THE PROPOSED HOSPITAL-BASED PROTON THERAPY LINEAR ACCELERATOR

Alexey S. Bogomolov, Ph.D.
Physical-Technical Instrument Making Department,
Siberian Branch of Russian Academy of Sciences,
630090 Novosibirsk, RUSSIA.

ABSTRACT

The investigation of BW-type structures, especially optimized for TW-use, permits to recommend two frequencies for designing the medical LAP :

- f_1 = 1.8 GHz for the initial high current part of the LA (up to 60-70 MeV, I = 30-50 mA), and
- f_2 = 5.4 GHz for the second high energy small current part (W= 60-230 MeV, I_b up to ~ 2.5 mA, with changing mode φ - phase shift per cell), and a set of structures.

The design parameters and features of the proposed BWLAP for proton therapy are discussed. The results obtained allow the design of a hospital-based proton therapy facility at a reasonable cost.

The reasons for such assumptions are:

- small size of the 230 MeV-BWLAP (24 meters long);
- very simple RF-supply containing two power (and one master) RF-stations only;
- both small diameter and emittance of the proton beam allow simple transport and delivery systems (including gantry and scanning);
- low running costs;
- extremely high Z_{sh} of BWLAP.
- low activation.

I. INTRODUCTION

The advanced approach and new device that can help to make hospital cancer therapy affordable for practically everybody has been developed by the Siberian Branch of the Russian Academy of Sciences. Variable energy accelerated protons have advantages over other forms of radiation for treating cancer diseases due to their increased cancer cell killing capacity and the possibility to focus and place them accurately inside a tumour. This leads to less destruction of healthy tissue during treatment.

Today, no reason to carry on propaganda for use Proton Cancer Therapy. Advantages have been demonstrated by all 40- year period of using them, beginning since 1954 of Wilson in Berkeley successful experiences to treat. But Proton Therapy is performed on a small scale because the cost of a Facility. There exists only fifteen medical facilities around the world equipped with high energy proton accelerators. Most of this equipment is rather obsolete, decades old, and quite often designed for fundamental scientific research rather than cancer treatment.

Unfortunately the technology is so costly that only one U.S. medical institution, Loma Linda University Medical Center in California, is using up to date equipment - gantry systems. The cost of the Facility was roughly $40,000,000.

Even at such a cost, the effectiveness of Proton Treatment is so high and attractive that U.S. businessmen and scientists (Dr.Carb, A.P.D.C.) are preparing to start the "protonization of the States" by creating eighteen new facilities based on Proton Synchrotrons and Linacs as injectors.

Transforming new physical concepts[1] into medical care reality, the Russian Proton Therapy Proposal provides a similar but even more advanced design at a less cost than the current paradigm. The staple and key of the Russian proposal is that the BWLAP = Backward Wave Linear Accelerator of Particles design is smaller, and more powerful than any proton accelerator suggested for proton therapy in the world today.

THE HOSPITAL-BASED PROTON THERAPY LINEAR ACCELERATOR

The proposal and sketch of BWLAP for proton therapy were discussed earlier (Loma Linda, U.S.A. PTCOG-XII, May 1990 [2]). The investigation of BW-type structures, especially optimized for TW-use, permits us to recommend two frequencies for designing the medical LAP :

- f_1= 1.8 GHz for the initial high current part of the LA (up to 60-70 MeV, I_b = 30-50 mA), and
- f_2 = 5.4 GHz for the second high energy small current part (W = 60-230 MeV, I_b up to ~ 2.5 mA, with changing mode φ - phase shift per cell), and a set of structures.

The design parameters and features of the hospital BWLAP for proton therapy are displayed in Table 1.

TABLE 1

CHARACTERISTICS	STRUCTURES	STRUCTURES 2
Energy W [MeV]	20 60	100 140 180 230
Beam current [mA]	30 - 50	2.4 - 2.6
Beam diameter [mm]	3	1.8
Wavelength λ [cm]	16.5	5.5
Mode φ [π rad]	5/6 1/2	1/2 1/2 1/2-1/4
Gain energy [MeV/m]	5 8	8 10 12 14
AS length [m]	4 5	5 4 3.3 3.3
Number of cells	710 270	530 370 280 250
Waveguide dia. [mm]	28-32 36-48	16 - 30
Shuntimped.[MOhm/m]	230 180	190 160 140 120
Total imp.RFpower[MW]	6.5	3.2
Efficiency η [%]	30	3
Longitudinal B field[T]	8.5	8.5 - 6.5

The results obtained allows the design of a hospitall based proton therapy facility at a reasonable cost.

The reasons for such assumptions are:

- small size of the 230 MeV-BWLAP (24 meters long);
- very simple RF-supply containing two power (and one master) RF-stations only;
- the small diameter and emittance of the proton beam allow to design simple systems (including gantry and scanning);
- low running cost;
- extremely high Z_{sh} of BWLAP;
- extremely low activation.

VARYING ENERGY IN BWLAP:

The results of the preliminary investigation, aimed to vary the proton energy by sweeping RF frequency, are shown in Table 2.

The experimental data were kindly provided by Dr.V.M.Pavlov (Budker INP,Novosibirsk).

TABLE 2

φ/π	f MHz	W_0 MeV	dW/df	W_0	W_{-10}	W_{+10}	$(W_{+10} - W_{-10})/W_0$
11/12	666.3	0.236					
10/12	940.9	0.571	1.7E-3	.554	.571	.588	5.9 %
9/12	1172.3	1.095					
11/12	873.0	17.51					
10/12	917.0	23.60	1.5E-1	22.1	23.6	25.1	12.8 %
9/12	982.3	33.98					
5/6	996.3	130.4	2.42	106.2	130.4	154.6	37.1 %
4/6	1056.2	275.5					

Here w_{-10} and w_{+10} are the varied particle energies if RF is swept to - 10 MHz, with nominal RF corresponding to w energy.

N.B.:The extremely high frequency gives us a possibility to:

a. design an efficient small current TW LAP with several percent efficiency (η);
b. the HF will create conditions in which breakdown does not occur within AS;
c. increases the guaranteed E - amplitude, and
d. will decrease the power, the number of RF supplies.

The theoretical backgrount is as follows:
The combination of important field parameters - $E\lambda/P^{-1/2}$ - is well known to be an invariant for similar structures. If the accelerated beam I is a small value, then the required RF power (i.e. the useful share of it) becomes a small value as well; this tends to decrease both the rated input power P and the E-field, since E is proportional to $P^{1/2}$. In this case, the best way to keep E constant is to decrease the wavelength (λ) because E is inverse to λ. Obviously, the required value of E needs a nominal input of RF power, the magnitude of which will constitute only one ninth of the power warranting the same value of E, if $\lambda = 5.5$ cm wave- length is used instead of $\lambda = 16.5$ cm. Decreasing the wavelength is also useful to save the dissipated RF power in the AS walls by augmenting the Z_{sh} proportionally to $\lambda^{-1/2}$, thus providing the improvement of the gross efficiency :

$$\eta = \frac{I_b*E*\cos\phi}{I_b*E*\cos\phi + E/Z_{sh}} \approx \frac{I_b}{I_b + E/Z_{sh}} = \frac{I_b}{I_b + I_w}$$

The high gradient (high E) small current LA makes it difficult to obtain , at the level of a few percent, and this problem is solved by using a kind of atypically short wavelength $\lambda = 5.5$ cm. We obtained $Z_{sh} = 160$ MOhm/m (W = 100 MeV, both $5\pi/6$- or $\pi/2$- mode) and $Z_{sh} = 120$ MOhm/m at n = 1.76 (W = 200 MeV,$\pi/2$- mode), and hence, for , one may reach , $\eta > 5\%$ and 2.5% in 100 and 200 MeV proton energy regions. (One may compare these η's and the efficiency of the proton synchrotrons, being about ~10^{-2} -10^{-3}% for equal radiation doses). It should be emphasized that a small diameter AS allows a design of an economical superconducting focusing system - SC-solenoid, and the AS may be attached into the solenoid.

PROPOSED STEPS FOR RUSSIAN PROTON THERAPY FACILITY

The first step to realize this advanced therapy facility is to design and manufacture the powerful, compact 20 MeV proton linear accelerator (BWLAP). The "linac" is the heart of the Proton Therapy Facility as well as the machine to produce short-lived radioisotopes necessary in Positron Emission Tomography. The primary cost of the first BWLAP-20 is roughly- \$2,000,000.00, due to the changing price of superconducting- materials in Russia: today the price is roughly 60-70% of world price. The price of BWLAP-20 will be more then \$2,500,000.00.

The commercialisation of this BWLAP will create a necessary income stream for the next step, which is the designing of the section modules to achieve a higher proton energy level - 70 MeV.

This level is helpful in treatment of tumours inside the eye such as ocular melanomas. Furthermore, it is necessary to emphasize that the powerful proton beam, achieved 70 MeV energy particles, is enough to obtain neutron flow from the special target.

Thus simultaneously with proton therapy the physicians are provided with the possibility of using neutron therapy. The final step is to manufacture and add the final sections of the "linac", which will increase its energy to 230 MeV. At this level, an effective beam can reach through the deepest parts of even a large body (up to 35 centimetres). The cost of proton treatment on a single patient makes an average of \$20,000.00-35,000.00 due to the kind of disease.

CONCLUSION

The realization of the above proposal gives the possibility to choose the best method for patient's treatment without any limitations, so typical of ordinary medical centre that is the decisive advantage of the Russian proposal. Basing upon the powerful linear accelerator of the proposed design, the medical centre obtains from one extremely radiation-free plant the chance to conduct the most modern, most protective treatment without knife: proton therapy, classic neutron therapy, advanced boron-capture-neutron therapy. It also provides the opportunity to produce short-lived isotopes for PET - positron-emission tomography and use this most sensitive and only method for observing metabolism processes dynamics of the patient.

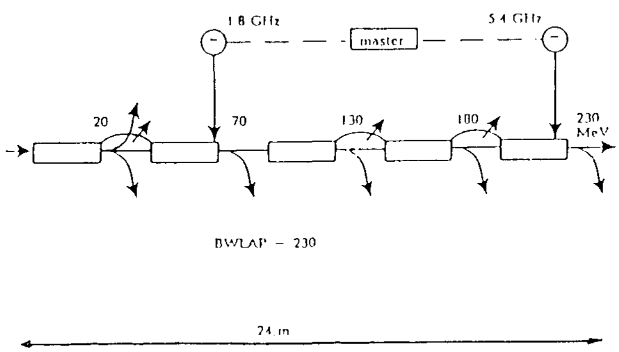
Furthermore 20 MeV BWLAP with the beam power of 10 kW is valuable by itself as a device for producing long-lived isotopes.

These features have significant practical advantage in comparison to conventional RFQ+DTL+CCL schemes of linacs.

It appears clear that this new high technological generation of proton linear accelerator, has reached 10 MeV/m energy gradient, cut down initial investments by saving time, materials, the space for equipment, and labour and gives the possibility to build the accelerator step by step (section by section!) and perform treatment with beams of achieved energies long before the accelerator is fully completed, and with readiness to adopt all know-how of radiation planning systems designed for electric linacs that are routined for physicians.

With the new, low cost, extremely compact and highly powerful BWLAP design, Beam Therapy (proton, neutron and isotopes) will bring cancer therapy a new "beam of hope".

Project price would be 20 million USD for the entire facility. Towards the end of realization it will be possible for producing more accurate estimate adding the specific features of the Russian manufacturing to decrease the prime cost.



REFERENCES:

[1] A.S.Bogomolov,"Method for linear acceleration of heavy charged particles and device for its realization", U.S. Patent No.3,651,417, March 21, 1972.
[2] A.S.Bogomolov, G.V.Makarova, "Siberian Proposal - BWLAP - 180 MeV Linac for Proton Therapy", commun. at PTCOG-XII, Loma Linda, Calif.,U.S.A. May 9, 1990.