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POSSIBLE PION SOURCES FOR RADIOTHERAPY

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Recently great interest has been shown in pi-meson irradiation as a possible modality for cancer radiation therapy. In order for this short lived particle to be more than an idle laboratory curiosity, it must be demonstrated that economical pion sources can be built which satisfy the necessary flux requirements for therapy within reasonable space and cost limitations. Several approaches have been taken to this problem, optimizing various aspects but seldom discussing all of the factors. I shall try to put some of the trade-offs in perspective and present some of the possibilities in an understandable form.

Protons have a much higher probability for producing pions per unit target mass than do electrons, so if there were no other consideration it is clear that proton accelerators would be superior to electron accelerators as pion sources. Unfortunately, proton accelerators are considerably more difficult to build than electron accelerators, requiring more precise control, more rf power, and probably more length than their counterparts. At 500 Mev the advantage of protons over electrons for production is about a factor of 50, that is, for the same total yield of pions, an electron accelerator must have 50 times the beam power required of an equivalent proton machine. One possible way around this problem is to design a much more efficient magnetic channel to collect the pions and focus them on the patient being treated. The workers at Stanford University have described such a system, utilizing 60 parallel magnetic spectrometers to focus a total of 1/12 the total pions produced in the pion production target on the patient, up a factor of 30 from the more conventional magnetic guidance system being built at Los Alamos. This system requires a more sophisticated control system and will take a lot of study to learn to use, but is certainly an indicator of a direction to go to reduce source cost. This approach also reduces the beam current requirements on a proton accelerator by a factor of 30 making a 30 microamp accelerator a possibility, rather than the 1 milliamp accelerator now in use in Los Alamos.

A brief description of four accelerator systems which might be suitable for hospital use, two electron accelerators and two proton accelerators, is given to illustrate the problems involved. These systems are certainly not optimized, and for a final design exact tube types, structures, etc. would have to be considered. On the other hand, they have been priced using the same criteria, and should be consistent within themselves. Experience at Los Alamos has been used to determine the unit costs for various components in each system.

1) A 30 microamp, 500 MeV proton linac with a high efficiency channel of the Stanford type. Technical developments required include (a) a 400 MHz drift tube accelerator operating at high gradient and (b) a 1200 MHz side coupled system operating at 5 MeV/M. The system is folded, e.g. the beam is accelerated up and back in the accelerator tunnel. This represents the minimum proton accelerator capable of theraputic application, assuming the successful development of a large solid angle magnetic channel.

2) A 150 microamp, 500 MeV proton linac with a more conventional pion channel, improved somewhat for increased acceptance over the present Los Alamos design. The accelerator is similar to the one described in case 1), but has a longer pulse length and higher average beam power. This represents the conventional pion channel source.

3) A side-coupled electron linac of what is now considered conventional design, run at 10 MeV/m. The length is 50 m, 600 microamp average current, and it is also folded back upon itself once. The operating frequency is to be 1200 MHz.

4) A recirculating electron accelerator with conventional standing wave accelerating section. This design is taken from a joint SLAC-Varian study reported at the 1973 National Accelerator Conference. The main advantage of recirculation seems to be substantially reduced building floor space requirements. As far as I know, no recirculating accelerator of this scale has ever been built, so some research and development will be required.

As far as risk is concerned, example 3) has the least involved, and all of the other solutions have substantial R and D required before a completely safe design can be insured. Table I lists some of the properties of the examples, and a crude cost estimate is included at the end for comparison. This cost is generated assuming that the engineering has been done, and that the costs here represented are for the hardware alone. A first-off cost might run as much as a factor of two or more higher than the quoted cost.

Finally, it should be remarked that the proton accelerator has a multiple use aspect, in that it is very effective in producing short lived radioisotopes in its final beam stop location, a function satisfied now in many hospitals by a dedicated small cyclotron.

Case	(1)	(2)	(3)	(4)
Particle accelerated	proton	proton	electron	electron
Energy	500 MeV	500 MeV	500 MeV	500 MeV
Peak current	60 mA	75 mA	120 mA	20 mA
Average current	30 μA	150 μA	600 μA	600 μA
Average beam power	15 KW	75 KW	300 KW	300 KW
Duty factor	0.0005	0.002	0.005	0.03
Peak rf power	34 MW + 55 MW 89 MW	37 MW + 60 MW 97 MW	110 MW	20 MW
Average rf power	17 KW + 28 KW 45 KW	74 KW + 120 KW 194 KW	550 KW 550 KW	600 KW
Accelerator length	2 x 60 m	2 x 60 m	2 x 50 m	15 m + magnets for recirculation
Type channel required	high accept.	standard	high accept.	high accept.
Channel acceptance ($\Delta\Omega$, $\Delta P/P$)	1 sterad ±3% $\Delta P/P$	50 msterad ±10% $\Delta P/P$	1 sterad ±3% $\Delta P/P$	1 sterad ±3% $\Delta P/P$
Pions/sec delivered	1×10^9	0.75×10^9	0.41×10^9	0.41×10^9
Dose rate into 1 liter	38 rad/min	28 rad/min	15 rad/min	15 rad/min
Approximate cost (accelerator only)	$2.2M	$2.5M	$2.2M	$2.0M