Technology at Fermilab and How to Access It

Richard A. Carrigan, Jr.
Fermilab

I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon. Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in and had not contributed to wave mechanics or the theory of electrons in solids. It so happened that inventors of transistors were versed in and contributed to the quantum theory of solids.

One might ask whether basic circuits in computers might have been found by people who wanted to build computers. As it happens, they were discovered in the '30s by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics.

One might ask whether there would be nuclear power because people wanted new power sources or whether the urge to have new power would have led to the discovery of the nucleus. Perhaps - only it didn't happen that way, and there were the Curies and Rutherford and Fermi and a few others.

One might ask whether an electronics industry could exist without the previous discovery of electrons by people like Thomson and H.A. Lorentz. Again, it didn't happen that way.

One might ask whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.

Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz who emphasized the beauty of physics and who based his work on the theoretical considerations of Maxwell. I think there is hardly any example of 20th century innovation which is not indebted in this way to basic scientific thought.

- Henrik Casimir, of N.V. Philips,
at the Symposium on Technology and World Trade (1966)

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Technology at Fermilab - what is it and how can it be used?

To answer these questions it is necessary to know a little more about Fermilab. Fermilab is home to the most powerful accelerator complex in the world. That complex uses superconducting magnets on an industrial scale for the first time. A sophisticated system has been built to store, accelerate, and collide antimatter with ordinary matter. All of this complex is used to study the most fundamental substructures of matter, the quarks and leptons we are all made of. The Laboratory is operated by the Universities Research Association, Inc., a consortium of 56 universities, for the United States Department of Energy. More than one hundred universities participate in the research program including many institutions from overseas.

Ninety-five per cent of the work done at Fermilab is basic research directly applied to the single mission of exploring the fundamental nature of matter. On the other hand, the track record of this area of basic research, the study of the roots of nature, has been astounding. On the facing page is the famous quotation due to H.G.B. Casimir, a well-known physicist and Director of the Research Laboratories of N.V. Philips in Holland. Casimir's point is that nearly all of what we now think of as high technology came out of the same line of scientific investigation carried out at Fermilab.

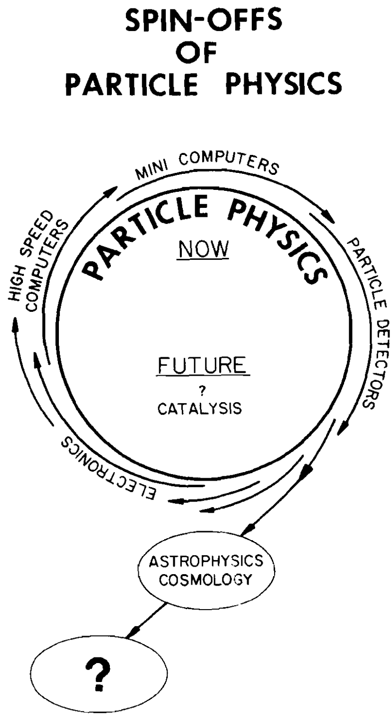

Figure 1

Spin-offs of particle physics

Figure 1 illustrates how applications flow out of a science like particle physics. There are at least three different ways:

One is that the physics itself has been turned directly to some new application. For example, the transistor and the laser came directly out of developments in atomic physics.

Another way science impacts on other fields is through its effect on associated sciences that may then later develop other applications.

Finally, there are the classical spin-offs - technology developed in the process of doing the science. Spin-offs from particle physics have included developments related to computer circuits, high-speed computing, and particle detectors for medicine.

Now for particle physics there is currently no direct application of that science. For the future, there are some possibilities. More on that in a moment. As far as impacts on other sciences, particle physics has had a profound influence on astrophysics and cosmology. In the last decade there has been a growing recognition of the fact that the birth of the Universe, the big bang, was strongly influenced by the laws of particle physics. The field has also had an important impact on accelerator science. In fact, much of the original interest in accelerators came out of investigations related to particle physics.

Materials science is another area where fundamental particles are being used as probes of the properties of solids. Muon spin resonance, discovered in the mid-1950s by Leon Lederman, Fermilab's Director, is now being used as a tool for solid-state material characterization.

In 1985, at the Industrial Affiliates annual meeting, we set up a Roundtable to speculate on the possibilities of applications for particle physics. The publication has taken some time to produce in part because one panelist was wrestling with the question of mining claims for quarks. At present, the best shot for a real application seems to be the possibility of negative muons catalyzing hydrogen fusion, so-called cryo-catalysis. Useful cryo-catalysis is very speculative but not completely ruled out at this point.

Another science at Fermilab also illustrates this flow of applications. This is accelerator science. Accelerator science shows many spin-offs. In the case of Fermilab, applied superconductivity is an example. In addition, accelerators have had an enormous impact both on particle physics and, of course, nuclear physics and material research. Nowadays many materials scientists rely on synchrotron radiation. The devices look very much like particle physics accelerators built 25 years ago. The number of direct applications of accelerators is enormous. The announcement of the 9th Conference on Applications of Accelerators at North Texas State in November of 1986 lists hundreds of talks in 20 different application areas. Just at Fermilab there are two different medical applications. X-ray machines are actually accelerators. The possibilities go on and on and include such

SPIN-OFFS OF ACCELERATOR PHYSICS

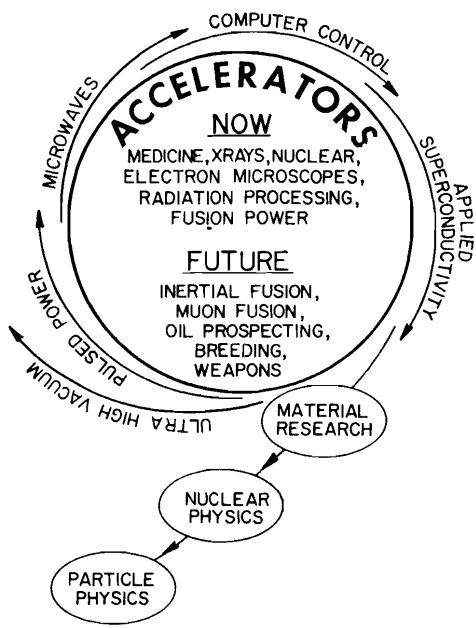

Figure 2

Spin-offs of accelerator physics

interesting topics as pellet fusion. Some of the applications listed as future possibilities in the spin-off diagram (Fig. 2) are now being actively investigated. Several of my colleagues have objected to having weapons on the diagram. However, this possibility has been extensively discussed in the popular press and can hardly be ignored.

What are the technologies that are available at Fermilab? Some of these have already been mentioned. Fermilab is a world center for accelerator science. This expertise goes far beyond producing mere TEVATRONS and colliding-beam facilities. After all, Fermilab has several Cockcroft-Waltons, a powerful Linac, two storage rings, and three circular accelerators. An example of how this technology is being applied is the proton accelerator for medical therapy. This project, sometimes called PAM, is headed by Phil Livdahl, the Deputy Director at Fermilab. TEVATRON technology will be used to build a hospital-scale accelerator with an energy of 250 MeV for Loma Linda University Medical Center in Southern California. Recently, the State of Illinois has funded the establishment of a Fermilab center to foster commercialization of that technology.

Another area already touched on is superconductivity and cryogenics. A good example is the development of the superconducting cable for the TEVATRON. The cable has now been applied to a wide range of applications and more are in the future. Wire based on TEVATRON technology has been used for a wide range of research magnets and is being used in accelerators in Germany and the U.S.S.R. A significant impact of TEVATRON wire development was the scale of the effort. More than 650 miles of niobium-titanium cable was fabricated. Wire was not available on anything like this scale when Fermilab started the TEVATRON. In an important sense, TEVATRON wire established a standard. A wire vendor could adopt a definitive commercial-scale approach without having to specially tailor the wire for each magnet. To make the cable, Fermilab had to cycle the raw material through a long chain of vendors that handled individual steps in fabrication. These included assembling billets of copper interspersed with thousands of niobium-titanium rods and extruding the billets to produce wire with micron-diameter fibers interleaved in a copper matrix. In other steps, the wire was assembled into a multi-strand cable. Fermilab provided a strong stimulation to the wire industry to manufacture the wire. Subsequently, companies such as Intermagnetics General Corporation, New England Electric, AirCo, and Teledyne-Wah Chang developed improved superconducting alloys, wire, and cable. The availability of wire on an industrial scale has led to the modern billion-dollar industry of magnetic resonance imaging systems for medicine.

Obviously, the TEVATRON is an important sandbox for the Superconducting Super Collider, or SSC, the proposed project to build a superconducting accelerator

20 times as large as the TEVATRON. Several years ago at the Affiliates annual meeting, we held a Roundtable on industrial participation in large science projects. What that Roundtable principally addressed was the question of participation in the SSC. That meeting offered the first forum for discussions about the kinds of technology that would be needed for that very large project.

There are also a number of useful developments in the computer field at Fermilab. Many practical and scientific problems have been identified that require

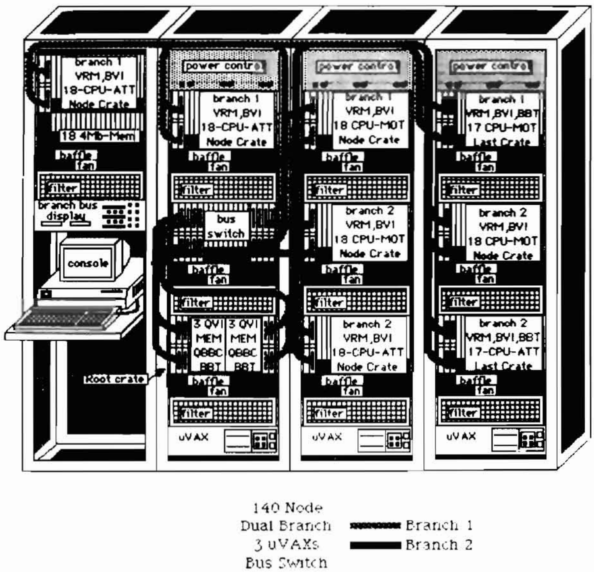

Figure 3

Computer-generated picture of the Advanced Computer Program (ACP)

computers hundreds of times more powerful than existing facilities. The most promising approach is the use of advanced computers with parallel processors. At Fermilab this solution has been attacked by devising a loosely parallel arrangement of hundreds of 32-bit microprocessors. A 140-node version of this device is shown in Fig. 3 above. Software has been developed that can manage these micro-processor farms on a device-independent basis so that new developments and different processors can be incorporated. This type of advanced computer is useful for analyzing thousands of events that must be handled in the same way but are only loosely related. Examples include inventory control and airline reservation systems. For certain problems a $100,000 Fermilab system is nearly as powerful as a CRAY XMP. The Fermilab device was recently awarded a 1986 IR-100 prize. Boards for the Fermilab ACP are being produced by Omnibyte, an Affiliate.

Another area where a great deal of technology has been developed and transferred out of the Laboratory is fast electronics. For many years Fermilab has been an important contributor to the development of the CAMAC modular electronic system. More recently Fermilab has been one of the keystones in the development of the new FASTBUS system. FASTBUS is a standard parallel bus system for high-speed data acquisition and processing. It has been designed for data gathering in the high-energy and nuclear physics research areas. The system is modular so that flexible arrays of different functions (timing, analogue signals, etc.) can be collected. Products developed at Fermilab are now produced by several companies including Kinetic Systems, an Affiliate.

The Fermilab accelerator complex is also a wonderful example of systems of distributed computer control. The control system for the TEVATRON incorporates more than 700 microprocessors. Control for complex refrigerators such as those on the TEVATRON are extremely non-linear. Much of the added complexity in TEVATRON control is due to the cryogenic system. The independent satellite refrigerators must have speed of control, and conversely the ability to control cycles with very long time constants, as well as good quench recovery. A flexible, modular control system has been developed at Fermilab that can handle unmanned remote locations and permit partly autonomous operation of the individual refrigerators. This has required the development of a refrigerator control philosophy as well as a wide variety of special CAMAC units. Much of this system can be applied to any large helium refrigeration system. No such multifunction cryogenic control system existed prior to the TEVATRON.

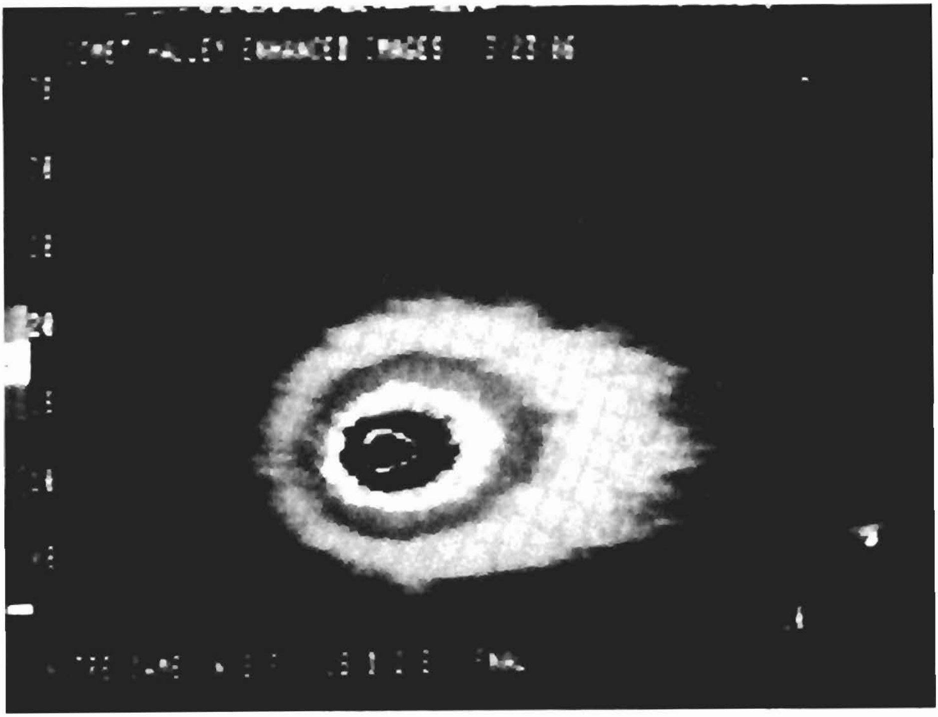

Figure 4

Halley's comet seen with the Fermilab-Notre Dame Video Data Acquisition System

Yet another area is instrumentation. An interesting example is a video imaging system developed jointly with Notre Dame University. The system was originally designed to record and store the extremely faint and fast light signals from particle tracks in scintillators. A very-high-speed data collection and analysis computer can process this information to average it and remove noise. In essence the system can take and analyze flash video pictures. The system was used recently to take real-time video tapes of Halley's comet (Fig. 4) looking for fluctuations in the comet tail in a period of minutes. This system received a 1986 IR-100 Award.

Now these are generally big, broad areas. Sometimes little individual developments can be fun and quite interesting to people involved in product development.

It turns out that a few of them are actually fairly big. The photograph below shows a technique that was used extensively in the construction of the TEVATRON magnets. I call it "laminated tooling." Basically the idea is to take what used to be magnet laminations, turn them inside out, and use them to actually form the magnet.

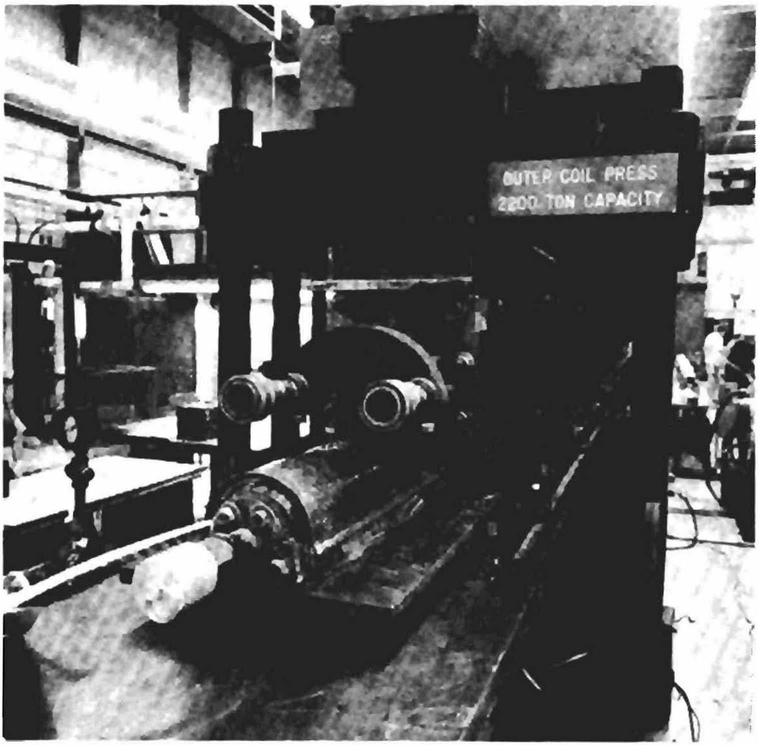

Figure 5

Laminated tooling

One advantage of looking at technology at Fermilab is that it is an open laboratory. I know that many industries would like to take a look at how their competitors are building things. Fermilab offers an opportunity to peek in and see how someone else is doing something, even if you know how to do it better.

Another neat piece of technology is a recent IR-100 winner. This is a wire-position transducer to accurately measure the position of several widely-spaced objects relative to a stretched wire. The idea is relatively old: you take a wire with an AC current on it and run it through some magnetic sensors. Fermilab physicist Hans Jöstlein recognized that modern circuitry made this concept much more feasible than it had been so that sensors with larger openings could be used.

Figure 6

Large printed-circuit board

The photograph above shows a very large printed circuit board produced at Fermilab. This kind of printed circuit board technology is employed for the enormous drift chambers we use for particle detectors. I wonder if this kind of technology could be used inside the dashboards of automobiles or maybe even in modern buildings to eliminate point-to-point wiring.

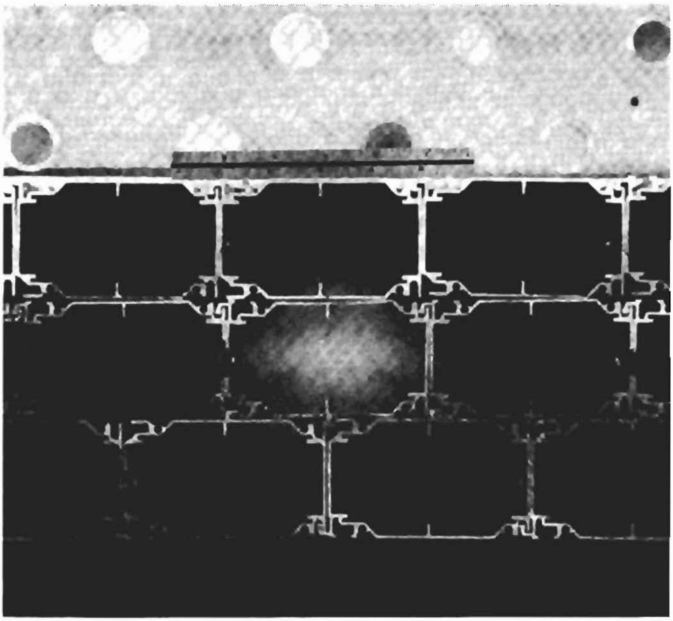

Figure 7
Interlocking extrusions

Another clever idea developed at the Laboratory for drift chamber construction works like Lego blocks for grown-ups. Basically it is a system for interlocking extrusions (Fig. 7). A University of Illinois/Chicago design class was asked to look into the possible applications of this material. They didn't receive much explanation about how it was used at Fermilab. The students developed a whole gamut of ideas, including using the material for making docks.

An example of software is a system developed here called MULTI. MULTI is a so-called event-driven programming system oriented to DIGITAL PDP11 systems. There are an enormous number of computers like this in laboratories scattered around the world. In fact, MULTI has now been transferred to more than

100 universities. Relatively few industrial research laboratories have picked up on it. The wonderful feature of MULTI is that one can do in several weekends of programming what used to take six months for an on-line computer system. Some of our staff here feel that MULTI is passing out of its useful lifetime. My own reaction would be that maturity is probably a good thing for something like this.

Finally, a device based on drift chamber principles has been developed at Fermilab that could be used in positron emission tomography (PET). Remember, this is another kind of CAT-scan-like medical imagery system. Patients swallow a cocktail of positrons, those positrons annihilate into photons, and the PET-scanner looks at those photons coming out. Modern PET-scanners use barium fluoride crystals which can give very narrow pulses. These narrow pulses make coincidences possible. The difficulty is that the phototubes used for these PET-scanners are very expensive so that one might invest $500,000 or so for phototubes for just one scanner. The Fermilab system would use drift chambers to replace those phototubes. These drift chambers are filled with a special gas called "TAMMAE" whose properties were first recognized by David Anderson, a staff member here at Fermilab.

How much technology is there at Fermilab like the individual items I've listed? For the last several years a patent survey has been maintained so that we now have an active invention inventory. That inventory now has more than 400 items in it, and material is being added at a rate of something like 30-40 items a year. We hope in the next year to find better ways to circulate information about this inventory to our Affiliates and the world at large.

How does industry interact with Fermilab? Remember that Fermilab really represents a mix of many, many universities working on a variety of different projects. The best way to establish contact with the Laboratory is to be a Fermilab Industrial Affiliate. In general the purpose of the Affiliate organization is to serve as an effective forum for transferring Fermilab technology to industry. The Affiliate concept gives a window to the Laboratory's technology. If an Affiliate is having trouble making contact with the people they are interested in at Fermilab, they should contact me to see what we can do to facilitate the process. The annual meeting is an important part of our attempt to give Affiliates an opportunity to see the Laboratory and find out what's going on.

The Affiliates receive technical reports from the Laboratory distributed on a monthly basis. These are profiled to the particular interests of the Affiliate, so that the piles shouldn't become too large. We also encourage Affiliates' visits. These have been taking place more and more frequently. Of course, the Laboratory is happy to have anyone visit; however, we find that this is particularly easy for members of the Affiliates.

Another classical way of interacting with the Laboratory occurs when Fermilab buys innovative equipment from vendors or jointly develops equipment with them. The development of the TEVATRON superconducting wire mentioned earlier is a beautiful illustration of this. In this regard, it would be interesting to hear from industry about other ways that we could work together. If you have any ideas for development projects, it might be that we could work together to our mutual advantage.

However, it must be emphasized that Fermilab is not an engineering development center. We can't help someone with their brother-in-law's lottery computer. We don't feel it's appropriate for us to be entering into a wide variety of different technology areas outside of our fundamental mission. For industries in Illinois, the state has now established a number of technology commercialization centers at universities and at Argonne that are more oriented in that direction. Occasionally, we can help someone by directing them to some other institution which handles such matters. In particular, we are happy to try to help Affiliates in this area.

In most discussions of transferring technology, the conversation eventually turns towards questions of licenses, patents, and proprietary relationships.

At Fermilab our general inclination is to publish most of the information developed here. We understand that this could prevent some ideas from coming to market because industry cannot have enough of a foothold to make it worthwhile to undertake the extensive development that is needed for a product. The current Fermilab patent situation is like most government-owned, contractor-operated laboratories in the federal system. In the old days the Department of Energy, our sponsoring organization, undertook all of our patent work. In this arrangement, the federal government owned all the patents.

Several years ago, a new law was passed called "Bayh-Dole." This gave laboratories, like Fermilab, rights to patents developed strictly at the laboratories. This means Universities Research Association, the Fermilab governing organization, would own the patents developed here. Interim implementing regulations have now been published. Based on this law we will begin to try to develop more licenses for material originating from Fermilab technologies.

I hope all of this has shown the advantages of belonging to the Fermilab Industrial Affiliates. If you are not an Affiliate, we hope that your organization will join. We are looking for companies that are generally interested in the technology of the Laboratory. We are not exclusive at all. If you are interested, contact:

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