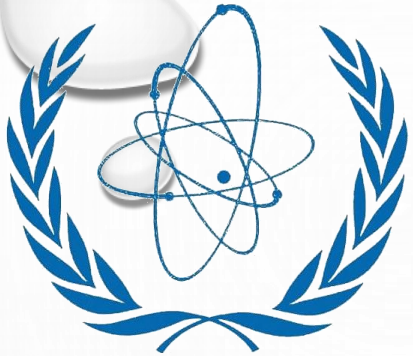
19th to 22nd September 2023



IAEA

INACTIVATION OF WATER-TRANSMISSIBLE VIRUSES BY COMBINING ADVANCED OXIDATION TECHNIQUES

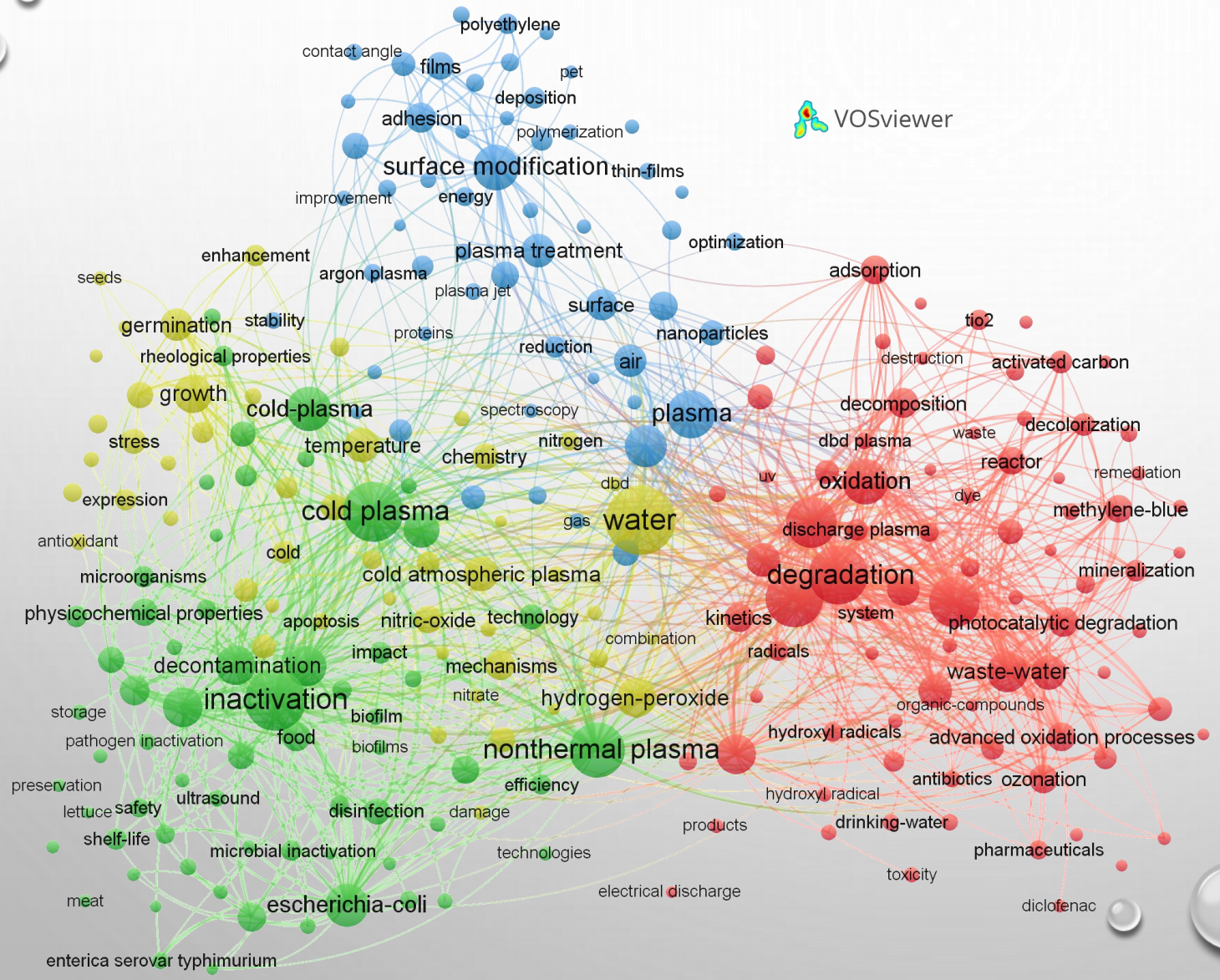
G. PRIMC, A. FILIPIĆ, M. MOZETIČ, M. DULAR, M. PETKOVŠEK, A. ŠTERN, B. ŽEGURA, I. GUTIERREZ AGUIRRE, D. DOBNIK, M. RAVNIKAR, AND R. ZAPLOTNIK

JOŽEF STEFAN INSTITUTE

OUTLINE

- TRENDS AND PERSPECTIVES
- VIRUSES
- COMBINING TECHNIQUES TO COMBAT VIRUS INACTIVATION
- CONCLUSIONS

BIBLIOMETRIC DATA



- DEGRADATION
  - AOP, PHOTOCAT., OH RAD.
  - MINERAL., PHARMA., WASTE, DYE, ORGANIC COMP.
  - DIFFERENT PLASMA TYPES
- GREEN
  - PAW, BACTERIA, BIOFILM, FOOD
- PLASMA-SURFACE MODIFICATIONS
  - NP, WCA, POLYMERS, ENERGY
- AGRICULTURE AND CELLS
  - GERMINATION, OXIDATIVE STRESS, NO, NH_2, NH_3

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FACTS

- > 2 BIL. PEOPLE LIVE IN WATER-STRESSED COUNTRIES (FECES AND MICROBIAL CONTAMINATION)
- 2 L/PERSON DAILY DRINKING / ~3000 L/PERSON PRODUCE DAILY FOOD NEEDS, ~70% OF WATER WORLDWIDE IS USED FOR IRRIGATION → 20% CULTIVATED LAND → 40% FOOD PRODUCED
- GLOBALLY, GROUNDWATER PROVIDES AROUND 50% OF ALL DRINKING WATER AND 43% OF ALL AGRICULTURAL IRRIGATION
- IN 2019, ANTIBIOTIC-RESISTANT INFECTIONS → DEATHS OF ~5 M PEOPLE

CONTAMINANTS OF EMERGING CONCERN

Sources: WHO, EU commission, FAO, Wise Freshwater, Prangya et. al. 10.1016/j.scitotenv.2020.141990

WHY VIRUSES

2ND LEADING CAUSE OF DEATH IN CHILDREN < 5 YEARS

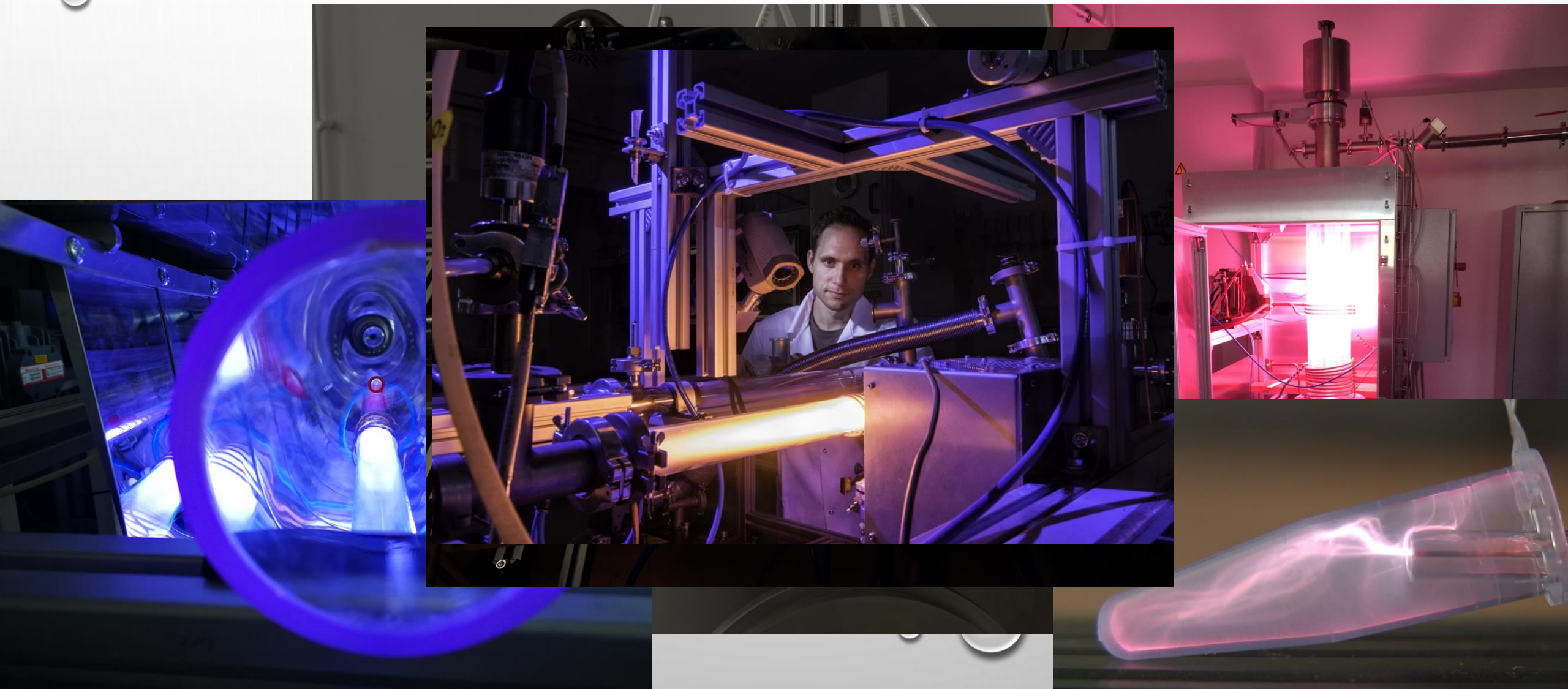
1.5 MILLION OF CHILDREN (200.000)

VIRUS REMOVAL

- NANO FILTRATION, SEDIMENTATION WITH FLOCCULATION
- HEAT, CHLORINATION, OZONATION, UV
- IONIZING RADIATION, PHOTOCATALYSIS
- **PLASMA, CAVITATION**

Organism	Temperature (°C)	Inactivation time(s)	Log_{10} reduction	Reference
BACTERIA				
Campylobacter spp.	60	300	3.9 log	D'Aoust et al. (1988)
	63	300	> 5 log	D'Aoust et al. (1988)
	60	8.2	Per log	Sörqvist (2003)
	62	15	3.5–5 log	Juffs & Deeth (2007)
Coxiella burnetii	79.4	25	No survivors	Juffs & Deeth (2007)
Escherichia coli	60	1 800	6 log	Moce-Llivina et al. (2003)
	65	< 2	Per log	Spinks et al. (2006)
	72	0.4	Per log	Sörqvist et al. (2003)
Escherichia coli 0157	60	300	1.5 log	D'Aoust et al. (1988)
	64.5	300	> 5 log	D'Aoust et al. (1988)
	65	3	Per log	Spinks et al. (2006)
	62	15	< 1–5 log	Juffs & Deeth (2007)
Enterococcus faecalis	65	7–19	Per log	Spinks et al. (2006)
Klebsiella pneumoniae	72	23	Per log	Sörqvist (2003)
	65	< 2	Per log	Spinks et al. (2006)
Legionella pneumophila	58	360	Per log	Dennis, Green & Jones (1984)
Legionella spp.	80	18–42	Per log	Stout, Best & Yu (1986)
Mycobacterium paratuberculosis	72	15	> 4 log	Juffs & Deeth (2007)
Pseudomonas aeruginosa	65	5	Per log	Spinks et al. (2006)
Salmonella typhimurium	65	< 2	Per log	Spinks et al. (2006)
Salmonella choleraesuis[a]	60	300	Per log[b]	Moce-Llivina et al. (2003)
Salmonella spp. except *Salmonella seftenberg*	72	0.1	Per log	Sörqvist (2003)
Salmonella seftenberg	60	340	Per log	Sörqvist (2003)
Serratia marcescens	65	< 2	Per log	Spinks et al. (2006)
Shigella sonnei	65	3	Per log	Spinks et al. (2006)
Vibrio cholerae	55	22.5	Per log	Johnston & Brown (2002)
	70	120	> 7 log	Johnston & Brown (2002)
Yersinia enterocolitica	64.5	300	> 5 log	D'Aoust et al. (1988)
	72	0.5	Per log	Sörqvist (2003)
VIRUSES				
Adenovirus 5	70	1 260	> 8 log	Maheshwari et al. (2004)
Coxsackievirus B4	60	1 800	5.1 log	Moce-Llivina et al. (2003)
Coxsackievirus B5	60	1 800	4.8 log	Moce-Llivina et al. (2003)
Echovirus 6	60	1 800	4.3 log	Moce-Llivina et al. (2003)
Enteroviruses	60	1 800	4.3 log	Moce-Llivina et al. (2003)
Hepatitis A	65	120	2 log	Parry & Mortimer (1984)
	65	1 320	3 log	Bidawid et al. (2000)
	75	30	5 log	Parry & Mortimer (1984)
	80	5	5 log	Parry & Mortimer (1984)
	85	< 30	5 log	Bidawid et al. (2000)
	85	< 1	5 log	Parry & Mortimer (1984)
Poliovirus 1	60	1 800	5.4 log	Moce-Llivina et al. (2003)
	62	1 800	> 5 log	Strazynski, Kramer & Becker (2002)
	72	30	> 5 log	Strazynski, Kramer & Becker (2002)
	95	15	> 5 log	Strazynski, Kramer & Becker (2002)

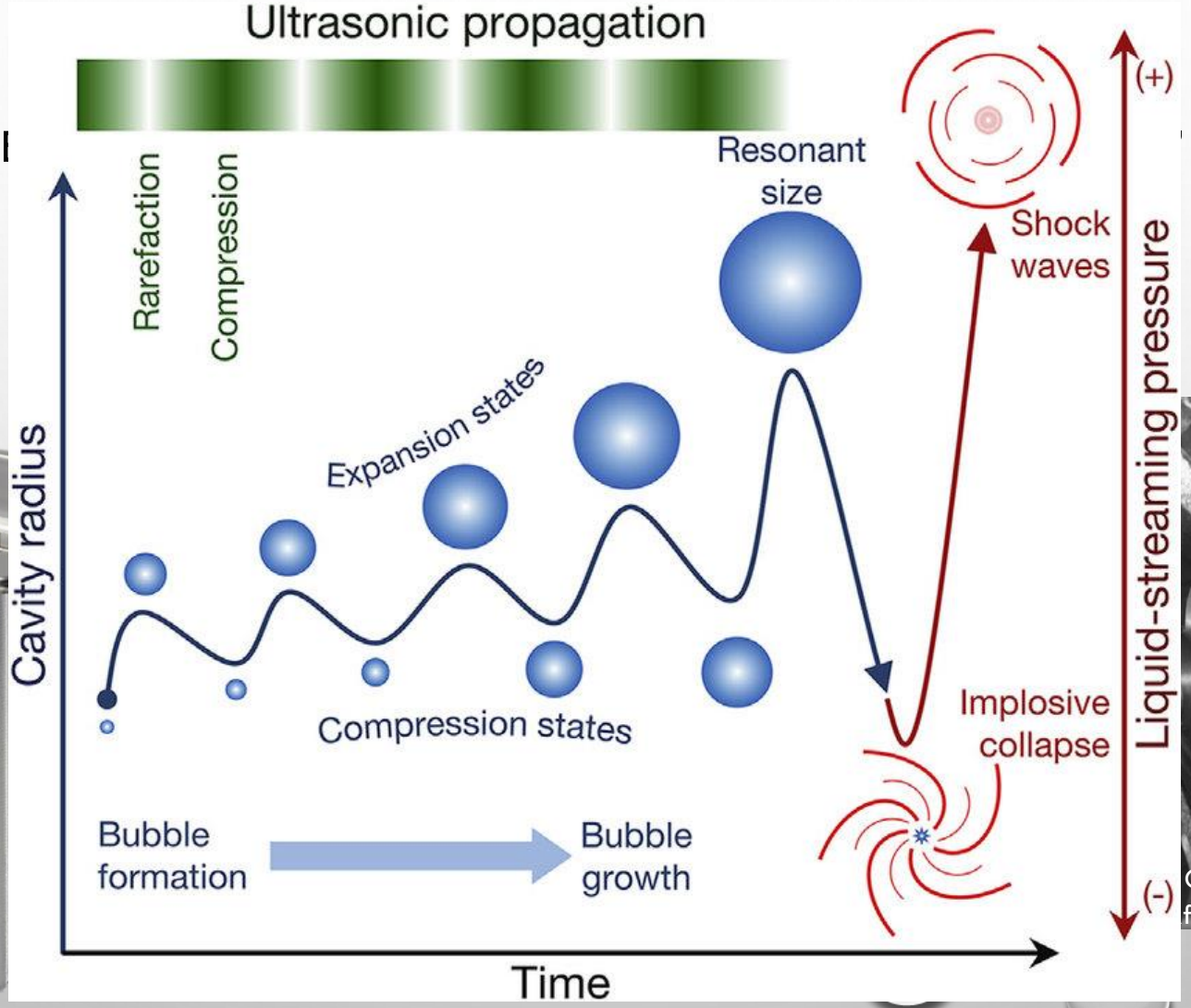
PLASMA

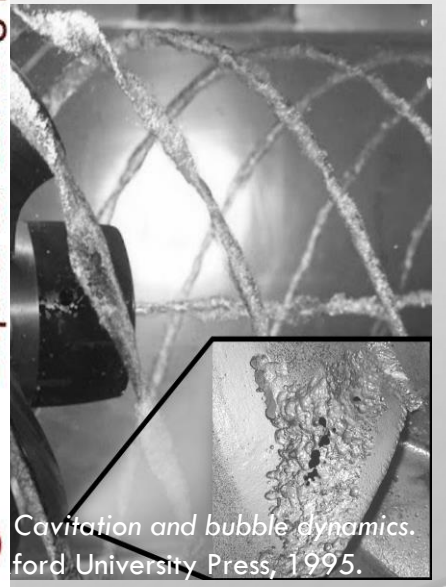


CAVITATION

ACOUSTIC AND HYDRODYNAMIC CAVITATION

- "WILD" PROCESSI TEMPERATURE)





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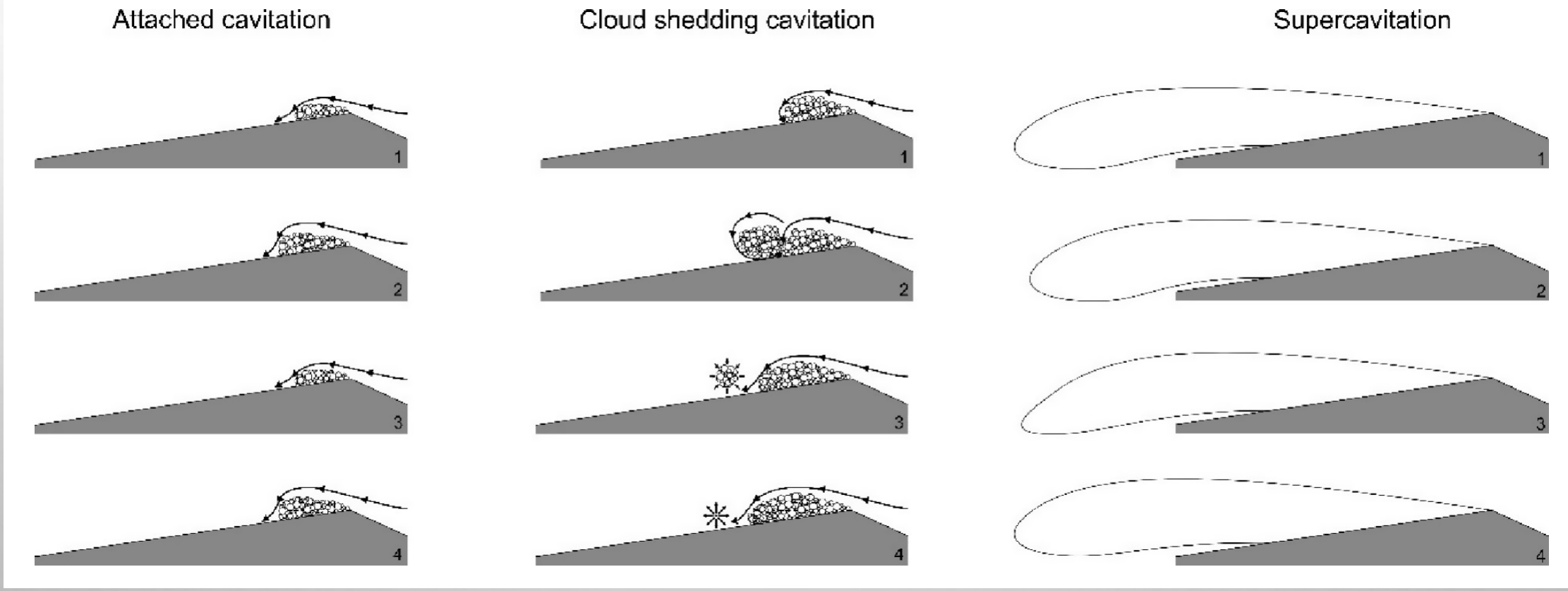
HYDRODYNAMIC CAVITATION



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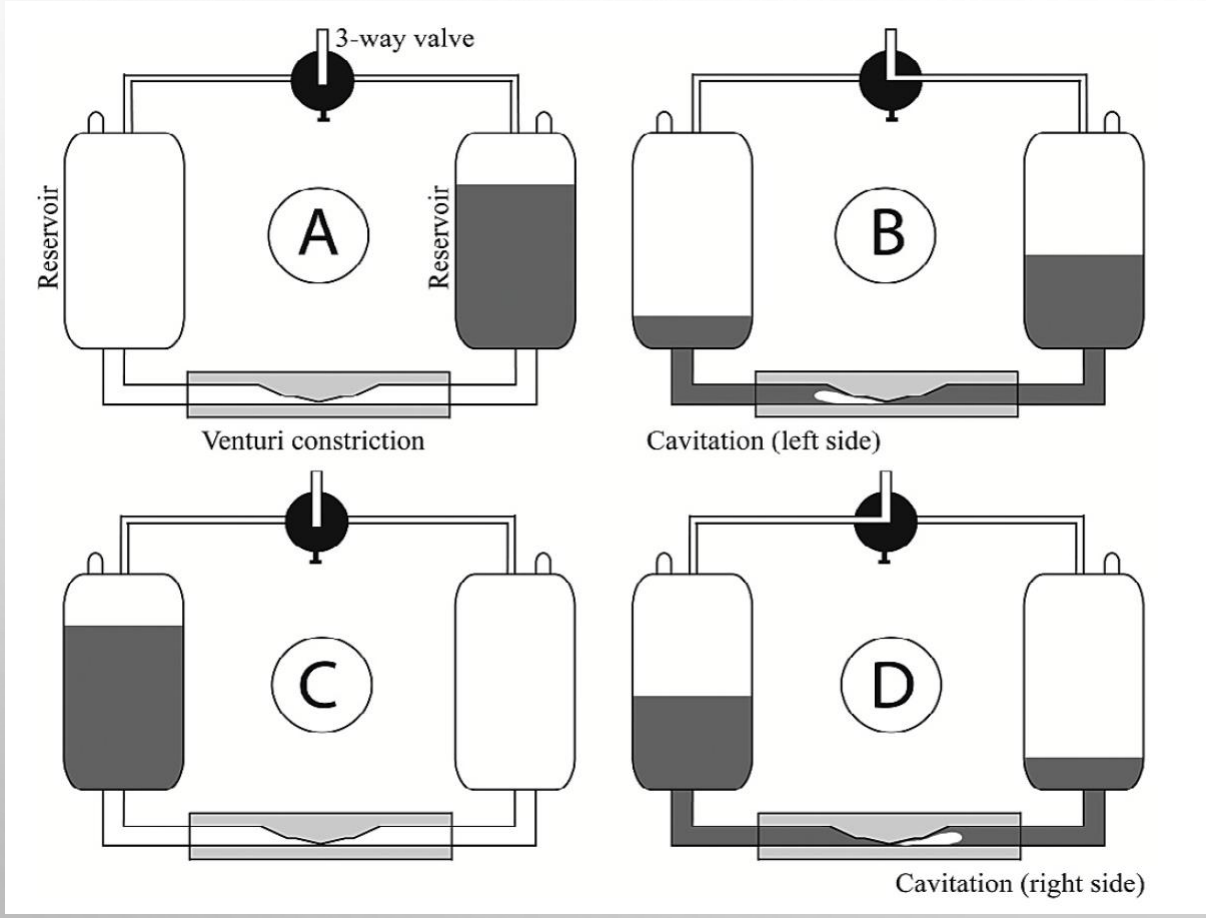
HYDRODYNAMIC CAVITATION



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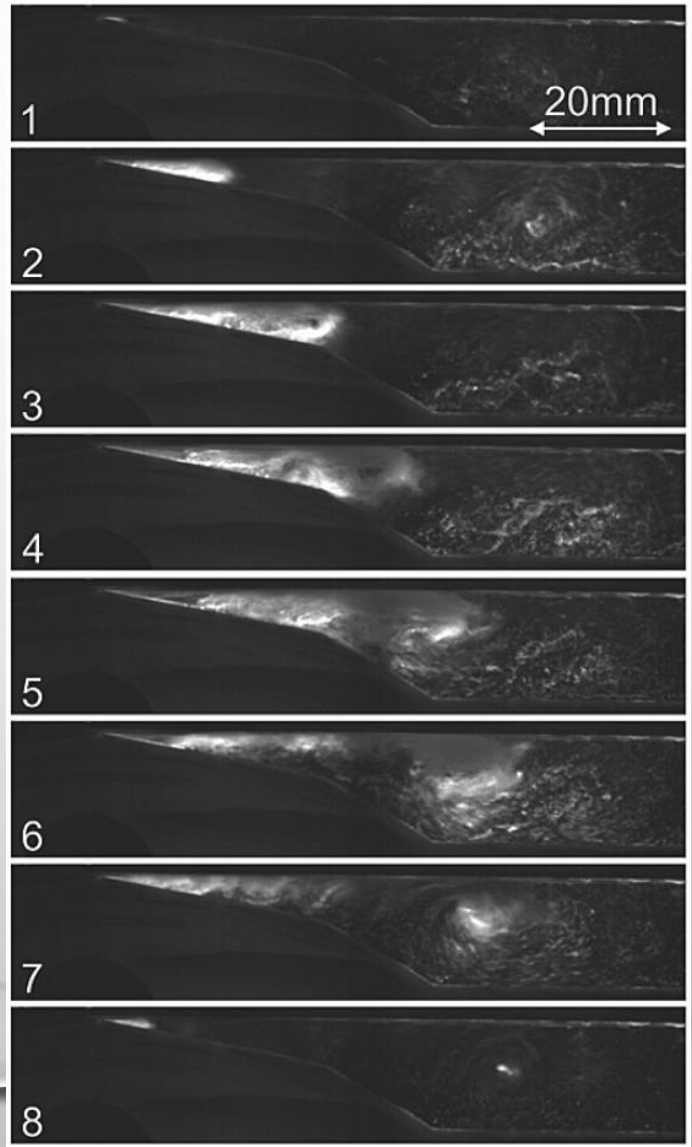
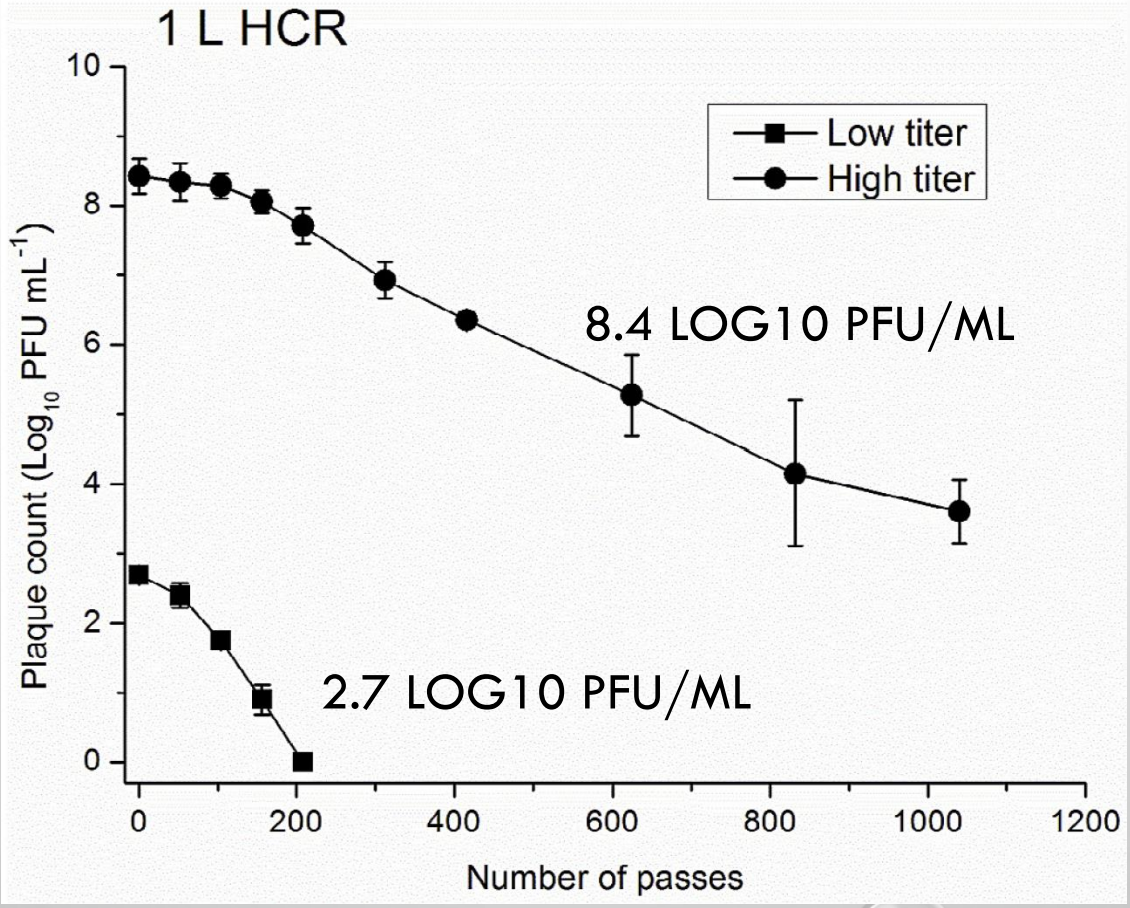


HYDRODYNAMIC CAVITATION



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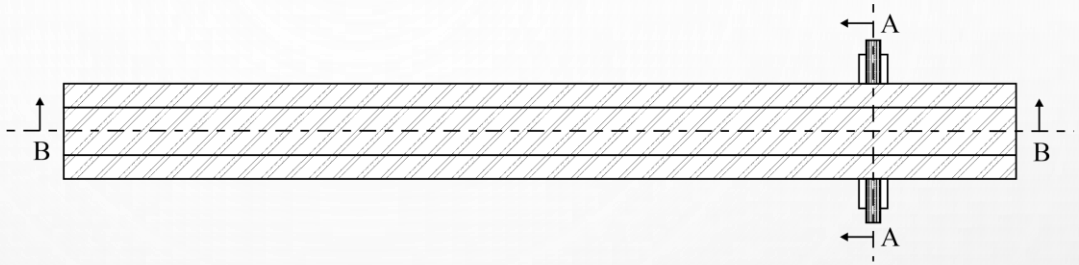
THE COMBINED DEVICE

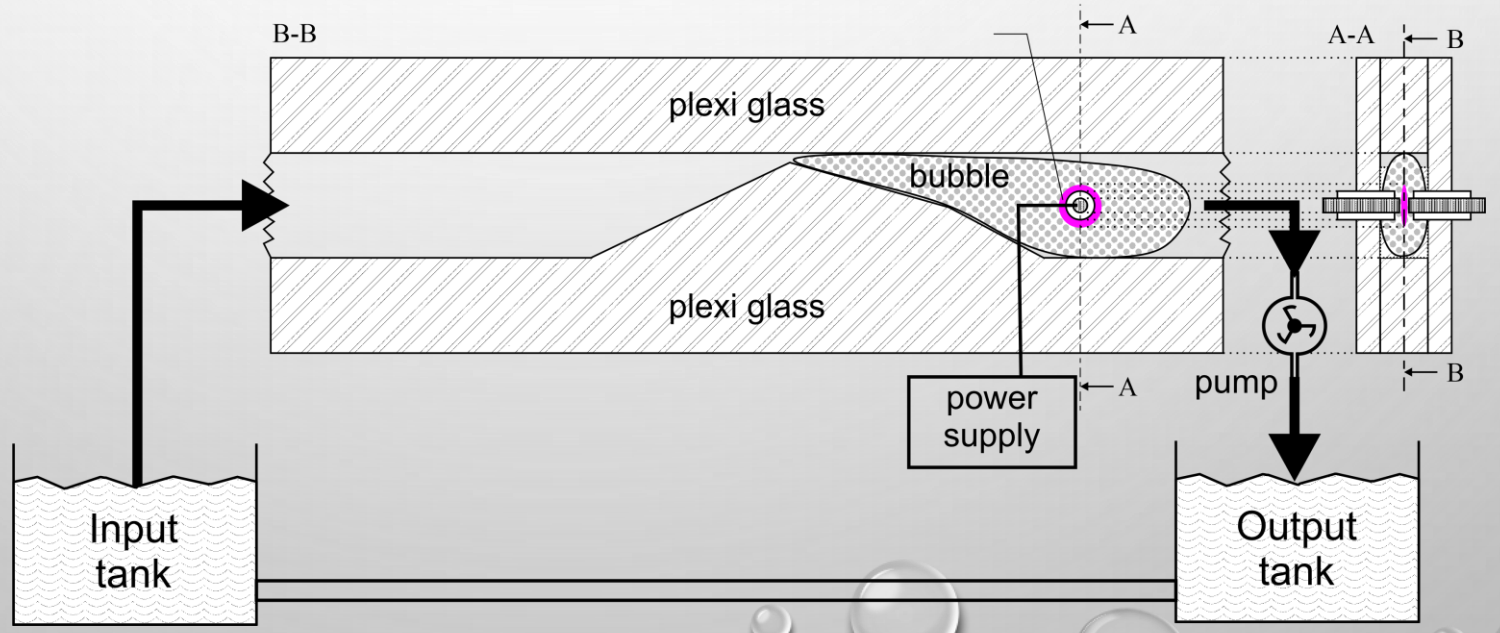


EU AND US

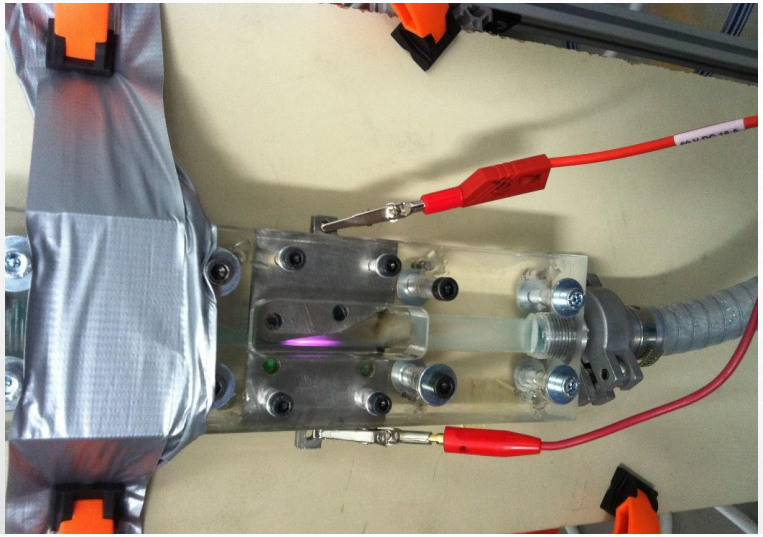
PATENT PENDING

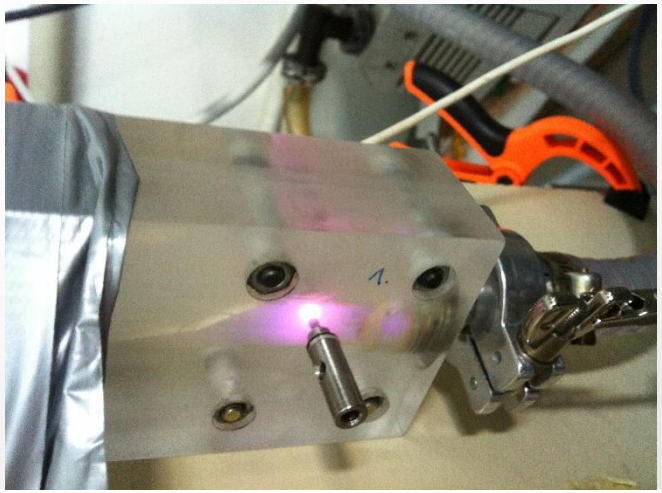
EP3981743A1

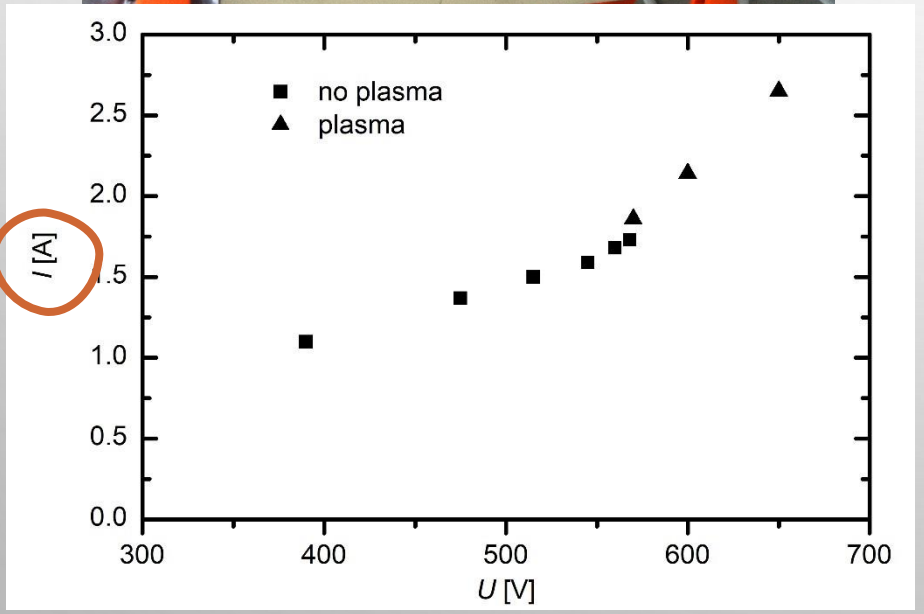
US2022106206A1

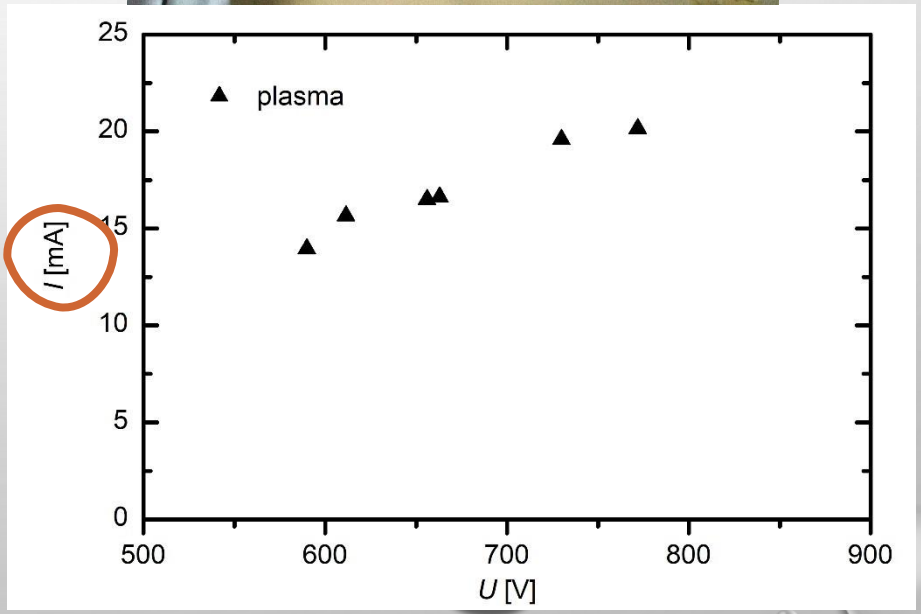


FIRST COMBINED DEVICE ITERATIONS

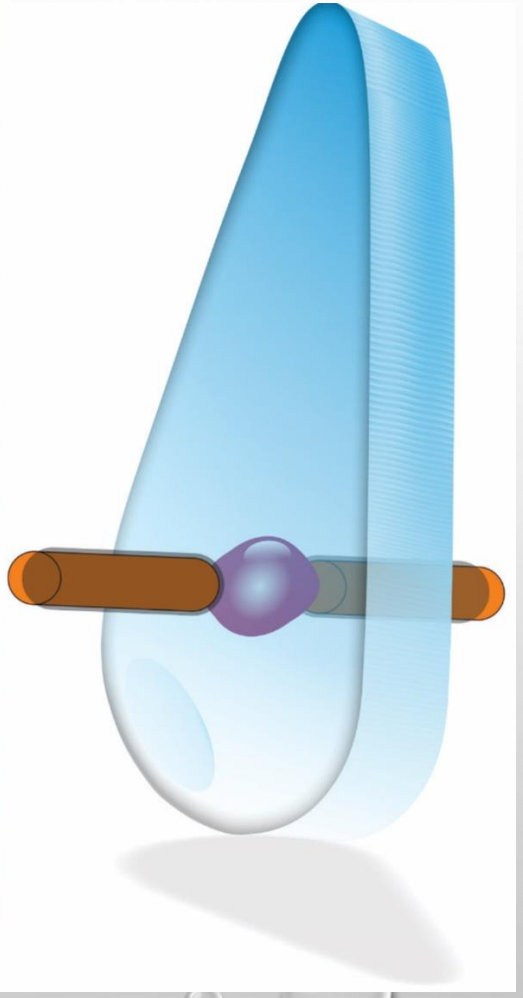




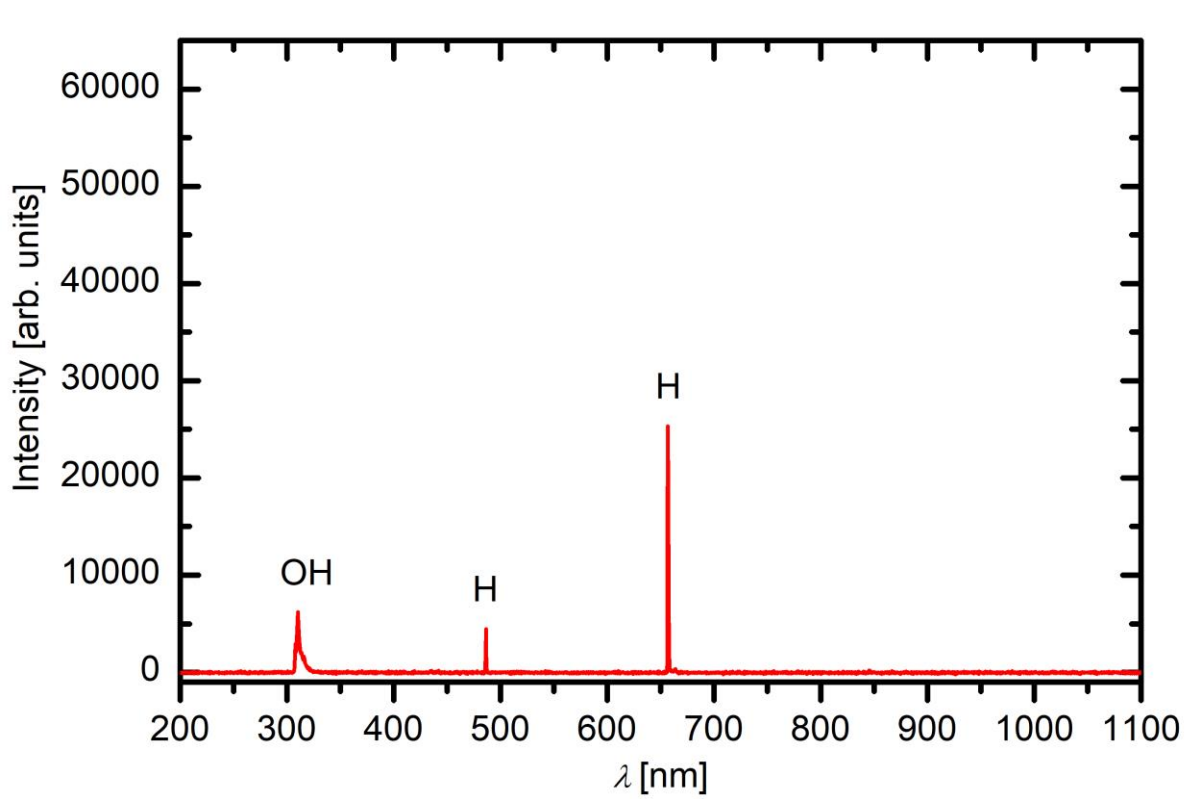


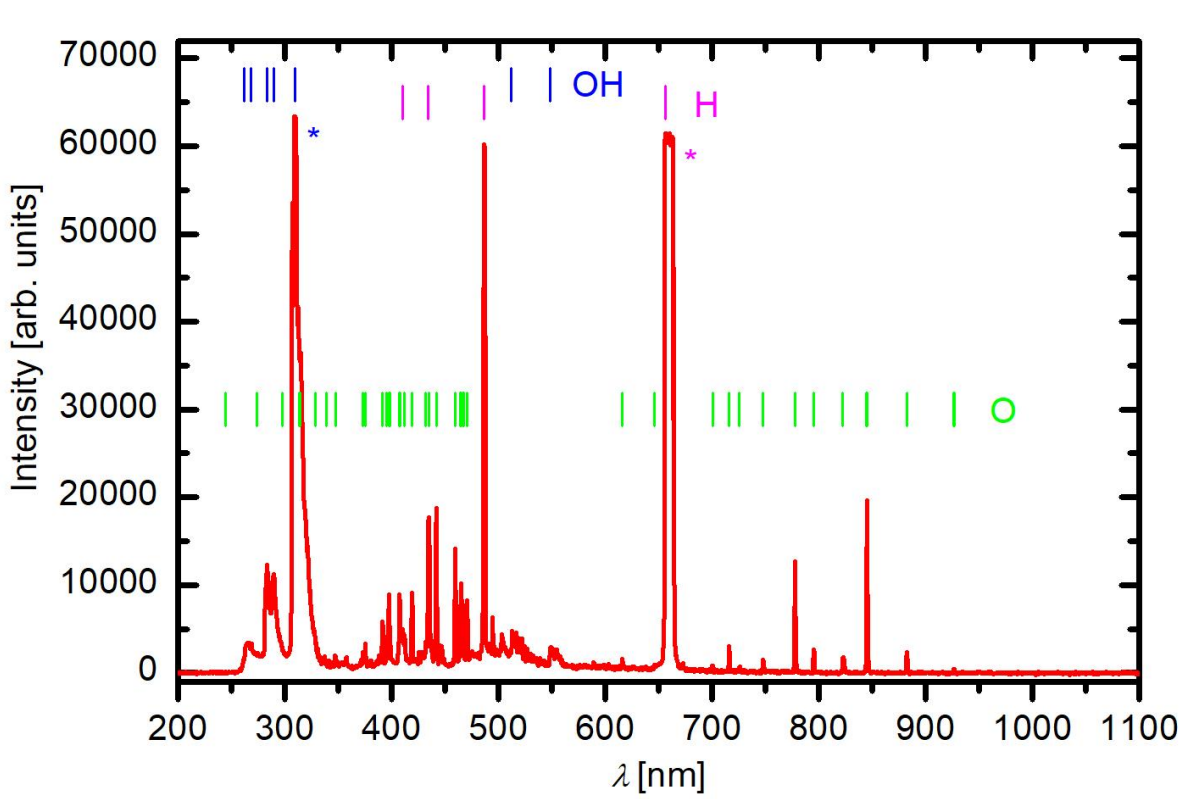


LATEST VERSION



OPTICAL EMISSION SPECTRUM





EXPERIMENTS

- IMMEDIATE MS2 INACTIVATION BY DIRECT TREATMENT
- CONTROL TREATMENTS
- CYTO AND GENO TOXICITY

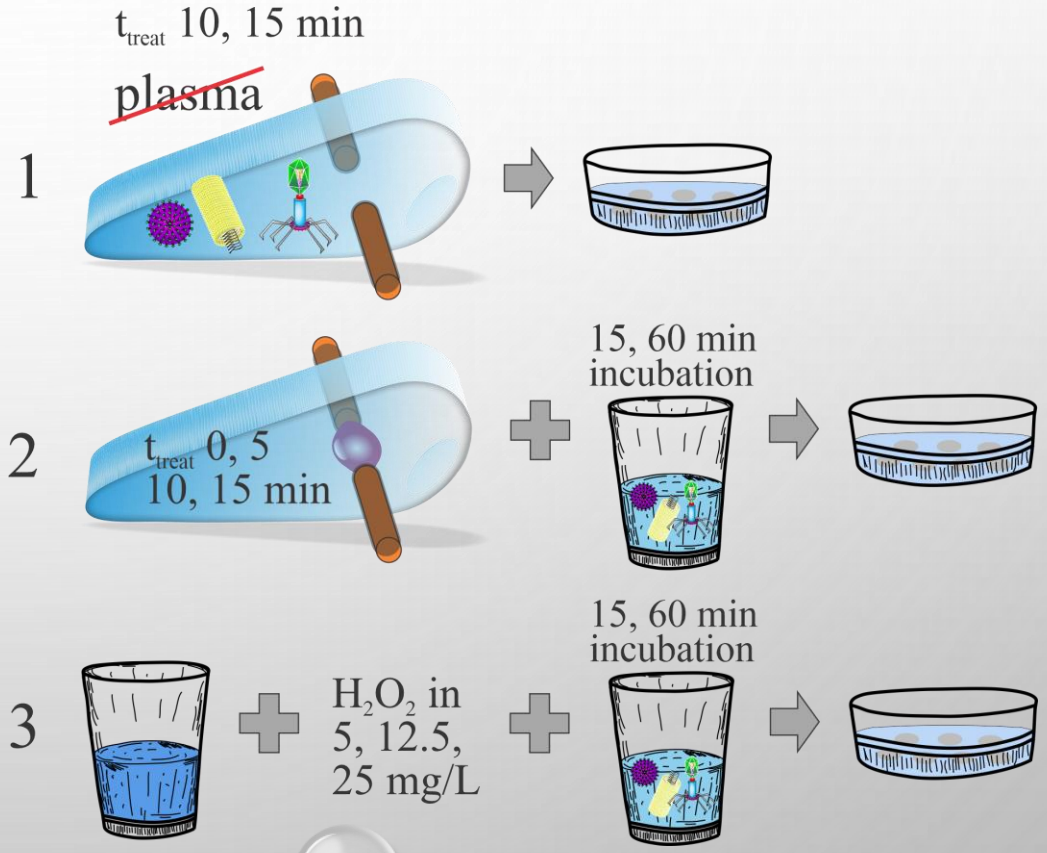
VIRUS INACTIVATION OF MS2 BACT.

Incubation (min)	Virus inactivation (%)						
	Treatment time (min)						
	1	2	3	4	5	10	15
0	71	99.8	99.97	99.9997	100	100	100
60	87	99.9993	100	100	100	100	100

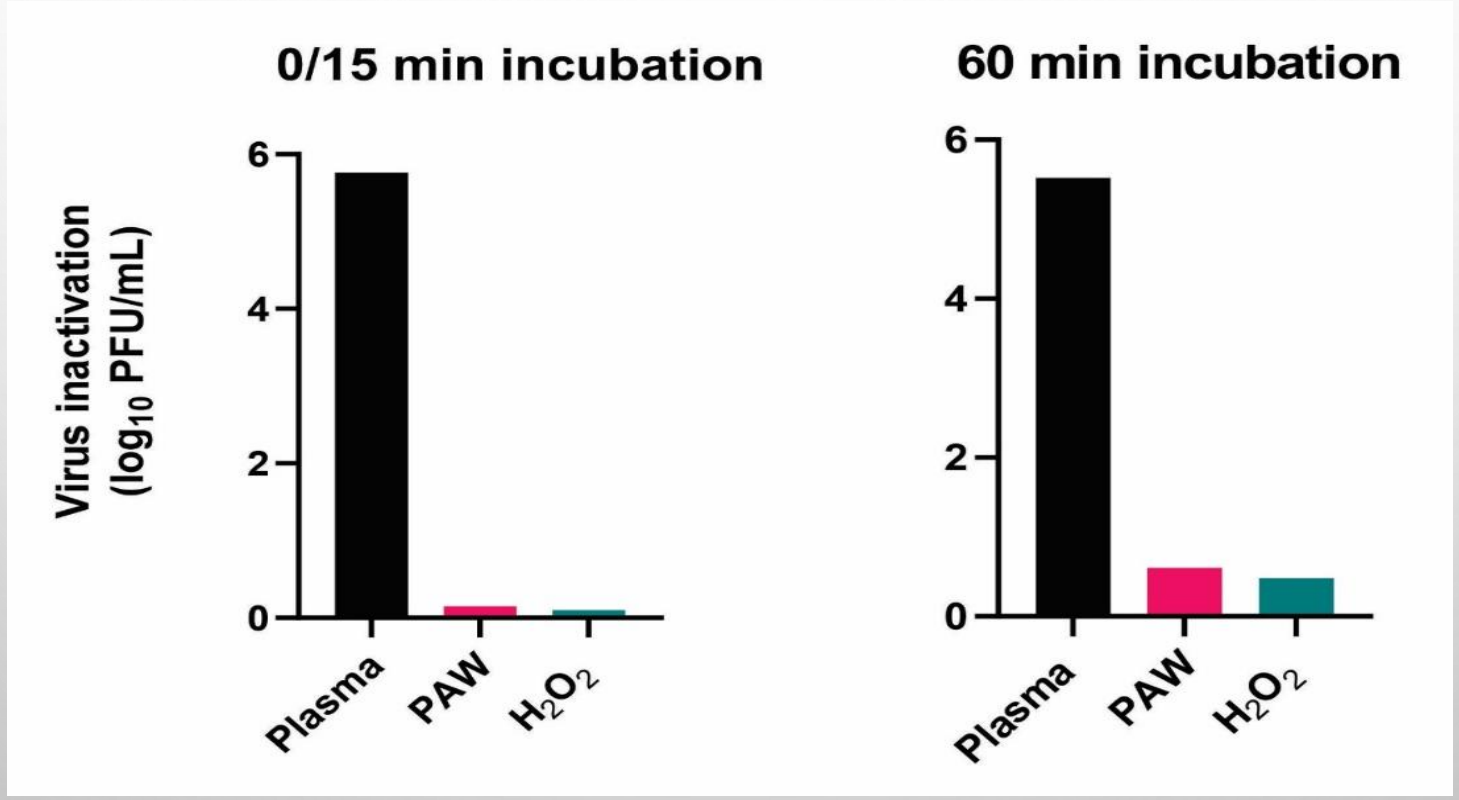
H_2O_2 concentration (mg/L)							
Treatment time (min)							
0	1	2	3	4	5	10	15
0	0.5-2	2	2-5	<5	5	10	**10**-25[a]

CONTROL TREATMENTS

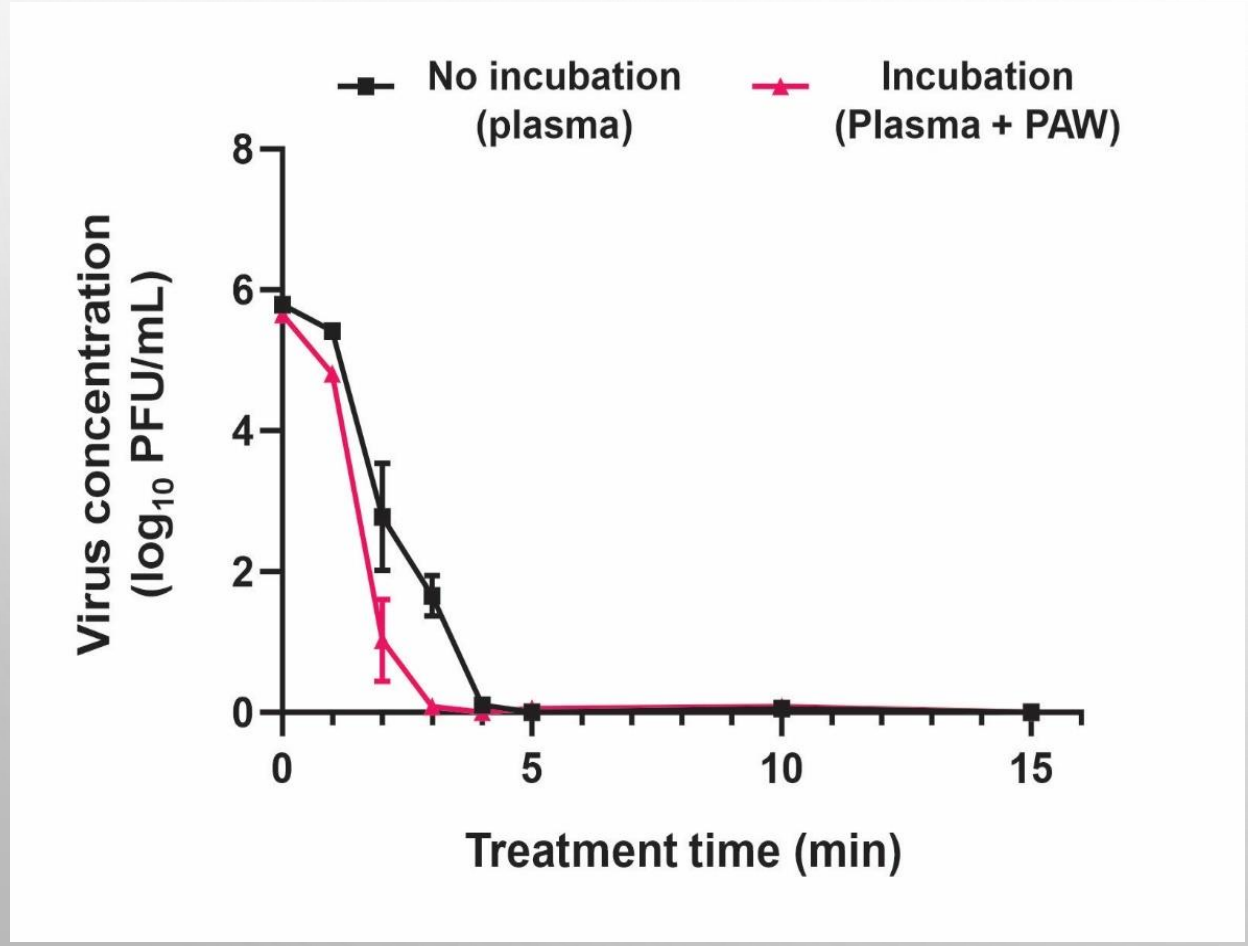
1. SUPERCAVITATION (NO PLASMA)
2. SUPERCAVITATION W. PLASMA + INCUBATION (PAW)
3. H_2O_2 + INCUBATION (H_2O_2)

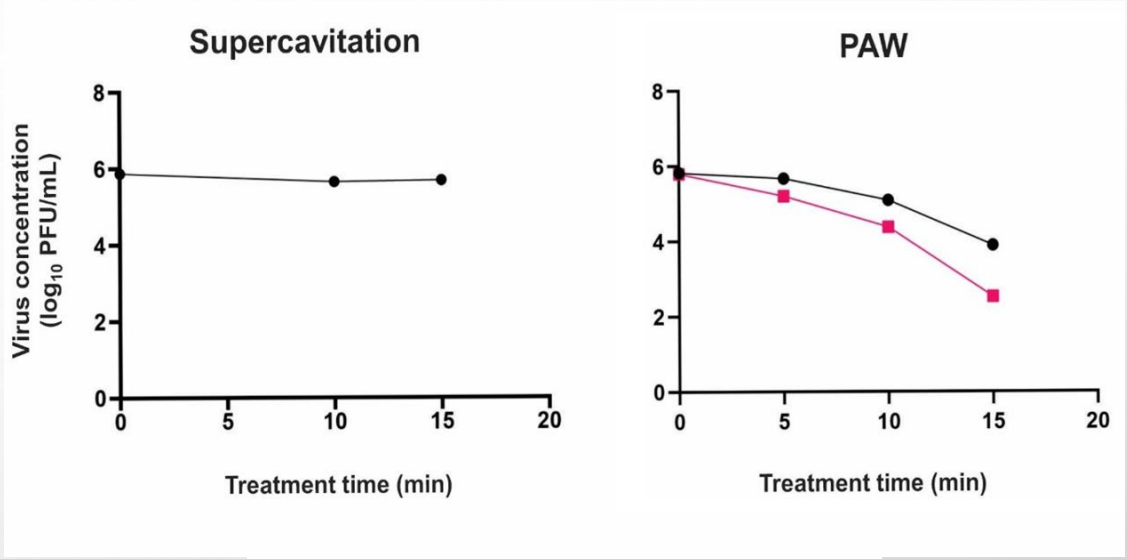


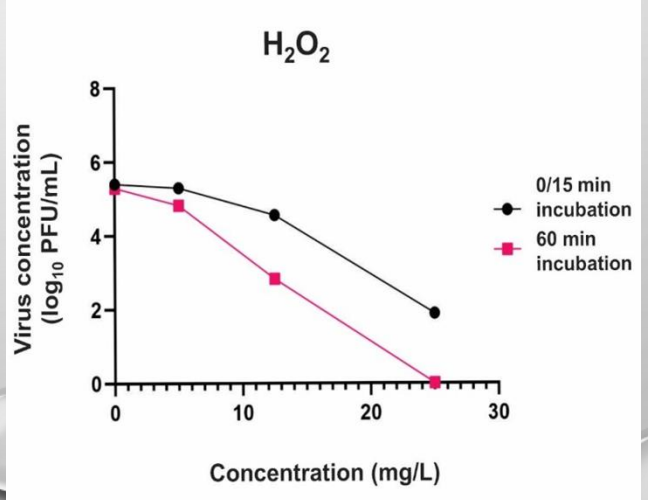
VIRUS INACTIVATION OF MS2 BACT.



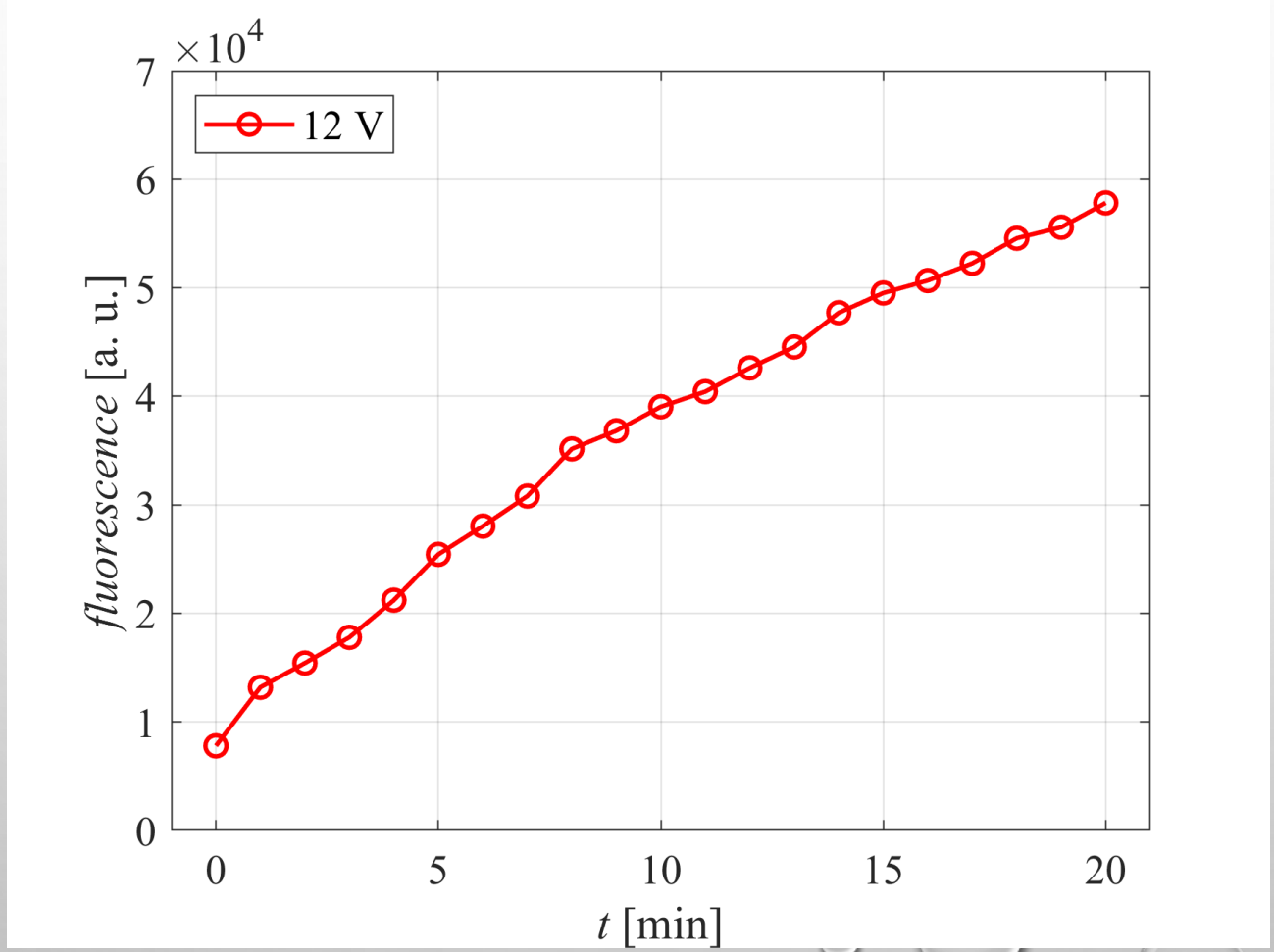
CONTROL TREATMENTS





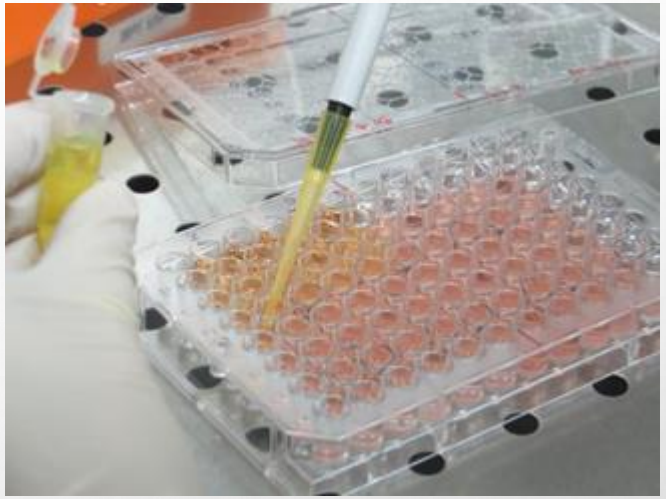


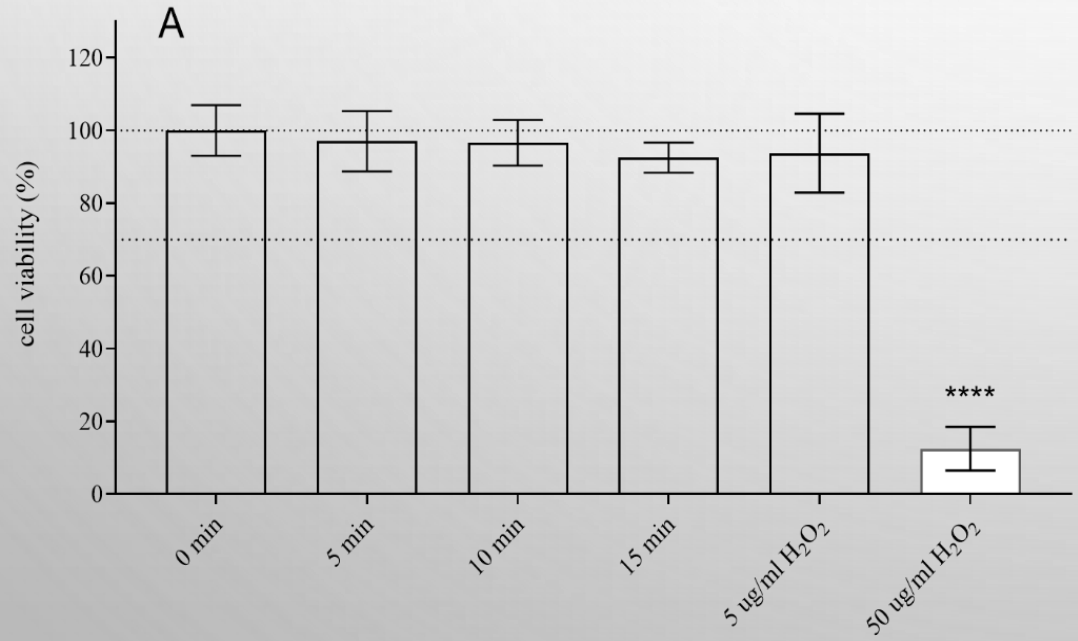
OH

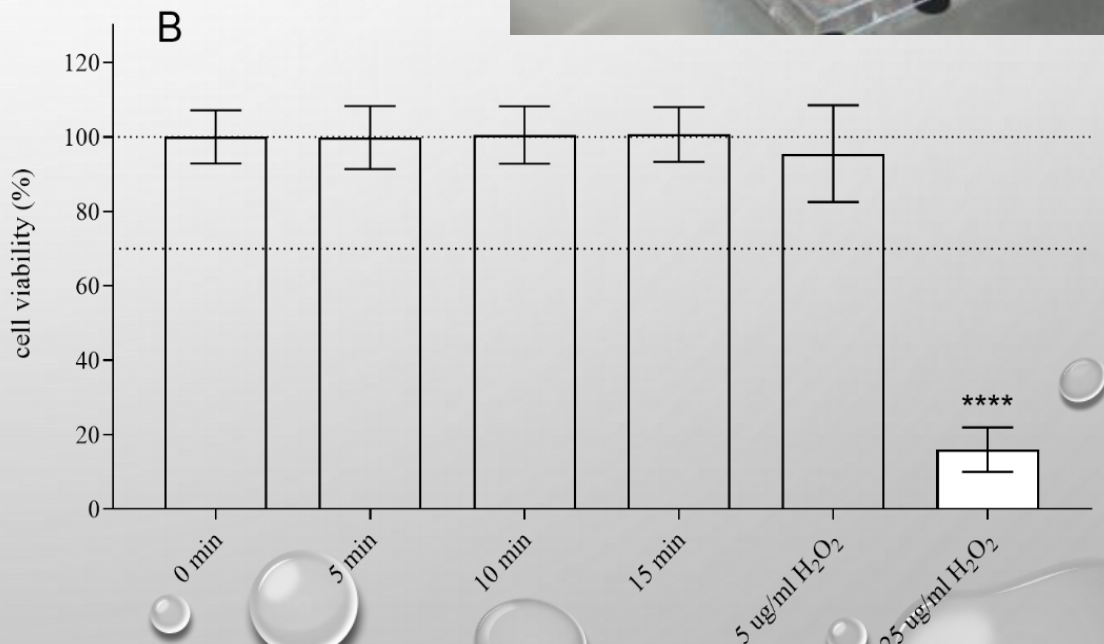


IS THE TREATMENT SAFE?

- PAW CYTOTOXICITY: MTS ASSAY AND HUMAN HEPATOCELLULAR CARCINOMA CELL LINE (HEPG2)
  - 2 HOURS (A)
  - 24 HOURS (B)







CONCLUSIONS

- SUCCESSFUL MS2 INACTIVATION FOR 6 LOG IN 5 MIN (0.4 L)
- NO ADVERSE EFFECTS

- CEC'S (ESTRADIOL, DICLOFENAC, BPA 100%, VALSARTAN, NAPROXEN 60%, 20 MIN.)
- COMBINATION WITH PHOTOCATALYTIC REACTOR (TETRACYCLINE → TOTAL DEGRADATION 10 MIN)
- CURRENTLY
  - UPSCALE AT 100 L/MIN
  - PFAS DEGRADATION
  - RESEARCH ON HUMAN NOROVIRUS AND ITS SURROGATE
- MECHANISMS (SCAVENGERS), BACTERIA, DIFFERENT WATER MATRICES, COMBINATIONS

THANKS!!!

Jožef Stefan Institute,
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NATIONAL INSTITUTE OF **BIOLOGY**

Univerza v Ljubljani
Fakulteta za strojništvo

Faculty of Mechanical Engineering
Laboratory for Hydraulic Machines LVTS