THE PIGMI PROGRAM AT LASL*

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ABSTRACT

A program aimed at the development of smaller, less expensive and more reliable proton linacs, for Pion Generators for Medical Applications (PIGMI), will be described. Major innovations in this program include: higher frequency structures (450 and 1350 MHz), higher accelerating gradients (5-8 MV/m), lower injection energy (few hundred kV), waveguide manifold rf distribution, and alternating phase focusing for the first few meters, followed by permanent -magnet quadrupole focusing for the remainder of the linac. Current status and eventual goals of the experimental program will be described.

The National Cancer Institute of the Division of Cancer Research Resources and Centers, Department of Health Education and Welfare is supporting a program of accelerator development at the Los Alamos Scientific Laboratory aimed at the extension of linac technologies in the directions to produce the most suitable pion generator for medical applications. The acronym PIGMI comes from the phrase Pion Generator for Medical Irradiations. The program is currently funded at a level of about two million dollars for the three-year period beginning in July 1976.

It seems to be generally agreed that a useful dose rate for pion radiotherapy is of the order of 50 rads/min in a volume of about 1 liter. The primary proton currents required to achieve such dose rates depends on the proton energy and on the collection efficiency of the pion channel. At the present time, we feel that 650 MeV is the most cost effective proton energy for producing pions for radiotherapy. Experiments are scheduled at LAMPF, SIN and TRIUMF to provide additional data on which to base this decision.

Channel collection efficiencies vary from 0.020 steradian in the most conventional channel to 1 steradian in the most advanced channel, the superconducting pion channel of Stanford University.[1] It seems unwise to select the primary beam current so as to meet the desired pion production rates for only the most advanced pion channel. There is reason to believe that advanced designs of more conventional channels can reach the range of 0.200 steradians. Assuming a collection efficiency in this range, the required current of 650 MeV protons is in the range of 100 μA.

From these parameters, it is clear that such machines fall in the category of meson factories, with the possible exception of duty factor, for which the medical application has no particular requirement. Linacs are recognized as the most potent source of mesons. LAMPF, the most intense of the meson factories, is now running reliably at 100 μA, and will be extended, in due course, to its design intensity of 1 mA.

But proton linacs are also considered to be on the expensive and complex side for the industrial/medical community. Every proton linac in the world is situated deep within a physics lab attended by a team of specialists, a distinction not shared with its lighter weight brother, the electron linac, which has found many applications outside the physics lab.

The designers and builders of LAMPF feel that the cost and complexity of the proton linac can be reduced by going up in frequency (down in cavity size and power consumption) and up in acceleration gradient (down in accelerator length.) However, doing so poses a number of technological problems, the solutions of which represent the goals of the PIGMI Program.

The proponents of the PIGMI Program have defined what they feel to be an optimized design of a pion generator suitable for a radiotherapy program at a major medical center. Figure 1 shows this design to consist of a 250-kV injector, followed by a short section of alternating phase focused linac, 50 meters of drift-tube linac, and 95 meters of side-coupled linac.

Figure 2 gives the major parameters for the pion generator, and identifies the major areas where extensions to current linac technology are proposed.

In the drift-tube linac sections, the major extensions to linac technology are the proposed increase in frequency from 200 MHz to 450 MHz, the proposed increase in acceleration gradient from 2.4 to 5 or 6 MV/m, and the use of permanent-magnet quadrupoles in the drift tubes for radial focusing.[2] The structure will be stabilized with post couplers,[3] where somewhat less than one post coupler per drift tube should be adequate. The choice of frequency coincides nicely with the availability of a 5-MW klystron power source. Three such sources would be needed to power the drift-tube linac sections. We propose to study the merits of combining the outputs of four such sources into an rf manifold[4] to gain the ability to survive the failure of any one klystron.

The higher frequency is in the direction to support a higher acceleration gradient. Additional gains in gradient holding capability will be sought through care for surface geometry, surface finish, surface materials and surface cleanliness. Techniques of ultra-high vacuum will be employed to gain cleanliness. The effects of baking the structure to increase the gradient holding capabilities will be studied.

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The move to higher frequencies and higher gradients compounds dramatically the problem of practical fabrication of the drift-tube linac structure at lower energies (below 5 MeV.) It was known from the very beginning of the project that some fundamental development in accelerator focusing schemes would be required in this low energy region in order to take full advantage of the higher frequencies and gradients in the higher energy portions of the machine.

One of the prime contenders to satisfy the accelerating and focusing requirements in the region below 5 MeV was the concept of alternating phase focusing (APF). We began to search for suitable APF structures in the Spring of 1975, and soon an array of such structures was found[5] which showed promise for acceleration of protons and heavy ions at higher frequency and from lower energies than currently possible with magnetically focused drift-tube linacs. In these structures, the transverse, as well as the longitudinal, focusing forces are produced by the rf fields. By arranging the drift-tube lengths, and hence, the gap positions, in an appropriate way, in a standing wave drift tube loaded structure, the particles can be made to experience acceleration and a succession of focusing and defocusing forces which result in satisfactory containment of the beam, without dependence on additional focusing fields.

The APF concept appears to work well enough to allow a reduction of the injection energy to only 250 kV.[6] This represents a major savings in the cost and complexity of the injector compared to the present practice in proton linac technology.

In the side-coupled linac section, the major extensions to linac technology are the proposed increase in frequency from 800 MHz to 1350 MHz, and the proposed increase in acceleration gradient from 1.25 MV/m to 8 MV/m. The choice of frequency again coincides nicely with the availability of 20-MW klystron power source, and we propose to use an rf manifold to combine the output of six such sources to power the 22 sections of side-coupled structure.

As for the side-coupled structure itself, we will concentrate on ways to simplify the fabrication of a more rugged piece of hardware. We are currently investigating copper-plated aluminum segments which can be electron-beam welded together. We are also investigating the washer and disk structure developed by the Soviets for their meson factory.[7] If, after these investigations, we return to the LAMPF structure,[8] we will investigate ways to increase the cell-to-cell coupling beyond the 5% value of LAMPF to further reduce the sensitivity to mechanical deformation and temperature imbalance.

Figure 3 summarizes the innovations in proton linac technology suggested by the PIGMI Program. Figure 4 is an artist's concept of a portion of the resulting product, which, because of its size, looks more like an electron linac than the proton linacs we are familiar with.

Each of the proposed extensions of linac technology will be evaluated within the PIGMI Program with a combination of theoretical studies, engineering studies, prototype design, prototype fabrication and prototype evaluation.

The main pieces of hardware to be designed, fabricated and evaluated under this program are:

1. A 450-MHz klystron power source.

2. A 6-cell bakeable power model of a section of the drift-tube linac (PIGLET) to determine the limits of excitation, to serve as a test of the engineering designs,[9] and to serve as a resonant load for the 450-MHz power source.

3. A 1350-MHz klystron power source.

4. A short section of one or more side-coupled structures to determine the limits of excitation, to test the engineering designs, and to serve as a resonant load for the 1350-MHz power source.

5. An operating prototype of the first 10 MeV of the proposed design to include a 250-kV injection system, a buncher cavity, a solenoid lens, an APF section, the first few MeV of the drift-tube linac complete with permanent magnet quadrupoles, and beam and accelerator diagnostic equipment.

In addition to the major engineering prototypes, a number of other pieces of hardware will be designed and fabricated in support of subsystem studies, namely:

1. Numerous permanent magnet quadrupole models.

2. A cavity model suitable for field distribution studies in a variety of APF structures.

3. Cavity models of the side-coupled structures.

4. An rf manifold model for studies of its properties.

5. A diagnostic and control system to facilitate beam and accelerator studies based on a minicomputer and an array of distributed microprocessor systems.

That pretty well concludes my description of our new PIGMI Program at LASL. You will hear more on many of these subjects in subsequent papers at this conference. I hope that by the time of the next linac conference that we can report on the successful completion of a majority of this program, and can start taking orders for little PIGMIs.

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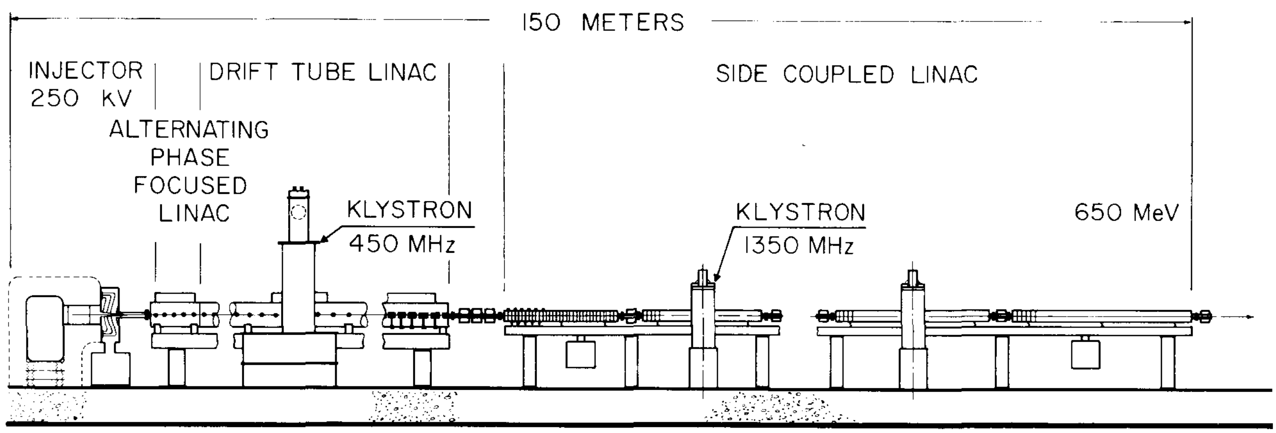

Fig. 1. Primary Segments of Pion Generator for Medical Irradiations.

PION GENERATOR FOR MEDICAL IRRADIATION (PIGMI)

PROTON LINAC:

Proton Energy	650 MeV
Average Current	100 μA
Pulse Length	10 μs
Repetition Rate	360 Hz
Total Length	150 Meters

EXTENSIONS OF PRESENT LINAC TECHNOLOGY:

LINAC SECTION:	Alternating Phase Focused Linac	Drift Tube Linac	Side-Coupled Linac
ENERGY (MeV)	.25 - 10	10 - 150	150 - 650
FREQUENCY (MHz)	450	450	1350
E. GRADIENT (MV/m)	4 - 10	4	8
QUADRUPOLES	NONE	PERMANENT MAGNETIC	ELECTRO-MAGNETIC
RF DISTRIBUTION	(PART OF DTL)	MANIFOLD	MANIFOLD

Fig. 2. Proposed Extensions of Proton Linac Technology.

INNOVATIONS IN PROTON LINAC TECHNOLOGY

Higher Frequency:
- Higher shunt impedance (efficiency).
- Smaller structure.
- More economical fabrication.
- Proven klystron power sources.

Higher Gradient:
- Made possible by higher frequencies.
- Shorter facilities.

Alternating Phase Focusing:
- New focusing development, necessitated by the higher frequencies and higher gradients.

Lower Injection Energy:
- Made possible by the alternating phase focusing.
- Smaller injection systems.
- More compact beam within accelerator.

Permanent-Magnetic Quadrupoles:
- Adaption of modern permanent-magnet technology to focusing role in the drift-tube linac.

RF Manifold Power Distribution:
- Allows use of fewer, higher-powered klystrons.
- Locks relative phase of all linac sections.
- Increased reliability by installation of one spare klystron.

Distributed Microprocessor Control:
- Reliable, powerful, inexpensive.

Fig. 3. Summary of Innovations in Proton Linac Technology.

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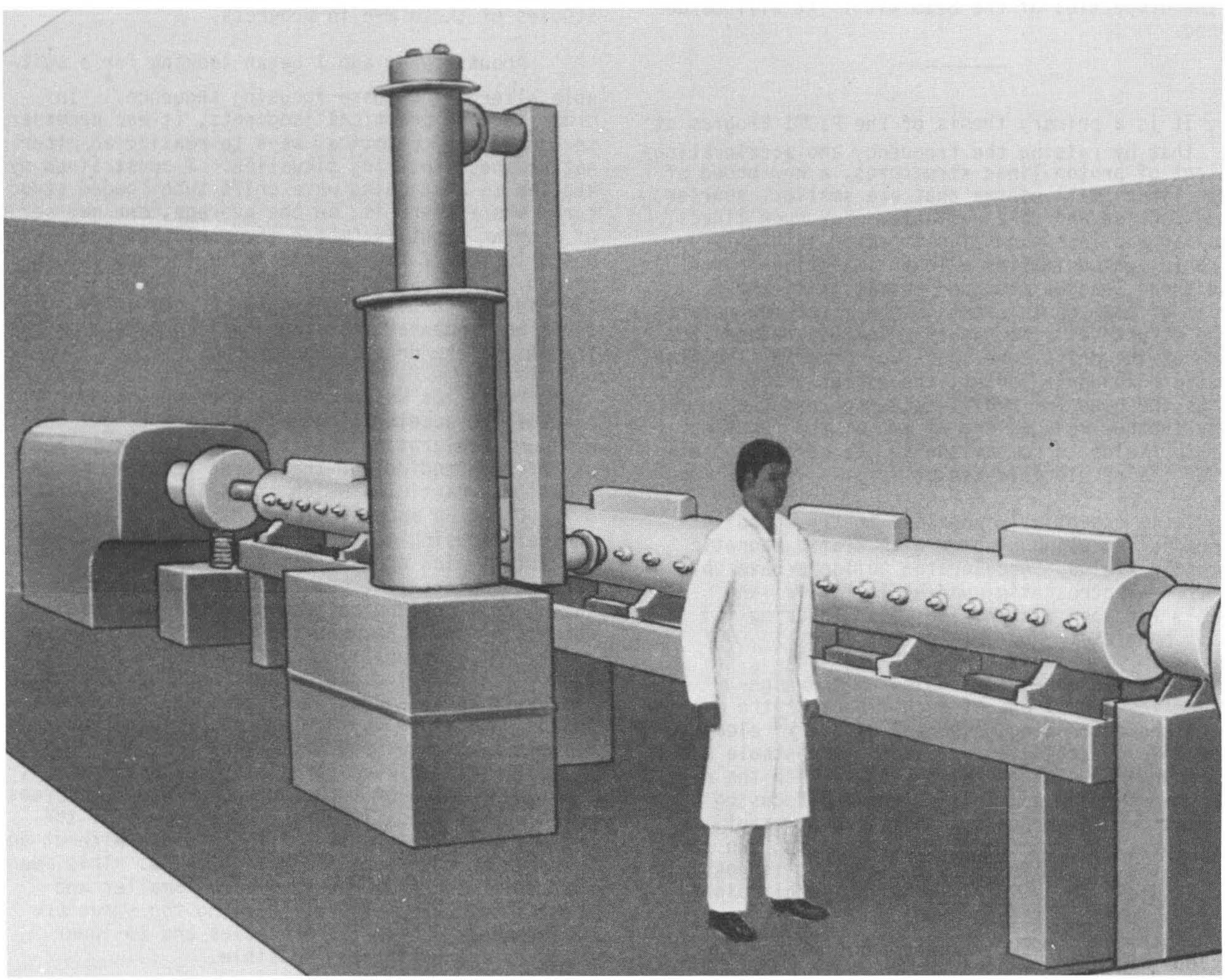

Fig. 4. Artist's Concept of Low Energy Portion of PIGMI.