Techniques

of

Proton Radiotherapy

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Harvard University,

the

Physics Department,

and the

Lab for Particle Physics and Cosmology

(**LPPC**)

made this course possible by their support.

BG Web Directory

My Web directory, maintained by courtesy of the Physics Department, is at

http://users.physics.harvard.edu /~gottschalk/

It currently has three ZIP files, all of which will change from time to time.

BGware is a collection of software including source code, Windows executables, icons and auxiliary files needed to run the programs. You are welcome to use, borrow from, or adapt these programs but please note the Disclaimer of Warranty (next slide).

The chief aim of this course is to explain the thinking behind these programs.

BGdocs is a collection of PDF files including README (a sort of site map), user guides for some of the programs, and PBS, a 2004 draft of a book on Passive Beam Spreading. I plan to keep this draft intact for the time being while adding a revised, expanded version called Techniques of Proton Radiotherapy (TPR).

BGtalks is a collection of PowerPoint files (this course), also under development.

PDF Files in BGdocs.ZIP, November 30, 2007

1. **FitDD :** User Guide to FitDD, a program that fits SOBP or transverse scan data (in text format) using the broken spline method.
2. **FitScan :** User Guide to FitScan, a program that fits SOBP data (in text format) with 3 polynomials. Obsolete.
3. **NEU :** User Guide to NEU, a program that designs single and double scattering systems (upstream modulator and contoured second scatterer) to meet clinical specifications (radius, depth and modulation).
4. **PBS :** 2004 draft of a book, 'Passive Beam Spreading in Proton Radiation Therapy'. I hope eventually to replace this by a larger work, 'Techniques of Proton Radiotherapy' (these lectures).
5. **PrestonAndKoehler1968 :** an unpublished manuscript. The first theoretical and experimental treatment of proton pencil beams.
6. **ReadMe :** a guide to the Web site.
7. **RVcal :** calibration of the IBA range verifier (as installed, for instance, at the Burr Center). Discusses how to analyze RV data and how well RV performs.
8. **SOBP :** on the characterization of SOBP's and the definition of 'depth' and 'modulation'. Polynomial fit method described here is obsolete.

Disclaimer of Warranty and Limitation of Liability

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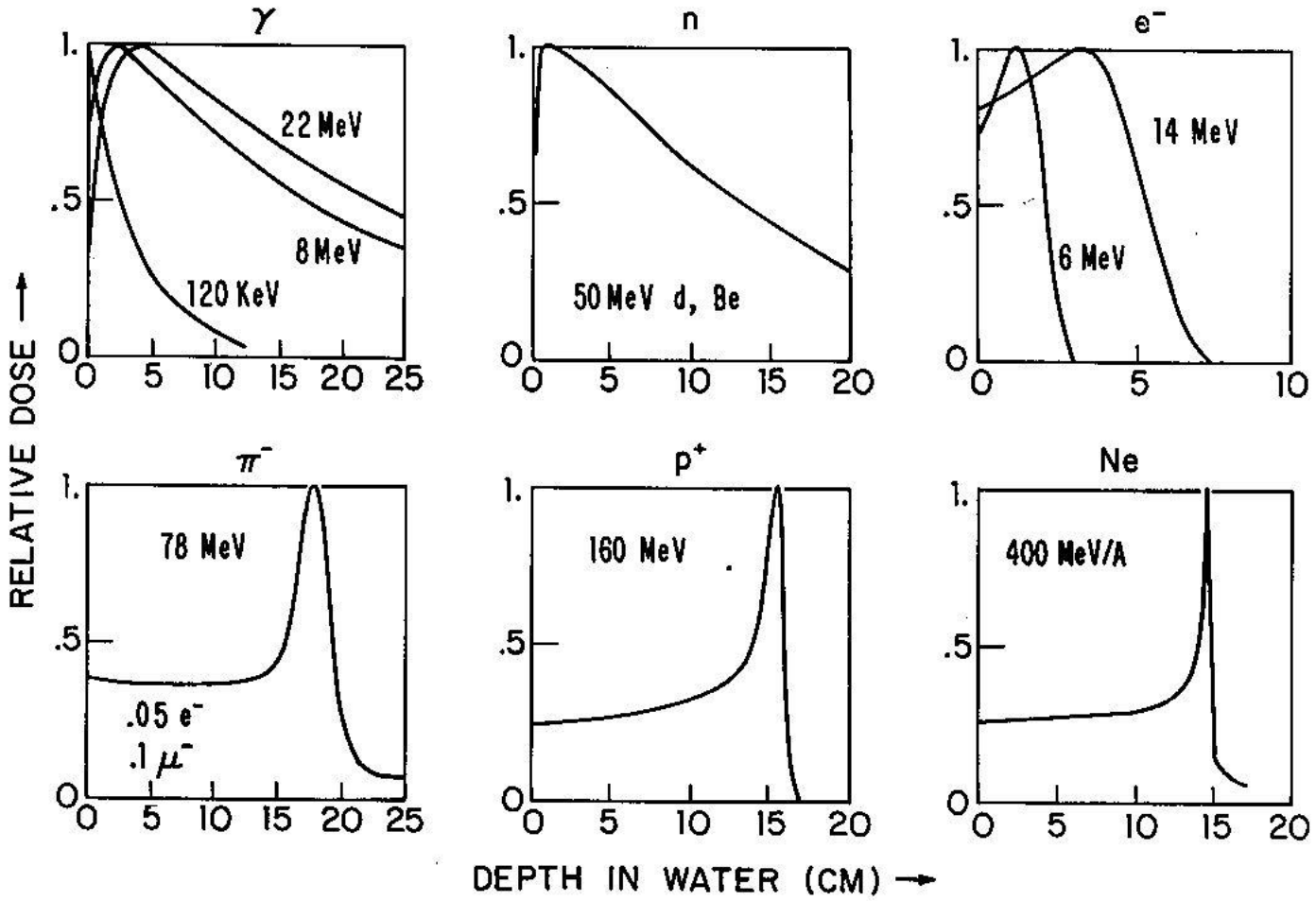
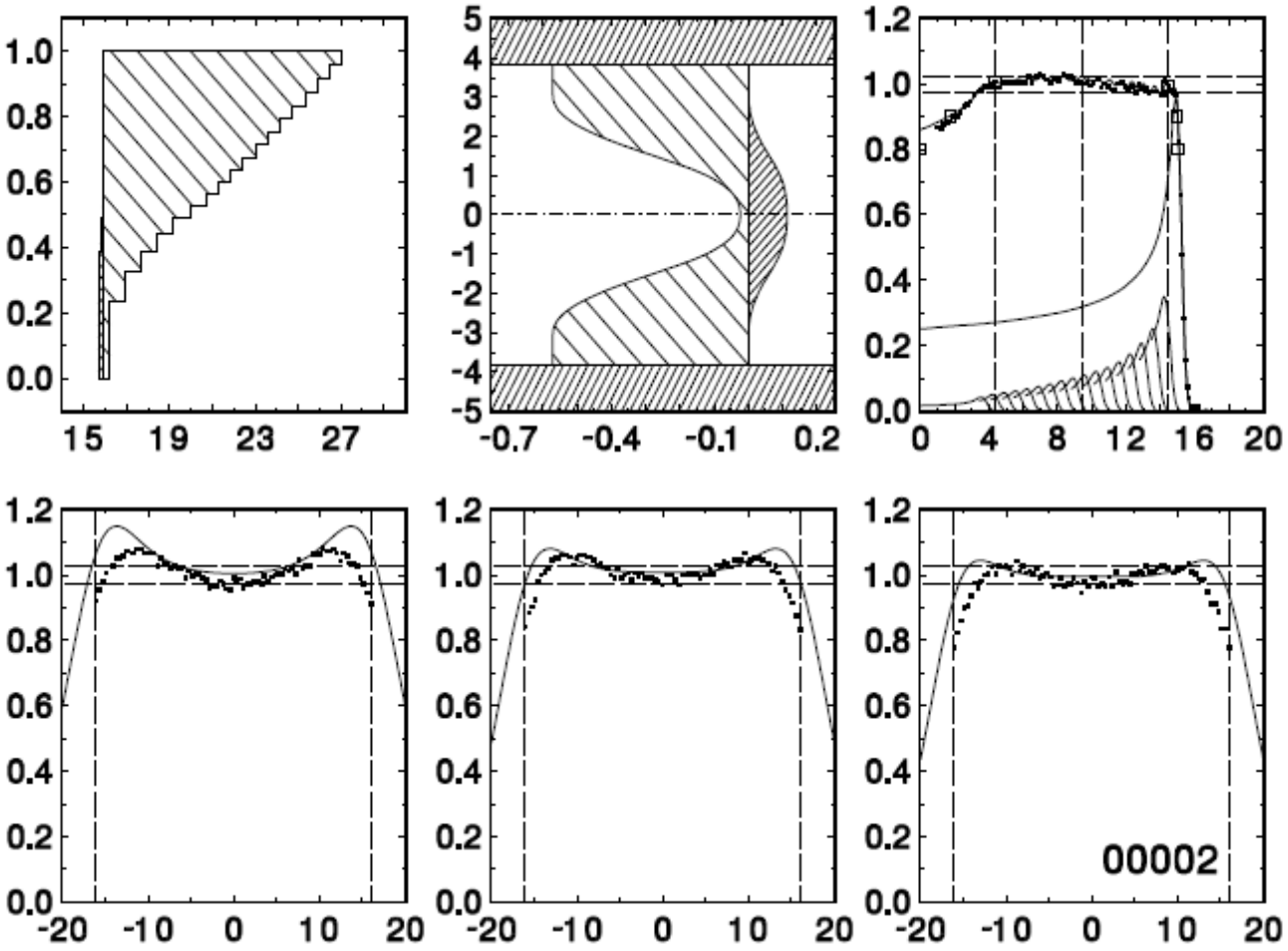
Rationale for Protons



Depth-dose distributions in water for particles used in radiotherapy. **Neutrals** fall **exponentially** (after the dose builds up at the entrance) as particles are lost to various interactions. **Charged particles** are not lost, but slow down by myriad collisions with atomic electrons. A slower particle loses more energy per cm because it spends more time interacting with the electrons, producing the **Bragg Peak** of dose.

Goal of the Course



This is the first proof of principle of the 'upstream everything' beam spreading system used at the Burr Center and other IBA facilities. The course will explore in detail the **basic physics** and **computational methods** underlying programs such as NEU, which designed this setup. Later, we will also cover some of the **experimental devices** which, singly and in arrays, are used to take this and similar data.

Goal of the Course (continued)

The course consists of three parts which are, roughly speaking, basic physics, engineering, and instrumentation. It is designed for persons who are, or plan to be, occupied with the design, maintenance or upgrade of proton radiotherapy facilities. A bachelor's level degree in some branch of science or engineering is an adequate prerequisite. No prior knowledge of particle physics is assumed.

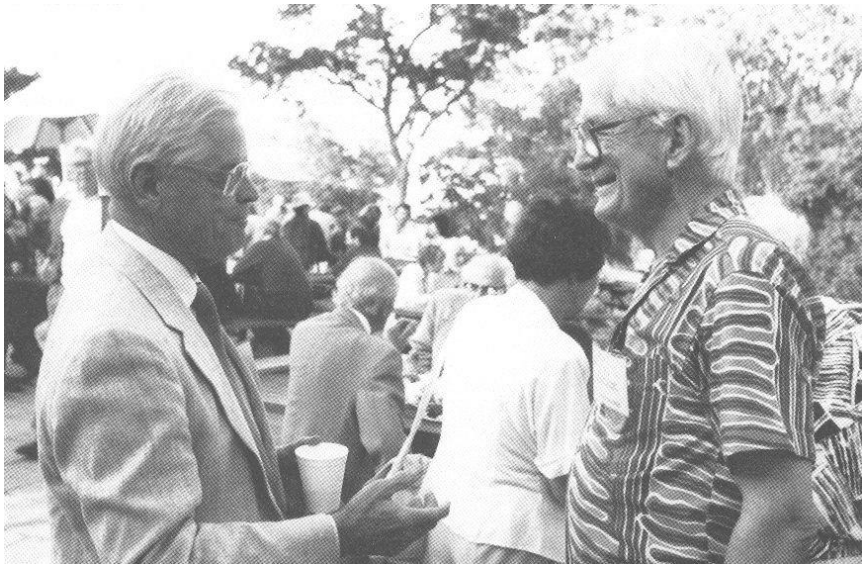
The physics is not complicated by today's standards. It was mostly worked out in the 1930's and 40's. Unfortunately all the good textbooks were written in the 50's and are out of print long since. In physics curricula the topic is somewhat analogous to anatomy or geography: essential but very unfashionable.

This course is meant to help fill that void. It is detailed, not a survey. Its main purpose is to develop an overall picture at a technical level: to help you *think like a proton*. It concentrates on scattered rather than scanned beams, because that is my field of expertise. However, much of it should be useful whatever the beam spreading technique.

I have tried to make the talks more or less self-contained. The typical slide consists of a picture with some explanatory material. I have deliberately avoided animation and the excessive use of color in order to keep the slides easy to read.

The rest of this Introduction recognizes colleagues who helped me and shaped my thinking as well as an institution, the Harvard Cyclotron Lab (HCL), which is inseparable from these old friends.

Two Pioneers



Robert R. Wilson (left) designed the cyclotron but joined Cornell before it was built. Norman Ramsey was its first Director. Earlier, Wilson wrote the short paper that launched proton radiotherapy ('Radiological use of fast protons,' Radiology **47** (1946) 487)

They are shown many years later at a SLAC Accelerator Conference.

The second Harvard Cyclotron was dedicated on 15 June 1949. Harry Truman was in his second term as US President, television and FM were gaining in popularity and commercial transistors were still a few years away. Nuclear physics dominated HCL through the upgrade in 1956 until the mid 1960's, when clinical use began after preliminary monkey studies and intensive promotion by Bill Preston and Andy Koehler. For a short while, Andy was the only HCL employee, at half time. The first treatments, by Dr. Ray Kjellberg, were single fraction 'radiosurgery' of intracranial targets. By 1974 the staff had grown to six and a second program, fractionated therapy of larger tumors, began under the supervision of Dr. Herman Suit and Michael Goitein. The last patient, a one year old infant, was treated 10 April 2002.

Last Treatment at HCL

Harvard Cyclotron Laboratory

Final

May 25, 1961 - April 10, 2002

Neurosurgery	3687 patients
Eye: Uveal Melanoma	2979
Radiation Oncology (large field)	2449
TOTAL	**9115**

Total Radiation Oncology Fractions: **46,055**

Karl Strauch

Karl Strauch (1922-2000) was the person I worked for when I first came to HCL in 1956 and he eventually became my thesis advisor. He was a fine teacher and physicist, taught me most of what I know about the art of experimental physics, and remained a good friend. His aphorisms, including

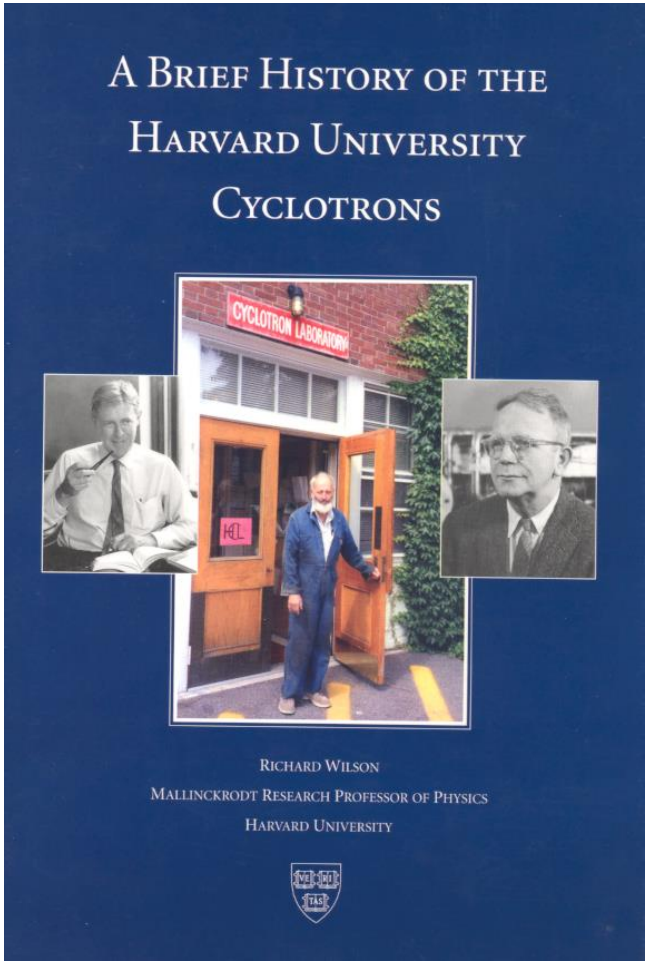
Only change one thing at a time.

(topped only by Jim Ziegler's '**Change nothing.**') live on in my mind.

George Brandenburg

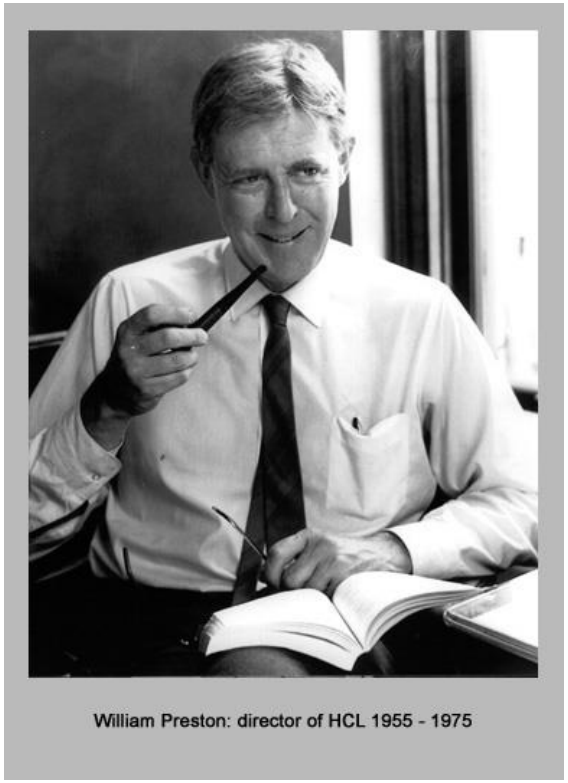
George Brandenburg died on September 15, 2013 at the age of 69. He was a fellow grad student and a friend. Though not personally involved in proton radiotherapy, as Director of the Harvard High Energy Physics Lab he arranged for me to have an office after the Harvard Cyclotron closed, making this course possible.

Richard Wilson

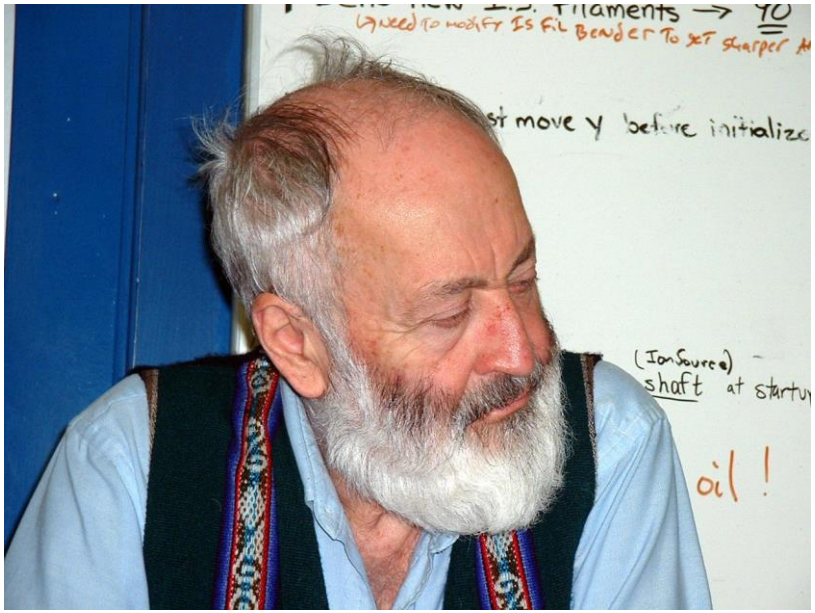


Richard Wilson (right) oversaw the cyclotron upgrade in 1956. Later, he was a staunch supporter of the HCL medical program throughout his tenure at the Physics Department. He published 'A Brief History of the Harvard Cyclotrons' in 2004 (Google it).

Bill Preston, Andy Koehler



Bill Preston (1910-1989)



Andy Koehler
in April 2002

Bill was Director of HCL during my graduate student days, and Andy was later on, when I returned in 1981. Their easygoing style set the tone and made HCL the best place one could hope to work at, emphasizing research and understanding for its own sake. In addition to running HCL and promoting proton radiotherapy, Andy and Bill made important technical contributions to the clinical use of proton beams.

A Seminal Paper by Preston and Koehler

The Effects of Scattering on Small Proton Beams

W. M. Preston and A. M. Koehler

Department of Physics, Harvard University

Cambridge, Massachusetts

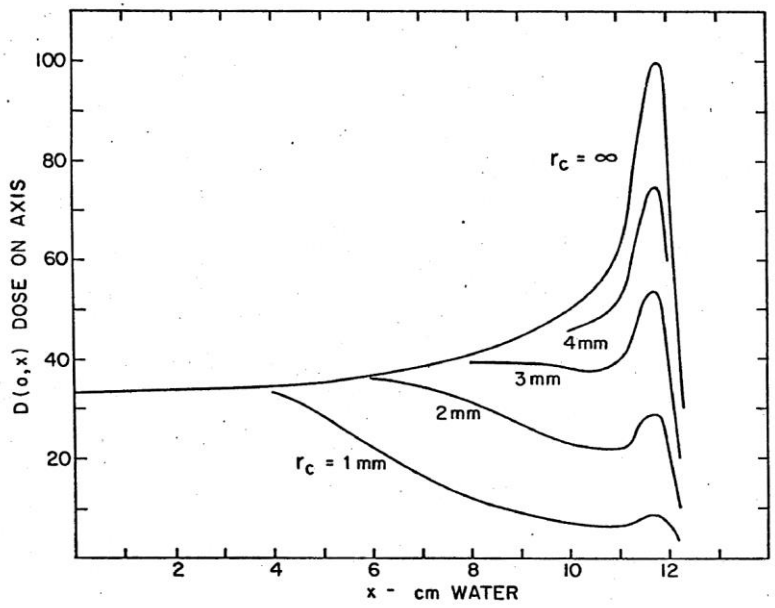


FIGURE 7

This MS ca. 1968 was rejected and never published. It describes (with experimental confirmation) the now ubiquitous proton *pencil beam* concept. Now available for download in my Web directory.

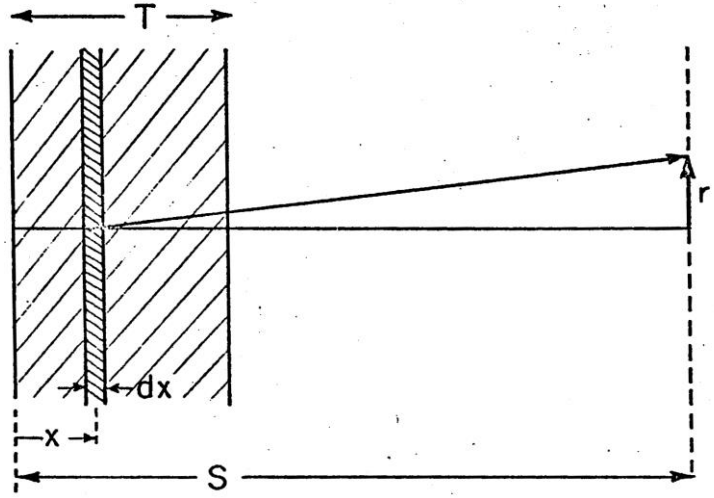


FIGURE 1

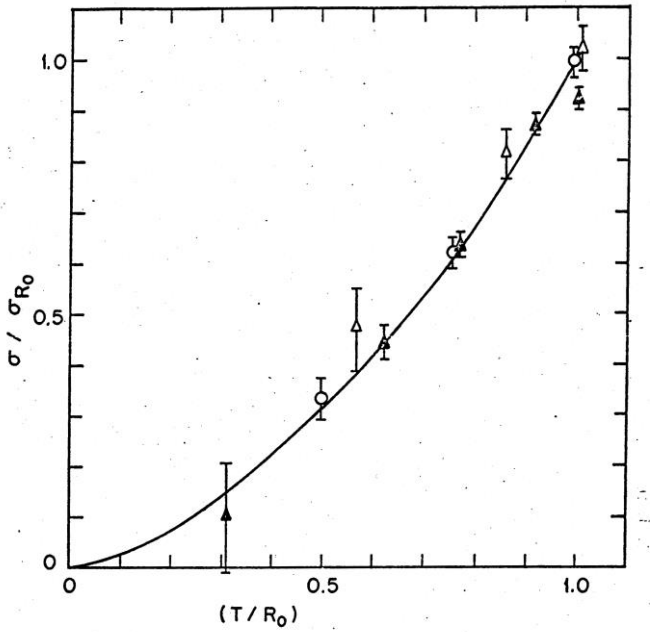


FIGURE 17

Miles Wagner

Miles Wagner became HCL Director after Andy retired. We worked together all the time. The equipment used to take much of the data I'll show was designed and built by him. After a period at the Burr Center, Miles is now at Still River Systems helping to design a compact low-cost proton therapy system using a superconducting FM cyclotron.

Sara Schechner, curator of the Harvard collection of early scientific instruments, acquired the HCL control console and some representative equipment when HCL was demolished. She baked a console cake for our last annual cookout. She and her daughters look on as Miles Wagner, the last HCL Director, cuts the cake. The actual console may be seen on the ground floor of the Science Center, weekdays 11-4.

Most years, Ethan Cascio, skilled in photography among other accomplishments, took an HCL staff photo. The last one is shown in the final slide. Ethan and his wife Allison sit in front.

Ethan now runs the 'outside user' (non-clinical) program at the Burr Center.