Ozone health and safety considerations for FLASH radiotherapy

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INTRODUCTION

Purpose

This study compares the ozone concentration produced in a medical linear accelerator (LINAC) vault during FLASH and non-FLASH radiotherapy.

Background

Ground-level ozone is a potential health hazard because it can cause a range of acute and chronic health problems (Table 1). LINACs produce ozone by the ionization and recombination of oxygen gas. Ozone production from LINACs depends on the dose rate, volume of air irradiated, and the beam-on time. Previous studies[1] have reported ozone concentrations < 15 ppb during LINAC x-ray and electron irradiation (dose rates of 0.07 – 0.42 Gy/s at isocentre) but FLASH radiotherapy beams (dose rates > 40 Gy/s) could produce much higher concentrations.

Table 1: Ozone exposure limits and toxic effects.

Ozone Exposure Limits		Toxic Effects of Ozone
Max Concentration (ppb)	Exposure Limit	
Long-term Exposure (8-hour average concentration)		
20	Residential indoor air[2]	
50	Heavy work[3]	
80	Moderate work[3]	
100	Light work[3,4]	Minor eye, nose, throat irritation
Short-term Exposures (≤ 2 hours)		
200	Any type of work[3]	Headache, dry cough, some reduction in lung function (2 – 5 hour exposure)
10,000	Immediately dangerous to life and health[3]	Severe pneumonia (intermittent exposure)

MATERIALS AND METHODS

Vault Design and Setup

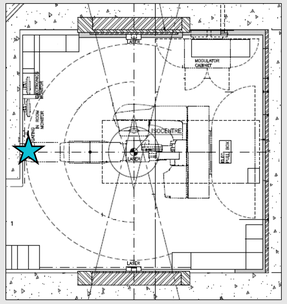

Figure 1: Schematic of the clinical vault equipped with a TrueBeam LINAC (Varian Medical Systems). The vault has 12 air changes per hour. The location of the air quality monitor is indicated by the blue star.

- FLASH electron beams (10, 15 MeV) produced by operating the LINAC at a high repetition rate, with the target and monitor chamber retracted and flattening filter replaced by an electron scattering foil
- Ozone concentration logged per minute with a portable air quality monitor (Aeroqual series 500):
  - Outside of treatment hours (no beam)
  - **Typical clinical workday**
  - **FLASH research irradiations (series of ~1s beam-on time)**
  - **Simulated non-FLASH and FLASH radiation surveys (series of ~30s beam-on time)**

Data Collection and Analysis

Temporal ground-level ozone concentration was decomposed into three time series components using seasonal-trend decomposition with locally estimated scatterplot smoothing[5] (STL):

- **Trend**: long-term changes in ground-level ozone
- **Seasonal**: pattern with fixed/known frequency (e.g., daily variation in ground-level ozone due to UV rays)
- **Residual**: irregular, short-term fluctuations

RESULTS AND DISCUSSION

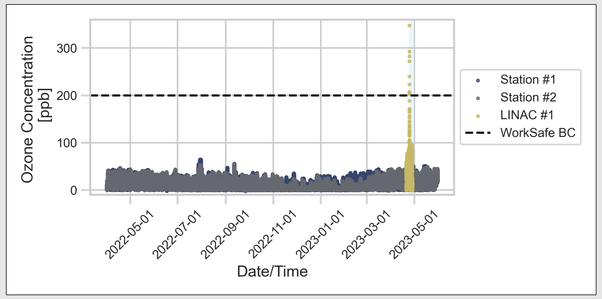

Figure 2: Ozone concentration measured in a LINAC vault compared to that measured at two nearby air quality monitoring stations.*

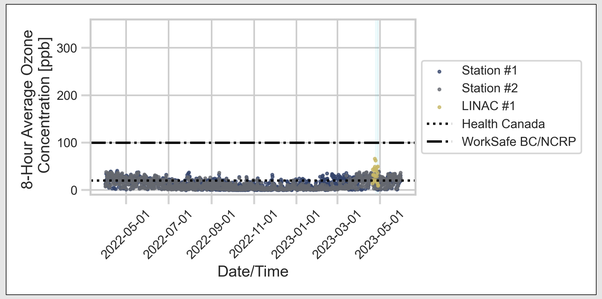

Figure 3: 8-hour average ozone concentration measured in a LINAC vault compared to that measured at two nearby air quality monitoring stations.*

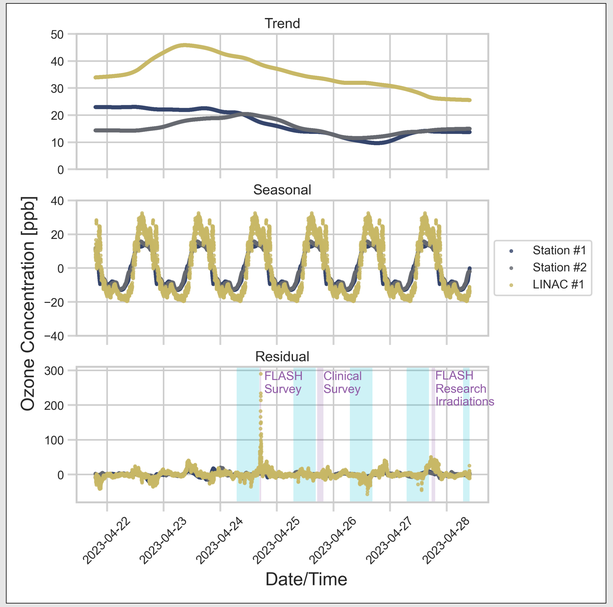

Figure 4: STL analysis of ozone concentration from Figure 2. The median (range) ozone concentration measured above background during a radiation survey of FLASH beams was 67 ppb (5 – 290 ppb). Following the radiation survey, the ozone concentration decayed approximately exponentially with a half-life of 7 minutes.

CONCLUSIONS

- Ozone concentration during clinical and research irradiations is safe and below recommended maximum exposure limits for staff
- Increased ventilation, increased time between irradiations, and/or room entry limitations are required to reduce staff ozone exposure during FLASH radiation surveys

REFERENCES

[1] Hara *et al Radiat Oncol* 17:39 (2022).

[2] Health Canada, "Residential Indoor Air Quality Guideline: Ozone" (2010).

[3] WorkSafe BC, "Ozone Safe Work Practices" (2006).

[4] NCRP Report No. 151 (2005).

[5] Cleveland *et al J Off Stat* 6(1): 3 – 33 (1990).

*Ground-level ozone data from nearby air quality monitoring stations was collected from the BC Data Catalogue (licensed under the Open Government Licence – British Columbia version 2.0).

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