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# Sensitivity Reliability of Gas Imaging Leak Detection of $SF_6$

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# IR Gas Leak Detection Sensitivity Reliability

- Infrared (IR) Gas Leak Detection Sensitivity
  - The minimum measured and certified leak rate the IR camera can image.
- Sensitivity Reliability
  - The ability of the IR camera to image a gas leak at the minimum certified leak rate 100 % of the time under predefined operational and environmental conditions.
- Why is this important?
  - When using IR gas imaging to locate gas leaks from $SF_6$ switchgear, the operator must have confidence in the camera's ability to reliably image leaks at or above a predefined sensitivity level.
- What controls the IR camera sensitivity reliability?

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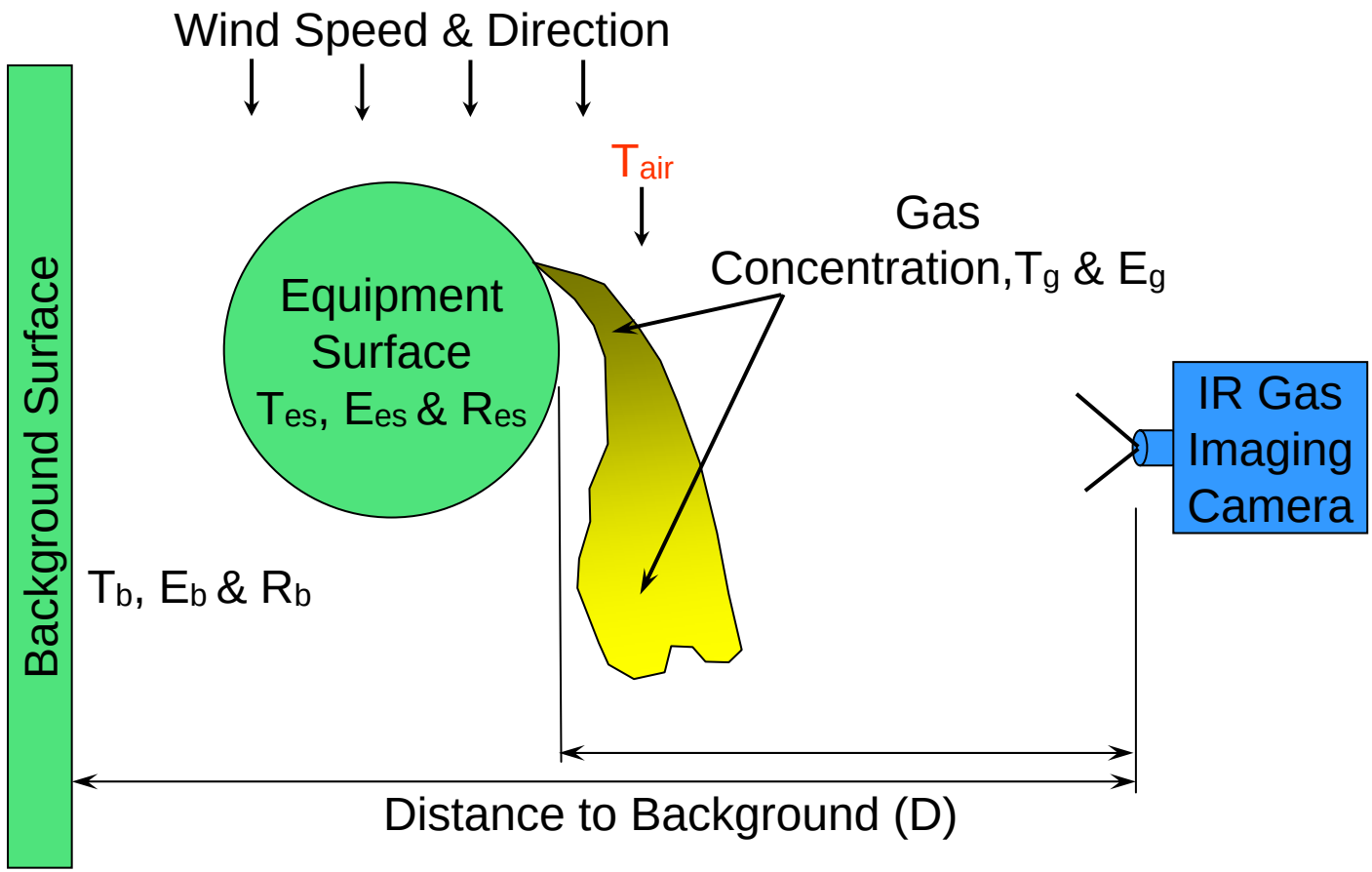
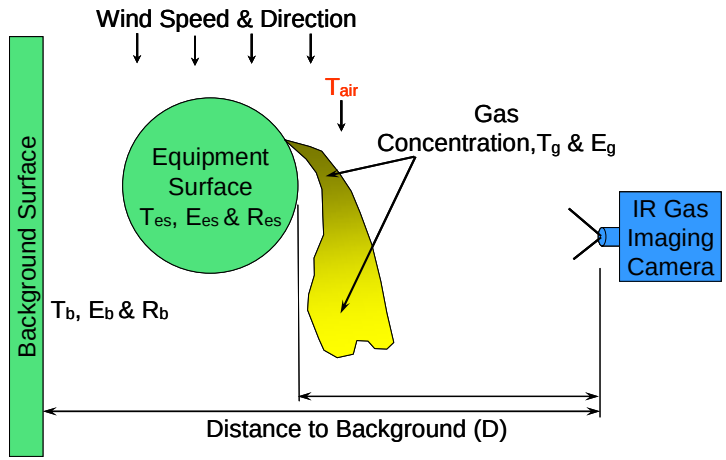
# Important IR Gas Imaging Variables



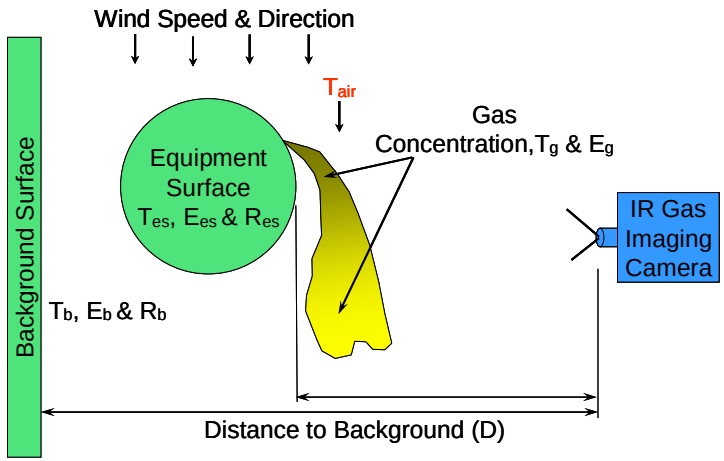
# IR Gas Imaging Variables (continued)

- The following physical variables determine the leak detection sensitivity of currently available IR gas imaging cameras.
  - Temperatures (T)
    - $T_b$ – temperature of the background.
    - $T_g$ – temperature of the gas to be surveyed.
    - $T_{es}$ – temperature of the equipment surface *(which in most cases is the background).*
    - $T_{air}$ – temperature of the air mixing with leaking gas changes the gas temperature.
  - Reflectivity (R) – a fraction representing the efficiency of reflection of laser light. Reflectivity is surface dependent.
    - $R_b$ – reflectivity of the background.
    - $R_{es}$ – reflectivity of the equipment surface.



# IR Gas Imaging Variables (continued)

- Emissivity (E)
  - $E_g$ – a fraction (value between 0 and 1) that represents the efficiency of the IR energy emitted and absorbed by the gas to be surveyed. Emissivity is gas dependent.
  - $E_b$ – a fraction that represents the efficiency of the IR energy emitted from the background.
  - $E_{es}$ – a fraction that represents the efficiency of the IR energy emitted from the equipment surface.




- Radiance
  - The IR light emitted from the gas and equipment/background surfaces.
  - Radiance is a function of temperature and emissivity, and is gas and surface dependent.

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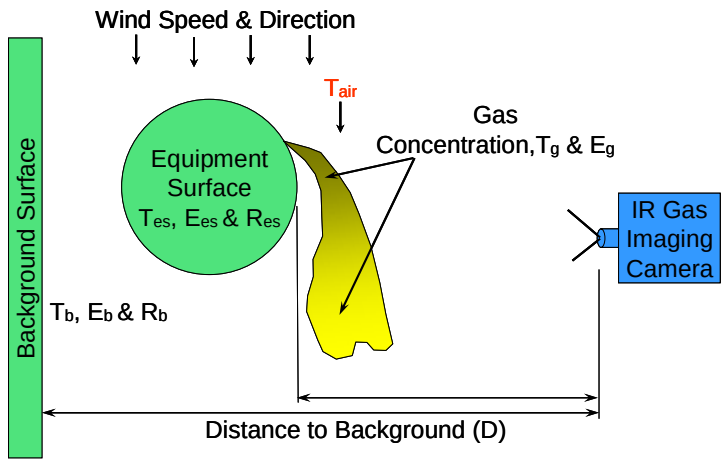
# IR Gas Imaging Variables (continued)

- Gas Concentration
  - Strongly dependent on the leak rate.
  - The higher the gas concentration, the stronger are its radiance and absorption of the laser light.




- Distance (D) – the distance from the IR gas imaging camera to the background.
- Wind Speed and Direction – high winds (20 to 30 knots) and direction reduce detection sensitivity as leaking gas is more rapidly dispersed from the leak source.

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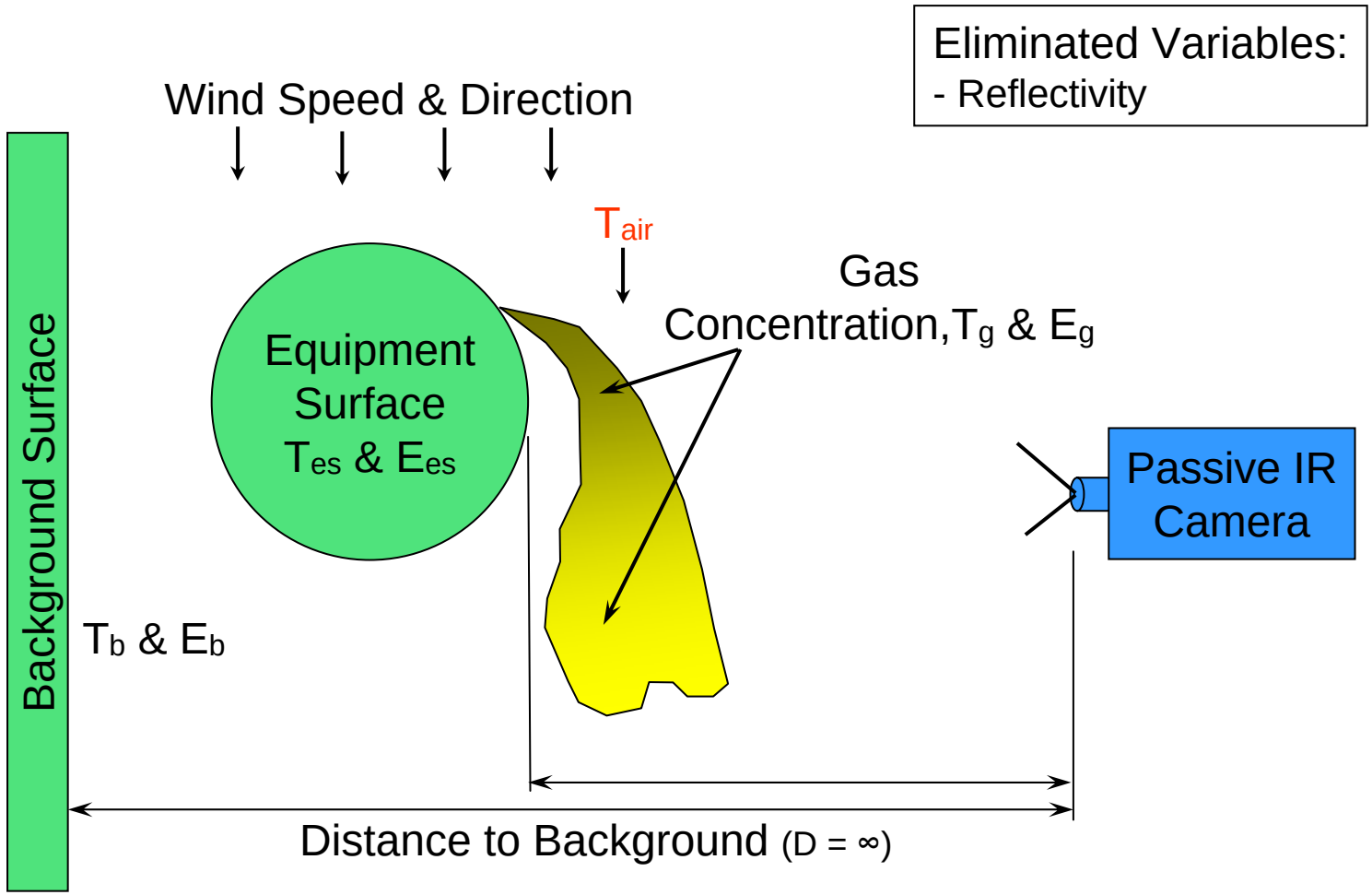
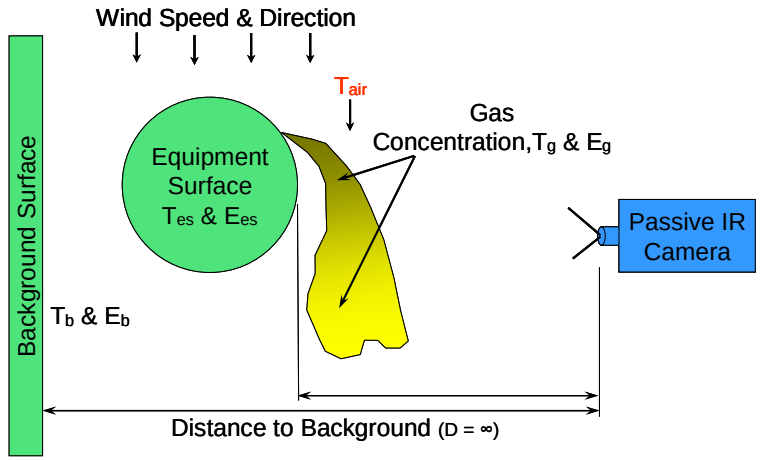
# *Passive* IR Gas Imaging Variables



# *Passive* IR Gas Imaging Fundamentals

- Camera detector spectral bandwidth must include maximum gas emissivity for best detection sensitivity.
- Gas detection range is unlimited.




- Leakage cloud image produced by net difference between cloud gas radiance and radiance from background surface.
  - The gas will appear either white or dark against the background depending on whether the gas radiance is greater or less than the background radiance.
  - When the gas radiance is equal to the background radiance the gas becomes transparent against the background.

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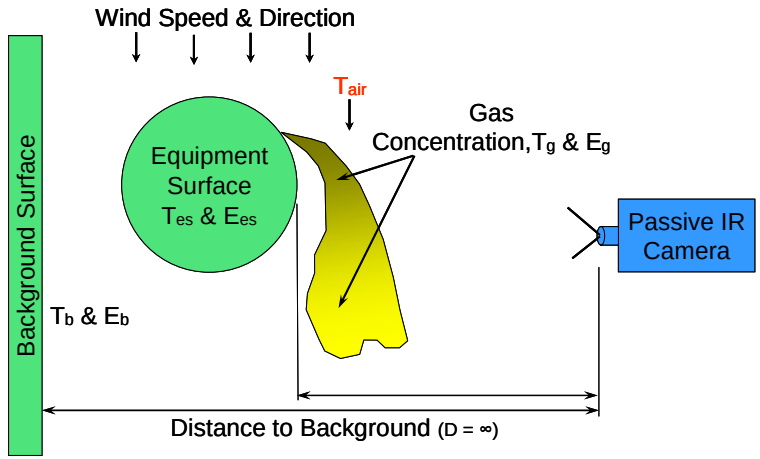
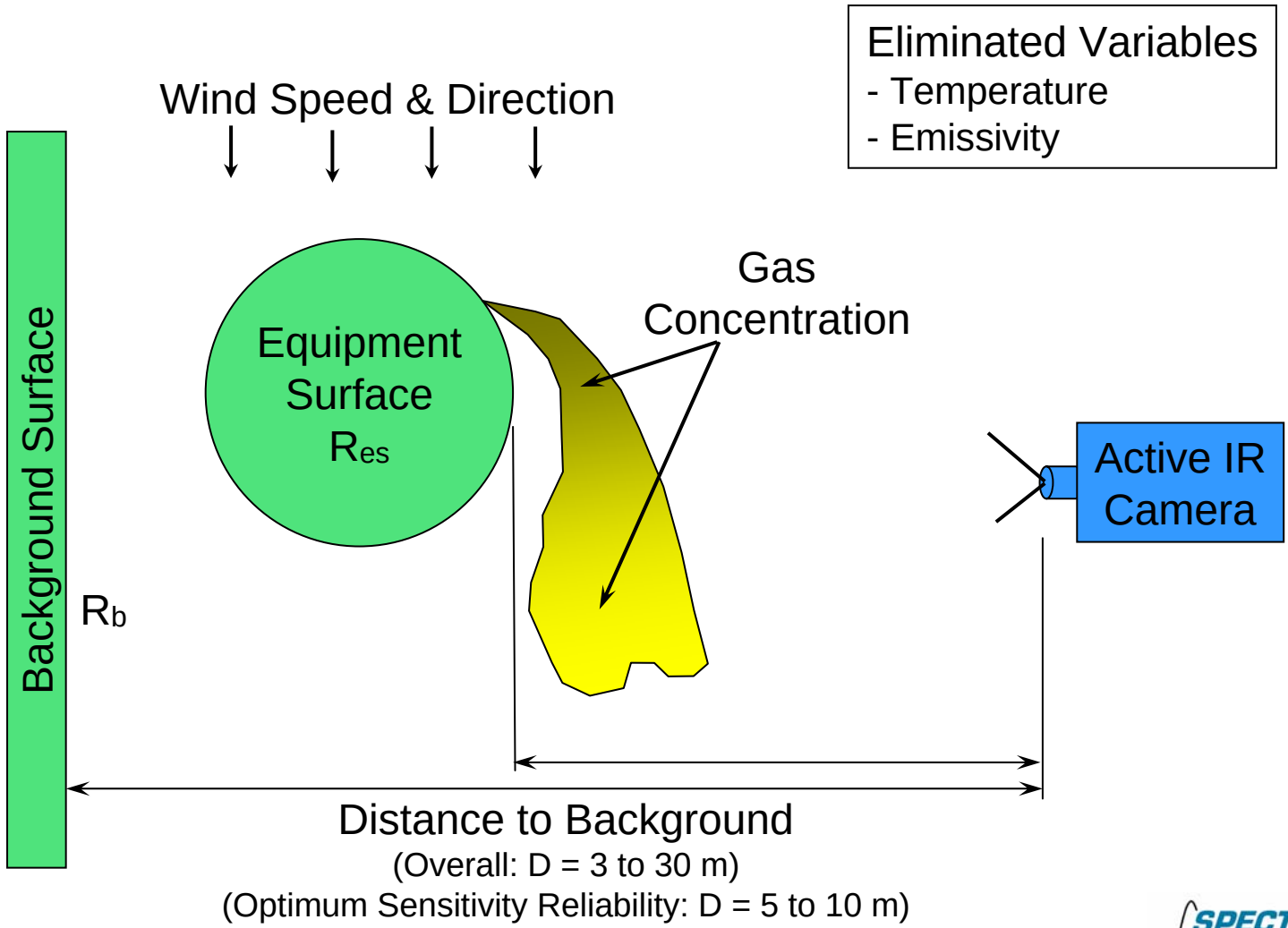
# *Passive* IR Gas Imaging Fundamentals (continued)



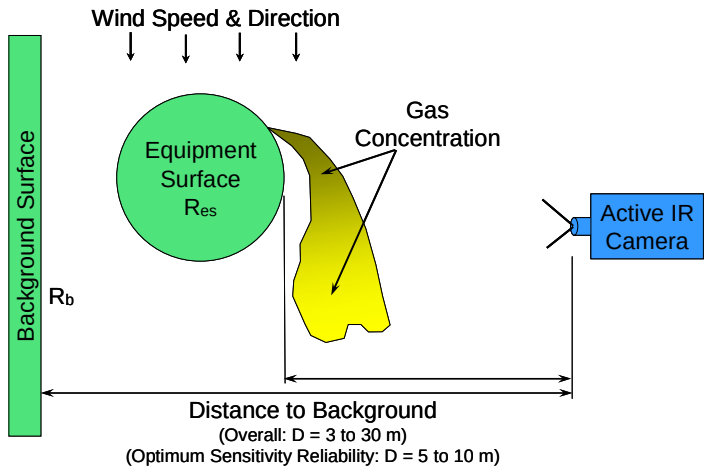

- Any number of combinations of temperature and emissivity for both or either the background and the gas can cause the radiance of the gas and background to be equal. For example, a background surface radiance with high $T_b$ and low $E_b$ can be equal to the gas radiance with a low $T_g$ and a high $E_g$ which would result in the gas being transparent to the operator.
- Due to the multiple combinations of background and gas temperatures and emissivity encountered during a normal Electric Utility $SF_6$ survey, it is impossible to predict when specific combinations might result in the gas becoming transparent. The operator is thus uncertain whether he has obtained a successful gas leak survey.

# *Active* IR Gas Imaging Variables



# *Active* IR Gas Imaging Fundamentals

- Requires a match between the laser wavelength and the maximum gas absorption wavelength for best detection sensitivity.
- A reflective surface must be behind the gas cloud (the equipment surface will suffice as this reflective background).
- The overall operational range is 3 to 30 meters.

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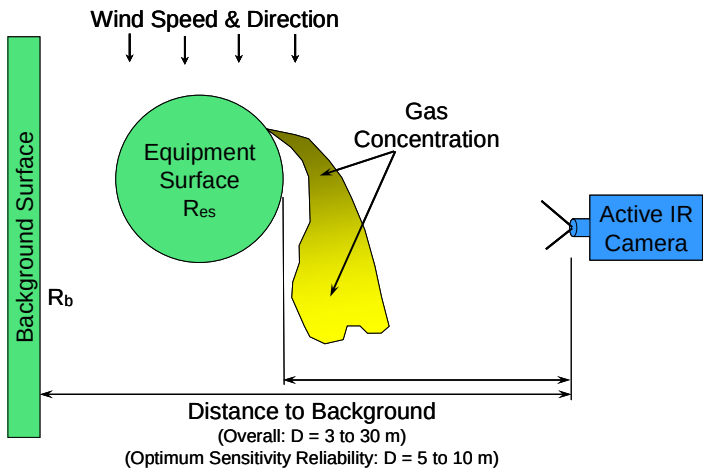
# *Active* IR Gas Imaging Fundamentals (continued)

- Gas leakage cloud image produced by absorption of laser illumination by gas cloud.
  - Detection sensitivity is independent of gas, background and air temperatures ($T_b$, $T_g$ and $T_{air}$).
  - Gas and background radiance are no longer controlling factors related to gas leak imaging.




- The non-controllable variables are gas concentration and background surface reflectivity which can be bounded within the calculation of a certified detection sensitivity simply be getting closer to the background (5 to 10 meters).

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# IR Camera Sensitivity Reliability (MDLR)

- Minimum Detectable Leak Rate (MDLR)
  - The lowest gas leak rate reliably observed (≥ 95%) by the gas imaging camera operator.
  - Since both Passive and Active cameras actually depend on the gas concentration (not the leak rate), a calibration of wind speed and gas flow direction will be required for minimum detectable leak rate certification.
- Passive IR Camera MDLR
  - Due to the unknown and constantly changing background and gas radiances, a certified $SF_6$ MDLR under typical substation survey conditions is not possible.
- Active IR Camera MDLR
  - Within the operational range, an active IR camera can deliver a certified MDLR (0.12 cc/min or 1 lb/yr) when surveying for $SF_6$ gas leaks under typical substation survey conditions.

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