This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

12.2 Design of advanced electron accelerator plant for biohazards treatment

Andrzej G. Chmielewski

Institute of Nuclear Chemistry and Technology

Warsaw, Poland

iFAST

I.FAST first Annual Meeting, 2-6.05.2022,Geneva,Switzerland,CERN

Partners

- **Institute of Nuclear Chemistry and Technology, Warsaw Poland**

Prof. Andrzej G. Chmielewski

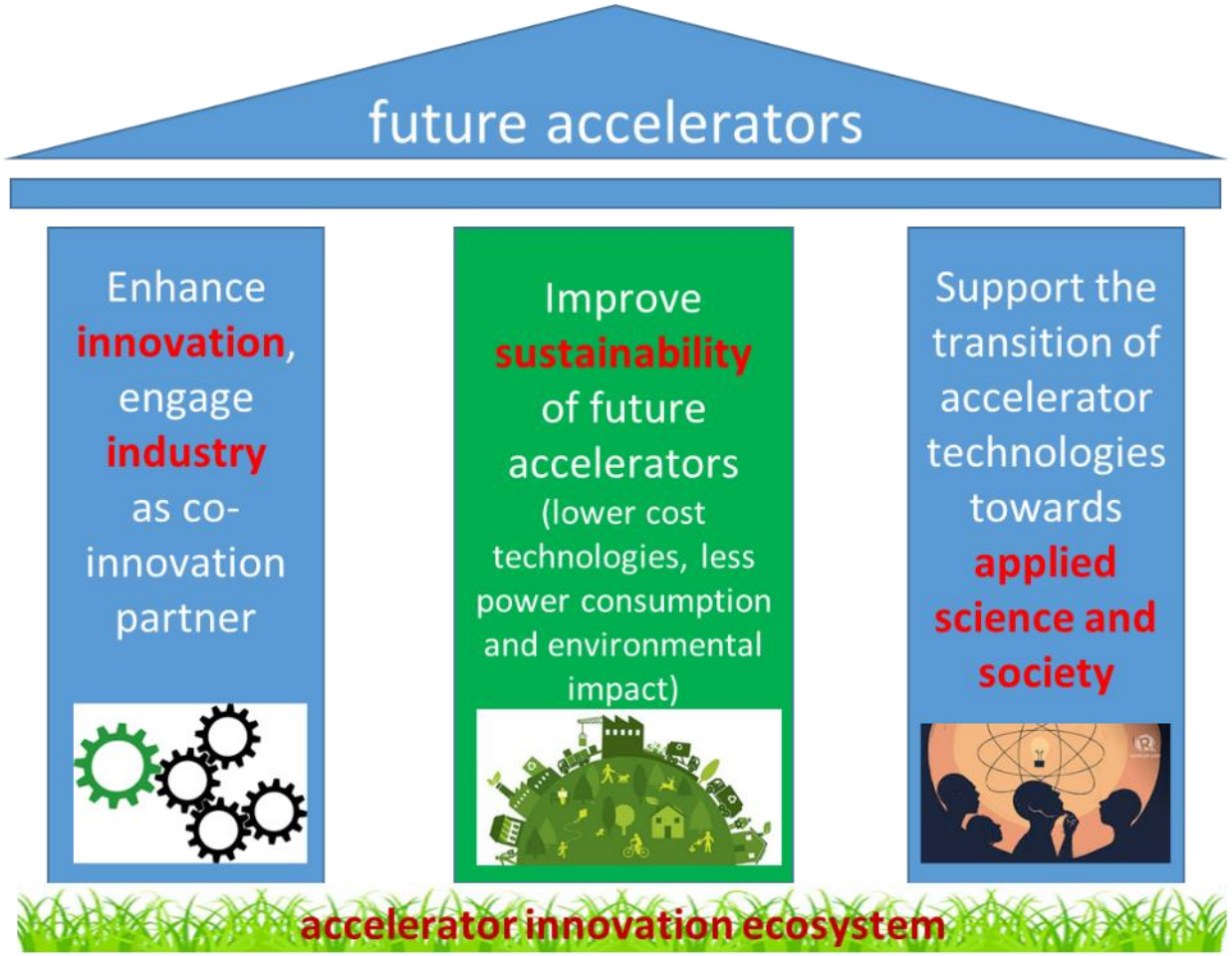
- **Slovak Technical University, Bratislava, Slovakia**

Assoc. Prof. Andrea Sagatova, PhD.
Institute of Nuclear and Physical Engineering
Faculty of Electrical Engineering and Information Technology

- **Biopolinex SA, Lublin , Poland**

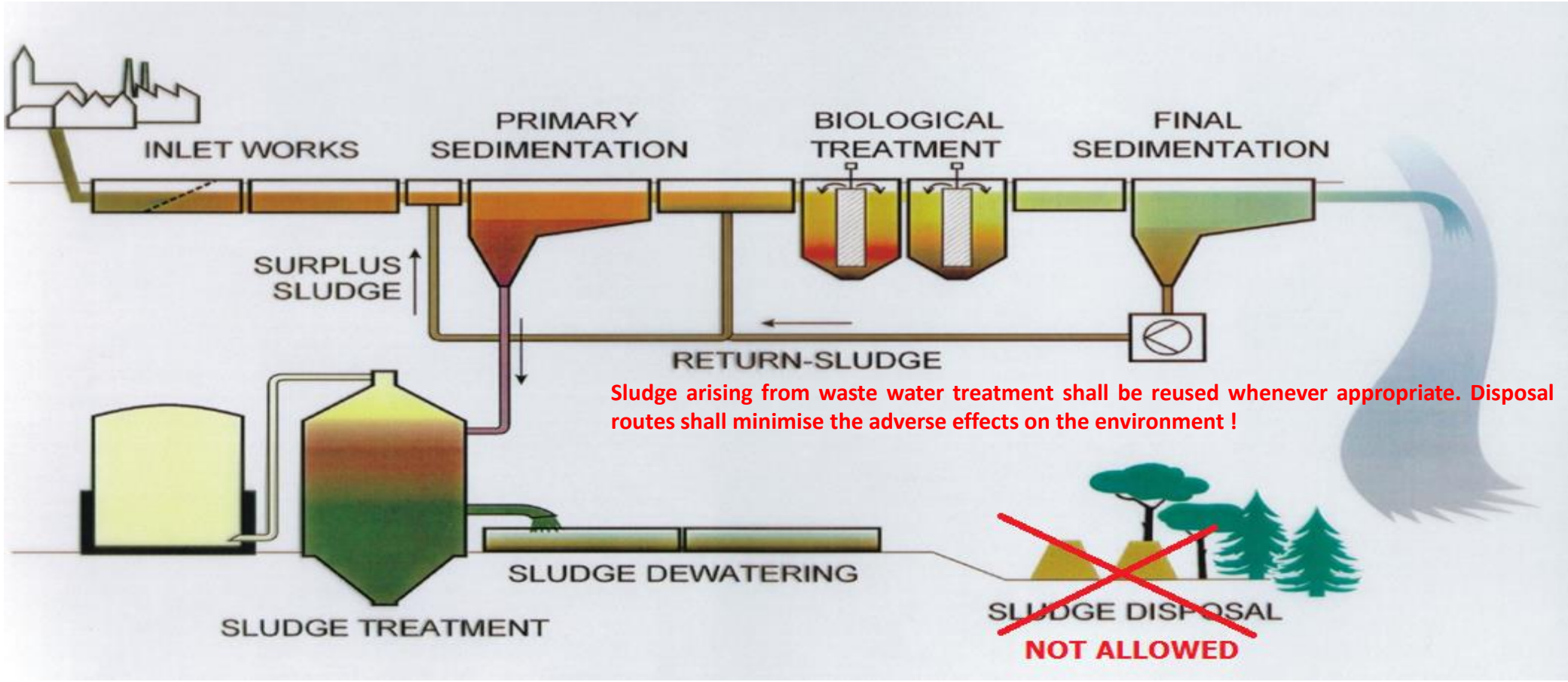
Mr. Krzysztof Pietrzak, President

The three I.FAST pillars



- These goals correspond to the three I.FAST «pillars», which defined the priorities given in the selection of I.FAST activities following the bottom-up call.
- Additional focus areas: training and management of technology infrastructure.
- This strategy is coherent with the priorities announced in the 2020 Update of the European Strategy for Particle Physics, and more at large with the priorities of the particle accelerator user communities.

SCHEME OF A MUNICIPAL WATER TREATMENT PLANT

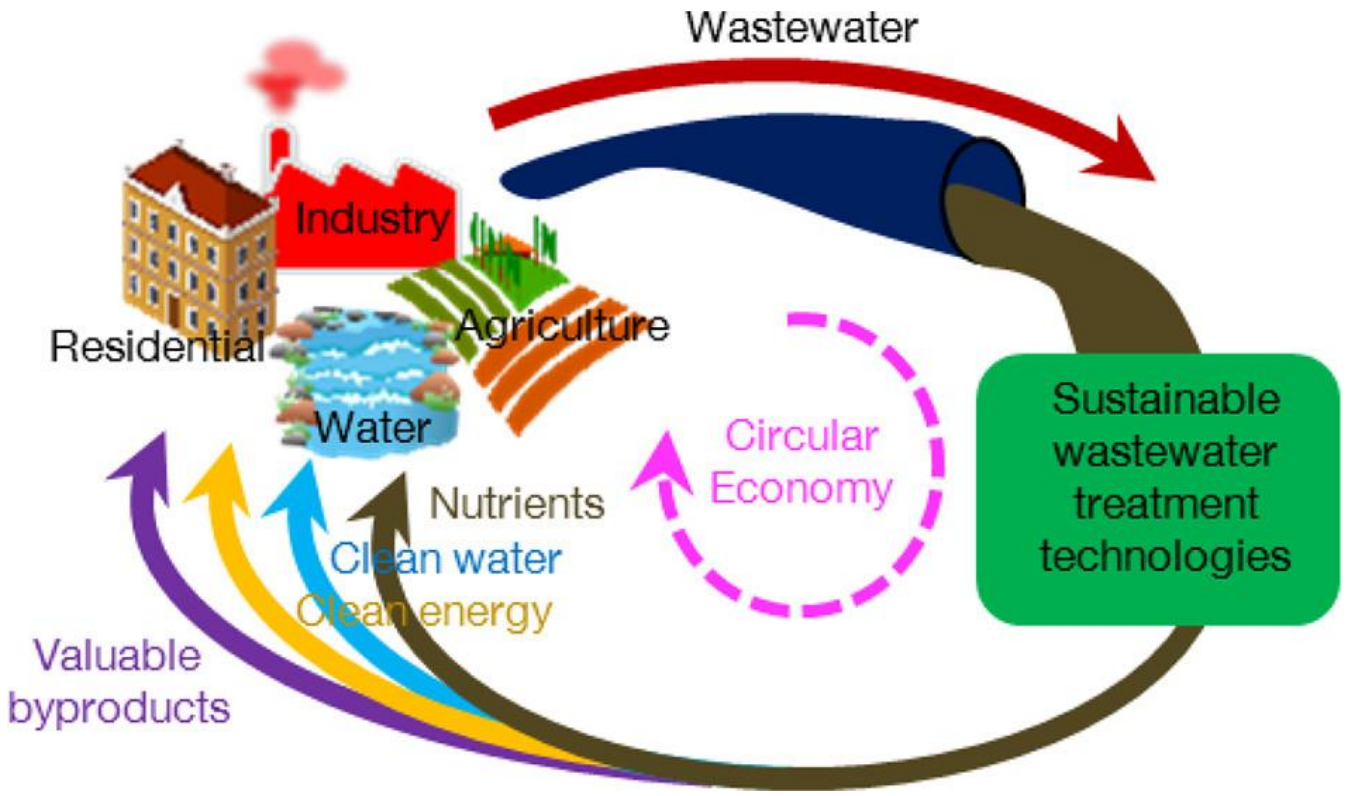


Sewage Sludge processing and management perspectives in Europe

- Increasing trend to recognise sludge (and WW) as valuable resources. (Water, P, N, org. C,..)
- 80 to 90 % P- removal at most of the treatment plants in central Europe (having no P - ores)
- P- recycling is a matter of intensive research in EU.
- EU commission is preparing a P-policy

Prof. Helmut Kroiss; Vienna University of Technology

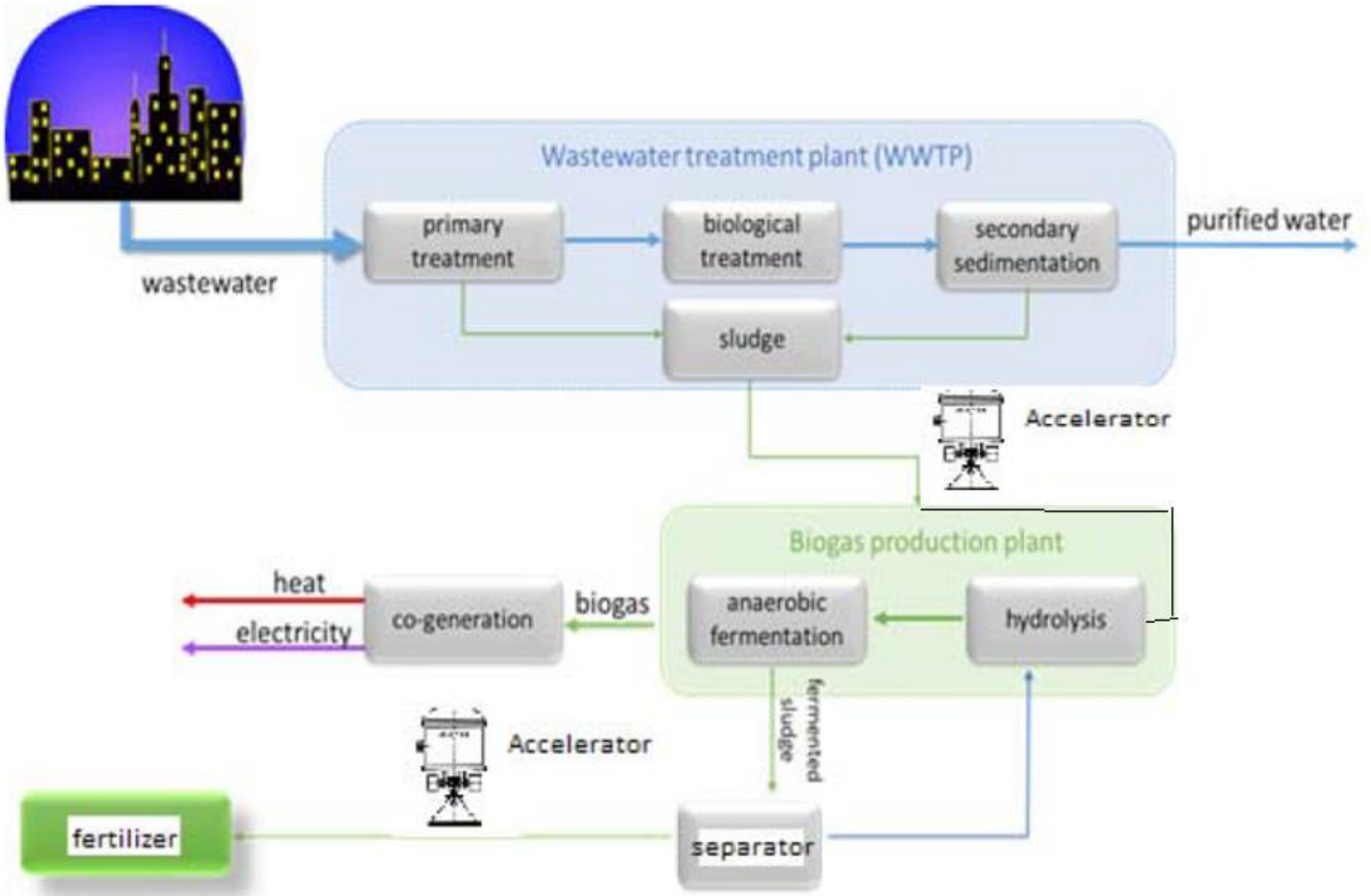
Transitioning Wastewater Treatment Plants toward Circular Economy and Energy Sustainability



We do it even better !

:U.Ghimire, G.Sarpong & V. G. Gude, ACS Omega 2021, 6, 11794−11803

„Zero energy”


Wastewater treatment plant (WWTP)
primary treatment
biological treatment
secondary sedimentation
purified water
wastewater
sludge
Accelerator
Biogas production plant
heat
electricity
co-generation
biogas
anaerobic fermentation
hydrolysis
fermented sludge
Accelerator
fertilizer
separator

Directives

Poland

- Regulation of the Minister for environment 02/2015
- Act of 14th December 2012 (law on waste)

EU

- Council directive 86/278/EEC on the protection of the environment, and in particular of the soil,when sewage sludge is used in agriculture
- Water Framework Directive 2000/60/EC on water protection
- Directive 91/271/EEC on urban waste water treatment
- Directive96/61/EC concerning integrated pollution prevention and control
- Directive 99/31/EC on the Landfill of Waste
- Waste framework Directive 2008/98/EC

Can we use municipal sludge as fertilizer?

- **Directive 91/271/EEC on urban waste water treatment**

  Sludge arising from waste water treatment shall be reused whenever appropriate. Disposal routes shall minimise the adverse effects on the environment.

- **Art. 96.4 Act from 14 December 2012 (law on waste)**

  Usage of municipal waste is possible only if they're stabilised and prepared directly to it's purpose and way of use, especially by biological, chemical, thermal or any other treatment that decreases tendency to rotting or eliminates threat for human health and environment.

Some important legal requirements.

- Council directive 86/278/EEC

  „treated sludge" means: Sludge which has undergone biological, chemical or heat treatment, long term storage or any other appropriate proces so as significantly to reduce its fermentability and health hazards resulting fro its use.

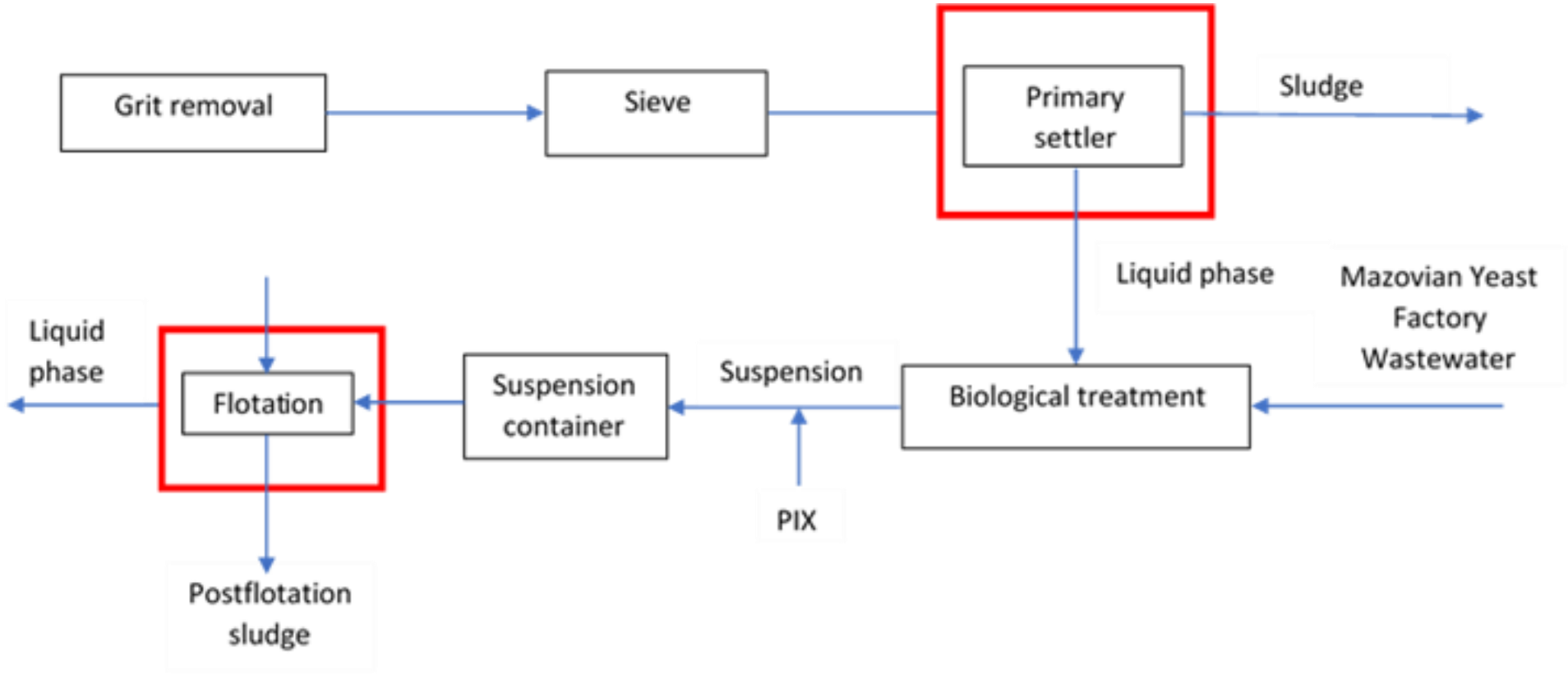
- Waste framework Directive 2008/98/EC

  The Directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest.

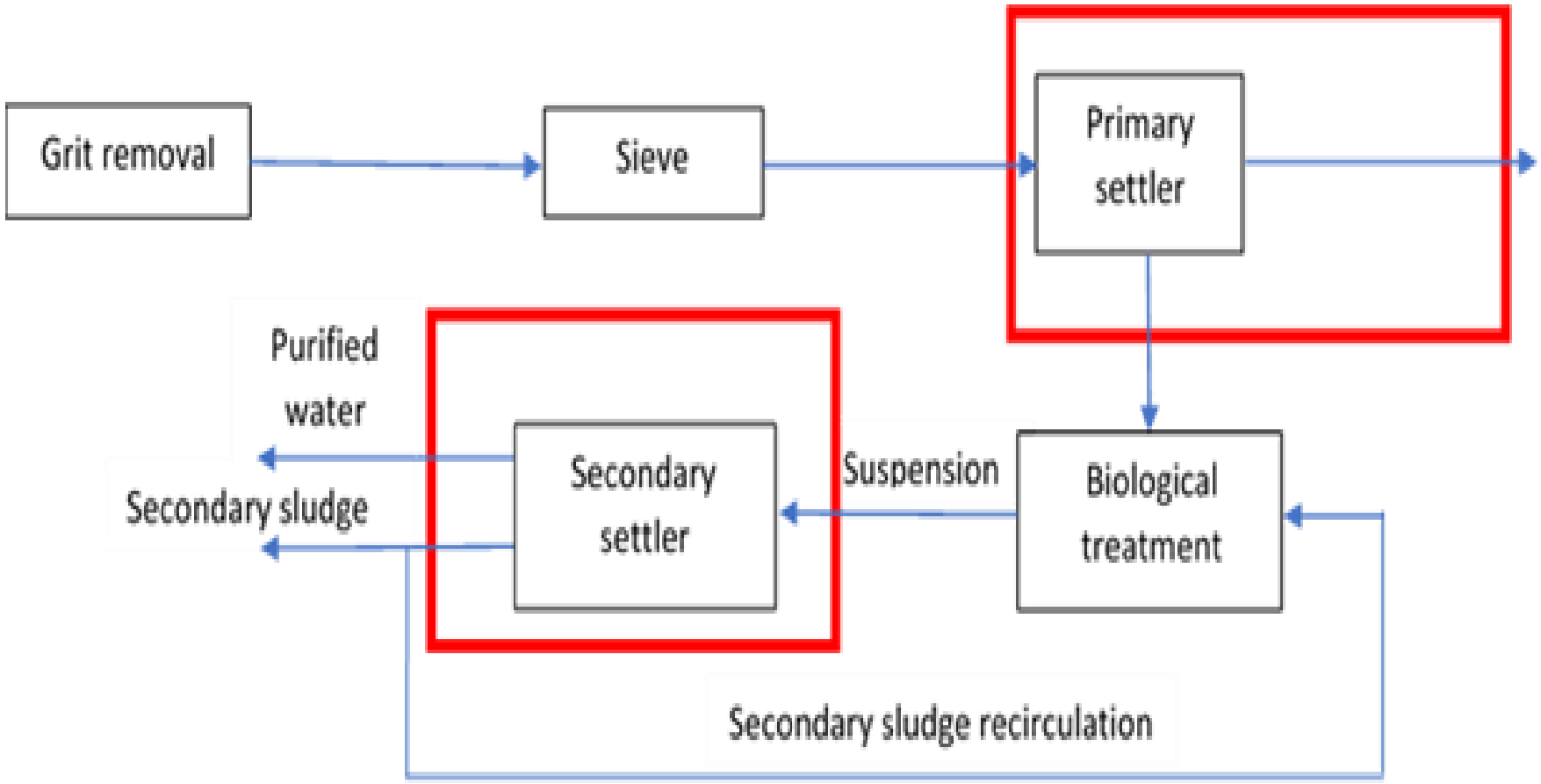
Problems to be solved with use of electron accelerator

- Develope sludge hygenization with use of eb.
- Increase the biogas production by eb sludge flocks desintegration and through cogeneration provide electricity supply for electrons accelerator.
- Ensure production of safe and effective organic fertilizer (with phosphorous recycling).

Simplified scheme of WWTP1. Sampling points are marked with red frames



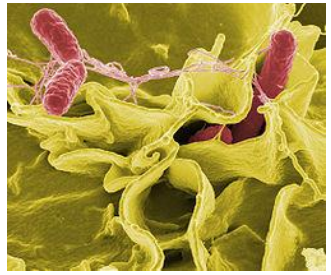
Simplified scheme of WWTP2. Sampling points are marked with red frames



Patogens to be removed

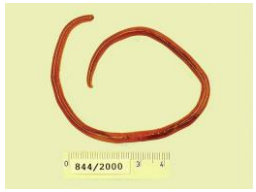
Pathogenic bacteria acceptable content

- In Poland one pathogenic bacteria species is considered: *Salmonella*
- None living cells of salmonella can be detected in 100g sample of municipal sludge

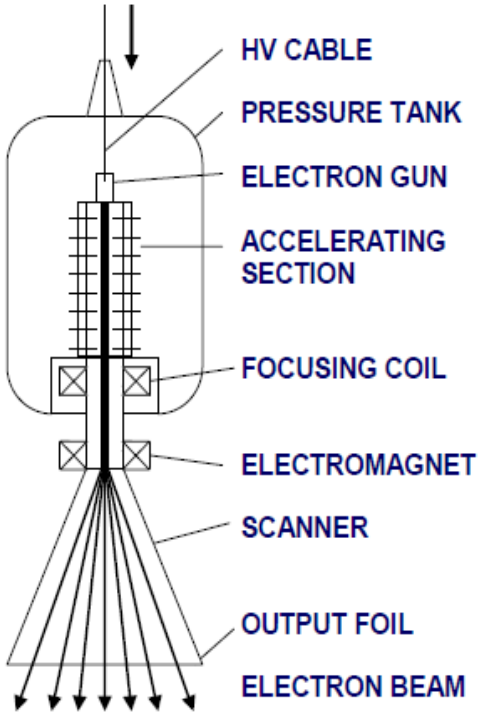


Species of parasites which have to be detected:

- *Ascaris sp.* – human parasitic roundworm
- *Trichuris sp.* – human whipworm
- *Toxocara sp.* – animal (mostly cats and dogs) parasitic worms
- Parasites and eggs acceptable content = 0

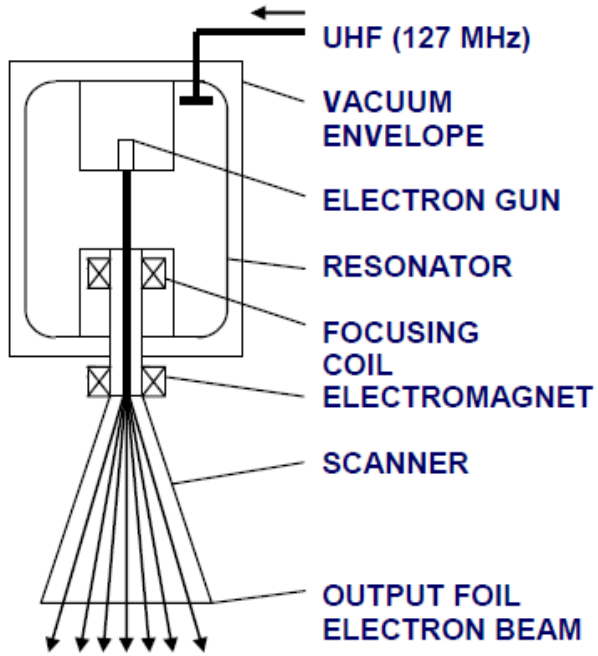


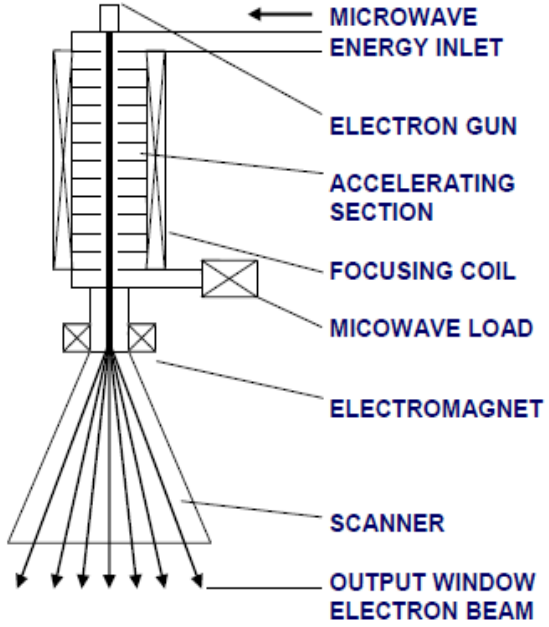
Our accelerators(lab & industry)



DIRECT DC (TRANSFORMER) ACCELERATORS

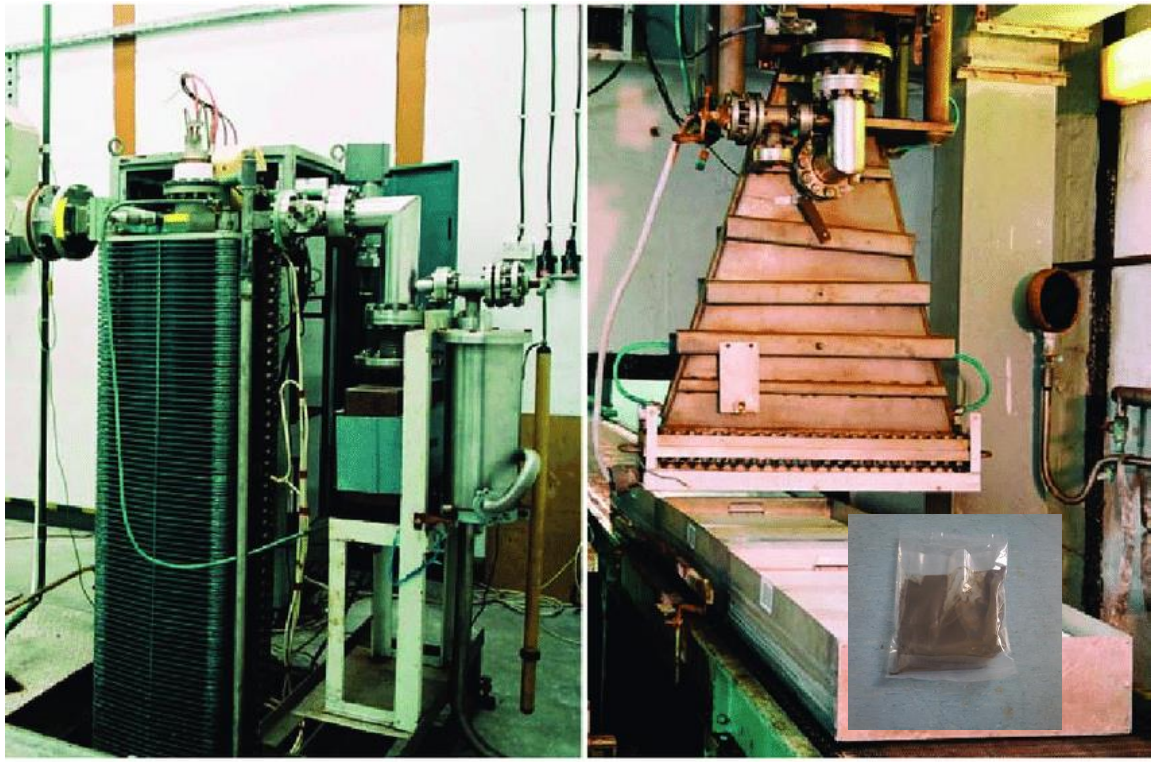
SINGLE CAVITY (RESONANCE) ACCELERATORS





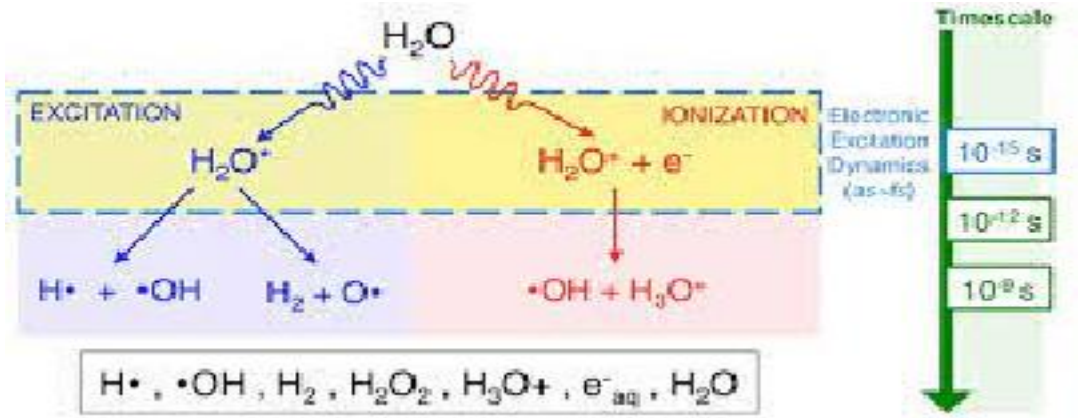
LINEAR (MICROWAVE) ACCELERATORS

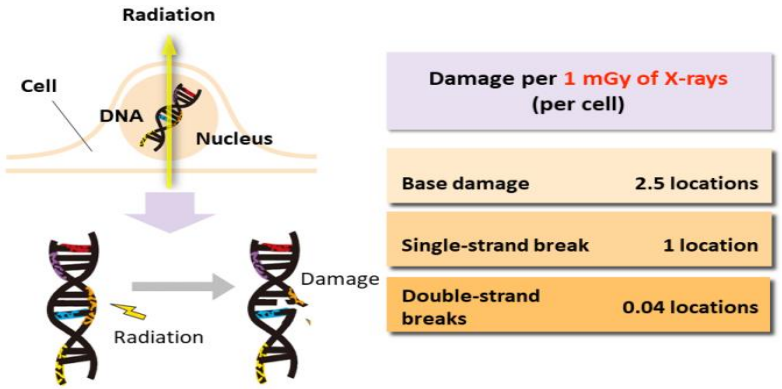
FIS installation used for the flow irradiation of sewage sludge connected to an ILU-6 electron accelerator.
Sample of sewage sludge sealed in a polyethylene bag (120 µm foil thickness) irradiated by an Elektronika 10/10 electron accelerator.

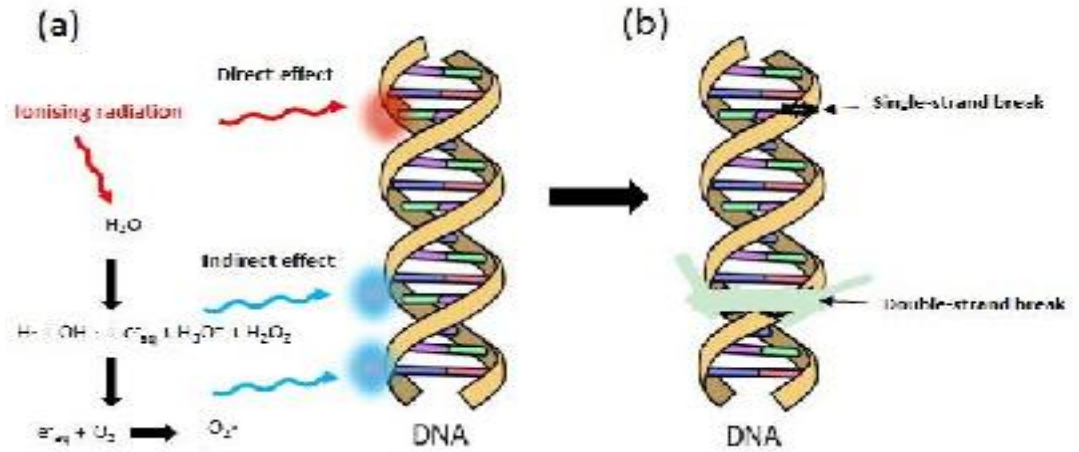


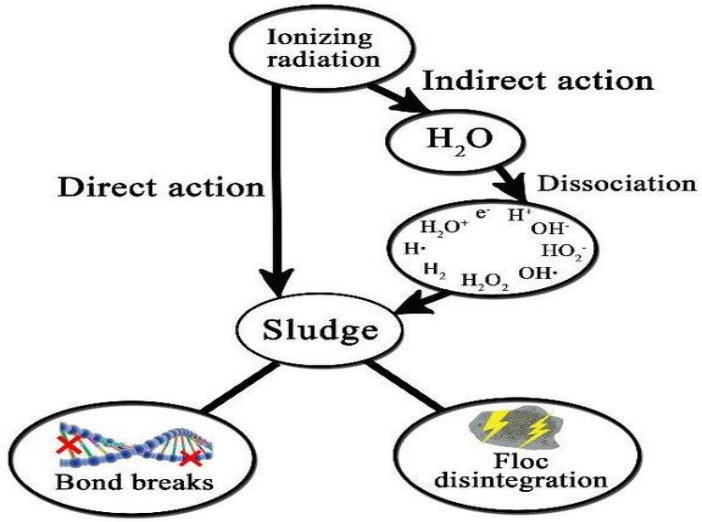
(a) (b)

Process chemistry and biochemistry



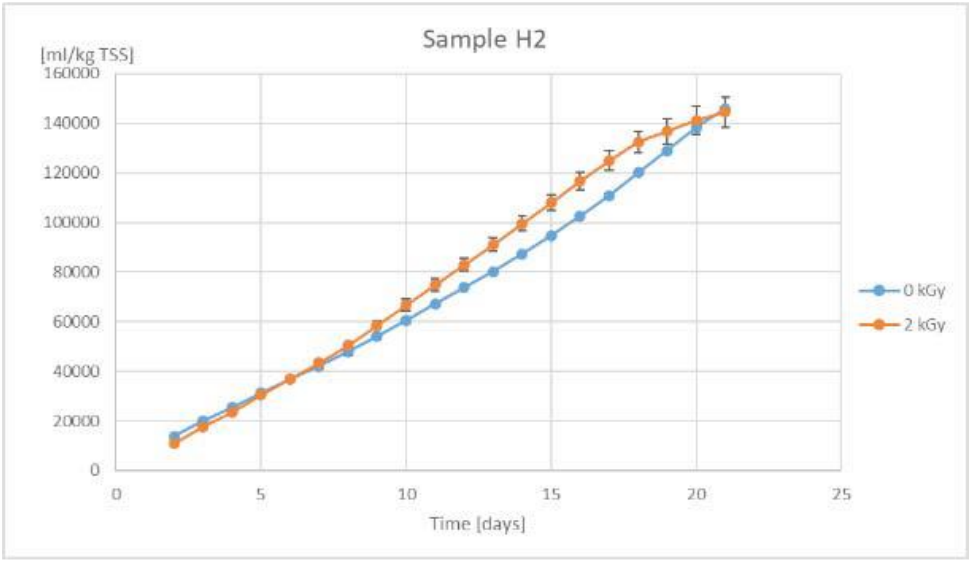


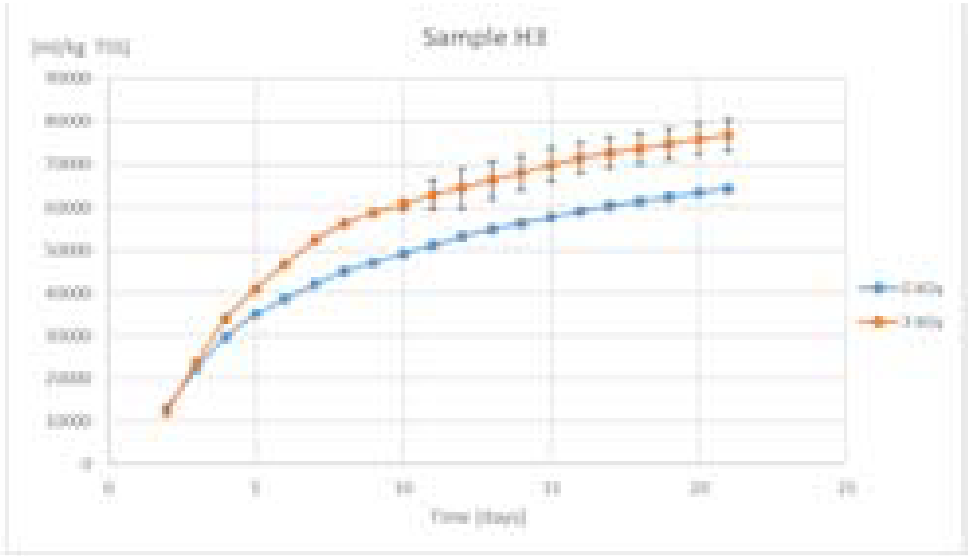




Experiments on sludge flocks eb desintegration

Methane generation over 21 days mesophilic digestion of wastewater treatment plant sludge pretreated at 1 kGy (A), 2 kGy (B) and 3 kGy (C) e-beam doses and data for references samples not irradiated (0 kGy). H1–H3 represent independent experiments performed on separatedays using different sludge samples.



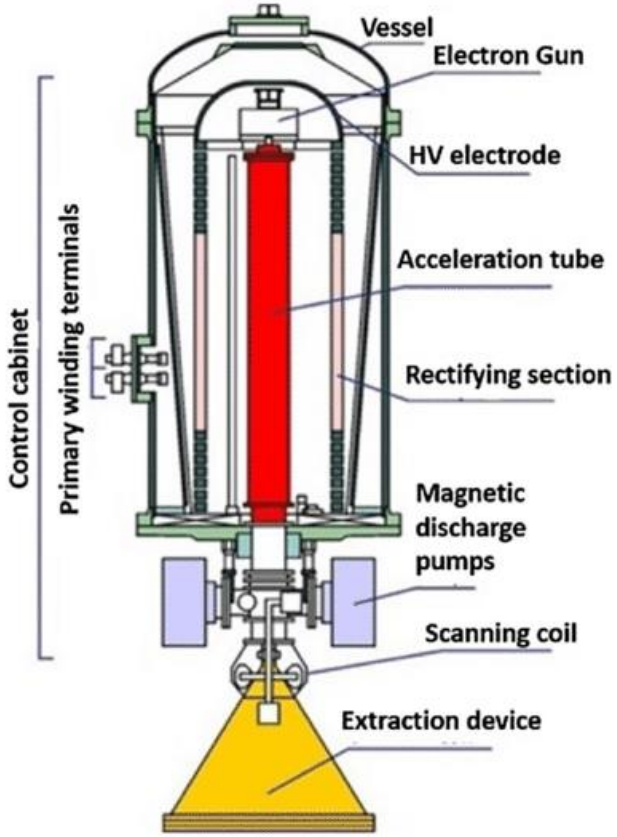


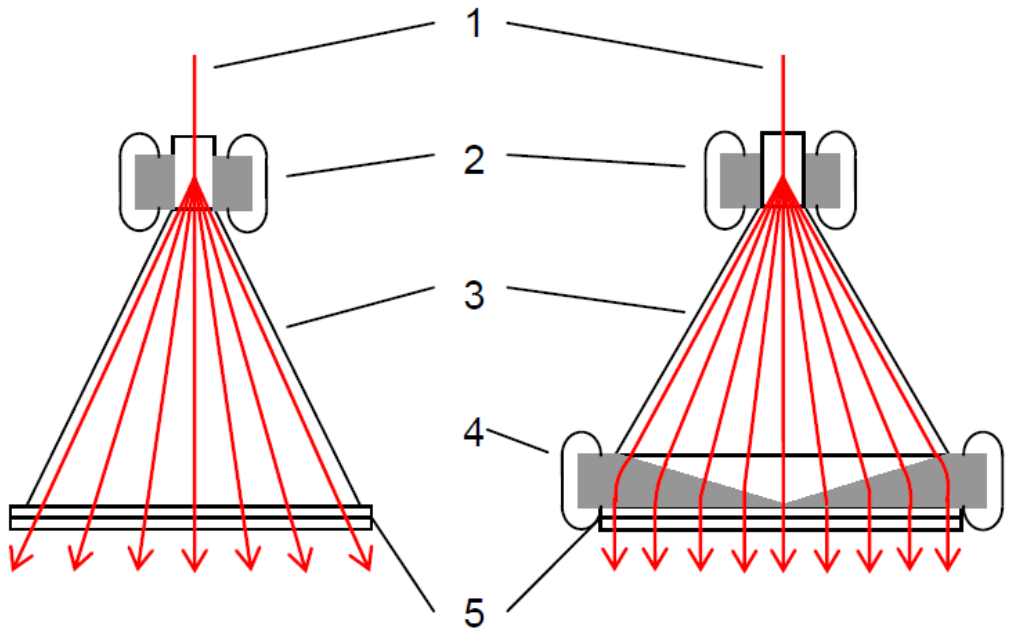
Bacteria & living eggs of helminths

Dose (kGy)	Detected Species	Result (CFU)
0	*Escherichia coli*,	6.2×10^4
	Salmonella spp.	9.2×10^2
	Clostridium perfringens	1.1×10^2
2	*Escherichia coli*,	9.8×10^3
	Salmonella spp.	1.3×10^2
	Clostridium perfringens	0.9×10^2
3	*Escherichia coli*,	1.4×10^2
	Salmonella spp.	0.4×10^2
	Clostridium perfringens	ca.0.2×10^2
4	*Escherichia coli*,	none detected
	Salmonella spp.	none detected
	Clostridium perfringens	none detected
5	*Escherichia coli*,	none detected
	Salmonella spp.	none detected
	Clostridium perfringens	none detected

Dose (kGy)	Detected Species	Result (Number of Living Eggs)
0	*Ascaris* spp.	21
	Trichuris spp.	9
	Toxocara spp.	3
2	*Ascaris* spp.	16
	Trichuris spp.	4
	Toxocara spp.	1
3	*Ascaris* spp.	4
	Trichuris spp.	none detected
	Toxocara spp.	none detected
4	*Ascaris* spp.	none detected
	Trichuris spp.	none detected
	Toxocara spp.	none detected
5	*Ascaris* spp.	none detected
	Trichuris spp.	none detected
	Toxocara spp.	none detected

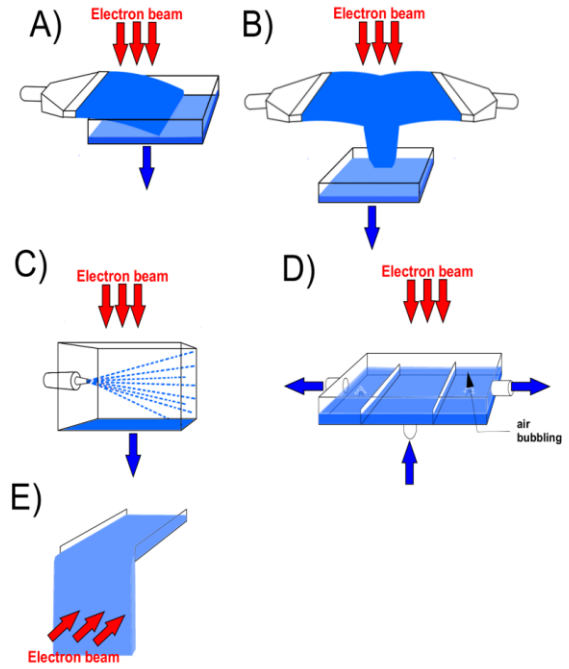
Coreless DC electron accelerator and beam configuration





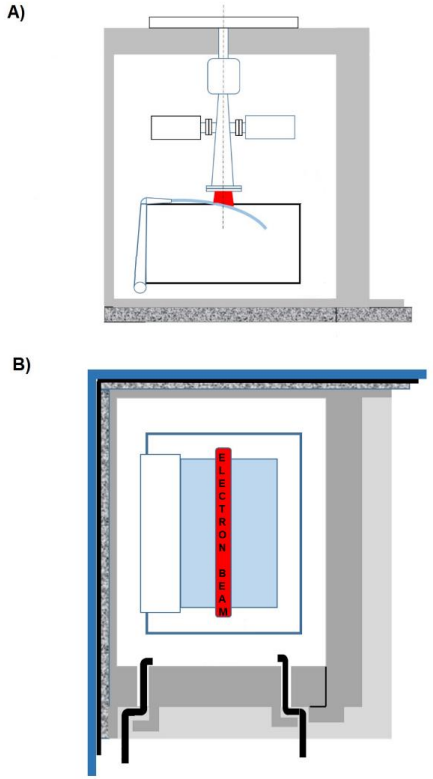
Sludge suspension irradiation and X-ray emission intensity reduction

Geometry of Technological Solution



The thickness of the irradiated layer of wastewater is correlated with the penetration of accelerated electrons which depends on accelerator energy. Irradiation of either falling film or up-flow mode or injected wastewater stream ensures the most efficient EB utilization.

Experimental set-up



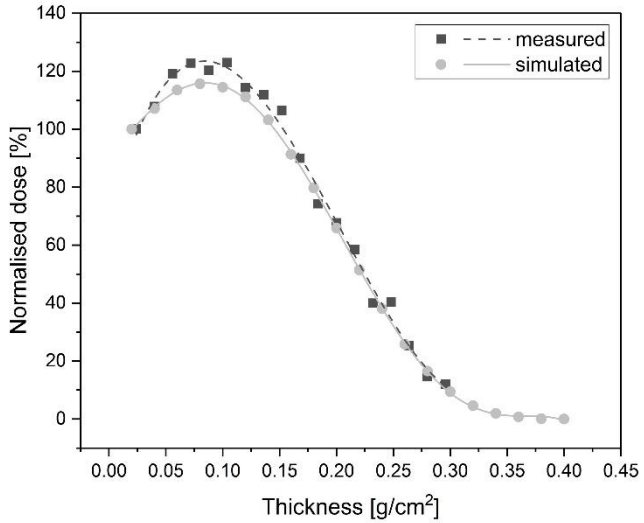
ILU 6 (INP, Russia) accelerator energy ranging from 0.2 to 2 MeV, average beam power up to 20 kW.

The parameters of the beam in experiments: accelerating voltage—930 keV, beam current — 1 mA, sweep width—50 cm.

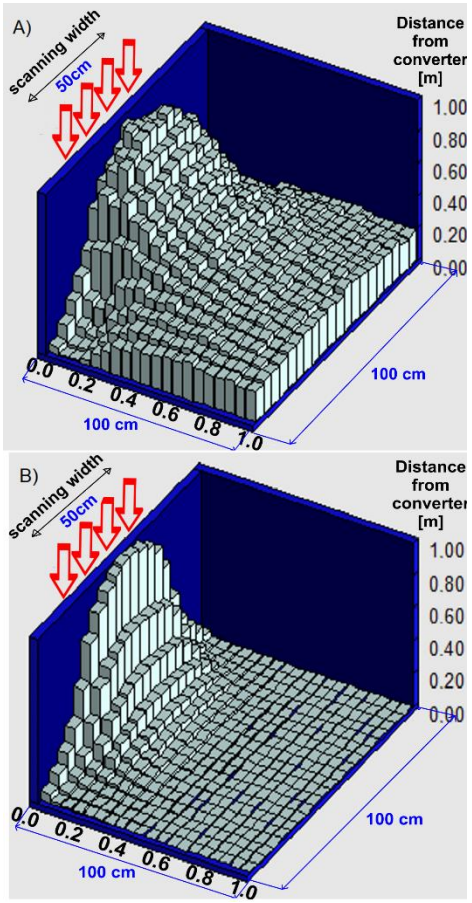
Mathematical modeling and experiment

- Determination of Electrons Penetration Ability

Observed penetration ability of the beam in water was about 3.3 mm.



- The simulated X-ray field intensity



in air

in water

- Determination of X-ray Dose Rate

The yield of electron of energy conversions into Electro - magnetic radiation, according to simulated data is 0.16 % for 5 mm thick water layer and 0.54 % for 0.5 mm thick steel converter.

Location of the highest dose and the decrease observed in the parallel and perpendicular direction to the scanned beam (converter : 5 mm thick layer)

Task 12.2 - Design of advanced electron accelerator plant for biohazards treatment (INCT, STU)

Done:

Experiments with use of different types of accelerators.

Review on industrial EB accelerator technologies:

- High-voltage DC accelerators: low electron energy, low price per W (80% el. efficiency)
- Resonant accelerators (Rhodotron): average and high electron energy, middle price per W
- Microwave linear accelerators (LINAC): high electron energy, high price per W (10% el. efficiency)

Solution for EB accelerator for biohazard treatment:

- High-voltage DC accelerator with maximum available energy and optimized thickness of treated sludge.

Plans for future:

Development of design of advanced electron accelerator plant for biohazard treatment.

Legal regulations on radiation processing of sludge from WWTP treatment in Slovakia.

Biopolinex SA, Lublin

The following works are being carried out:

- collecting data and information on the economic and financial aspects of the operation of urban waste water treatment plants,
- assumptions for the construction of a radiation hygienization module (ICHTJ) and assumptions for the design of a biogas module of a prototype installation (Biopolinex) have been developed,
- the documentation necessary to obtain environmental consents has been prepared,
- basic engineering preparation and approval.

Papers & patents related to I.FAST -12.2.

- Polish Patent; Sudlitz, M.; Chmielewski, A.G. ”Method of producing biogas, in particular from excess sludge in municipal wastewater treatment plants or from a mixture of substrates containing sludge”, P 433229, 2022
- Urszula Gryczka , Zbigniew Zimek, Marta Walo, Dagmara Chmielewska-Smietanko and Sylwester Bułka, „Advanced Electron Beam (EB) Wastewater Treatment System with Low Background X-ray Intensity Generation”, Appl. Sci. 2021, 11(23), 11194; https://doi.org/10.3390/app112311194
- Chmielewski A,G. et al.,„Radiation chemistry and technology as a basis for environmental protection technologies” Invited paper, 63 Congress of Polish Chemical Society, Łódź, 13-17 September 2021

Invitation to the conference

- International Conference on Accelerators for Research and Sustainable Development: From Good Practices Towards Socioeconomic Impact, May 23 – 26 , 2022; The Conference is envisioned to be in-person, with the possibility of remote connection. https://dash.superevent.com/clients/registration/?event_id=5542
- Our invited paper at openning plenary session ELECTRON ACCELERATOR BASED SYSTEMS FOR AIR, WATER AND SOIL POLLUTION CONTROL

EURO-LABS

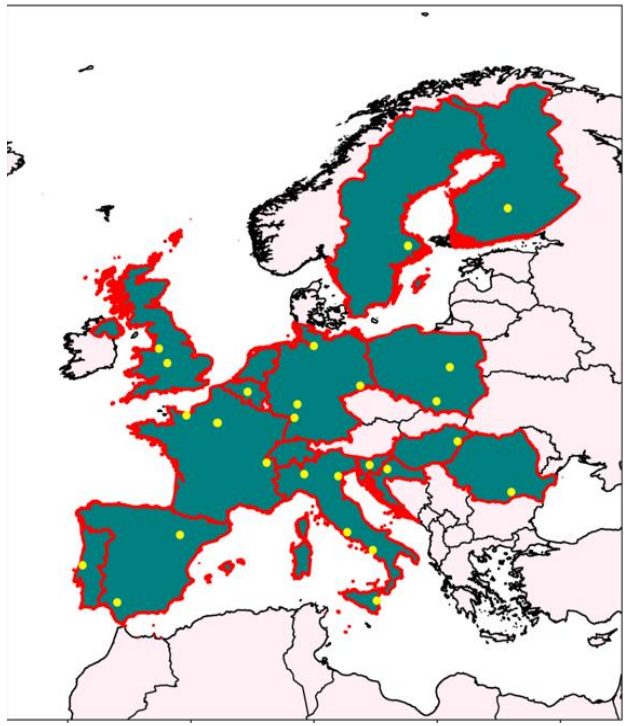
HORIZON-INFRA-2021-SERV-01-07

Research Infrastructures services advancing frontier knowledge

Project EURO-LABS

- **EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCE**
- SHORT NAME: EURO-LABS
- Budget about 15 000 000 Euro
- Type of action: HORIZON-RIA HORIZON Research and Innovation Actions
- Coordinatior: Istituto Nazionale di Fisica Nucleare (INFN), Italy
- 34 participating organizations
- Realization period – **48 months**

January 2022 – approved!!!



Acknowledgements.

- Sludge hygenization research is being developed under NCBiR POIR 04.04-0078/17-00 „BBNawOrg” POIR.04.01.04-00-0078/17 “Zero-energy technology for the manufacturing of biologically safe organic fertilizers based on sewage sludge” and International cooperation financed by European Union’s Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730 - Innovation Fostering in Accelerator Science and Technology (I.FAST)and IAEA CRP RC-22642 and co-financed by ME&S.
- Special thanks to Gea Nova Sp. Z o.o., a company that delivered us sewage sludge samples, food processing waste samples and biogas plant digestate for the experiment. We also thank the Ziemia Polska Sp. Z o.o. company for delivering another type of sludge for the tests.

iFAST

Thank you for your attantion !

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