LINEAR ELECTRON ACCELERATOR FOR THE MEDICAL ISOTOPES PRODUCTION

Yu. D. TUR, on behalf of the Kharkov 2 GeV Linac Team, NSC KIPT, Kharkov, Ukraine

Abstract

Since few years the main part of the Kharkov 2 GeV Linac Team have been involved in the investigations on the development of the medical radionuclides production technology by use linear electron accelerators. During design complete inter alia the channels of ^{99}Mo production was researched and shown that the using of reactions ^{100}Mo(γ,n)^{99}Mo and ^{98}Mo(n,γ)^{99}Mo and others allows to get ^{99}Mo with activity more than 4 Curie per day with target consisting from natural isotopes or more than 18 Curie per day with target enriched ^{100}Mo by using accelerator with beam power 20kW and beam energy 25Mev. The low-waste close looping type technology of production of ^{99}Mo and ^{99m}Tc may be realised. For this a physical ground and a general design of the accelerator and the target complex have been worked out.

1 INTRODUCTION

The radioactive nuclides are widely used in medicine for diagnostics and treatment [1]. The acceptable nuclear and chemical performances ^{99m}Tc have allowed especially widely using this radionuclide in clinical diagnostics. The consumption ^{99m}Tc all over the world achieves huge amounts (more than 150000 Ci on a mother isotope ^{99}Mo per one year) [2] and this index continuously grows (up to 15 % per one year).

The main method molibdenium-99 (the parental isotope of ^{99m}Tc) production is irradiation of enriched by ^{235}U uranium target, by neutron flux from nucleon reactor with reaction ^{235}U(n,f)^{99}Mo, and extraction ^{99}Mo from irradiation target with complex “wet” chemonuclear procedures. Whereas traditional technology lets get big volume of nuclide product with high activity per unit (about 5000 Curie per 1g of Mo), it the main disadvantage is big number of radwaste (about 50 Curie per 1 Curie of ^{99}Mo). Taking into account that fact, that the determinate process of technology of a burial of the RW until now is not present, this problem especially attracts attention while construction and operation of reactors and factories on production ^{99}Mo in industrialized countries [3]. There is why community of nuclear medical profession long time aim to creation of alternative source of ^{99}Mo production [4]. All of this ground modernization of large manufactures outfit for ^{99}Mo production and new technology development.

Production of ^{99}Mo by accelerators has been suggested a many times through the years[5]. In the paper[6] electron and ion accelerators are compared as producers of ^{99}Mo, and the advantage of electron accelerators is shown. In particular, the superiority of electron accelerators to ion accelerators used to produce ^{99}Mo through direct reaction such as ^{98}Mo(*d, p*) ^{99}Mo is shown by comparing the ^{99}Mo production rate per unit beam power for ion and electron accelerators. Processes based on spallation neutrons look even more favorable. However, the very high energy of the protons puts these accelerators in a completely different class. Because of these reasons team at INEEL and we had developed the ^{99m}Tc production concept based on distributed electron accelerators and thermal (INEEL)[6] and electrolyze (NSC-KIPT)[7] separations currently last years. This report presents the detailed summary of physical ground and a general design of the accelerator and the target complex for this technology.

2 ACCELERATOR DESIGN

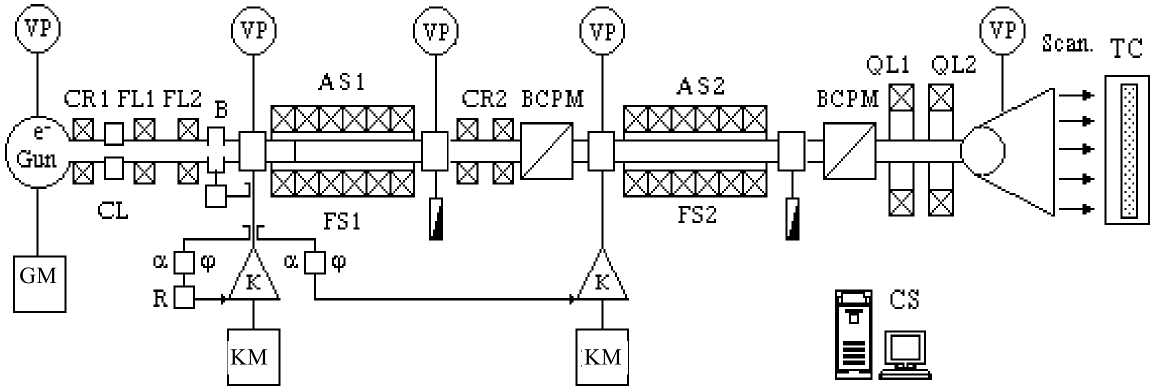
2.1 General Description of Accelerator Lay-out.

A physical ground and a general design of the accelerator and the target complex have been worked out (see Fig.1).

The choice of the power level of the electron flow of the accelerator is determined by the following factors: (i)-maximum possible load of the converter and target; (ii)-maximum output power of used SHF-sources; (iii)-conditions of the nuclear safety; (iv)-possibility of production of Tc-99m with efficiency about 10 Ci per day.

The above mentioned reasons defined the output parameters of accelerator beam: energy up to 25 MeV; beam power - 20...25 kW. On the other hand, the analysis of nuclear-physical data showed that the electrons with an energy more than 25 MeV produce undesirable radionuclides such as Zircon-89 and Yttrium-87. That’s way it is necessary to minimize beam energy spread. Besides that, it is necessary to provide a high safety of accelerator work with the minimization of operation expenditures.

The calculations showed that when input power is 10 MW on the injection section ($L = 3.07$ m, $R_s = 0.46$ MOhm/m, $\alpha = 6.8 \cdot 10^{-4}$) and it is 12 MW on the second accelerating section ($L=3.03$m, $R_s = 0.46$ MOhm/m, $\alpha = 6.8 \cdot 10^{-4}$) at a beam pulse current of 0.8A, a pulse length of 4μs, a pulse repetition rate of 300 p.p.s., the electron energy at the accelerator exit reaches 24 MeV at maximal accelerator efficiency equal to 87% and average pulse power 24 kW. The beam characteristics for the injector section are presented in Fig. 2.



GM - electron gun modulator, VP - vacuum pump, CL - beam collimator, B - buncher, K - klystron, KM – klystron modulators, R - stabilazing cavity, AS1, 2 - acceleration sections, FL1, 2 - focussing lenses, FS1, 2 - focusing solenoids, BCPM - beam current and position monitors, QL1, 2 - quadruple lenses, Scan - scanner, TC - target complex, CS - control system.

Figure 1: Lay-out of the accelerator.

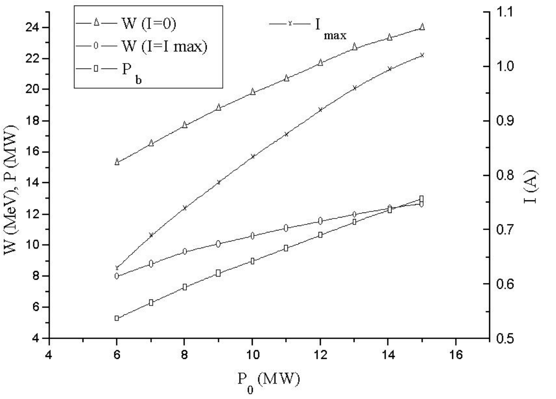


Figure 2: The beam characteristics for the injector section.

2.2 Systems design and improvement.

The main systems and elements which had to be essentially improved were designed. It is such systems, as (a) injection systems; (b) accelerating systems; (c) RF- and HV- systems; (d) systems of target complex; (e) control and protection systems; (f) power supply and cooling systems.

(i)The investigations have shown that the HV diode guns in combination with the forming system (collimator, deflector, buncher) are the most suitable for the use in injector accelerating structures with a high-power beam. The testing of parameters of injector system as component of accelerator facility is corresponded to technical requirements and provide pulse current up to 1.1A for energy 120keV, pulse width 3.5μs and repetition frequency up to 300Hz on exit of injector section with efficiency about 70%. next capture of electron stream to accelerating process.

(ii)The accelerating structure design was caused by necessity to fulfill the following conditions: (a) maximal efficiency of using RF-power; (b)minimization of effects of beam loading and beam breaking up; (c)-injected beam maximal catching in acceleration regime. Injector and accelerating structures have been manufactured and the RF adjustment and testing as component of accelerator facility have been come out. The measured parameters of accelerating structures are in conformity with design values.

(iii) According to the necessity of minimization of beam energy spread in accelerator and on the target program for computer design of beam dynamics was created and analysis of energy spread decreasing methods was done. We have designed, manufactured and tested the “time delays” synchronization system. The testing of the “time delays” synchronization system parameters as component of accelerator facility is corresponded to technical requirements and provide beam energy spread don’t more 3 %.

(iv) The RF-system of a powerful electron accelerator is aimed at RF supply of an accelerating structures and electron bunch forming elements of the injector. As for the chosen variant, the RF system is based on two powerful S-band RF-stations, which, according to the calculations, have to provide a pulse power not less then 10-12 MW with a pulse length of 4-5 μs and repetition rate of 300 Hz at the entrance of each accelerating section. Two samples of the RF-station have been designed and fabricated and assembled and tested from our supplied drawing and specification. The end-to-end tests of parameters of RF-stations have shown, that the developed type RF-system completely satisfy to the engineering requirements and its parameters are in conformity with design values. Really we have pulse output power not less 12 MW, average output power up to 13 kW.

(v) The testing of parameters of creation output system, as component of accelerator facility, have shown that developing scanner, power supply and control system are corresponded to the technical requirements.

2.3 Accelerating Facility Testing Results

The maintenance, testing and start operation of accelerator and target facilities and measurement of output parameters of systems and radiation facilities were made. The research allowed to create high-power and reliability electron accelerator with next parameters pulsed beam current up to 1 A in energy range 20..30 MeV for average beam power up to 22 kW, energy spread 3% and efficiency of RF power using no less than 80%.

Table 1: Operation parameters of LINAC-20.

The output beam parameters	Units	Results	Notes
Energy range	MeV	10..30	
Optimal energy	MeV	25	Average
Pulse current	A	0.75	Optimum
Average current	mA	0.9	
Average beam power	kW	22.6	
Energy spread	%	3	85% of beam
Frequency of repetition	Hz	300	Maximum
Pulse duration of current	μs	4	
Power consumption	kW	117	

3 CONCLUSION

It was showed that by using this accelerator may be realised low-waste close looping type technology of production of ^{99}Mo and ^{99m}Tc. The channels of ^{99}Mo production was researched and shown that the using of photoneutron and others reactions allows to get ^{99}Mo with activity more than 4 Curie per day with target consisting from natural isotopes or more than 18 Curie per day with target enriched ^{100}Mo.

During design complete the regularities of production ^{99}Mo under two schemes - the exposure of the rigid Mo target, and also solution Mo are investigated. The “liquid” technology envisage use of minimum radiochemical procedures, connected with extraction ^{99m}Tc from the irradiated target and target full regeneration before the next radiation. This technology allows to create close cycle production of ^{99}Mo with rotation high active target only between accelerator and chemonuclear equipment, on the base electron accelerators. The developed technique of electrolytic extraction Tc-99m from solution Mo-99 with activity per unit 1 Curie/litre provides enough isotopes purity of Tc-99m-pertechnetate. The produced isotope of Tc-99m was tested for using it for raidonuclide diagnostic. The tests showed that its parameters correspond to the medical and radiochemical requirements for radiofarmceutical.

We are concerned with production methods of other isotopes by electron accelerator also. A linac is allowed to produce many isotopes. For example a linac is allowed to produce the isotopes for intranuclear localization (I-125, Rh-103m, Nb-91m, Pt-195m, Sb-119, As-73), treatment of metastatic bone pain (Ca-45, P-32, As-73, Re-186, Re-188), generators systems for PET imaging (Rb-82, F-18, Ga-68) etc. Most of these isotopes may be commercially available.

ACKNOWLEDGMENTS

These works have done by a multidisciplinary team at NSC-KIPT. Work was supported through the 2-GeV Linac Laboratory NSC-KIPT under Science and Technology Center in Ukraine (Contract #432 STCU).

REFERENCES

[1] Kurenkov N.V., Shubin Y.N. "Radionuclides in nuclear medicine" Med Rad. and Radiation Safety, 1996, N5, p. 54-63.

[2] Ruth T.J. ”The production of Radionuclides for Biosciences” TRI-PP, 1992, 92-68, p.1-3.

[3] Villiers W.Z, “The management of radioactive waste from fission Mo-99 production” Proc. Int. Top. Meet Nucl. and Hazardous waste managment, August, 14-18,1994, p.2190-2192.

[4] Rojas-Burke J., “The future supply of Molobdenum “, J. Nucl. Med., 1995, v.36, No.11, p.15N.

[5] Davydov M.G., Mareskin C.A. “ About Possibility ^{99}Mo and ^{99m}Tc Production with Electron Accelerator” Radiochemistry, 1993, V.35,No.5, pp.91-96 (in Russian).

[6] Bennett R.G. et al. "A System of ^{99m}Tc Production Based on Distributed Electron Accelerators and Thermal Separation" Nuclear Technology, Vol. 126, April 1999, pp 102.

[7] Dovbnya A.N., Medvedeva E.P., Tur Yu.D. et al. "Electron Accelerator’s Production of Technetium-99m for Nuclear Medicine", Proceedings of the 1997 PAC, Canada , 12-16 May 1997 , p. 3840.
Dovbnya A.N., Dikiy N.P., Pilipenko M.I., Tur Yu.D., Uvarov V.L. "New Technologies of Tc-99m Production", Ukrainian Journal of Radiology, 1999, No 1, p.23.