

## **Pulsed UV Disintegration (PUVD): a new sterilisation mechanism for packaging and broad medical-hospital applications.**

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### **Abstract**

The recently discovered (by Wekhof, [1]) disinfection mechanism with a pulsed UV light has been found to have a unique potential for the control of various hospital-acquired infections and for the sterilisation of food packaging or of packaged medical solutions. One requirement of this UV mechanism is the need to adjust the percentile components of UVC, UVB and UVA emitted by the pulse source to suit specific sterilization conditions. Our data show that it can be also effective with only UVB and UVA light, and without any UVC component. The exact sterilisation effect is due to a targeted and momentous overheating effect which ruptures the micro-organisms. The strength of this effect was checked at various peak power loads and on different substrates for micro-organisms, and the nature of the cell damage verified with e-m photography. This has shown that this new mechanism is actually a stand-alone disinfection method and is highly flexible as to the contaminated media presented, such as medical solutions packaged into clear PET, (PVC, PP, etc.) foil bags, or to plastic food packaging, without inducing noticeable changes. It has also been shown that the energy efficiency of this sterilisation mechanism is very competitive with that of five known basic disinfection methods such as by thermal means, by ionising radiation, by electro-polation, by chemical means or by mechanical means. Examples of potential applications in controlling hospital acquired infections, sterilising medical tools, food packaging or packaged medical solutions are given.

### **Introduction**

Historically, only five disinfection mechanisms have been recognised and understood: by heating of the whole treated media, by chemical means, through electro-polation (a rapture by electrical fields) ) and by ionising radiation (this class includes electron and ion beams, gamma and UVC rays, and the use of various plasmas). In addition, various means of washing, filtering, purging, vacuuming and dehydration can be considered as mechanical approaches to the disinfection/sterilization (Table 1).

To this list we can now add a newly published disinfection mechanism of Pulsed UV-Disinfection (which occurs during disinfection with flash lamps) [1], which we will refer to in future as Pulsed UV Disintegration (PUVD) to underline the specific

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role of the pulsed UV light where even UVB and UVA photons could perform the whole sterilization alone. This terminology also helps to better distinguish the mechanism.

General information on flashlamp usage, spectra, and applications during the last 70 years and on flash lamp manufacturers is given in [2, 3] and is not covered here except for two points of note on lamp parameters:

NOTE A). The UV spectrum is divided up into 3 bands [3, 4]:  
UVC -180 - 280nm, UVB -280 - 315nm and UVA -315 - 400nm  
UVC photons have energies between 7 and 4.5 eV, sufficient to dissociate some molecules. Because of that UVC is also referred as ionising radiation [3, 4].

NOTE B). The pulse energy  $P_{pe}$  is the energy deposited per  $cm^2$  of a treated surface,  $J/cm^2$ , or Fluence.  
The radiation peak power is the energy  $P_{pk}$ , deposited to  $1 cm^2$  of a treated surface during the duration of a single pulse  $t(sec)$ ,  $J/sec.cm^2$  or  $w/cm^2$ . It is also known as the Fluence Rate.  
That is to say the latter is the maximum rate of energy transfer, the former is the sum of total transfer.

The technique of disinfection with flashlamps originated during late 1970's in Japan and was patented in 1984 [5]. This work suggested that both UVC band radiation and perhaps also visible radiation are responsible for the disinfection effect. In 1988 the newly formed PurePulse Inc. (Ca) acquired this patent and since then have put in considerable effort to prove that the major role in such sterilisation belongs to the Pulsed White Light (PWL), see their [6-8]. During the same period an alternative approach stressed the exclusive role of the pulsed UV light in achieving effective decontamination from both toxic organic substances and from micro-organisms [9-11]). It did, however, take 8 years before the actual disinfection mechanism of the flash lamp action was found and summarised by the same author [1]:

1. This disinfection mechanism has two components: one is the standard germicidal action of UVC from the flashlamp light, and the other is a rupture and disintegration of micro-organisms through overheating after absorption of all the incident UV photons emitted in the light pulse.
2. The visible light plays no major role in flashlamp sterilization.
3. The overheating and disintegration of a micro-organism can be achieved with UVB and UVA light only, and this can be a stand alone disinfection method.
4. The calculated temperature rise for a treated micro-organism during a single light pulse is a steep and narrow function of  $P_{pk}$  and  $P_{pe}$ , with no sterilization below a threshold level of  $P_{pk}$  and with saturation at power levels a few times higher, which heats the object to in excess of  $130^\circ C$ , generally causing terminal overheating - see Figure 1.
5. The required minimum value of peak power  $P_{pk}$  to get this sterilization effect depends both on the physical parameters of the micro-organism to be treated (its size, mass, thermal-conductivity, UV absorption) and on the UV

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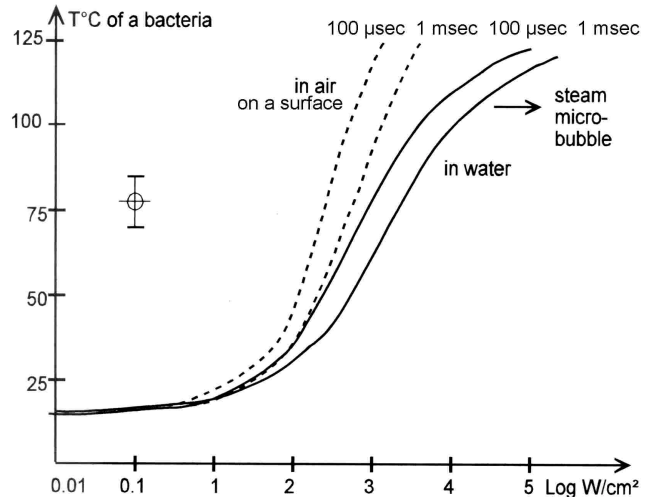
absorption and thermal conductivity of the media or object being sterilized.

- At lower levels of  $P_{pk}$  therefore, before the ramp takes off, the sterilization depends entirely on UVC light and has an accumulative nature for many light pulses.

**Figure 1** (from [1]):

Calculated dependence of bacterial (e-coli) temperature  $T/^\circ\text{C}$  (and of the UVC dose in  $\text{mJ}/\text{cm}^2$ ); as a function of Fluence Rate in ( $\text{W}/\text{cm}^2$ ) on a dry sample (transparent to UV) or in air and for water for 2 selected pulse durations: 1) 100  $\mu\text{sec}$ , 2) 1 msec.

The current study was carried out in order to check the validity of above premises by targeted experimental data, including obtaining direct evidence of the momentous overheating and consequent disintegration of the micro-organisms. We also compared the energy efficiency of this mechanism with that of the five known sterilization methods and provided concrete examples of this sterilization for medical and packaging applications.



## Materials and Methods.

### A. The flash lamp system and UV filters.

A desk-top, simple to use laboratory flash lamp system from Wek-Tec was used in all tests [12]. A photo of this system is provided on Fig. 2. The system had a stainless steel enclosure, of approximately the following dimensions:

36 cm (14") wide, 25 cm (10") high, 36 cm (14") deep containing a test area of: 16 cm (6.5") wide x 12 cm (5") deep and 15 cm (6") high.

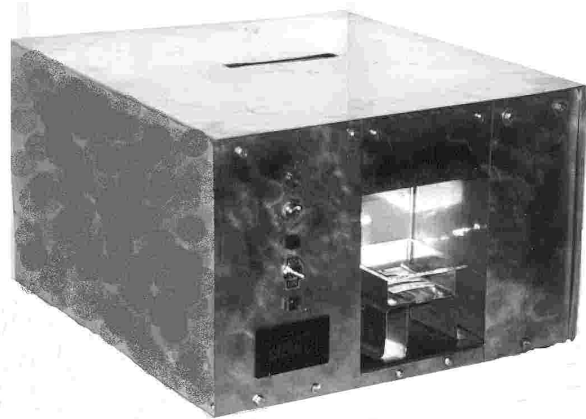


Figure 2: Wek-Tec Flash Lamp Labor unit

The irradiation chamber had holders for placing UV filters between the lamp and samples and to allow samples to be positioned at various distances from the lamp. The system had a linear xenon flashlamp of a special design, with air cooling and with a 99% effective reflector. The variation of light intensity within the processing chamber was about +/- 20%.

Spectral output of the lamp was as follows: the UV output was ca. 30% of the total, UVC, UVB and UVA bands respectively comprising about 12%, 10%, and 8%.

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The front panel was used to select desired lamp pulse parameters. The pulse's peak power  $P_{pk}$  at the sample level could be varied between  $1 \text{ kw/cm}^2$  ( $0.1 \text{ J/cm}^2$ ) and  $40 \text{ kw/cm}^2$  ( $8 \text{ J/cm}^2$ ). Pulse duration was  $200 \text{ } \mu\text{sec}$  ( $2 \times 10^{-4} \text{ sec}$ ), and samples were exposed to direct light from the flashlamp with no shadowing.

The test data were taken both with the open lamp and with filters placed directly over samples without any direct contact to samples. Three types of UV filters were used (all had a  $10 \text{ cm} \times 10 \text{ cm}$  surface):

1. Pyrex filter, 2 mm thick: cuts off all light below 305 nm and allows some UVB, and all UVA and visible light to pass through with an efficiency of 92%;
2. Glass filter: cuts off all light below 330 nm and allows the majority of UVA and all visible light to pass through with the efficiency of ca. 90%;
3. Makrolon plastic filter: cuts off all light below 400 nm (i.e. all UV light) and allows only the visible light to pass through with an efficiency of 87%.

### ***B. Micro-organisms, sample carriers and evaluation methods:***

For tests we used spores of *Aspergillus niger* and of *Bacillus Subtilis*. These spores are known for their resistance to the UV sterilization methods.

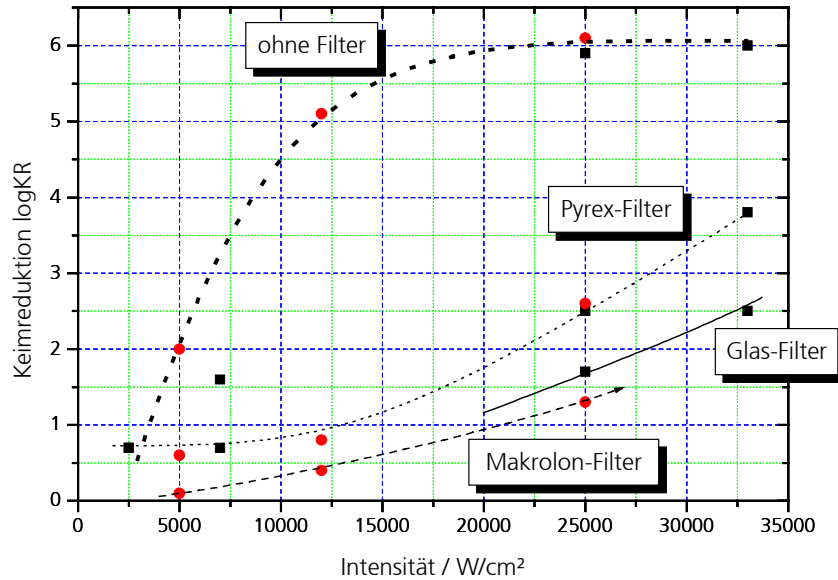
Each type of spores was separately doped on clear PET pieces ( $10 \text{ cm} \times 10 \text{ cm}$ , 0.2 mm thick), or onto 2 mm thick clear glass plates sized to  $10 \times 10 \text{ cm}$ . The spore doping was uniform over the central sample area, and the spore density was about  $10^5 / \text{cm}^2$  (There were in total  $10^6$  spores over an area of  $50 \text{ cm}^2$ , i.e. ca.  $10^5 / \text{cm}^2$ ) To check repeatability of the test procedure 5 samples were exposed at each selected energy/power.

To measure the sterilization effect on spores, the evaluation method described in [13] was used and is also known as the reduction method. In operating this procedure correctly, both treated and control samples were immediately dropped into prepared bags containing the respective recovery solutions and sealed, refrigerated and within 24 hours processed in a laboratory.

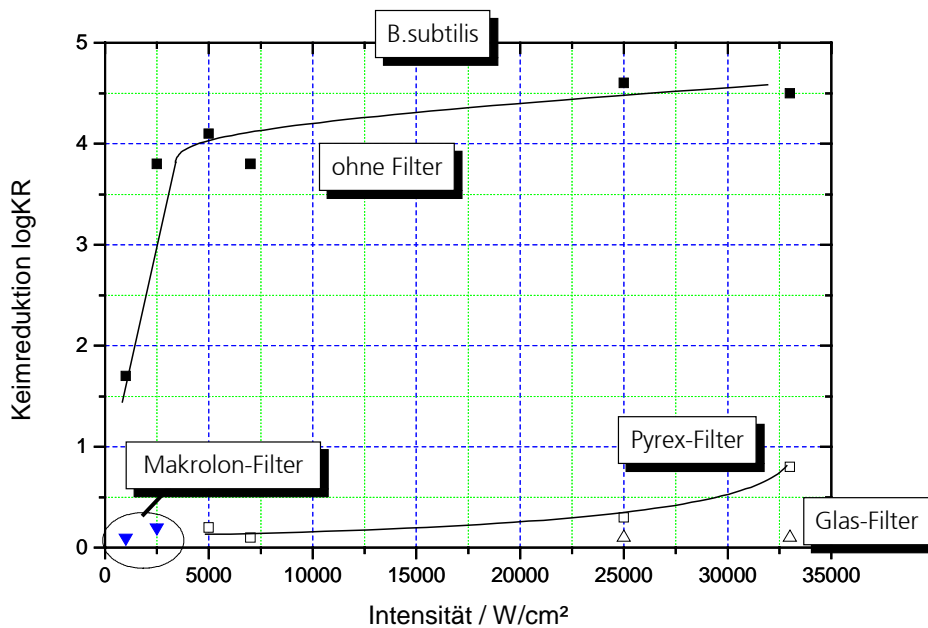
A. *Niger* and B. *Subtilis* spores were subjected to electron microscopy to investigate any changes induced in the treated spores by UV light and also on the underlying plastic or glass surfaces. This was done for each tested power range. A special precaution was paid so the electron beam of the microscope does not induce damages to spores. For that reason the maximum magnification was limited to  $\times 20.000$  which allowed to see structures of down to 0.1 microns.

### Experimental Observations

Data on sterilization of *Aspergillus Niger* spores for various conditions are presented in Figure 3, and for sterilization of *Bacillus Subtilis* spores in Figure 4.



**Figure 3:** the reduction in the population of *Aspergillus Niger* spores as a function of applied peak power of a single pulse.



**Figure 4:** Reduction in the population of *Bacillus Subtilis* spores as a function of applied peak power of a single pulse.

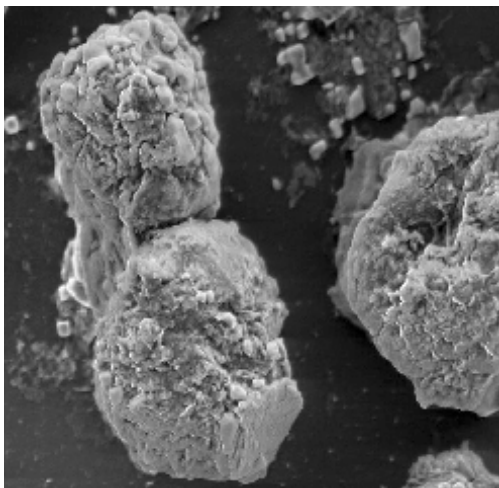
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Data on the accumulative dose of a repetitive action is given below as the Table 2:

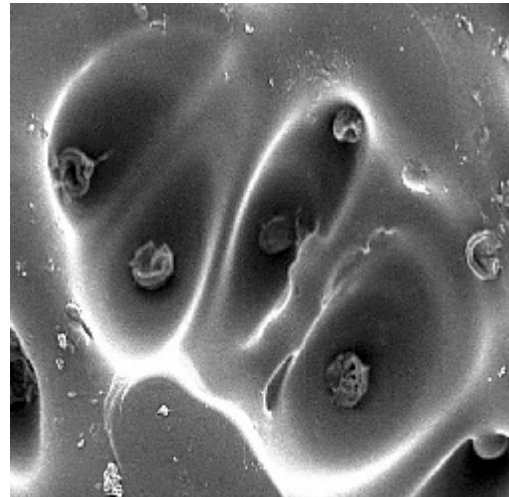
Treatment Condition for A. Niger	1 weak pulse 1J/cm <sup>2</sup> , 5 kw/cm <sup>2</sup> open lamp	5 weak pulses 1J/cm <sup>2</sup> , 5 kw/cm <sup>2</sup> open lamp	1 strong pulse 5J/cm <sup>2</sup> , 25 kw/cm <sup>2</sup> open lamp
Log Reduction	0.8 –1	4.8	5 - 6

Selected data with the electron microscopy presented on Figures 5 and 6.

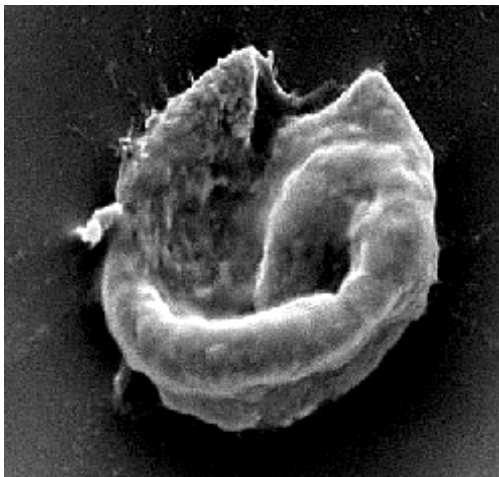
**Figure 5. 5A:** Untreated spores of A. Niger, **5B:** Spores of Aspergillus Niger treated to two pulses at 33 kw/cm<sup>2</sup>. Note craters around spores formed by sinking of heated spored into the PET substrate.



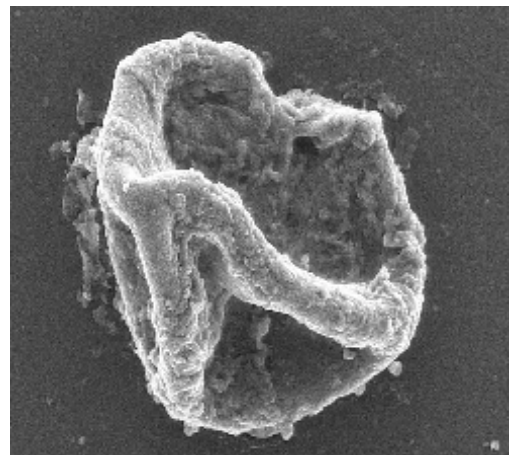
5A: x 10.000 >--- 1 µm ---<



5B: x 2.000 >--- 10 µm ----<



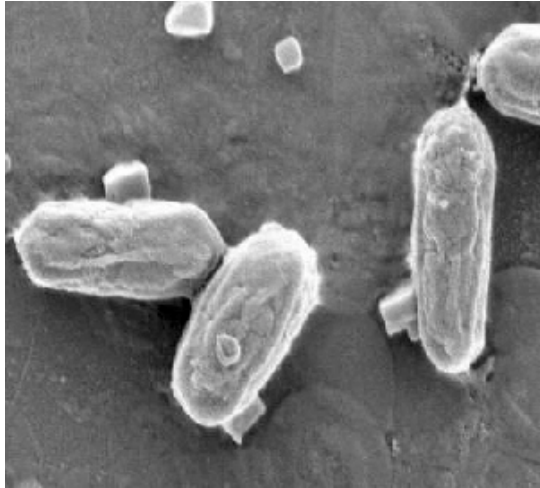
5C: x 10.000 >-----1 µm-----<



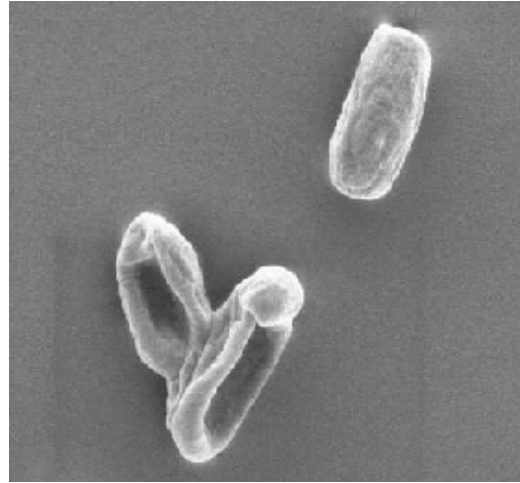
5D: x 20.000 >-----1 µm-----<

**5C.** A single spore treated to two pulses of 33 kW/cm<sup>2</sup>. Note how the spore top was ruptured by an escape of an overheated content of the spore. Note also the crater around the spore. **5D.** a single spore treated to 5 pulses of 5 kw/cm<sup>2</sup> each, open lamp.

**Figure 6:** Untreated (A) and treated (B) *Bacillus Subtilis* spores. Note the deformation of the spore and the absence of any cratering of around the spore.



**6A: x10.000** >----1µm----<



**6B: x 10.000** >----1µm----<

Measurements of the light absorption from 200 nm to 800 nm by *Aspergillus Niger* spores and by *Bacillus Subtilis* spores has shown that the *A. Niger* has on average about 5 times greater light absorption than *B. Subtilis* for similar populations. Respective sizes were found to be about 2 to 4 µm for the former and for the latter about 2 µm long by 0.5 µm thick.

Our observation of all the microscopy data for *B. Subtilis* spores showed that disintegration or deformation of spores after the treatment was far less than in the case with *A. Niger*, about 10 or more times lesser. There was no cratering observed for *B. Subtilis* spores, even for spores deformed by the treatment, like on Fig. 6b. The total reduction in spore population (deactivation) was a bit (one 1-1.5 logs lesser) for *B. Subtilis* than that for *A. Niger* for higher Fluencies and Fluence rates, however started at lesser values of fluencies, as one can see by comparing data on Figures 3 and 4.

## Data Analysis.

### ***Shape of sterilization curves obtained.***

As can clearly be seen from Fig. 3 and 4, the disinfection efficiency sharply rises for fluence rates from about 3 kw/cm<sup>2</sup> for *B. Subtilis* and from about 5 kw/cm<sup>2</sup> for *A. Niger*. It reaches the reduction of 5 or 6 logs at the fluence rate of 5 kw/cm<sup>2</sup> and 15 kw/cm<sup>2</sup> respectively, at which levels all the spores in the target population had been inactivated.

It seems reasonable to suggest that the technique could offer far greater levels of the reduction in proportion with the applied power, if it were tested on greater spore

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populations. Some limited data for the reduction up to 10-12 logs for a *B. Subtilis*, *A. Niger* and *E-coli* are cited in [1] for a special type of a UV source operated at the pulse duration of about 30  $\mu$ sec and with the respective fluence rate of 200  $\text{kw}/\text{cm}^2$ . This source was made as an R&D source to check radiation effects at extremely high fluence rates.

In all the available data are sufficient to confirm that the premise n4 of the model [1] cited in the Introduction is valid: each micro-organism can be successfully sterilized within its own narrow range of the fluence rate required for the efficient pulsed UV sterilization.

### ***Spore's disintegration through overheating:***

Electron-microscope photographs of treated spores (*A. Niger*, Fig. 5c, 5d) strongly support this premise since these photos show severe deformation and rupture when compared with the untreated ones on Fig. 5a. Fig. 5c. Shows a ruptured top of the spore evidently punctured by an escape of an overheated content of the spore. The collapsed and deformed shell of the spore shows that the spore became empty after such an internal "explosion" and "evacuation" of its content took place during the light pulse.

The direct evidence of the spore overheating during the light pulse comes from Fig. 5b and Fig. 5 c, where one can see deep craters around spores. The only obvious cause for such craters is the sinking of heated spores into the PET substrate. The melting temperature of PET is about 120°C, and the calculated overheating temperature of micro-organisms with a similar size to *A. Niger* spores (*E-coli*, a few  $\mu\text{m}$ ) is also in the same range, Fig. 1.

The ruptured spore on Figure 5d shows no sinking into the substrate since it was treated with low power (5  $\text{kW}/\text{cm}^2$ ) pulses. Thus this sterilization method can be used without damaging the PET substrate, which is an important consideration for practical applications. It is also important to note that, unlike damage to DNA caused by ionizing radiation, thermal disintegration of the micro-organisms leaves little chance of recovery.

Disintegration of *B. Subtilis* spores is also evident from Figures 6a and 6b, however at a far lesser extent. This can be due to smaller size of these spore which dependance is discussed further on.

In all, the available data strongly support the premise listed under n4 of Introduction, that the major characteristic of this new sterilization mechanism is the physical disintegration of spores caused by momentous overheating after absorbing pulsed light.

It is evident from photos of disintegrated spores and from cratering around spores which is the direct evidence for the values of the temperature rise during the pulse. This temperature values are in a good agreement with values projected in [1].



***Contributions to the Sterilizing Effect by the major spectral intervals:***

Data from the various filters can be used to identify the effects of different components of the light emitted by the bulb such as of UVC, UVB, UVA and of the visible light, as shown in Figures 3 and 4. This data show that PUVD can be achieved without the UVC component. The contribution of UVB and UVA light becomes more pronounced with an increased fluence rate so to "compensate" the absence of the UVC light, which evidently also contributes to the heating, besides having a known germicidal action on micro-organisms. Indeed, at lower values of the fluence rate (before the ramp "takes off"), the UVC contributes 80-90% (or more) of the sterilizing action while UVB and UVA light contributes only 10-20% for both types of spores. At higher fluence rates from 25 to 33 kw/cm<sup>2</sup> the contribution of UVB and UVA into the log reduction rises from 10%-20 to 40% to 60% for A. Niger spores and to 10%-15% for B. Subtilis spores.

The lower contribution of the UVB and UVC light to the reduction of B. Subtilis is due to its smaller size and its higher cooling rate as it is explained in the section above. Thus in this case the major reduction was reached with the open lamp by the UVC light.

Let us compare our data with spore reduction achieved with CW (standard) UVC sources. Data in [14] show that both types of spores can be deactivated with standard CW light sources emitting 222 nm light (Excimer lamp), 254 nm light (mercury lamp) and 282 nm light (Excimer lamp). Fluencies for 4 logs reduction were in the range from 80 to 300 mJ/cm<sup>2</sup> for B. Subtilis and 1400 to 2130 mJ/cm<sup>2</sup> for A. Niger with exposure times of up to 100 seconds. Thus the required UVC fluencies were 5 to 3 times as much for A. Niger as for B. Subtilis.

It is impressive to learn from these data that the same 4 log reduction can be reached with CW UVC light and with pulsing UVC light, providing it has a fluence rate below the "ramp" (or PUVD) takes place. That confirms the premise 6 of the Introduction that when using pulsed light source at lower fluence rates it is only UVC at work and there only advantage is in a shorter processing time to use such a method instead of using standard CW sources of UV light.

To elaborate further on the use of UVB and UVA light alone one has to take into account that the UVC energy is also contributes to heating. Therefore, its absence has to be compensated for both by higher fluencies and fluence rates of UVB and UVA light, making their total energy level comparable to that previous carried by all three UV bands together.

As to the role of visible light, the data for both spores under the Makrolon filter (with a cut-off above 400 nm) show that it plays no role in sterilization with pulsed light. This fully supports premise of the sterilization model, listed as n2 in the Introduction.

***Action of a several pulses in succession.***

Tests on the combined action of many pulses each of a lower energy showed the accumulative action of such repetitions, which can be seen from the Table 1 to

support premise n6 of the model. It is worth noting, however, that tests at higher powers have shown that if all spores present have been already inactivated, then adding more pulses could only bring about damage to the PET substrate. Tests on a possible damage induced by light pulses to a substrate or to a surrounding media (like medical solutions, etc) are necessary to take for each specific application.

***The dependance between the size of micro-organism and the minimal required fluence rate.***

It is very informative to consider the difference in disintegration of A. Niger and B. Subtilis spores. As it was found ( Fig. 4), B. Subtilis sterilization required a lesser fluence rate however was not so effective with the Pyrex filter. As one can see from Figure 6, B. Subtilis spores were damaged at a lesser extend that those of A. Niger. The explanation can be found in the sterilization model [1], which projects that the heating by a light pulse of smaller micro-organisms is less effective since smaller objects cool faster due to their higher volume to surface ratio.

Let us compare these ratios for A. Niger and B. Subtilis. First let us approximate the former one as a ball with the diameter of 3  $\mu\text{m}$ , and the latter as the cylinder, which is 2  $\mu\text{m}$  long and 0.5  $\mu\text{m}$  in diameter. Then one can come to numbers showing that the volume-to-surface ratio for the B. Subtilis is about 8 times as much as for A. Niger. That in turn means that the cooling rate of B. Subtilis spores is about 7 times as much as for A. Niger spores. To offset such a higher cooling rate, one needs to rise the fluence rate by shortening the pulse duration (also by somewhat reducing the fluence as well to prevent the damage of the substrate). Otherwise it will be the UVC light which does most of the deactivation of B. Subtilis spores during the light pulse.

It seems reasonable to conclude that the higher power threshold for A. Niger spores (approximately a 3 fold increase) is also the direct consequence of this 7 times greater volume-to-surface ratio and its higher (3 times as much) mass of these spores as compared to those of B. Subtilis spores. The larger size of A. Niger spores also explain why their adsorption of UV light is higher, as is given above in the section "Experimental Observations" above.

In all, it seems to be that the effect of the pulsed UV sterilization indeed depends on the size of the micro-organism, which confirms the model premise n5 of Introduction.

Therefore, all six premises of the sterilization model by Wekhof [1] have been fully supported by presented experimental data.

## **Applications**

***Comparisons of the energy efficiency of different sterilization methods.***

In order to compare this sterilization with existing methods let us look into its energy efficiency. The minimum dose of pulsed UV light to inactivate micro-organisms can be derived from Figs. 3 and 4 by multiplying  $P_{pk}$  (fluence rate) on the pulse duration

(here it was 200  $\mu$ sec). It gives 1 J/cm<sup>2</sup> and 4 J/cm<sup>2</sup> fluencies for the 5 logs reduction for *B. Subtilis* and *A. Niger* spores respectively. If one were to use the UVC light from a standard CW UV lamp, then according to [14], the same reduction requires from 0.5 - 1.5 J/cm<sup>2</sup> for *B. Subtilis* and 15 J/cm<sup>2</sup> *Aspergillus Niger* respectively (this is the fluence at the treated surface). These data are the average fluencies listed in [14].

Besides possibly needing higher energy fluxes, sterilization with CW (standard mercury) UV lamp takes much longer exposures (at least a few seconds) and there is no known to us data for the 6 log reduction. Thus the pulsed UV process can provide a higher efficiency in comparison with that of a steady emitted UVC radiation. Additionally, both types of spores used here are known as UV resistant micro-organisms.

Now let us to compare the efficiency of this PUVD process with a sterilization of by direct heating the whole media (e.g. to eliminate e-coli). To do so one can use the example of heating one litre of water from a typical room temperature of 20°C to 100°C. This requires the energy of 800 calories (3000 Joules).

By contrast, one flash of 80-100 Joules sterilizes this quantity of water by 2 logs [1, 10]. This makes the pulsed UV sterilization 30 to 40 times more efficient at the sample.

Similar estimates for other methods are summarised in the Table 1 and show that the pulsed UV sterilization has a potential to penetrate into applications where its advantages are commercially justified, like into packaging and medical industries.

### ***Outlook: food and medical packaging, medical tools.***

Sterilization of packaging, certain foodstuffs, of PET and other plastic bottles for beverages, packaged medical solutions, or contact lenses packaged into sterile solutions, and sterilizing of simple medical tools (with no shadowed surfaces or grooves). When considering this method for any of the above applications, the potential user must first decide if the use of UVC light is either possible or necessary. If it is not, then the UVC band needs to be filtered out of a lamp spectra.

The filtering of the UVC band needs to be compensated for by boosting the UVB and UVA content of the pulsed source. This is possible simply by increasing the peak power of pulses (in other words by increasing the fluence rate to a sample). In turn that will lead to a higher pulse energy (a higher fluence to a sample) and to an increase of the electrical consumption for a pulsed system). It will also increase the system capital cost.

Thus it is really important first to check that the targeted micro-organisms absorb UVB and UVA at a rate sufficient for the selected PUVD system to perform a required work in order to justify higher costs of disinfecting only with UVB and UVA light. Certainly, such higher costs of disinfection-sterilizing with UVB and UVC light alone are well justified for many medical-hospital and food applications, since alternative sterilization methods may not be compatible with increasing demands of

respective industries. These advantages can be well seen in the Table 1.

**TABLE 1. Comparison of disinfection / sterilization methods**

(NOTE: we compare the energy consumption on the product, not the production cost)

Type of Sterilization	Advantages:	Limitations	PUVD Efficiency is Higher by x N:
<b>1. Mechanical by a physical removal of bacteria, spores or its content through washing, filtering, scabbing, drying/ vacuuming (dehydration).</b>	Simple, effective for dirty air, for dirty liquids or for dirty surfaces	a full sterilization at higher logs is hard to achieve, it is limited to simple however useful situations.	x 50 - x 100
<b>2. Thermal by disintegrating bacteria or spores through a direct heating of a whole treated media, also by steam or by micro-waves.</b>	simple, its many variations are used for packaging and for some food products.	must heat the whole treated media, can degrade products, or packages, ineffective against heat-resistant micro-organisms	x 30 - x 50
<b>3. Chemical by inducing lethal chemical changes to bacteria or to spores through chlorination, or by peroxide, ozone, etc.</b>	Inexpensive, simple	a danger for health, and environment, being gradually phased out.	direct energy estimate is not possible
<b>4. Electrical By stretching bacteria to its rapture in applied electrical fields, in part in some plasmas (electro-polation)</b>	low energy consumption, low maintenance.	uses high voltages up to 100 kV, ineffective with spores and viruses.	x 0.2
<b>5. Ionizing radiation deactivation of bacteria (or spores) through a disruption of DNA, or through a physical damage to cells by gamma or UVC photons, by electron and ion beams, by electrons and ions of non-thermal plasmas.</b>	full and uniform penetration including through a packaging material, versatile, UVC lamps and gamma-ray sources (cobalt) are inexpensive.	e-or ion beams accelerators are expensive. The same beams can cause undesirable changes in food items. UVC rays are ineffective for UV-resistant micro-organisms.	x2 - x30
<b>6. Pulsed UV disintegration (PUVD) a physical disintegration of bacteria or spores through a momentous overheating after absorbing pulsed UV light and also by a lethal damage to DNA by the UVC component of the light pulse if its presence is justified [1].</b>	Sterilization in a small fraction of a second, high through-put, low operating costs, does not degrade packaging or food items, can disinfect through clear packaging, wipes out UV- and thermal resistant micro-organisms.	treated media and its packaging must be transparent to UV light; Pulsed White Light does not contribute to the disinfection; shadow effects must be avoided; data on sterilizing of viruses must be accumulated.	x 1

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### ***Projected applications: infection control in hospitals.***

Nosocomial infections are defined as infections acquired by patients or workers in health care facilities by unintended exposure through inhalation or direct contact with wounds or contaminated instruments, contaminated medical solutions being injected directly into blood streams, etc. [15,16]. Nosocomial infections affect over 2 million patients annually in the US [15]. At least 5% of patients hospitalized in acute care institutions acquire an infection that was not present on admission. In ICU's (Intensive Care Units) patients have nosocomial rates that are 5-10 times higher than those in general wards [16]. Pneumonia is the second most common nosocomial infection in the USA which together with surgical wound infections accounts for approximately 15% of all hospital-acquired infections [17, 18]. Nosocomial pneumonia affected 16.6% of patients in ICU's. The mortality rate of these patients was 52.4% compared with 22.4% for patients without ICU-acquired pneumonia [17-20]. In coronary care units, for example, as many as 70% of nosocomial infections (which include pneumonia, lower respiratory tract, and skin infections) are of the type transmitted via direct contact, airborne or settling, or equipment contamination [18].

Since our data show a high efficiency of sterilization for *Aspergillus Niger* and on e-coli in [1, 10], and since pneumonia could be in part be caused by similar micro-organisms [18-19] then it is reasonable to expect that this technology could be used to effectively control pneumonia and other respiratory diseases by sterilizing air and medical tools etc., in hospitals, office and industrial facilities. This technology can be also applied during operative procedures and on open tissues (the first such practices are suggested and referred in [1]). Thus it would allow sterilization at the infection site before the infection can develop, therefore promising a high degree of effectiveness through application in a manner not previously achievable. Moreover, sterilizing of air, etc. in operating rooms with only UVA and UVB (and no UVC component) has safety advantages. Although it may not be possible to intercept all such infections, this technology has the potential to reduce them. Only further clinical trials will be able to establish the full extent of these benefits.

## **Conclusions**

Presented here experimental data and its analysis provide the full support to the earlier defined [1] pulsed UV sterilization mechanism and offer new alternatives for sterilization of packaging, medical tools, etc. and for the control of some nosocomial infections that result from air and surface bio-contamination.

To have this mechanism work, the rate of the energy deposition into a micro-organism (the fluence rate) must be higher than its rate of cooling to a surrounding media. In this case a micro-organism undergoes momentous overheating and disintegration. It is shown that only the Pulsed UV light of a broad spectra can do effectively this work while Pulsed White Light (PWL) plays no role. Because of this disintegration action on a micro-organism this pulsed UV sterilization method is named as the Pulsed UV-Disintegration (PUVD) to better position it to other sterilization methods.

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It is especially promising that such a sterilization could be done without the presence of the UVC component, which can be filtered out on purpose or absorbed by packaging materials. Advantages and limitations of this method are compared with those of other established sterilization methods.

The range of infections that can be feasibly controlled in this manner can be approximated for pneumonia from the data on *Aspergillus Niger*. Other respiratory tract infections, surgical site infections, skin and soft tissue infections can be considered as likely to be vulnerable to the technique as well. Clinical trials are necessary for implementation of this technology into general hospital use.

Applications for the sterilization of packaging, medical tools and so on could be implemented using data and recommendations provided.

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