Electron Beam Treatment of Wastewater and Biosolids: Current State of the Science

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eBeam Technology for Cleaning, Healing, Feeding, and Shaping this World and Beyond…

Presentation Outline

1. Experience with high energy (10 MeV) eBeam and X-ray technology platforms
2. Efficacy of eBeam technology against microbial and chemical pathogens
    1. Conventional contaminants
    2. Emerging contaminants
3. Our commercialization strategy for the environmental industries

Experience with high energy eBeam and X-ray technologies

- **16,000 sq. feet commercial scale facility**

- Dual Modality facility
  - High energy (10 MeV) Electron Beam technology
  - High energy (5 MeV) X-Ray technology

- 3 linear accelerators
  - Two eBeam accelerators (10 Mev, 15kW)
  - One X-ray accelerator (5 MeV, 18 kW)

- State of the art Dosimetry
  - Alanine (Gold standard in dosimetry)
  - Radiochromic film dosimetry

- Facility inspected and certified
  - FDA, USDA-FSIS, and USDA-APHIS

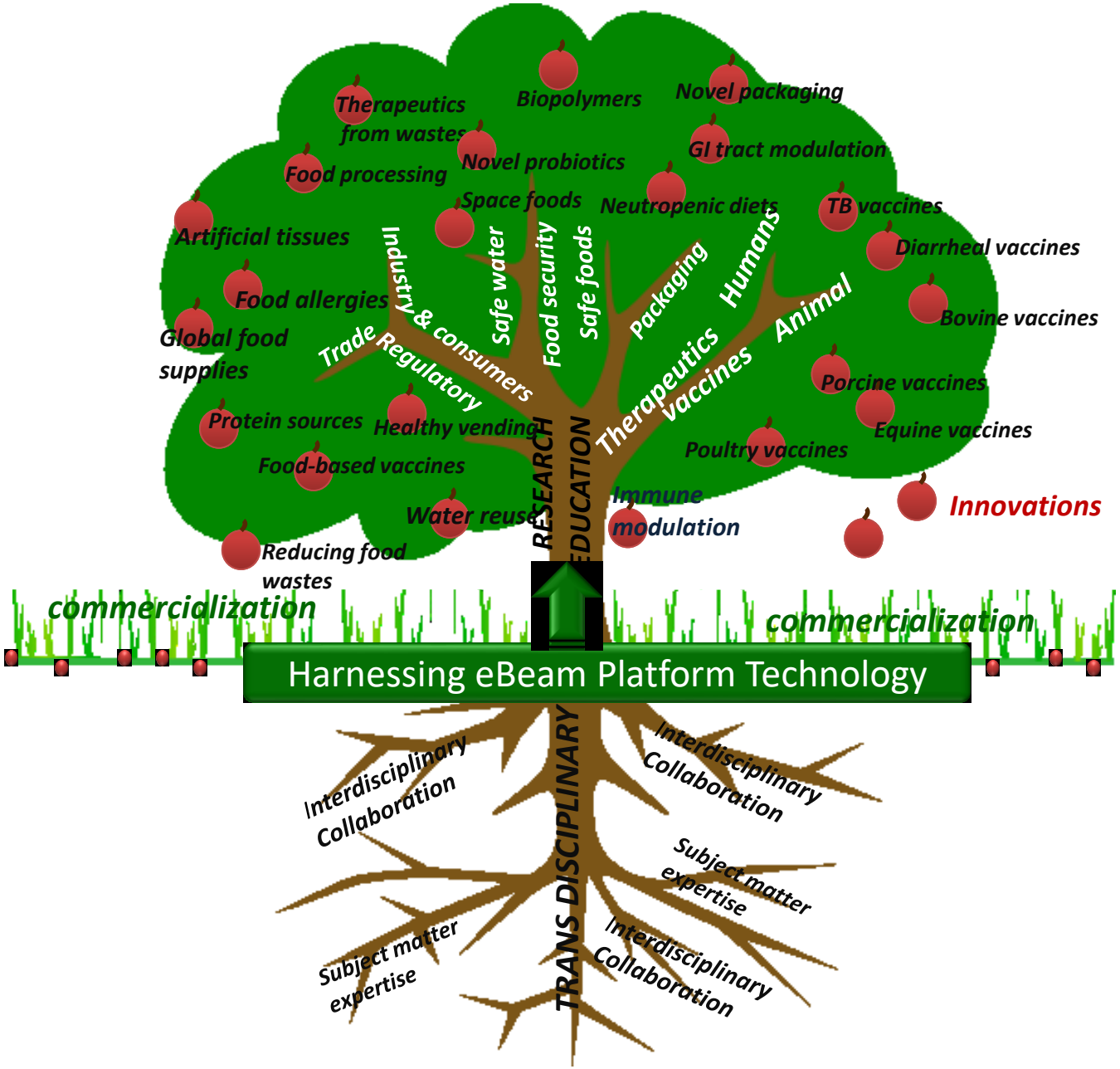
- **75% of Time : Commercial - 25% Research**
- **FDA, USDA-APHIS, USDA-FSIS approved facility**
  - Currently
  - ~ spices, pet food, medical devices, fruits, biotech products
  - 5 million lbs of fresh produce, 1 million pounds of other items

Exploiting eBeam Technologies for *Cleaning, Healing, Feeding, and Shaping* this World and *Beyond*……

Cleaning : Environmental remediation
Healing: Novel therapeutics
Feeding: Food security and food safety
Shaping: Develop bioplastics and novel polymers

..and Beyond: sterilization and disinfection solutions for NASA's Space Station and long-duration mission to asteroids and possibly Mars

Just Beam it!

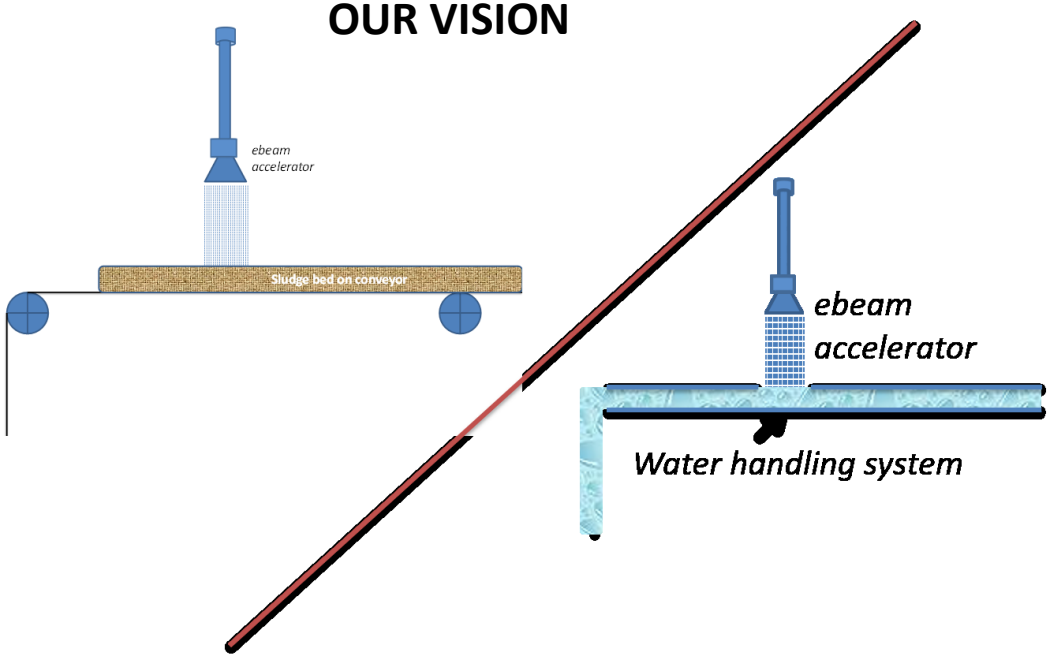

Therapeutics from wastes
Biopolymers
Novel packaging
Novel probiotics
GI tract modulation
Food processing
Space foods
Neutropenic diets
TB vaccines
Artificial tissues
Diarrheal vaccines
Food allergies
Bovine vaccines
Global food supplies
Trade Regulatory
Industry & consumers
Safe water
Food security
Safe foods
Packaging
Humans
Animal
Therapeutics
Vaccines
Porcine vaccines
Protein sources
Healthy vending
Equine vaccines
Poultry vaccines
Food-based vaccines
RESEARCH
EDUCATION
Immune modulation
Innovations
Water reuse
Reducing food wastes
commercialization
commercialization
Harnessing eBeam Platform Technology
TRANS DISCIPLINARY
Interdisciplinary Collaboration
Interdisciplinary Collaboration
Subject matter expertise
Subject matter expertise
Interdisciplinary Collaboration

Efficacy of eBeam technology against conventional and emerging pathogens and chemical contaminants

Pathogen Reduction Criteria

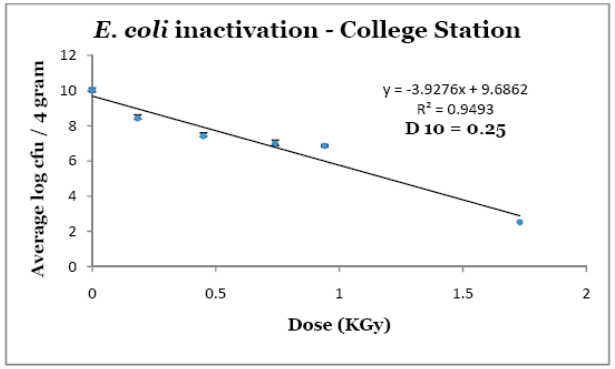
- **Process to Further Reduce Pathogens (PFRP) processes as approved by EPA for Class A biosolids**
  - ***Composting (55°C for 3 days)***
  - ***Heat drying (80°C)***
  - ***Heat treatment (180°C for 30 min)***
  - ***Thermophilic aerobic digestion (55°C – 60°C for 10 days)***
  - ***Pasteurization (>70°C for 30 min)***
  - ***Irradiation (10 kGy)***

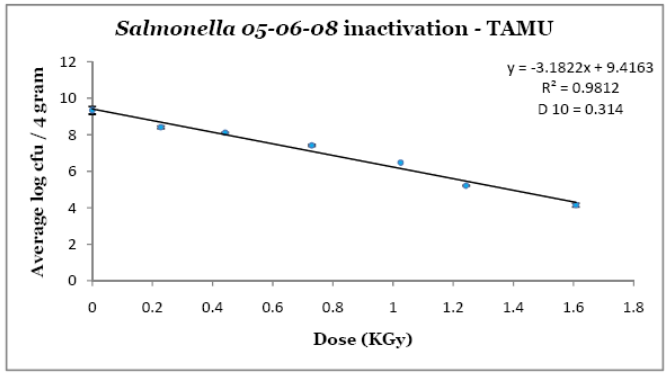
OUR VISION

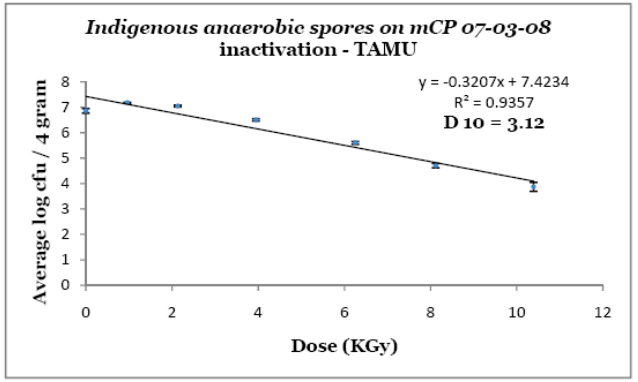


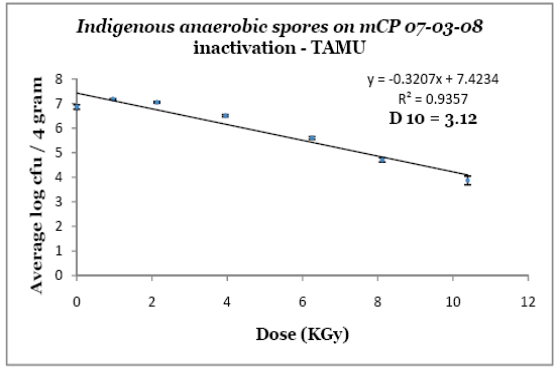
- Pre-treatment of raw sewage
- Alternative to thermal hydrolysis (THP)
- Conversion of Class B to Class A sludges
- Effluent treatment
- Water Reuse
- Drinking water treatment
- Treatment plant residual remediation

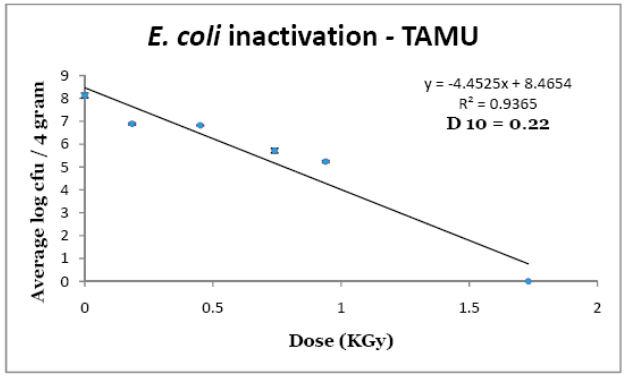
eBeam Inactivation of Key Indicator Organisms and Pathogens of Concern in Sludges and Effluent

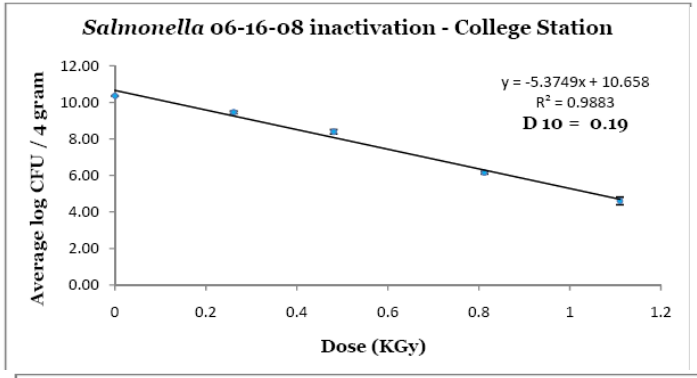


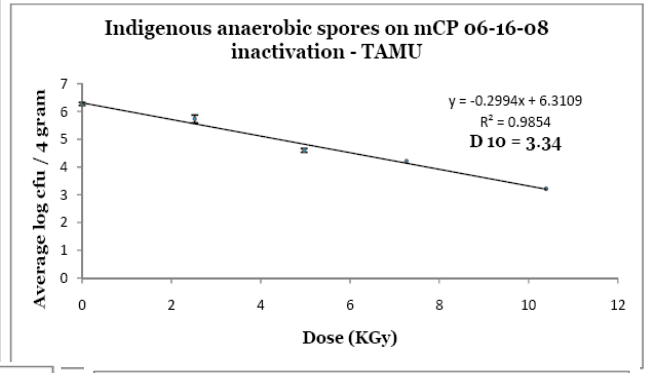


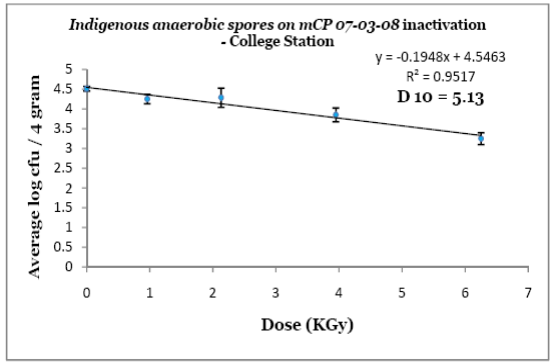


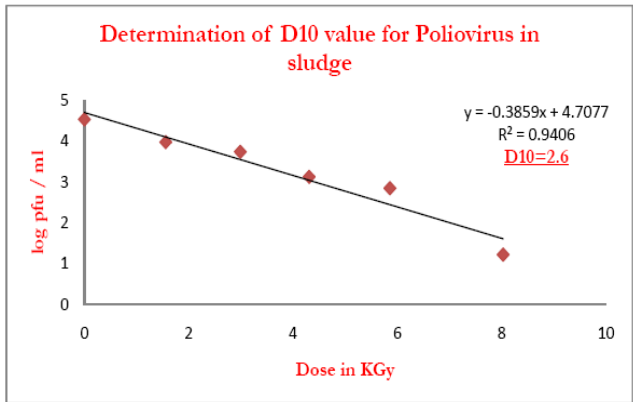


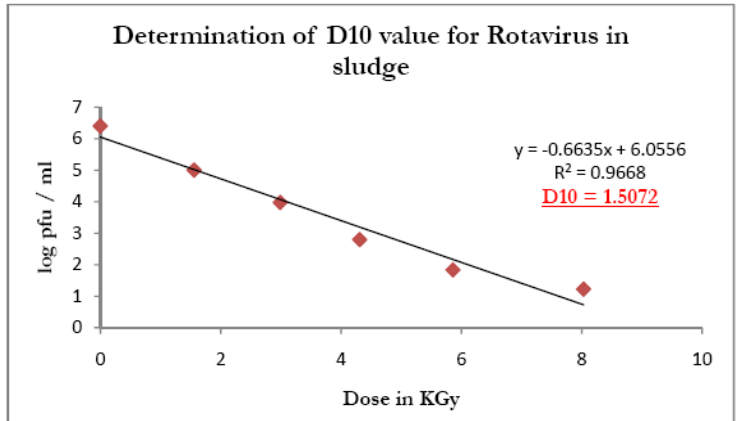


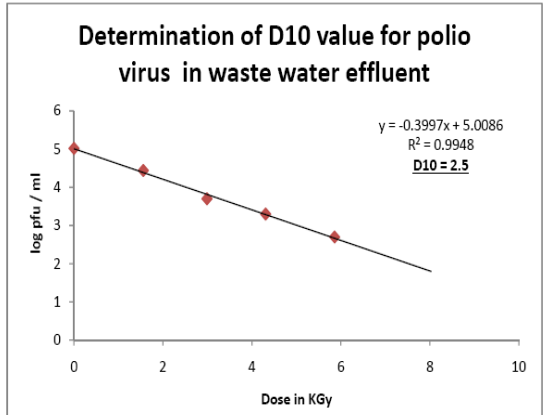












D-values of Key Indicator Organisms and Pathogens of Concern in Sludges

Target Organism	Sludge Matrix	D_{10} value (range) kGy
E.coli	Aerobic digester sample	0.26 – 0.41
E.coli	Anaerobic digester sample	0.25 -0.35
Spiked Salmonella sp.	Aerobic digester sample	0.18 -0.35
Spiked Salmonella sp.	Anaerobic digester sample	0.23 -0.33
Aerobic spores	Aerobic digester sample	2.43-4.81
Aerobic spores	Anaerobic digester sample	2.68 – 3.08
Anaerobic spores*	Aerobic digester sample	3.34-5.13
Anaerobic spores*	Anaerobic digester sample	3.12
Spiked Poliovirus	Anaerobic digester sample	2.6
Spiked Rotavirus	Anaerobic digester sample	1.5

If eBeam is used (10 kGy) as the a PFRP process….

Target Organism2	Sludge Matrix	D_{10} value (range) kGy	Log Reduction that can be achieved (conservatively)
E.coli	Aerobic digester sample	0.26 – 0.41	~ 24 logs
E.coli	Anaerobic digester sample	0.25 -0.35	~29 logs
Salmonella sp.	Aerobic digester sample	0.18 -0.35	~ 29 logs
Salmonella sp.	Anaerobic digester sample	0.23 -0.33	~ 30 logs
Aerobic spores	Aerobic digester sample	2.43-4.81	~ 2 logs
Aerobic spores	Anaerobic digester sample	2.68 – 3.08	~ 3 logs
Anaerobic spores*	Aerobic digester sample	3.34-5.13	~ 2 logs
Anaerobic spores*	Anaerobic digester sample	3.12	~ 3.2 logs
Poliovirus	Anaerobic digester sample	2.6	~ 3.8 logs
Rotavirus	Anaerobic digester sample	1.5	~ 6.6 logs

U4R06

Disinfecting And Stabilizing Biosolids Using E-Beam And Chemical Oxidants

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2009

WERF

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Electron beam inactivation of selected microbial pathogens and indicator organisms in aerobically and anaerobically digested sewage sludge

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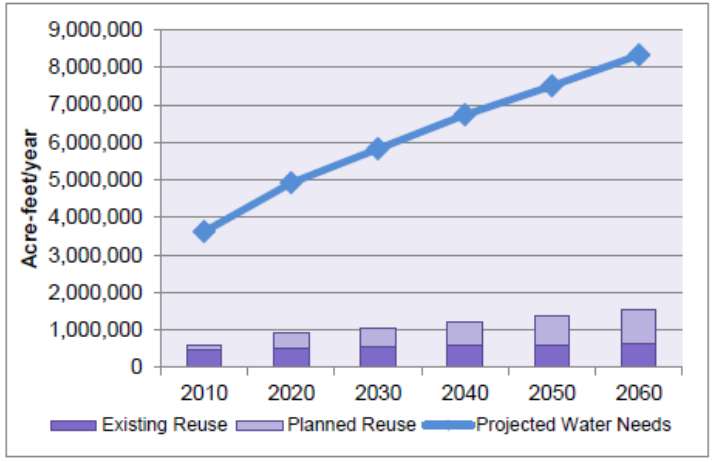
Can eBeam Irradiation be used for Converting Class B to Class A Sludges?

- eBeam irradiation will **de-stabilize** sludge solids

- There is a need to couple eBeam irradiation with one or more technologies to achieve long-term stabilization to allow Class A designation
  - *Ongoing research in our labs*

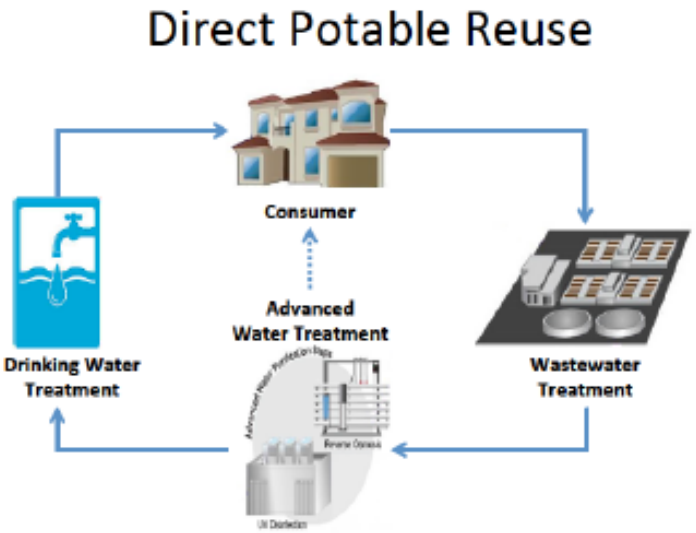
eBeam applications for direct potable water reuse

Potable Water Needs in the US



Source: TWDB, 2012

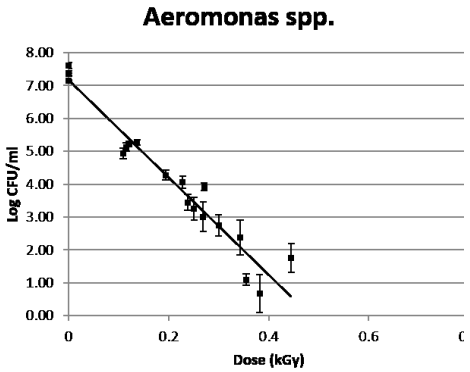
Figure 1-1: Role of water reuse by decade in 2012 State Water Plan

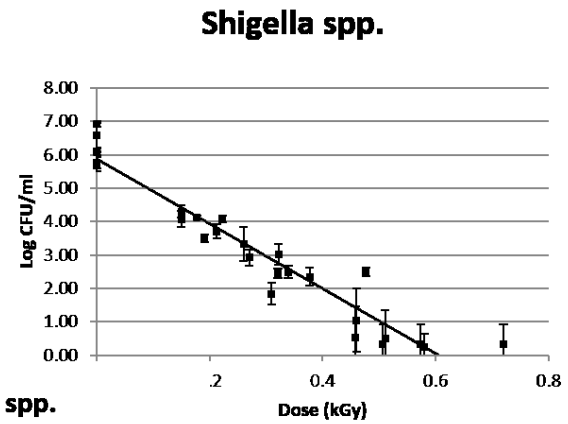


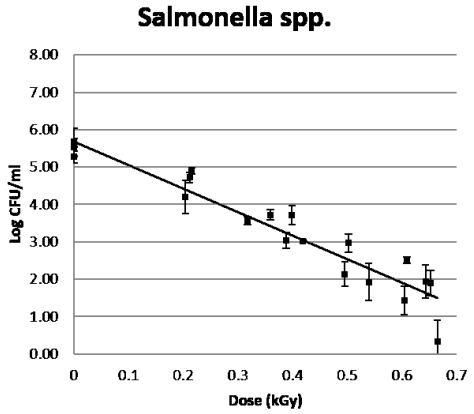
Chemical Contaminants	Microbial Contaminants
Disinfection by products (bromoform, bromate, chloroform, trihalomethanes)	Cryptosporidium oocysts
Household products and food additives (Bisphenol A, Perflurooctanoic acid, Perfluorooctane sulfonate)	Giardia cysts
Estrogenic compounds (17β-estradiol)	Enteric viruses, Norovirus
	Total coliforms, *E.coli*
	Bacterial pathogens

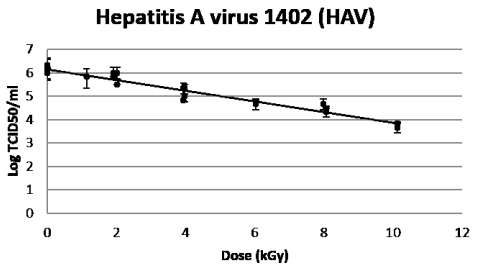
eBeam for Potable Water Reuse – Microbial Contaminants

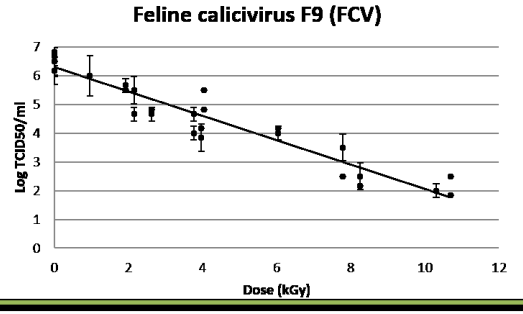
Radiation Dose	% Reduction in Estrogenic Activity*	
	Drinking Water (n=3)	Sewage Effluent (n=3)
2 kGy	92%	72%
4 kGy	92%	76%
6 kGy	92%	72%
8 kGy	91%	79%
10 kGy	93%	78%
12 kGy	92%	71%
*% reduction calculated as a function of estrogenic activity in respective spiked sample		

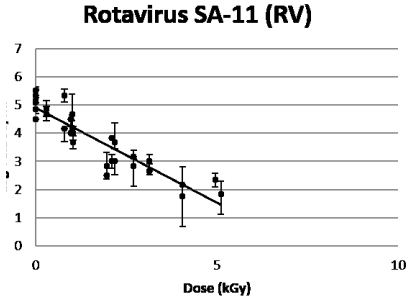


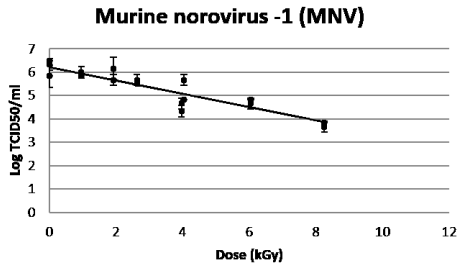






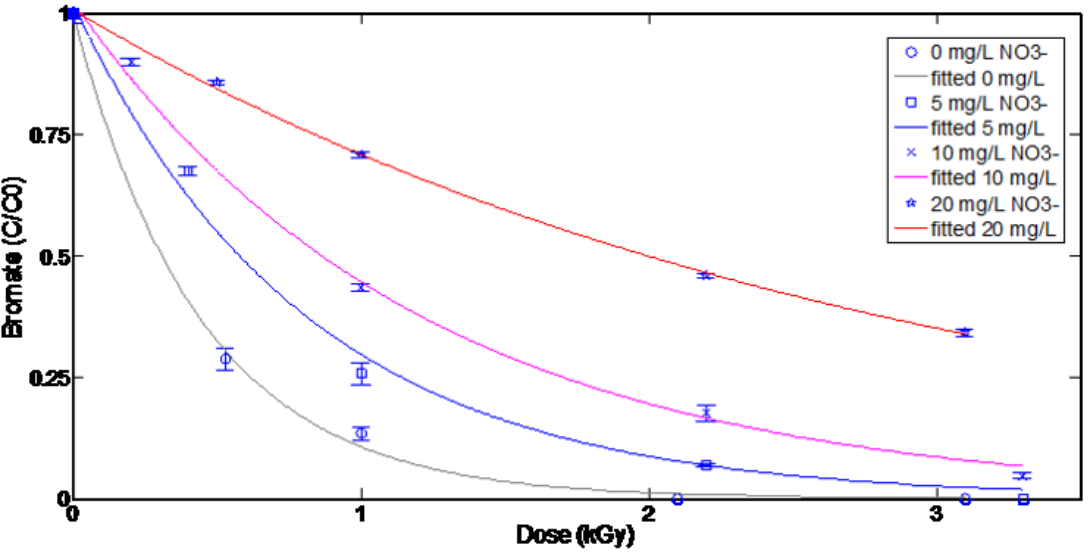


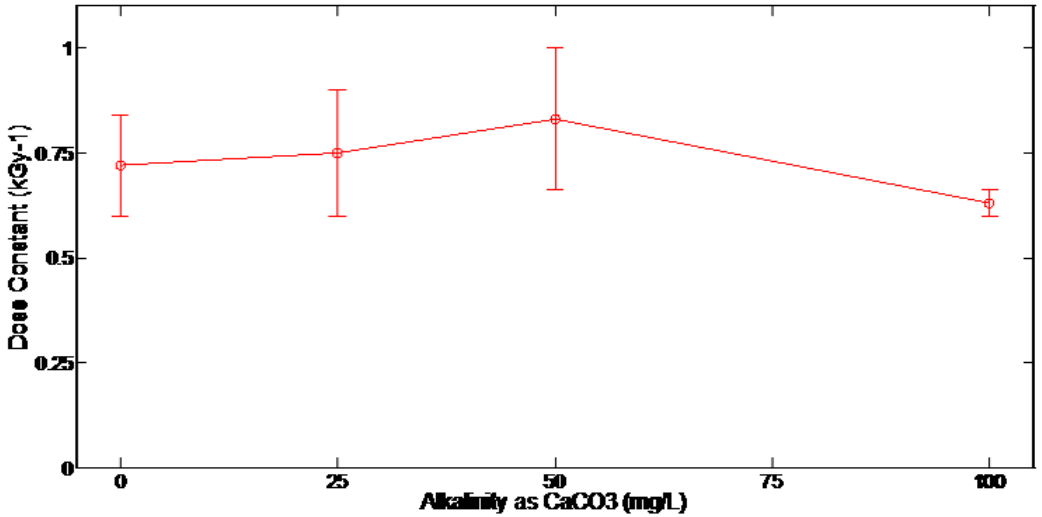


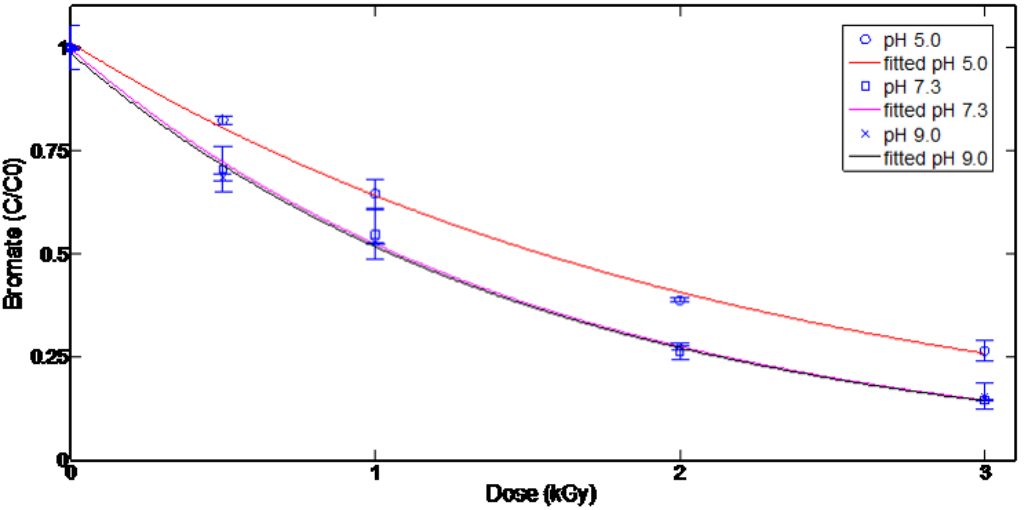


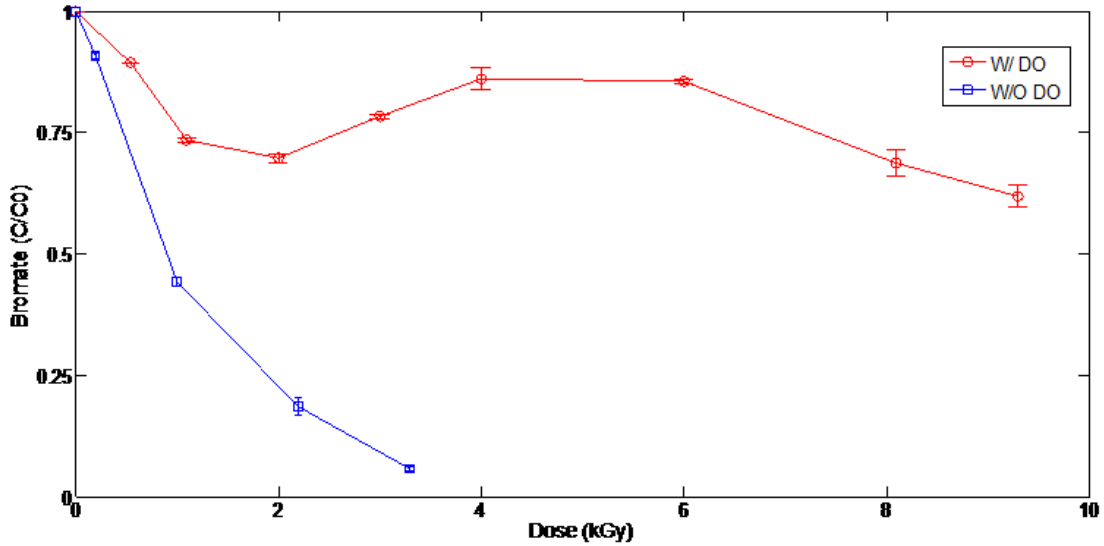
Pathogen	TCEQ Target	eBeam dose that can achieve TCEQ Target
Viruses	8-log reduction	15 kGy
Cryptosporidium oocyst infectivity	5.5 log reduction	2 kGy
Giardia cysts	6 log reduction	2 kGy
Coliform bacteria	9 log reduction	2 kGy

eBeam for Potable Water Reuse – Chemical Contaminants – (Bromate)

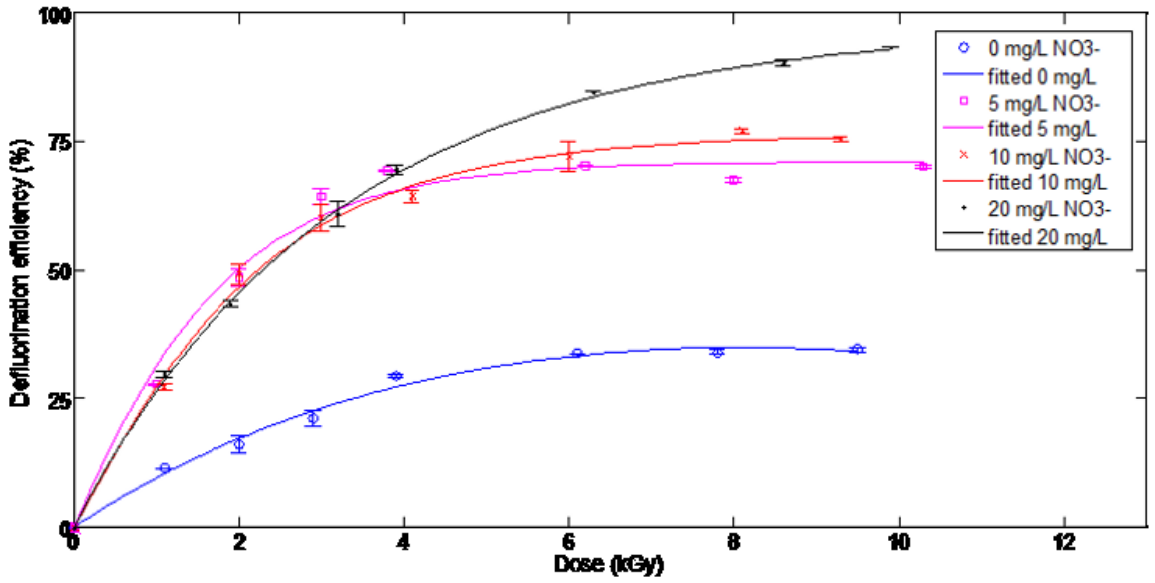




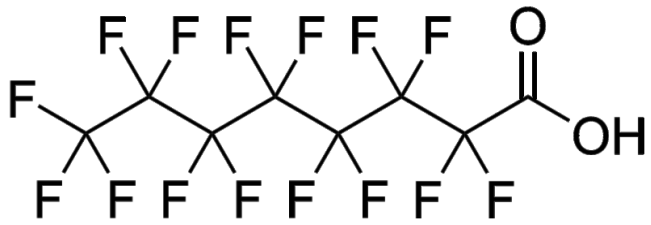


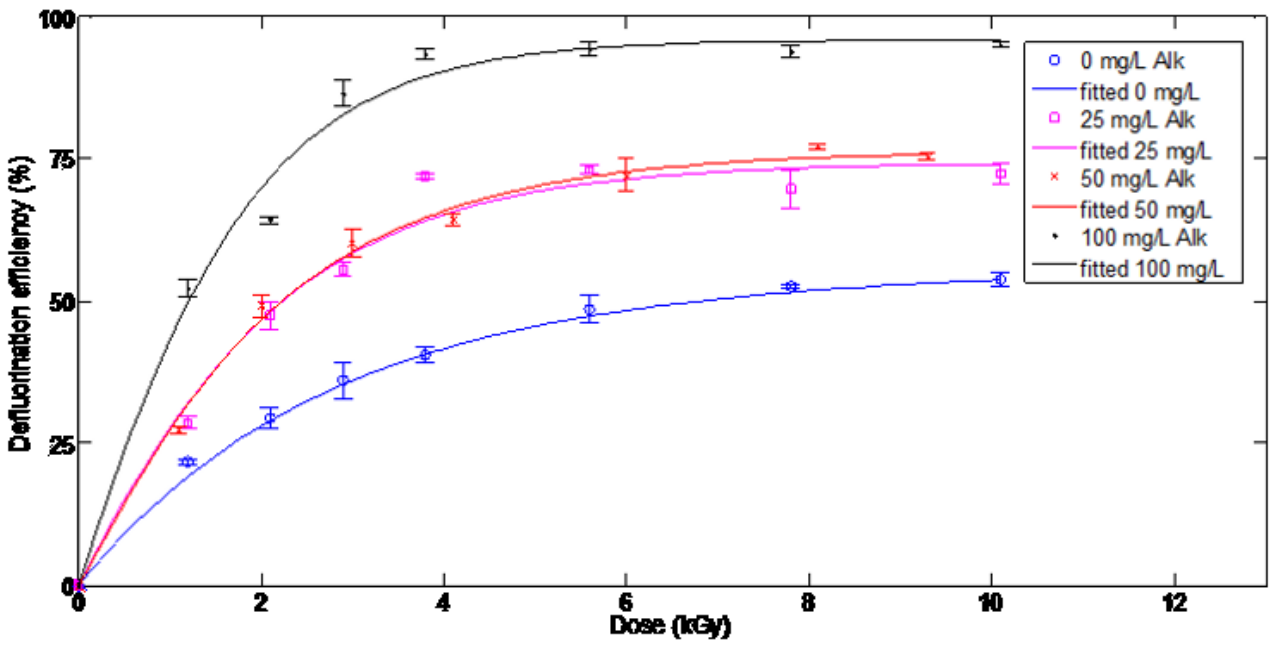


eBeam for Potable Water Reuse – Chemical Contaminants – (PFOA)



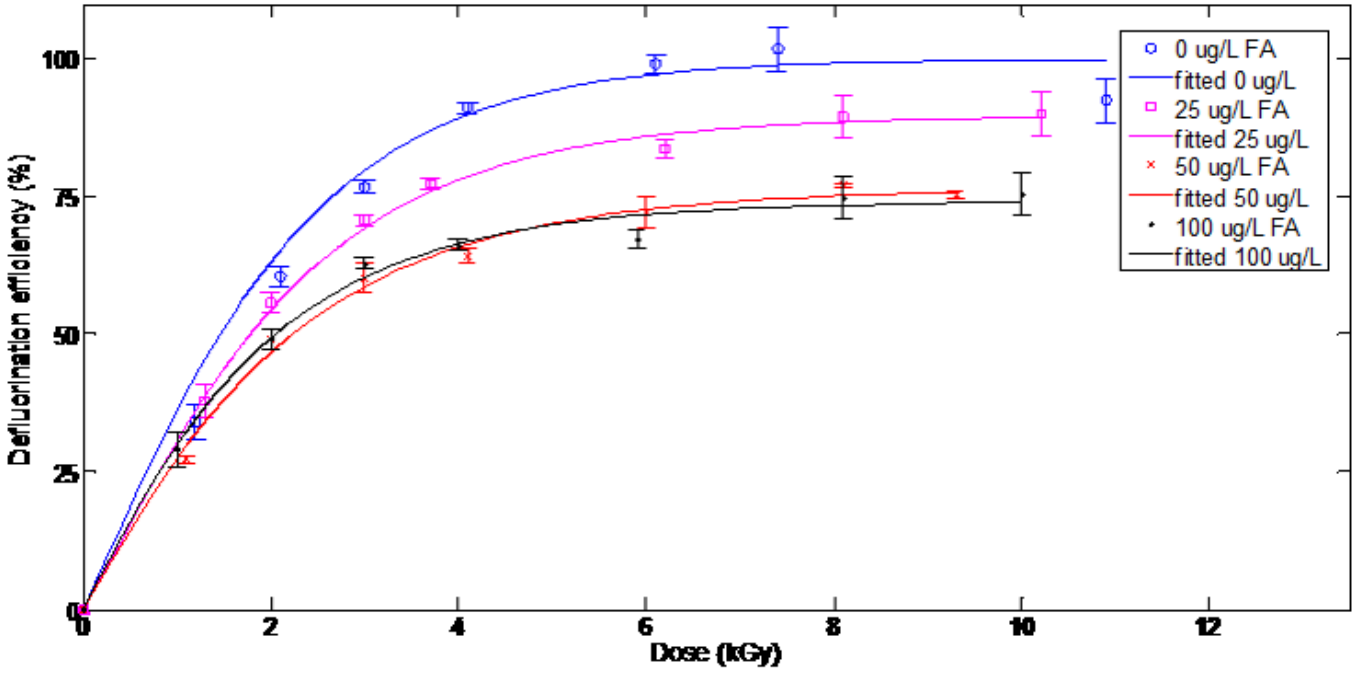
NO_3^- (mg/L)	Defluorination(%)
5	70
20	93

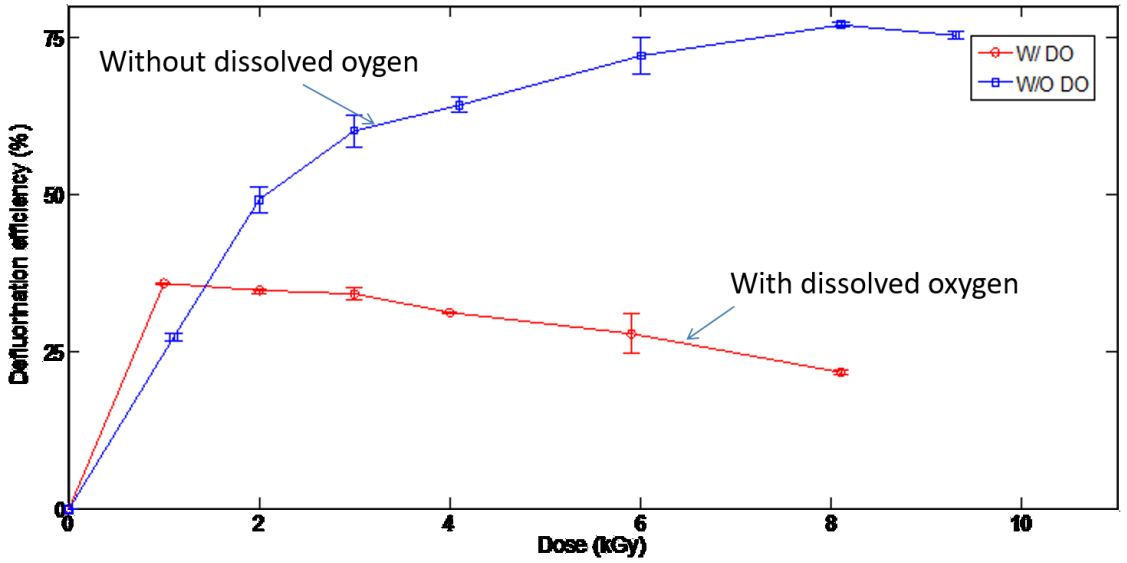




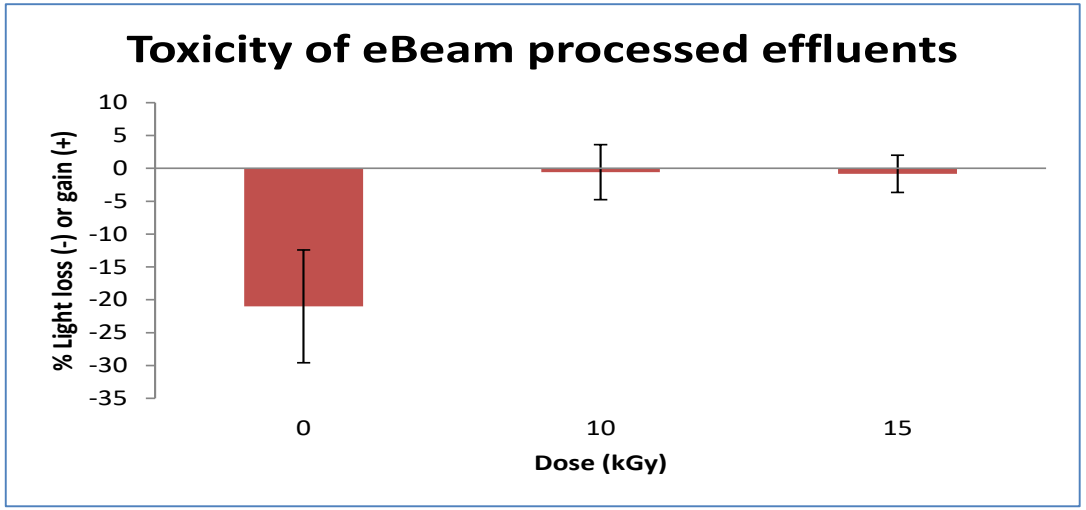
Alk (mg/L)	Defluorination(%)
25	72
100	95

eBeam for Potable Water Reuse – Chemical Contaminants – (PFOA)





FA(µg /L)	Defluorination(%)
25	89
100	72



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Electron beam treatment for potable water reuse: Removal of bromate and perfluorooctanoic acid

Li Wang [a,*], Bill Batchelor [a], Suresh D. Pillai [b], Venkata S.V. Botlaguduru [a]

***Table 4**: PFOA defluorination efficiency of eBeam irradiation as a function of nitrate, alkalinity and fulvic acids[1]*

Parameters	Concentration	Defluorination efficiency (%)
Nitrate (mg/L)	0	34.6
	5	70.1
	10	77.0
	20	93.3
Alkalinity (mg/L as $CaCO_3$)	0	53.8
	25	72.4
	50	77.0
	100	94.9
Fulvic acids (µg- C/L)	0	100
	25	90.0
	50	77.0
	100	75.4

Commercialization Strategy

- eBeam technology has to address a problem for which a solution
  - does not exist or is currently too expensive

- eBeam technology has to be robust and ready for the “big time”
  - Need high energy , high power accelerators
  - Need robust and reliable accelerators
  - Needs to be off the shelf and ready for use in a working facility
  - Need redundancy
  - Unfortunately no one wants equipment with Serial # 1 in their facility..

Our Commercialization Strategy for the Environmental Industry

- Environmental Industry extremely conservative
- Ionizing irradiation is not in their “playbook”
- Partner with stakeholders who are willing to be pioneers
  - Technology providers
  - Financial industry
  - Consulting companies
  - Water utilities who have specific problems/issues that need solutions

Ex-Situ Remediation of Investigation-Derived Wastes containing PFAS by Electron Beam Technology

in collaboration with

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