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PRELIMINARY DESIGN OF A 30 MeV DEUTERON LINEAR ACCELERATOR FOR THE PRODUCTION OF INTENSE BEAMS OF 14 MeV NEUTRONS*

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Introduction

The study of radiation damage to materials used to build containers for a fusion reactor requires a beam of neutrons with energy peaked at ~ 14 MeV and with a total flux of ≥ 10^{14} neutrons/cm^2 sec in order to carry out tests in a reasonable time scale. This report describes a Deuteron Linear Accelerator, utilizing an Alvarez structure, which is designed to produce neutron energy and flux of the above values by allowing a 30 MeV deuteron beam of 100 mA continuous current to strike a liquid lithium target. A second report[1] describes the neutron spectrum obtained by this process.

Basic Machine Parameters

The basic machine parameters are summarized in Table I, together with the expected output beam parameters. The beam size and current density at the target is not discussed here since it will be determined largely by the requirements of the target and transport system.

TABLE I - BASIC MACHINE PARAMETERS

INJECTION ENERGY	0.500 MeV
INJECTION CURRENT	200-400 mA
INJECTED RADIAL EMITTANCE ($\beta\gamma\epsilon$)	$7\pi \times 10^{-6}$ m Rad.
OPERATING FREQUENCY	50 MHZ
AVERAGE ACCELERATION RATE	0.75 MeV/m
STABLE PHASE ANGLE	30°
NO. OF ACCELERATING CAVITY SECTIONS	8
TOTAL CAVITY LENGTH	39.5 METERS
TOTAL NO. OF DRIFT TUBES	66
TOTAL RADIO FREQ. CAVITY POWER	1.4 MW
TOTAL BEAM POWER	3-6 MW
OUTPUT ENERGY	30.1 MeV
OUTPUT CURRENT	100-200 mA
OUTPUT ENERGY SPREAD F.W.M.H.	~ 200 KeV
OUTPUT RADIAL EMITTANCE ($\beta\gamma\epsilon$)	~$2\pi \times 10^{-5}$ m. Rad.

Injection System

The proposed injection system is shown in schematic form in Fig. 1. It utilizes two 500 kV, 500 mA dc generators each feeding a single gap accelerating column, one with a D^+ and the other a D^- ion source. The ion sources will be of the duoplasmatron type capable of delivering up to 500 mA of deuteron current. An electromagnetic bunching scheme [2] utilizing a bending magnet and a coaxial line type radiofrequency accelerating cavity will be used to bunch the beam to within the linac acceptance. This type of bunching will allow optimization of the beam transmission through the accelerating cavities and thus reduce beam losses and hence radiation from the accelerator induced by the beam striking the drift-tubes. Figure 1 is a schematic of the injection system.

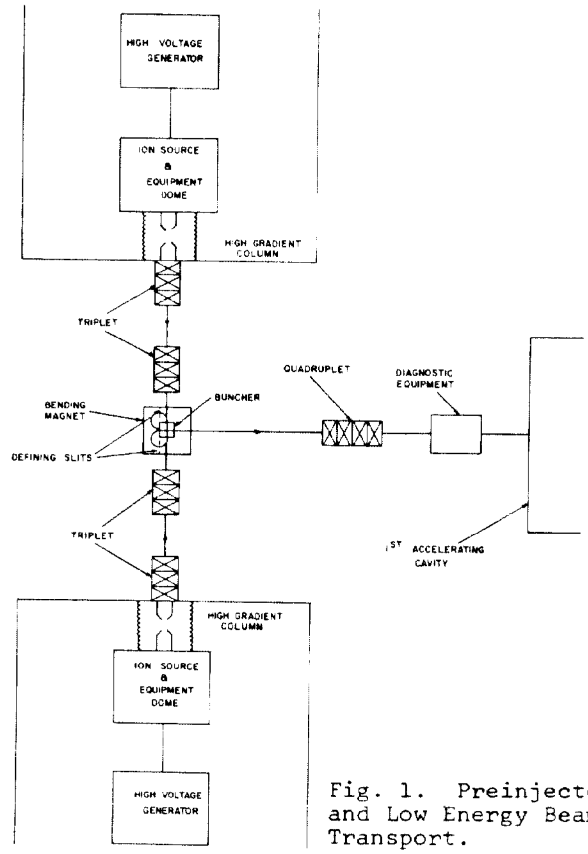

Fig. 1. Preinjector and Low Energy Beam Transport.

Accelerator Systems

In order to allow operation at a reasonable number of intermediate energies, the accelerator will be divided into eight cavities, each powered by its own radiofrequency system.

Table II lists the major cavity parameters as extrapolated from the 200 MHz, 200 MeV proton linear accelerator at BNL. These parameters are far from being optimized, they will serve however to establish a design basis for the machine.

As stated, the accelerator will be an Alvarez structure of conventional, state-of-the-art design. It will be different, however, from existing modern proton linacs in that its duty factor will be 100%, hence particular attention will be paid to the thermal and radiation problems.

At 50 MHz and an acceleration rate of about 0.75 MeV/m, the total length of the machine will be about 40 meters, plus allowance for some drift lengths between cavities. These however will be kept short, about 3λ, to avoid longitudinal debunching. In order then to limit the space between cavities, the eight cavities will be contained in a single vacuum tank, 12 ft diameter and 140 ft long. The tank will be constructed of copper clad steel containing both vacuum and rf power in an integral envelope, like all modern proton linacs. Water-cooled copper boundary plates will be mounted inside to provide the separation between the 8 rf resonators.

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TABLE II - BASIC CAVITY PARAMETERS

CAVITY*	1	2	3	4	5	6	7	8
INPUT ENERGY (MeV)	0.500	3.967	7.772	11.352	15.048	18.636	22.614	26.226
INPUT $\beta\gamma$	0.023	0.063	0.089	0.108	0.125	0.139	0.153	0.165
OUTPUT ENERGY (MeV)	3.967	7.772	11.352	15.048	18.636	22.614	26.226	30.109
OUTPUT $\beta\gamma$	0.063	0.089	0.108	0.125	0.139	0.153	0.165	0.177
CAVITY DIA. (m)	3.78	3.78	3.78	3.78	3.78	3.78	3.78	3.78
CAVITY LENGTH (m)	4.662	5.075	4.773	4.928	4.784	5.303	4.816	5.178
INPUT CELL LENGTH (m)	0.139	0.390	0.547	0.661	0.761	0.848	0.934	1.007
OUTPUT CELL LENGTH (m)	0.376	0.532	0.647	0.747	0.833	0.920	0.992	1.067
INPUT GAP / LENGTH RATIO ($\frac{g}{L}$)	0.200	0.236	0.259	0.275	0.290	0.304	0.319	0.334
OUTPUT GAP / LENGTH RATIO ($\frac{g}{L}$)	0.234	0.257	0.273	0.288	0.301	0.316	0.330	0.350
INPUT DRIFT TUBE LENGTH (m)	0.111	0.298	0.405	0.479	0.540	0.590	0.636	0.671
OUTPUT DRIFT TUBE LENGTH (m)	0.288	0.395	0.470	0.532	0.582	0.629	0.665	0.694
DRIFT TUBE DIAMETER (m)	0.720	0.720	0.720	0.720	0.720	0.720	0.720	0.720
DRIFT TUBE APERTURE (m)	0.040	0.060	0.060	0.080	0.080	0.080	0.080	0.080
DRIFT TUBE INNER CORNER RADIUS (m)	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
DRIFT TUBE OUTER CORNER RADIUS (m)	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
DRIFT TUBE STEM DIA. (m)	0.050	0.080	0.080	0.080	0.080	0.080	0.080	0.080
QUAD. APERTURE (m)	0.050	0.070	0.070	0.090	0.090	0.090	0.090	0.090
QUAD. LENGTH (m)	0.100	0.200	0.200	0.400	0.400	0.400	0.400	0.400
QUAD. FIELD STRENGTH (kg/cm)	~1.00	~0.50	~0.25	~0.25	~0.25	~0.25	~0.25	~0.25

The 66 copper drift tubes mounted on the axis of the accelerator will each contain a dc, water-cooled, electromagnetic quadrupole. The drift tubes have a single support stem, we do not contemplate utilizing "stem couplers", posts or multistems to equalize the E field distribution, because each cavity is very short, less than one wavelength. The drift tubes and the tanks will demand an efficient water-cooling system to dissipate the ~ 1.5 MW of excitation power and maintain a constant temperature. The accelerator will operate at about 100°F, and the cavity resonant frequencies will be maintained and adjusted by means of a servo system controlling the operating mean temperature. This scheme is being successfully used presently on the Brookhaven proton linac.

Radiation damage considerations dictate that the accelerator be built excluding all organic materials. Rubber hoses, vacuum viton seals, electrical organic insulation, etc., will all be replaced by radiation hardened materials. Although these are design constraints, today, radiation hardening is becoming standard procedure in new accelerator designs and the technology is well developed. It is however, raising the machine costs, especially when one has to decide on the seals of vacuum valves.

The vacuum system requirements are a clean system with an operating pressure of 10^{-7} torr. The high vacuum will be maintained with the help of ion pumps, these are now well understood, reliable and practically maintenance free. The roughing system however presents a problem because of the large volume to be evacuated in a reasonable time. The logical approach here is the use of cryogenic pumping where high pumping speeds can be achieved at reasonable cost. Although it is intended to operate the accelerator at 10^{-7} torr, the liquid lithium target will operate in the 1 torr region, this will necessitate very efficient differential pumping in the beam transport system. The 1 torr pressure at the target is predicated upon the vapor pressure of lithium at the operating temperature which will reach 900-100°F.

Radiofrequency System

The basic radiofrequency parameters are given in Table III and the proposed radiofrequency power supply system is shown in Fig. 2. Each cavity section will be

TABLE III - RADIO FREQUENCY PARAMETERS

CAVITY*	1	2	3	4	5	6	7	8
STORED ENERGY (Joules)	90.32	91.96	81.59	91.92	89.66	100.05	91.12	101.90
AVERAGE SHUNT IMPEDANCE (MΩ/m)	32.0	35.8	36.0	36.2	36.9	36.8	36.8	36.7
TOTAL CAVITY PWR (KW)	206.7	181.8	157.6	168.6	161.5	177.7	161.8	176.8
TOTAL BEAM PWR FOR 100mA (KW)	346.7	380.5	358.0	369.6	358.8	397.8	361.2	388.3
UNLOADED Q VALUE	137280	158900	162650	171270	174400	176900	176910	181060
INPUT TRANSIT TIME FACTOR	0.693	0.800	0.846	0.810	0.815	0.811	0.805	0.798
OUTPUT TRANSIT TIME FACTOR	0.827	0.842	0.859	0.815	0.812	0.806	0.799	0.790
STABLE PHASE ANGLE	30°	30°	30°	30°	30°	30°	30°	30°

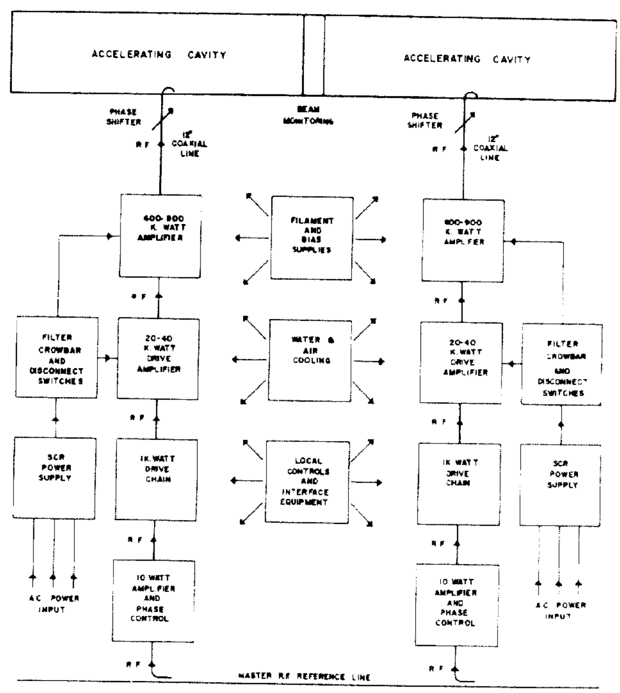

Fig. 2. Radio Frequency System.

fed by a drive chain fed from a master reference line and phase locked to it. Each of the 8 drive chains will have an output capability of 600-900 kW average power thus providing for acceleration of beam currents of 100 mA for both D^+ and D^- beams. Phase control will be affected in the low level stages of the drive system with comparison being made between accelerating cavity section and the reference line. The final amplifier will probably be drive modulated to allow for radiofrequency amplitude control. An S.C.R. controlled power supply at a voltage of ~ 20 kV and a current of ~ 60 A will be required for the final amplifier. Possible tubes for the desired rf power level are the C.F.T.H. 518 and the EIMAC X 2159. Crow bar protection will be provided for the power supply or to turn off the rf if the beam is interrupted. Twelve inch diameter coaxial line will be used to transport the power from the final amplifiers to the accelerating cavities with an adjustable coupling loop being used to couple the power into the cavity. The master reference line will be fed from a drive system utilizing a quartz crystal controlled oscillator at low frequency with varactor multipliers and suitable amplification.

Controls and Beam Diagnostics

The basic control system is shown in Fig. 3. It

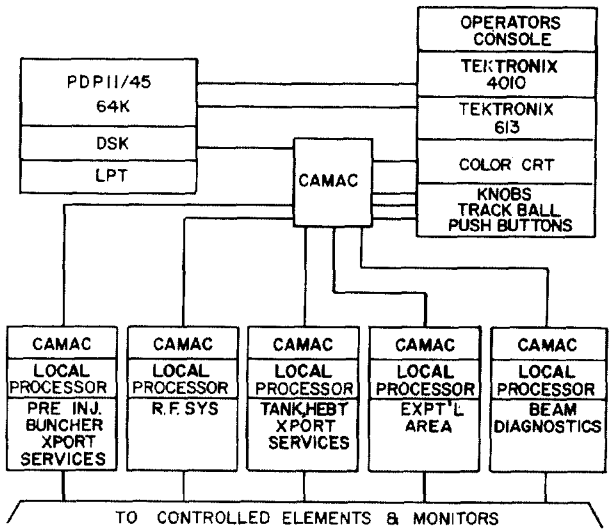

Fig. 3. Control System Block Diagram.

will make use of local dedicated computers performing real time operations and receiving commands from and transmitting data to a larger central control computer which will carry out computations and interact with an operations console. CAMAC hardware will be used to interface with the local computers and to interact directly in a hard wired fashion with a malfunction and machine protection system for the linac.

Because of the huge potential for radiation induced by beam interception, beam losses must be kept to a minimum and a radiation monitor system with various types of monitors including detectors in each drift tube of the high energy end will be an important diagnostic tool. Non-intercepting instrumentation will include a dc beam transformer,[3] rf position[4] and bunch length[5] detectors and residual gas profile monitors.[6] At the low energy end conventional emittance measuring units[7,8] may be employed.

Facilities

Figure 4 shows a plan view of the 30 MeV deuteron linac facility. It will be located at Brookhaven, adjacent to the existing 200 MeV proton linac, allowing for efficient use of operating and maintenance personnel as well as use of Laboratory space.

The accelerator will be housed in a 20-ft wide shielded tunnel with the beam height 5 ft below ground level. Adjacent to the tunnel a light structure will house the rf systems and adjoining assembly area. The control room which is located at the high energy end of the machine will monitor the experimental areas as well. With the use of local computers and CAMAC controllers, we expect to greatly diminish the need for a large number of cables.

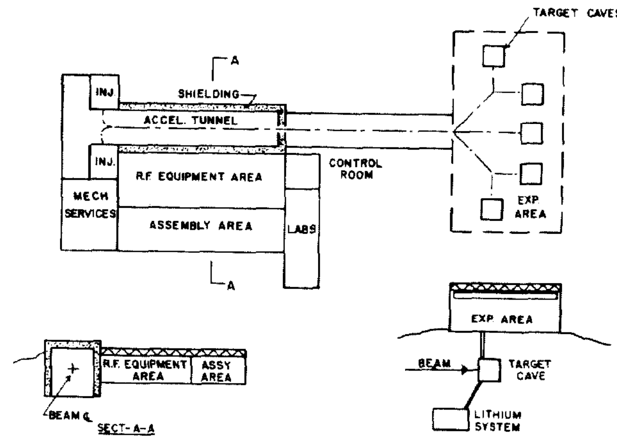

Fig. 4. Plan View of LINAC Facility.

Downstream from the accelerator the experimental building consists of a staging area with the necessary hot cells built on top of the target caves. The material samples to be irradiated will be transferred from the staging area to the target through a duct system. The lithium target circulating and cooling systems is housed adjacent to the experimental area. This loop circulates 400 gpm of liquid lithium and dissipates 3.5 MW in a heat exchanger to air.

Target System

The target system is shown in schematic form in Fig. 5: It consists of an exposed liquid lithium jet of dimensions 10 x 10 x 2 cm operating at a temperature of $\sim 700^{\circ}$C and a pressure of $\sim$ 1 torr. For a beam power of 3 MW and a jet flow of 6 m/sec (20 ft/sec) and a deuteron range of 1 cm, the average target energy density is 0.5 MW/liter. Part of this energy is rapidly absorbed by the excess lithium in the jet by turbulent mixing. The exit end window which seals the system will be exposed to the maximum available neutron flux and would be made of material useful to the study of CTR radiation damage.

Conclusion

A deuteron linac of the type presented represents a practical and efficient way of producing the intense neutron beams needed for CTR materials studies. The accelerator technology has already been developed and the flexibility in beam size, duration and intensity provided by an accelerator of this type greatly facilitates a viable experimental program.

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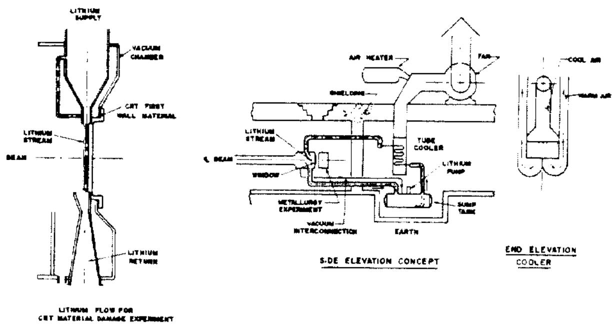

Fig. 5. Lithium Target System.

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