A few thoughts on why we love particle accelerators

(and why we should communicate about them even more to "outsiders")

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THE UNIVERSITY OF NEW MEXICO

Before I begin, just a moment of reflection and a couple of stories

Thanks to my family, friends, and my accelerator family, including the IEEE

Thanks to my mother Gail, my recently-deceased father Emil, my husband Stephen, our son Sebastian, my extended family, the accelerator community family, and many friends for years of rallying and support for science, engineering, and me.

Thanks especially to the IEEE for recognizing my efforts and inspiring me to keep rallying for science and engineering as well as giving me and many other unlimited technical and leadership opportunities. (For example, 2018 IEEE President Jim Jefferies will visit UNM on 26 September to meet with students and members from around New Mexico – Please join us!)

Taking inspiration from a former boss

- When my former boss, Lee Teng, had to give a talk for the APS Wilson Prize, he got up to the podium and said “You suggested a title for me and I decided, since I am the prize winner, to talk about what I want.” He told all of us about his journey through particle accelerators including the many friends and science he found along the way. It was lovely.
- So I suppose this inspired me to talk about what I want to talk about - ***why accelerators mean so much to all of us and to society AND why we should communicate to <u>more people</u> in society about them***
- I will come back to Lee in a minute…

Accelerator people are *sciency* and *techie* people

- Accelerator expertise demands a mix of talents unlike any other field – vacuum science, mathematics, physics, materials science, chemistry, controls, mechanical engineering, electrical engineering, systems engineering, computing, etc.
- **We are people who use their unique and diverse skills sets to do truly exceptional**

My own diverse background

- I also have training and research experience outside of accelerators, physics and electrical engineering – as I was also trained in chemistry, biology and mathematics.
- This diverse background, I believe, gives me a unique perspective on bridging to the accelerator applications which I dreamt about early on (and continue to dream about).
- The full utilization of this diverse background in my career was also ***greatly*** encouraged by several of my colleagues and/or mentors, including Professor Ingolf Lindau, Professor Mikael Eriksson, Professor Börje Larsson (1931–1998), and Professor Porter Johnson.
- Larsson together with Sven Kullander, wrote two popular scientific books, including one in 1994 entitled *Out of Sight—from Quarks to Living Cells* - which should sum up his interest in encouraging and inspiring multi-disciplinary investigations.

(See obituary - Professor Börje Larsson, 1931–1998: A Multidisciplinary Scientist Acta Oncologica Vol. 38, No. 3, pp. 389–390, 1999.)

Example
Soil contamination with explosives after WWII

- After WWII, many weapons were disassembled at places such as the Joliet Army Arsenal and the Burlington Iowa Ammunition Plant and distributed in the soils in large fields.
- In the early 1990s as an Argonne employee, with research supported by the Army, I participated on all kinds of measurements, including plant uptake studies of the explosives and tried to come up with ways of getting these contaminants out of the soil.
- ***How I dreamed of a day when we could perhaps use powerful particle beams to treat the soil layers to cause, for instance, radiation induced heating.***

S. Biedron and W. Triebold at the Burlington, Iowa Ammunition Plant, 1993 – Photo courtesy John Schneider (Argonne)

B. Lee, M. Lee, "Decomposition of 2,4,6-Trinitrotoluene (TNT) by Gamma Irradiation," Environ. Sci. Technol., 2005, 39 (23), pp 9278–9285.
K. Holbert, "Thermal Initiation of Explosive Materials Using Photon-Based Active Interrogation Methods," LANL – 0574 UR.

Example
Process control of chemicals in the the U.S. fabric industry

- Several DOE labs were involved in the AMTEX Textile Alliance in the early 1990s.
- Through research funded at Argonne through this Alliance, I was involved with research involving the measurements of chemicals used in the textile fabrication process, specifically in the finishing process, to help with controlling unnecessary exposure of employees to harmful chemicals as well as help them better have better control their process engineering.
- The analytical process was tedious and we had to retreat each time to a mobile lab external to the factory to perform the air analysis.
- ***How I dreamed of a day when we could do stand-off, real-time detection of the contaminants in the air.***

Photographer Christopher Payne Shines a Light on the Hidden World of America's Textile Industry

Examples

- And my list could go on and on here
  - Chemical speciation with synchrotron light sources for developing remediation schemes for mixed waste streams
  - XRF for metal detection in soils
  - Bulk analysis of composite aircraft parts
  - Etc.

And with my diverse background

- When I worked for Lee Teng in the mid to late 90s, because of my diverse background and maybe because he was seeing tightening budgets and fewer high risk high payoff projects that he was used to, he used to say almost every day “Why don’t you quit accelerators and do some thing interesting like **BLANK**.”
- Where blank was *anything* but **ACCELERATORS**.
- **Good thing I did not always listen to him I suppose.** ☺

Lee and Nancy Teng and I at the Fermilab 50th in 2017

Accelerators have a *real* purpose and a *real* impact
(and there is STILL much R&D to do for the next machines)

Us sciency and techie people

- We are ***really*** different than most as we like to build things that are game changing, needed and useful.
- I don't think any of us would like to build a mobile phone for instance. We don't like routine and we are multi-disciplinary.
- We like to be on teams that have our own victory (i.e. delivering first beam) and being part of the greater victory (helping others do their discoveries and jobs).

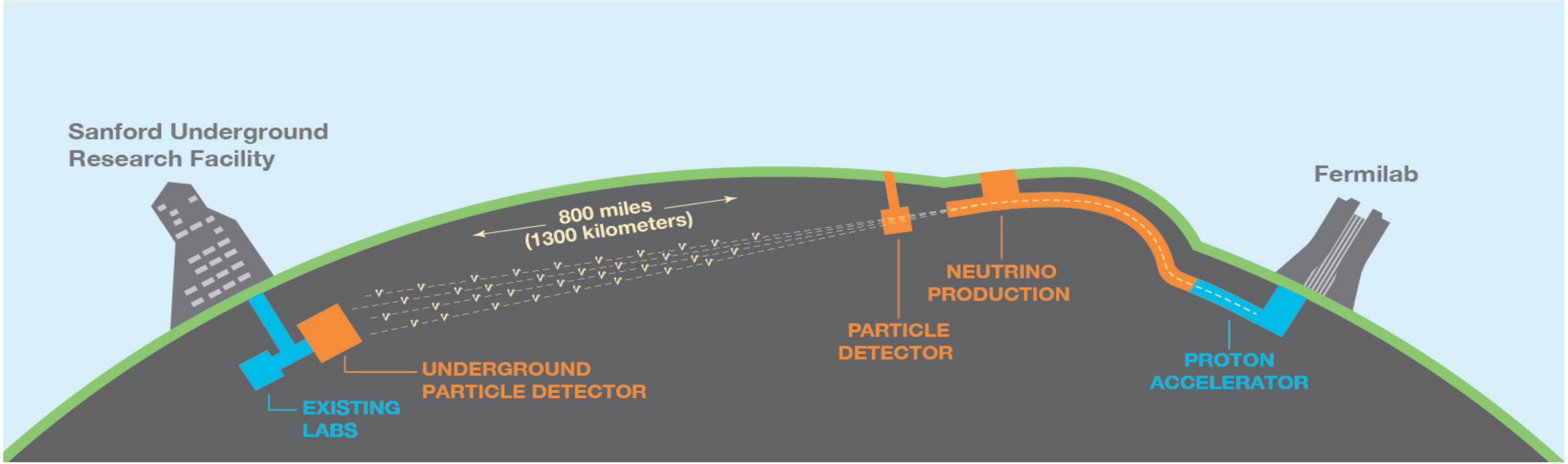
VS

Accelerators are game changing

On phones you can change games

Example *Big Science*

Long-Baseline Neutrino Facility/ Deep Underground Neutrino Experiment (LBNF/DUNE)



The LBNF/DUNE project will be the first internationally conceived, constructed, and operated mega-science project hosted by the Department of Energy in the United States.

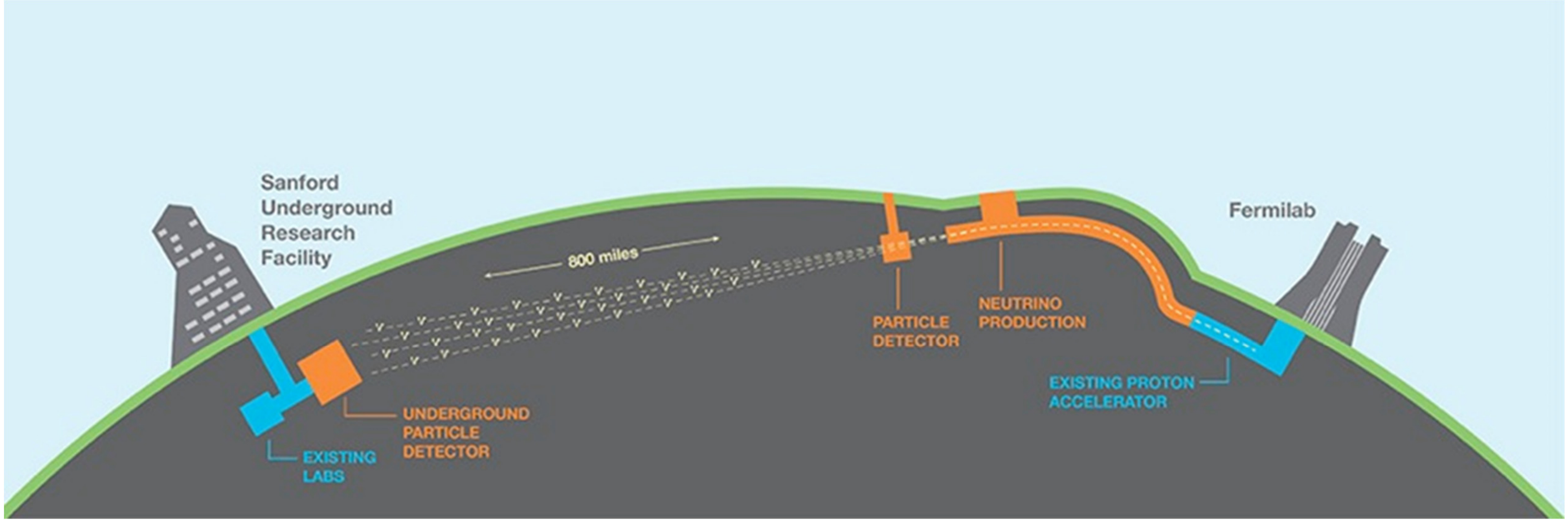
Slide courtesy of Tim Meyer, Fermilab

Example *Big Science*

Long-Baseline Neutrino Facility/ Deep Underground Neutrino Experiment (LBNF/DUNE)

The Basic Program…4 defining features

- A 1.2 MW (2.4 MW phase 2) wide-band neutrino beam
- Detector deep underground (1.5 km) 70kt liquid argon
- A long baseline (1300 km)
- Liquid Argon is next generation neutrino detector technology ….a lot more development needed to perfect



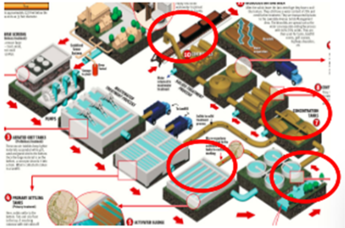
Slide courtesy of
Tim Meyer, Fermilab

Example *Environmental Applications*

Application: Waste Water/Sludge Treatment

Accelerator above is 3 stories tall!

- Electron beams create highly reactive species
- Demonstrated effective for:
  - Disinfection of municipal bio-solids
  - Destruction of organics, pharmaceuticals
- Yet, despite demonstrations ~no market penetration
- Why? Municipalities are conservative; don't finance R&D
  - High power, cost effective, industrial accelerators have not been available to deploy* e.g. * http://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Energy_Environment_Report_Final.pdf
  - Compact SRF accelerators can change this situation
- IARC is partnered with the Chicago Metropolitan Water Reclamation District (MWRD)
  - Operate largest treatment plant in the world
  - Identified multiple areas to evaluate EB
  - Bio-solids, cell lysis, destroy pharmaceuticals



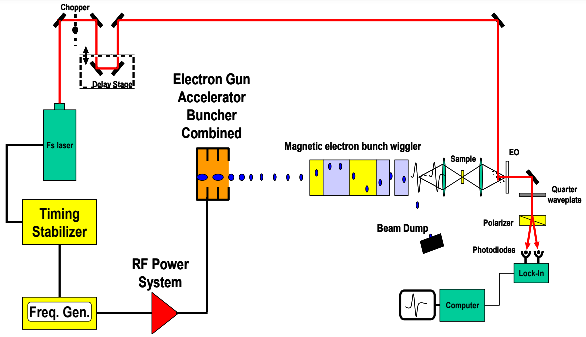
Fermilab

I'm getting my wish!

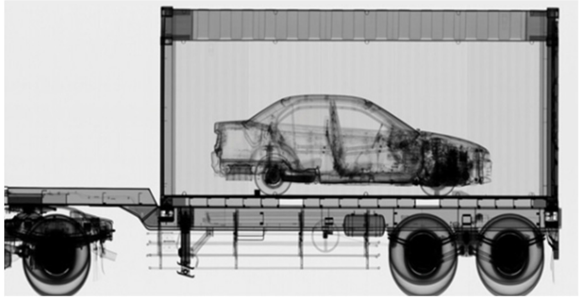
See for example, R. Kephart, B. Chase, I. Gonin, A. Grassellino, S. Kazakov, T. Khabiboulline, S. Nagaitsev, R. Pasquinelli, S. Posen, O. Pronitchev, A. Romanenko, V. Yakovlev (Fermi National Accelerator Laboratory), S. Biedron, S. Milton, N. Sipahi (Colorado State University), and S. Chattopadhyay and P. Piot (Northern Illinois University), 2015, "SRF, Compact Accelerators for Industry & Society," In: Proceedings of SRF2015, www.JACoW.org, paper FRBA03, 1467-1473.

Example *Security and Other Stand Off Applications*

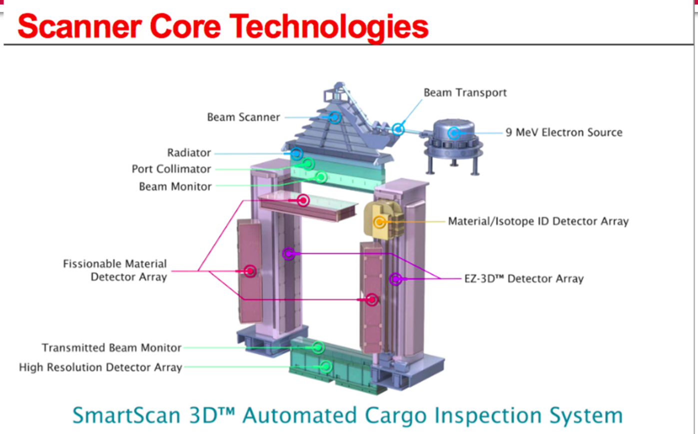
I got my wish!



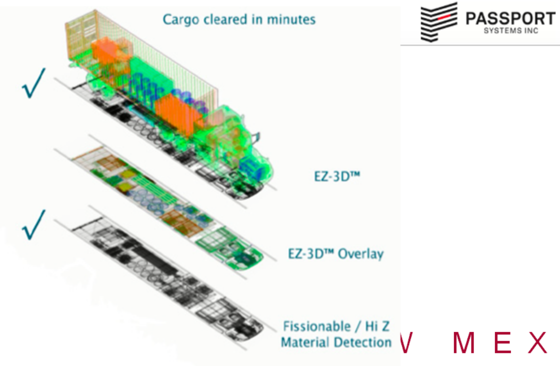
S.G. Biedron, J.W. Lewellen, S.V. Milton et al., 2007, "Compact, High-Power Electron Beam Based Terahertz Sources," Proceedings of the IEEE 95(8), 1666-1678.



Varian and Symmetry



Steve Korbly, Passport Systems



Container Inspection at Busan port (2002)

Container Inspection at Incheon port (2003)

Byung-Ho Choi

Example *Security Applications*

More research and development ongoing – From 2016 Department of Homeland Security – Domestic Nuclear Detection Office Call for Proposals

3. RTA-03: Development of Accelerators with Applications to Homeland Security

A longstanding technical Grand Challenge for the DNDO mission is the detection of nuclear threat materials even when shielded. The Transformational and Applied Research Directorate (TAR) within DNDO has been sponsored a range of research and development efforts that utilize active detection approaches (e.g., radiography, induced fission) to overcome this challenge. These applications require the use of a radiation source of penetrating particles capable of inspecting large cargo containers, conveyances or objects, and providing information in either the transmitted beam or from induced signatures on the presence of high atomic number or nuclear materials.

Historically, the requirements for development of these types of radiation sources have been driven by medical and industrial applications. Demand for Homeland Security applications is relatively small by comparison. Currently only a handful radiation sources can be used for Homeland Security applications because of such factors as cost, performance or required operational footprint. For example, sources used in non-intrusive inspection (NII) systems that are capable of achieving high performance have a trade-off of being large in size; alternatively, compact sources exist but achieve limited penetration performance. Therefore, there is a need for high performance, compact sources that enable NII and active interrogation (AI) systems that specifically support Homeland Security requirements.

Examples *Defense*

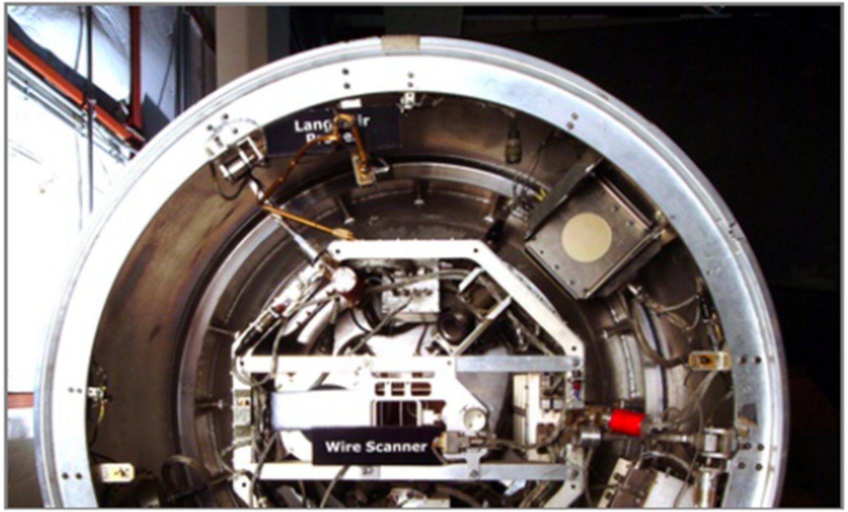
Free Electron Laser Thrust

- Advantages
  - Tunable wavelength for maritime propagation
  - Shipboard protection against asymmetric threat
  - No hazardous gases or chemicals
- Opportunities
  - All electric ship integration
  - Megawatt potential
- Challenges
  - Injectors and Cathodes
  - High Intensity Optical Components
  - Efficient wiggler

Courtesy Don Seeley and Nancy Wilson

Example *Defense*

- March 2018 - **“Directed energy is more than just big lasers,” said Michael Griffin Undersecretary for Defense for Science and Engineering. “That’s important. High-powered microwave approaches can affect an electronics kill. The same with the neutral particle beam systems we explored briefly in the 1990s”** for use in space-based anti-missile systems. Such weapons can be “useful in a variety of environments” and have the “advantage of being non-attributable,” meaning that it can be hard to pin an attack with a particle weapon on any particular culprit since it leaves no evidence behind of who or even what did the damage.

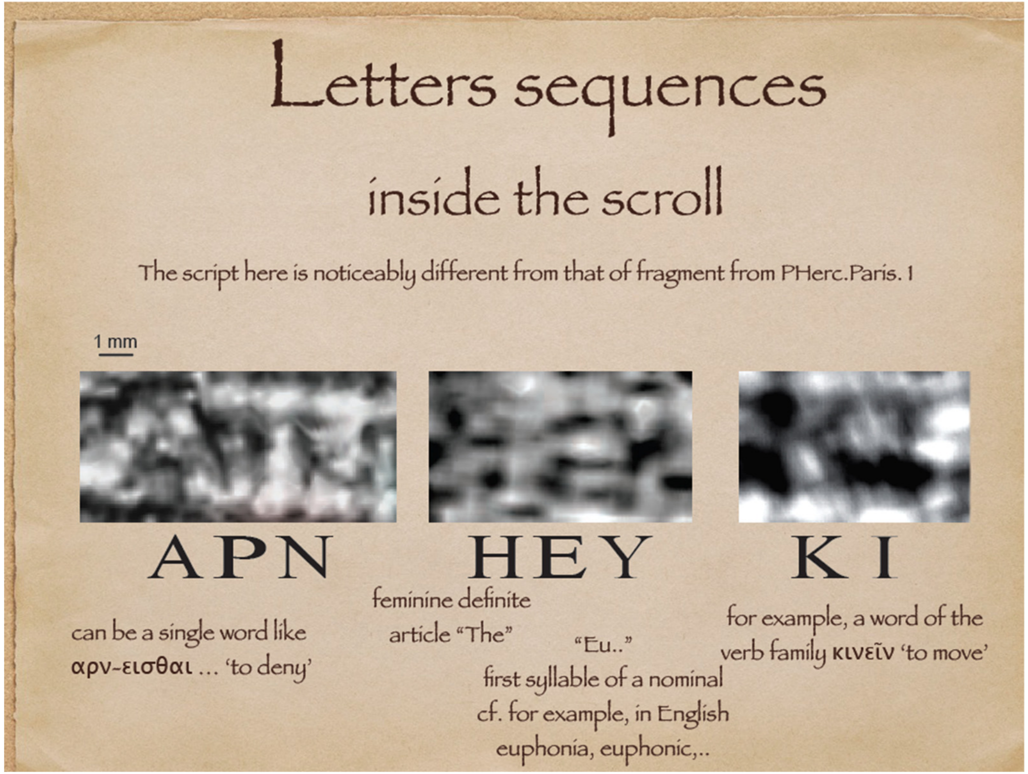


As part of the Beam Experiments Aboard Rocket project, this neutral particle beam accelerator was launched from White Sands in July 1989 to an altitude of 200 kilometers (124 miles), operated successfully in space in July, 1989. National Air and Space Museum Collection

Example *Humanity*

Revealing letters in rolled Herculaneum papyri by X-ray phase-contrast imaging

Nature Communications volume 6, Article number: 5895 (2015)



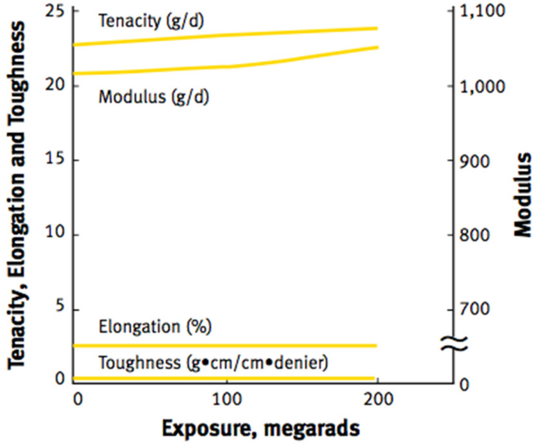
Slide courtesy of Vito Mocella

Example *Industry*

EFFECT OF ELECTRON RADIATION ON KEVLAR®

Electron radiation is not harmful to Kevlar®. In fact, filaments of Kevlar® 49 exposed to 200 megarads show a very slight increase in tenacity and modulus (Figure 2.10).

Figure 2.10 Effect of Electron Radiation on the Tenacity, Elongation, Modulus and Toughness of Filaments of Kevlar® 49.



A G.E. resonant transformer is used at 0.5 milliamps and 2 megavolts to generate 1 megarad every 13.4 sec. The filament distance from the radiation source is 30 cm [11.8 in.]. The filament is wrapped in aluminum foil and kept over dry ice.

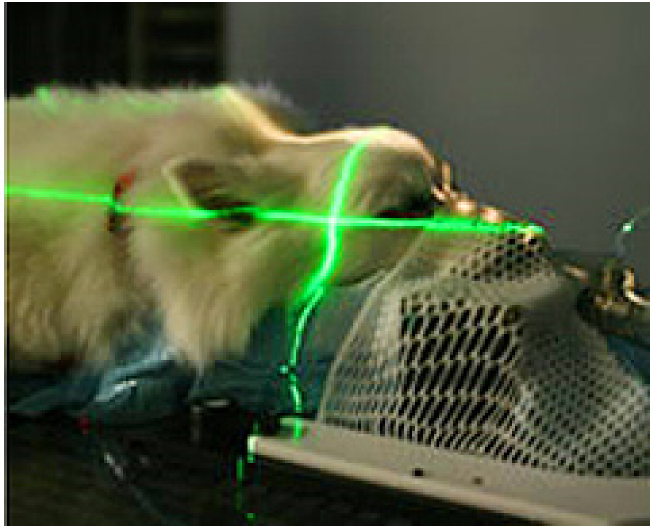
Biedron/Infodelity™ discussions with DuPont

Example *Medicine*

Companion Animal Radiotherapy at CSU

- CSU Animal Cancer Center is #1 in the world
- Leads in general cancer care (surgery, chemotherapy)
- Leads in radiation oncology, and houses a top program in radiology

Courtesy Jac Nickoloff



Example *Medicine*
Advantages of Large vs Small Animal Cancer Models

- Naturally occurring tumors
- Functional immune systems (combined immuno-radiotherapy)
- Similar treatment responses in large animals and humans
- Superior tumor imaging
- Superior model for surgery, chemo- and radiotherapy
- Dogs 85% genetically identical to humans
- Breeds offer unique genetic tools
- Tissue biopsies can be performed more frequently

Courtesy Jac Nickoloff

"It's not just about doing more research…it's about doing better research"

Dr. Andrew Thorburn
Univ of Colorado Cancer Center

Institute of Medicine Workshop (2015)
"Role of Clinical Studies for Pets with Naturally Occurring Tumors in Translational Research"
PBS Special: The Answer to Cancer May Be Walking Beside Us

helped create data on α/β ratios that are still used by both veterinary and human radiation oncologists (181-191). But it was Gillette's work using spontaneous tumors to evaluate radiation biological principles that elevated the value of the naturally occurring tumor model. Therapeutic gain in the context of radiotherapy was based on the concept that to improve treatment outcome (tumor control) while maintaining quality of life (limited late effects), both tumor control and late effects needed to be evaluated and compared between different treatments. Tumor control without complications is the ultimate exploitation of differences in DNA repair characteristics between tumor cells and late responding normal tissues. Gillette was able to prove this principle because of the flexibility for trial design in the naturally occurring tumor model in veterinary patients. He first conducted a trial in which dogs with naturally occurring squamous cell carcinomas of the oral cavity were randomized to receive different total doses of fractionated radiation. The patients were followed through their lifetime for tumor control and late radiation effects. He used this information to determine the dose that provided the best tumor control with least complications, and these radiation dose groups were also tested with hyperthermia treatments (192,193). These studies helped inform the design of clinical trials in human patients.

These early clinical studies of normal tissue and tumor

Courtesy Jac Nickoloff

These Vets and the Cancer researchers would like to see a He and Carbon facility in the U.S. for similar research with companion animals with spontaneous occurring cancers.

"Dead cells don't mutate!" – Jac's favorite line

Example Medicine

- The video you are about to see speaks for itself
- https://drive.google.com/file/d/0BzwnSZnaqjRZWUQ4V1BVcFcyeUU/view

- **Video courtesy of Fermilab**

Conclusions

What's next

- Like I said earlier, we are different than most as we like to build things that are game changing, needed and useful.
- This means we are continually adding to our long list of specialized skills.
- So what's next?

What’s next?

- AI
- More reliance on high-performance computing
- Materials
- Etc.

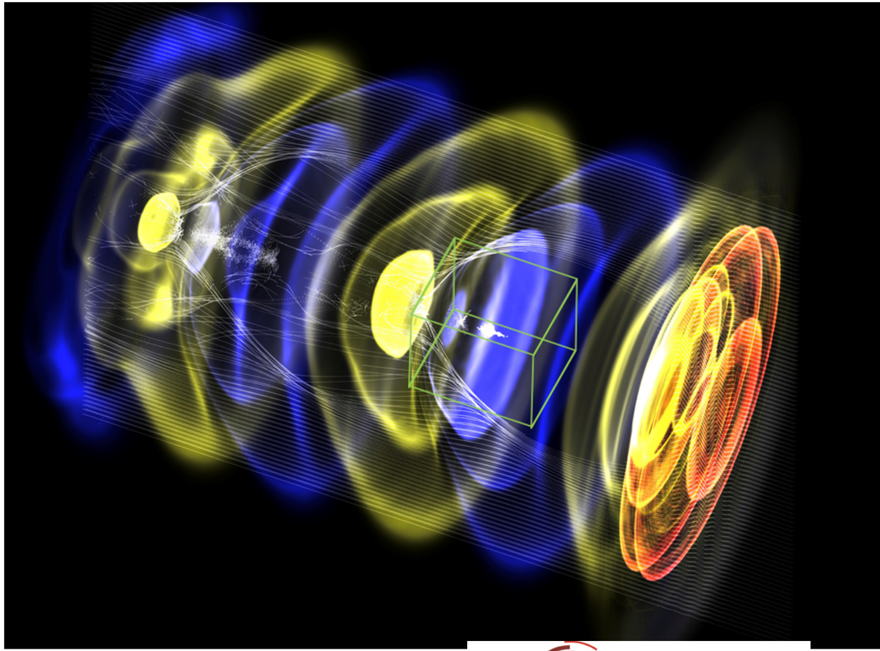
What's next? Example
Plasma-based advanced colliders need extreme computing

Code to include advanced algorithms such as boosted frame, adaptive mesh refinement, …

Need to simulate ensembles of chains of tens of stages for collider design: but simulating 1 stage now takes days in 3-D.

➔ Development of new code WarpX as part of DOE Exascale Project Applications

First WarpX simulation of laser-driven plasma accelerator with mesh refinement patch around accelerated beam. Simulation performed on NERSC



Courtesy of Jean-Luc Vay - LBL

What's next? Example – Computing for AI
Argonne Leadership Computing Facility (ALCF)

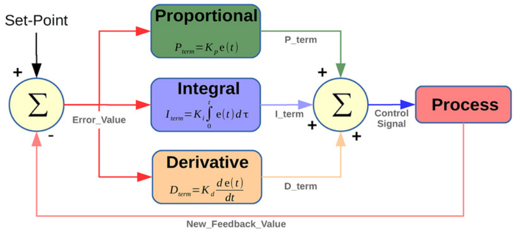
Slide content courtesy of B. Cerny and M. Papka, ALCF Argonne

- **Our team already has access to THETA at ALCF for highly-parallelized simulations, AI-based model development, and control of large machines and sub-systems.**
- Supported by the U.S. Department of Energy's (DOE) Office of Science, Advanced Scientific Computing Research (ASCR) program, the ALCF is one of two DOE Leadership Computing Facilities in the nation dedicated to open science.
- ALCF is a DOE Office of Science User Facility that helps accelerate the pace of discovery and innovation by providing supercomputing resources that are 10 to 100 times more powerful than systems typically used for scientific research.
- The use of computing centers will only continue to increase for applications of and to particle accelerators

What's next? Example
Accelerators as Intelligent Systems

- I've been fortunate enough to work on all sorts of controls, including those for laser and particle accelerator systems, general aviation aircraft for security applications, for a directed energy demonstrator for a weapons system and since 2002 I've been interested in intelligent control. Why? We need to make machines better so we needed AI as a tool. Since 2004 we have worked to demonstrate intelligent techniques as applied to accelerators!
  - Learned neutral network models (from simulation or measurements) to speed up computational time and increase accuracy to real system. The models can be updated with additional measured/collected data. Have found better than codes/models based on first principles only.
  - Model Predictive Control (Prediction + Planning)
  - Model and Policy Learning
  - Image Processing

See reference slides and talk by colleague Auralee Edelen earlier today



THIS IS ONLY GOING TO BE MORE A PART OF OUR FIELD

Closing thoughts

- We are people who use their unique and diverse skills sets to do truly exceptional actions.
- We care deeply about the end-uses of our machines and peripherals.
- Maybe a little challenge for 2018 and every year thereafter - ***If I had one wish for the community is that if we could each reach out to just a few more partners and/or users every year, we could help the planet, our knowledge, the lives of humans (even animals and plants!), etc… even more.***

Questions?

Thanks community for your attention, ongoing collaboration, support, and ENDLESS opportunities!

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