OSU Experience with the eFLASH Mobetron

Sagarika Jain, MS, DABR

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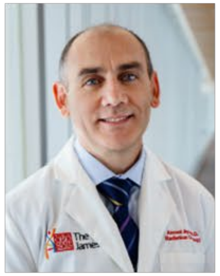
Creating a cancer-free world. One person, one discovery at a time.

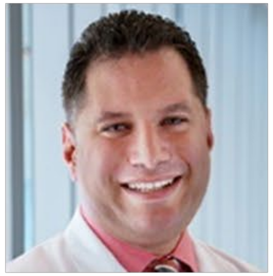
OSU FLASH Team

Arnab Chakravarti, MD
Chair, Radiation Oncology

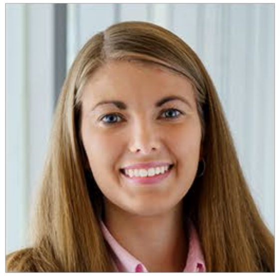
Department of Radiation Oncology



Ahmet Ayan, PhD
Medical Physicist



Dukagjin Blakaj, MD, PhD
Radiation Oncologist



Ashley Cetnar, PhD
Medical Physicist

Cecilia Cuitino, DVM, PhD, DACVP
Veterinary Pathologist

Jessica Fleming, PhD
Radiobiologist

John Grecula, MD
Radiation Oncologist

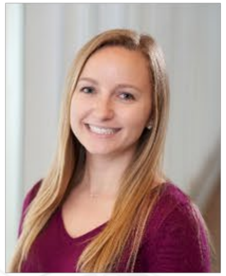
Nilendu Gupta, PhD
Chief, Medical Physics

Sagarika Jain, MS
Medical Physicist

Kim Mahler, MS
Director, Research Operations

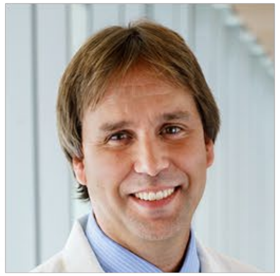
Heather Manring, PhD
Senior Research Associate

Wei Meng, PhD
Radiobiologist



Kelsey Oskey
Radiation Safety Specialist

Julie Sussi, MA
Chief Administrative Officer



Jeff Woollard, PhD
Medical Physicist

College of Veterinary Medicine

Rustin Moore, DVM, PhD DACVS
Chair, Veterinary Medicine

William Kisseberth, DVM, MS, PhD, DACVIM
Medical Oncologist, Veterinary Medicine

Eric Green, DVM, DACVR
Radiation Oncologist, Veterinary Medicine

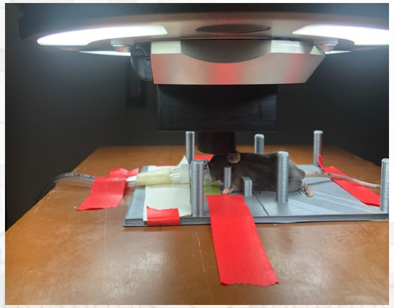
Timeline for Ohio State's Flash Adventure

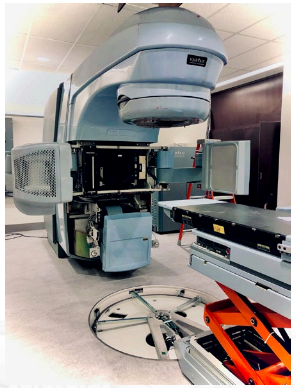
IntraOp FLASH Mobetron

Varian FLASH Research Extension (FLEX) Toolkit

2020	2021	2022	2023

Small Animal Research





Proton FLASH with Varian ProBeam

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Contents

- Configuration, Hardware and Collimation
- Dosimetry Tools and Beam Data Acquisition
- UHDR Production and Pulse Parameters
- Stability across pulse parameters
- Summary and needs for standardization

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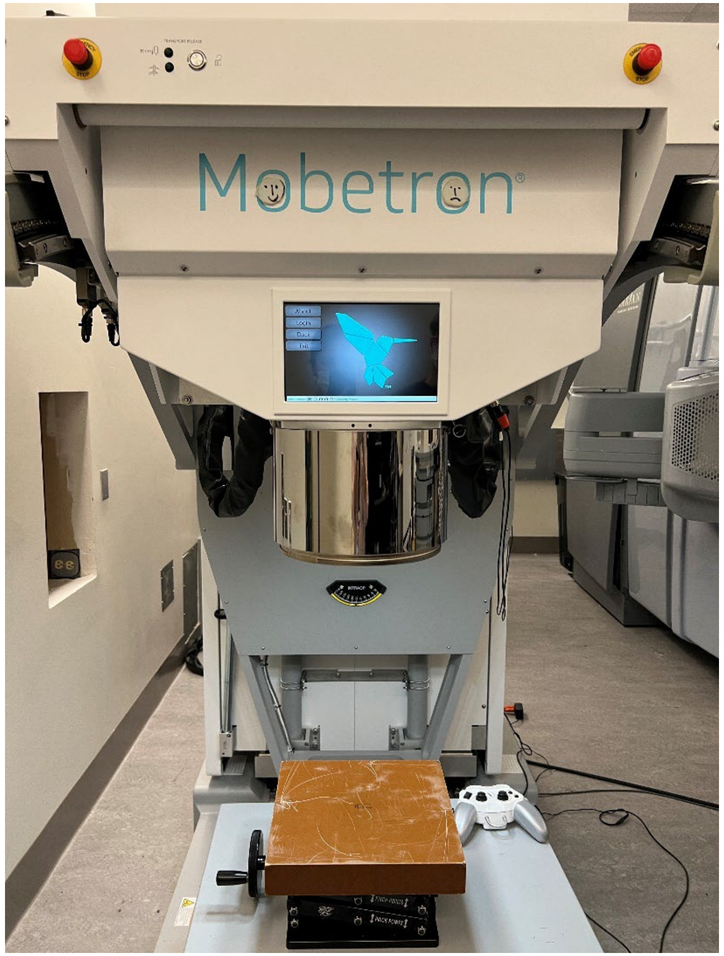
IntraOp Mobetron



- X-band Mobile pulsed electron linear accelerator
- IORT Configuration
- 9 MeV Conventional, 9 MeV and 11 MeV UHDR (> 40 Gy/s)
- Standard SSD = 50 cm, cones from 3 cm to 10cm

Commissioning of an ultra-high dose rate pulsed electron beam medical LINAC for FLASH RT preclinical animal experiments and future clinical human protocols

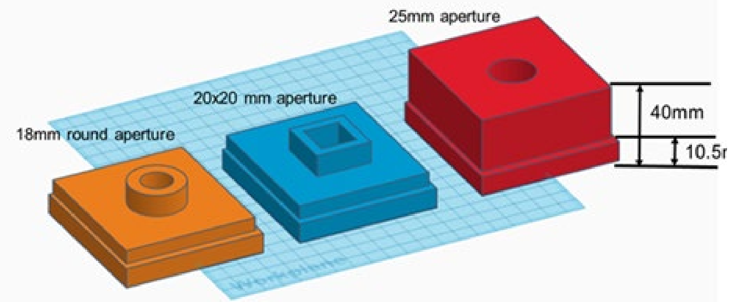
Raphaël Moeckli [1], Patrik Gonçalves Jorge [1], Veljko Grilj [1], Roxane Oesterle [1], Nicolas Cherbuin [1], Jean Bourhis [2], Marie-Catherine Vozenin [2], Jean-François Germond [1], François Bochud [1], Claude Bailat [1]

eFLASH Mobetron

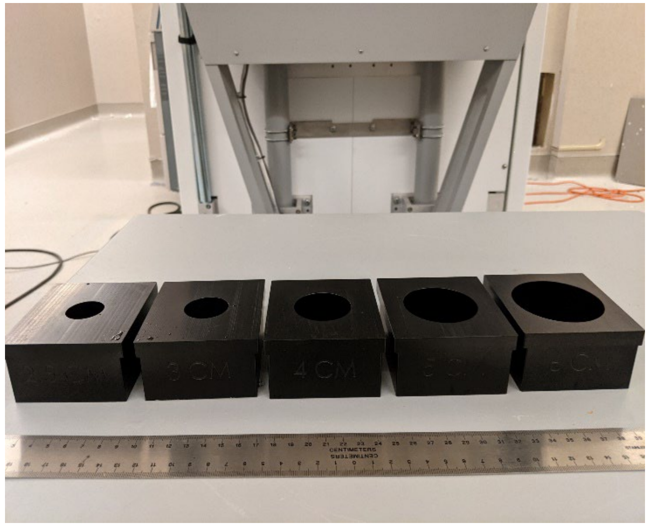
Dpp > 8 Gy
Mean Dose Rate > 500 Gy/s

Dpp > 3 Gy
Mean Dose Rate > 200 Gy/s

Custom Collimators (2.5 – 6 cm)

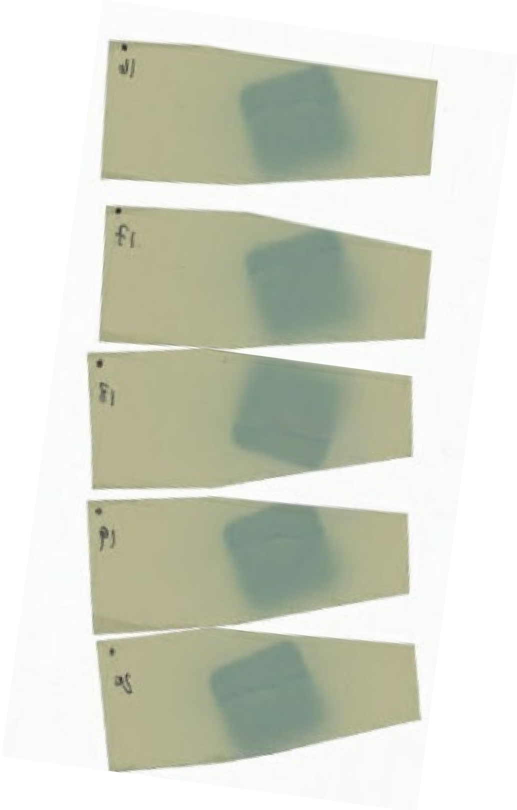


Standard Collimators (2.5 – 6 cm)



Dosimetry

EBT-XD Film



Alanine

Adv Markus

ACCT

In-Air ACCT

Alanine Dosimetry

- Electron paramagnetic resonance (EPR) dosimetry system

α-alanine: CH_3-CH(NH_2)-COOH

dosimetric material

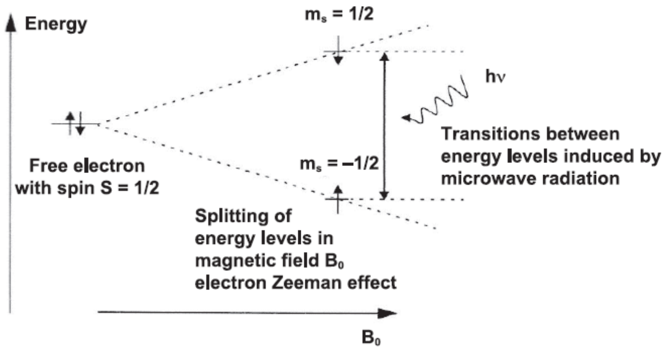


FIG. 1. Zeeman effect is described by a splitting of energetic levels when applying an external magnetic field B_0. In the case of an electron, two energetic levels are created with a difference of energy depending on B_0. An electron can change energetic level by absorption of a photon with corresponding energy hν.

- Stable signal
- Wide dose range (1Gy – 100 kGy)
- Linear dose dependance
- Dose per pulse independent

FRPT 2022 FLASH RADIOTHERAPY & PARTICLE THERAPY BARCELONA & ONLINE 30 NOVEMBER – 2 DECEMBER 2022

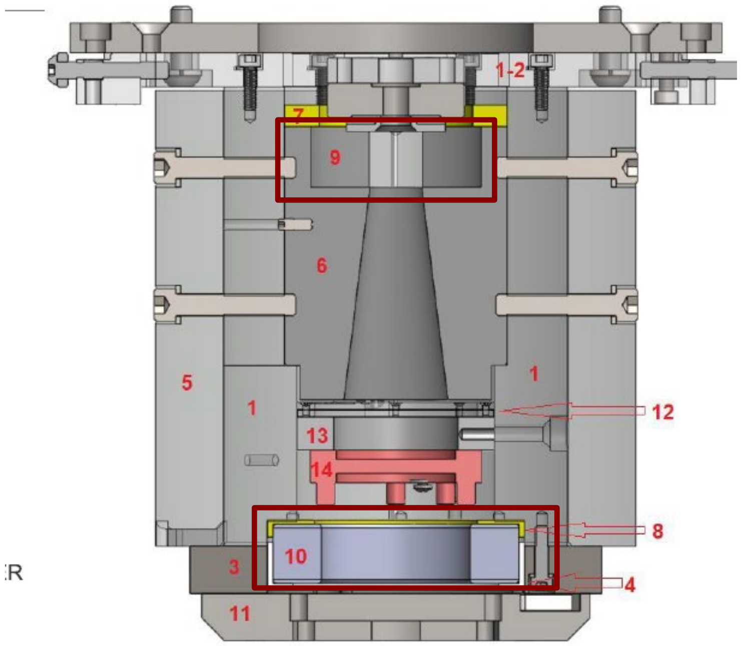
Commissioning and User Experience with Alanine Dosimetry System

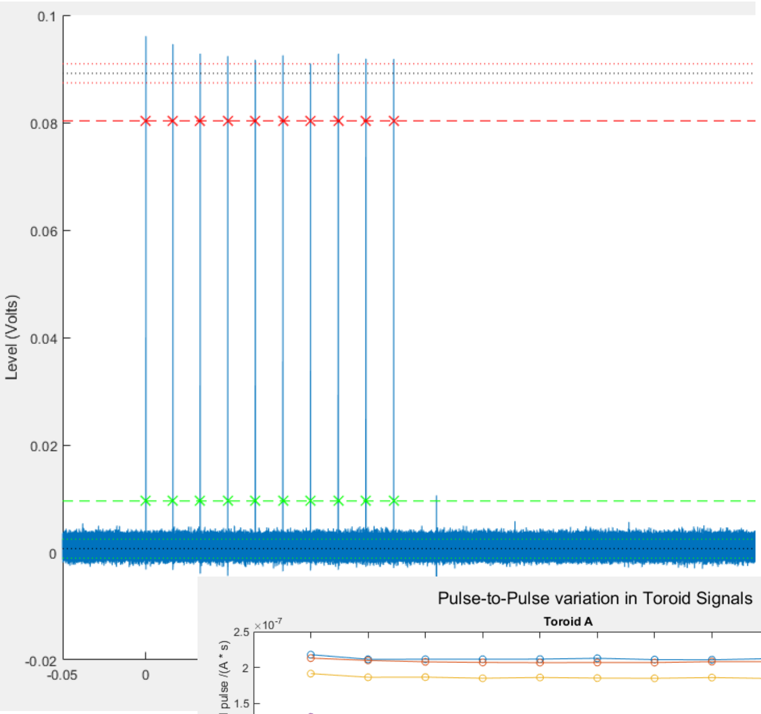
Ashley Cetnar, Sagarika Jain, Ahmet Ayan, Jeffrey Woollard, Nilendu Gupta, Dukagjin M. Blakaj, Arnab Chakravarti
The Ohio State University, Department of Radiation Oncology, Columbus, OH

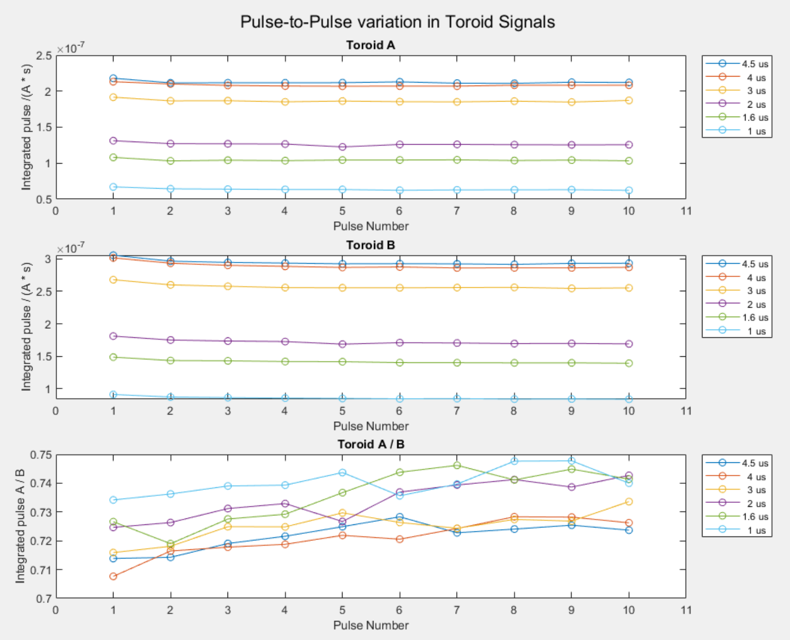
Gondre et. al. (2020) Optimization of Alanine Measurements for Fast and Accurate Dosimetry in FLASH Radiation Therapy
https://www.nist.gov/programs-projects/basic-metrology-dosedose-rate-effects-alanine-dosimetry

ACCTs

In-Air ACCT







- measure induced current of electrons passing through them.
- can be used for characterization and verification of pulse parameters
- fast instantaneous response can be used for active dosimetry.

Implementation and validation of a beam-current transformer on a medical pulsed electron beam LINAC for FLASH-RT beam monitoring

Correction(s) for this article

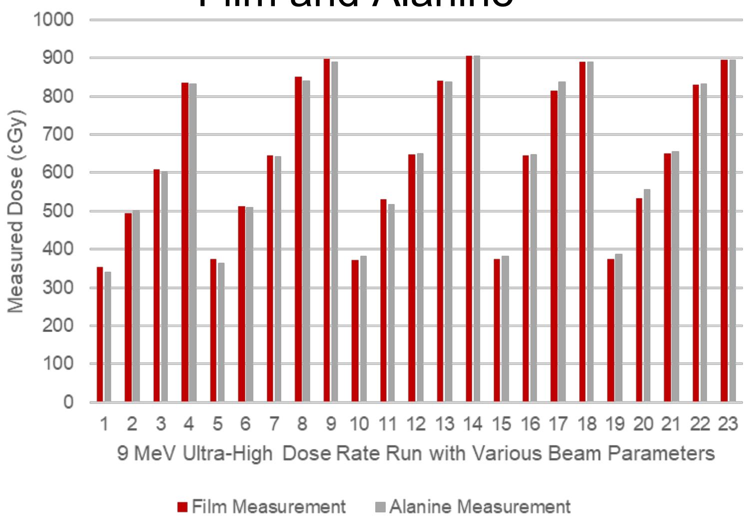
Roxane Oesterle, Patrik Gonçalves Jorge, Veljko Grilj, Jean Bourhis, Marie-Catherine Vozenin, Jean-François Germond, François Bochud, Claude Bailat, Raphaël Moeckli

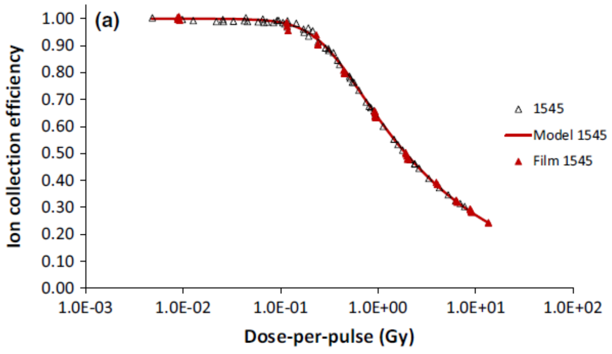
Dual beam-current transformer design for monitoring and reporting of electron ultra-high dose rate (FLASH) beam parameters

Kevin Liu [1,2], Allison Palmiero [1], Nitish Chopra [1], Brett Velasquez [1], Ziyi Li [3], Sam Beddar [1,2], Emil Schüler [1,2]

Dosimeter Cross Comparison

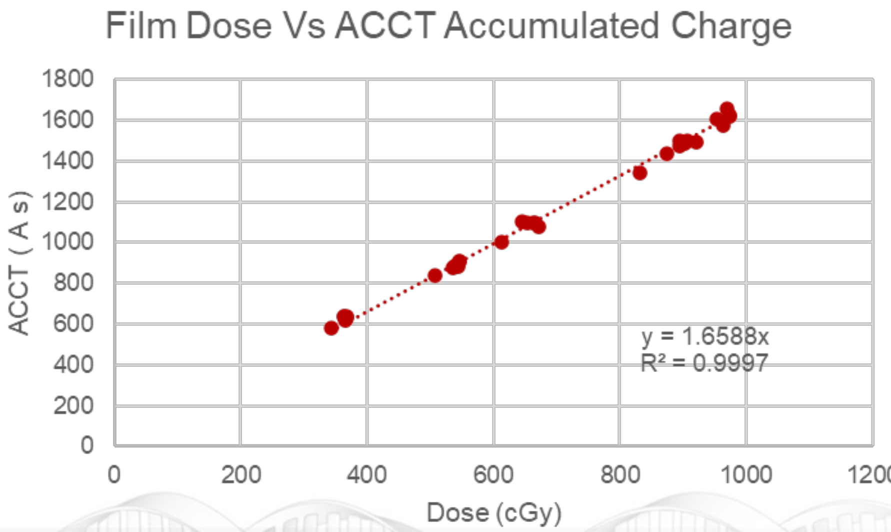
- Film and Alanine



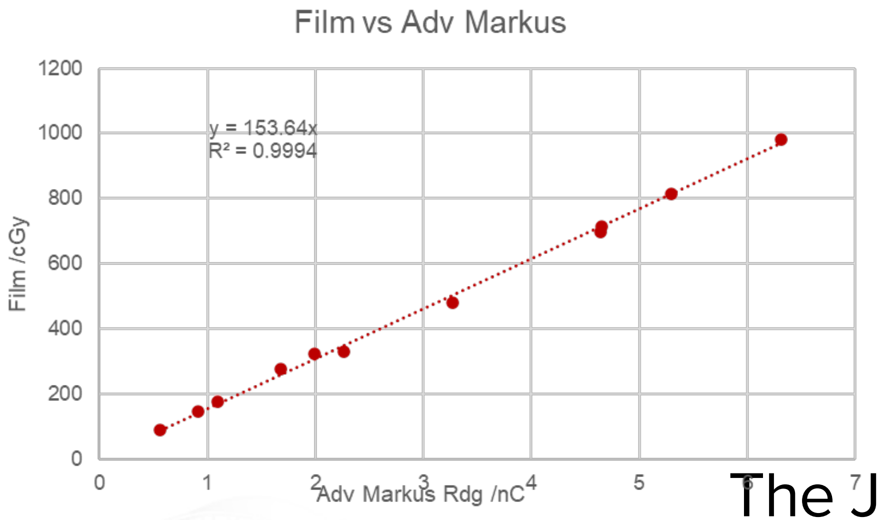


High dose-per-pulse electron beam dosimetry – A model to correct for the ion recombination in the Advanced Markus ionization chamber

Kristoffer Petersson [1], Maud Jaccard [1], Jean-François Germond [1], Thierry Buchillier [1], François Bochud [1], Jean Bourhis [2], Marie-Catherine Vozenin [2], Claude Bailat [1]

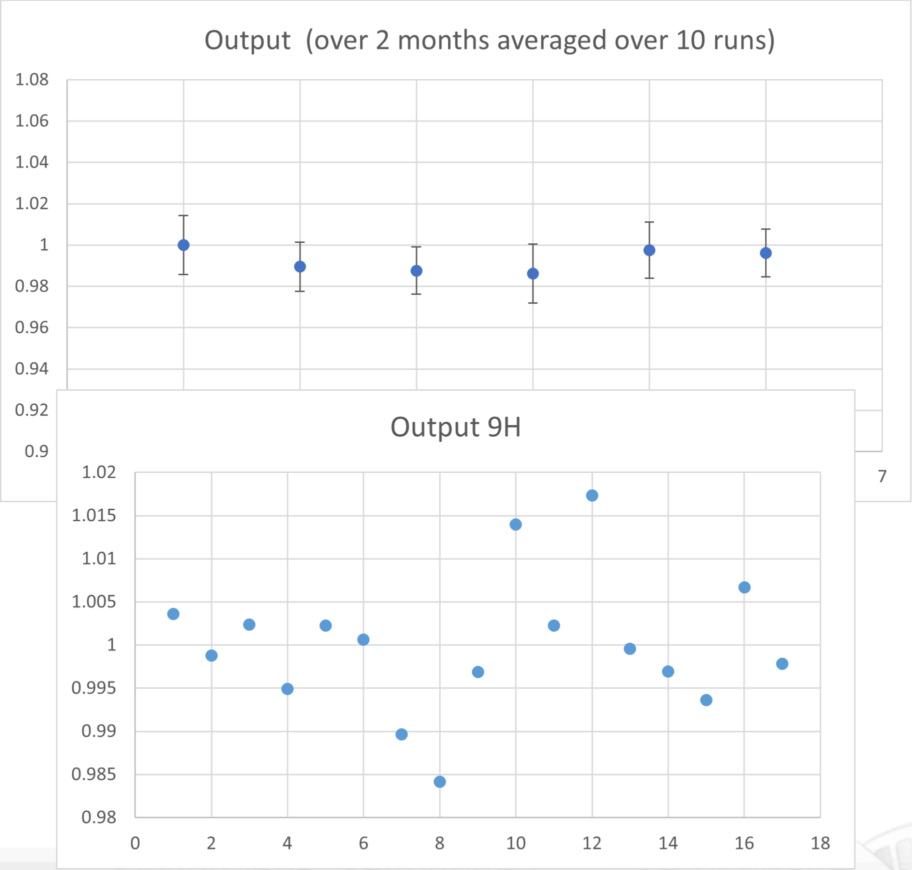


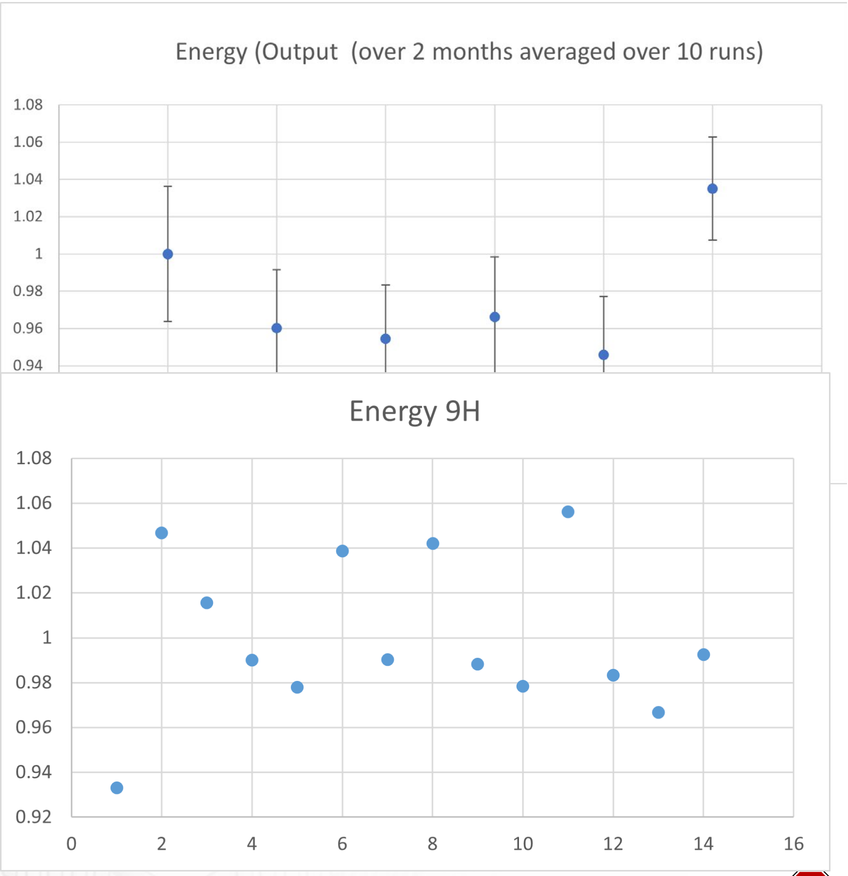
- Film and Adv Markus @ Extended SSD



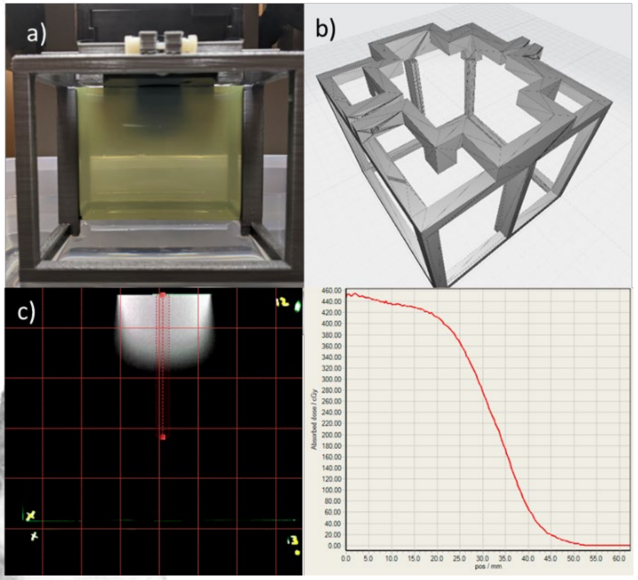
Daily output stability tests

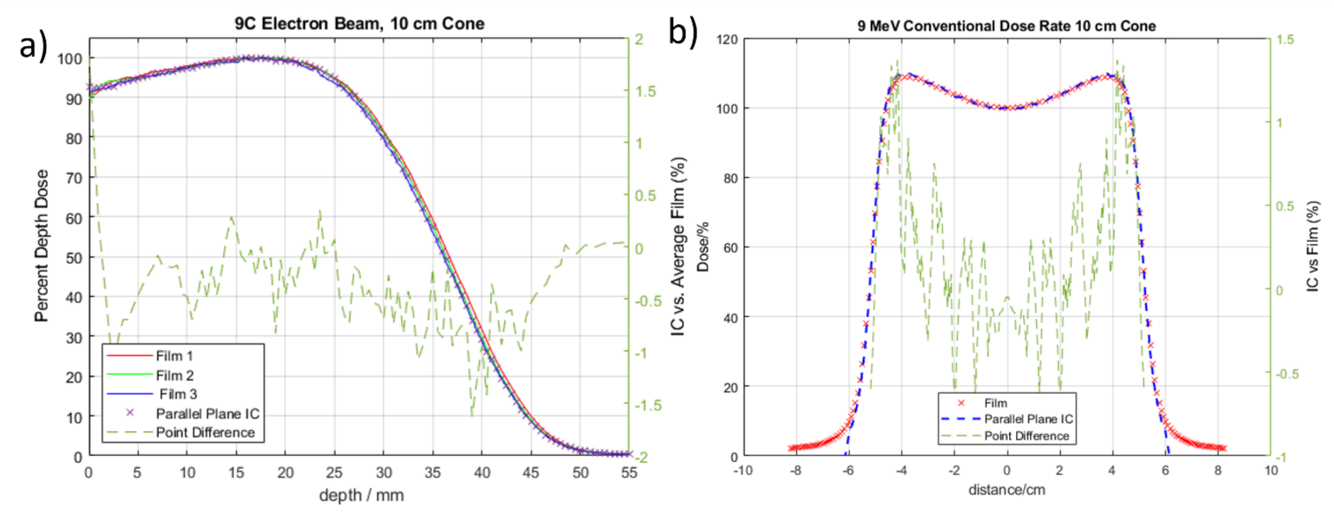
- Extended SSD ~ 100 cm on the laser device
- 2000 MU warmup, 1us PW @ dmax for output, 3cm depth for energy

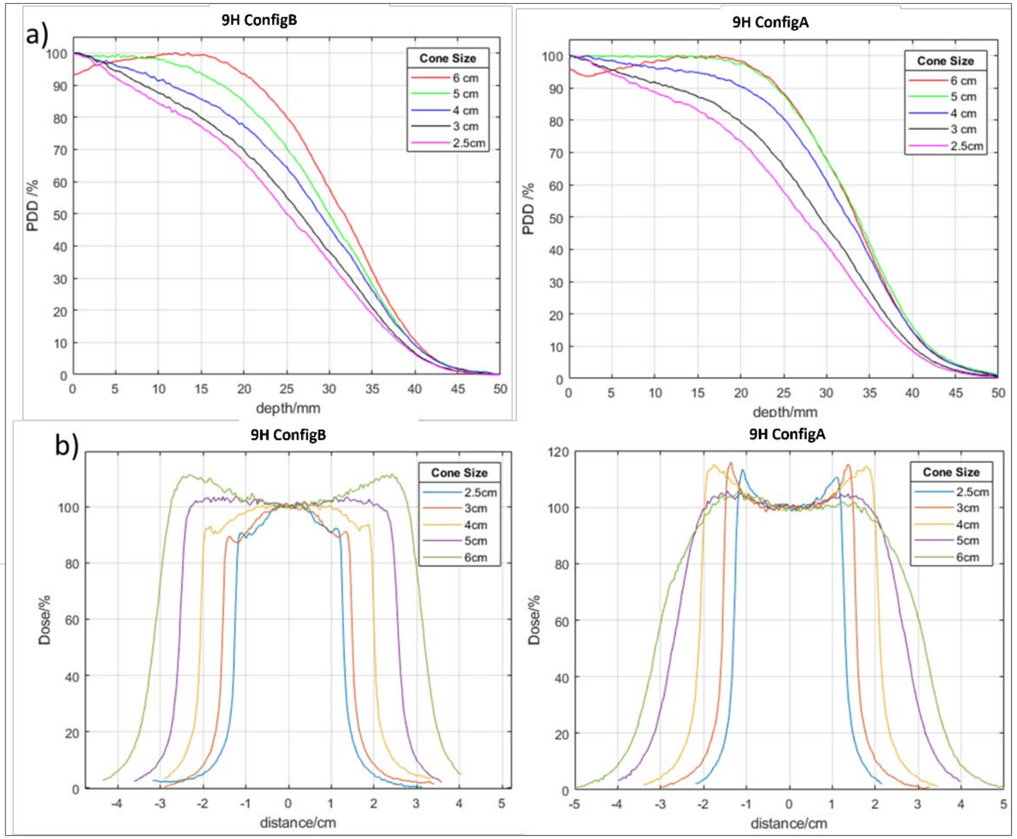




UHDR Beam Data Acquisition with Film







Session: FLASH RT - Instrumentation and Dosimetry [Return to Session]

Validation of a Novel Device for Characterizing Ultra High Dose Rate (FLASH) Electron Beams

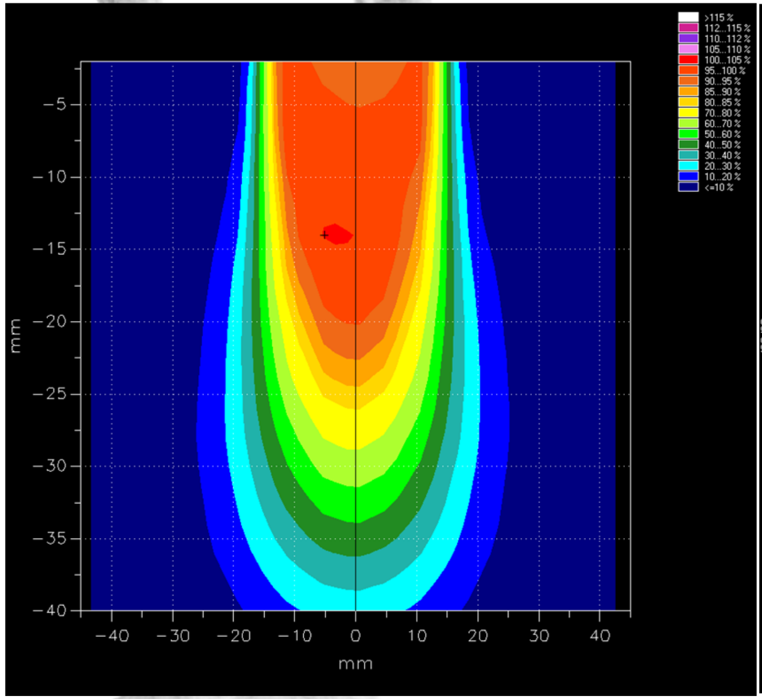
S Jain*, J Woollard, A Cetnar, N Gupta, A Ayan, Ohio State Univ, Dublin, OH

nes

The Ohio State University
Wexner Medical Center

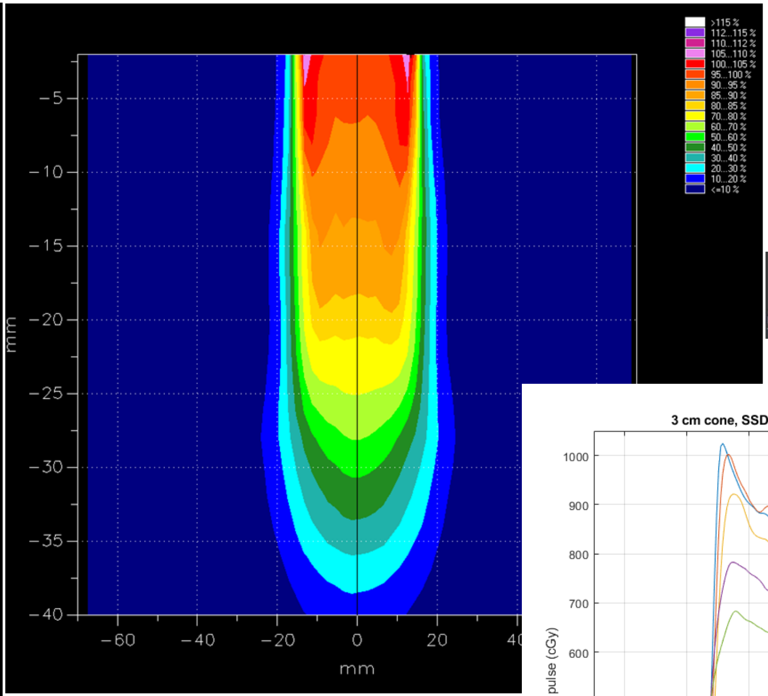
Dose distribution considerations

9MeV 50cm SSD 3cm Cone



Clinical Configuration

9UHDR 18.3cm SSD 3cm Cone

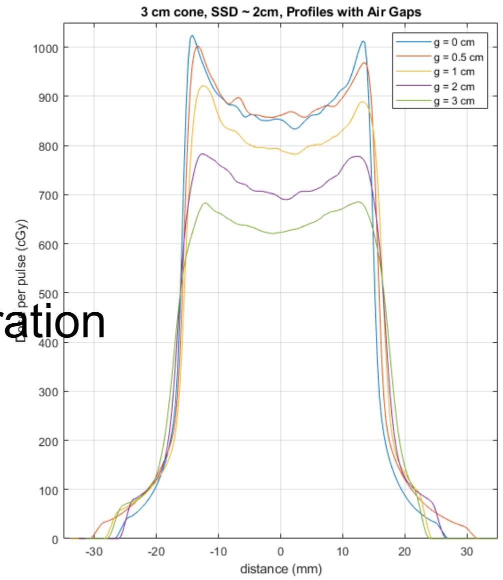


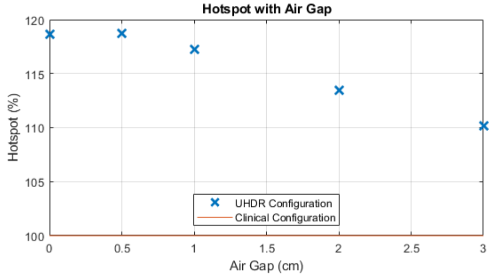
Max DPP Configuration

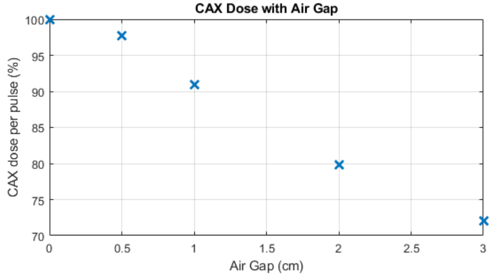
E-FLASH Dose Distribution considerations for designing Clinical Trials

Nilendu Gupta, Jeff Woollard, Ahmet Ayan, Sagarika Jain, Ashley Cetnar, Jessica Fleming, Dukagjin Blakaj and Arnab Chakravarti.
The Ohio State University – James Cancer Hospital and Solove Research Institute

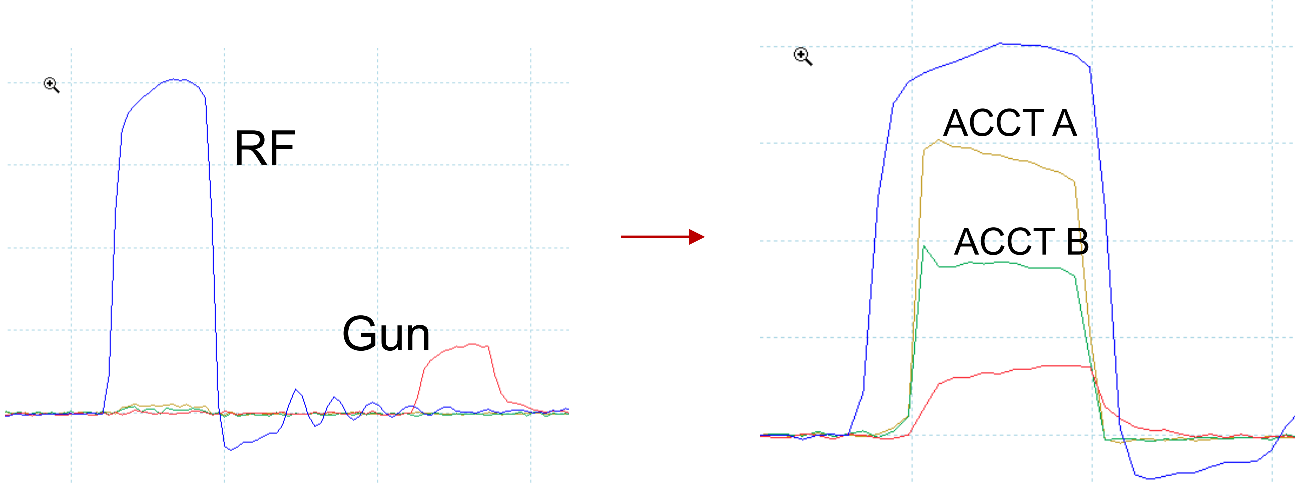
FRPT 2022







Mobetron UHDR delivery

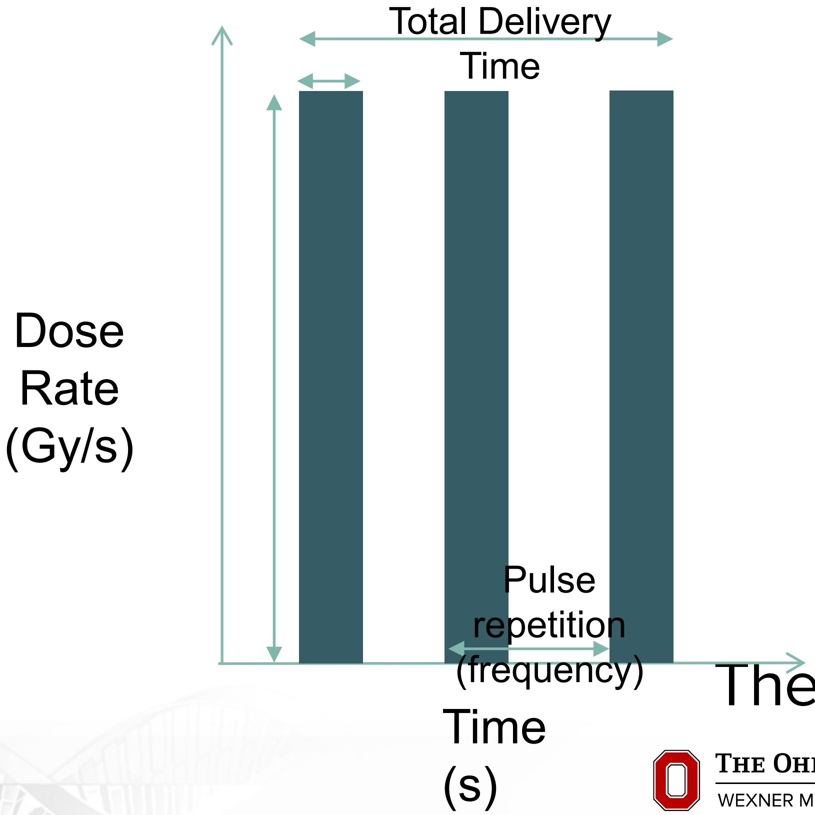


Temporal Coincidence of RF and Gun waveforms

Pulse Duration (s) x Dose Rate (Gy/s) = Dose-per-pulse (Gy)

Dose-per-pulse (Gy) x Number of Pulses = Total Dose (Gy)

Total Dose (Gy) / Total Delivery Time = Mean Dose Rate (Gy/s)



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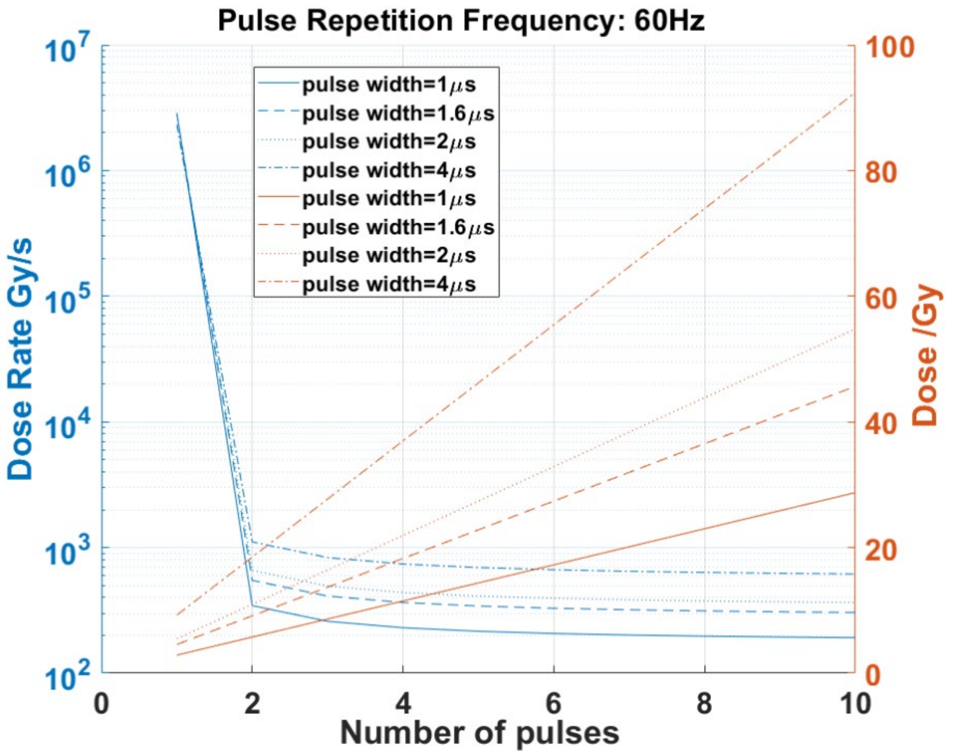
Dose and Dose Rate Interdependence

- $D\ (Gy) = N * DPP\ (60\ Hz, 4\ \mu s) * PWF * g\ (cone, SSD)$

$$\dot{D}\left(\frac{Gy}{s}\right) = \frac{D\ (Gy)}{\frac{N-1}{PRF\ (Hz)} + PW\ (\mu s)}$$



Edit — USING FILM TRIPLE CH UNIFORM CORREC. PROTOCOL

9H Dpp /Gy /4us	nominal pw	multip.	PRF	PW	DOSE /Gy N=1	2	3	4	5	6	7	8	9	10
2.42	4	1.00030868		2.40766	2.42	4.84	7.26	9.68	12.10	14.52	16.95	19.37	21.79	24.21
	3	0.93286003		2.3292	2.26	4.52	6.77	9.03	11.29	13.55	15.80	18.06	20.32	22.58
35 config, 17mm 6022022 data	2	0.72337397	60	1.75198	1.75	3.50	5.25	7.00	8.75	10.50	12.25	14.00	15.76	17.51
	1.6	0.58695978		1.43711	1.42	2.84	4.26	5.68	7.10	8.52	9.94	11.36	12.78	14.20
	1	0.4201916		1	1.02	2.03	3.05	4.07	5.08	6.10	7.12	8.13	9.15	10.17

PW	DOSE RATE / Gy/s N=1	2	3	4	5	6	7	8
4	1.01E+06	2.90E+02	2.18E+02	1.94E+02	1.82E+02	1.74E+02	1.69E+02	1.66E+0
3	9.69E+05	2.71E+02	2.03E+02	1.81E+02	1.69E+02	1.63E+02	1.58E+02	1.55E+0
2	9.99E+05	2.10E+02	1.58E+02	1.40E+02	1.31E+02	1.26E+02	1.23E+02	1.20E+0
1.6	9.88E+05	1.70E+02	1.28E+02	1.14E+02	1.07E+02	1.02E+02	9.94E+01	9.74E+0
1	1.02E+06	1.22E+02	9.15E+01	8.13E+01	7.63E+01	7.32E+01	7.12E+01	6.97E+0

9H Dpp /Gy /4us	pw	multip.	PRF	PW	DOSE /Gy N=1	2	3	4	5	6	7	8	9	10
7.72	4	1.00030868		2.40766	7.7	15.4	23.2	30.9	38.6	46.3	54.0	61.8	69.5	77.2
	3	0.93286003		2.3292	7.2	14.4	21.6	28.8	36.0	43.2	50.4	57.6	64.8	72.0
2 config, 17mm 06022022 data	2	0.72337397	60	1.75198	5.58	11.2	16.7	22.3	27.9	33.5	39.1	44.7	50.2	55.8
	1.6	0.58695978		1.43711	4.5	9.1	13.6	18.1	22.7	27.2	31.7	36.2	40.8	45.3
	1	0.4201916		1	3.2	6.5	9.7	13.0	16.2	19.5	22.7	25.9	29.2	32.4

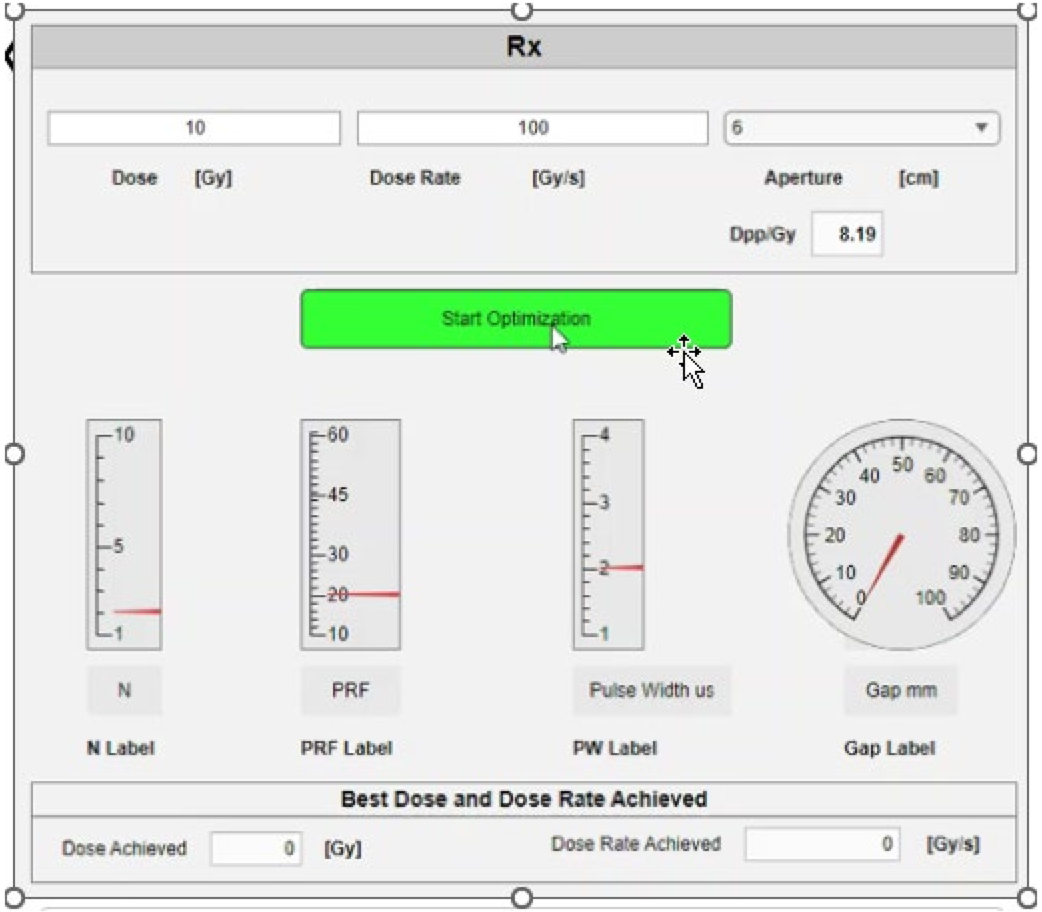
PW	DOSE RATE / Gy/s N=1	2	3	4	5	6	7	8
4	3.21E+06	9.26E+02	6.95E+02	6.18E+02	5.79E+02	5.56E+02	5.40E+02	5.29E+0
	3.09E+06	8.64E+02	6.48E+02	5.76E+02	5.40E+02	5.18E+02	5.04E+02	4.94E+0
2	3.19E+06	6.70E+02	5.02E+02	4.47E+02	4.19E+02	4.02E+02	3.91E+02	3.83E+0
1.6	3.15E+06	5.44E+02	4.08E+02	3.62E+02	3.40E+02	3.26E+02	3.17E+02	3.11E+0
1	3.24E+06	3.89E+02	2.92E+02	2.59E+02	2.43E+02	2.33E+02	2.27E+02	2.22E+0

Conventional	Output	dmax
35 Config, 6cm	1.467	surface
45 PRF 4us		

Formalism:

$$D(PW, PRF) = Dpp(4us, Hz) * \#pulses * \frac{Charge\ (PW, PRF)}{Charge\ (4us, 60Hz)}$$

Optimizer Demo



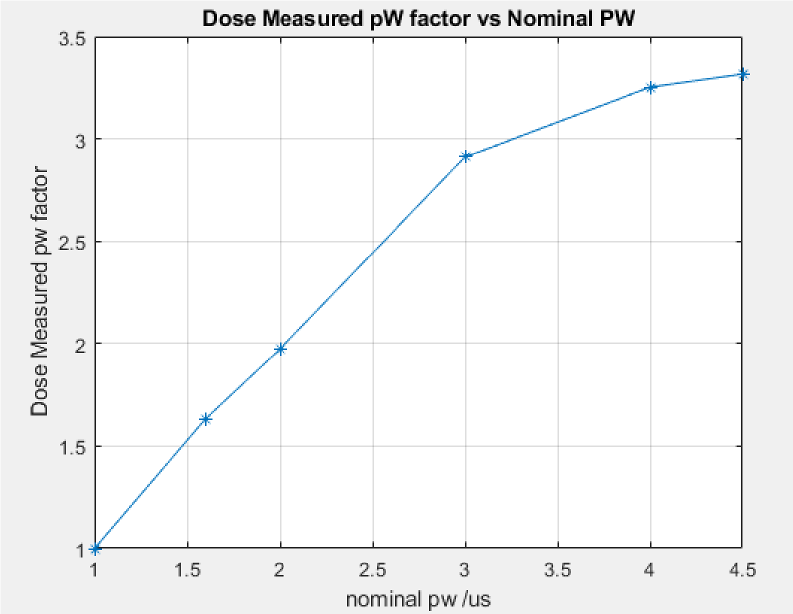
Session: Therapy General ePoster Viewing [Return to Session]

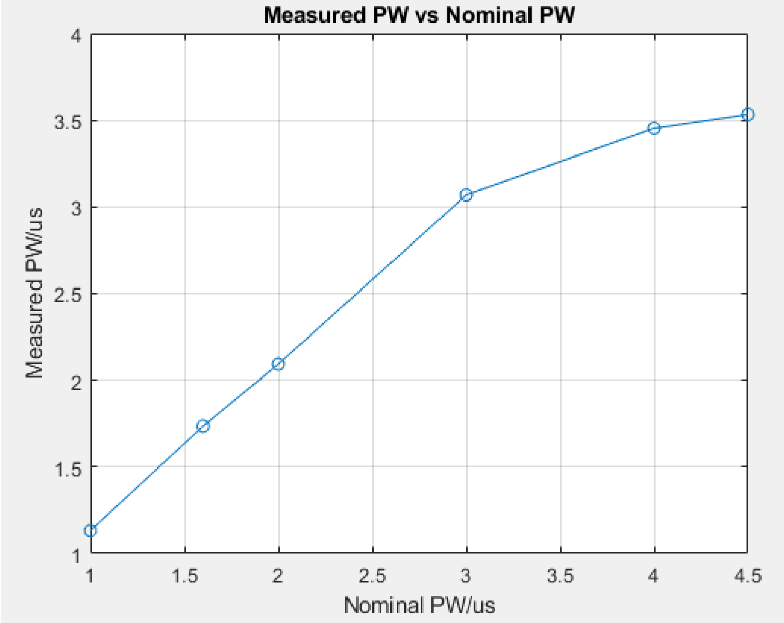
Development of a Software Tool for FLASH Dose and Dose Rate Optimization for IntraOp Mobetron

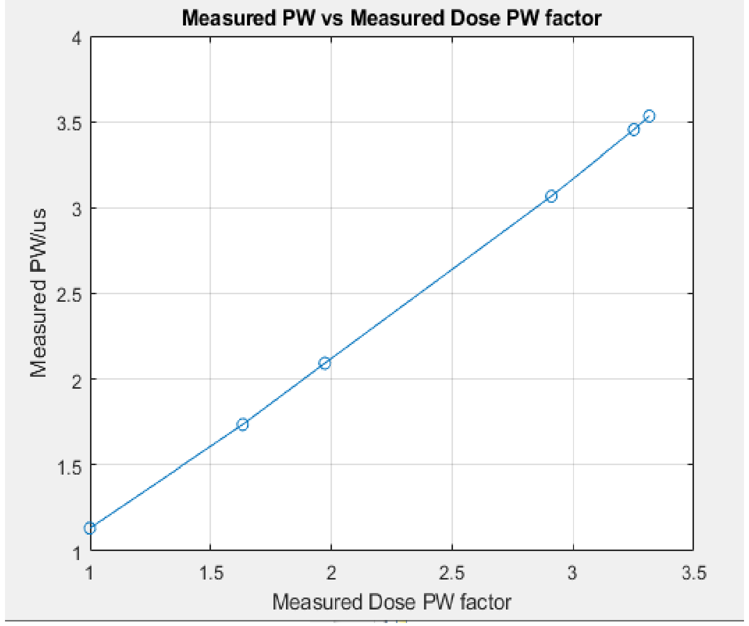
A Ayan*, D Blakaj, A Chakravarti, N Gupta, J Woollard, Ohio State Univ, Dublin, OH

Characterizing PW

- Nominal PW (labels on the dial) does not necessarily correspond to Measured PW
- Consequently, change in dose is not linear with change in nominal PW







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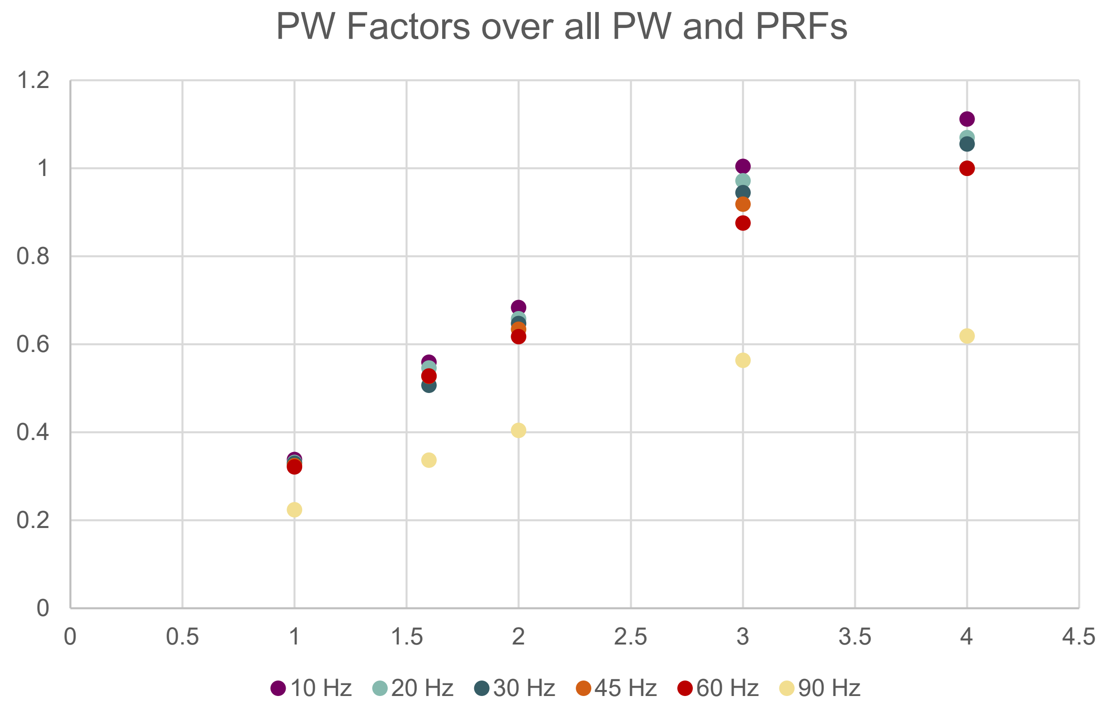
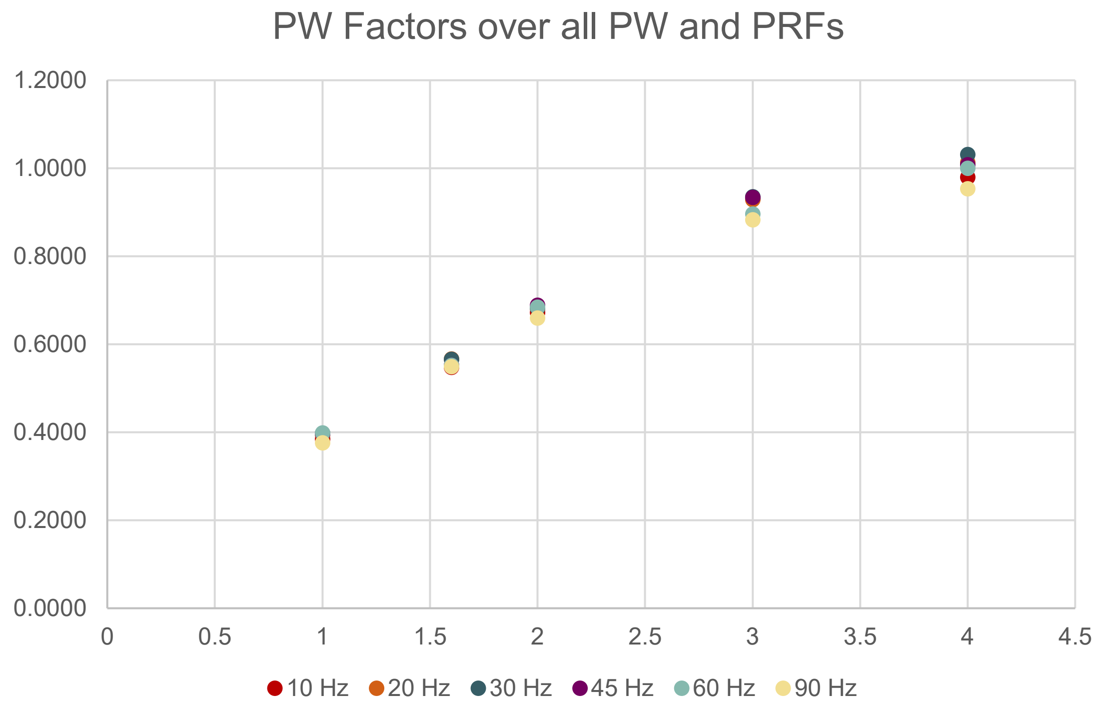
Standardization in Pulse Parameters

- initially saw change in Dpp with PRF and drop in the last pulse for 90 Hz. Worked with vendor to achieve better stability across PRFs.

$$Pulse\ Width\ Factor = \frac{Dose\ @\ PW, PRF}{Dose\ @\ 4\mu s, 60\ Hz}$$





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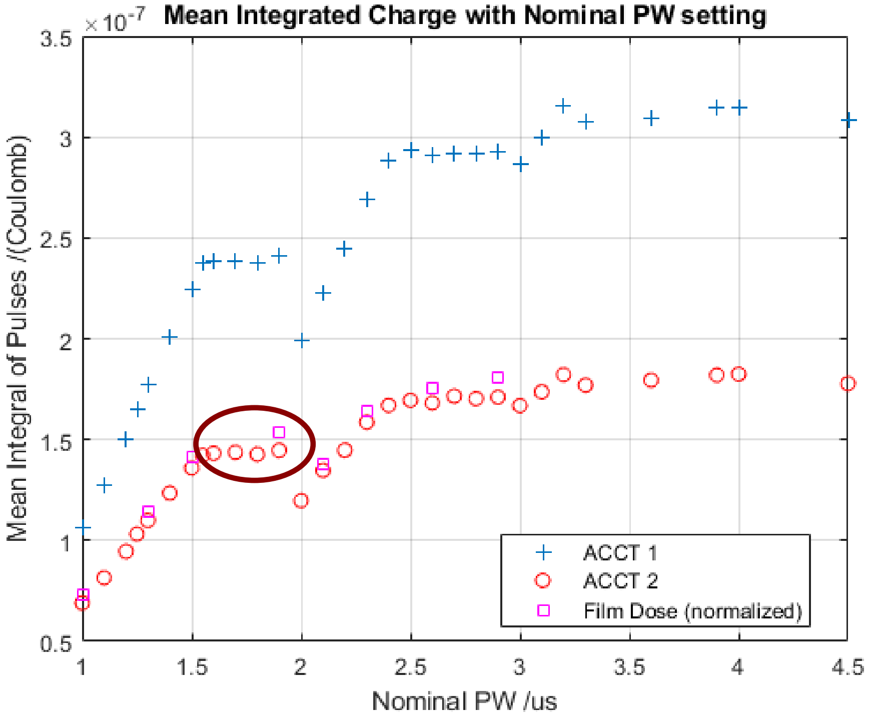
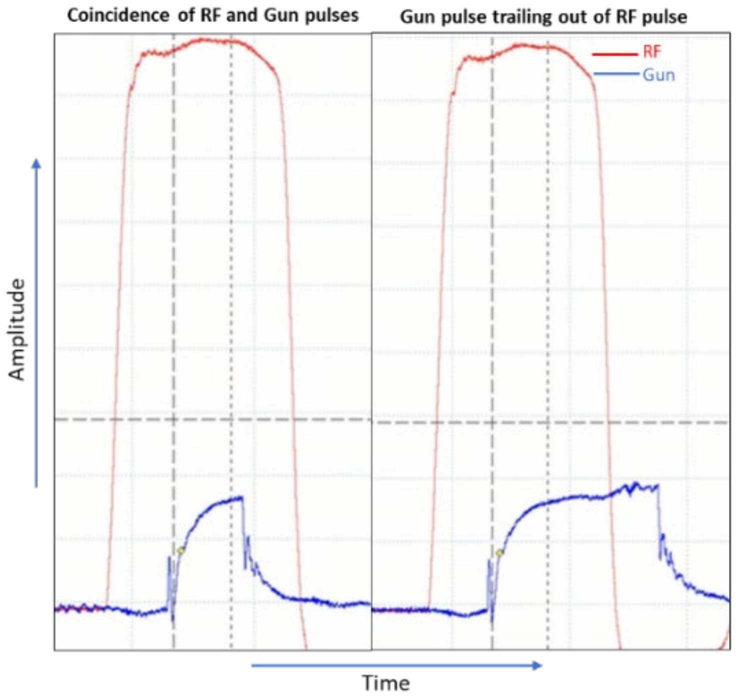
Variable PW Adjuster

- There is now also the ability to fine tune output by changing the pulse width.
- We characterized the response of this device with ACCTs





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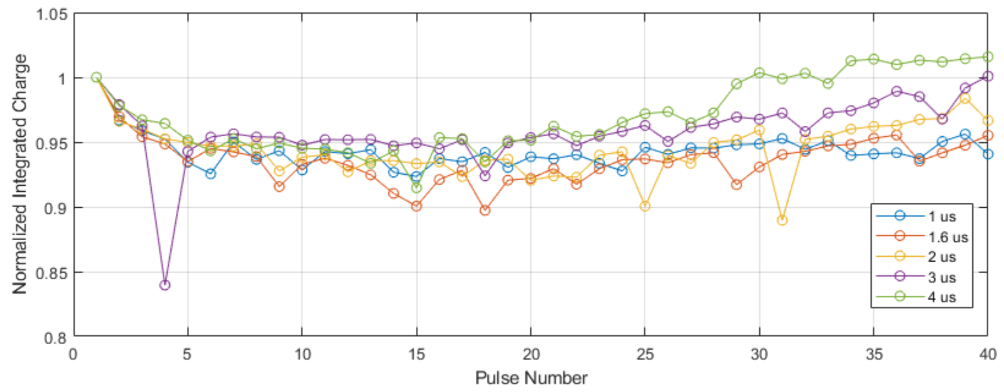
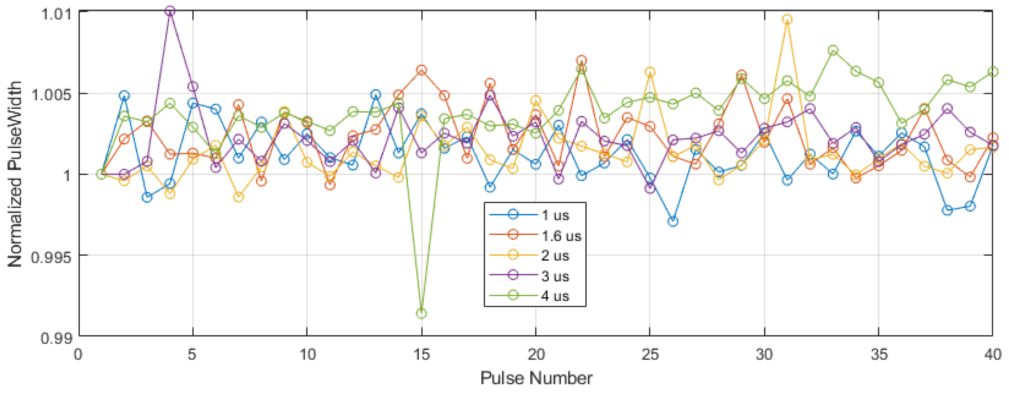
Pulse-to-Pulse Stability





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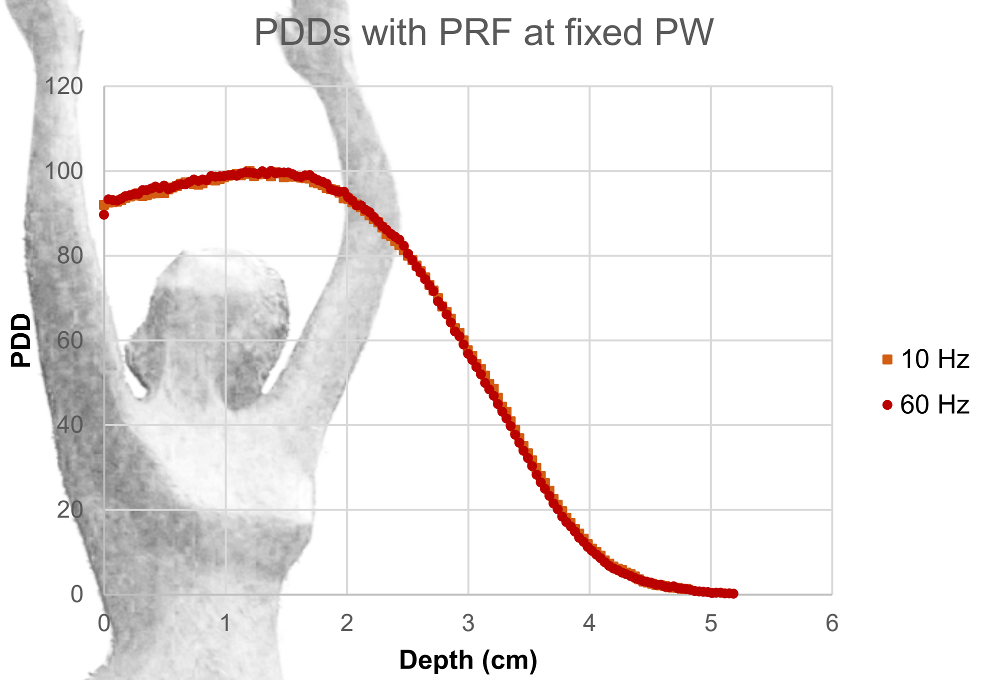
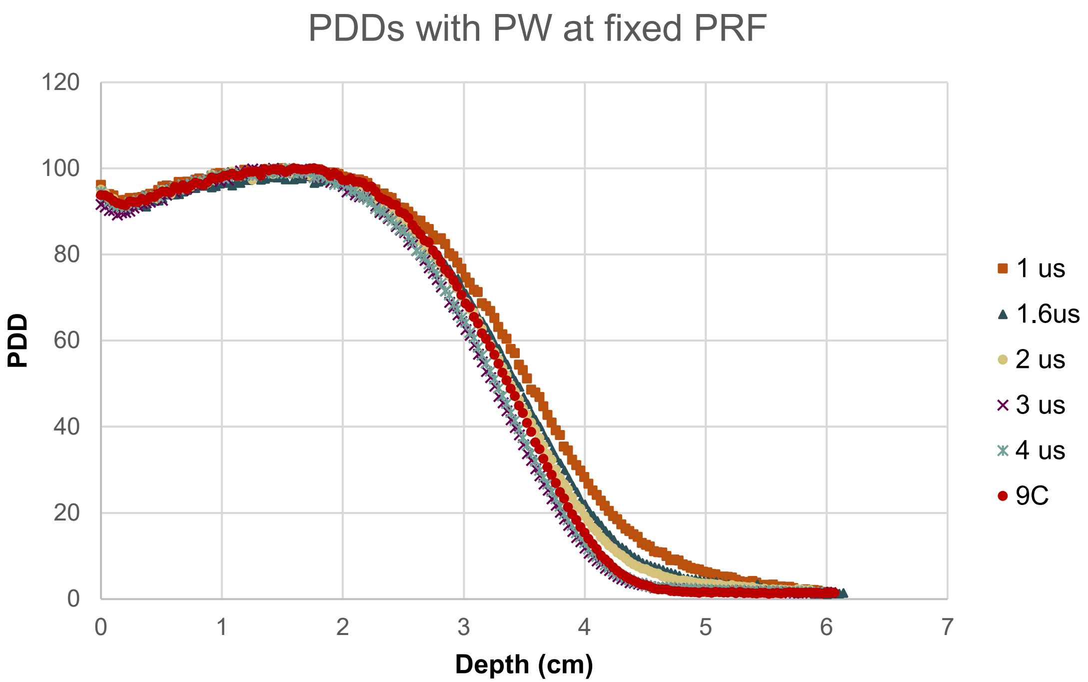
Changes in energy with PW, PRF





	Nominal PW (μs)				
	1	1.6	2	3	4
R80 (cm)	2.9	2.8	2.7	2.6	2.6
R50 (cm)	3.5	3.4	3.4	3.3	3.2
R30 (cm)	3.9	3.8	3.8	3.6	3.6

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Cross comparison between institutions

- Every machine is tuned differently – comparison with Moeckli et al data
- Ours even has different hardware (older SSM)
- Matching parameters is difficult due to discretized nature of parameters and different Dpp across machines

	OSU				CHUV				Differences			
	6H, 3 cm cone		6H, 6 cm cone		6H, 3 cm cone		6H, 6 cm cone		6H, 3 cm cone		6H, 6 cm cone	
Metric	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
R100 /mm	6.74	2.49	11.59	8.5								
R90 /mm	14.37	12.16	16.57	14.2	9	7	22	21	5.37	5.16	-5.33	-6.8
R50 /mm	22.06	20.67	23.31	21.6	28	26	32	31	-5.94	-5.33	-8.69	-9.4
Rp /mm	29.93	29.16	30.67	29.51								
E0 (MeV)	5.14	4.82	5.43	5.03								
	9H, 3 cm cone		9H, 6 cm cone		9H, 3 cm cone		9H, 6 cm cone		9H, 3 cm cone		9H, 6 cm cone	
Metric	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
R100 /mm	0.4	0.7	15.51	13.41								
R90 /mm	12.16	8.2	24.64	21.78	13	7	22	25	-0.84	1.2	2.64	-3.22
R50 /mm	29.17	26.55	33.67	31.47	33	29	38	37	-3.83	-2.45	-4.33	-5.53
Rp /mm	42.63	41.18	42.02	41.67								
E0 (MeV)	6.8	6.2	7.85	7.33								

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Summary of Needs for Standardization

- Standardization in characterization and reporting of pulse parameters
- Efforts to homogenize machines
- Inter-institutional comparisons are needed
- Traceable primary standards for dosimetry
- New QA standards need to be developed for when pulse parameters are changed
- Additional QA requirements for ACCT, Alanine, Film etc dosimetry

UHDpulse

AAPM COMMITTEE TREE

Task Group No. 359 - FLASH (ultra-high dose rate) radiation dosimetry (TG359)

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Thank You!

To learn more about Ohio State's cancer program, please visit **cancer.osu.edu** or follow us in social media:

And please visit the Department of Radiation Oncology at **radiationoncology.osu.edu**

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