Illinois Accelerator Research Center (IARC)

What is it and why should you care?

Bob Kephart
IARC: What is it?

• A partnership between Department of Energy and the State of Illinois

To enable Fermilab to work more closely with industry and university partners on Accelerator Technology Development and Accelerator Education

To develop new accelerator technology based products and high tech industries in the U.S. (especially Illinois)
Why do this? Growing use of Accelerators

• About 30,000 accelerators are in use in the U.S.
  
  Sales > $2 B in U.S. and growing, touches $500B in products

• Health and environment: medical accelerators for cancer treatment, medical isotopes, electron microscopes, etc.

• Digital electronics: all computers, cell phones, televisions, etc. use accelerators to implant ions to make IC’s

• Industrial fabrication: Electron beam welders used for auto fuel injectors, transmissions, to harden gears, & in aircraft construction

• Industrial Processes: Radial tires are cured and your car under hood wiring is made heat resistant with accelerators

• Sterilization: medical supplies & instruments

• Food industry: shrink wrap on your turkey, preservation of army field rations & Omaha steaks, irradiation of seeds to induce new variants, sterilize bee hives (to prevent colony collapse disorder)
Many future uses of accelerators are envisioned

- **Preservation of the Environment**
  - **Coal**: removal of NOx and SOx from flue gas ($500 M/yr business?)
  - **Water**: treatment of drinking water to remove pesticides and pharmaceuticals
  - **Water**: sterilization of municipal waste into Nitrogen and Phosphorus rich fertilizers vs pollution
  - **Nuclear**: Destruction of long-lived nuclear waste via ADS
  - **Oil and Gas**: Conversion of natural gas to liquid hydrocarbons (fracking ➞ estimated $500 M/yr of natural gas flamed at well heads ~ 2015-17)

- **New Sources of sustainable Energy**
  - **Nuclear**: Accelerator Driven systems that burn Thorium and other new fissile materials (Safer, cleaner, more abundant fuels)

- **Improved cancer treatment** (e.g. Carbon ions)

- **Medical isotopes** (Created locally at hospitals, without reactors, highly enriched uranium, and nuclear chemistry)

- **New industrial process applications** (many!)
What is the Problem?

• New applications of accelerator technology seem to die for one of three reasons

  Feasibility not proven: Inadequate resources: (financial, personnel, infrastructure) in industry, universities, or labs to demonstrate the basic feasibility of an idea

  During transition from small scale technology demonstration to a commercial product (may require large investments & infrastructure)

  Lack of acceptance of the new technology by potential customers (ignorance or prejudice) that is cured only by large scale demonstrations that lower perceived risk

• IARC is intended to help fill these gaps by providing access to accelerator experts and laboratory infrastructure
IARC: The Opportunity for Fermilab

• Opportunity to put substance behind the claim that HEP is the developer/steward of accelerator technology within the Office of Science

• Opportunity to function as a center for accelerator based projects (e.g. Project X, NGLS) in the Office of Science and to partner with industry and labs (e.g. ANL) on new accelerator applications

• Opportunity for Fermilab to become a National center for accelerator education

• Opportunity to establish additional funding sources outside HEP or with industry to develop intellectual property (patents, royalties)

• Opportunity to develop technologies that benefit society bringing recognition to the DOE SC laboratories and to Fermilab
IARC: The Opportunity for Industry

• Fermilab has:
  → a world-leading accelerator engineering and scientific staff that have the potential to make an impact beyond the field of high-energy physics. (with addition resources at nearby ANL)
  
  → core capabilities and infrastructure that are unique, and that could potentially be used in application beyond the field of high-energy physics.
  
  → And will have the IARC physical plant in FY15

• Industry can leverage these assets to create new accelerator based products and capabilities
IARC: The Opportunity for Universities

• Universities can:
  → Use their engineering and accelerator scientific staff to partner with industry to develop accelerator ideas into new products or services
  → Use their engineering and accelerator scientific staff to leverage the IARC infrastructure and FNAL staff to create new accelerator based products and capabilities (ie to enable your entrepreneurs)
  → Use IARC to support their existing Accelerator Education programs or partner with Fermilab to create a larger national center for accelerator education
IARC: Physical Plant

- The State of Illinois, Department of Commerce and Economic Opportunity (DCEO) provided a $20 M grant for the construction of a new building (we have all the funds).

- DOE/OHEP committed to $13 M direct contribution and a refurbished $38 M heavy assembly building at Fermilab.

- Together these will create a $70 M complex to enable the IARC mission.

- IARC = New state funded Office, Technical, and Education (OTE) building + refurbished CDF heavy assembly building (HAB) + infrastructure to enable the IARC program.
IARC OTE Building (State funded)

- 48,000 gross square footage
- 23,000 SF of Office Space (145 offices); 3,700 SF Light Tech Space
- 3,900 SF New Lecture Hall (175 seats); 900 SF Meeting Rooms
- New 250 car parking lot
Status of Physical Plant

- State funded Office Technical & Education (OTE) building
  - Conceptual design complete (DOE funded)
  - Site prep/new utilities complete (DOE funded)
  - Engineering design complete (State funded)
  - Construction contract awarded (> $17 million, state funded)
  - Construction in progress (pictures)
  - 1st occupancy for outfitting in ~ Mar 2014

- FESS staff funded for OTE oversight (DOE funded)

- $2 M in FY13 VOIP, and contingency (DOE funded)

- OTE is ballistic and funding in place through the point where we have to outfit it with partitions, conference rooms, furniture, video equipment, etc
IARC OTE Building (State funded)
IARC construction Status

- State funded building Oct 11, 2012
IARC construction Status

- State funded building Jan 28, 2013
IARC construction Status

- State funded building Dec, 2012
- Sheathing supports, pouring floors, roof, etc
Heavy Assembly Building (CDF)

- Heavy assembly building used for the construction of the CDF experiment at the Tevatron
- 42,000 sq ft: 50 T crane; deep pit for radiation shielding of accelerators; cryogenic, electrical and cooling water infrastructure; IT networks; 40 offices, etc
- More than a dozen industries have expressed interest, the deep pit area is particularly interesting to them
Heavy Assembly Building (HAB) Status

• CDF experimental equipment removal (big job!)
  → Demolition & Decontamination (D&D): in progress, but funding limited
  → Focus in FY12 was on Assembly Hall to prepare for OTE construction
  → Removal of Collision hall equipment required for future Kaon experiment (ORKA)
  → Removal of Central Detector would be very disruptive of IARC program
  → FY13 budget provides $1.5 M of D&D funds in FY13 and another $1 M in FY14

• HAB: Great building but infrastructure is >25 yrs old
  → A number of life safety and ADA issues (fire protection, exits, pipes in stairwells…)
  → HVAC, water systems, crane, pumps, etc must be renewed/refurbished
  → Building rehab will be started via FY13 GPP Project $3.1 M (est total = $9 M)

• OHEP will provide funds for Accel stewardship in FY14 but expect…
  Start of the full IARC program will be determined by date when the Heavy Assembly Building is refurbished and operational.

• Meanwhile several IARC initiatives will bring equipment in ~ 1 year
Geometry and Sequences

Nova Test Device

Shield door
Approach: Creating a successful IARC Program

- **Listen to Industry** (SPAFOA meetings, meetings with heads of accelerator businesses who will be our customers, workshop planned for spring 2013)

- **Use Industry Experts**
  Hired consultant: Bob Hamm, former head Varian Medical R&D and owned his own accelerator company for a decade

- **Use Business Experts**
  Chicago Booth business school used IARC business plan as an example for their class (closeout and recommendations Oct 10)
  Recommended Hire an IARC business manager!

- **Learn from Others**
  NREL facility (ESIF) is very similar lab-industry center for development of renewable energy, talked to their project manager, joint approach to DOE on the nature and “rules” for such a facility. Trip to NREL is planned.

- **Work closely with DOE**
  Discussions with Fermi site office (IARC as a user facility… What are the rules?)
  Mike Weiss and Mark Bollinger have been very supportive
Creating the IARC Business model

Key Partners
- Companies
- Universities
- Entrepreneurs
- Intrapreneurs
- Other labs

Key Resources
- Lab Staff
- Infrastructure

Value Propositions
- What value do we offer?
- What is the ROI?
- Why should companies want to work at IARC?

Customer Relationships

Channels
- How do we reach customers/stakeholders

Customer Segments
- Who are our key customers?

Key Activities

Cost Structure

Revenue Streams

Approach used by very successful high tech company FNAL works with
Who is interested in using IARC?

- Even in the absence of an official announcements, many partners have contacted me about working at IARC (yellow = IARC EOI)

  - ANL: education, SBIR, joint work with industry
  - AES: SBIR’s, possible test site for DHS accelerator
  - Euclid: SBIR/STTR including PX SRF cavities
  - LLNL: test accelerators funded by DTRA and/or DARPA
  - **Muons Inc**: SBIR/STTR’s including magnetron RF power
  - National Instr: accelerator instrumentation and controls
  - **Niowave**: possible accelerator test site
  - NIU: Source Development, SBIR/STTR, new RF sources, education
  - Omega-P: SBIR/STTR idea relevant to Project X
  - **PAVAC**: Flue gas test accelerator, Several SRF based SBIR ideas
  - Radiabeam: SBIR, access to accelerator experts, project fabrication
  - Harvard Medical: Moly 99 and med isotopes
  - Tandell systems: accelerator reliability, integration, and simulation
  - UC Irvine: Water treatment with accelerators
  - U of Wisc & others: Carbon ion accelerator
  - Varian Medical: test cell for medical machines, water treatment?

- **Recurrent theme**: funding, clear program rules, IP protection, predictable schedule and processes, access to deep pit & infra to test accelerators!
Conclusions

• Steady Progress on the IARC physical plant. 1st availability in FY15 for projects

• Anticipate OHEP Accelerator Stewardship funds in FY14 to hire staff and prepare infrastructure

• Working on IARC business model, DOE user facility designation, NDA, ORTA office, etc all with limited manpower

• Important that we define the rules for Industry/users!

• Even without a “formal” IARC program announcement there is lots of interest from Industry

• Unique opportunity for Industry and Universities!

See Web site IARC.fnal.gov
These Accelerators have transformed our understanding of the nature of the universe we live in but represent only 1% of all accelerators in use.
Industrial Accelerators are already big business

Industrial Accelerator Business*

<table>
<thead>
<tr>
<th>Industrial Application</th>
<th>Systems thru 2008</th>
<th>Systems sold/yr</th>
<th>Sales/yr ($)</th>
<th>System price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Implantation</td>
<td>~10,000</td>
<td>500</td>
<td>1,500</td>
<td>1.5 – 5.0</td>
</tr>
<tr>
<td>Electron beam modifications</td>
<td>~7,000</td>
<td>100</td>
<td>150</td>
<td>0.5 – 2.5</td>
</tr>
<tr>
<td>Electron beam &amp; X-ray irradiators</td>
<td>~2,000</td>
<td>75</td>
<td>130</td>
<td>0.2 – 8.0</td>
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<tr>
<td>Ion beam analysis (including AMS)</td>
<td>~200</td>
<td>25</td>
<td>30</td>
<td>0.4 – 1.5</td>
</tr>
<tr>
<td>Radioisotope production (including PET)</td>
<td>~600</td>
<td>50</td>
<td>70</td>
<td>1.0 – 30</td>
</tr>
<tr>
<td>High energy x-ray inspection</td>
<td>~750</td>
<td>100</td>
<td>70</td>
<td>0.3 – 2.0</td>
</tr>
<tr>
<td>Neutron generators (including sealed tubes)</td>
<td>~2,000</td>
<td>50</td>
<td>30</td>
<td>0.1 – 3.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22,550</strong></td>
<td><strong>900</strong></td>
<td><strong>1880</strong></td>
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</tr>
</tbody>
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*New preliminary numbers from book chapters.

**Total sales increasing almost 10% per year.**

All the products that are processed, treated or inspected by particle beams have an annual value exceeding US$500B.
Electron Beam Welding and Machining
  e.g. PAVAC Energy Corp.
  Deep welds, low weld shrinkage, dissimilar or refractory metals, etc
  Widely used in automotive and aerospace industry
  Drill 3000 holes/sec!

Electron Beam Irradiation
  (e.g. improving heat resistance of coatings wire and Cable, crosslinking polymers (tires!), curing paint and inks, etc)
  1500 dedicated facilities worldwide
Accelerators for Industrial Processes
Ion Implantation

Semiconductors
- CMOS transistor fab for essentially all IC devices.
- CCD & CMOS imagers for cell phones & digital cameras
- Cleaving silicon for producing photovoltaic solar cells

Metals
- Harden cutting tools
- Reducing friction in metal parts
- Biomaterials for implants

Ceramics & glasses
- Harden surfaces
- Modify optics

All digital electronics now dependent on ion implantation. Typical IC has 25-30 implants during fabrication.

$1.5 B in Accelerator sales each yr
More than two billion tons of cargo pass through U.S. ports and waterways annually. Many ports now screen cargo for weapons or nuclear materials with gamma-ray scanners, based on radioactive isotopes such as cobalt-60. However, high-energy X-rays generated by particle accelerators can make this process faster, cheaper, and safer.
Accelerators in Medicine

Electron accelerator
Based X-Ray facility
For cancer treatment
(Varian Medical systems)

Rhodotron, commercial
electron beam accelerator used
For sterilization of medical devices
Loma Linda Proton Therapy and Treatment Center

World’s 1\textsuperscript{st} proton accelerator built specifically for proton therapy

Designed and built at Fermilab

Technology Demonstration → Industry
Accelerators in Medicine
Carbon Ion’s: An opportunity!

- > 5000 electron linacs are used to treat over 10,000,000 cancer patients each year, Proton therapy is becoming more popular because it is more effective at destroying tumor vs benign tissues.
- Medical Accelerators based on Carbon Ions have the potential to deliver even larger doses to tumors with high Relative Biological Effect (RBE) at precisely controlled locations.
Accelerators for the Medical Isotopes

- “Turn key” cyclotrons produced by industry are routinely used to produce radio-pharmacy isotopes for molecular imaging ($^{18}$F, $^{11}$CO$_2$, $^{11}$CH$_4$, $^{13}$N, $^{15}$O, etc)
- PET = Positron Emission Tomography
Great ideas and capability is the starting point
Successful fielding of accelerator products depends on products with reliable designs, support services, training programs, demonstrated cost feasibility and acceptance by the potential customer base!
Accelerators for the Environment

- Electron accelerators are effective for
  Purifying drinking water (destroying pesticides, organics, pharmaceuticals, etc)
  Treating industrial/municipal waste water
  Disinfecting sewage sludge
  Removal of Nitrogen and Sulfur oxides from flue gases from coal-fired power plants

- However, despite many R&D demonstrations and pilot plants the penetration of these promising technologies into the U.S. market is very limited

- Why?
  Lack of funding for follow on projects and full product development
  Potential users are conservative and need turn-key solutions
Key to use of Nuclear Energy for carbon free energy production is reduction of radio-toxicity and lifetime of nuclear waste

Accelerator based transmutation when combined with geological disposal has the potential to make nuclear power acceptable to society

ADS can also potentially make use of non-fissile fuels like Thorium

Superconducting RF Linac’s can provide high beam power & efficiency
Other applications

• There are many other accelerator applications that I cannot cover in this talk due to time constraints

• Examples:

  Synchrotron light sources for medical and materials studies:
  Protein structure, DNA research, etc (large & growing demand, increasingly important for commercial drug development)
  Food preservation (Need public acceptance!)
  Accelerator based radiography for large industrial castings, rocket motors, munitions, large castings, etc
  Ion beam based materials analysis (many techniques)
  Accelerator based Mass Spectrometry
  Heavy Ion Fusion, Inertial fusion accelerators (e.g. neutral beam injectors for ITER) for energy production
  Defense (e.g. FEL based ship board missile defense systems)

• e.g see also “Industrial Accelerators & Their Applications” by Robert Hamm
Other accelerator applications

- Medical waste sterilization
- Sterilization of bee hives to prevent Colony Collapse Disorder
- Mo$^{100}$ → Tc$^{99}$ (proton beams)
- Hard rock tunneling with e beams