

# UVGI - Friend or foe?

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Presented by Geoff Abbott

for the **architectural engineering research** group

CSIR Built Environment unit

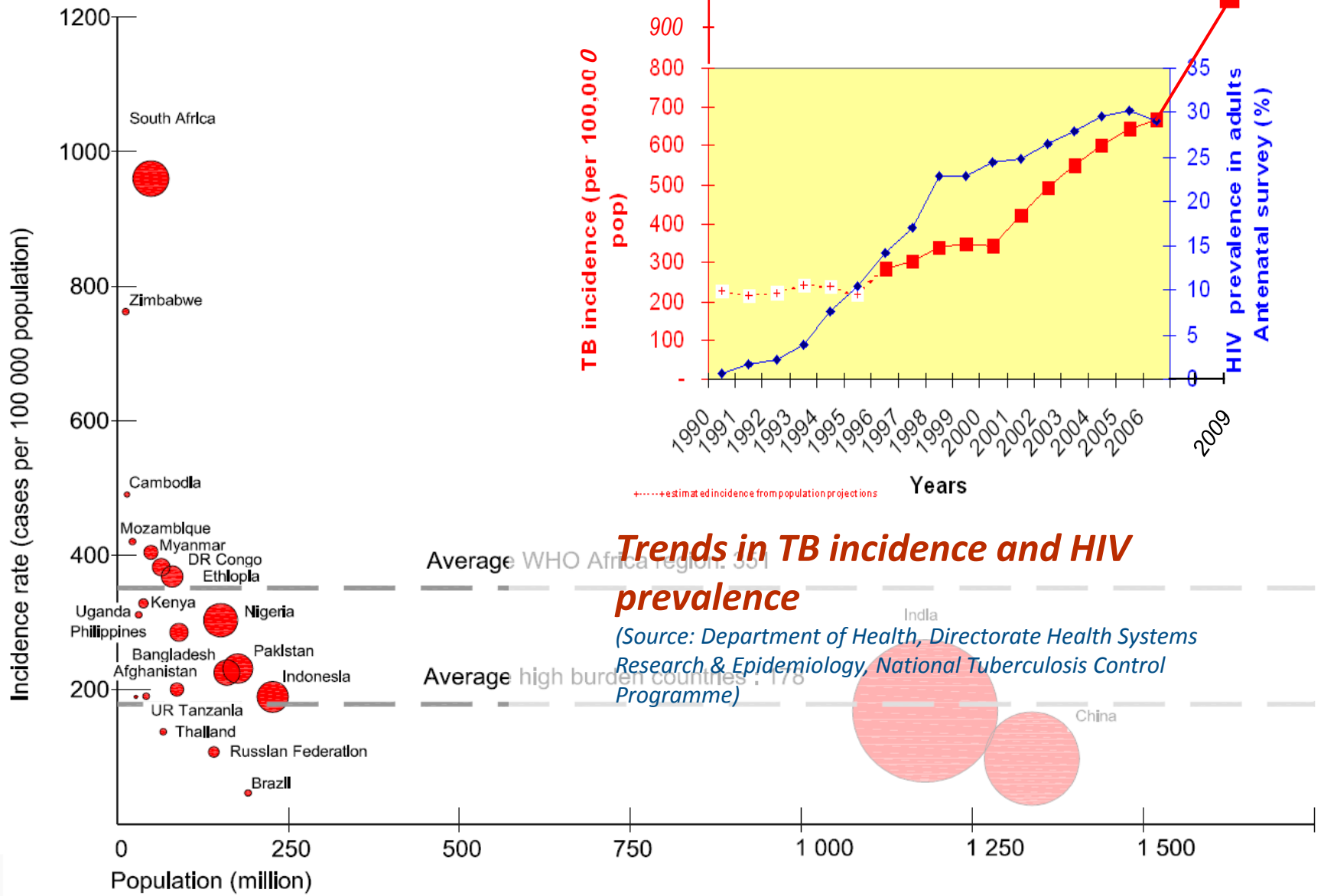
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# Overview of the presentation:

- Transmission of TB
- What is UVGI?
- Inactivation mechanism of UVGI on TB
- UVGI applications
- Upper-room UVGI
- Scientific studies
- UVGI advisory note
- Natural ventilation comparator
- Conclusion



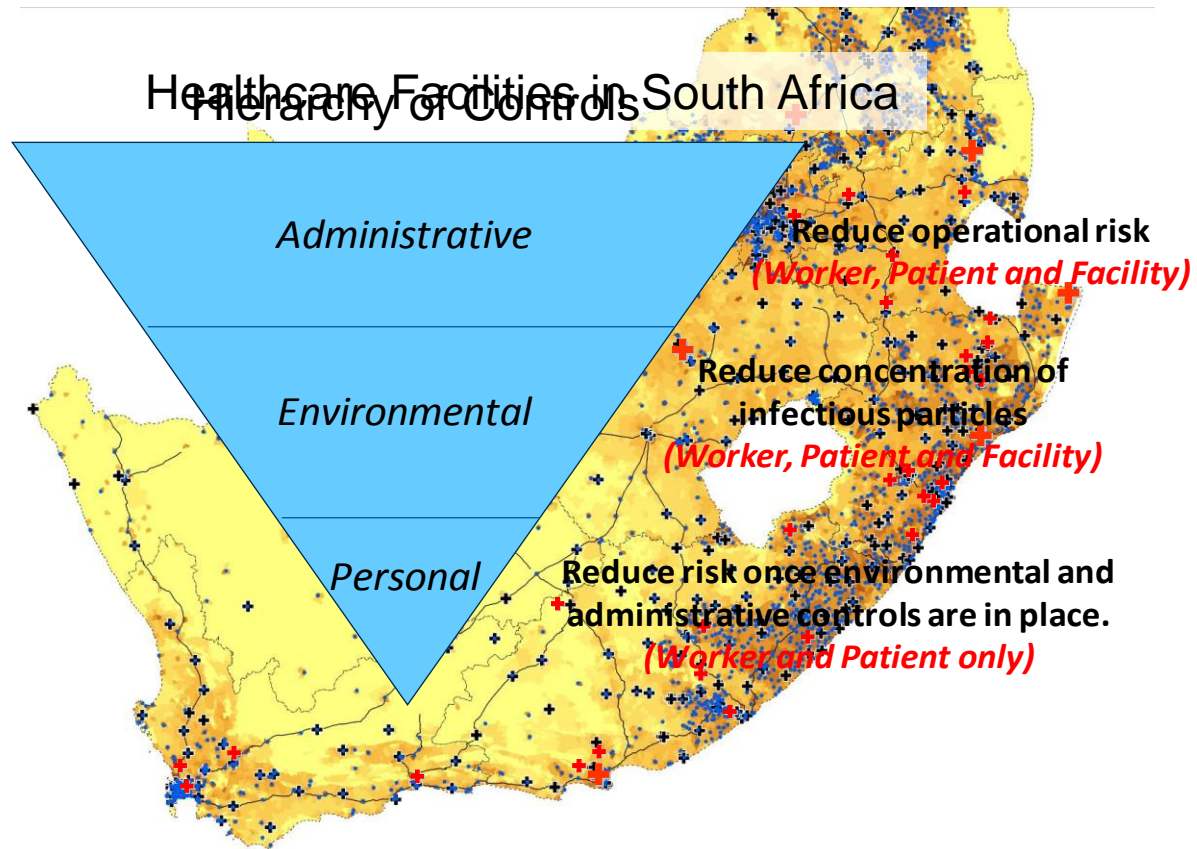
Healthcare facilities bring susceptible and infectious individuals together

And

we have 4000 facilities which cannot all be readily re-engineered for infection prevention and control

So

Wouldn't it be useful to have a sterilisation device which could be retrofitted?



# Airborne pathogens

- Bacteria
  - Measles
  - Tuberculosis
  - Varicella
- Bacterial spores
- Viruses
  - Influenza A
  - Picornavirus
  - Adenovirus
  - Coronavirus (SARS)
- Fungal spores

Possibility of bioterrorism

Collateral benefit - allergenic or odour relief

Re-suspension and flushing



*Riley Wells experimental TB ward, Baltimore 1958-62:  
Source Nardell 2010*

# The airborne transmission of TB

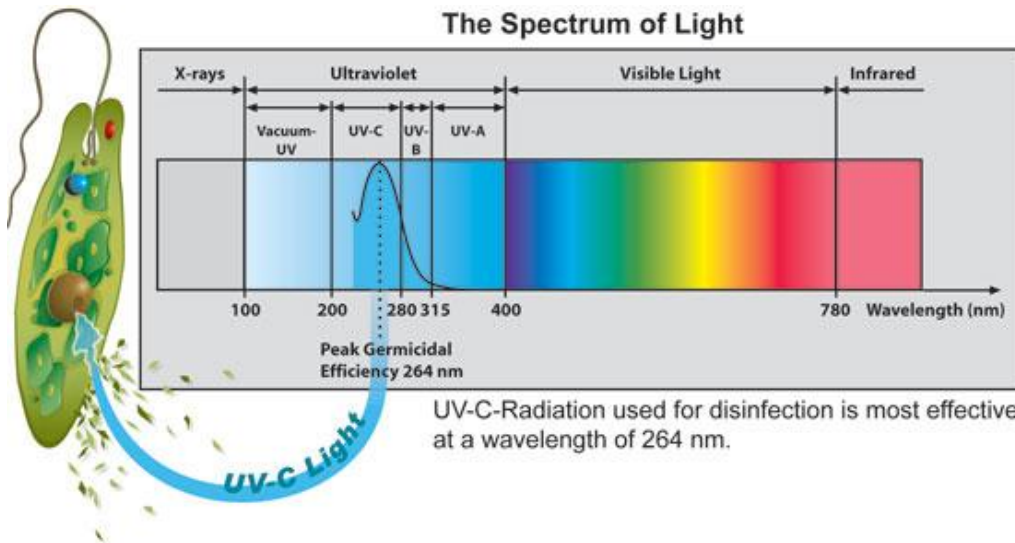


- Large droplets fall to the floor
- Smaller drops become aerosolised
- Droplet nuclei of about 5 microns are formed
- Environmental conditions must be conducive to pathogen survival (temperature, humidity)

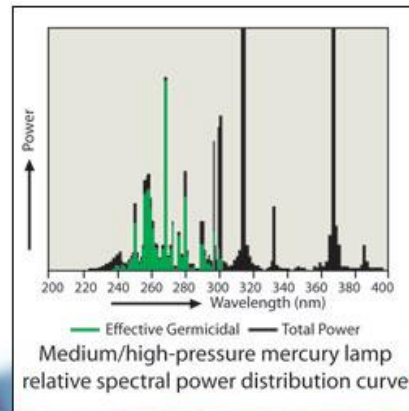
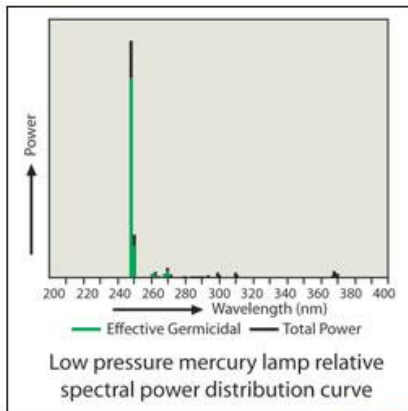
*Tang and Settles  
Schlieren photography*

<http://www.multimedia.kolobrzeg.pl/tag/th-image/>

# What is UVGI? Ultraviolet Germicidal Irradiation



- germicidal peak – 264 nm
- UV-C - 253.7 nm
- NOT IN SUNLIGHT



Comparison between low pressure mercury arc lamps and medium/high pressure mercury lamps

Examples of UVGI fittings found in South African healthcare facilities (Source Technilamp)

# Inactivation mechanism of UVGI

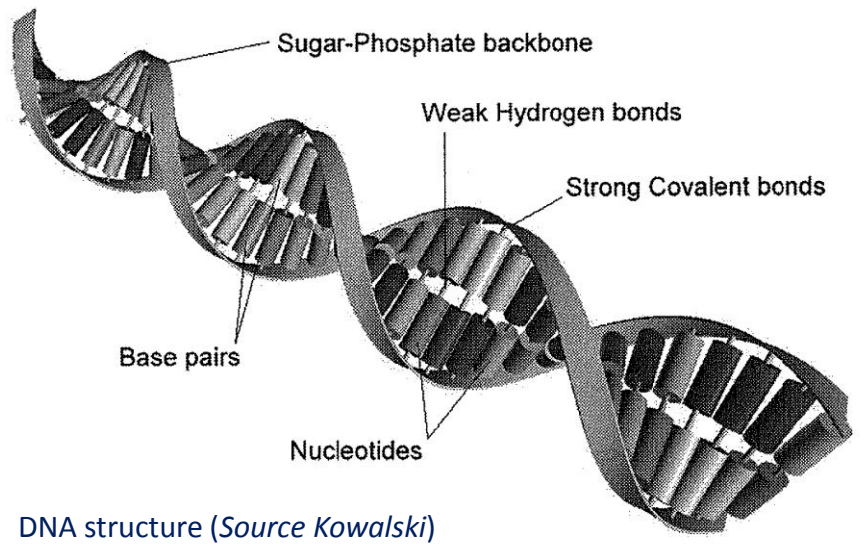
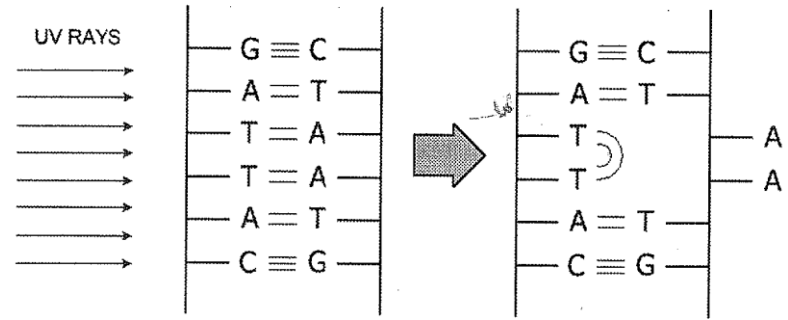
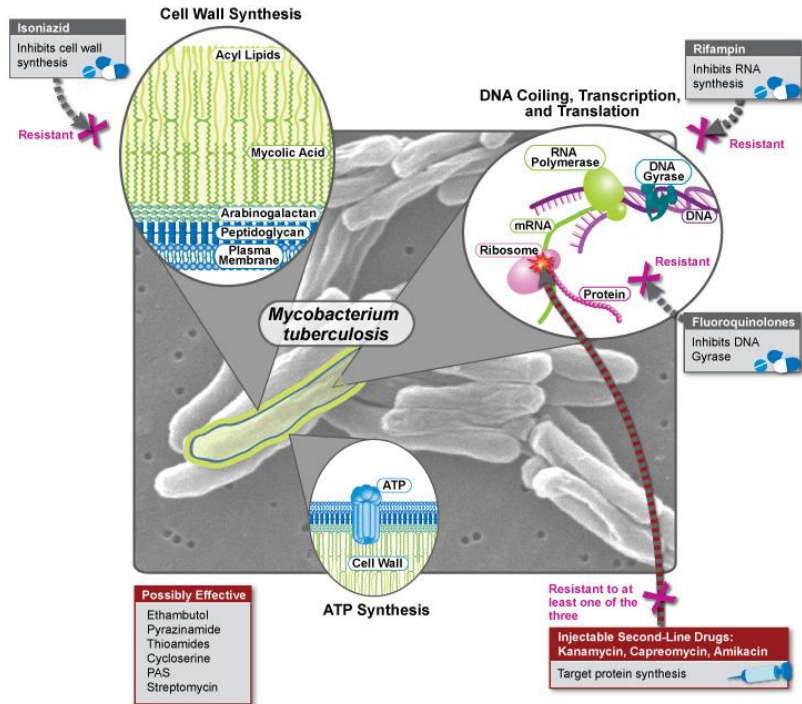


Figure 2: *Mycobacterium tuberculosis* (Source National Institute of Allergy and Infectious Diseases (NIAID))

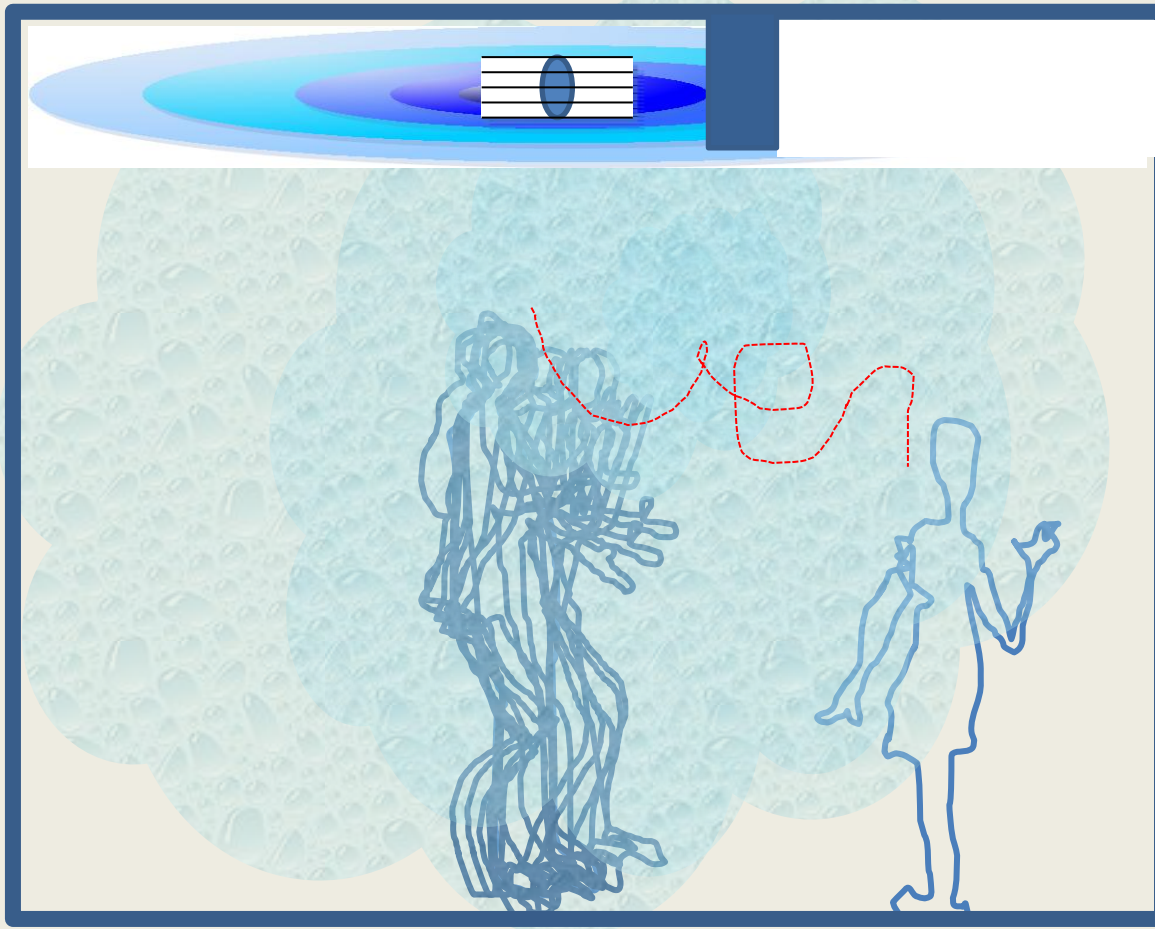
DNA structure (Source Kowalski)



Increased relative humidity favours TB survival

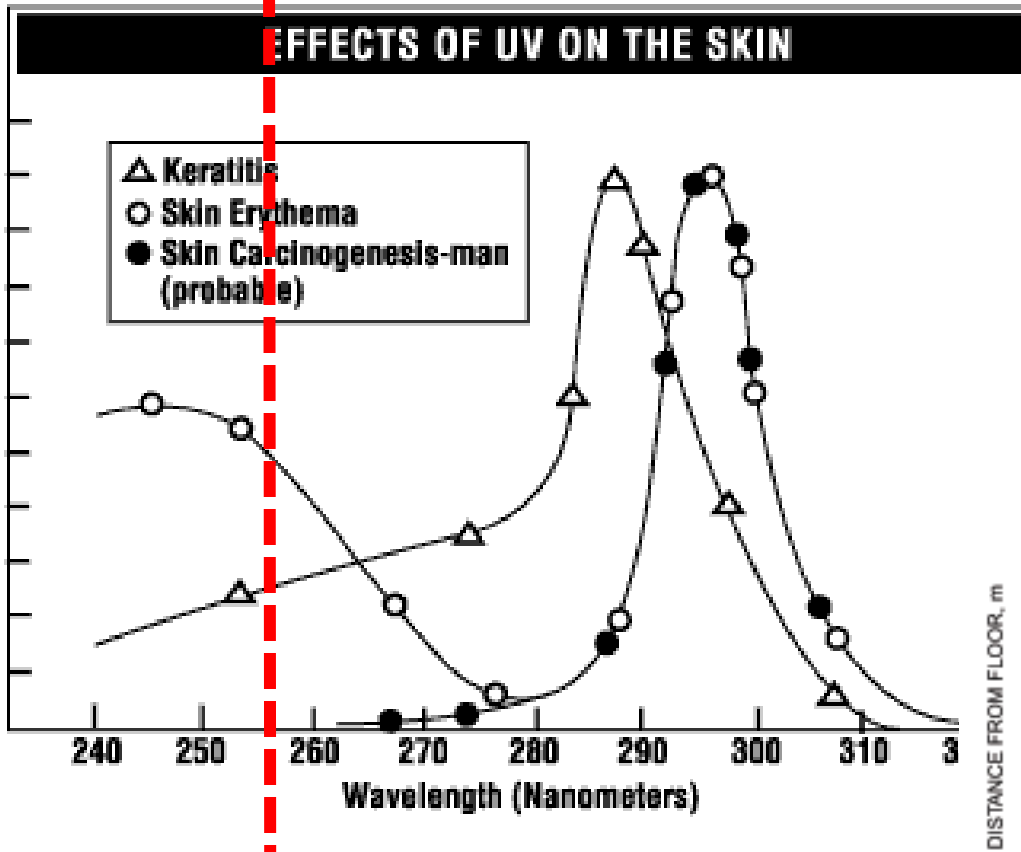
Year	Event	Reference
1672	Isaac Newton uses prisms to disperse sunlight	
1814	Fraunhofer maps spectral bands of sunlight	Hockberger 2002
1835	Wheatstone invents mercury vapor arc lamp	Hockberger 2002
1850	Stokes invents quartz arc lamp that produces 185 nm	Hockberger 2002
1842	Becquerel and Draper find 340-400nm light photoreactive	Hockberger 2002
1877	Bactericidal effects of sunlight demonstrated	Downs and Blunt
1889	UV light demonstrated to be erythematous	Widmark
1892	UV component of sunlight identified as biocidal	Ward
1892	Geissler demonstrates arc lamps lethal to <i>B. typhosus</i>	Hockberger 2002
1903	UV spectrum from 226 to 328nm found to be germicidal	Barnard and Morgan
1904	First quartz lamp for UV developed	Lorch 1987
1906	UV used to disinfect drinking water	van Recklinghausen 1914
1921	UV photoreactivity with TiO <sub>2</sub> demonstrated	Renz
1925	UV photodegradation of materials demonstrated	Luckiesh and Taylor
1927	Erythematous action spectrum published	Hausser and Vahle
1927	Bactericidal action scientifically quantified	Bedford and Gates
1928	Virucidal action scientifically quantified	Rivers and Gates
1929	Fungicidal action scientifically quantified	Fulton and Coblentz
1932	UV germicidal peak at 253.7nm isolated	Ehrismann and Noethling
1932	Erythematous action spectrum quantified	Coblentz <i>et al.</i>
1936	Overhead UV system in hospitals	Wells and Wells, Hart
1936	UV photoreactivation phenomena identified	Pratt
1937	Upper air UV to schools	Wells
1938	Fluorescent gas discharge UV lamp	Whitby and Scheible 2004
1940	UV to airconditioning systems	Rentschler and Nagy
1942	UV air disinfection sizing guidelines	Luckiesh and Holladay
1950	First catalogue sizing methods (General Electric)	Buttolph and Haynes
1954	UV reduce micro-organisms impingement on AHU	Harstad <i>et al.</i>
1954	UV is ineffective (faulty study)	MRC
1957	UV is effective for TB	Riley
1959	Microbes on cooling equipment causes respiratory infection	Anderson
1974	Microbial growth control systems	Grun and Pitz
1985	Cooling coil UVGI (European Breweries)	Phillips
1997	UV LED's at 265nm	Guha and Bojarczuk
2003	In-duct UVGI demonstrated to reduce illness symptoms	Menzies <i>et al.</i>
2007	Overhead UV system reduces surgical site infections	Ritter <i>et al.</i>

# Upper room UVGI installations

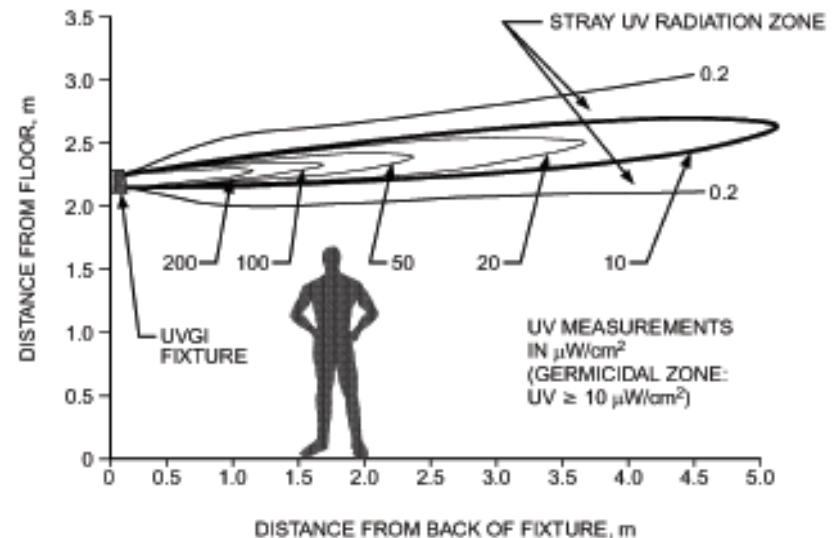


- For inactivation to occur, droplet nuclei need to reach the disinfection zone
- Inactivation is a time dependant process
- This inactivation time is also dependant on the fluence rate
- There is reflection off surfaces (ceilings)
- There are shadows behind objects in the room

# Upper room UVGI safety



- CDC/NIOSH guidelines recommend a maximum fluence rate of 6mJ/cm<sup>2</sup> for 8 hours in the lower room
- High fluence rates in the lower room may lead to keratitis and skin erythema



# Considerations

Is the technology

- non-harmful,
- effective,
- useful,
  - cost effective
  - compatible with existing circumstance (for example ergonomics of retrofitting), and
- user-friendly
  - should not undermine comfort conditions
  - easy to maintain
  - acceptable noise levels
  - energy efficient

?

# Upper room UVGI safety

- Ozone generation (toxic)
- Mercury content
- Reactivation
  
- FALSE SENSE OF SECURITY:
  - Lamps deteriorate over time but still emit reassuring glow
    - “identical” lamps do not perform the same
  - Maintenance schedules (annual at best)
  - No budget for maintenance (maintenance \$ = installation \$ at +/-5years)
  - Power supply uncertainty
  
- Legislation on UVGI limited to electrical compliance
- Lack of measuring equipment, awareness and expertise
- Policy and guidelines not easily accessible or actively distributed

# Determination of UV susceptibility of various airborne organisms Z value

The Z-value represents the ratio of the inactivation rate normalized by UV irradiance:

$$Z = \frac{\ln N_0/N_{uv}}{\text{Dose } (\mu\text{Watt} \times \text{sec} \times \text{cm}^{-2})} \quad [\text{Kethley 1973}]$$

where  $N_0$  is the number of surviving microorganisms with no UVGI exposure,  $N_{UV}$  is the number of surviving microorganisms following UV exposure, and  $D$  is the UVGI dose in  $\mu\text{W}\cdot\text{s}/\text{cm}^2$ .

Z is the slope of the plot of the natural logarithm of colony count against UV dose:

M. tb at 50% humidity =	33 (23-42) Erdman strain
	48 (44-55) 1 99RB
M. bovis BCG	37 (33-39)
Serratia marcescens	214 (183-245)

Theoretically, the higher the Z-value for a target microorganism, the greater the susceptibility to UVGI and the more quickly the microorganism will be inactivated.

# Determination of UV effectiveness

**Effectiveness:** A measure of the ability of an upper-room UVGI system to kill or inactivate microorganisms. This may be expressed as either eACH in decay experiments or the percentage of microorganisms killed or inactivated by UVGI in constant generation experiments. This latter measure of effectiveness may be expressed by the following equation:

$$E_{UV} = 100 \times (1 - C_{UV} / C_0),$$

Where:

$E_{UV}$  represents the effectiveness of UVGI as a percentage,  
 $C_{UV}$  is the concentration of culturable micro organisms with UVGI exposure,  
and  
 $C_0$  is the concentration of culturable micro organisms without UVGI exposure.

According to First *et al* [8]:

- When a volume equivalent to the volume of the room enters and is exhausted
- 1 ACH well-mixed air removes 63% of air contaminants
- 2 ACH well-mixed air removes 84% of air contaminants
- Any air disinfection method that is 63% effective produces 1 Equivalent ACH

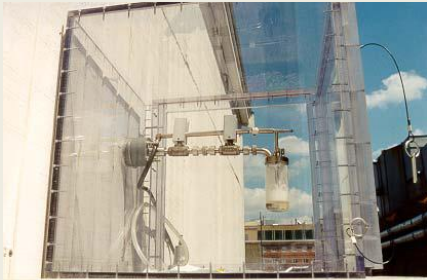
This equivalence is not uncontested

# Scientific studies

experimental difficulties in working with bio aerosols include:

- the low concentration of particles
- insensitivity of culture methods in some cases (especially TB)
- potential inactivation during aerosol-sampling

# STUDIES: Upper Air UV1 Riley-Middlebrook, 1976 - aerosolized BCG



Exposure chamber, interior, Anderson air sampling equipment, aerosol generator

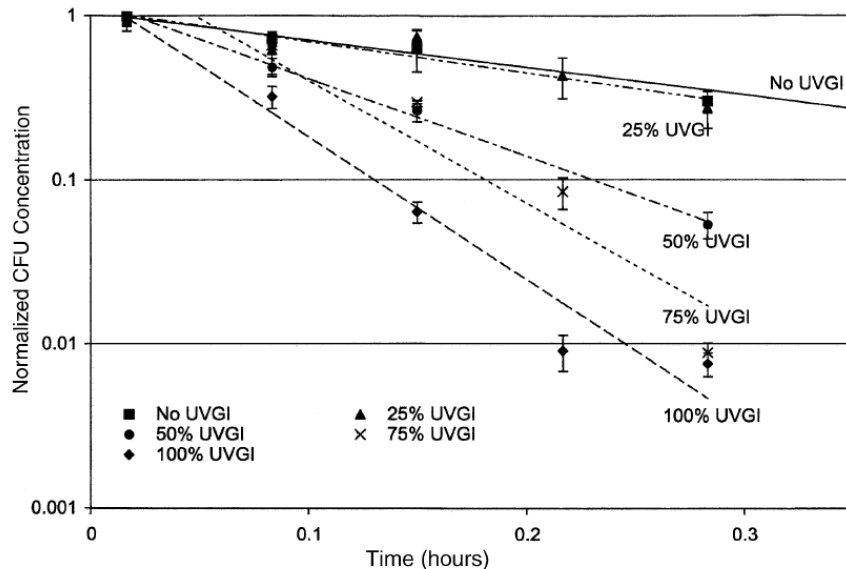
Riley 1976 (Source Nardell 2010)

# Xu, Et al 2002

- Full scale room studies – 87 m<sup>2</sup> test chamber
- *B. subtilis*, *M. parafortuitum*, and *M. bovis*.
- Two experiments:
  - constant generation – effectiveness
  - inactivation rate – equivalent ACH

At 50% RH with all lamps:  
culturable airborne bacteria reduced:

- *B. subtilis* spores - 46% - 80%
- *M. parafortuitum* - 83% - 98%
- *M. bovis* BCG - 96% - 97%



Increasing the ventilation rate from 0 to 6 ACH decreased microbial inactivation for *M. parafortuitum* and *B. subtilis* spores

Reducing lamp numbers decreased effectiveness

# Case study –AIR laboratory, Witbank



# Case study 2 -Escombe *et al*



Airborne transmission study facility with three parallel ward air exposure chambers

TB/HIV ward



Air injection vent

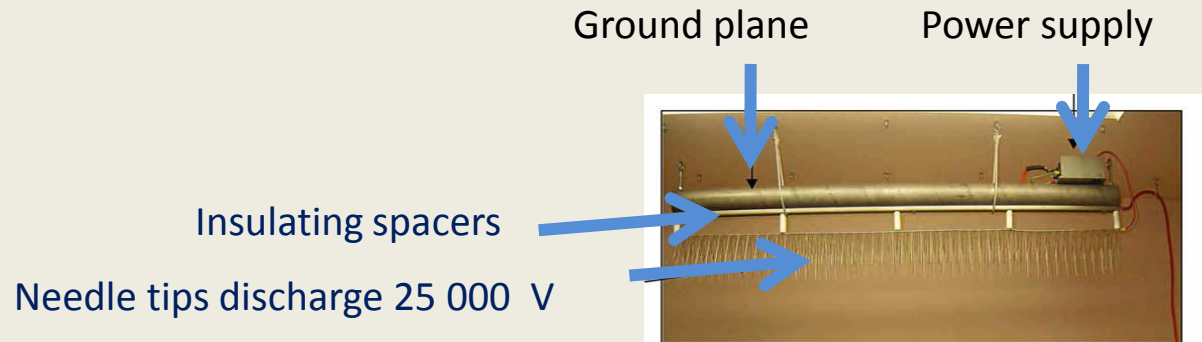
Upward-facing UVGI fixture  
Simple mixing fan

Air extraction

*Source Escombe, et al 2009*

# Escombe *et al* 2009

- 535 days, 150 guinea pigs per enclosure, using a 2-d cycle.
- UV-off days: Control and negative ioniser chambers (chamber 1 &2)
- UV-on days: UV lights and mixing fans were turned on in the ward (chamber 3)
- TB infection in guinea pigs was defined by monthly tuberculin skin tests
  - control group 35%
  - ionizers 14 %
  - UVGI 9.5 %
- Guinea pigs underwent autopsy to test for TB disease
  - control group 8.5%
  - ionizers 4.3 %
  - UVGI 3.6 %



Source Escombe, et al 2009

# UVGI advisory note

- Serious concern about abuse of UVGI technology
- Submitted to National Health Technology Committee, and to the National Health Council
- Recommendation accepted for a moratorium on the installation of UVGI devices pending resolution of concerns
- Discussed at the Ministerial Advisory Committee, accepted as a case study for input to Medical Regulations Summit
- Move towards decision to include as a listed device under Hazardous Substances Act and for inclusion as a Listed Electronic Product (new list being developed)
- Development of standards and guidelines

# Conclusion

UVGI should be applied as part of a comprehensive integrated strategy to reduce the risk of TB cross infection including administrative, environmental and personal protection measures, **provided**

- Appropriate use and application of the technology.
- Evidence-based professional design and installation.
- Procedures for procurement, commissioning, maintenance, replacement and disposal.
- Independent and competent system validation at commissioning and ongoing monitoring.
- Training programs for health workers, cleaning staff and maintenance personnel.

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The logo for the Council for Scientific and Industrial Research (CSIR) of South Africa. It features the letters 'CSIR' in a bold, blue, sans-serif font. The 'C' is a large, rounded shape, and the 'S' is a vertical bar with a horizontal top bar. The 'I' is a vertical bar with a horizontal top bar, and the 'R' is a vertical bar with a horizontal top bar and a diagonal leg.

*our future through science*

Thank you



health

Department:  
Health  
REPUBLIC OF SOUTH AFRICA



UVGI - Friend or foe?



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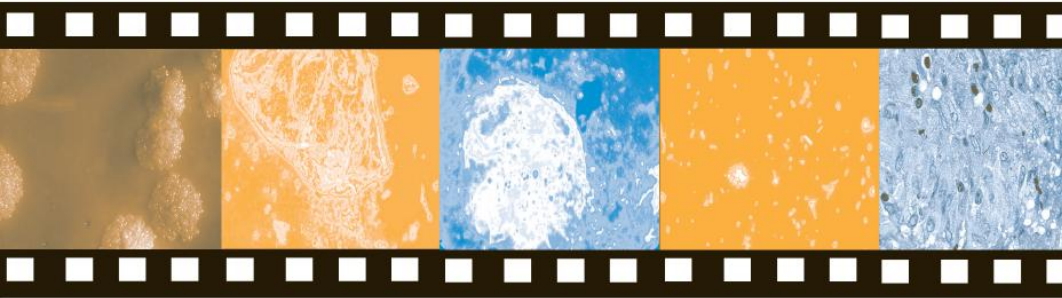
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## Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings



### UPPER AIR UVGI Summary Guidance DHHS

Temperature	20 - 24 °C
Ceiling supply air	room t °C - 3 °C
ACH	< 6
RH	30 - 60%

min. ave. fluence	12 μW/cm <sup>2</sup>
ave. UV fluence rate	30 - 50 μW/cm <sup>2</sup>
Lamps	Low-pressure mercury arc or Medium-pressure (low ozone)
Irradiance	1.87 W/m <sup>2</sup>

Power	6 W/m <sup>3</sup>
Mercury	< 5mg

Max lower room irradiance	0.2 μW/cm <sup>2</sup> (conservative?)
CDC/NIOSH REL	6 mJ/cm <sup>2</sup> per 8 hours
ACGIH TLV	6 mJ/cm <sup>2</sup> per 8 hours

Ballast harmonic distortion	< 10%
Ceiling > 2.7m	unshielded
Ceiling 2.4 - 2.7m	shielded

Department of Health and Human Services  
Centers for Disease Control and Prevention  
National Institute for Occupational Safety and Health



**NIOSH**