UV Disinfection in Moscow Metro Public Transport Systems

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ABSTRACT

Growing concerns about the hygienic situation and air contamination in the often heavily populated Moscow Metro underground railway system were reason to investigate the effects of UV disinfection on the internal surfaces of train carriages, escalator handrails and the air in passage ways and platforms of railway stations. The adequate UV doses to inactivate micro-organisms and parasites were determined for all three situations.

The required UV doses to disinfect the surfaces of carriage interiors and handrails were much higher than expected, due to the fact that micro-organisms are embedded and protected against UV by layers mainly consisting of proteins. Devices, providing high UV irradiances, equipped with Low Pressure High Output (LPHO) mercury amalgam lamps were introduced to meet the requirements.

Key words: UV disinfection; Public transport; Air disinfection; Surface disinfection; Amalgam UV lamps.

INTRODUCTION

During the last fifteen years, UV disinfection has rapidly gained popularity for water and air treatment. The advantages are well illustrated in the mean time. No chemicals are added, the reaction time is very short and the method does not alter smell or taste. Ultraviolet radiation is very effective to inactivate air or waterborne pathogens, viruses, but also pathogens like Cryptosporidium, due to the high absorption of DNA for UV radiation. UV-C radiation damages the DNA of micro-organisms, destroying their ability to replicate and thus rendering them non-infectious.

The Moscow Metro is one of the oldest and, with up to 9 million passengers per day, one of the most frequently used underground train systems in the world. Growing concerns over deteriorating indoor air quality and possible cross-infections via airborne micro-organisms or indirect contacts induced Moscow authorities to introduce effective and permanent solutions.

1.1 AIR AND SURFACE TREATMENT

Indoor air in offices, factories, homes hospitals and other public buildings is trapped, often re-circulated and always full of contaminants such as bacteria, viruses and moulds. Most people live and work in buildings which are sealed as much as possible to preserve energy. The indoor environment is controlled by automated heating, air-conditioning and ventilation. Microbial contamination plays an important role in the health problems, related to these environments.

This was reason for intensive investigations for the effect of disinfection of air and surfaces by UV radiation. The wealth of research reports which have been published over the last 100 years provided the basis to show that ultraviolet germicidal irradiation decreases the concentration of airborne organisms in buildings. Some infectious agents that affect human respiratory systems and that are susceptible to UV radiation are tuberculosis, measles, adenovirus and smallpox.

LIT Technologies and the Russian Research Institute of Railway Hygiene have teamed up to investigate the possibilities of UVGI (Ultraviolet Germicidal Irradiance) in a few distinct areas:

- Internal surfaces of train carriages
- Escalator hand rails
- Air in passage ways and platforms in railway stations

The adequate UV doses to inactivate micro-organisms and pathogens were determined for all three typical situations.

2. SURFACE TREATMENT

Attempts to eliminate surface contaminates from railway carriages range from antiseptic swaps to fumigation. Such methods are time consuming, hazardous and environmentally unwise. The UVGI process would be much simpler. It was found however, that micro-organisms on surfaces are always embedded in and shielded by protective layers of proteins.

Aromatic amino acids are the main agents causing UV absorption between 220 and 280 nm. Around 254 nm (the optimum UVGI efficiency wavelength), the absorption is determined by sulfhydryl (–SH) and disulfate (–SS–) groups of cysteine/cystine proteins.

Apart from the media in which the target micro-organisms are hidden, also the type and structure of typical interior components like imitation-leather seats, linoleum, rubber escalator hand rails, as well as glass and metal surfaces have a strong influence. As fig. 1 demonstrates the uneven relief structure of rubber (a) and linoleum (b) will create shadows for the UV radiation; the overall UVGI efficiency will drop.

a) b)

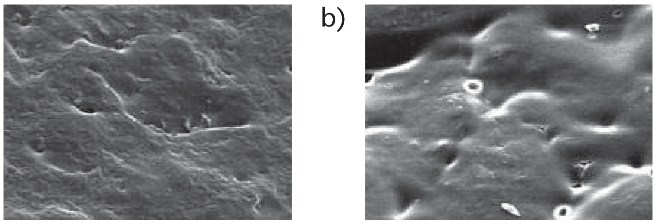

Figure 1. ***Microstructure of surface of rubber (a) and linoleum (b)***

In-vitro tests were carried out at the Russian Scientific Research Institute of Railway Hygiene, to establish lethal UV doses. Target micro-organisms were immersed in protein-containing media, modelled after real-life Moscow Metro conditions.

Figure 2 represents the medium UV transmittance factor at 253.7 nm versus concentration levels in distilled water (V_{pm}/V_{dw} - ratio of protein content in the medium and distilled water).

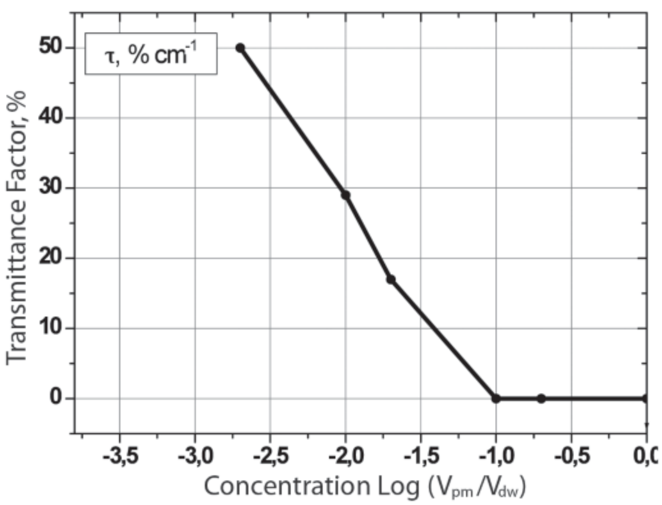

Figure 2. ***Experimental UVT (at 253,7 nm) of protective protein medium vs. Distilled water concentration levels.***

The *Staphylococcus aureus* (strain 906) organism was used for the tests. Imitation leather, rubber and plastic were used as test surfaces. Figure 3 shows the UVGI disinfection efficiency for the test culture in a protective protein environment on rubber. It also represents the reference values of UVGI doses for *Staphylococcus aureus* in "ideal laboratory conditions".

Relevant, frequently touched surfaces in the metro system may be contaminated up to 1000 CFU/cm^2. It required 300-450 J/m^2 to achieve a disinfection rate of more than 90%. This is 5 to 10 times higher than in ideal situations.

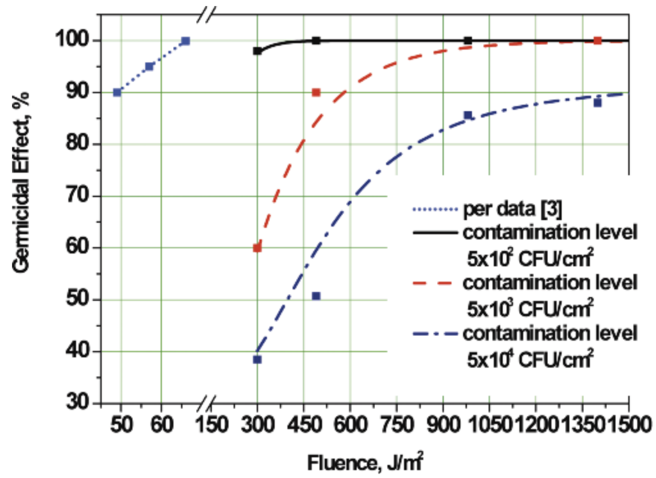

Figure 3. ***UV effectiveness vs. Initial seeding densities of protein-protected test-culture of St. aureus on rubber surfaces.***

Yet higher UV doses are required to inactivate pathogens such as viable ascaride eggs *(Ascaris suum)*, pinworms *(Enterobius vermicularis)* and lamblia cysts *(Lamblia (Giardia) intestinalis)*. During the tests these microorganisms were placed on typical test surfaces such as imitation leather, plastic, wood, chrome plated metal, rubber, and glass. Various UV doses at 253.7 nm were used to disinfect the microorganisms. The type of materials influences the effectiveness of UVGI disinfection to a great extent. Figure 4 shows the relative dependency of the UV dose versus the type of surface.

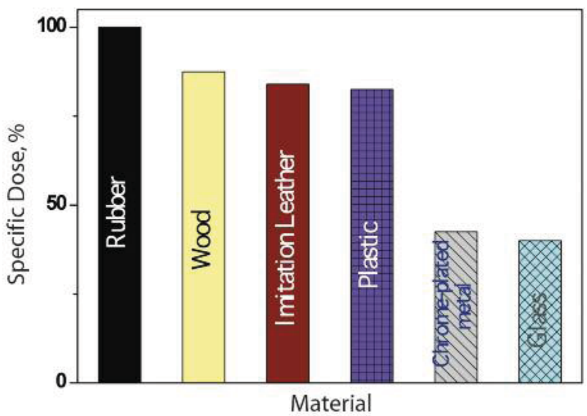

Figure 4. ***Relative changes in UV doses providing 90% inactivation in test pathogens vs. type of surface.***

Black rubber escalator handrail surface and window seals in train carriages require a two times higher dose for the same disinfection rate than required for glass and metals. Plastic, wood, and imitation leather score values in-between. To define the required UV doses in the Metro system, we will refer to the UV doses for inactivation of microorganisms on black rubber surfaces.

Figure 5 represents the inactivation efficiency of UVGI for 3 pathogens on black rubber surfaces.

For 99% disinfection, the required UV dose was established to be 4500 J/m^2.

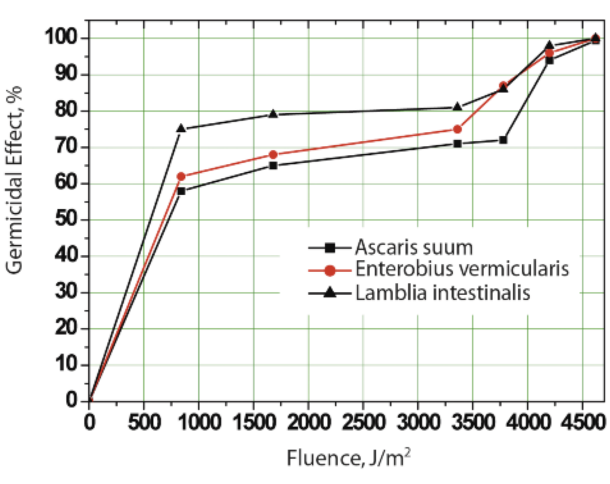

Figure 5. ***Germicidal UV effectiveness for three pathogens on black rubber surfaces.***

After the first stage of the research program it became clear that it is possible to employ UVGI technology to effectively disinfect relevant surfaces of the metro interior. However, the required UV doses are very much higher than expected on theoretical grounds. Practically, it is not possible to use conventional UV equipment low pressure mercury UV lamps. The energy efficiency of medium pressure lamps was considered to be too low. LIT Technology developed a series of straight and U-shaped LPHO "Amalgam" UV lamps, coated on the inside to restrict UV depreciation, tailored especially for Metro disinfection applications.

2.1 AMALGAM UV LAMPS

Low pressure mercury lamps are very attractive due to their extremely good UV efficiency, but their output, specified as UV-watts per unit of length, is very low. Increasing the specific UV output by increasing the lamp power will increase the lamp temperature, hence the (saturated) mercury pressure in the lamp; the UV efficiency will drop progressively.

It is a well-known fact that the mercury pressure can be decreased spectacularly by applying certain alloys, which combine with mercury to form so-called amalgams. In practice, this means that higher bulb temperatures are allowed and that the lamps can be "overpowered". Instead of the standard low pressure mercury lamp currents of up to 800 mA, now typical currents up to 4000 mA are possible. An additional advantage is that, in accidental case that the lamp breaks, no liquid mercury is released. The saturated mercury pressure at room temperature above the amalgam is much lower than above metallic mercury.

It goes without saying that the relevant lamp components have to be adapted to the higher power setting. Especially the choice of electrodes and inert gas filling plays an important role for the conservation of lamp efficiency and lamp life. Neon additions to the standard Argon filling gas determine the lamp power, judiciously keeping an eye on lamp life, typically between 10.000 and 15.000 hours.

Quite a few potential amalgams, each with their typical temperature requirements, are available. The tertiary type InAgHg, applicable with bulb wall temperatures between 115 and 140 °C is popular for lamps, ranging between 200 and 400 W. Four- and five component amalgams broaden the possible temperature area, allowing amalgam lamps to be used in a wide variation of temperatures and applications like UV air and surface treatment. Such lamps can be regulated in a wide variation of lamp powers.

2.2 SURFACE DISINFECTION OF CARRIAGE INTERIORS IN PRACTICE

A special trolley was developed to disinfect the air and surfaces in metro train carriages, incorporating two 170 W U-shaped amalgam lamps and equipped with a timer, to shut off the system after disinfection (Figure 6.).

Figure 6. *UV system for interior disinfection, with two U-shaped 170 W UV lamps.*

A series of experiments were carried out, aimed to reveal the impact of UV irradiation on materials used in the metro carriages. Four different materials were tested: imitation leather used for seats in carriages, plastic used for carriage floors, imitation-wood plastic for the walls and coated tin plates used for the carriage ceilings.

The samples were treated with a UV dose of 3.7 x 10^6 J/m^2, which effectively corresponds to 514 UVGI cycles with a maximum calculated dose of 7200 J/m^2.The tests revealed no physical or chemical changes in materials. It can be concluded that the materials tested showed a high resistance to UV irradiation.

Another series of tests revealed that no harmful chemical compounds or odors were formed by UV irradiation (Table I).

Table I. *CHEMICAL ANALYSIS RESULTS OF AIR IN METRO CARRIAGES PRIOR TO AND AFTER 25-MINUTE UV TREATMENT USING UOP VOZUF-170-P-2 (2 * 170W) LIT SYSTEM, WITHOUT VENTILATION.*

No	Chemical	Chemical concentrations								
		Max contaminant level, (MCL) mg/m3	Carriage No.1 before UV	MCL compliance	Carriage No.1 after UV	MCL compliance	Carriage No.2 before UV	MCL compliance	Carriage No.2 after UV	MCL compliance
1.	Benzol	0,300	0,057	yes	no	yes	0,035	yes	no	yes
2.	Xylol	0,200	1,680	no	no	yes	0,481	no	no	yes
3.	Ethyl benzol	0,020	0,441	no	0,249	no	0,246	no	no	yes
4.	Ethyl acetate	0,100	1,53	no	0,310	no	0,631	no	no	yes
5.	Styrol	0,040	0,279	no	no	yes	0,121	no	no	yes
6.	Toluol	0,600	1,11	no	0,653	no	0,320	yes	no	yes
7.	Phenol	0,01	no	yes	no	yes	no	yes	no	yes
8.	Formaldehyde	0,035	0,001	yes	0,001	yes	no	yes	no	yes
9.	Methyl-metacrylat	0,100	0,016	yes	no	yes	0,008	yes	no	yes
10.	M-cresol	0,005	0,025	no	0,021	no	0,009	no	no	yes
11.	Vinyl-chloride	0,01*	0,002	yes	no	yes	0,001	yes	no	yes
12.	Acrolein	0,03	0,054	no	0,017	yes	0,015	yes	0,011	yes
13.	Acetone	0,35	3,63	no	1,21	no	1,99	no	no	yes
14.	Ammonia	0,20	0,045	yes	0,052	yes	0,120	yes	0,122	yes
15.	Ozone	0,16	no	yes	0,15	yes	no	yes	0,14	yes

* Average daily concentration was taken as peak concentration value was not available

The effect of UV irradiation on disinfection of train carriage surfaces was established by practical examples. Overall microbial contamination levels as well as concentrations of the test-culture S. aureus (strain 906) were measured before and after administering doses of UV radiation, by means of the imprint method. See table II

Table II

#	Sampling area		Contamination, CFU/100 cm^2 Surface contamination prior to UV	After UV treatment	reduction (%)
	Irradiation cycle - 21 min, UV dose -4025-4600 J/m^2 for seats; -5750-7475 J/m^2 for the backs of the seats				
1	Left end of the carriage	seat	1×10^3	30	99,7
2		back	8×10^2	20	97,5
3	Middle of the carriage	seat	1×10^3	8	99,2
4		back	8×10^2	40	95
5		seat	1×10^2	8	92,0
6		back	5×10^2	4	92,8
7	Right end of the carriage	seat	8×10^2	4	95,0
8		back	8×10^2	4	99,5
	Irradiation cycle - 15 min UV dose -2625-3000 J/m^2 for seats; -5750-7475 J/m^2 for the backs of the seats				
1	Left end of the carriage	seat	1×10^2	4	96,0
2		back	8×10^2	16	98,0
3	Middle of the carriage	seat	1×10^3	24	97,6
4		back	2×10^2	16	92
5	Right end of the carriage	seat	8×10^2	32	96
6		back	$8 \times 10^1 - 8 \times 10^2$	0	100,0
	Irradiation cycle –6 min UV dose - 1 155-1320 J/m^2 for seats; - 1650-2145 J/m^2 for the backs of the seats				
1	Left end of the carriage	seat	$\sim 8 \times 10^2$	2×10^2	Non disinfected
3	Middle of the carriage	seat	5×10^2	2×10^2	Non disinfected
5	Right end of the carriage	seat	8×10^2	1×10^3	Non disinfected
	Irradiation cycle - 3 min UV dose - 190-216 J/m^2 for seats; 270-350 J/m^2 for the backs of the seats				
1	Left end of the carriage	seat	1×10^2	1×10^2	Non disinfected
2		back	2×10^2	2×10^2	
3	Middle of the carriage	seat	1×10^2	1×10^2	
4		back	2×10^2	2×10^2	
5	Right end of the carriage	seat	1×10^2	1×10^2	

The results confirmed the germicidal effectiveness of the applied UV treatment.

Train interiors are at present regularly exposed to 25 minute doses of UV-C. Key benefits of this operation are a reduced amount of chemicals used, time and labor costs savings and an improved environment within the metro depot. Figure 7 shows a few pictures of UV disinfection systems in operation at the "Kaluzhskoe" metro depot.

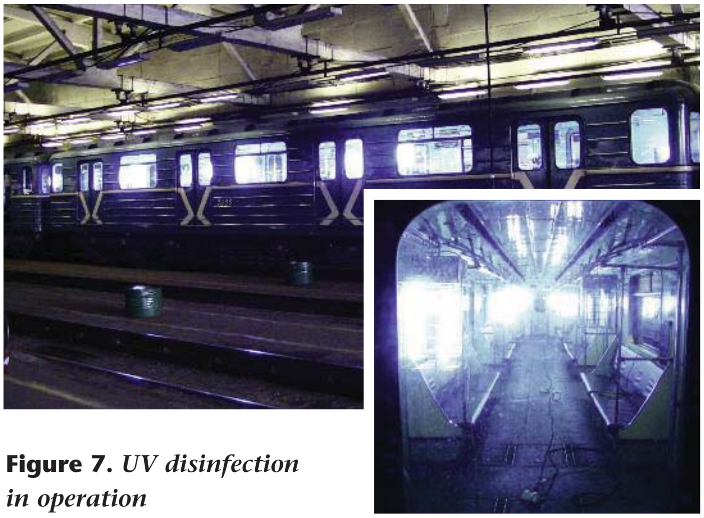

Figure 7. ***UV disinfection in operation***

2.3 DISINFECTION OF ESCALATOR HANDRAILS

Another UV system, with again two LIT U-shaped amalgam 170W lamps, was developed to disinfect the surfaces of escalator handrails automatically. (See Figure 8.)

It was established through a series of tests on these handrails that it takes an exposure time of only 10 seconds under two lamps of 170 W to achieve 99 % disinfection.

Figure 8. ***UV system mounted on a handrail return stretch at the "Kitai-Gorod" metro station.***

3. IMPROVEMENT OF AIR QUALITY

Three different principles of UV air treatment have proven their effect these days.

- Closed, stand-alone devices, recycling the air in occupied spaces via well-selected types of UV germicidal lamps provide a simple way to improve the indoor air quality. They dilute the microbial contaminant concentration and act in principle similar to extra ventilation, in a controlled and very efficient way. Such units, which may range in capacity from 150 till 20.000 m^3 per hour, are easy to install and do not harm people or affect furniture and surroundings.
- UV segments, incorporated in air ducts, decrease the concentration of airborne pathogens and protect against microbial pollution via the incoming air inlets. These UV units are available in the most popular geometrical duct sizes. Typical capacities are between 3.000 and 35.000 m^3 per hour.
- Air conditioning cooling coils are almost always wet and dusty and thus serve as ideal breeding grounds for moulds. Coil irradiation with UV drastically reduces or prohibits growth of these moulds. At the same time heat exchange efficiency is improved and the pressure drops decrease.

The air quality in often heavily populated underground railway stations forms a constant source of concern. The Moscow Metro is one of the oldest and, with up to 9 million passengers per day, one of the most frequently used underground train systems in the world. Growing concerns over deteriorating indoor air quality and possible cross-infections via airborne micro-organisms or indirect contacts induced Moscow authorities to introduce effective and permanent solutions.

Powerful UV disinfection air re-circulators with a capacity of 400 m^3/h were developed to be mounted in the underground premises. These systems allow for UV disinfection to be carried out with people inside the facility, for a 24/7 operation. Figure 9 shows how a re-circulator of type AR-UF-170P-2 (with two 170W lamps inside) is mounted in a passenger passage connecting two Moscow metro stations "Paveletskaya-Radial'naya" and "Paveletskaya-Koltsevaya".

Figure 9. ***Recirculator AR-UF-170-2 mounted in the passage between "Paveletskaya-Radial'naya" and Paveletskaya-Koltsevaya".***

One re-circulator of type AR-UF-170-2 with a capacity of 400 m^3/h is used for every 80 m2 of the passages and platforms. The 1260 square meter passage of the "Paveletskaya" metro station was equipped with 16 of these UV re-circulators. The air contamination during peak passenger hours was reduced on average by a factor 2,5.

4. CONCLUSIONS

By means of both laboratory and field tests, the feasibility of UV disinfection for the Moscow Metro system was proven. New generations of UV equipment, fitted with effective LPHO amalgam lamps, were developed for the occasion. The microbial air quality was improved. Replacing labor sensitive, hazardous and environmentally unfriendly disinfection methods, Moscow Metro was glad to embrace the new technology. Introduction of LIT UV systems will provide an extra and reliable barrier for infectious diseases in Moscow's congested public transport system.

Key words:

UV disinfection; Public transport; Air disinfection; Surface disinfection; Amalgam UV lamps

5. REFERENCES

1. Kostyuchenko, S.V., Krasnochub, A.V., Kudryavtsev, N.N. "New Generation of Germicidal Sources for Air and Water Disinfection, based on High Output Amalgam Lamps", Svetotechnika 4:15-19 (2004).
2. Vasserman, A.L., Shandala, M.G., Yuzbashev, V.G. "UV Irradiation in Preventing Infectious Deseases", Medicine 208 (2003)
3. Vladimirov, Y.A. "UV Inactivation of Enzymes", Sorovsky Obrazovatelny Zhurnal 7(2):20-27 (2001).