**Risk assessment for Carbon Monoxide exhausted from MW Plasma reactors in S110 and S111**

Use of CO2/CH4/H2 plasmas within the microwave plasma enhanced CVD reactors results in the production of CO as a by-product. This CO will be present within the exhaust gas. Use of an input CO2 flow rate of 200 sccm (diluted with CH4 and H2 to a total flow of ~500 sccm) will result in a comparable CO flow rate in the exhaust gas leaving the chamber.

**Carbon Monoxide (CO):**

Toxic by inhalation. risk phrase, R23

Danger of cumulative effects. R33

Danger of serious damage to health by prolonged exposure. R48

May cause harm to the unborn child. R61.

Highly flammable gas. R12

Readily forms explosive mixtures with air. Explosive limit 12-75% in air.

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| **Concentration** | **Symptoms** |
| 35 ppm (0.0035%) | Headache and dizziness within six to eight hours of constant exposure |
| 100 ppm (0.01%) | Slight headache in two to three hours |
| 200 ppm (0.02%) | Slight headache within two to three hours; loss of judgment |
| 400 ppm (0.04%) | Frontal headache within one to two hours |
| 800 ppm (0.08%) | Dizziness, nausea, and convulsions within 45 min; insensible within 2 hours |
| 1,600 ppm (0.16%) | Headache, tachycardia, dizziness, and nausea within 20 min; death in less than 2 hours |
| 3,200 ppm (0.32%) | Headache, dizziness and nausea in five to ten minutes. Death within 30 minutes. |
| 6,400 ppm (0.64%) | Headache and dizziness in one to two minutes. Convulsions, respiratory arrest, and death in less than 20 minutes. |
| 12,800 ppm (1.28%) | Unconsciousness after 2-3 breaths. Death in less than three minutes. |

**Precautions**

The output mixture is diluted with a large flow of air so as not to reach toxic or explosive limits and exhausted from the laboratory through ducting that is linked to a fan on the roof of the School of Chemistry. The air flow in this ducting is monitored continuously; an alarm sounds if the flow drops below a pre-set level. CO monitors are located near the exhaust pump and the air intakes into the ducting; these are set to sound if the local CO concentration exceeds 10 ppm.

If the air-flow alarm or CO-monitor alarms go off, the microwave power supply and the mass flow controllers (MFCs) and regulators on all gas cylinders (but especially CO2) should be shut off immediately, and the reactor chamber left to pump down to vacuum.

CO monitors need to be tested regularly, by exposure to dilute CO/air mixture.

**Worst case CO concentration in the exhaust gas flow**

If we assume that all carbon containing gases in the input feed are completely converted to CO, the maximum possible flow rate of CO out of the chamber would be 400 sccm.

The exhaust pipe has a radius of ~8 cm, and the flow velocity through the pipe is 4.7 m s-1.

Total air flow per min = 4.7 × 0.082 × π = 0.0945 m3 s-1 = 5.67 m3 min-1

of which F(CO) ≤ 400 sccm

 = 4×10-4 m3 min-1

Mixing ratio of CO in the gas *in the duct* is ≤ 4×10-4 / 5.67 ≈ 70.54 ppm; in the laboratory it should be orders of magnitude lower.