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Hazards from uncharacterized secondary reflected emissions: findings from a Canadian Armed Forces Laser Safety Investigation

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Declaration of Conflicts of Interest

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The authors of the investigation reports and presentations have not received any funding from industry and have no financial ties to any laser commercial interests.

The findings presented are the analysis and opinion of the Canadian Armed Forces National Defence Laser Safety Office and are meant to be used as lessons learned and to implement preventative measures and should not be interpreted as comment on any individual manufacturer or supplier of laser systems.

Outline

- The incident
- Analysis of the laser system
- Findings of emissions from the illumination of the incident material
- Analysis of the SOPs and PPE used during the incident
- Recommendations
- Questions

The incident

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- on 18 Sep 24 Shop 111 was set up in the High Bay area within D252 to conduct P Laser System trials and testing. During this most recent use of the 100 W laser system, three employees presented varying levels of eye discomfort to their supervisor and the FMF CB First Aid Attendant. This discomfort appeared after using the ablation equipment for approximately 1 hour duration during equipment trials. There were no previous reports of any injury on the eyes of operators previously.
- Employees attended FMFCB first aid and then individual follow up exams with their optometrists: one on 18 Sep 24 and one on 19 Sep 24:
- Employee one was diagnosed on 18 Sep 24 with photokeratitis. His symptoms completely resolved and employee one returned to work - fit full duties.
- Employee two was examined by first aid and follow on optometrist visit on 19 Sep 24 with no detectable injury to the eyes. He did not miss any work time as a result of his eye discomfort and his symptoms have completely resolved.
- Employee three was acting as a fire-watch, monitoring the temperature of the backside of a plate during laser activity. While another Laser SME was operating the laser to remove paint coatings from metal. The laser was in operation from 0830 to 0930, then took a break resuming from 1100-1130. The symptoms he described, such as blinking and seeing lines, eye straining, which lasted 12 hours. Employee three was also diagnosed with photokeratitis on 18 Sep 24.
- Employees were wearing the approved laser eyewear which have been procured with the laser equipment and subsequently tested by QETE prior to employees using them. No previous history of eye fatigue, soreness or discomfort was noted by equipment operators.
- Subsequent investigation found no history that could have produced photokeratitis other than the lasing activity.

Analysis of the laser system

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- In 2022, the Canadian Armed Forces (CAF) brought into service a QF-100, also known as the “P-Laser”. It is an inline pulsed laser cleaner system utilized by FMF Cape Breton. Independent laser safety evaluation of the P-Laser was conducted by Defense Research and Development Canada (DRDC) in November of 2019
- The CAF Technical Authority the Quality Engineering and Testing Establishment (QETE) performed the following tests;
- Ultraviolet Radiation (UVR) evaluation
- QF-100 operational functional evaluation
- Infrared (IR) spectra evaluation
- LEP recharacterization,
- QF-100 P-Laser functional test
- Laser Safety Industry LEP helmet (Shade 3) characterization and evaluation

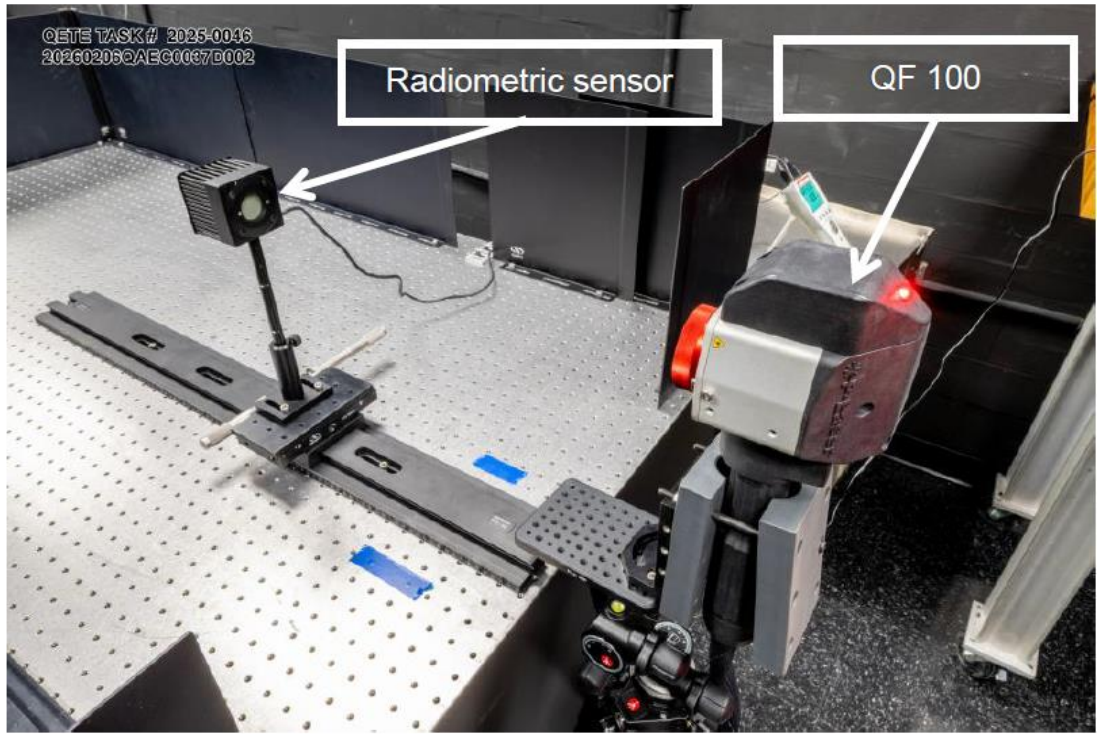
Figure 1: QF-100 P-laser

Table 2:QF-100 DRDC Laser Safety evaluation

Laser system	Class	NOHD (m)	ENOHD (m)	OD (Unaided)	OD (Aided)	NSHD (Skin)
QF-100	4	138	797	4.71	4.55	10.4

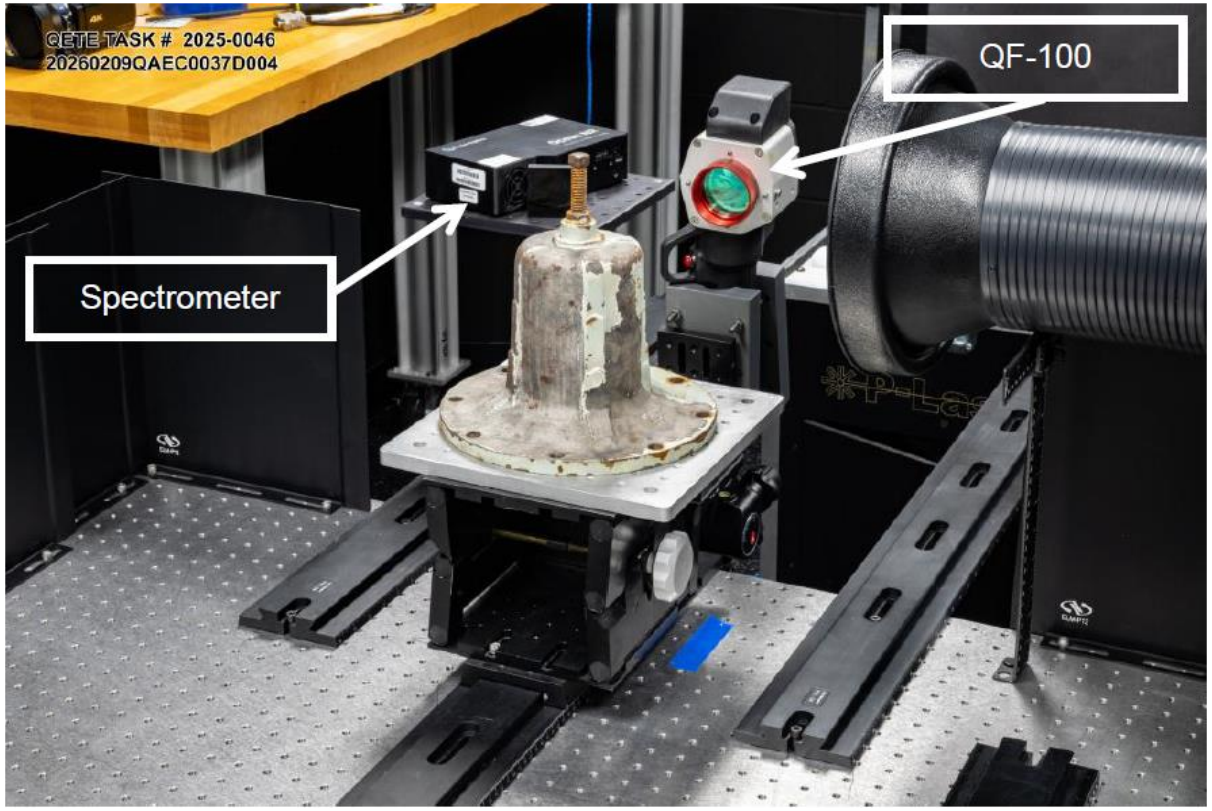
Findings

- *The UVR assessment of the QF-100 P-Laser system confirmed that no ultraviolet emissions were produced during the ablation process. Furthermore, the Vunivet laser eye protection (LEP) provides an additional optical density (OD) 6 of protection within the 200–400 nm UVR range.*
- The laser system was re-assessed and found to be working with in the specifications from the manufacture and previous testing of the system by DRDC.



Findings

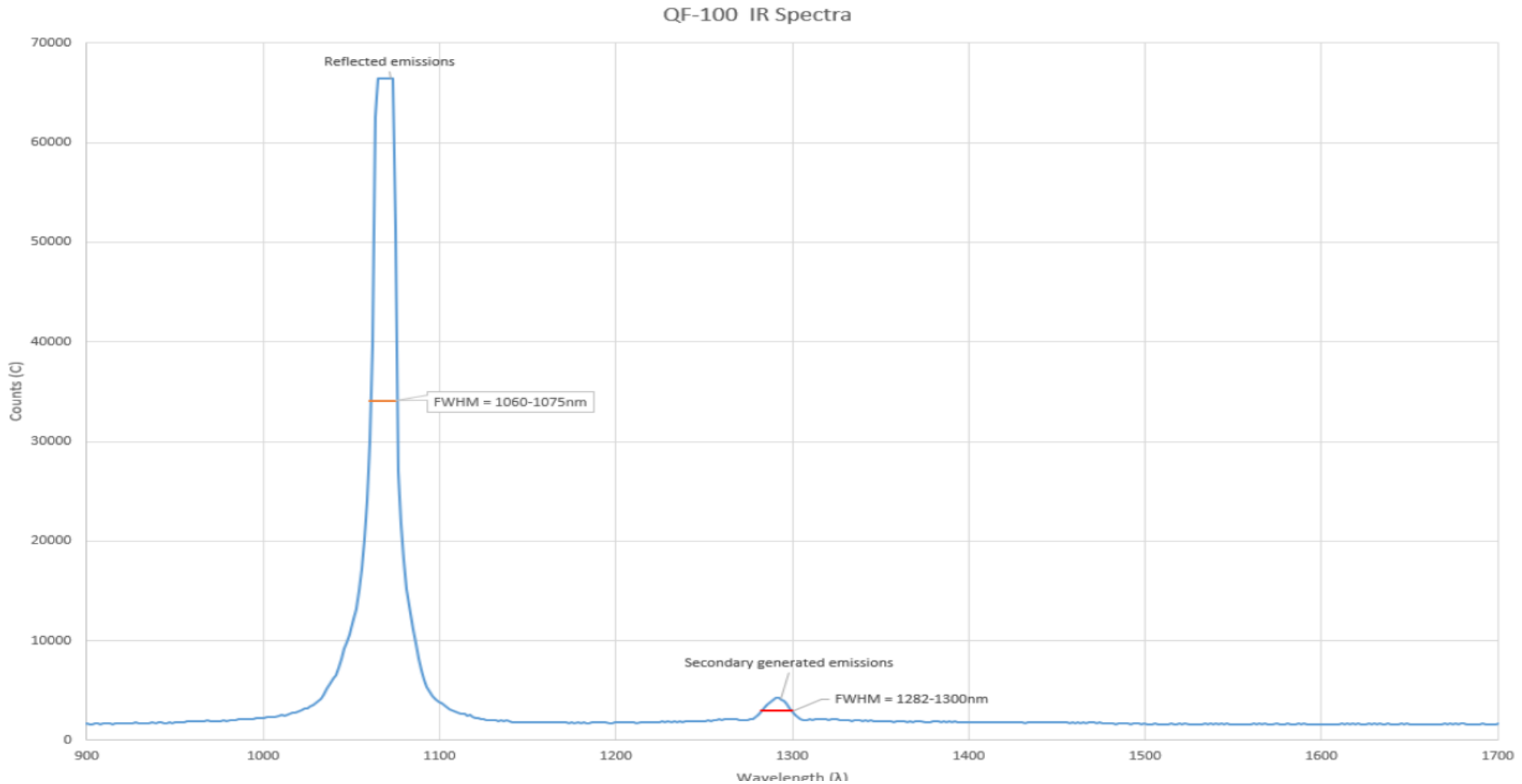
- An infrared (IR) spectral evaluation was conducted to identify the reflected beam wavelength and assess any potential secondary emissions or shifts into the retinal-corneal transition zone.



QF-100 P-Laser system (100% average power output)	Wavelength Range (nm)
Reflected IR emissions	1060-1075
Secondary IR emissions	1282-1300

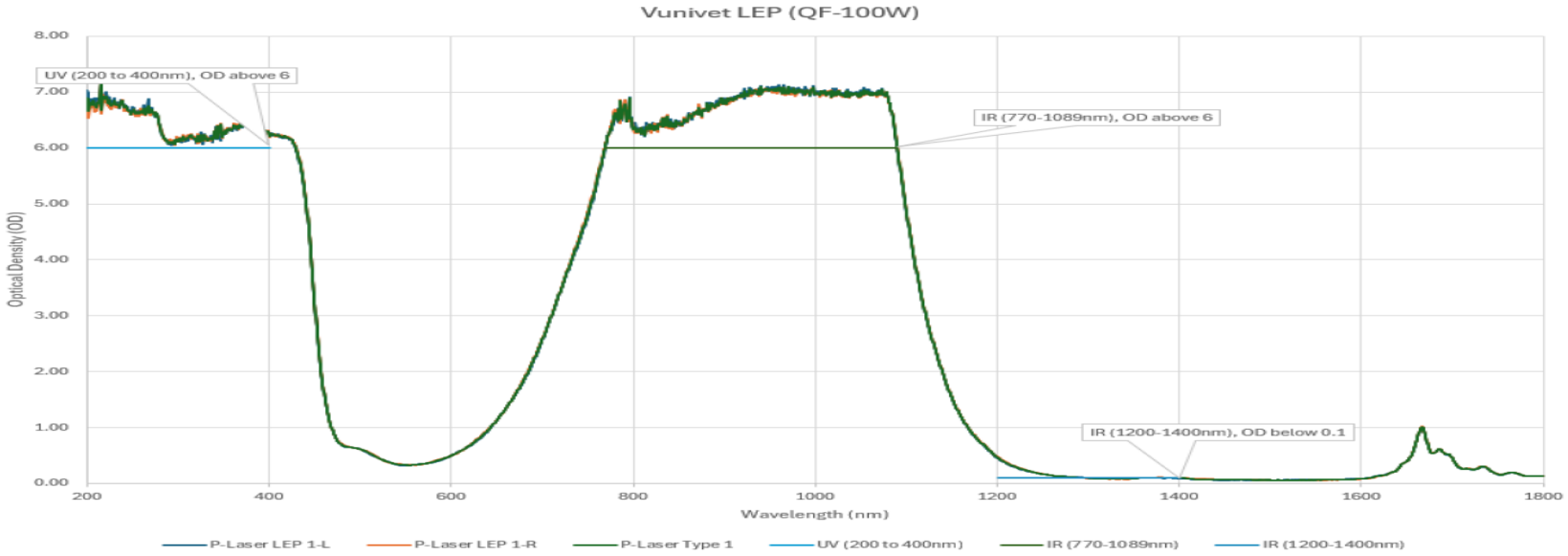
Secondary emissions were observed only when the QF-100 operated at its elevated radiometric-output setting

Findings


QF-100 IR Spectra
Reflected emissions
FWHM = 1060-1075nm
Secondary generated emissions
FWHM = 1282-1300nm
Counts (C)
Wavelength (λ)
70000
60000
50000
40000
30000
20000
10000
0
900
1000
1100
1200
1300
1400
1500
1600
1700

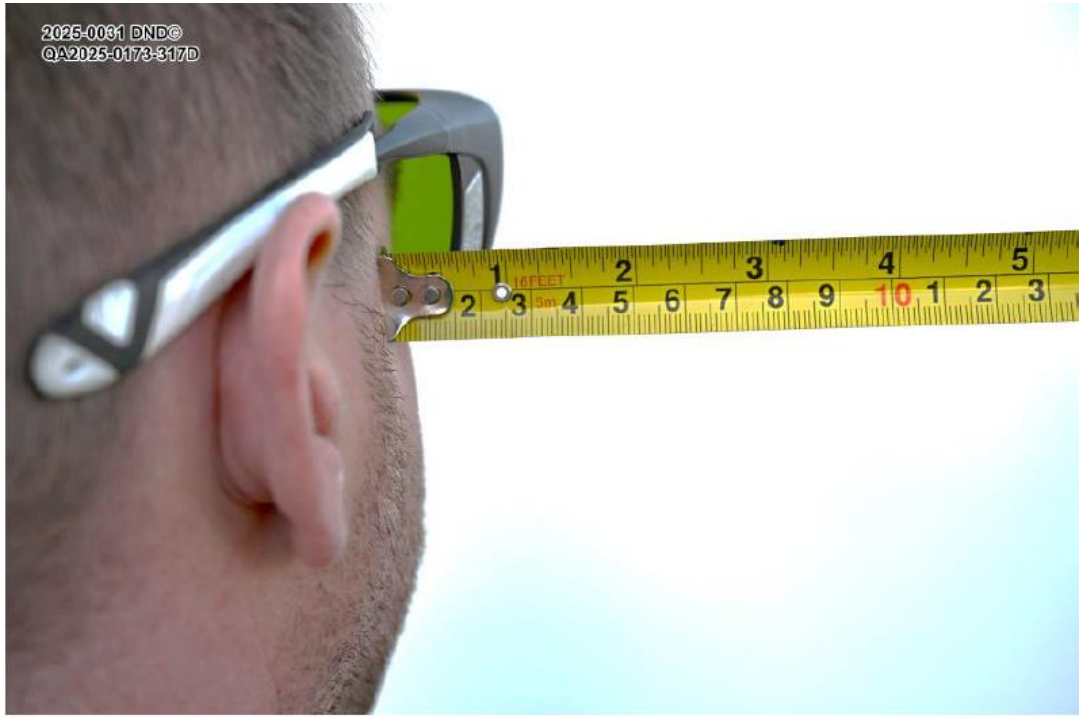
LEP Findings

Vunivet LEP	Wavelength Range (nm)	Optical Density (OD)
UV	200-400	6+
IR	770-1089	6+
	1200-1400	0.10



LEP Findings

- *The Vunivet LEP was found to provide inadequate protection against side-entering laser beams. The side shields do not sufficiently prevent exposure to reflections or stray beam ingress. A gap measuring approximately 5 × 2 cm was observed*
- The Vunivet LEP provided an average optical density (OD) of 0.10 across the secondary emission spectral band, which is insufficient to ensure adequate protection from these emissions. A minimum OD of 1 within the 1200–1400 nm range is required to provide appropriate protection against the observed secondary emissions.



Other Findings

- The employee 1 reported that employee 3 repeatedly exited and re-entered the laser safety enclosure during ablation, increasing the risk of side-entering stray beam exposure due to inconsistent positioning at a zero-degree angle to the ablation point
- Secondary emissions were observed only when the QF-100 operated at its elevated radiometric-output setting. Although these emissions were significantly lower in intensity than the primary reflected emissions, their angular distribution made it possible for lateral stray radiation to enter the small eyewear-to-face gap (“LEP gap”) at the perimeter of the bystanders’ Laser Eye Protection. The operators, positioned on-axis at a zero-degree line of sight, did not experience comparable exposure.
- The Laser Ablation created significant laser generated aerosols that may be smaller than filtration masks can block.
- Affected employees were clinically diagnosed with photokeratitis; however, spectral analysis revealed no detectable ultraviolet components. This absence of UV strongly indicates that the observed injuries were more consistent with infrared-induced corneal damage resulting from off-axis secondary emissions, rather than true photochemical photokeratitis. The combination of off-axis positioning and stray-beam ingress through the LEP gap likely elevated corneal radiant exposure sufficiently to produce the reported irritation and erythema.

Recommendations

- Laser ablating lasers and other industrial lasers that can expose workers to energy should be assessed on the intended materials to evaluate any secondary emissions.
- LEP must be appropriate and tested for OD to any secondary emissions prior to use
- Human Factors such as LEP fit, compliance and safety measures to ensure a “zero degree angle line of sight” are maintained.
- SOPs must be regularly evaluated and assessed for areas of unintended non-compliance, such as entering and exiting procedures regularly. Proper training and supervision are required.

Questions

- The NDLSO appreciates the assessment work done by QETE and Mr. Suniljeet Sandhu and his team for their work in assessing the technical laser safety issues.