RIGA TECHNICAL UNIVERSITY

Development of hybrid electron accelerator system for the treatment of marine diesel exhaust gases

ARIES proof-of-concept project

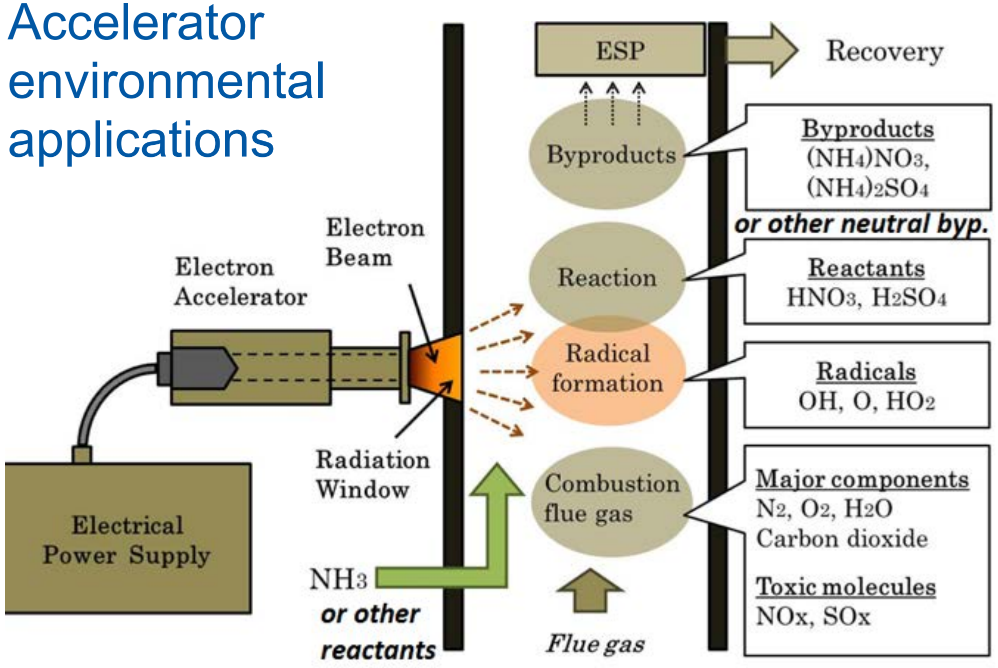
Prof. Toms Torims, Riga Technical University

Final Project Meeting
23 Apr 2020

Idea and motivation

Accelerator community-
promising technology

Accelerator environmental applications



Maritime industry-
demand for better solution

- MARPOL Annex VI - sulphur content shall be reduced to 0.50%
- Economically viable solution is still not there
- No technology can remove simultaneously SOx and NOx

ARIES PoC

How to proceed?

Stakeholders → **Identification of Challenges** → **Pilot project** → ~~SOx NOx~~

Stakeholders

- ✓ To inform
- ✓ To get feed-back
- ✓ To see if there is interest
- ✓ To get support
- ✓ To identify the Goal
- ✓ Maritime Community support

Done

Identification of Challenges

- Ideological
- Acceptance
- Legislative
- Statutory req.
- Class req.
- Technical
- Safety
- Economical
- Environmental

Done

Pilot project

- Development of full scale on-shoar system
- To verify functionality
- To enhance industrial application of accelerators

Done

ARIES

Partners

RTU – Riga Technical University, Center of High Energy Physics and Accelerator Technologies – Latvia

INCT – Institute of Nuclear Chemistry and Technology – Poland

Fraunhofer FEP – Institute for Organic Electronics, Electron Beam and Plasma Technology – Germany

CERN – Switzerland

Remontowa Marine Design – Poland

Riga Ship Yard – Latvia

Biopolinex – Poland

Advisors

Italian Coast Guard – **IT CG**

American Bureau of Shipping – **ABS** – USA

Two distinct and well developed communities

Accelerator community

some

Ships ~~don't~~ speak Accelerator'

Shipping community

some

Accelerators ~~don't~~ speak Ship'

ARIES PoC

Project objectives have been achieved and exceeded

To proof EB accelerator **application** to marine off-gas treatment

To proof technical **feasibility** in ship environment

To demonstrate that hybrid technology is removing SOx a NOx

To calculate the economic feasibility of technology

To engage stakeholders and to inform

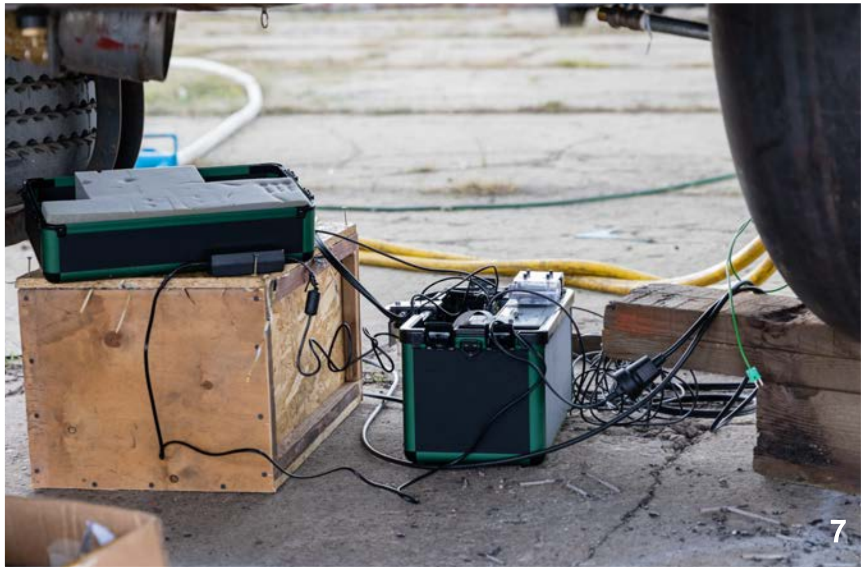
The main project Tasks

- To ensure effective project management, transparent coordination and targeted communication

- To connect the accelerator with the marine diesel engine working in real-life conditions

- To take measurements of the off-gases, process parameters and relevant technical data

- To see how process parameters impact the removal efficiency of NOx and SO_2



Brief history of the Project

From the outset very strong consortium has been created and stakeholders were involved. Series of the Project Partners, stakeholders and technical meetings, on-site visits:

Aug 2017 @ CERN https://indico.cern.ch/event/658601/

Dec 2017 @ CERN https://indico.cern.ch/event/659434

March 2018 in Genova hosted by Italian Coast Guard
https://indico.cern.ch/event/704222/

May and Sept 2018 in Riga https://indico.cern.ch/event/728806/
https://indico.cern.ch/event/754836/

+ meeting with IACS in Brussels
+ meeting with ABS in London
+ series of meetings with ship-owners (Grimaldi, MSC)
+ several meetings with EC DG MOVE in Brussels
+ on-site visit to Remontowa shipyard in Gdansk
+ on-site visit to e-beams technologies - Swiss

List of all events and relevant documentation https://indico.cern.ch/category/9244/

Execution

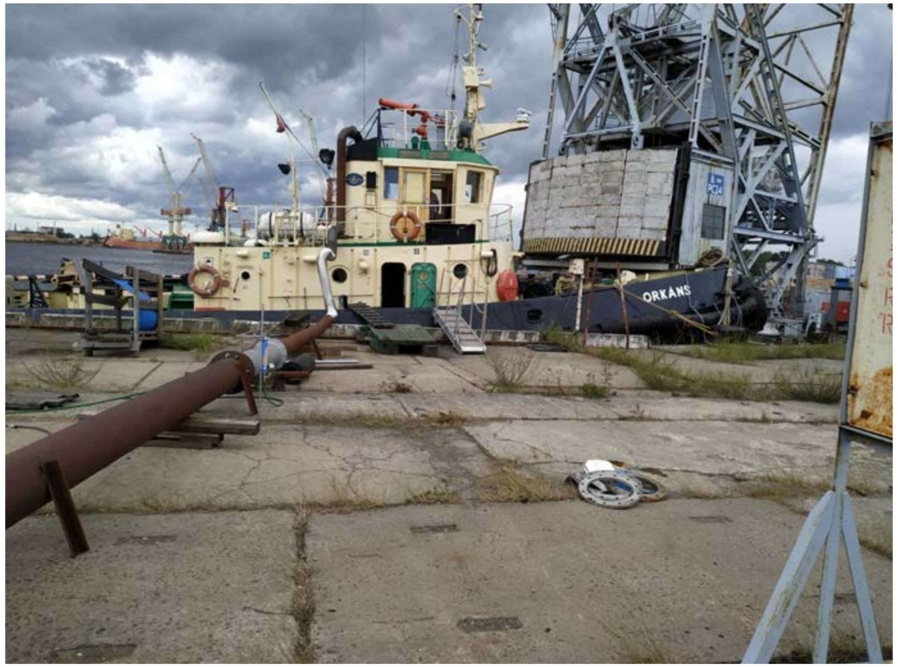
- Oct 2018 Project kick-off meeting in Warsaw @ INCT. https://indico.cern.ch/event/757275/

- series of virtual technical, coordination and management meetings trough-out the project, e.g. https://indico.cern.ch/event/810009/

- June 2019 tests of the technological system @ Riga Shipyard

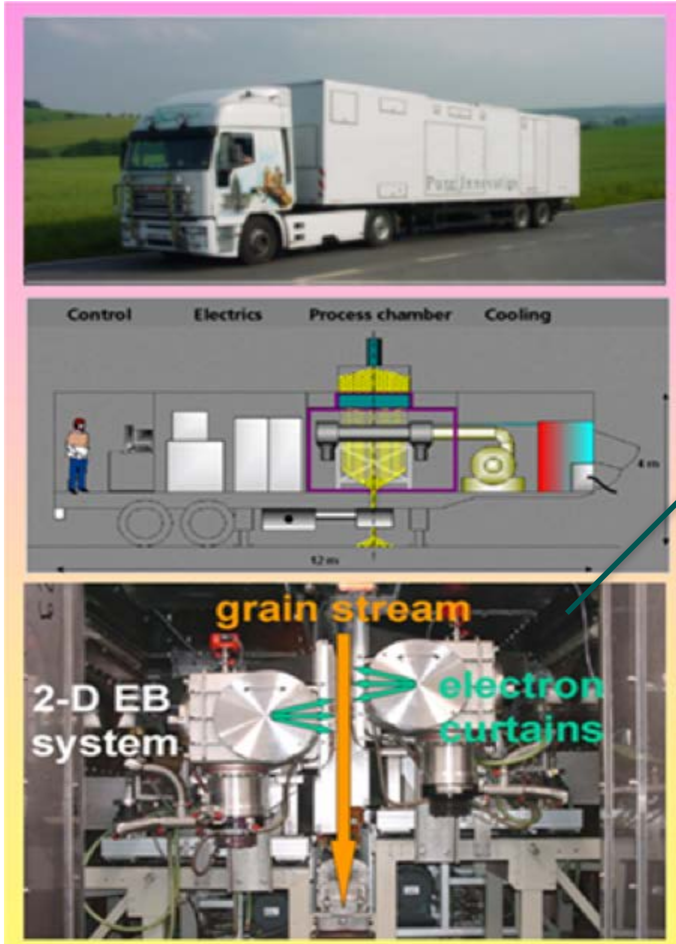
- regular progress reports delivered to ARIES community and project coordinators

- we have executed all our deliverables with slight adaptation of D4 – instead of dry-dock — a tug boat



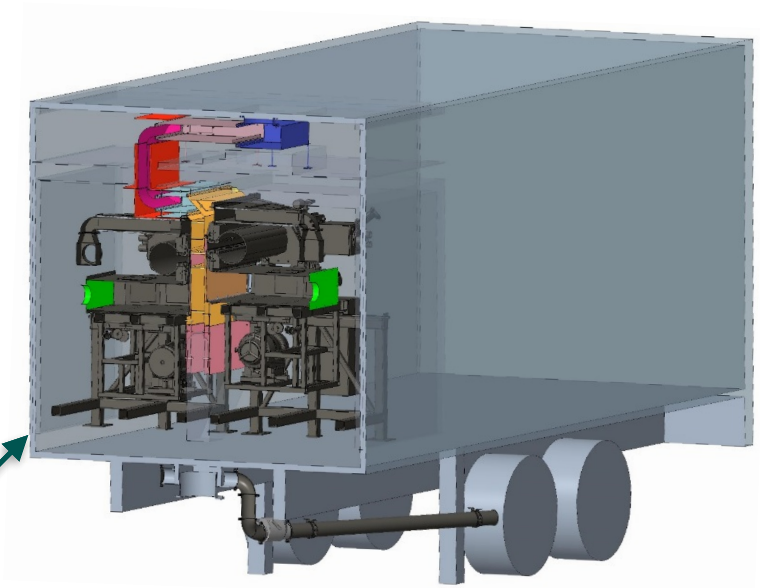
FEP's WESENITZ-II – A mobile and versatile EB Plant

From EB Dressing of Seeds…

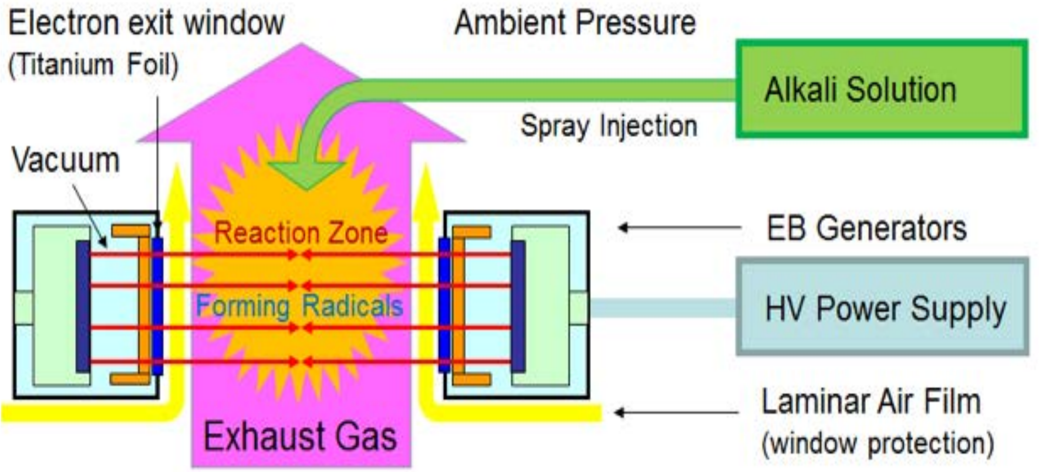


Mobile e-Dressing plant WESENITZ-II

2D EB systems:	2 x 150 kV / 30 kW
treatment width:	1 400 mm
throughput:	30 000 kg / h
work pressure:	ambient (1 bar)



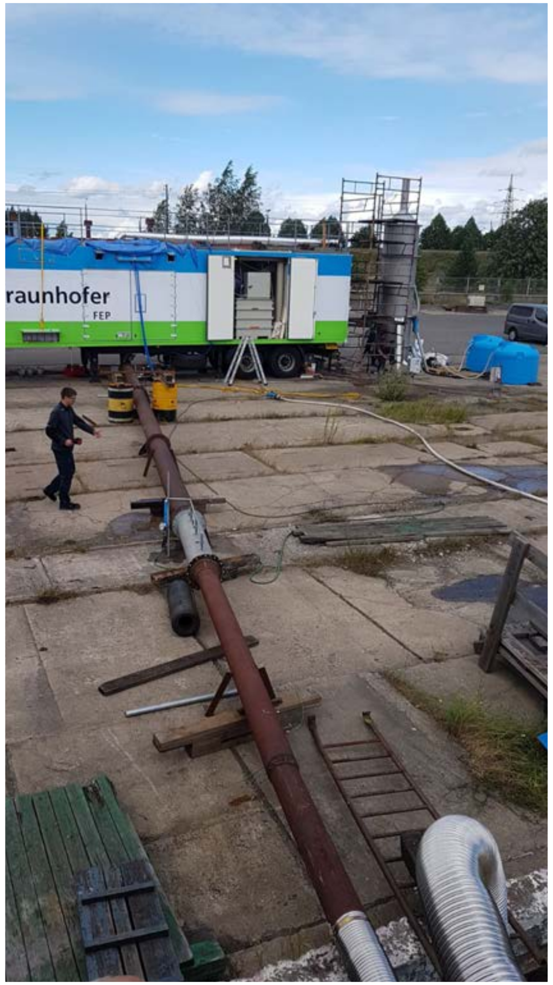
…to
Exhaust Gas Cleaning for Ship Diesel Engines



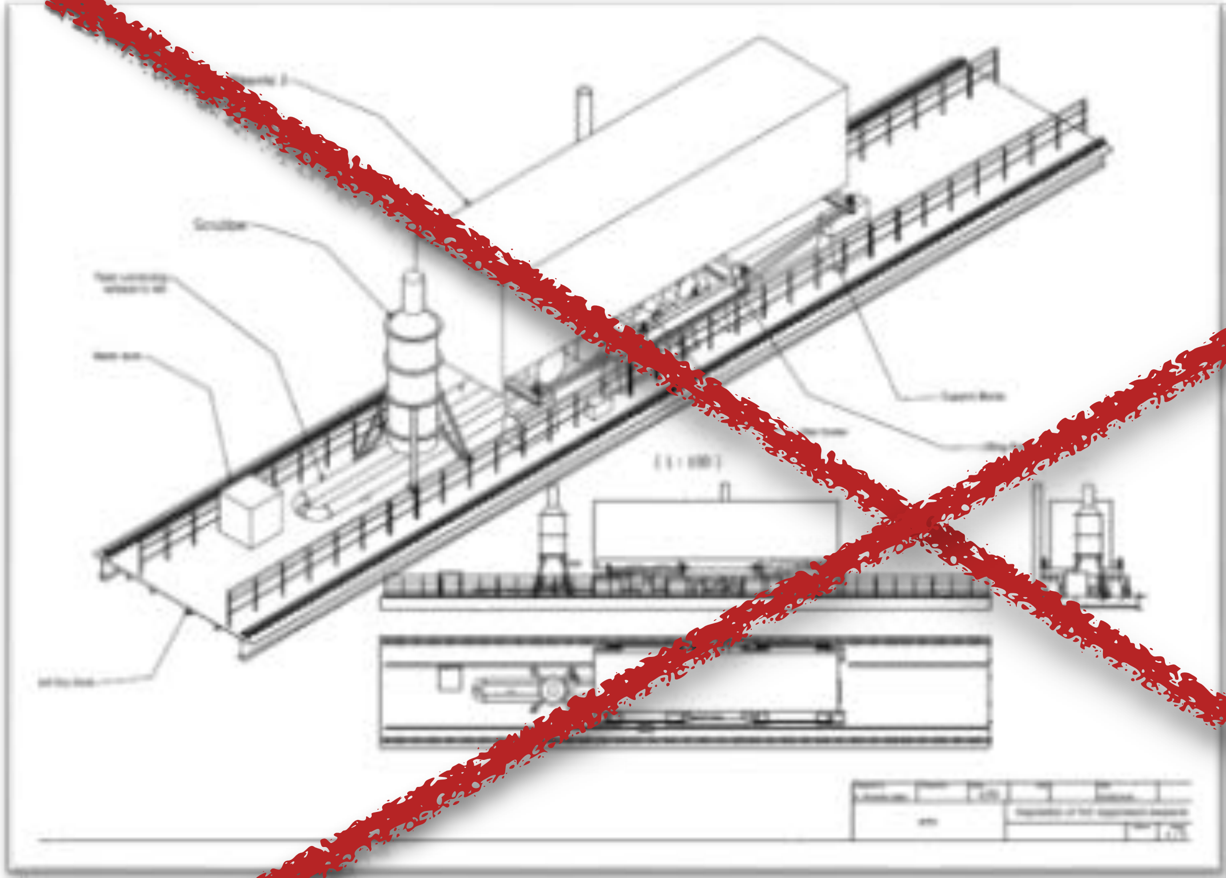
ARIES Fraunhofer FEP

Milestones and Deliverables

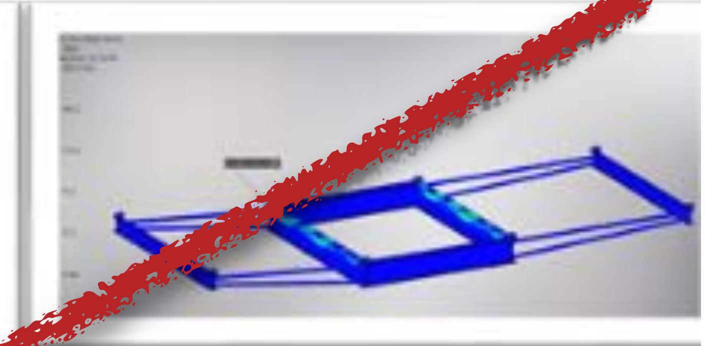
NAME	RESPONSIBLE	DESCRIPTION	ESTIMATED DELIVERY MONTH
D1	RTU	The project kick-off meeting is organized	M0
D2	RKB	Functioning marine diesel engine is made available at the Riga Shipyard	M2
M1	All	• Design and drawings of the mobile accelerator unit WESENITZ II are provided to RTU and RKB by FEP and INCT. • Design of the scrubber and its elements is provided to RTU and RKB by INCT. • Design and integration of the control and monitoring devices are provided to RTU and RKB by FEP and INCT.	M6-M7
D3	RTU	The overall design of the Proof-of-concept system	M7
D4	RKB	Lifting/positioning platform for the [illegible] accelerator unit and [illegible] is manufactured and [illegible] at the dry-dock	



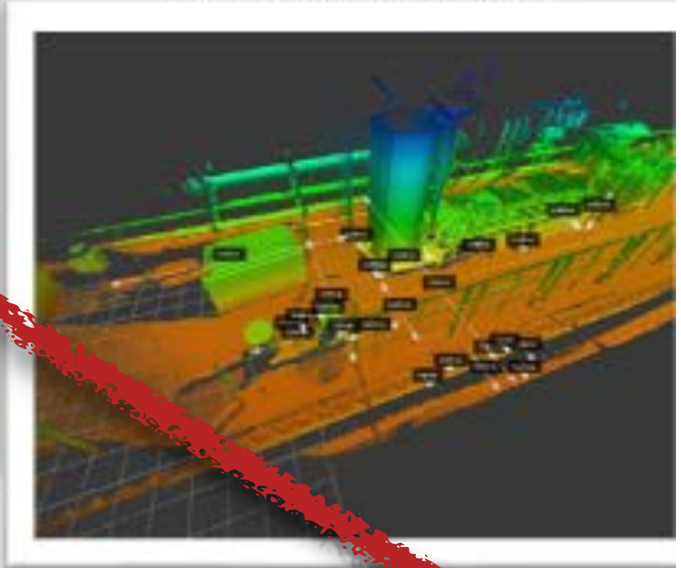
Execution



a) Experiment layout

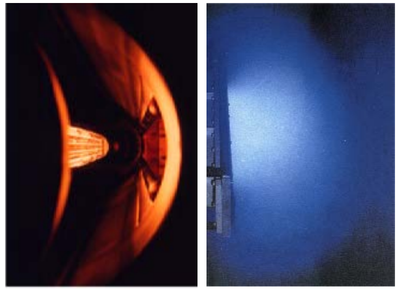


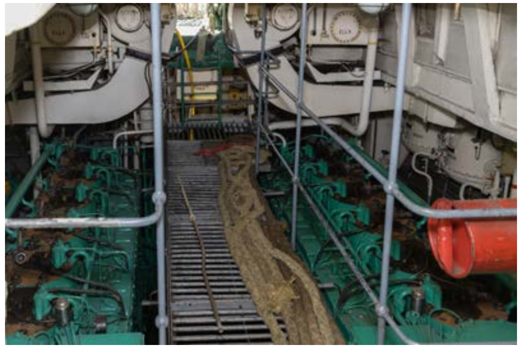
b) FEA simulations

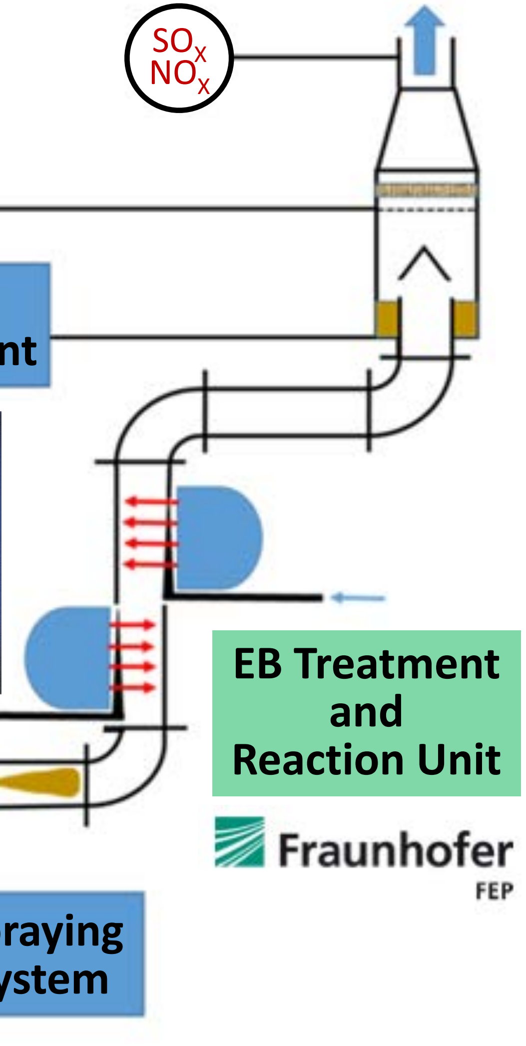


c) laser scanning of the roof

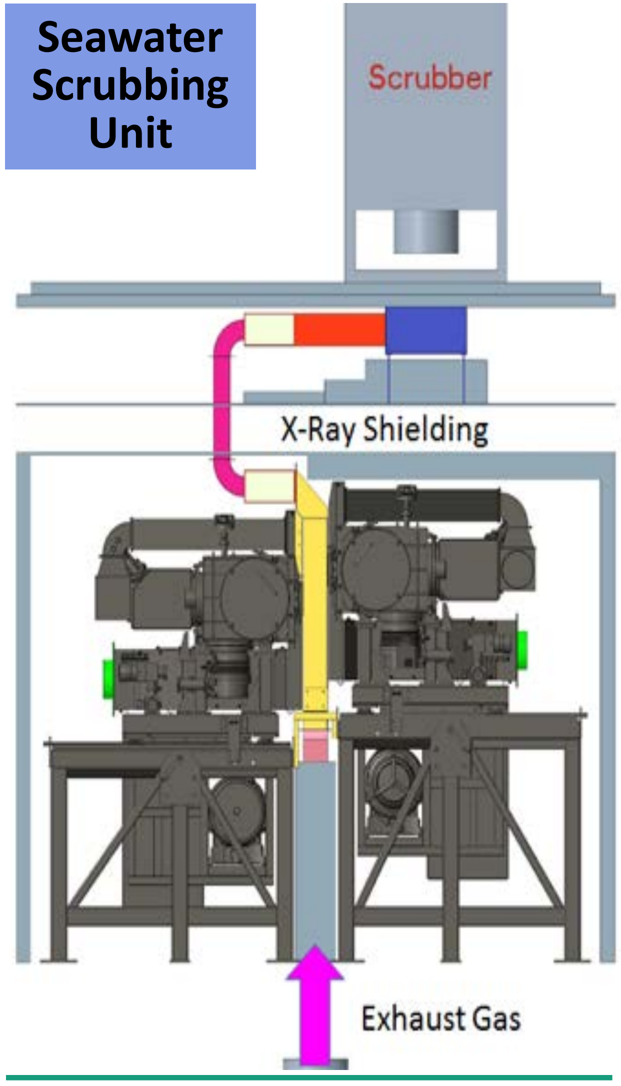
PoC Hybrid Electron Accelerator System







Fraunhofer FEP



ARIES

Milestones and Deliverables

D5	FEP	Mobile accelerator unit WESENITZ II is delivered to RKB	M8
D6	INCT	The scrubber is manufactured and delivered to RKB	M8
D7	RTU, RKB, INCT, FEP	All parts and systems are assembled and connected to the dry-dock Measuring devices are provided and installed on the system	M9
M 2	All	The system is made ready for the tests	M9
D8	INCT	Experimental measurements are performed, and relevant conclusions compiled in the technical report	M9

Per aspera ad astra

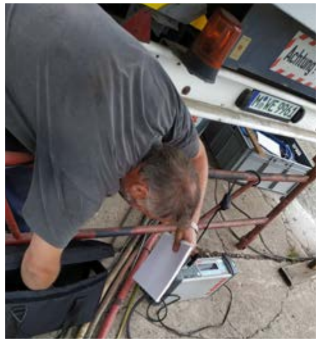
Per aspera ad astra

14-18 June 2019: scrubber and measuring equipment arrives to Riga

16 June: mobile accelerator complex Wesenitz II arrives to Riga

25 June: last minute experimental design setup change to tug-boat

26 June: beginning of installation @ Riga Shipyard



28 June: issues identified on accelerator part — one of the high voltage power source steering is faulty

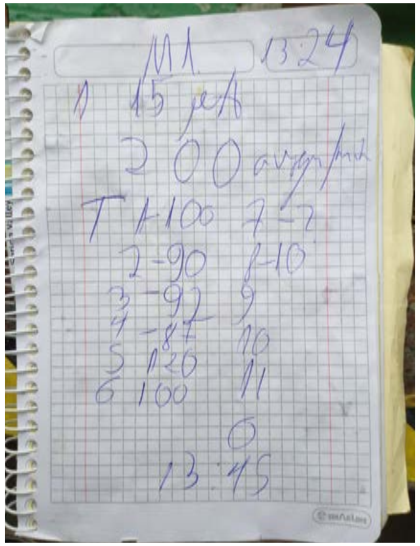
1 July: additional technical stuff from Fraunhofer FEP joins for repair

3 July: first test run of PoC installation, other technical issues identified (precooling, overheating)

5 July: PoC show day in a presence of project partners and stakeholders

6 July: Last experiment day

9 July: Wesenitz II leaves Shipyard

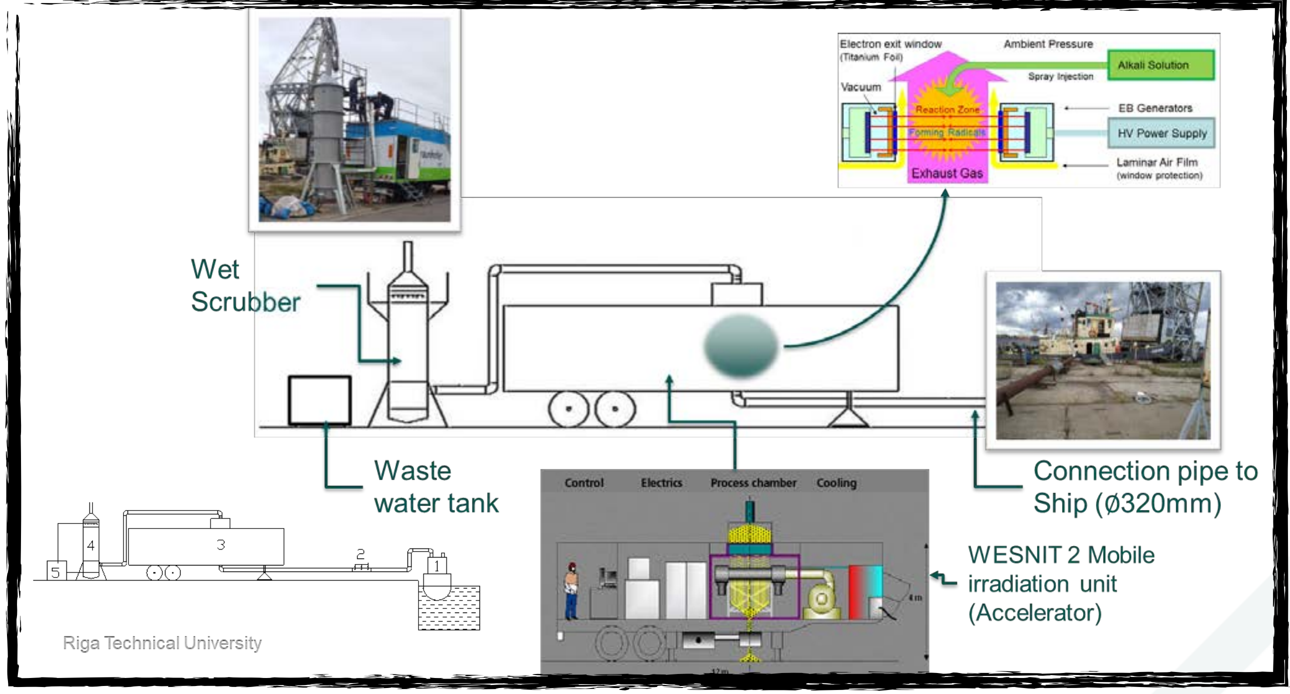


Milestones and Deliverables

D9	INCT	Process parameters, experimental - such as gas temperature, flow rate, droplet size, L/G ratio of droplet; based on modelling - process vessel dimension influence	M11
D10	Biopolinex	Economic analysis is concluded, and results are provided to the Consortium	M11
D11	RTU	Project closing meeting is organised	
D12	RTU + All	The final report is compiled and made available to the relevant stakeholders	

Engine load		%	0	50											100		
Gas flow rate		Nm^3/h	3316,1	4763,9	4831,2	4771,8	4703,0	4807,1	4942,7	4751,7	4915,2	4950,0	4917,8	4927,6	4605,5	4494,6	4804,1
Removal rate	NO	%	81,8	48,2	39,1	58,2	39,2	46,3	55,3	57,4	65,2	60,4	100,0	100,0	43,2	26,5	77,6
	NO_x	%	38,8	30,0	25,0	35,1	27,3	29,6	38,1	38,0	45,8	38,1	44,2	44,4	29,2	18,7	45,0

Execution Overview



<u>Challenges and give-in's:</u>

2 days of field test were granted = *more time needed in the next activities*

- Preparation of the set and change to the tug-boat
- Limited access time to the accelerator

No spray was introduced to the irradiation zone = *chemical part still to be developed and tested*

Only one side irradiation has been applied

- Due to mechanical breakdown of one side of 125 KV accelerator = *non-homogenous field*

No heavy fuel could be used = *no SOx measured*

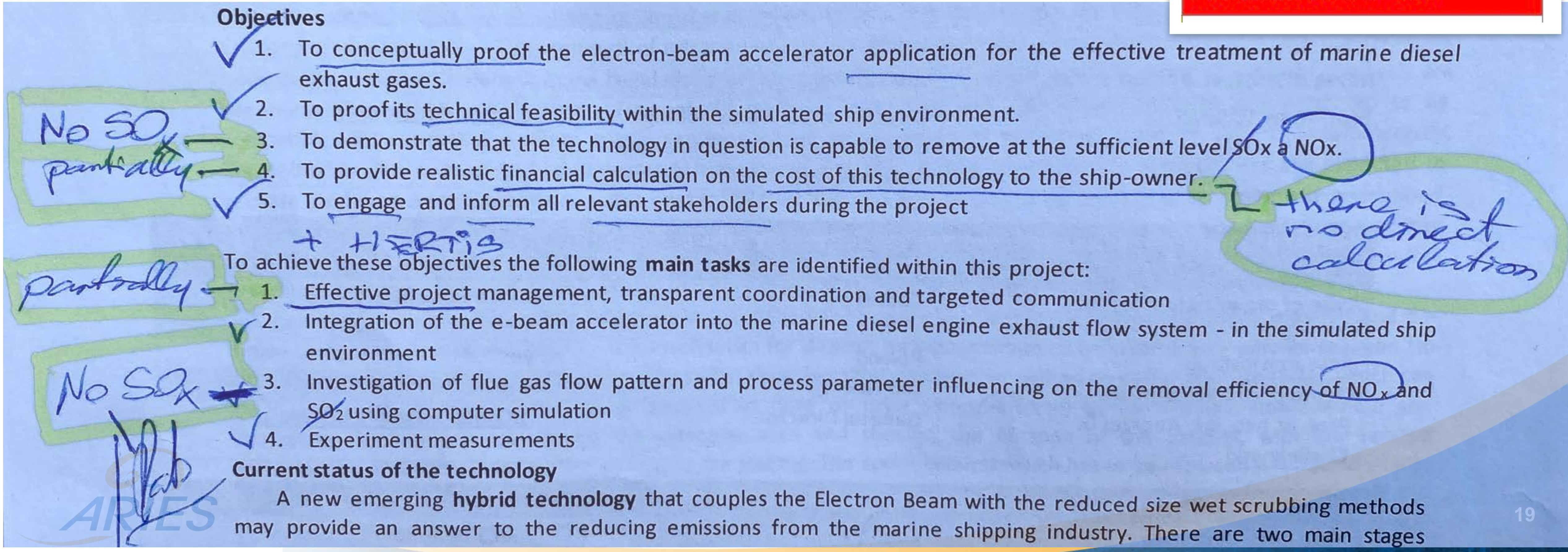
- Environmental restrictions in the port area
- Purchase of heavy fuel was impossible in small quantity

Basis for the future work

We acknowledge project management challenges and difficulties which Consortium have faced:

- ensuring engagement of all partners, risk management
- administrative management — documents, contracts and legal issues
- this was risky project from the outset… and we succeeded!

- Compressed schedule
- Activities developed only to conceptual level (some invalidated assumptions)
- Resources uncommitted



Objectives

1. To conceptually proof the electron-beam accelerator application for the effective treatment of marine diesel exhaust gases.
2. To proof its technical feasibility within the simulated ship environment.
3. To demonstrate that the technology in question is capable to remove at the sufficient level SOx a NOx.
4. To provide realistic financial calculation on the cost of this technology to the ship-owner.
5. To engage and inform all relevant stakeholders during the project

To achieve these objectives the following **main tasks** are identified within this project:

1. Effective project management, transparent coordination and targeted communication
2. Integration of the e-beam accelerator into the marine diesel engine exhaust flow system - in the simulated ship environment
3. Investigation of flue gas flow pattern and process parameter influencing on the removal efficiency of NO_x and SO_2 using computer simulation
4. Experiment measurements

Current status of the technology

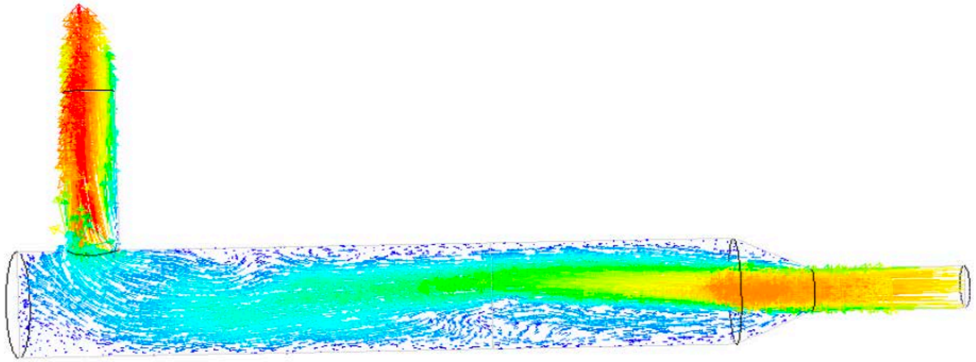
A new emerging **hybrid technology** that couples the Electron Beam with the reduced size wet scrubbing methods may provide an answer to the reducing emissions from the marine shipping industry. There are two main stages

Basis for the future work

Work Package #3 (leader INCT): Investigation of flue gas flow pattern and process parameter influencing on the removal efficiency of NOx and SO2 using computer simulation

Partner	Responsibility / Task	Expected outcome
INCT	6.1. CFD (computer fluid dynamics) computer simulation will be used to model the **gas flow dynamic** inside the process vessel.	1. Process parameters, experimental - such as gas temperature, flow rate, droplet size, L/G ratio of droplet; based on modeling - process vessel dimension influence on removal efficiency of SO2 and NOx are investigated using MATLAB and KINETIC.

6 **ARIES Proof of Concept Fund**
Development of hybrid electron accelerator system for the treatment of marine diesel exhaust gases



Not done
- insuficiant data and time.
- only one accelerator.

Stakeholders engagement

Stakeholders

- Ship owners
- Ship management companies
- Flag States
- Class Societies/IACS
- IMO
- European Commission
- EMSA
- US CG
- Engine manufacturers
- Scrubber manufacturers
- Shipyards and ship repair companies

↔

- Accelerator designers, like
- Research institutes
- Universities
- Big labs
- Accelerator producers
- Controlling and monitoring devices producers
- Funding agencies

- NGO's and environmentalists

Economic analysis

Cost calculations were based on discounted cash flow method:

- Net Present Value (**NPV**),
- Internal Rate of Return (**IRR**),
- Modified Internal Rate of Return (**MIRR**),
- Profitability index (**PI**),
- Discounted Payback Period (**DPP**).

Based on a comparison of the marine diesel (low SOx) price v/s HFO together with the purification cost.

Three scenarios:

- OPTIMAL,
- OPTIMISTIC
- PESSIMISTIC

[sic] … definitely show profitability of both optimistic and optimal scenario… The results of the analysis indicate the high market potential of the technology being developed

Overall conclusions

- The tests were performed for NOx containing ship Diesel off gases

- The operation of the plant was the first case of examination of the hybrid electron beam technology in the real conditions

- Taking in account the experiment conditions, good agreement was obtained with laboratory tests in the maximum available at field test dose range

- On the base of theoretical and laboratory works, the process was examined under real conditions in a pilot scale

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Tangible results of the project

- scientific/technical report by INCT - presentation by Prof. Chmielewski

- economic feasibility analysis report by Biopolinex - presentation by Mr. Piatkowski

- project financial report - presentation by Ms. Rūse

- final report and dissemination of results & further actions - presentation by Toms

Our achievements

- We have worked well together and formed a strong multidisciplinary core team which moves-on the whole idea — **we trust each-other and we are strong together**!

- We have proved our strength trough-out the project. We have faced many challenges, which we have turned somehow in opportunities — **we have succeeded in the combat**!

- We have bridged the maritime and accelerator communities — **we are unique blend and connection**!

ARIES

Our achievements

- Our work is appreciated by these two communities, policy makers and stakeholders in general — **our work and results are valuable and appreciated**!

- Based on PoC work we have continued HERTIS proposal — **our idea is flying**!

- We have effectively used allocated resources and attracted much more — **big gains with the small money**!

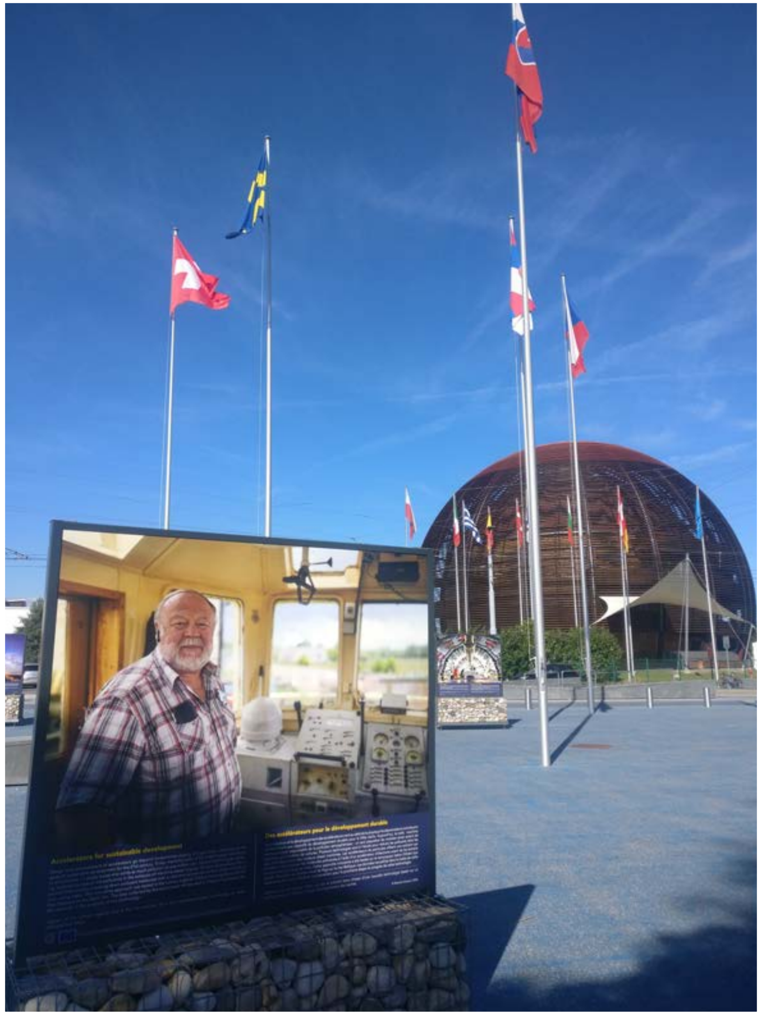
- We have delivered much more than it was mearly promised within the PoC - **we have** considerably **contributed to the ARIES** and its ideas!

Our achievements

- we have demonstrated that particle accelerator can be successfully deployed in the maritime conditions — we have proved the concept and **achieved TRL 3**

- the main critical points were identified for the future development of the technology; e.g., proper emitter selection, proper fuel, control and monitoring systems, process parameters. More insight was gained re chemistry and optimisation of hardware, especially after the first-stage — **we have learned a lot!**

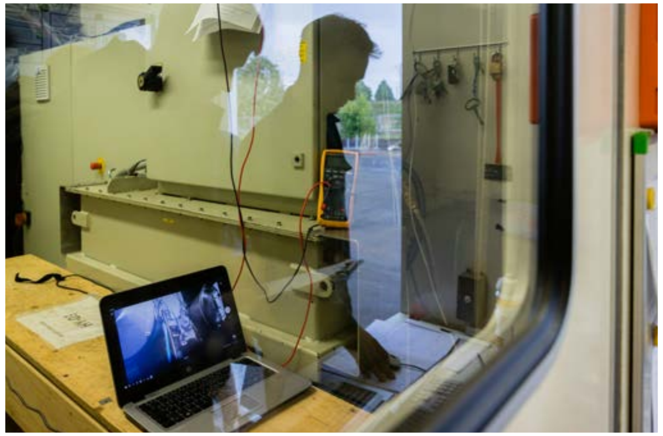
- toroidal e-beam accelerator appears to be the best option for the environmental applications - this is **key to the wider collaboration in future**



Two distinct and well developed communities

ARIES PoC

Accelerator community



Maritime community

Special thanks to

Dr. Zimek (INCT)

Dr. Mattausch (FEP)

Prof. Chmielewski (INCT)

Dr. Kravalis (RTU)

chapeau to

Eng. Pawelec (INCT)

Eng. Pikurs (RTU)

Thank you