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DESIGN OF HIGH ENERGY LINAC FOR GENERATION OF ISOTOPES FOR MEDICAL APPLICATIONS*

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Abstract

After successful implementation of 6 and 15 MeV electron linear accelerator (linac) technology for Cancer Therapy in India, we initiated development of high energy high current accelerator for production of radioisotopes for diagnostic applications. The accelerator will be of 30 MeV energy with 350 µA average current provided by a gridded gun. The linac is a side coupled standing wave accelerator operating at 2998 MHz frequency operating at π/2 mode. The choice of π/2 operating mode is particularly suitable for this case where the repetition rate will be around 400 Hz. Klystron with 7 MW peak power and 36 kW average power will be used as the RF source. The modulator will be a solid state modulator. The control system is FPGA based setup developed in-house at SAMEER. A retractable target with tungsten will be used as converter to generate X-rays via bremsstrahlung. The x-rays will then interact with enriched ^{100}Mo target to produce ^{99}Mo via (γ, n) reaction. Eluted ^{99m}Tc will be used for diagnostic applications. The paper lists the challenges and novel schemes developed at SAMEER to make a compact, rugged and easy to use system keeping in mind local conditions.

INTRODUCTION

Based on the successful development of 15 MeV electron linac with beam power of 1.5 kW, we proposed the development of 30 MeV, 5 to 10 kW electron linac which can be used for generation of radioisotopes for medical imaging applications [1].

Technetium (^{99m}Tc) is one of the main radio isotope used in almost 85% of nuclear diagnostics procedures done worldwide. At present it is eluted from Molybdenum ^{99}Mo which has half-life of 66 hrs. The parent isotope ^{99}Mo, is obtained from almost everywhere from reactors [2]. Many hospitals in India, import the generator and elute ^{99m}Tc locally at the hospital. The Board of Radioactive Isotope Technology (BRIT), Mumbai has focused to enhance the indigenous generation and distribution of ^{99}Mo generators. However, the dependence on reactors is very high when it comes to the generation of ^{99}Mo. We proposed the linac based technology as an alternate, cheap and clean technology as compared to reactor based ^{99}Mo. In our case the enriched ^{100}Mo targets will be irradiated with high energy photons to produce ^{99}Mo. The photonuclear reaction of interest is:

$$^{100}\text{Mo}\ (\gamma, n)\ ^{99}\text{Mo} \quad \text{(reaction threshold, } E_{th} = 8.29\ \text{MeV)}$$

^{99m}Tc is then eluted from ^{99}Mo by chemical process. The production yield of ^{99}Mo is proportional to the electron beam power for different electron energies. The optimum electron energy should be 30 ~ 40 MeV for generation of ^{99}Mo using bremsstrahlung flux. A maximum activity of 1.8 Ci/kW is reported for ^{100}Mo target after irradiation at 30 MeV electron energy and for a given target geometry [3].

We proposed 30 MeV, 10 KW linac based system to generate ^{99}Mo using above mechanism.

ELECTRON GUN

We have designed and developed a 20 kV Triode Gun [4]. The design of gun was done using EGUN code and subsequently validated using CST Particle Studio. The cathode used is Dispenser Cathode with current density of about 3 A/cm^2. The parts were fabricated in-house and the gun was assembled at SAMEER. Figure 1 shows the SAMEER gun. The gun was baked at 100 ºC for about 250 hours and was tested using ETM make power supply at Injection Voltage of 20 kV and filament voltage of 7 V. Emission current of over 650 mA was observed. The grid voltage was varied to confirm the control over emission current. The gun has been tested on test bend and is operating as per the design specifications.

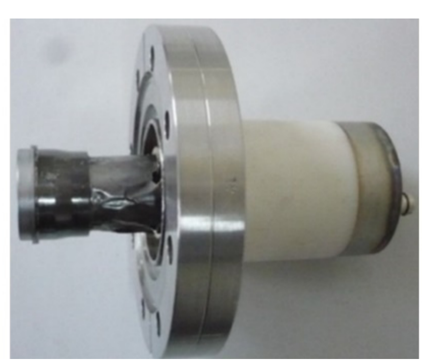

Figure 1: Triode Gun.

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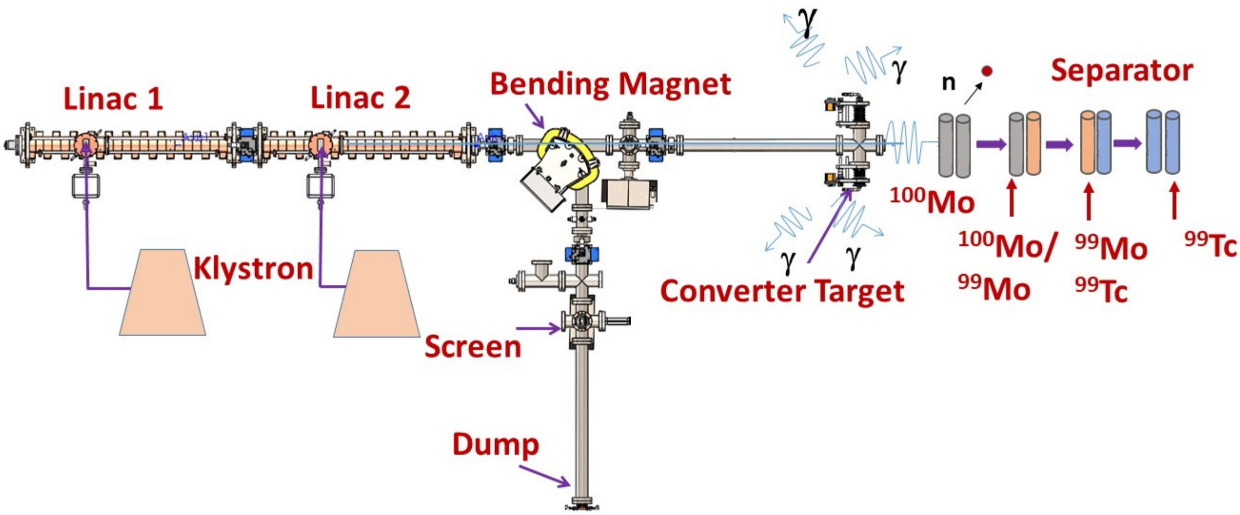

Figure 2: Schematic of SAMEER Linac based system for isotope generation.

LINAC AND THERMAL ISSUES

The schematic of the proposed system is shown in Fig. 2 above.

The linac developed at SAMEER is side coupled, bi-periodic standing wave accelerator operating at π/2 mode [5, 6]. The complete linac tube is shown in Fig. 3. A single structure of 1.2-meter length contains 2 ½ buncher cells followed by 21 accelerating cells. The shunt impedance is the linac is sufficiently high to achieve 15 MeV energy with moderately high average current. With 6 MW input power, we are able to deliver 15 MeV energy with over 75 µA average current.

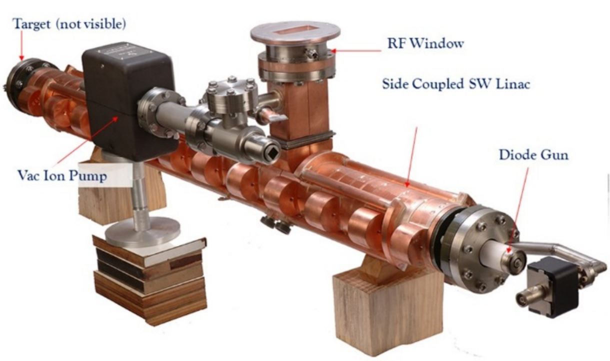

Figure 3: SAMEER side coupled structure.

In SAMEER high current linac, the peak current will be maintained at the level of the prototype linac. Our prototype has delivered 75 mA peak current with 6 µs pulse width. We have tested that the Klystron peak power of around 6 MW is sufficient to deliver about 16 MeV/ m. To achieve higher average power, we have to operate at much higher duty cycle. For this system we use CPI Klystron with 7.5 MW peak power and 36 KW average power. The duty to 0.4% will be sufficient to achieve desired beam power.

The main area of concern is therefore the thermal issues and the cooling scheme implemented to mitigate the heat problems. Detail thermal analysis of the setup was done using ANSYS Fluent. Table 1 shows the results of the simulations [7].

Table 1: Parameters for Thermal Estimation

Parameter	Value
Beam Energy	30 MeV
Beam Power	10 KW
Peak power	7.5 MW
Average power per linac	36 KW
Duty	0.00514
Type of flow	Parallel flow
Water flow, (for 5 °C rise)	64 lpm
Surface area	0.376 m^2
Heat Flux	2.6363 x 10^4 W/m^3

RF SYSTEM

We have already developed a line type modulator for the prototype linac with duty cycle of 0.1%. For high energy system, we are procuring a solid state modulator. The CPI Klystron 8262K which has 7.5 MW peak power and average power of about 36 kW will be used. Scandinova make solid state modulator capable of delivering RF pulses with 12 to 16 µs pulse width with 400 Hz rep rate and pulse-to-pulse stability of less than 0.1% will be used to drive the Klystron. Four port RF circulators with over 15 MW peak, 45 kW average power handling capacity at 2998 MHz frequency along with suitable water loads will be used to ensure safety of the system during the operation.

CONTROL SYSTEM

We have developed FPGA based control system for our accelerators. This has customized FPGA boards which help generating, monitoring, and controlling various signals for the entire system. The control system interacts with the gun injection supplies, modulator system as well as all the

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magnet supplies, vacuum, temperature, high pressure system, diagnostic devices etc. Systematic data logs are maintained from maintenance point of view. GUI is also developed in-house. The prototype is developed and at present implemented in our test set-up. Bergoz make ACCT are part of system to help monitor the current. A bending magnet is integrated down the line for beam characterization.

SHIELDING DESIGN

The entire system will be integrated in one of the test facility at SAMEER. Assuming the maximum energy with maximum average current beam, the source term calculations were initiated to verify if the wall thickness of 2.165 meter in forward direction is sufficient to shield the photons and neutrons coming from the system. As the wall thickness is not sufficient, design of suitable local shielding structure was initiated. Details of the FLUKA simulations show that using 4 TVL lead followed by 3 TVL of HDPE and 1 TVL of borated HDPE with 3 mm thick 40% Boron rubber makes the system safe for operation [8]. The system with local cube is depicted in Fig. 4 below.

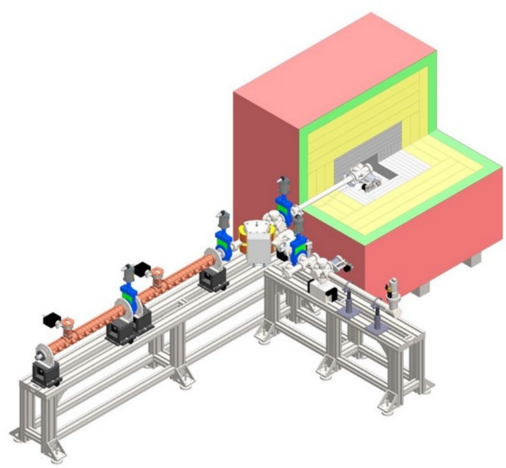

Figure 4: System with local shielding structure.

DISCUSSION

Work is under progress at SAMEER for the proposed linac base isotope generation. The high current linac will be able to deliver 30 MeV with around 10 kW beam power at the retractable target location. The mechanism ensures that the target can be Tungsten target for achieving high flux X-rays in forward direction. These X-rays will then bombard the enriched ^{100}Mo target to deliver ^{99}Mo. In this approach we estimate around 0.4 Ci/g activity at our ratings. Further optimization will ensure that the system can deliver desired ^{99}Mo for usage for nearby hospitals. Recently, we initiated simulations to use Molybdenum target as convertor as well as generator [9]. The results show that if such mechanism is feasible the activity enhance over 10 times and very good activity of about 7 Ci/g can be achieved. The target mechanism is proving to be a major challenge as the target needs to be cooled to ensure safe operation. Further, at the end of cycle we need to remove the target and send it for elution. At present, our efforts are on-going to finalize the design of this complicated target setup.

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