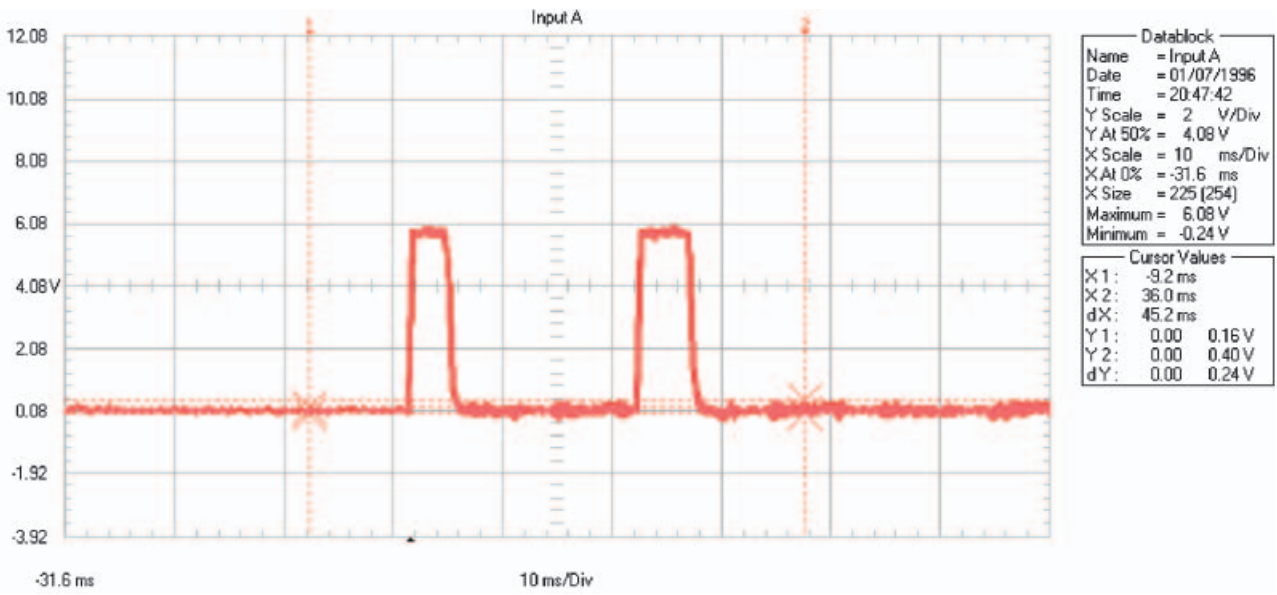


Figure 5. Example standardized lamp discharge duration measurements showing IPL system 'F' which is a triple pulse system with one pulse missing; thus, one-third of the energy is lost. System display values: T1 3 ms, T2 20 ms, T3 4.5 ms, T4 30 ms, T5 4.5 ms (T3 4.5 ms sub-pulse missing). It is assumed that this is due to an error when writing the system software or when calibrating the microprocessor control system.

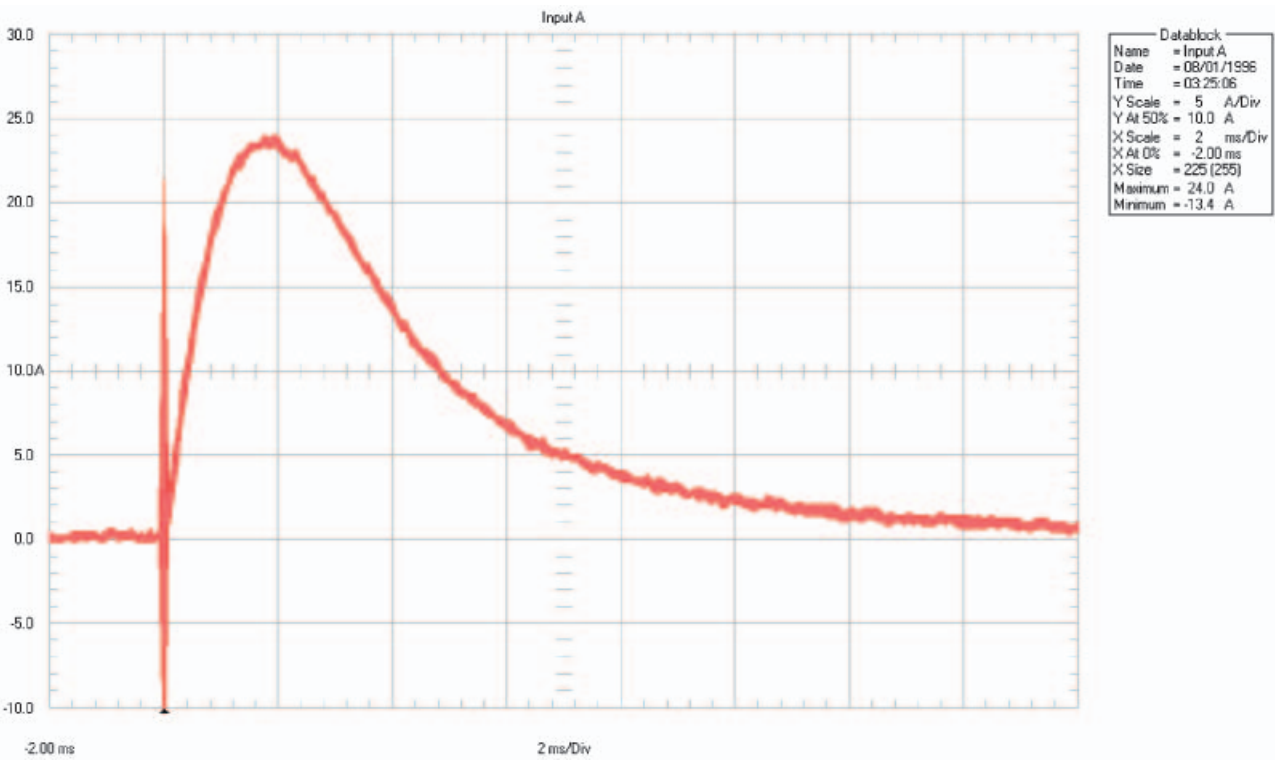


Figure 6. Example standardized lamp discharge profile measurement showing IPL system 'B' discharge profile of a free-discharge IPL system.

Example spectral output

In this initial measurement study, spectral output measurements included both an average value for the complete pulse or pulse train and time-resolved spectral measurements produced by the tested IPL applicators. The spectrum graphs of the entire output are useful as they give an indication of

accuracy of cut-off filter wavelengths and the presence of unwanted ultraviolet or infrared wavelengths. Of the 30 applicators tested, seven IPLs measured more than 1% and two measured more than 2% of unwanted UV output below 400 nm when cut-off filters were set significantly higher (Table II, Figures 8, 9, 10).

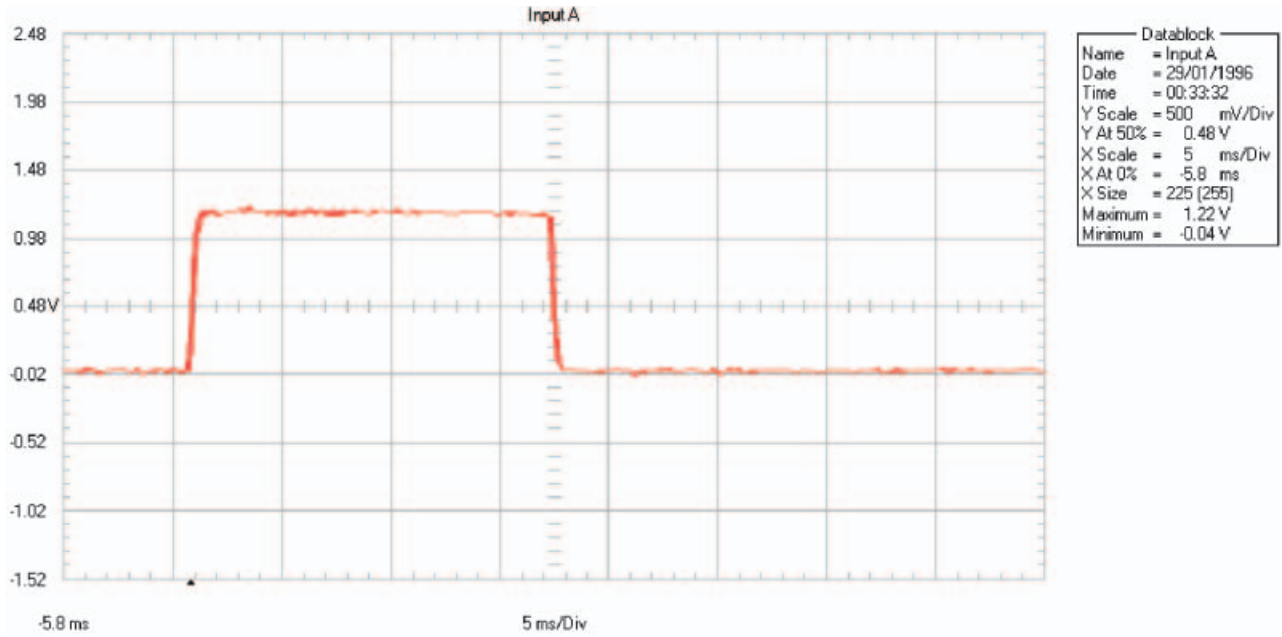


Figure 7. Example standardized lamp discharge profile measurement showing IPL system ‘E’ discharge profile of a ‘square pulse’ constant current discharge.

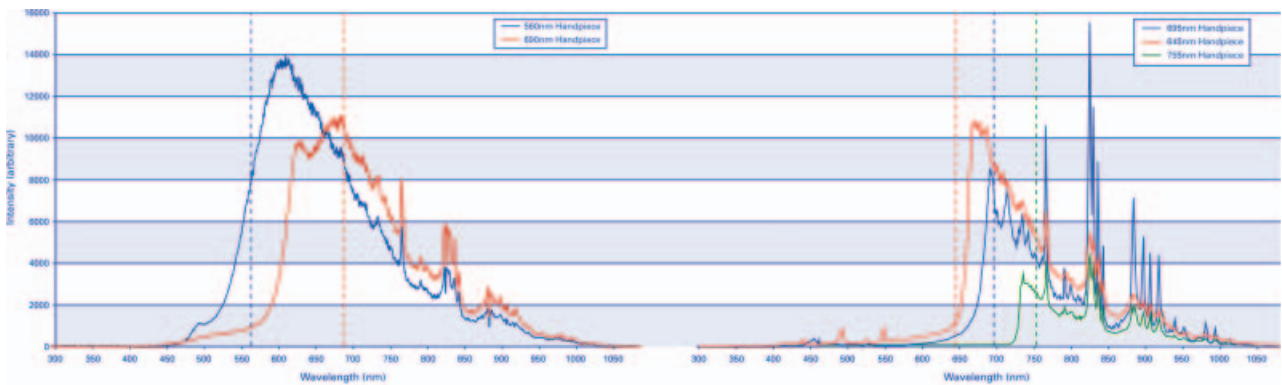


Figure 8. Example standardized spectral output measurement showing (left) IPL ‘F’ with applicators with cut-off filters at 560 nm and 690 nm demonstrating poor (shallow slope) cut-off profiles and inaccurate cut-off (620 nm red rather than 690 nm as stated in the manufacturer’s user manual) and (right) IPL ‘I’ with cut-off filters at 645 nm, 695 nm and 755 nm showing good but inaccurate (steep slope) cut-off profiles compared with manufacturer’s operators manual: intensity is irrelevant.

Measurements on 29 applicators showed 19 (65.5%) with cut-off filters that were inaccurate by more than 20 nm versus the claimed cut-off value given by the manufacturer. Only 10 applicators (34.5%) were within 20 nm of the stated cut-off (Figure 8).

As with the energy density measurements, the intensity of the spectral output is not traceable to national standards. This means that an accurate determination of the retinal thermal hazard cannot be made. Most monochromators suffer from stray light, which effectively means light of a particular wavelength could be recorded incorrectly at a different wavelength. It is possible that this could be the case with the HR2000+ spectrometer, although the manufacturer claims a stray light level of less than 0.1%. Therefore, assuming an accurate wavelength calibration, it is possible from this measurement procedure to identify the filter cut-off

wavelength and any unwanted radiation. Until accurate traceability can be established, the main value is in recording regular spectral output measurements that allow changes in the spectrum or deterioration in the filter to be detected.

Recent studies report the theoretical consequential benefits resulting from a ‘square pulse’ profile resulting in a constant spectral output across the entire pulse or sub-pulse duration and leading to greater treatment efficiency (25,26). In a free-discharge IPL, as the xenon lamp reaches its maximum current density within approximately 200 μ s, there is a shift in the spectral output shown by output decay, particularly in the yellow/red region of the spectrum compared with the blue/green. Energy output at the atomic lines remains virtually constant throughout the pulse. Therefore, much of the discharged energy is wasted due to uneven distribution of wavelengths. In a later comparative

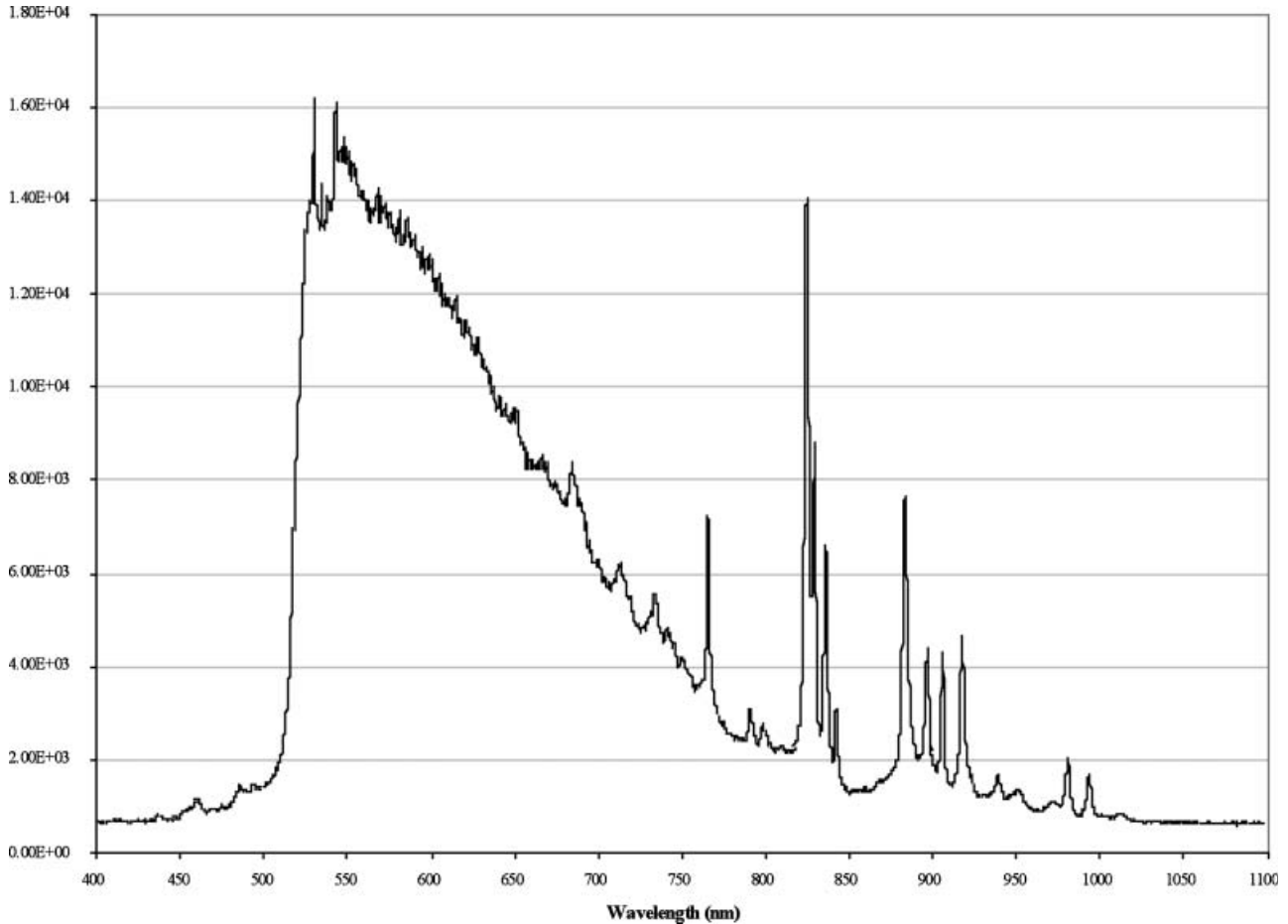


Figure 9. Example standardized spectral output measurement showing IPL 'E' with a sharp cut-off at 530 nm and typical xenon lamp spectral profile: intensity is irrelevant.

study it is intended to show time-resolved spectral output data for different devices to investigate the 'square pulse' partial discharge versus 'free discharge' argument and the potential impact on clinical outcomes (Figures 9 and 10).

Conclusions

Measurement of IPL devices is becoming an important issue but is still at a very early stage after being neglected for years because of commercial pressures and a lack of regulation. However, the popularity of IPL as a treatment is growing and there is now a definite need for measurement to help improve both safety and efficacy.

The measurements in this paper will give technicians working with IPLs a useful tool for checking output consistency and diagnosing performance issues. Discrepancies can be seen between measured parameters and manufacturer claims but caution must be exercised with this comparison because the techniques described in the paper are subject to ongoing development. In particular, traceability to national standards is a pre-requisite to accurate absolute, as opposed to relative, measurements. On the other hand, comparing different devices is useful

as discrepancies highlight the need for legislation to produce standard measurement procedures.

This study has determined easily reproducible test methods for key parameters of IPL devices and tested their validity on 18 example systems. As mentioned, further work is required if measurement results are to be made traceable to national standards. It is also hoped that a homogeneity test can be developed to provide objective measurable values to ensure even distribution of energy across skin contact areas.

Further research is required and a second trial is now underway to evaluate and compare a larger number of popularly available IPL devices in use in the United Kingdom using the test methods described in this paper.

Acknowledgements

The authors wish to thank the following companies for their contribution in reviewing the fluence test methodology used in this study: Cyden Ltd, Swansea, Wales, UK (www.cyden.co.uk); Energist Ltd, Swansea, Wales, UK (www.energist-international.com); Instinctive Technologies Ltd, Bedford, UK (www.instinctiveuk.com); and Lynton Lasers Ltd, Cheshire, UK (www.lynton.co.uk).

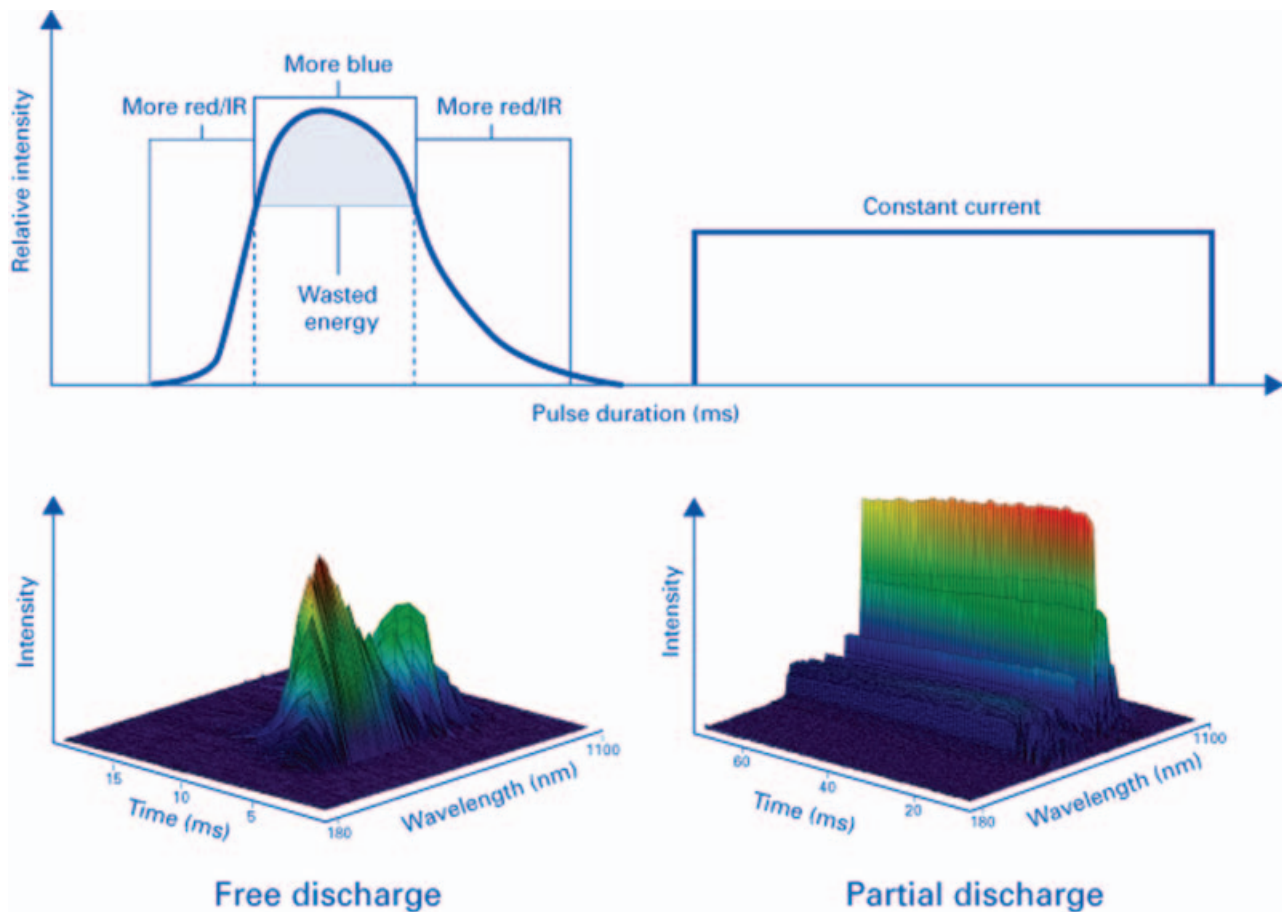


Figure 10. (Above) Schematic illustration of the difference in the spatial and temporal characteristics of a free discharge and partial discharge pulse to an IPL xenon lamp and (below) time-resolved spectral measurements of example IPL devices: free discharge (IPL ‘C’) and partial discharge (IPL ‘E’).

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