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Exploring the Effectiveness of Electron Beam Treatment for Ballast Water Management at Fermi National Accelerator Laboratory

Christine N. Polkinghorne[+], Kimberly M. Eller[+], Michael A. Nagel[+], Heidi J. Saillard[+], Samantha R. McClung[+], Desi N. Niewinski[+], Jennifer A. Maki[+], Matthew C. TenEyck[+], Yichen Ji[*], Slavica Grdanovska[*], and Charles A. Cooper[*]

[+] Lake Superior Research Institute, [*] Fermi National Accelerator Laboratory

Background

- Transport of aquatic organisms between ports via ballast water is a well known concern. A variety of treatments have been developed to eliminate organisms from ballast water prior to discharge, but Great Lakes water poses unique challenges to treatment systems utilizing UV light, ozone, and chlorination due to low transparency and high organic carbon content. Furthermore, chemical treatments may lead to toxic byproducts in discharge water.

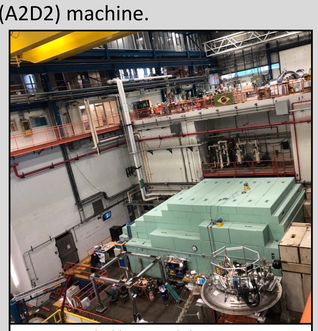
Wilson Hall, located near the entrance to Fermilab

- An initial trip to Fermilab examined immediate effects of the electron beam as a potential ballast treatment while a second trip examined delayed mortality and hatch rates of ephippia treated with the electron beam.

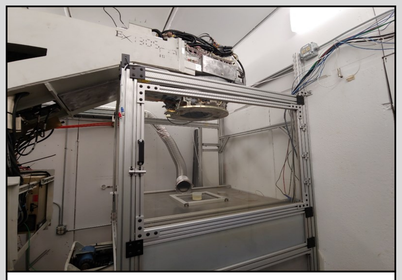
Methods

Organisms Tested	Water Types	Exposure Doses (kGy)
Escherichia coli	• Dechlorinated lab water • Lab water amended with Arizona test dust, Micromate™, and humic acid sodium salt	0-Control
Selenastrum capricornutum		1
Eucyclops spp.		2
Daphnia magna		5
		10
Daphnia magna ephippia		20
		50

- Multiple irradiation tests were conducted by Fermilab staff in the Illinois Accelerator Research Center's (IARC's) Accelerator Applications Development and Demonstration (A2D2) machine.

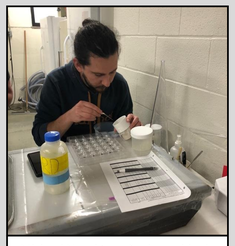


IARC building pit and electron cave



A2D2 in the electron cave with a sample in the exposure location

- Organisms were added to exposure vessels containing the appropriate water type. Three to five organism replicates and one chemistry replicate were exposed to each dose.
- Water quality measurements included percent transmittance, particulate organic matter, total organic carbon, alkalinity, hardness, dissolved oxygen, temperature, specific conductivity, and pH.
- Organisms were enumerated at timepoints up to 48 hours following treatment.



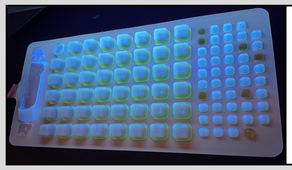
Michael Nagel transferring ephippia from sieve to hatching tray

Results

Immediately After Exposure:

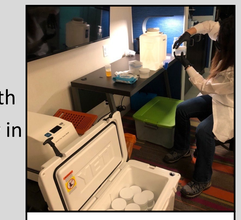
- Water quality parameters were affected in all samples as dose increased.
- All *E.coli* samples in both water types experienced ≥99.99% reduction at all doses.

Dose (kGy)	*S. capricornutum*					
	Lab Water			Amended Lab Water		
	Temp. (°C)	pH	DO (mg/L)	Temp. (°C)	pH	DO (mg/L)
0-Control	21.4	7.77	8.6	20.7	7.64	9.0
1	21.5	7.65	7.6	20.9	7.46	7.8
2	21.7	7.61	7.3	21.2	7.38	6.9
5	22.2	7.57	7.3	21.6	7.18	5.8
10	23.0	7.54	6.9	22.3	7.07	4.9
20	25.2	7.51	6.3	24.2	6.92	3.6
50	33.9	7.48	4.9	30.2	6.72	3.1

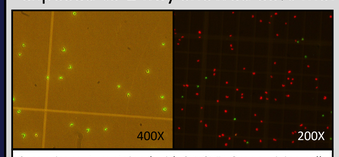


The number of fluorescing wells of a Quanti-tray correspond to the amount of *E. coli* present in the sample

- *S. capricornutum* samples showed increasing mortality with increasing dose. The 50 kGy dose produced 99% mortality in lab water and 85% mortality in amended lab water.
- *S. capricornutum* samples in amended lab water were incubated for seven days after exposure. 100% mortality was observed in doses of 2 kGy and greater while samples exposed to 1 kGy showed 83% mortality.

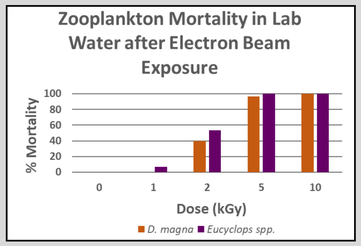


Heidi Saillard conducting microbial analysis in a mobile laboratory



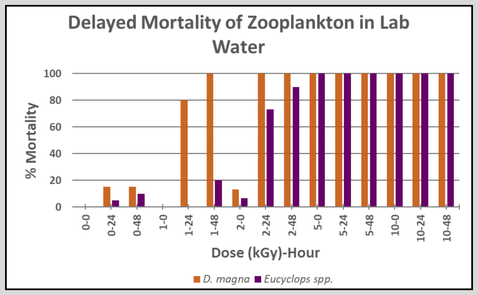
S. capricornutum stained with SYTOX™ Green. Living cells glow red under fluorescence while dead cells have a green nucleus

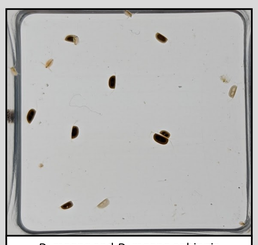
- Mortality of 100% for both *D. magna* and *Eucyclops* spp. was achieved at the 10 kGy exposure in both water types.



Delayed Mortality:

- *S. capricornutum* displayed 100% mortality in doses greater than 2 kGy and 99.6% mortality in the 2 kGy dose at 48-hours post-treatment.
- *D. magna* experienced 100% mortality at all doses at 48-hours post-treatment.
- *Eucyclops* spp., exposed simultaneously with the *D. magna,* experienced 20% mortality at the 1 kGy dose and 90% mortality at the 2 kGy dose at 48-hours post-treatment.
- *D.magna* ephippia incubated for 72-hours post-treatment in optimal hatching conditions experienced a 0% hatching rate.





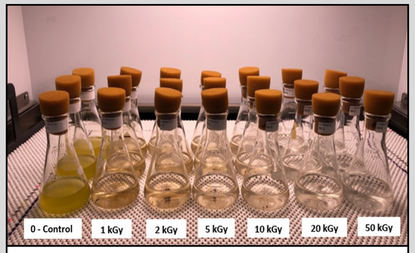
D. magna and *D. magna* ephippia

Electron Beam Treatment is Highly Effective at 2 kGy!

Conclusions and Future Studies

E-beam Treatment Effectiveness in Standard Test Organisms				
Electron Beam Dose (kGy)	*E. coli*	*S. capricornutum*	*D. magna*	*Eucyclops spp.*
1		69%		20%
2		>99%		>90%
5				
10				
20				
50				

- *D. magna* ephippia exposed to treatment as low as 1 kGy *and provided optimal hatching conditions,* experienced a 0% hatching rate, whereas the control samples had an average of 12 young ± 4.1 young emerging.
- Treatment impacted the water quality parameters by increasing temperature and percent transmittance and causing a decrease in pH and DO. There was no impact on conductivity.
- There was little difference in effectiveness of the e-beam between the low challenge lab water and the challenge of the amended lab water.



Algae sample flasks after a seven-day incubation period

Future research opportunities:

- Examining the environmental acceptability of water treated with the electron beam in relation to percent transmittance and disinfection byproducts.
- If the system is made portable and safe for use on board ships or in ports, further examination at the shipboard level would be warranted.

For more information and to view the report on this research, scan the QR code below:

Acknowledgements

- Fermi Research Alliance for their application to our laboratory-based testing program and from providing the electron beam accelerator for ballast water treatment evaluation.
- MARAD, EPA Office of Water, and EPA GLRI for their support.